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NATURALLY OCCURRING RADIOACTIVE MATERIALS: HUMAN HEALTH & REGULATION

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I. INTRODUCTION

Each year more than one billion metric tons of Naturally Occurring Radioactive Material (NORM) wastes are generated in the human environment.[1] The generation, transportation and disposal of NORM was largely unregulated until recently. Now, ten states have NORM regulations, and the federal government is sponsoring studies of the potential health and environmental effects that can result from NORM.[2] The Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA) or the Department of Energy (DOE) may develop and implement NORM regulations on the basis of these studies. The EPA's Science Advisory Board (SAB) rejected[3] the first Diffuse NORM Study,[4] and a second study is being developed. In the wake of EPA's studies, the National Academy of Sciences (NAS) was commissioned by Congress to review the variability of NORM regulations, and to determine if some metric has been left out of the study of NORM.[5]

The NAS's questions cut to the bone of the NORM debate when, in substance, they ask: "Why do different state's regulations vary?" and "Has anything been left out of the risk analysis of NORM?" This article broadly address these questions, and responds by stating that: 1) Non-cancer human health effects[6] have been left out of the regulation of NORM, and they ought to be studied because they might be as important as cancer; 2) the state regulations do vary, and in many cases the reasons are not readily apparent, nor do the variations always seem to be based on scientific foundations.

A review of the literature reveals that non-cancer health effects are potentially more of a problem than cancer. The lack of focus on the potentially significant non-cancer health effects of NORM distorts the risk analyses that EPA is re-conducting under the supervision of the SAB, leading to a skewed determination for the need–or lack thereof–for federal NORM regulation. The NAS review of NORM regulation and risk assessment should find that the exclusion of non-cancer health effects from the risk analysis of NORM is a major deficit

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1. SC&A, INC. AND ROGERS & ASSOC. ENGINEERING CORP., RAE-9232/1-2, DIFFUSE NORM WASTES: WASTE CHARACTERIZATION AND PRELIMINARY RISK ASSESSMENT ES-2 (1993) [hereinafter DIFFUSE NORM STUDY].

2. ENVIRONMENTAL PROTECTION AGENCY, 402-R-97-016, MULTI-AGENCY RADIATION SURVEY AND SITE INVESTIGATION MANUAL (MARSSIM) (1997) (visited March 2, 1998) <http://www.epa.gov/radiation/marssim/>; NATIONAL ACADEMY OF SCIENCES, BRER-K-97-02-A, EVALUATION OF EPA GUIDELINES FOR EXPOSURES TO INDOOR RADON AND NATURALLY OCCURRING RADIOACTIVE MATERIALS (visited March 2, 1998) <http://www.nas.edu>.

3. ENVIRONMENTAL PROTECTION AGENCY, EPA-SAB-RAC-94-103, AN SAB REPORT: REVIEW OF DIFFUSE NORM DRAFT SCOPING DOCUMENT (1994) [hereinafter SAB NORM REPORT].

4. DIFFUSE NORM STUDY, *supra* note 1.

5. *See* National Academy of Sciences, *supra* note 2 and accompanying text.

6. It is reasonable to assume that radioactive materials in the environment can cause harm to the variety of organisms that are in the environment, and to the ecological balance of certain life systems. This paper, for limitations of time and space, does not seek to investigate those other risks. For an interesting discussion of the ecological protection mandates that exist in United States law, and the corresponding inability of risk assessment to determine the risk of harm to natural systems because risk analysis focuses on human health and not on larger life systems, see Lakshman Guruswamy, *Global Warming: Integrating United States and International Law*, 32 ARIZ. L. REV. 221, 242 (1990).

in the effort to protect human health from NORM risks.

The literature also reveals that NORM regulations are in more of an embryonic than fully developed state. This is demonstrated by the fact that current state regulations and the focus of recent studies resemble the early efforts in radiation protection. A review of the historical development of radiation protection guidelines shows that differing rules and measurement units that are now being used in NORM regulations are hallmarks of the "bottom of the learning curve." In the nuclear industry it took a great deal of time to develop meaningful regulations as the industry itself developed.[7] With NORM, however, the industries are in place, generating NORM now. There is no extra time to take in the development of these rules. Furthermore, the longer these rules don't exist, the longer industries will likely be developing future problems because they cannot hope to comply with regulations that do not exist.[8]

While this time factor has become increasingly important, rhetoric has been building about certain elements of the risk analysis of NORM and radioactive materials in general. Arguments over the effects of low doses of radiation and whether certain dose-response theories exist do not help solve the NORM problem. They are simply constructs that have been devised because science can question whether one argument is right or wrong, but science cannot supply an answer. When scientists and industry complain that proposed regulations are based upon the "no-threshold" dose-response theory and are therefore too stringent, they may simply be "fiddling while Rome burns." Each year another billion tons of NORM wastes are produced. A more useful response might be finding novel and less expensive methods for meeting these stringent requirements.

Part II describes the physical, chemical and health problems that are presented by NORM. The second section of part II broadly addresses the nature of radiation and pathways for human exposure so that the reader can make a better analysis of NORM regulation. The third section of part II addresses the cancer and non-cancer health effects that may be caused by radiation, and provides some discussion—and references—for why non-cancer health effects are important to consider in radiation regulation. Part II continues in a fourth section by generally reviewing risk analysis, and then discussing why low doses of radiation should be viewed—from the regulator's perspective—as potentially substantial risks. Part II concludes by arguing that the dose-response rhetoric that exists in the NORM debate today is useless.[9]

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7. The first binding United States regulations were promulgated more than 60 years after radiation's discovery. *See infra* note 217 and accompanying text.

8. Hazardous waste regulation provides an excellent example of the liabilities that can result when real problems are neglected either for lack of knowledge or regulation.

9. Clayton Gillete & James Krier, *Risk, Courts and Agencies*, 138 U. PA. L. REV. 1027 (1990). Many industries simply view the NORM issue as a nuisance. Producing radioactive materials was not the goal. Rather, the industries are trying to make the development of mineral resources like petroleum or gypsum a viable business. From an industry perspective, risk equals liability. If these risks really do impinge upon someone or some group, the industry is likely to see the results of this risk in the form of litigation. To limit liability, then, Industry's focus should be on limiting risk. But, instead of taking a proactive stance in making

Part III describes some of the legal issues that exist in the NORM debate. It begins by briefly discussing the history of radiation protection guidelines, and then reviews the existing NORM regulations in ten states. In the third section of Part III the state regulations are compared with each other to see where some of the inconsistencies lay, and the state regulations are compared with the history of radiation protection guidelines to see if it can be determined how much more might be required to fully develop NORM regulations.

To conclude, in Part IV it is noted that NORM exposure, concentration, and accumulation can result from a number of different industrial activities that relate to many different businesses throughout the country.[10] Because the potential effects of NORM are so widespread, and because the state regulation of NORM is not consistent, it is argued that only federal regulation can adequately deal with NORM problems. Simple and transparent federal rules might have the best chance of containing any possible negative public health effects that can result from NORM exposures.

II. THE PHYSICAL PROBLEM

NORM[11] has existed since the creation of the earth. However, only since the technological revolution has man been using and concentrating commodity resources which contain radioactive materials.[12] While scientists, geologists, and engineers have known about the radioactive component of many such com-

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sure that radioactive materials do not cause harm, rhetoric over the dose-response relationship has been developed.

10. The authors of the DIFFUSE NORM STUDY investigated nine different type of industrial wastes, those from: 1) Uranium Mining, 2) Phosphogypsum Mining, 3) Phosphate slag, and 4) Fertilizer, 5) Coal Ash, 6) Oil & Gas Production, 7) Water Treatment, 8) Rare Earth Mining and 9) Geothermal Energy Production. The investigation was limited to a preliminary assessment of increased cancer risks that might be associated with these wastes. See DIFFUSE NORM STUDY, *supra* note 1 at ES-1.

11. The common definition of NORM is: "any nuclide which is radioactive in its natural physical state . . . but does not include source, by-product or special nuclear material." Bryan R. Reynolds, *Who's Going to Regulate NORM?*, 22 N. KY. L. REV. 5, 7 (1995). This definition includes any radionuclide, regardless of whether it was concentrated by natural or industrial processes. The common definition has changed over the past few years:

> Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) means naturally occurring materials not regulated under the AEA whose radionuclide concentrations have been increased by or as a result of human practices. TENORM does not include the natural radioactivity of rocks or soils, or background radiation, but instead refers to materials whose radioactivity is technologically enhanced by controllable practices (or by past practices).

Conference for Radiation Control Program Directors (CRCPD), Draft Part N Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) (Feb. 1997).

The most significant change in this definition is the addition of the term "technologically enhanced." The definition now includes only those human activities that manipulate natural resources thereby concentrating NORM in areas where it would otherwise remain unearthed. Since NORM contamination is not limited to the petroleum industry, the definition is broad enough to encompass a number of different industries whose processes technologically enhance NORM. Of course NORM wastes can become "discrete" if they are concentrated, but in most instances NORM wastes accumulated by industrial processes tend to be diffuse. DIFFUSE NORM STUDY, *supra* note 1 at A-5. "NORM" is used in this article for simplicity's sake, and the concept of "technological enhancement" is included in the use of the term NORM.

12. By most accounts, NORM was first identified in the oilfield (at least in the literature it was so identified) in 1904. James Cox, *Naturally Occurring Radioactive Materials in the Oilfield: Change the NORM*, 67 TUL. L. REV. 1197 (1993).

modity resources since 1904,[13] the protection of human health and the environment from these sources of radiation has only recently become an important issue.[14] As the NORM debate continues to mature, questions concerning the need for NORM regulation, who should regulate NORM,[15] and how to regulate NORM are just beginning to be decided.[16]

A. *The Nature of Radiation: Origin and Sources of NORM*

In a geologic sense, NORM consists of "primordial radionuclides" naturally found in the rocks and minerals of the earth's crust.[17] More specifically, NORM exists in sedimentary formations where elements such as Uranium, Thorium, and/or Potassium are present.[18] The geology of NORM is a complex subject, but a baseline understanding of its origin and sources of it will aid a later discussion of NORM regulation.

Radiation is the energy that is released when "the nuclei of unstable atoms undergo spontaneous transformations to ultimately achieve a stable state."[19] As they transform, or decay, the unstable atoms (radioactive isotopes) emit particles and/or energy, resulting in "daughter products."[20] The daughter product may or may not be radioactive.[21] If it is radioactive, the daughter will undergo another series of radiation emissions creating yet another daughter product, until the element is no longer radioactive.[22] This series of transmutations is called a "decay series."[23] The quantity of radioactivity that an isotope releases as it decays is called its *activity*.[24] The time required for a given radioactive element to decrease by half of its original amount is known as the element's *half-life*.[25] There tends to be an inverse relationship between an isotope's activity and its

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13. *Id.*
14. *See* Keith Schneider, Radiation Danger Found in Oilfields Across the Nation, New York Times, Dec. 3, 1990, at A3.
15. Bryan Reynolds, *supra* note 11 at 5, 7.
16. For instance, an interstate radiation control organization has developed model NORM rules that are beginning to gain acceptance in some states. *See* Conference for Radiation Control Program Directors Draft Part N Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Materials (Feb. 1997).
17. Diffuse NORM Study, supra note 1 at A-1; *See also*, Bryan Reynolds, *supra* note 10 at 5. In the industrial sense, NORM is a nuisance because it is generated by companies that are trying to make a profit by producing a non-radioactive mineral resource.
18. Sherwin T. Fontenot, *Dealing with NORM in the Oil and Gas Industry, in* PROCEEDINGS OF THE CONFERENCE OF PETRO-SAFE 98 (1992).
19. SAMUEL GLASSTONE & WALTER JORDAN, NUCLEAR POWER AND ITS ENVIRONMENTAL EFFECTS 8 (1980) [hereinafter GLASSTONE AND JORDAN].
20. In a nuclear power plant, the accelerated decay, or fission, of enriched Uranium creates more than 300 daughter products. *Id* at 9. The spontaneous change in the nucleus of the atom results in an atom which is "at a lower energy state," or in other words, an atom that contains less energy than the unstable atom. Much of the energy that is released in this spontaneous change, or decay, is lost as heat to the matter surrounding decayed isotope(s). Nuclear power plants trap this heat in water, which makes steam and the steam is used to mechanically turn a turbine which propels a generator that makes electricity. *Id.* at 1-12.
21. *Id.* at 9.
22. *Id.*
23. DIFFUSE NORM STUDY, *supra* note 1 at A-2 & A-3.
24. SAMUEL GLASSTONE & WALTER JORDAN, NUCLEAR POWER AND ITS ENVIRONMENTAL EFFECTS 10 (1980).
25. *Id.*

half-life.[26] That is, those isotopes that release more energy in the form of radioactivity per given unit of time are also more short-lived.

Much time passes as radioactive isotopes decay, and the parent and daughter products often have much different half-lives. For instance, Uranium's (^{238}U)[27] half-life is 4.47 billion years, and one of it's daughter products, Radium (^{226}Ra), has a half-life of 1,600 years. Thorium (^{232}Th) has a half-life of 14 billion years, and its Radium daughter (^{228}Ra)[28] has a half life of 5.75 years. The result is that the parent product decays, creating a daughter, and after a period of time an equilibrium is established between the concentrations of parent atoms and daughter atoms. In the case of a parent with a long half life and a short-lived daughter, the two elements come into "secular equilibrium." That is, at some time there becomes about as much radioactivity from the daughter as there is from the parent. In the result, there is about twice as much radioactivity with the equilibrium of parent and daughter radioactivity than there was when the parent was originally formed.[29]

This concept of equilibrium is very important to the discussion of NORM. For instance, in the case of petroleum production, it is not only the Radium in the "produced water"[30] that is a source of radioactive pollution.[31] Rather, Radium (^{226}Ra) dissolves out of naturally Uranium-bearing rocks, and into the aqueous solutions[32] that are in petroleum reservoirs. Radium passes through oilfield equipment on a continual basis, and some of the Radium in the production stream spontaneously decays to Radon (^{222}Rn).[33] The Radon has a half-life of a little less than 4 days. Within hours after Radon's decay to Polonium (^{218}Po) it turns into radioactive lead (^{210}Pb). The result is a waste stream with many different radioactive substances.

The chemistry of the different elements will be different. As a result, the different radioactive substances can end up in different parts of an industrial process. Radium is a "group IIA" element—that is, it appears on the periodic table in the same group as Magnesium and Calcium. Therefore, basic principles of chemistry tell us that Radium tends to behave chemically like Calcium and Magnesium; it forms salts and dissolves well in water. Radon, however, is in the "Noble Gas" series—which means that it does not tend to chemically react

26. RONALD L KATHREN, RADIOACTIVITY IN THE ENVIRONMENT: SOURCES, DISTRIBUTION AND SURVEILLANCE 56 (Harwood 1984).

27. Note, that where ever a superscripted number precedes an element's symbol, this number is the isotopic number, and for the purposes of this article, the element can be assumed to be radioactive.

28. Radium daughter for Uranium and Thorium is different. Chemically, both forms of Radium will act in the same manner. But, they have different rates of radioactivity and they have different half-lives. *See generally* DOUGLAS, MCDANIEL & ALEXANDER, *infra* note 34.

29. This paragraph is derived primarily from RONALD L KATHREN, *supra* note 26 at 54-63.

30. Produced water is brought to the surface when oil and gas is produced.

31. In this hypothetical example, the source of radiation is Uranium. In any case, Uranium and Thorium are relatively insoluble in water or in hydrocarbons and they tend to remain in the reservoir rocks when oil and gas are produced. DIFFUSE NORM STUDY, *supra* note 1 at B-5-1.

32. UNION OF CONCERNED SCIENTISTS, THE NUCLEAR FUEL CYCLE 47 (MIT Press 1975).

33. This example uses the decay series for ^{238}U. The Uranium (^{238}U) and Thorium (^{232}Th) decay series are the principal decay series of NORM that are associated with the exploration and production of petroleum. Diffuse NORM Study, *supra* note 1 at B-5-1.

easily. Lead, on the other hand, is a metal and acts much like Tin—its neighbor in group IVB on the periodic table.[34]

We can then imagine a hypothetical NORM waste stream in the oilfield with radioactive Radium either dissolved or dispersed in the produced water from petroleum operation.[35] The produced water is a continuous stream and the Radium will be spontaneously decaying, ultimately creating Radon (^{222}Rn) radioactive Lead (^{210}Pb), radioactive Bismuth (^{210}Bi) and radioactive Polonium (^{210}Po). The Radium might be incorporated directly into the salt scales that often deposit on the metal surfaces of petroleum production equipment. The Lead, Bismuth and Polonium might deposit directly on production, refining or transportation equipment, or they might be incorporated into salts either in solution, or in scales on pipe, pump and tank walls and sludge.[36]

The Radon goes on as part of the hydrocarbon stream since it is a gas and physically behaves like light hydrocarbons that are also gasses under atmospheric temperatures and pressures.[37] As the Radon moves with the petroleum, an equilibrium begins to form between the Radon and its decay products. It is important to note that petroleum gasses that are thought to contain Radon are usually allowed to decay for enough time to allow the Radon to change to an element that does not stay in the petroleum stream.[38] Nonetheless, Radon has been measured in the exhaust from natural gas, and the use of natural gas is thought to deliver "an average annual tracheobronchial dose equivalent of 54 mrem, with a maximum of 4.25 rem."[39]

The chemistries of these different decay products, and the fact that they each exist in some petroleum waste streams makes dealing with NORM wastes a potentially complex undertaking. While the clean-up might be made more complicated by NORM's changing character, the potential that NORM has for impacting human health is also made more complex. Since the chemistry of each daughter product is different, the differing chemistries may allow for different pathways for human exposure.[40]

The analysis—in terms of human health effects—becomes even more complex when the type of radiation is considered. Most radiation energy takes the form of alpha particles, beta particles, or gamma radiation.[41] Alpha particles are two protons and two neutrons and have a high velocity when emitted from a radionuclide.[42] They travel two to three inches in air, but because of their large

34. The relative chemistries of these elements is derived from BODIE DOUGLAS, DARL H. MCDANIEL & JOHN J. ALEXANDER, CONCEPTS AND MODELS OF INORGANIC CHEMISTRY (John Wiley & Sons 2 ed. 1983).

35. This hypothetical also has Uranium in the source rock, *see supra* note 28.

36. DIFFUSE NORM STUDY, *supra* note 1, at B-5-10 to B-5-21.

37. Radon has a similar partial pressure to light hydrocarbons and therefore moves with natural gas. DIFFUSE NORM STUDY, *supra* note 1, at B-5-13.

38. Industry practice dictates that the Radon should be decayed out of the gaseous fraction of the petroleum stream. Conversation with Peter Gray at the Cracker Barrel Restaurant in Tulsa, OK on Oct 16, 1997.

39. RONALD L KATHREN, *supra* note 26, at 54-63.

40. DIFFUSE NORM STUDY, *supra* note 1, at A-10 to A-11.

41. SAMUEL GLASSTONE & WALTER JORDAN, NUCLEAR POWER AND ITS ENVIRONMENTAL EFFECTS 9 (1980).

42. *Id.*

relative mass they are unable to penetrate far beyond the human skin, unless they are ingested.[43] Beta particles are free electrons, which are given off when the nucleus of an atom spontaneously changes.[44] Beta particles have the potential to move several feet in air and can penetrate the skin and bodily tissue to a fraction of an inch.[45] Gamma rays are photons of electromagnetic radiation that have the ability to penetrate dense materials such as rocks, walls, and biological tissues.[46] Any one of these radiations travels though space in a certain range of frequencies.[47] The exact frequency is determined by the source. Most radiation sources emit more than one type of radiation, and they may emit the same types of radiation at more than one frequency.[48]

When alpha and beta particles pass through matter they remove an electron from the atoms present in the material, leaving "positively charged residues called *ions*."[49] This process is known as *ionization*; alpha particles, beta particles, and gamma rays are classified as *ionizing radiations*.[50] These different types of radiations are emitted by sources—the radioactive elements and isotopes that we have been discussing. Because radiation imparts energy, it is measured by this energy. As is discussed below in part IV units of source measurement were developed, and today these measurements are expressed as Rads (R)[51] or Grays (Gy).[52]

The concept of penetration by radiation is a tricky one because the problem is not just radiation penetration—it is radiation absorption.[53] If radiation just passed right through everything, it wouldn't really matter because it would not ionize anything, and it would not cause any injuries. In fact, we wouldn't even be able to measure it because no energy would be imparted to substances. In principle, less penetration means more absorption.[54] While alpha and beta particles have relatively low penetrating abilities, gamma rays can pass entirely through objects. The inability to penetrate means that the energy contained in the less penetrating radiations is more completely absorbed by the objects it is incident upon.[55]

"Radiation quality" is roughly the idea that some radiations have a greater

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43. *Id.*
44. *Id.*
45. *Id.*
46. GLASSTONE & JORDAN, *supra* note 19, at 11.
47. NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, THE RELATIVE BIOLOGICAL EFFECTIVENESS OF RADIATIONS OF DIFFERENT QUALITY REPORT 10 (Dec. 15, 1990).
48. RONALD L KATHREN, *supra* note 26, at 46-53.
49. GLASSTONE & JORDAN, *supra* note 19, at 11.
50. *Supra* note 47, at 28-48.
51. A Rad is 100 ergs of energy that is absorbed per gram of absorbing tissue. An erg is a basic unit of energy. JOHN W. GOFMAN, RADIATION AND HUMAN HEALTH 46 (Sierra Club 1981).
52. A Gray is 1 joule of energy absorbed per kilogram of absorbing tissue. Again, a joule is a basic unit of energy. *Id.* The Gy is related to the R because 1 joule equals 10 million ergs. After completing the conversion, there are 100 R per Gy. To see the conversion, *see id.*
53. *See generally id.*
54. Health physicists call this "Linear Energy Transfer (LET)." Alpha radiation is a high-LET radiation. Roughly, the idea is that energies that are absorbed in matter tend to transfer their energy to the matter in the absorption. *Id.* at 2.
55. JOHN W. GOFMAN, *supra* note 51, at 46.

effect on biological tissue than others do. Alpha radiations are of much higher absorbing quality than[56] gamma radiations—for the same reason they do not penetrate well—because they are absorbed. The result is that for the same amount of a radiation source, alpha radiations are likely to have greater effects on biological tissue that gamma radiations do. The term that describes this is "Relative Biological Effectiveness ("RBE").[57] The RBE and the R together create a new unit, the rem (r).[58] The rem is a measure of dose. Where the Rad measures the source of radiation, the rem measures how much radiation is absorbed by biological tissue. This can be expressed mathematically, and the concept is best understood in terms of an equation:

$$\text{rem} = (\text{Rad}) * (\text{RBE})$$

The RBE is different for each different type of radiation, and for each different type of absorbing medium and even for each different type of radiation effect that is being investigated.[59] As we have seen above, determining ways that NORM might impact human health can be complex. Now it seems that for all the characterization in the world, the exact measurement of radiation absorption as a rem is even more complicated because the calculation requires knowledge of the biological tissue that is absorbing the energy. Because there may not be a way to adequately know exactly what tissue might be impacted, or even the exact mix of radioactive isotopes that serve as the radioactive source, the rem is only an approximation when used to describe the environmental effects of radiation.[60]

B. Pathways of Exposure

People come in contact with NORM through a number of different sources including soil derived from rocks that once contained some radioactive source. Some of the pathways by which radioactive materials from soil may enter the human body include breathing contaminated dust, eating crops, meat, milk and poultry, drinking contaminated water, and the intake of contaminated fish, shellfish, and seaweed.[61]

Radionuclide concentrations depend on their source, their chemical behavior, and the status of the environment they are entering.[62] Water is an impor-

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56. The term "Relative Biological Effectiveness (RBE)" is highly dependent on the amount of energy that is absorbed by the medium. *See generally*, *supra* note 46.

57. JOHN W. GOFMAN, *supra* note 51, at 47.

58. Many of the state and Federal regulations refer to mrem, which are simply 1/1000 of a rem, e.g., 1 rem = 1000 mrem. *See, e.g*, Standards for Protection Against Radiation, 10 C.F.R. § 20.1101 (1997).

59. JOHN W. GOFMAN, RADIATION AND HUMAN HEALTH 47 (Sierra Club 1981).

60. *Id.* Because the amount of absorbed radiation is dependant upon so many factors, the NRC's regulations set occupational limits for the activity of sources of radioactive materials that, if incident upon a person or an organ, will result in their absorption of the maximally allowed radiation dose. *See* Standards for Protection Against Radiation, 10 C.F.R. pt. 20 at app. B (1997).

61. Y. Yamamoto, *Soil-Borne Radionuclides*, *in* RADIONUCLIDES IN THE FOOD CHAIN 120 (M.W. Carter, ed. 1988). The accumulation of radionuclides in food chains, particularly leading to humans can be very long and complex. R.J. Penreath, *Radionuclides in the Aquatic Environment*, *in* RADIONUCLIDES IN THE FOOD CHAIN 99 (M.W. Carter ed., 1988).

62. R.J. Pentreath, *Radionuclides in the Aquatic Environment*, *in* RADIONUCLIDES IN THE FOODCHAIN 99

tant medium by which people are exposed to NORM radionuclides. Water can dissolve radioactive substances from rocks and soil. One example of this occurs with the production of petroleum that often contains saline or "produced water."[63] Produced water discharged into fresh-water streams and coastal waters and can raise the level of Radium isotopes.[64] NORM might also affect drinking water sources by leaching from waste piles, or by leaking from pipes or waste repositories.[65] NORM radionuclides have been discovered in oceans, lakes and rivers.[66] The study of some fish shows that some radioactive materials can bioaccumulate in aquatic environments.[67]

Air can also provide an important pathway for human exposure to NORM. Radon is a gas, which if confined can provide the source for radiation doses.[68] The inhalation of Radon can be particularly damaging, and the EPA has studied its health effects in detail.[69] The air can also be a conduit for dust inhalation[70] from soil or mining wastes.[71]

Regardless of the pathway, NORM usually takes a particulate or gaseous form and the greatest risk of harm is not usually from external exposure. Rather the greatest risks are usually associated with the ingestion of radioactive materials.[72]

C. Health Effects of Radiation

1. Cancer Health Effects

The knowledge that ionizing radiation causes biological damage has existed for quite some time. Radiation's adverse effects on the human body were noticed shortly after radioactivity's discovery. For instance, Madame Curie and other scientists studying radiation died of leukemia.[73] The first cancers recognized as being induced by radiation were on the skin of pioneer radiation workers, beginning as "chronic radiodermatitis."[74] There are no historical records of

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(M.W. Carter, ed. 1988).

63. AMERICAN PETROLEUM INSTITUTE, PUB. NO. 4532, PRODUCED WATER RADIONUCLIDE HAZARD/RISK ASSESSMENT PHASE I 1 (1991) (This study predicts the dose and potential health and environmental effects of exposure to Radium from data about actual discharges in Louisiana.).

64. *Id.*

65. DIFFUSE NORM STUDY, *supra* note 1, at D-1-20.

66. R.J. Pentreath, *supra* note 61, at 99.

67. Y. Yamamoto, *supra* note 61, at 120; AMERICAN PETROLEUM INSTITUTE, PUB. NO. 4532, PRODUCED WATER RADIONUCLIDE HAZARD/RISK ASSESSMENT PHASE I 55-80 (1991).

68. See generally, ENVIRONMENTAL PROTECTION AGENCY, DOC. NO. 520/7-79-006, RADIOLOGICAL IMPACT CAUSED BY EMISSIONS OF RADIONUCLIDES INTO AIR IN THE UNITED STATES (1979).

69. ENVIRONMENTAL PROTECTION AGENCY, AN SAB REPORT, FUTURE ISSUES IN ENVIRONMENTAL RADIATION REPORT ON FUTURE ISSUES AND CHALLENGES IN THE STUDY OF ENVIRONMENTAL RADIATION, WITH A FOCUS TOWARD FUTURE INSTITUTIONAL READINESS (March 1995).

70. JOHN W. GOFMAN, *supra* note 51, at 477-494 (discussing plutonium dust and lung cancer).

71. See generally, James Kuntz, *Nuclear Incidents on Indian Reservations: Who Has Jurisdiction? Tribal Court Exhaustion v. The Price-Anderson Act*, 21 AM. INDIAN L. REV. 103 (1997).

72. *See* AMERICAN PETROLEUM INSTITUTE, PUB. NO. 4532, PRODUCED WATER RADIONUCLIDE HAZARD/RISK ASSESSMENT PHASE I (1991); JOHN W. GOFMAN, *supra* note 51, at 42-45.

73. *See infra* note 190 and accompanying text.

74. P. BROWN AMERICAN MARTYRS TO SCIENCE THROUGH THE ROENTGEN RAY (Charles C. Thomas 1936); S.A. Henry, *Cutaneous Cancer In Relation To Occupation*, 7 ANNUAL REVIEW COLLEGE OF SURGERY,

the associated doses. However, children whose ringworm of the scalp was treated with X-rays developed basal cell carcinomas from exposures of 0.1-0.5 Gy (10-50 rads).[75] Interestingly, the basal cells occurred on the face, where the effects appeared to be enhanced from previous ultraviolet ray exposure, rather than on the scalp where the dosage was greatest.[76]

NORM human health threats are of a stochastic (not immediately evident) nature because the source of radioactive material in NORM is usually quite "diffuse" and relatively "inactive." Nevertheless, the accumulated dose can be quite large.[77] If a source of Radium is ingested, it could lodge in a particular part of the body where radiation could be absorbed at a rate of 2 mrem per hour. This seems like an innocuous exposure. However, if the source remains in the body for one year an accumulated dose of 175 rems would result, clearly putting the person at high risk of developing cancer during his lifetime and at risk from other health problems.

One of the most famous examples of occupational radiation exposure occurred early in this century when the effects of radiation were not well understood by the public.[78] Young women painted the faces of watches and clocks with Radium so they would glow in the dark.[79] The women would tip the bristles of the brushes on their tongues to form a fine point. Many of these women later in life developed bone sarcomas and other malignancies from the ingestion of Radium, which accumulated in their bones.[80]

Additional evidence concerning the long-term effects of radiation on the human body has been accumulated since World War II. This data comes from the studies of effects of the atomic bombs dropped on Japan,[81] and the Marshall Islands,[82] and follow-up studies of patients treated by radiation therapy for tinea capitis (scalp ringworm), ankolosing spondilitis, tuberculosis or cervical cancer.[83] The nuclear power plant accidents at Three Mile Island and Chernobyl also provide additional information on the possible health effects of radiation.

ENGLAND. 245 (1950); BIER V, *infra* note 85, at 325.

75. R.E. Shore, et al., *Skin Cancer Incidence Among Children Irradiated for Ringworm of the Scalp*. 100 RADIATION RESEARCH 192 (1984); BIER V, *infra* note 85, at 325.

76. N. Harley, et al., *Epidemiology Related to Health Physics: The Skin Dose and Response for the Head and in Patients Irradiated with X-Ray for Tinea Capitis: Implications for Environmental Radioactivity*, 16 MIDYEAR TOPICAL MEETING OF THE HEALTH PHYSICS SOCIETY, CONF-8301 125-142 (1983). BIER V, *infra* note 85, at 325-326. R.E. Shore, et al., *Skin Cancer Incidence Among Children Irradiated for Ringworm of the Scalp*. 100 RADIATION RESEARCH 192 (1984). BIER V, *infra* note 85, at 325.

77. JOHN W. GOFMAN, *supra* note 51, at 47-49.

78. Dr. Gofman called the use of Radium in watches "use first, learn later." JOHN GOFMAN, *supra* note 51, at 432.

79. Allan Mazur, *Why Do We Worry About Trace Poisons?*, RISK: HEALTH, SAFETY AND ENVIRONMENT 35, 38 (1996).

80. *Id.*

81. BEIR V, *infra* note 85; COMMITTEE FOR THE COMPILATION OF MATERIALS ON DAMAGE CAUSED BY THE ATOMIC BOMBS IN HIROSHIMA AND NAGASAKI, HIROSHIMA AND NAGASAKI 202 (1981) [hereinafter HIROSHIMA AND NAGASAKI].

82. J. EDWARD RALL, ET AL., REPORT OF THE NATIONAL INSTITUTES OF HEALTH AD HOC WORKING GROUP TO DEVELOP RADIOEPIDEMIOLOGICAL TABLES 15 (U.S. Dept. of Health and Human Serv. 1985).

83. *Id.* at 27-30.

The official guidance for estimating risk of radiation exposure has been provided by the National Research Council.[84] Their committees on the biological effects of low doses of radiation issued six apparently authoritative reports, and a letter report, the latest this year.[85] The focus of each was on the excess risk of cancer death from gamma and X-ray exposures, using epidemiological studies of A-bomb survivors, and survivors of therapeutic treatment of various diseases.[86] Estimates have been consistently revised upward, being three times larger for solid tumors and four times larger for leukemia in 1990 compared to 1980.[87]

Although the BEIR reports appear to be comprehensive, the Committee acknowledges otherwise.[88] For lack of laboratory and epidemiological information, the committee adopted a linear model for the dose-effect relationship, whereas smaller doses may cause proportionately more serious effects in a total population.[89] There is evidence, convincing to some scientists, of a supralinear effect of very low doses.[90] Without question, the epidemiological study of the A-bomb survivors is incomplete until all have died and most were still alive in 1990—at the time of the BEIR V report. Those irradiated as children or in utero will now be entering the years of greatest risk. Follow-up of survivors has

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84. EDWARD RALL, ET AL., *supra* note 82, at 15 (U.S. Dept. of Health and Human Serv. 1985) (referencing "authoritative reports [such] as the 1980 (BEIR III) report of the National Academy of Sciences"). To access the most recent NAS reports on the Biological Effectiveness of Ionizing Radiation (BEIR) visit http://www.nas.edu.

85. COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, THE EFFECTS ON POPULATIONS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION (BEIR) (1972); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCG COUNCIL, CONSIDERATIONS OF HEALTH BENEFIT-COST ANALYSIS FOR ACTIVITIES INVOLVING RADIATION EXPOSURE AND ALTERNATIVES (BEIR II) (1977); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, THE EFFECTS ON POPULATIONS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION (BEIR III) (1980); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, HEALTH RISKS OF RADON AND OTHER INTERNALLY DEPOSITED ALPHA-EMITTERS (BEIR IV) (1988); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, HEALTH EFFECTS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION (BEIR V) (1990); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, HEALTH EFFECTS OF EXPOSURE TO RADON (BEIR VI) (1998); COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION, NAT'L RESEARCH COUNCIL, HEALTH RISKS FROM EXPOSURE TO LOW LEVELS OF IONIZING RADIATION: BEIR VII, PHASE I, LETTER REPORT (1998) (visited March 28, 1998) < http://www.nap.edu/readingroom/>.

86. BEIR VII, PHASE I, LETTER REPORT, *supra* note 85, at 1-5.

87. BEIR V, *supra* note 85, at 1-8.

88. BEIR VI, *supra* note 85, at 5.

> Quantitative estimates of the lung cancer risk imposed by Radon are subject to uncertainties—uncertainties that need to be understood in using the risk projections as a basis for making risk-management decisions (see table ES-5). Broad categories of uncertainties can be identified, including uncertainties arising from the miner data used to derive the lung-cancer risk models and the models themselves, from the representation of the relationship between exposure and dose, from the exposure-distribution data, from the demographic and lung-cancer mortality data, and from the assumptions made in extending the committee's models from the exposures received by the miners to those received by the general population. The committee addressed those sources of uncertainty qualitatively and, to a certain extent, quantitatively.
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> The committee's models may not correctly specify the true relationship between Radon exposure and lung cancer risk.

BEIR VI, *supra* note 85, at 5.

89. JOHN W. GOFMAN, RADIATION AND HUMAN HEALTH 385 (Sierra Club Books 1981).

90. *Id.*

shown that the relative risk increased with attained age.[91] Another way of saying this is that radiation doses that accumulate when the person is young have the greatest chance of becoming cancers later in that person's life.[92]

The radiation cancer-risk for individuals with particular exposures can also be estimated. This estimation is perhaps easier to understand from an individual's perspective. Modeling from the A-bomb data, a 24 year old male radiologist, accidentally exposed to 78 rads of whole body radiation, could have a 39% chance of developing cancer in his lifetime. A 32 year-old male, accidentally exposed to 288 rads of radiation, could have a 100% chance.[93] If extrapolated to low doses, a nuclear power plant worker, age 26, receiving approximately the allowable annual dose prior to 1991, or approximately 5 rads per year for just five years, might have an additional 10% risk of developing cancer. This is a significant health risk for five years of employment, and it underestimates—by as yet unknown amounts—the worker's total health risk.

2. Non-Cancer Health Effects

Radiation's involvement in non-cancer health ailments is less widely understood than its involvement in carcinogenesis. And, as was discussed above, even radiation's role in carcinogenesis is only poorly understood.[94] There is, however, some literature that is relevant to this issue. In 1964, the Atomic Energy Commission published an encyclopedia of biological effects from radiation exposure.[95] The effects described range from changes in the blood that result from relatively low doses to radiation illness syndrome and immediate death resulting from high (600 rem) whole body penetrating doses.[96]

Only the least exposed and healthiest residents of Hiroshima and Nagasaki survived the thermal blast, radiation exposure and social disruption. Of the 91,231 survivors, the average age was 28.4 years and approximately 66,000 received a dose of less than 10 rems.[97] Those survivors showed a very wide range or ailments, including, but not limited to, cancer.[98] After the Japanese bomb blasts a large population existed who had been exposed to radiation and who had lived through the exposure.[99] The event, as tragic as any in human

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91. *Id.* at 271.
92. *Id.* at 289-323.
93. *Id.*
94.

> Information on Radon carcinogenesis comes from molecular, cellular, animal, and human (or epidemiologic) studies. Radiation carcinogenesis, in common with any other form of cancer induction, is likely to be a complex multistep process that can be influenced by other agents and genetic factors at each step. Since our current state of knowledge precludes a systematic quantitative description of all steps from early subcellular lesions to observed malignancy, the committee used epidemiologic data to develop and quantify an empirical model of the exposure-risk relationship for lung cancer. The committee did draw extensively, however, on findings from molecular, cellular, and animal studies in developing its risk assessment for the general population.

BEIR VI, supra note 85, at 2.

95. ATOMIC ENERGY ENCYCLOPEDIA IN THE LIFE SCIENCES (Charles Shilling ed., 1964).
96. *See generally id.*
97. JOHN W. GOFMAN, *supra* note 51, at t. 26-E.
98. HIROSHIMA AND NAGASAKI, *supra* note 80, at 8 & 86 to 251.
99. *See generally* Hiroshima and Nagasaki *supra* note 80.

experience, yielded some very important observations concerning radiation's effect on the human body. Distances from the bomb's hypocenters were drawn in some studies and the human dose at those distances was approximated.[100] The resulting data, in any event, provides a *qualitative* description[101] of the types of health effects that can result from radiation exposure.[102] The inventory of these maladies includes blood disorders, immuno-deficiency, anemia, ocular lesions,[103] disorders of the ovaries, abnormal menstrual cycles, birth disorders, complications with the proper growth of fetus, microencephaly, mental retardation, changed childhood growth and development, enamel hypoplasia, matured children grew to be smaller than those who were not exposed, mental disorders, complaints of fatigue liver dysfunction, gastrointestinal disease, endocrinological diseases, and cardiovascular disorders.[104]

Forty years later another tragic event, the Chernobyl accident, exposed hundreds of thousands of Russian and Eastern Europeans to ionizing radiation. The Russian registry of those who have been exposed numbers 435,276 people.[105] The recently published Chernobyl data supports the observations that were made at Hiroshima and Nagasaki: Non-cancer health effects did result from exposure to radiation from Chernobyl.[106] The Chernobyl data clearly shows that individuals who participated as "liquidators" of the former power plant experienced the same litany of health effects, experiencing 5 times a greater incidence of general health disorders than the general Russian population.[107] These liquidators clearly were exposed to high levels of radioactivity, and it can be inferred that they received large radiation doses.

Whether the same non-cancer health effects are seen at lower doses may still be an unsettled issue, and hopefully one on which the NAS will require some study. The Chernobyl data does suggest an answer. Studies have also been completed of people who merely lived in the countryside surrounding Chernobyl. Some of these individuals were at a great distance from the plant, and one study estimated that region was contaminated with radioactivity around 15 Ci/km2.[108] Although 15 Ci of radioactivity is quite a strong source, when spread over 1 square kilometer it becomes quite "diffuse." The dose that any

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100. Hiroshima and Nagasaki, *supra* note 80, at 8.
101. Hiroshima and Nagasaki, *supra* note 80, at 186-251.
102. Dr. Alice Stewart recently criticized the quantitative aspects of the Japanese Bomb data, and she is cited earlier for that proposition. This section is using the same data for a purpose that it is suited–the qualitative discussion of different health effects that might result from radiation exposure. In other words, Dr. Stewart said that the Bomb data is not useful for the third and fourth level of risk analysis–but it probably is good enough to use in the debate that relates to the first two stages of risk analysis–particularly the first stage, risk characterization. Rob Edward, *Living Dangerously: Standard Radiation Safety Limits Used Around the World may have to be Revised to Protect the Young and Old*, NEW SCIENTIST, February 28, 1998, at 12.
103. "The lens of the eyes are especially sensitive to radiation," Hiroshima and Nagasaki, *supra* note 80, at 203.
104. Hiroshima and Nagasaki, *supra* note 80, at 186-251.
105. Human Health, *infra* note 112, at 13.
106. Human Health, *infra* note 112, at 17.
107. Human Health, *infra* note 112, at 17.
108. T.V. Belookaya, et al., *Dynamics of State of Health for Children's Population of Belarus under Present-day Environmental Conditions*, *in* HUMAN HEALTH *infra* note 112, at 206-218.

individual might receive from the 15 Ci source would be spread out over a long period of time, and in the result the doses to humans in the countryside around Chernobyl might be similar to the types of doses that result from NORM exposure. In any event radiation sources in the Chernobyl countryside are lower in activity than at either the Japanese bombings or at the site of the Chernobyl accident.

Nonetheless, individuals in the Russian countryside have exhibited the same types of non-cancer health effects that were first observed in Japan and later among the Chernobyl liquidators.[109] The Chernobyl researchers have documented immune system deficiency, enhanced fatigue, frequent viral infections, blood and circulatory disease, asthma, rheumatism, respiratory diseases, urinary and skin diseases, bone and muscle diseases, and alimentary organ diseases.[110]

The U.S. Department of Energy has recently solicited joint studies by American and Russian scientists of exposed Russian populations in order to refine risk estimates on a molecular level.[111] Recent developments in molecular biology make possible the scoring of chromosome abnormalities to reliably establish, years afterward, the dosage at exposure.[112] The workers at the Mayak nuclear facility and the surrounding population, exposed to radiation developing nuclear weapons in the "cold war"[113] have been studied by the Russian Academy of Sciences in Moscow.[114] Investigations have also been made of the effects of the Chernobyl accident on fetuses and children.[115] In the "children of Chernobyl" an excess incidence of metastic thyroid cancer, increased diabetes in children, increased congenital defects, and a declining birthrate is well-documented.[116]

Frequent experiences of intense anxiety of nearby residents after the Three Mile Island and Chernobyl accident have been alternatively attributed to psychological and physiological mechanisms.[117] Radiation (as described in the

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109. I.V. Oradovskay, *Clinical and Immunological Indices in Health Estimation of Adult Population in Bryansk Region Localities Contaminated with Radionuclides as a Result of Accident at the Chernobyl Nuclear Power Station, in* Human Health *infra* note 112, at 154.

110. I.V. Oradovskay, *Clinical and Immunological Indices in Health Estimation of Adult Population in Bryansk Region Localities Contaminated with Radionuclides as a Result of Accident at the Chernobyl Nuclear Power Station, in* Human Health *infra* note 112, at 154.

111. Department Of Energy, Energy Research Financial Assistance Program Notice 98-11; Cellular Biology Research Program—Mechanisms of Cellular Responses to Low Dose, Low Dose-Rate Exposures, 63 Fed. Reg. 7775-01 (1998).

112. Vladamir Schevchenko & G.P. Signirova, *Cytogenic Effects of Ionizing Radiations on Human Populations, in* HUMAN HEALTH 23 (Russian Academy of Sciences E.B. Burlakova, Ed. 1996).

113. "The Mayak disaster in 1957 created one billion curies of radioactive waste, which is either in underground containers or reservoirs." Karen DaPonte, et al., *Foreign Publications and Book Summaries*, 8 GEO. INT'L ENVTL. L. REV. 375, 378 (1996).

114. Vladamir Schevchenko, Draft Research Proposal: Genetic and Carcinogenic Effects of Chronic Irradiation (Feb. 3, 1998) (on file with author).

115. T.V.Belookaya, et al., *Dynamics of State of Health for Children's Population of Belarus Under Present-day Environmental Conditions, in* HUMAN HEALTH, *supra* note 112, at 206, 211 (describing the "children of Chernobyl"); L.S. Baleva, et al., *Chernobyl and Child's Health, in* HUMAN HEALTH, *supra* note 112, at 219.

116. T.V.Belookaya, et al., *Dynamics of State of Health for Children's Population of Belarus Under Present-day Environmental Conditions, in* HUMAN HEALTH, *supra* note 112, at 206, 212.

117. SOHEI KONDO, HEALTH EFFECTS OF LOW-LEVEL RADIATION 19-25 (1993).

AEC encyclopedia) was observed to affect the endocrine system so as to create an "alarm reaction" or "stress syndrome."[118] At the time of the AEC's investigation, radiation's role in this stress effect was poorly understood.[119] It may be that fear alone results from nuclear catastrophes. Or, it may be that even relatively low doses of radiation can cause an endocrine response that causes the feeling of fear. An adequate study of this effect has not been forthcoming from the author's research. This aspect of radiation exposure needs to be resolved because different societal, legislative or regulatory responses would be required to deal with the different causes.

New light is also coming to the issues surrounding radiation's role in the development of diseases other than cancer.[120] For a long period of time it has been known that radiation can suppress the immune system.[121] However, it was assumed from the Japanese bomb survivor data that the immune system is only compromised when the dose is very significant.[122] New data that is being developed from health studies of populations who live at a distance from the Chernobyl accident site suggests that serious health effects may result from relatively small doses of radiation.[123] The effects on the immune and hormonal systems from moderate doses (50 rems) are informative in that these systems modulate disease in the body. If these systems fail to work properly, life may be shortened. In Russia, the non-cancer health problems that resulted from radiation exposure around Chernobyl are becoming more clearly understood as studies of the Chernobyl survivors continue.[124]

In the United States, the NAS is just coming alive to the problems of non-cancer health effects from radiation in their periodic reports of the Biological Effects of Ionizing Radiation.[125] "Cancer is the unusual result from exposure to radioactive materials," says Dr. Thomas Callander of Shreveport, La. Dr. Callander treats a number of NORM patients in his practice.[126] In conversation with the author, he related that many of his NORM patients have health problems resulting from radiation exposure that run the gamut from immuno-deficiency and respiratory aliments to micro-fractures of the bone and arthritis.[127]

The "new learning" concerning the non-cancer health effects from radiation is taking place in Russia[128] and it is beginning to be understood in the United States by medical practitioners and through the National Academy of Sciences.

118. *Id.* at 140.

119. *Id.*

120. *See generally* HUMAN HEALTH, *supra* note 112.

121. HIROSHIMA AND NAGASAKI, *supra* note 80.

122. Because the bomb blasts released huge amounts of radioactivity in a relatively small area, the biological results from those radiation exposures could only be related to high-dose exposures. HIROSHIMA AND NAGASAKI, *supra* note 80.

123. E.B. Burlakova, *Introduction, in* Human Health, *supra* note 112, at 9.

124. *See generally* CONSEQUENCES OF THE CHERNOBYL CATASTROPHE: HUMAN HEALTH (Russian Academy of Sciences E.B. Burlakova, ed. 1996).

125. For instance, from pages 352-370 of BEIR V the focus is placed upon cataracts effects, life shortening and fertility problems. *See* BIER V, supra note 85.

126. Conversation between Dr. Callander and Mr. Aamodt on Sept. 8, 1997.

127. *Id.*

128. *See generally supra* note 112.

It should be a part of the study of NORM that the NAS recommends in its study of NORM regulation because it is a radiation effect that has been "left out" of the regulatory analysis.

Radioactivity has many more health consequences than cancer. The case studies that are discussed above relate to the NORM problem only for the reason that they provide empirical data on the human health effects caused by radiation in the environment. It is clear from the review of the NORM literature, and from a review of almost all literature that relates to radiation exposure, the focus is on cancer.[129] The study of NORM health risks should include the study of non-cancer health effects. Non-cancer health effects are something that the National Academy of Sciences should find has been "left out" of the study and regulation of NORM health effects, and of radiation health effects in general.

D. Risk Analysis and NORM

Risk means different things to different people.[130] A risk analyst might define risk as "the probability of an adverse event."[131] Environmental risk analysis has developed into a decision making tool to aid legal and policy choices that must be made about public exposure to pollutants.[132] Risk assessment is often referred to as a combination of established disciplines including biostatistics, economics, epidemiology, demography and toxicology.[133] The goal of risk assessment is to determine (1) the *probability* that an individual will suffer disease or death as a result of a specified exposure to a pollutant; and (2) the *consequences* of such an exposure to an entire population.[134]

Risk assessment is different from risk management. While there is an interconnection between the two, risk assessment tries to characterize the risk in qualitative terms. More specifically, it uses scientific research to try to define the probability of harm an individual or a population will suffer as a result of exposure.[135] Risk management, on the other hand, is the process of deciding what to do where a risk or group of risks has been determined to exist. Policy decisions are required to manage the risk in light of legal, economic, social, political and scientific factors.[136]

In its most basic model, risk assessment is a four-step process:

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129. The EPA notes "Cancer is the major effect of concern from radionuclides . . . ." (accessed March 15, 1998)<http://www.eap.gov/ttnuatwl/hlthef/radionuc.html>.

130. Many articles have been written about risk perception. For an interesting examination of differing risk perceptions, see Howard Margolis, *A New Account Of Expert/Lay Conflicts Of Risk Intuition*, 8 DUKE ENVTL. L. & POL'Y F. 115 (1997).

131. THOMAS J. SCHOENBAUM & RONALD H. ROSENBERG, ENVIRONMENTAL POLICY LAW: PROBLEMS, CASES AND READINGS 623 (3d ed. 1996)[herinafter SCHOENBAUM & ROSENBERG].

132. *Id.*

133. CARNEGIE COMMISSION ON SCIENCE, TECHNOLOGY, AND GOVERNMENT, RISK AND THE ENVIRONMENT: IMPROVING REGULATORY DECISIONMAKING 76-79 (1993) [hereinafter RISK AND THE ENVIRONMENT].

134. *Id.*

135. William D. Ruckelshaus, *Risk in a Free Society*, 14 ENVTL. L. REP. 10190 (1984).

136. *Supra* note 9.

1. *Hazard Identification*: where a qualitative determination is made as to the kinds of adverse health or ecological effects a substance can cause. Typically, agencies have focused on whether an "agent" (i.e., an industrial chemical, a natural product in the environment, or a particular lifestyle) increases a person's risk of developing cancer. Cancer is the effect that usually drives further analysis and regulation.[137]

2. *Exposure Assessment*: a determination is made as to the amounts of a substance to which a hypothetical person (usually the "maximally exposed individual") and/or the total population are exposed.[138]

3. *Dose-Response Assessment*: here, an estimate is made as to the probability or extent of an injury at the exposure levels determined above, by determining the "potency" of the chemical in question. Essentially, this step illustrates how the likelihood of *cancer* changes with the level of exposure.[139]

4. *Risk Characterization*: after the above steps have been determined, the numbers are integrated to yield an overall estimate that describes the nature of the adverse effects and the strength of the evidence. This is usually expressed numerically as the "lifetime risk of cancer due to a particular agent at a particular level of exposure."[140]

There is no doubt that regulatory agencies will continue to use risk analysis in setting exposure levels. Scientific questions require scientific justifications and this is the role that risk assessment plays in regulation. There are, however, some scientific questions that scientific methodologies cannot answer.[141] The exact effect of exposures to low doses of radiation is one such question. Risk assessment can be particularly useful if those who rely on it understand its nature and its limitations. Consequently, decision-makers should be made to understand where the limitations exist in the basic science, where assumptions were used in the assessment, and what policy values those assumptions reflect. Decision- and policy-makers must also understand that in many cases the assessment is really a quantified range, and that real risks will likely be significantly higher or lower than the average expressed.[142]

The free flow of information concerning the limits of risk assessment is as important as the risk assessment information itself. If policy-makers think that the science lying behind a risk assessment is "bullet proof"—and in fact it is

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137. RISK AND THE ENVIRONMENT, *supra* note 133, at 624.

138. RISK AND THE ENVIRONMENT, *supra* note 133, at 624.

139. RISK AND THE ENVIRONMENT, *supra* note 133, at 624 (emphasis added). Note, the traditional focus for risk assessment has been cancer. Should it continue to be? *See supra* Section II.C.2. Non-Cancer Health Effects.

140. Alon Rosenthal, et al., *Legislating Acceptable Cancer Risk from Exposure to Toxic Chemicals*, 19 ECOLOGY L.Q. 269, 278-279 (1992).

141. This ability for science to pose a question, but lack the ability to provide an answer creates what some commentators have called "trans-science." *See, e.g.*, Wendy Wagner, *The Science Charade in Toxic Risk Regulation*, 95 COLUMB. L. REV. 1613, 1620 (1995).

142. SCHOENBAUM & ROSENBERG, *supra* note 131, at 626.

not—they will have allowed the scientists to make the policy judgements for them in the form of "scientific assumptions."[143]

1. Low Doses of Radiation Can Cause Health Risks

A debate over the effects of low doses of radiation is resurfacing within the discussion of NORM.[144] This discussion relates to the third part of a general risk assessment—the determination of the dose-response relationship.[145] National and international radiation protection agencies have uniformly adopted the "linear, no-threshold" dose response theory.[146] But, other theories about the effects of radiation in the human body have been developed.[147] These theoretical viewpoints affect the assumptions that are built into risk assessment and regulation. For instance, if it is assumed that low doses of radiation do not adversely affect human health, or if the risks posed by low doses are viewed as not worthy of the cost of regulation, then, no mater what the scientific inquiry finds, regulation will not be developed to protect against low doses to radiation. Conversely, application of the assumption that even the minutest exposure to radiation holds the potential for risk of harm to human health logically develops very stringent regulations.

Part of the problem that exists in understanding risk is the way it is characterized. Some say that the potential for excess cancers as a result of exposures to low doses of radiation is so small that they do not merit the expense of regulation.[148] Some commentators say that the possibility of contracting a fatal cancer as a result of living near a nuclear power plant is so low that it doesn't hurt anyone.[149] And, at the same time, some risk commentators point out that a person who drives a car has a much greater chance of dying in a car crash than a person who is exposed to "low doses" of radiation has of getting cancer.[150] Therefore, these greater risks are thought to overshadow the lesser ones. If driving a car is thought such a great risk, then a person is likely to die in a car accident before they have a chance to develop a cancer. As we will see, this logic is flawed.

When it has been determined that some use of radioactive materials will cause 1 excess cancer fatality in 10,000 people, it can also be expressed as 1 chance in 10,000 for an individual to contract cancer from some risk. This "individual based" view of risk causes the risk to be perceived as small. This

143. To read about the affect that scientific assumptions have had on the Clean Air Act, see Joshua D. Sarnoff, *The Continuing Imperative (But Only From A National Perspective) For Federal Environmental Protection*, 7 DUKE ENVTL. L. & POL'Y F. 225, 309 (1997).

144. Peter Gray & Assoc., THE NORM REPORT (Summer/Fall 1997).

145. *See infra* notes 159 to 182 and accompanying text.

146. Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991).

147. Patterson, *Setting Standards for Radiation Protection: the Process Appraised*, 72 HEALTH PHYSICS 450 (1997). Bernard Cohen, *Low Level Radiation Regulations: Costs Far Outweighing Risks*, in Peter Gray & Assoc. THE NORM REPORT 21 (Winter 1998).

148. Bernard Cohen, *supra* note 147, at 21.

149. SOHEI KONDO, HEALTH EFFECTS OF LOW-LEVEL RADIATION 11-26 (1993).

150. RISK AND THE ENVIRONMENT, *supra* note 133, at 624.

individual-based analysis is misleading when authorities charged with protecting the public health use it. If it has been determined that some exposure to radioactivity will cause 1 cancer in a 10,000 persons, it really means that 1 cancer will result in that population of 10,000. Assuming that the risk analysis is correct, there is no uncertainty concerning how many cancers will occur.

Dr. Gofman, in one of his many writings on the effects of low doses of radiation, dispels the popular myth that low risks of cancer that translate to low risks for each individual mean there is little or no reason to regulate low doses of radiation.[151] Dr. Gofman addressed the idea of low doses corresponding to "low risks," carefully pointing out that "the difference between risk considered from an individual's point of view and from the point of view of public health is striking."[152] He succinctly put the problem this way:

> Not everyone who gets exposed to 100 millirads will develop a radiation-induced cancer. If we use 270 person-rads as the whole-body cancer dose for an equilibrium population of mixed ages,[153] we mean that if 2,700 people are each exposed to 100 millirads (an aggregate exposure of 270 person-rads), only one of them will get a radiation induced cancer. The dose will be "safe" for 2,699, and lethal for one! If the dose is doubled to 200 millirads, the risk of every individual doubles from one chance in 2,700 (or an individual risk of 0.00037) to two chances in 2,700 (an individual risk of 0.00074).
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>
> A small individual risk of 1 in 2,700 would translate into nearly 100,000 radiation-induced cancers if everyone in an equilibrium population of 250 million persons received a "low dose" of 100 millirads. That each of these 250 million individuals has only a risk of developing cancer does not mean that no one at all is harmed.[154]

In the Diffuse NORM study[155] the EPA estimated an additional 0.00012 (1 in 8,333) risk of developing cancer in a lifetime is caused by radiation exposures from oil and gas sludge and scale.[156] The EPA's assessment for oil and gas NORM waste is in the same order of magnitude[157] as Dr. Gofman's hypothetical that resulted in 100,000 excess cancer deaths in a population of

151. JOHN W. GOFMAN, *supra* note 51, at 412-13.

152. JOHN W. GOFMAN, *supra* note 51, at 412-13.

153. Earlier in his work, Dr. Gofman had, from a review of empirical evidence, deduced that an exposure to 270 rads of radiation would create, statistically, a 100% chance of a person of about 25 years developing a cancer. *See* JOHN W. GOFMAN, *supra* note 51, at ch. 9.

154. JOHN W. GOFMAN, *supra* note 51, at ch. 9.

155. DIFFUSE NORM STUDY *supra* note 1.

156. The DIFFUSE NORM STUDY earlier points out that more than 1 billion tons of NORM waste are generated by all industry sectors (DIFFUSE NORM STUDY, *supra* note 1, at ES-2), and that oil and gas production is responsible for about 260,000 metric tons of NORM waste each year (DIFFUSE NORM STUDY, *supra* note 1, at ES-6).

157. In English, the "same order of magnitude" translates to the same number of decimal places behind the zero, or to numbers that have the same number of decimal places. In this case, the risk of contracting cancer from NORM is 1 in about 2,000 while the risk in Dr. Gofman's example is about 1 in 8,000 . Although the hypothetical risk is about 4 times greater than the calculated NORM risk, one order of magnitude is a ten-times change.

250,000,000 (an additional risk of 0.00037, or 1 in 2,702).

The relation of Dr. Gofman's hypothetical to real-world excess cancers that might result from NORM wastes is highly dependent on the definition of the Critical Population Group (CPG).[158] If it is assumed that the CPG is likely to be small because not many individuals will have direct access to oil and gas production sites and the related downstream operations that deal with NORM, it can be further assumed that—from a public health stand-point—there will be few excess cancers (a small risk carried in a small population yields a small total number of cancers). If, however, it turns out that the NORM from oil & gas production is widespread (and this may be a valid assumption that can be inferred from the fact that oil and gas production creates more that 260,000 metric tons of NORM waste), then the CPG is quite large, and one would expect to see a large total number of excess cancers (a small risk borne by a large population yields a large number of cancers).

2. The Debate Over a Radiation Threshold is Rhetoric

For humans,[159] the health problems that are caused by NORM lay in ionizing radiation's ability to change the chemical structure and reactivity of materials. In a DNA sequence, for example, one nucleic acid can be instantly transformed into another by ionizing radiation.[160] The biological result may be innocuous—or the cell may simply be killed by the change. In any event, the incidence of ionizing radiation on cellular material may cause severe health effects.[161] The problem with determining the risk of these exposures to an individual is that they are very difficult to measure empirically. As stated by Dr. Lindell of the Swedish Institute of Radiation Protection, a "no threshold" theory that states that any radiation exposure is potentially harmful is often assumed into radiation risk analyses:

> The dose response relationship at low radiation doses is not known because the [individual] risk is so low that it is difficult to distinguish the radiation-induced harm from naturally occurring harm of the same type. However, it is usually assumed that the risk increases in proportion to the effective dose equivalent, a quantity that sums up radiation doses in all body organs and tissues after weighting for differences in sensitivities.[162]

The major American[163] and international bodies which are charged with protecting human radiation health effects of radiation subscribe to this "no

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158. The risk estimates are highly dependent on the Critical Population Group (CPG). Although the DIFFUSE NORM STUDY spends 40 pages trying to define the CPG, the study finally just infers that all or part of the population that lives and works within 50 miles of a "reference site." DIFFUSE NORM STUDY, *supra* note 1, at A-11 & D-1-1 to D-1-40.

159. *See supra* note 6.

160. JOHN W. GOFMAN, RADIATION AND HUMAN HEALTH 84-5 (Sierra Club Books 1981).

161. *Id.*

162. *Id.*

163. "If there is in fact a threshold of exposure below which carcinogenic effects do not occur, science has not yet proven or disproven it, thus any current measurement of such a threshold must be termed a threshold or non-threshold hypothesis." Johnston v. United States, 597 F. Supp. 374, 392 (D. Kan. 1984).

threshold" concept.[164] The United Nations Scientific Committee on the Effects of Atomic Radiation, in 1977, clearly indicated that there is not any threshold below which radiation can be presumed to not cause harm:

> Regarding the possible existence of thresholds in dose-effect relationships there is consistent evidence showing that doses as low as 5 rads may still be effective in inducing selected malformations. Direct experimental tests of the absence of thresholds in this dose region would tend to exclude their existence at lower doses. Theoretically, the possibility does exist that thresholds might occur at even lower doses, but experiments of sufficient precision to reveal them would be technically difficult or even impossible for statistical reasons.[165]

The scientific understanding of the effects of low doses of radiation has been advanced through the study of the effects of tragedies like the Chernobyl accident and the bombings in Japan. These studies do not provide the same type of clinical information that is possible, say, with risk assessments that are performed for proposed drugs, or food additives where the stresses are controlled and elements of causation are clearly defined.[166]

Even with these limitations, Dr. Gofman's statistical work with populations provides very solid evidence that low doses of radiation to populations have resulted in excess cancers on a population level.[167] He begins his analysis from first principles, examines the origins of human cancer,[168] and from a cellular model develops proof for the statement that even a single ionization can cause cancer.[169] Linus Pauling may have been one of the earliest proponents of this view, when in the course of his research on the chemistry of radioactive matters he concluded, "[t]here is no safe amount of radiation or of radioactive material, even small amounts do harm."[170]

This conservative scientific policy is challenged.[171] Other theoreticians posit that there is some incidence below which there is no biological effect (that there is a threshold in the dose-response curve).[172] Some even say that some very low levels of radiation are good for you.[173] The following figure (Fig. 1)

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164. Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991).

165. UNSCEAR, Sources and Effects of Ionizing Radiation, UNGA 1977, *reprinted in* JOHN W. GOFMAN, *supra* note 50, at 758 (Sierra Club Books 1981).

166. NATIONAL RESEARCH COUNCIL, ENVIRONMENTAL EPIDEMIOLOGY 41 (1991).

167. JOHN W. GOFMAN, RADIATION AND HUMAN HEALTH 102-122 (Sierra Club Books 1981).

168. *Id.* at 54-101.

169. *Id.* at 82-83.

170. LINUS PAULING, NO MORE WAR! 82 (1958).

171. The term "policy" is used in this context because the choice of which theory to use is not based upon science since there is not direct scientific evidence on this issue. Rather, the decision to use one theory or another is a policy decision.

> [T]he linear nonthreshold dose-effect relationship implies that the potential health risk is proportional to the dose received and that there is an incremental health risk associated with even very small doses, even radiation doses much smaller than doses received from naturally occurring radiation sources. These health risks, such as cancer, are termed stochastic because they are statistical in nature; i.e., for a given level of dose, not every person exposed would exhibit the effect.

Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991).

172. SOHEI KNODO, *supra* note 149, at 16 (1993).

173. SOHEI KNODO, *supra* note 149, at 16 (1993).

roughly sets out the different dose response theories that exist. In the graph, the "T" represents the threshold theory. The threshold theory states that there is a cutoff below which no radiation effects occur.[174] "NT" represents the no threshold theory, which is explained above. "B" represents the beneficial theory which states that at some low dose there are fewer observed health effects than there are at either higher or lower doses—some minute amount of radiation is good for you.[175]

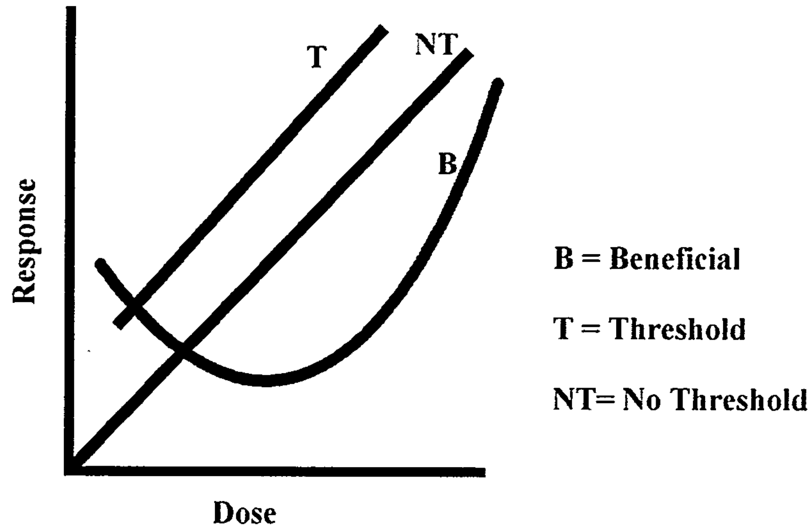

FIGURE 1. THREE THEORIES OF THE DOSE-RESPONSE RELATIONSHIP OF IONIZING RADIATION'S IMPACT ON HUMAN HEALTH.

Although science can not prove the no-threshold theory, there is a great deal of circumstantial evidence that militates for its application, and for the exclusion of the other theories. As has been repeatedly pointed out in connection with the Radium dial painters:[176]

> A milligram of Radium bromide is not much larger than a small grain of sand. One microgram is only one thousandth as large, is invisible, and

174. Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991). "[T]here are effects, termed nonstochastic effects, for which there is an apparent threshold; i.e., a dose level below which the effect is unlikely to occur." *Id.*

175. Even in the face of ever-stricter standards, some activists tout the use of radioactive materials as home remedies as evidence of the beneficial effects of low doses of radioactivity. *See* Sohei Kondo, *supra* note 117. Recently, one scientist described this use of radioactive materials as "quack" medicine. Allan Mazur, *supra* note 79, at 35, 38.

176. Allan Mazur, *supra* note 79, at 35 (1996). The Radium dial painters were women who were employed to paint the faces of watches with Radium so that they would glow at night. To make fine tips that produce fine lines, the women licked the Radium-laced brushes. As a population they exhibited an enormous excess of cancer, particularly bone cancer. *See, e.g.*, Johnston v. United States, 597 F.Supp. 374, 395 (D. Kan. 1984), which discusses the facts of the New Jersey Radium Dial workers in light of similar facts in Kansas. The Johnston court took a hard swipe at the plaintiffs experts in that trial, and later courts have criticized the Johnston court's treatment of the biological effects of radiation that was the subject of the expert testimony. *See In re* TMI III, 927 F. Supp. 834, 841, n. 11 (M.D. Pa. 1996).

> cannot be detected by any known chemical method. It is necessary to have only ten micrograms, or one hundred thousandth of a gram, distributed over the entire skeleton to produce a horrible death years after it has been ingested.[177]

Furthermore, the threshold and beneficial theories look less appealing in light of the NRC's newly lowered exposure limits for the public. The NRC's allowable public doses from nuclear power plants were lowered from 500 mrem/year to 100 mr/year[178] on the basis of ICRP recommendations.[179] And, the NRC has adopted guidelines for the operation of nuclear power plants which further lower the permitted yearly public exposures from 100 mr/year to 10 mr/year.[180]

It may be that the three theories of the dose response relationship for radioactive material's effects on human health exist because not enough is understood about the biological effects of very low levels of radiation from an empirical standpoint. The no-threshold theory is sometimes supported on the premise that uncertainty requires conservatism, with the regulator claiming that it is imperative to provide for the public health and safety to the greatest extent in the face of uncertainty.[181] For instance, a recognized expert in radiation safety noted that, "[W]e do not have a single set of useful, straightforward recommendations on radionuclides in food to present to the food industry and to a worried world."[182] This comment was made at the close of a conference that hoped to provide guidance on the levels of radioactive materials that might be safe in European foodstuffs that were contaminated by the Chernobyl accident.

A corollary example from outside the realm of radioactivity, but still within the practice of risk assessment can help shed some light on the development of radiation risk assessment sciences. This example is drawn from the EPA's development of data concerning the health effects of carcinogenic materials. The EPA, in April of 1996 released proposed cancer risk guidelines that completely change the risk assessment of cancer for many materials.[183]

This drastic change in the EPA's guidelines illustrates the recent "climb up the learning curve" concerning the toxicology of carcinogens.[184] The new guidelines presumably reflect more exacting scientific inquiry and therefore, a simpler task of applying the science to the regulation is possible. For the pur-

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177. Allan Mazur, *supra* note 79, at 37.

178. *Compare* 10 C.F.R. § 20.105 (1986) *with* 10 C.F.R. 20.1301 (1992).

179. National Emissions Standards for Radionuclide Emissions From Facilities Licensed by the Nuclear Regulatory Commission and Federal Facilities not Covered by Subpart H, 61 Fed. Reg. 68972 (1996).

180. Thomas H. Pigford, *Maximum Individual & Vicinity-average Dose for a Geologic Repository Containing Radioactive Waste*, 8 RISK: HEALTH SAFETY & ENV'T 9 (1997).

181. Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991).

182. W. Sinclair, *Radionuclides in the Food Chain*, *in* RADIONUCLIDES IN THE FOOD CHAIN 475, 483 (J. Harley ed. 1988).

183. Proposed Guidelines for Carcinogenic Risk Assessment, 61 Fed. Reg. 17960 (Apr. 23, 1996).

184. *See, e.g.*, Bruce Molholt, *The Environmental Impacts of USEPA's New Cancer Risk Guidelines*, POLLUTION ENGINEERING (June 17, 1997). Dr. Molholt points out that many carcinogens were regulated far below the level at which they cause an appreciable risk of harm in humans. Prior guidelines were based upon more uncertain science, and the regulations that were previously developed incorporated a degree of "cushion" between doses known to cause effects and those that were uncertain.

pose of this paper, it is most important to note that the proposed guidelines were almost twenty years in development at the EPA, and will only become final after years of comment and refinement—if then.

The great time lag that is necessary to develop reliable empirical data is the lesson that may be learned from the EPA's regulation of carcinogens and applied to the NORM issue. With NORM, the EPA has only begun to embark on a process that has only recently included the NAS. More precise regulation of NORM will be possible when more precise scientific studies that indicate the true health effects of NORM are conducted such that the regulations can be crafted around the scientific results.

The debate over threshold responses and the weight of unrealistic models really dissolves into one theme: Should industry try to limit its future NORM liability by changing—perhaps artificially—the theories about radiation's ability to cause harm? Or should industry try to reduce future liability by reducing real future risks by addressing the problem of NORM waste head-on?

With respect to other environmental pollutants, the United States government and industry have spent billions of dollars on the remediation of waste sites, costs that might have been prevented.[185] Will the same thing occur with NORM? Selection of a non-conservative dose-response relationship could sweepingly reduce the perception of NORM liabilities and result in short-term savings in the implementation of less rigorous regulations. However, these short-term savings could be very well followed by high costs for remediation and litigation.

One fact stands out concerning many empirical studies of radiation risks—they are flawed.[186] Selective perception of risks does not change this reality. Therefore, the theory that bottoms regulatory action will be chosen as a policy decision—not as a scientifically provable fact. It would be a relatively simple matter for an aggrieved plaintiff to show that these types of radiation protection standards are based on policy and not scientific decisions. This proved, industry might have little by way of defense in the regulations, and ultimately might bear the cost of any real risks imposed on others.

In the short-run, selecting a non-conservative dose-response theory might be less costly than proactively cleaning up sites to stringent standards to make sure that risks are minimized. But, in the long run the costs created by putting risk in the public may well be "internalized." That is, at least some of those people who may be injured by exposure to NORM will seek redress from the companies that have been accumulating NORM. If the industry as a whole has adopted a proactive stance concerning NORM, each of the individual companies might have an effective shield against future liabilities. And, it is likely that the risks and corresponding heath effects will not be caused in the first place because the industries will be conservatively regulating themselves.

185. Richard L. Fruehauf, *The Cost Of Knowledge: Making Sense Of "Nonfortuity" Defenses In Environmental Liability Insurance Coverage Disputes*, 84 VA. L. REV. 107 (1998).

186. NATIONAL RESEARCH COUNCIL, *supra* note 166.

Furthermore, these "risks" really might be substantial, one-way changes to real human lives. Cancer and other deadly health effects—including genetic effects—are terrible for individuals and for entire families and communities. There are strong ethical reasons for preventing these "risks" that are just as important as the economic ones.

Therefore, from an industry perspective, even "pounds of prevention" may ultimately prove to be economical. Using the rhetoric over the dose-response relationship of radiation to health effects as the basis for risk management models may result in the creation of greater than necessary risks to public health,[187] which may in turn result in great personal and financial liabilities in the future.

III. THE LEGAL PROBLEM

A. The Development of Radiological Protection Guidelines

We have been discussing some of the current concepts in radiation risk assessment, and we have found that the science of radiation risk assessment is "climbing the learning curve." Effective, science based regulation requires a great deal of knowledge. Further, the regulation of radioactive materials has been evolving over the past century. It began by applying the science of broad observations, and has been become more sophisticated as measurement techniques, units and the understanding of radiation's biological effects have become more clearly understood.

In the late 1800's radioactivity was discovered through the very beginning of research on X-Rays,[188] Uranium[189] and Radium.[190] This opened up a new world of physics and chemistry to science. It soon became apparent that this new world might be dangerous. Marie Curie, who discovered the element Radium, was one of the first people to be injured by exposure to radioactive materials.[191] At about the same time, those who were experimenting with and using X-rays noticed that some level of exposure resulted in reddened skin (erythema)[192] and even caused lesions.[193]

These operators developed an early "dose limit" so that no reddening or lesions would occur from their exposure to the X-ray machines.[194] This standard for radiation protection was called the Human Erythema Dose (HED).[195]

187. *See generally* DANIEL FORD, THE CULT OF THE ATOM (Simon & Schuster 1982).

188. W.C. Roentgen discovered X-Rays in 1895. ATOMIC ENERGY *supra* note 95, at 378.

189. Henri Becquerel discovered the spontaneous decay of Uranium. EVE CURIE, MADAM CURIE 153 (Vincent Sheen trans., Doubleday, Doran & Co. 1937).

190. It was in the examination of pitchblende ores that Marie Curie determined that the radioactivity in pitchblende was too great to be ascribed solely to Uranium, and the discovery of the more radioactive substance Radium was made. For an interesting description of the Curie's lives *see supra* note 189.

191. *Id.* at 385.

192. Reddened skin is technically termed erythema.

193. GLASSTONE & JORDAN, *supra* note 19, at 113.

194. ATOMIC ENERGY ENCYCLOPEDIA IN THE LIFE SCIENCES 145 (Charles Shilling ed., 1964).

195. *Id.*

Later experimentation determined that erythema is only caused when a person is exposed to at least 289 roentgen equivalents.[196] The HED is roughly 3000 times the total yearly exposure that the public is allowed to receive from nuclear power plants in the United States today.[197] The development of this change in protection guidelines is described below.

The British Roentgen Society was the first scientific body to develop radiation protection guides when it recommended protective measures in 1916.[198] In the following decade recommendations were made by similar "societies" in the United States, France, Germany, Holland, Sweden and the former Soviet Union.[199] These protection standards were limited to personnel operating X-rays. Advanced protection guides were still needed for other uses of radioactive materials.

As a result, in 1921 the First International Congress of Radiology was convened at London. The first agenda item was the development of a standard unit of measurement for radiation exposure.[200] The Congress created the International Commission on Radiation Units and Measurements (ICRU), and in 1928 at the Second International Congress of Radiology at Stockholm the unit for measuring radiation, the Roentgen (R), was proposed by the ICRU.[201] The Roentgen is still used, with a number of other units, as a basic unit of radiation exposure.[202]

The Roentgen is limited to electromagnetic wave radiations, and can not describe the dose that results from particle radiations. It is important to remember that radiation takes a number of different forms, including particles[203] and electromagnetic rays, and it develops from the interaction of certain types of radiation with matter.[204] Therefore, to develop meaningful radiation protection guides, standard methods and units were developed to accommodate this spectrum of radiations.[205]

The ICRP was founded at the Second International Congress of Radiology in Stockholm.[206] Early recommendations by the ICRP were aimed at develop-

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196. *Id.*

197. Standards for Protection Against Radiation, 10 C.F.R. § 20.1101 (1997).

198. GLASSTONE & JORDAN, NUCLEAR POWER AND ITS ENVIRONMENTAL EFFECTS 114 (American Nuclear Society 1980).

199. *Id.*

200. *Id.*

201. *Id.* The Roentgen is the quantity of X or gamma radiation 0.001293 grams of air is caused to contain ions of one electrostatic quantity of energy, either positive or negative. ATOMIC ENERGY ENCYCLOPEDIA, *supra* note 94, at 378. Alternatively, the Roentgen can be defined as the quantity of X or gamma rays that produce, in 1 Kilogram of dry air, charge particles carrying a total charge of 0.000258 Coulomb. ATOMIC ENERGY ENCYCLOPEDIA, *supra* note 194, at 378.

202. The units that are currently used are called Sieverts, Grays, Rems and Rads. For a full description of these units which describe the absorption of radioactivity by matter, particularly living cells, see JOHN W. GOFMAN, *supra* note 51, at 45-9.

203. When discussing naturally occurring radioactive materials, most of the radiation that will result from oil and gas operations is in a particulate form. In fact, the most common radiation source is Radium, which emits primarily alpha particles and is most often found in particulate form.

204. *See supra* notes 41 to 52 and accompanying text.

205. *See supra* notes 53 to 60 and accompanying text.

206. B. Lindell, *International Recommendations on Radiation Protection*, in Radionuclides in the

ing basic radiation protection units, and for establishing guidelines for protecting radiation workers. Later, the ICRP began to suggest dose limitations for members of the general public-beginning in the 1950s.[207] The ICRP has established three basic principles for radiation protection:

> 1. The practice causing radiation exposure must be justified, i.e., its introduction must produce a positive net benefit.
>
> 2. There should be limits for the individual doses and hence the individual risks for those who are exposed to radiation.
>
> 3. Even below these dose limits, all exposures should be kept As Low As Reasonably Achievable; economic and social factors being taken into account.[208]

In the United States an advisory committee was established under the auspices of the National Bureau of Standards ("NBS"). The NBS advisory committee soon found that radiation protection must be extended beyond X-ray radiation protection. In 1956 the National Committee on Radiation Protection ("NCRP") was created from the NBS committee. There was an inherent weakness in the NBS and the NCRP that resulted from the fact that neither body had any legal authority to establish guidelines that would be binding on those who dealt with radioactive materials. Rather, the NCRP was simply another name for the advisory committee established by the NBS under its administrative authority, and the NBS had no statutory authority to develop binding radiation protection guidelines.[209]

In an effort to obtain the authority to develop meaningful radiation protection standards, the NCRP severed its ties with the NBS, and obtained a charter from Congress in 1964,[210] changing its name from the National *Committee* on Radiation Protection to the National *Council* on Radiation Protection.[211] The

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Foodchain (M.W. Carter, ed. 1988).

207. *Id.*

208. *Id.* at 73.

209. Information on the NBS is based generally on the work of SAMUEL GLASSTONE & WALTER JORDAN, *supra* note 18, at 115.

210. An Act to Incorporate the National Committee on Radiation Protection and Measurements, Pub. L. 88-376, 78 Stat. 320 (1964) (codified at 36 U.S.C.A. § 4503 (West 1998)). In section 3, the objects and purposes of the Committee are stated as:

> To collect, analyze, develop and disseminate in the public interest information and recommendations about (a) Protection against radiation, . . . (b) radiation measurements, quantities and units, particularly those concerned with radiation protection; To provide a [means for organizational and scientific cooperation];
>
> To develop basic concepts about radiation quantities, units, and measurements, about the application of these concepts and about radiation protection; to cooperate with the Federal Radiation Council, the International Commission on Radiological Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units, measurements and radiation protection.

Id.

211. The National Council on Radiation Protection and Measurements (NCRP) is a non-profit organization chartered by the United States Congress to provide government, the public, and industry with recommendations and guidance concerning human exposure to ionizing and non-ionizing radiation. The Commission, along with other government agencies and organizations, has an official relationship with NCRP as a "collaborating organization." Dwight H. Merriam, *Dealing With Locally Unwanted Land Uses (LULUS): Wireless*

NCRP has been responsible for a great deal of research concerning radiation protection guides.[212]

While the NCRP was maturing, Congress, in response to the development of nuclear weapons and the perceived potential for the peaceful splitting of atoms, created the Atomic Energy Commission ("AEC") in 1946.[213] The AEC was later dissolved[214] with its duties split between the newly formed Nuclear Regulatory Commission ("NRC/AEC")[215] and the Energy Research and Development Administration.[216] The NRC/AEC was the first legally established body in the United States that had the authority to both establish radiation protection measures and enforce them. In 1957, the first federal radiation safety standards were promulgated in 10 C.F.R. tit. 20. These standards, however, were and continue to be limited in scope and they expressly apply only to the licensing, construction and operation of nuclear power plants and the use and development of nuclear fuel materials.[217]

One might think that the NRC/AEC would be responsible for developing radiation protection guides for NORM, but they have expressly declined to do so,[218] stating that NORMs fall without the definition of radioactive materials that the NRC is required to regulate. That is, NORMs are not "source and special nuclear material, production facilities, and utilization facilities [sic] affected with the public interest."[219]

The NRC/AEC's 1957 standards substantially remained the same until 1991,[220] when the Nuclear Regulatory Commission ("NRC") reformulated its

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Communications Facilities, "Super" Service Stations, "Satellite" Fast Food Restaurants, Etc, SC10 ALI-ABA 173 (1997).

212. *See, e.g.*, NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, NCRP REPORT (1967); NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, THE RELATIVE BIOLOGICAL EFFECTIVENESS OF RADIATIONS OF DIFFERENT QUALITIES (1990); NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, RECOMMENDATIONS ON LIMITS FOR EXPOSURE TO IONIZING RADIATION (1993).

213. Atomic Energy Act of 1946, 60 Stat. 755 (codified as amended at 42 U.S.C.A. § 2011-2297g-4 (West 1998)).

214. The AEC was initially established with two purposes. The first was to promote the use of nuclear materials to foster "world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise." Atomic Energy Act of 1954, ch. 1073, § 1(b), 68 Stat. 919, 921 (codified as amended at 42 U.S.C. § 2011 (1998)). The second purpose was to "to protect the health and safety of the public." Id. § 2(b), 68 Stat. at 921. These two roles were inconsistent because the placed the agency under the obligation to promote nuclear power, which can create large health risks while it was also to police nuclear operators to protect human health. Prior to the Energy Reorganization Act of 1974 there was a developing consensus that the separation of these duties was required. *See, e.g.*, WILLIAM WOOD, NUCLEAR SAFETY: RISKS AND REGULATION 5 (1983); Neal Smith & Michael Baram, *The Nuclear Regulatory Commission's Regulation Of Radiation Hazards In The Workplace: Present Problems And New Approaches To Reproductive Health*, 13 ECOLOGY L.Q. 879 (1987).

215. 42 U.S.C.A. § 5841 (West 1998).

216. 42 U.S.C.A. § 5801 (West 1998).

217. 42 U.S.C.A. § 2012 (e) "Source and special nuclear material, production facilities, and utilization facilities are affected with the public interest, and regulation by the United States of the production and utilization of atomic energy and of the facilities used in connection therewith is necessary in the national interest to assure the common defense and security and to protect the health and safety of the public." *Id.*

218. *See* Radiological Criteria for License Termination, 62 Fed. Reg. 39,058 (1997).

219. *Id.*

220. Note, a basic principle of radiation protection, the As Low As is Reasonably Achievable, or ALARA, principle was established by the AEC in 1970. 35 Fed. Reg. 18,385 (1970).

Standards for Radiation Protection to come more in line with the recommendations that had been made in 1977[221] by the ICRP.[222] The main purpose of the 1991 revision was to reduce the amount of exposures to the public that can result from nuclear power plant operations from 500 mrem/year to any one person to 100 mrem/year.[223]

The Federal Radiation Council ("FRC") was first established by executive order in 1959,[224] and then provided of statutory authority in the same year.[225] The purpose of the FRC was to:

> advise the President with respect to radiation matters directly or indirectly affecting health, including matters pertinent to the general guidance of

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221. ICRP, Recommendations of the International Commission on Radiological Protection, Pub. No. 26 (1977).

222. Standards for Protection Against Radiation, 56 Fed. Reg. 23,360 (1991).

> The AEC and the NRC have generally followed the basic radiation protection recommendations of the International Commission on Radiological Protection (ICRP) and its U.S. counterpart, the National Council on Radiation Protection and Measurements (NCRP), in formulating basic radiation protection standards. In 1977, ICRP issued revised recommendations for a system of radiation dose limitation. This system, which was described in ICRP Publication 26, introduced a number of significant modifications to existing concepts and recommendations of the ICRP and the NCRP that are now being incorporated in the NRC regulations.

Id.

223. *Compare* 20 C.F.R. § 20.105 (1986) *with* 20 C.F.R. § 20.1301 (1998). It is interesting to note that the revised regulations are currently being used by the Third Circuit Court of Appeals as the standard of care in a tort suit that was brought by more than 2,000 plaintiffs who claim to have been adversely impacted by the Three Mile Island accident in 1979. *In re* TMI, 67 F.3d 1103 (3d Cir 1995). The court found that the ALARA principle, which stands for "As Low As is Reasonably Achievable" could not apply to the TMI case as the standard of care because the ALARA regulations make reference to Appendix I of 10 C.F.R. pt 20, which said that the "numerical guides for design objectives and limiting conditions for operation are not to be construed as radiation protection standards." *In re* TMI, 67 F.3d at 1109. The court did not discuss the NRC's recently published guidance in the Federal Register which stated that:

> Some of the concentration limits for the general public are higher or lower than previous concentration limits; and some are of the same magnitude as the previous limits.
>
> Despite the changes in the dose and concentration limits, the Commission believes that issuance of the final rule will not have a major impact on the environment. The primary basis for this conclusion is that NRC (and Agreement State) licensees have implemented radiation protection measures that keep radiation exposures and radioactive effluents as low as reasonably achievable (ALARA) in accordance with provisions of 10 CFR 20.1(c) and comparable State provisions. These measures, whether established by rule, license, or good management practice, have been particularly successful in minimizing effluents to the general environment and exposures to members of the public and radiation workers. The final rule will make such ALARA programs mandatory as a part of licensee radiation protection programs.

Standards for Protection Against Radiation, 56 Fed. Reg. 23,360, 23,388 (1991).

Instead, the Court in the TMI cases cited to the titles of the various radiation protection regulations, focusing on the word "permissible" with respect to "dose" in those titles, constructing an analysis that essentially said that the regulatory agencies found these "doses" to be "permissible" so the court won't inquire any further. 67 F.3d at 1114-1115. The Third Circuit's perception of the TMI case seems flawed since the Court was not engaged in regulating the TMI plant after the fact, but was supposed to be trying to determine what duties existed on the operating utility at the time of the accident in March, 1979. The Court should not have been trying to see what "doses" were "permissible," but what actions the licensee did or did not undertake to limit exposures to the public during an accident. Somehow, the Court seemed to forget that TMI was in an accident when the alleged exposures took place. In an accident scenario, the operating limits have no relevance. Rather, the licensee's actions that caused the accident were the issue. The NRC guidance stated that ALARA comprised the basic operating standard that nuclear power plant licensees are bound by-requirements that are much stricter than the operating limits alone. Standards for Protection Against Radiation, *supra*; *see*, Jason Aamodt, *Comment, Regulating the Standard of Care Owed to the Public During an Emergency at a Nuclear Power Plant*, 16 ENERGY L.J. 181 (1995).

224. Dwight D. Eisenhower, Establishing the Federal Radiation Council, Exec. Order No. 10,831, 24 Fed. Reg. 6669 (1959).

225. Atomic Energy Act Amendments of 1959, Pub. L. No. 86-373, 73 Stat. 690 (1959).

> executive agencies by the President with respect to the development by such agencies of criteria for the protection of humans against ionizing radiation applicable to the affairs of the respective agencies. The Council shall take steps designed to further the interagency coordination of measures for protecting humans against ionizing radiation.[226]

With the reorganization of a number of executive departments in 1970,[227] the FRC was dissolved and its duties were incorporated into the newly created EPA. At the EPA's creation, its authority to regulate radioactive materials was limited to the authority given to the FRC, which consisted primarily of providing guidance to the President. Under the Clean Air Act Amendments of 1977, however, the EPA was given the authority to regulate all air-borne radioactive effluents, including emissions from nuclear power plants licensed and regulated by the NRC.[228] The statute specifically required the EPA and the NRC to consult and enter into an agreement concerning the standards that the EPA may set for any NRC-licensed facilities.[229]

In 1990, with the Clean Air Act Amendments, the EPA was required to refrain from regulating any NRC-licensed facility if the NRC regulations "provide [sic] an ample margin of safety to protect the public health."[230] In any event, the EPA retained the authority to regulate sources of radioactive material that may "contribute to air pollution which may reasonably be anticipated to endanger public health."[231] Interestingly, the EPA forced the NRC to revise its emission standards for nuclear power plants down from 100 mrem/year to 10 mrem/year for any member of the public, finding that this would provide the statutorily required "ample margin of safety."[232]

B. State Regulation

While the theoretical debate over who should regulate NORM continues,[233] several states have begun to control it. After examining the approaches different states have taken to NORM regulation, it becomes apparent that there is a vast difference in the strength and coverage of these regulations from state

226. *Id.* at § 2.

227. Reorg. Plan No. 3 of 1970, 3 C.F.R. 1072 (1966-1970). President Nixon had was delegated the authority to create the EPA from many different existing federal agencies in the Reorganization Act of 1949, then codified at 5 USC §§ 901, 913 (1970).

228. 42 U.S.C.A. § 7422 (West 1998).

229. *Id.* at § (c).

230. 42 U.S.C.A. § 7412(d)(9) (West 1998). The meaning of this term "ample margin of safety" has been criticized as ambiguous and because it may have created by a struggle for regulatory authority. *See* Richard Goldsmith, *Nuclear Power Meets the 101st Congress, A "One Act" Comedy: Regulation of NRC Licensees under the Clean Air Act*, 12 VA. ENVTL. L.J. 103 (1992).

231. 42 U.S.C.A. § 7422 (a) (West 1998). With this mandate, the EPA forced the NRC to lower its effluent limitations on nuclear power plant operators to 10 mrem from 100 mrem in December of 1996. (61 Fed. Reg. 65,120 (Dec. 10, 1996)). The EPA responded later that same month by removing its regulation of NRC-licensed power plants, stating that the new NRC program would provide an adequate margin of safety for the public.

232. *See* Resolution of Dual Regulation of Airborne Effluents of Radioactive Materials; Clean Air Act, 61 Fed. Reg. 65120 (1996).

233. *See, e.g.*, Bryan R. Reynolds, *supra* note 11, at 5, 7.

to state. The purpose of this section is to summarize the different state NORM regulations that exist in Arkansas, Florida, Georgia, Louisiana, Mississippi, New Jersey, New Mexico, Oregon, South Carolina, and Texas.[234]

1. Arkansas

Arkansas' regulations establish standards for worker protection,[235] tanks containing NORM,[236] survey and counting instrumentation,[237] selling NORM contaminated property[238] and the transportation of NORM.[239] Arkansas provides a general license[240] for activities that generate NORM wastes.[241] NORM is exempt from regulation in Arkansas if it does not exceed "5 picocuries per gram of Radium-226 and/or Radium-228, 0.05% by weight of Uranium or Thorium, or 150 picocuries per gram of any other NORM radionuclide . . . ." A specific license is required if the NORM is not exempted or provided with a general license.[242] "[T]he manufacturing and distribution of any material or product containing NORM shall be specifically licensed pursuant to the requirements of this Section or pursuant to equivalent regulations of another Licensing State."[243] Worker safety criteria[244] limit doses on an organ basis, measured in mrem.[245] Public exposures to NORM are limited to 100 mrem per year, or 2 mrem per hour.[246] Testing equipment called for under the regulations has to be sensitive down to 1 mR per hour.[247]

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234. *See generally* Peter Gray & Assoc., *Naturally Occurring Radioactive Material Contamination*, THE NORM REPORT, Summer/Fall 1997. This publication summarizes state regulation activity of naturally occurring radioactive materials. It is published quarterly.

235. See *infra* notes 244 to 245.

236. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6019, *available in* Westlaw, ENFLEX—AR database. Standards for tanks containing NORM require the licensee to develop a schedule and procedure for assessing the condition of each tank containing NORM waste. "The schedule and procedure must be adequate to detect cracks, leaks, corrosion and erosion that may lead to cracks, leaks, or wall thinning to less than the required thickness to maintain vessel integrity." *Id.* Procedures for emptying the tank and inspection of the interior are also specified. *Id.*

237. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6017, Radiation and Survey Counting Instrumentation, *available in* Westlaw, ENFLEX—AR database.

238. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6032, Vacating Premises, *available in* Westlaw, ENFLEX—AR database.

239. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6016, Transportation of NORM, *available in* Westlaw, ENFLEX—AR database. Arkansas transportation rules require a license to transport NORM and a manifest.

240. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6010, General License, *available in* Westlaw, ENFLEX—AR database.

241. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6005, Exemptions, *available in* Westlaw, ENFLEX—AR database.

242. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6020, Specific License, *available in* Westlaw, ENFLEX—AR database.

243. *Id.*

244. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6023, Safety Criteria, *available in* Westlaw, ENFLEX—AR database.

245. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6024, Table of Organ Doses, *available in* Westlaw, ENFLEX—AR database.

246. Rules and Regulations for Control of Sources of Ionizing Radiation, § 7, Pt. A at RH-6008, Dose Limits for Individual Members of the Public, *available in* Westlaw, ENFLEX—AR database.

247. *See supra* note 51. The term "mR" stands for millirad. As is discussed above, translating from rads to rems can be difficult. *See supra* note 56 to 58.

2. Florida

In Florida phosphate mining is more prevalent than other industries which accumulate NORM. As a result, Florida's NORM regulations are specifically aimed at controlling radiation exposures resulting from technologically enhanced concentrations of NORM in the Phosphogypsum industry.[248] Florida's regulations prohibit the disposal of unpermitted phosphogypsum,[249] set general stack system criteria[250] followed by the requirements for permitting of such stack systems.[251] Florida's regulations require operator financial responsibility,[252] long-term care (50 years),[253] and closure procedures.[254] In addition to its phosphogypsum requirements, Florida has also established general requirements for radionuclide monitoring.[255] Florida regulations limit worker radiation exposures to 5 rem,[256] and public exposures to 100 mrem per year or 2 mrem per hour.[257] Most survey instruments are required to have a range of sensitivities from 0.1 mrem to 50 mrem per hour.[258]

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248. Phosphogypsum management program, FLA. STAT. ANN. § 403.4154 (West 1993).

> It is the intent of the Legislature that the department to develop a program for the sound and effective regulation of phosphogypsum stack systems in the state. It is further the intent of the Legislature that such regulatory program include the imposition of an annual registration fee on stacks that have not been closed and that such fees be used for the purpose of paying the costs of the department's review of applications to permit the closure of stack systems or the construction of new or expanded stack systems and of the department's review of requests for deferral of mandatory closure requirements.

Id.

249. Phosphogypsum Management: Prohibitions, FLA. ADMIN. CODE ANN. r. 62-673.300 (1993), *available in* Westlaw, ENFLEX-FL database.

250. Phosphogypsum Management: Phosphogypsum Stack System General Criteria, FLA. ADMIN. CODE ANN. r. 62-673.340 (1993), *available in* Westlaw, ENFLEX-FL database.

251. Phosphogypsum Management: Permitting of Phosphogypsum Stack Systems, FLA. ADMIN. CODE ANN. r. 62-673.320 (1993), *available in* Westlaw, ENFLEX-FL database.

252. Phosphogypsum Management: Financial Responsibility, FLA. ADMIN. CODE ANN. 62-673.640 (1993), *available in* Westlaw, ENFLEX-FL database.

253. Phosphogypsum Management: Long-Term Care, FLA. ADMIN. CODE ANN. r. 62-673.630 (1993), *available in* Westlaw, ENFLEX-FL database.

254. Phosphogypsum Management: Closure of Phosphogypsum Stacks, FLA. ADMIN. CODE ANN. r. 62-673.600 (1993), *available in* Westlaw, ENFLEX-FL database; Phosphogypsum Management: Closure Plan Requirements, FLA. ADMIN. CODE ANN. r. 62-673.610 (1993), *available in* Westlaw, ENFLEX-FL database; Phosphogypsum Management: Closure Procedures, FLA. ADMIN. CODE ANN. r. 62-673.620 (1993), *available in* Westlaw, ENFLEX-FL database; Phosphogypsum Management: Closure of Unlined Systems, FLA. ADMIN. CODE ANN. r. 62-673.650 (1993), *available in* Westlaw, ENFLEX-FL database.

255. Radionuclides Monitoring Requirement, FLA. ADMIN. CODE ANN. r. 62-550.519 (1995), *available in* Westlaw, ENFLEX-FL database. These requirements fall into two categories: (1) monitoring requirements for naturally occurring radionuclides for community and non-transient non-community water systems, and (2) monitoring requirements for man-made radioactivity in community water systems using surface water and serving more than 100,000 persons, and public water systems vulnerable to man-made radioactive contamination as determined by the Department. *Id.*

256. Occupational Dose Limits for Adults, FLA. ADMIN. CODE ANN. r. 64E-5.309 (1995), *available in* Westlaw, ENFLEX-FL database.

257. Dose Limits for Individual Members of the Public, FLA. ADMIN. CODE ANN. r. 64E-5.312 (1995), *available in* Westlaw, ENFLEX-FL database.

258. *See, e.g.*, Use, Calibration and Check of Survey Instruments, FLA. ADMIN. CODE ANN. r. 64E-5.615 (1995), *available in* Westlaw, ENFLEX-FL database.

3. Georgia

Georgia's regulations for the control of NORM became effective in October 1994.[259] The regulations exempt Radium with activities less than 30 pCi per gram where the Radon emanation rate is less than 20 pCi per minute.[260] Produced water from petroleum production is exempted if it is reinjected into an approved well.[261] And, recycled materials are exempted if they do not exceed 50 mR per hour.[262] The regulations provide a general license "to mine, extract, receive, possess, own, use, store, transfer, process, and *dispose* of NORM *not* exempted in [these regulations] *without regard to quantity*."[263] The regulations do require a manifest when NORM is transported to a radioactive waste facility—but apparently not when the generator disposes of it without transporting it.[264] Georgia's worker safety regulations,[265] and public doses are derived by reference to the federal register appendix for dosage limits.[266] They limit worker doses to 5 rem whole body, or 50 rem to any organ.[267] Public doses are limited to 100 mrem per year, or 2 mrem per hour.[268] Georgia requires that radiation survey meters can measure from 1mR per hour to 500 mR per hour.[269]

4. Louisiana

Louisiana, one of the first states to develop NORM regulations, set standards for worker protection,[270] the treatment, transfer and disposal of NORM,[271] requires NORM manifests,[272] limits the release of NORM contaminated land for unrestricted use,[273] regulates waste piles,[274] and containers holding NORM wastes.[275] There are also specific inspection provisions for

259. Regulation and Licensing of NORM, GA. COMP. R. & REGS. r. 391-3-17-.08(1) & (2) (1997). The purpose of Georgia's NORM regulation is to establish radiation protection standards for the possession, use, transfer, and disposal of NORM.

260. *Id.* § (4)(a).

261. *Id.* § (4)(g).

262. *Id.* § (4)(f).

263. *Id.* § (7). The general license seems to provide blanket authority to deal with NORM wastes, including disposing of them any way the operator sees fit – as long as the operator created them (This general license does not authorize the . . . the disposal of wastes from other persons.). Regulation and Licensing of NORM, GA. COMP. R. & REGS. r. 391-3-17-.08 at § (7)(a).

264. Standards for Protection Against Radiation, GA. COMP. R. & REGS. r. 391-3-17-.03 (1997).

265. Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage, GA. COMP. R. & REGS. r. 391-3-17-.03 app. B (1997) (citing 10 C.F.R. pt. 20 app. B (1997)).

266. *Id.*

267. Standards for Protection Against Radiation, GA. COMP. R. & REGS. r. 391-3-17-.03 § (5)(a).

268. *Id.* § (5)(j).

269. Regulation and Licensing of NORM, GA. COMP. R. & REGS. r. 391-3-17-.08 § (5) (1997).

270. Regulation and Licensing of Naturally Occurring Radioactive Materials, LA. ADMIN. CODE tit. 33, pt. XV, ch. 14, § 1402 (1995).

271. Regulation and Licensing of Naturally Occurring Radioactive Materials: Treatment, Transfer, and Disposal of NORM, LA. ADMIN. CODE tit. 33, pt. XV, ch. 14, § 1412 (1995).

272. *Id.* § 1418.

273. *Id.* § 1417.

274. *Id.* § 1415.

275. *Id.* § 1414.

storage tanks containing NORM.[276] Louisiana exempts NORM wastes from regulation if they contain less than 5 pCi per gram of Radium, or 150 pCi of any other NORM radionuclide—with a provision for the state to approve different limits on a case-by-case basis.[277] The Louisiana NORM regulations exempt the wholesale and retail distribution, possession and use of phosphate and potash fertilizer, phosphogypsum for agricultural uses, materials used for building construction if such materials contain NORM that has not been technologically enhanced, *as well as natural gas and natural gas products, and crude oil and crude oil products and produced water*.[278] Louisiana's general radiation worker protection regulations limit occupational exposures to 5 rem whole body, and 50 rem to a specific organ.[279] One regulation says that public exposures are to be limited to 100 mrem per year or 2 mrem per hour,[280] while another says that "concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals shall not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other organ of any member of the public."[281]

5. Mississippi

In Mississippi the Oil and Gas Board has jurisdiction over NORM at the well site,[282] but after it leaves the well site, the NORM comes under the authority of the Department of Health.[283] The State Oil and Gas Board's regulations seek "to ensure that radiation exposures of workers and members of the general public resulting from oil field NORM are prevented, eliminated or reduced to acceptable levels in order to protect the public health, safety and environment."[284] Mississippi's health regulations provide a general license "to mine, extract, receive, possess, own, use, process, and transfer NORM not exempted in section 801.N.4 without regard to quantity."[285] Disposal of wastes generated by the licensee is not generally permitted or unpermitted under the general license, but disposal is required to meet certain management practices.[286] Specific licenses[287] are required for NORM decontaminators. NORM

276. Regulation and Licensing of Naturally Occurring Radioactive Materials: Inspection of Storage Tanks Containing NORM Wastes, LA. ADMIN. CODE tit. 33, pt. XV, ch. 14, § 1416 (1995).

277. *Id.* § 1404.

278. *Id.* § 1404 (H).

279. Occupational Dose Limits for Adults, LA. ADMIN. CODE tit. 33, pt. XV, Ch. 4, Subch. B § 410(A) (1998).

280. Radiation Dose Limits for Individual Members of the Public, LA. ADMIN. CODE tit. 33, pt. XV, Ch. 4, Subch. B § 421(A) (1998).

281. Protection of the General Population from Releases of Radioactivity, LA. ADMIN. CODE tit. 33, pt. XV, Ch. 4, Subch. B § 1319 (1998) (promulgated 1987).

282. Control of Oil Field Naturally Occurring Radioactive Materials (NORM) § 69, available in Westlaw ENFLEX-MS (1992).

283. Protection of Workers and the General Population, Safety Criteria § 801 pt. N, available in Westlaw ENFLEX-MS (1992).

284. Control of Oil Field Naturally Occurring Radioactive Materials (NORM) § 69(1)(a), available in Westlaw ENFLEX-MS (1992).

285. General Licenses § 801.N.10, available in Westlaw ENFLEX-MS (1992).

286. Disposal and Transfer of Waste for Disposal, § 801.N.12, available in Westlaw ENFLEX-MS (1992).

clean up standards are set for Radium at 30 pCi per gram in soil, or at Radon emanation rates not exceeding 20 pCi per minute when the Radium concentration is either 5 or 15 pCi per gram, depending on depth.[288] Those who apply for specific licenses must keep occupational and public exposures below either 5 rem or 500 mrem per year to a worker's or a member of the general public's whole body.[289] Radiation survey instruments are required to be able to measure between 1 and 500 mR per hour.[290]

6. New Jersey

In New Jersey, certain very low concentrations of NORM are exempted from state regulation.[291] If not exempted, a "license is required for production, transfer, receipt, acquisition, ownership, possession or use of all naturally occurring and accelerator produced radioactive materials."[292] NORM exposure limits in "controlled areas" at 1/25 rems to the whole body.[293] Outside "controlled areas" exposures are limited to 500 mrem per year.[294] The regulations require periodic radiation surveys,[295] and limit NORM disposal.[296]

7. New Mexico

New Mexico's regulations address NORM in the environment by licensing NORM waste disposal.[297] The regulations deal specifically with the disposal of NORM in pipelines, and the disposal of NORM in underground injection wells.[298] General radiation licensees in New Mexico are required to keep occupational exposures below 5 rem.[299] Public exposures are limited to 100 mrem.[300] However, "Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals shall not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other

287. Requirements for the Issuance of Specific Licenses § 801.N.22, available in Westlaw ENFLEX-MS (1992).

288. General Licenses § 801.N.10, available in Westlaw ENFLEX-MS (1992).

289. Table for organ doses § 801.N.24, available in Westlaw ENFLEX-MS (1992)(this regulation also provides for other exposure limits for organs).

290. Radiation Survey Instruments § 801.N.6, available in Westlaw ENFLEX-MS (1992).

291. Exemption From Requirement for a License for Production, Transfer, Receipt, Acquisition, Ownership, Possession or Use of All Naturally Occurring and Accelerator Produced Radioactive Materials, N.J. ADMIN. CODE tit. 7 § 28-4.3 (1996).

292. License Required for Production, Transfer, Receipt, Acquisition, Ownership, Possession or Use of All Naturally Occurring and Accelerator Produced Radioactive Materials, N.J. ADMIN. CODE tit. 7 § 28-4.1 (1996).

293. Exposure of Individuals in Controlled Areas, N.J. ADMIN. CODE tit. 7 § 28-6.1(1996).

294. Radiation Levels Outside Controlled Areas, N.J. ADMIN. CODE tit. 7 § 28-6.2 (1996).

295. Radiation Surveys and Personnel, N.J. ADMIN. CODE tit. 7 § 28-7.1 to 28-7.5 (1996); Radioactive Contamination Control, N.J. ADMIN. CODE tit. 7 § 28-9.1 to 28-9.4 (1996).

296. Disposal of Radioactive Materials, N.J. ADMIN. CODE tit. 7 § 28-11.1 to 28-11.7 (1996).

297. Disposal of Regulated Naturally Occurring Radioactive Material (Regulated NORM), N.M. ADMIN. CODE tit. 19 § 714 (1996).

298. *Id.* § 714 (B) & (E).

299. Occupational Dose Limits for Adults, N.M. ADMIN. CODE tit. 20 § 405 (1998).

300. Dose Limits For Individual Members of the Public, N.M. ADMIN. CODE tit. 20 § 413 (1998).

organ of any member of the public."[301]

8. Oregon

Oregon provides a general license to "mine, extract, receive, possess, own, use, process and dispose of NORM not exempted in [section] 333-117-0040 without regard to quantity."[302] NORM wastes that come from operations subject to licensing requirements must be disposed of according to EPA management practices, or disposed of in an NRC or state-licensed landfill.[303] Oregon's regulations limit releases of radioactivity from causing doses of "25 mrem (0.25 mSv) to the whole body or 75 mrem (0.75 mSv) to the critical organ of any member of the public."[304] Oregon also sets specific NORM worker radiation exposure standards.[305] Oregon restricts the transfer of land with Radium having an activity greater than either 5 or 15 pCi per gram, depending on depth,[306] and exempts NORM contamination from regulation when it has less than 5pCi per gram of Radium or Thorium, or 150 pCi of other NORM radionuclides.[307]

9. South Carolina

South Carolina NORM regulations were added to the state register May 26, 1995, and are part of South Carolina's general provisions on radiation.[308] The regulations provide specific exemptions,[309] for Radium contamination below 30 pCi per gram in soil that has a Radon emanation rate of less than 20 pCi per minute, or for soil that has 5pCi per gram Radium with a greater Radon emanation rate, or for any other NORM contamination up to 150 pCi per gram.[310] South Carolina also exempts surface NORM contamination that averages less than either 5,000 or 15,000 disintegrations per minute per square meter.[311] South Carolina provides a general license to work with NORM, which allows persons to "mine, receive, possess, own, use, process, transport,

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301. Protection of the General Population from Release of Radioactivity, N.M. ADMIN. CODE tit. 20 § 1317 (1998).

302. General License, OR. ADMIN. R. 333-117-0100 (1998).

303. Disposal and Transfer of Waste for Disposal, OR. ADMIN. R. 333-117-0130 (1998).

304. Protection of the General Population From Releases of Radioactivity, OR. ADMIN. R. 333-117-1020 (1991).

305. Protection of Workers During Operations, OR. ADMIN. R. 333-117-0110 to 333-117-0110 (1995).

306. General License, OR. ADMIN. R. 333-117-0100 (1998).

307. Exemptions, OR. ADMIN. R. 333-117-0040 (1998).

> The possession and use of natural gas and natural gas products as a fuel are exempt from the requirements of these rules. The distribution of natural gas and the manufacturing and distribution of natural gas products are exempt from the specific license requirements of this Division but are subject to the general license requirements . . . .

Id.

308. Licensing of Naturally Occurring Radioactive Material (NORM), 61-63 S.C. Code Ann. Regs pt. 9 (Supp. 1997).

309. *Id.* § 9.3.

310. Licensing of Naturally Occurring Radioactive Material (NORM), 61-63 S.C. Code Ann. Regs §§ 9.1 to 9.7.5 (1997).

311. *Id.*

store and transfer for disposal NORM, or to recycle NORM contaminated NORM contaminated materials not exempted . . . without regard to quantity."[312] South Carolina requires that permitted NORM wastes be disposed of in facilities that are specifically licensed to receive NORM.[313] Specific licenses are required for NORM cleanup activities.[314] Exposure limits are measured in rems, with exposure limits set at 5 mrem and 500 mrem.[315] Radiation sensing equipment is required to be sensitive between the ranges of 10 mR and 500 mR per hour.[316]

10. Texas

Texas takes control of NORM waste by bifurcating responsibilities. The Texas Department of Health ("TDH") has jurisdiction over NORM except for its disposal and the Texas Natural Resource Conservation Commission ("TNRCC") has authority over the disposal of oil and gas NORM wastes.[317] Texas NORM rules, enacted in February 1, 1995, regulate the disposal of NORM associated with oil and gas wastes, allowing for on-site burial,[318] disposal at a licensed facility,[319] or for reinjection.[320] Texas rules exempt a number of NORM wastes from regulation.[321] Texas worker standards[322] allow for 5 rem whole body and 50 rem organ doses.[323] Public dose limits are set at 100 mrem.[324]

C. NORM Regulation: Today and Tomorrow

According to the authority that the EPA has under the Clean Air Act,[325] and the authority that it may have under the Toxic Substances Control Act,[326] or the Clean Water Act,[327] the EPA is reviewing the public health dangers from NORM contamination in "The Diffuse NORM Study."[328] The Diffuse NORM Study was the first federally organized risk assessment of NORM as it exists in the oil field and in other industries. The EPA's preliminary findings on

312. *Id.* § 9.5.
313. *Id.* § 9.6.
314. *Id.* § 9.7.
315. Licensing of Naturally Occurring Radioactive Material (NORM), 61-63 S.C. Code Ann. Regs § 9.5 (1997).
316. *Id.* § 9.4
317. Radiation Rules General Provisions: Memorandum of Understanding Between the Texas Department of Health and the Texas Natural Resource Conservation Commission Regarding Radiation Control Function, TEX. ADMIN. CODE § 336.11, app. a to s (1996).
318. Disposal of Oil and Gas NORM Waste, TEX. ADMIN. CODE § 3.94 (1996).
319. *Id.* at (e)(3).
320. *Id.* at (e)(4).
321. Disposal of Oil and Gas NORM Waste, TEX. ADMIN. CODE § 3.94(e)(1) (1998).
322. Disposal of Oil and Gas NORM Waste, TEX. ADMIN. CODE § 3.94(c) (1998).
323. Radiation Control, TEX. ADMIN. CODE § 289.202 (1998).
324. Standards for Protection Against Radiation TEX. ADMIN. CODE § 289.202(n) (1998).
325. *Supra* notes 228 to 232, and accompanying text.
326. Regulation of Hazardous Chemical Substances And Mixtures, 15 U.S.C.A. § 2605 (West 1998).
327. Water Pollution Prevention and Control, 33 U.S.C.A. § 1317 (West 1998).
328. *See* DIFFUSE NORM STUDY, *supra* note 1.

NORM risks are summarized in Figure 2.[329]

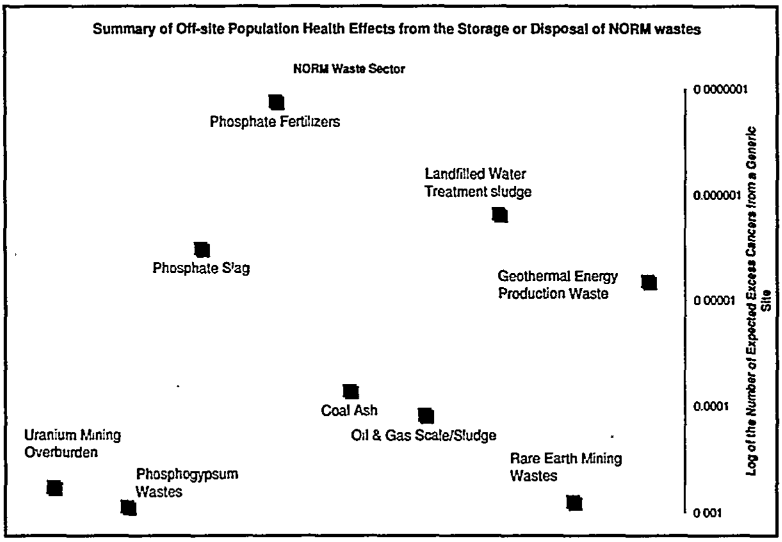

FIGURE 2. EPA'S PRELIMINARY ASSESSMENT OF NORM RISKS

The EPA's Science Advisory Board reviewed the Diffuse NORM Study, and found it to be lacking.[330] Among other things, the Diffuse NORM study "did not adequately convey the deficiencies and uncertainties in the information available to characterize the sources of NORM."[331]

Because of the SAB's determination, and because of the perceived variability in the existing regulation of radioactive materials, Congress charged the EPA to negotiate with the NAS to have the NAS study the "scientific basis for EPA's recommendations relative to indoor Radon and other naturally occurring radioactive materials."[332] The specific duties of the NAS were set forth in an earlier House Conference Report:

> The Academy shall summarize the principal areas of agreement and disagreement among these bodies and shall evaluate the scientific and technical basis for any differences that exist. EPA is to submit this report to the appropriate committees of Congress within 18 months of the date of enactment of this Act, and state its views on the need to revise the guidelines for Radon and NORM in light of the Academy's evaluation. The agency also shall explain the technical and policy basis for such views.[333]

329. The data for this figure was taken directly from the DIFFUSE NORM STUDY, *supra* note 1.

330. SAB NORM REPORT, supra note 3, at 1. " [T]he RAC does not believe that the NORM document meets its goal of providing a scoping analysis of the NORM problem sufficient to determine the need for additional investigations or regulatory initiatives." *Id.*

331. SAB NORM REPORT, supra note 3, at cover letter from EPA Administrator Carol Browner.

332. Sen. Rep. No. 104-318 (1996).

333. H.R. Conf. Rep. No. 104-384 (1995).

The NAS has defined the issues it must address as:

> [E]xamining whether [the differing numerical values that exist in state and federal NORM regulations] are based upon scientific and technical information, or on policy decisions related to risk management. If there are differences in the scientific and technical bases for these guidelines, whether there is merit for the different scientific and technical assumptions [that were] made. Whether there is relevant and appropriate scientific information that has not been used in the development of contemporary risk analyses for NORM.[334]

More simply put, the NAS[335] is asking: 1) what is the reason for differing health and safety regulations for NORM versus other radioactive materials when the regulations hope to provide protection against essentially the same materials and, 2) is there anything that regulators are not investigating?

The first question posed by the NAS drives to the heart of the regulatory issue: If the regulations are variable, and there is not scientific justification for the variability, then there seems to be a great deal left to learn and do with respect to NORM. From the limited review of the 10 state regulations above, clear reasons can be found for some variations, and not for others. For instance, Florida's regulations have to be different than Louisiana's because the problem in Florida is different. However, in some cases the different ways that NORM waste disposal is treated among the states does not seem supported by any scientific reason. The harms caused by diffuse radioactive waste probably are the same in each state, and the costs of disposal should also be similar. However, in Georgia, a NORM waste generator can dispose of its own wastes without any permit as long as it does not transport them.[336] In New Jersey, however, it appears that NORM wastes cannot be disposed of absent some regulatory oversight.[337]

NORM clean-up standards, or the standards at which NORM in the soil is not regulated, vary widely. Many states set Radium standards at 5, 15, or 30 pCi per gram. South Carolina has an alternative NORM exemption standard set at either 5,000 or 15,000 disintegrations per second.[338] New Jersey's exemption standard is based upon the dose that an individual might receive[339]—which, ostensibly means that the clean up standard would vary with each isotope, location and expected exposure pathway(s).

The radiation measurement tools that are required by regulation also differs among the states. For instance, Arkansas requires a radiation meter that can measure 1 mR per hour,[340] while South Carolina requires an instrument that

334. Evaluation of EPA Guidelines for Exposures to Indoor Radon and Naturally Occurring Radioactive Materials, BRER-K-97-02-A, (accessed March 1, 1998)<http://www.nas.edu>.

335. The full NAS report will be available this spring or summer. Conversation between Author and Steven Simon, Staff Officer, NAS by telephone on Feb. 13, 1998.

336. *See supra* note 264.

337. *See supra* note 296.

338. *See supra* note 311.

339. *See supra* note 293 to 296.

340. *See supra* note 247.

can measure 10 mR per hour.[341] Both states have similar NORM exemption standards.[342]

Most disturbingly, there does not seem to be a requirement in either state's NORM regulations regarding the measurement tools for alpha radiation. Radiation meters that record in mR units describe "wave" radiations—gamma and X-rays, while those that measure disintegrations per minute describe wave radiations and "particle radiations"—beta and alpha radiation emitters.[343] The vast majority of radioactivity that is emitted by Radium (^{226}Ra) is alpha.[344] If technicians are allowed to measure Radium contamination with a meter that measures Rads—the gamma portion of Radium's radioactivity—only a small fraction of the radioactivity that is actually there will be measured. Worse yet, the alpha radiation, if the source is ingested, is much more biologically damaging and imparts more rems per Rad than the alpha radiation that is measured.[345]

There are many other variations between the state regulations on issues, such as posting radiation signs in contaminated areas. Some states adopt federal guidelines for allowable sources of radioactive materials, while others do not. Some states set storage requirements for NORM, others do not.

What is most surprising about this variability is the fact that it exists although a national advisory conference exists, and that conference provided specific recommendations about NORM regulation.[346] The Conference of Radiation Control Protection Directors ("CRCPD"), a group made up of the radiation officers from many different states, developed a model set of rules.[347] These rules were adopted by a number of states, although the adaptations vary from the model rule in most states.[348]

The history of radiation protection was reviewed in short-form above to illustrate the different changes that occurred in the evolution of existing regulations. It seems the regulation of NORM is only in its infancy. The CRCPD acknowledged this fact when it published in a policy statement:

> There is first a need to develop and agree upon a common methodology for assessing risks and thereby defining standards and guidance for all NORM sources.
>
> * * *
>
> There is a need to better identify and catalog the various types of NORM sources and the risks and regulatory control problems which they present.[349]

341. *See supra* note 316.
342. *Compare supra* note 242 *with supra* note 310.
343. *See supra* note 40 to 59 and accompanying text.
344. *Supra* note 25, at 50.
345. *See supra* note 41 to 60.
346. *See supra* note 11.
347. *See supra* note 11.
348. *Compare supra* notes 235 to 247 *with supra* notes 308 to 316.
349. Board Position Relating to a Strategy for Uniform Regulation and Control of Naturally Occurring and Accelerator Produced Radioactive Material (accessed 8/24/97), http://www.webpub.com/~crcpd/r_nl3str.htm.

This policy statement was written after the CRCPD's model NORM rules were drafted.

The current state regulations are varied, control different risks, and do not seem to do so for objectively scientific reasons. It also seems that there are nation-wide flaws in the way that the measurements of some radionuclides are being controlled. Whether or not there actually is a scientific basis for these differences has yet to be determined. The variations and the flaws do, however, need to be studied and investigated.

VI. CONCLUSION

The radiation in NORM is harmful. Non-cancer health effects that might be caused by NORM require study and attention. Current NORM regulations may not adequately protect human health because this important perspective has been forgotten in the study of radiation health effects. The references above show that, at the very least, non-specific health effects are a very real possible result from NORM exposure. The NAS review of NORM regulation and risk assessment should find that current NORM regulations have wrongly forgotten the non-cancer health effects of radioactive materials.

Fortunately, a large regulatory bureaucracy has not been established to deal with NORM. A few states have regulations; a few studies are underway. Comparing NORM regulations to the way that general radiation protection guidelines developed shows that we are at "bottom of the learning curve" with NORM. New federal efforts may have a chance to be developed without being crippled by existing bureaucracies.

However, the fact that a large regulatory system does not exist to deal with NORM is also a problem. NORM contamination exists now and is being compounded daily in many different industry segments making this position all the more challenging. Clever theoretical constructs and arguments over dose-response theories are not going to make NORM less of a problem in the future. Action—driven by industry—that seeks to lower future NORM wastes and looks for more efficient ways of dealing with past NORM problems is needed. And, if industries that concentrate NORM hope to reduce future liabilities for NORM pollution this action is needed before regulation requires it.

Many arguments can be made in support of regulating NORM at the federal level.[350] The single most important is the fact that NORM is not an issue solely affecting the petroleum industry. NORM in an unwanted by-product in chemical plants, paper and pulp plants, fertilizer plants, refineries, public water wells and treatment plants, mineral processing, geothermal plants and wells, petrochemical plants, and glass and ceramic manufacturing. Because NORM touches such a wide cross-section of industry, there is a need for a centralized form of regulation to effectively manage NORM that keeps workers and the general public from NORM-related risks. Because industry's competitiveness can be impacted by variable state regulation, NORM regulation can only be effective if it applies to all industries that technologically enhance NORM, and only if it fairly allocates the costs of NORM by applying in a manner which does unfairly alter the market forces within a single industry or between several industries. It seems that only the long arm of the federal government can meet

350. Professor Esty discusses a number of legal arguments for centralized environmental regulation Daniel Esty, Revitalizing Environmental Federalism, 95 MICH. L. REV. 600 (1996).

these needs.

The object of any regulation will be the adequate protection of human health and the environment from the potentially deleterious effects of NORM. Private action that meets that goal before it is officially set will only serve to strengthen the companies that implement such measures and the industries that support them.