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Protection Agency

Science Advisory
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May 1994

AN SAB REPORT: REVIEW OF DIFFUSE NORM DRAFT SCOPING DOCUMENT

REVIEW OF THE OFFICE OF RADIATION AND INDOOR AIR DRAFT DOCUMENT ON DIFFUSE NATURALLY-OCCURRING RADIOACTIVE MATERIAL (NORM): WASTE CHARACTERIZATION AND PRELIMINARY RISK ASSESSMENT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

May 16, 1994

EPA-SAB-RAC-94-013

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, DC 20460

Re: Naturally Occurring Radioactive Materials (NORM)

Dear Ms. Browner:

At the request of the Office of Radiation and Indoor Air (ORIA), the Science Advisory Board (through its Radiation Advisory Committee) has reviewed the Agency's draft document titled "Diffuse NORM - Waste Characterization and Preliminary Risk Assessment," dated May 1993 (hereinafter called the "NORM document"). This Committee has responded to the six specific questions asked by ORIA and has also provided more general comments and suggestions.

The NORM document is the latest draft in a series that spans several years and reflects the responsiveness of ORIA to comments by EPA internal reviewers, by the public, and by the Radiation Advisory Committee (RAC). It appears to have accessed and summarized most of the information about diffuse NORM that was generally available at the time the document was prepared. However, the NORM document does not meet its stated goal of providing a scoping analysis of the NORM problem sufficient to determine the need for additional investigations or for regulatory initiatives.

With regard to the six specific questions asked in the charge, the RAC finds the following:

1. The NORM document does not adequately convey the deficiencies and uncertainties in the information available to characterize the sources of NORM. The choices of nominal values for volume and concentration used in the risk assessment are not sufficiently justified. Some values appear to be overestimates (especially for concentrations), while others appear to be underestimates.

2. The justification provided for parameter values used in the risk assessment is not sufficient. In addition, the NORM document uses aggregate factors for food uptake and dose conversion that incorporate many other assumptions and parameter choices, making evaluation difficult. The RAC suspects that the food uptake factors may tend to underestimate exposures.

3. With few exceptions as noted in the RAC report, the NORM document has selected reasonable scenarios and pathways of exposure for analysis.

4. The NORM document has used appropriate models for the most part. The RAC notes, however, that advective flow was not considered in the model for radon exposures, and suspects that this omission may have led to underestimates of exposures for radium in the waste.

5. While the greatest uncertainties are in the estimates of risks from pathways that probably do not contribute much to total risk, the risks from specific sources are probably not known within a factor of three, despite what might be inferred from the language in the NORM document.

6. The NORM document does not meet its stated goal of providing a scoping analysis of the NORM problem sufficient to determine the need for additional investigations or for regulatory initiatives. The RAC believes that, if the EPA addressed the deficiencies identified in this review, then the revised NORM document could serve as a useful compilation of information for the public on NORM source terms and potential exposure scenarios. Any language suggesting that the NORM document could be used to justify regulatory decisions should be removed from the document. To go beyond this limited use and to meet the goal of serving as a screening tool for identifying those categories that may require regulatory attention, it would be necessary for the Agency to conduct its risk assessment analysis using a consistent approach in addressing uncertainties, such as the methodology suggested by the RAC in its report.

The RAC believes that, despite its shortcomings, the NORM document nonetheless provides indications that some categories of NORM may produce risks that exceed those of concern from other sources of radiation. Consequently, the RAC is of the opinion that the issue of NORM deserves substantial attention within EPA, and is concerned that timely resolution of this issue will require an increased commitment of resources.

The Radiation Advisory Committee appreciates the opportunity to comment on the NORM assessment. We look forward to receiving the EPA's plans for further work on the NORM issue, particularly as it relates to our explicit recommendations.

Sincerely,

Genevieve M. Matanoski
Dr. Genevieve M. Matanoski
Chair, Executive Committee
Science Advisory Board

James E Watson, Jr.
Dr.James E. Watson, Jr.
Chair, Radiation Advisory Committee
Science Advisory Board

NOTICE

This report has been written as a part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency; hence, the comments of this report do not necessarily represent the views and policies of the Environmental Protection Agency or of other Federal agencies. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

The bulk of this report was prepared while Dr. Genevieve M. Matanoski was Chair of the SAB's Radiation Advisory Committee (RAC), and Dr. Raymond C. Loehr was Chair of the SAB's Executive Committee. Subsequently, Ms. Carol M. Browner, Administrator of the EPA, selected Dr. Matanoski as Chair of the SAB's Executive Committee and Dr. James E. Watson, Jr., as Chair of the SAB's RAC.

ABSTRACT

The Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) has reviewed the Agency's Office of Radiation and Indoor Air (ORIA) study entitled "Diffuse NORM - Waste Characterization and Preliminary Risk Assessment," dated May, 1993. The RAC responded to the six specific questions asked by ORIA and also provided more general comments and suggestions.

The RAC believes that, despite its shortcomings, the NORM document nonetheless provides indications that some categories of NORM may produce risks that exceed those of concern from other sources of radiation. Consequently, the RAC is of the opinion that the issue of NORM deserves substantial attention within EPA, and is concerned that resolution of this issue will require an increased commitment of resources. If the EPA addressed the deficiencies identified by the RAC in its response to the charge, then the revised NORM scoping document could serve as a useful and much-needed compilation of information for the public on NORM source terms and potential exposure pathways.

However, to go beyond this limited use and to meet the goal of serving as a screening tool for identifying those categories that may require possible regulatory attention, it would be necessary for the Agency to conduct its risk assessment analysis using a consistent approach for addressing uncertainties, such as the methodology suggested by the RAC in its report. Care should be taken to recognize the differences between those categories of NORM that may be rated high with respect to individual risk and those that may be rated high with respect to population risk.

Key Words: Diffuse Naturally Occurring Radioactive Material (NORM), NORM, NORM Sources, NORM Exposures, NORM Risks

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1. EXECUTIVE SUMMARY

At the request of the Office of Radiation and Indoor Air (ORIA), the Science Advisory Board (through its Radiation Advisory Committee) has reviewed the Agency's May 1993 draft report titled "Diffuse NORM - Waste Characterization and Preliminary Risk Assessment," prepared by SC&A, Inc., and Rogers & Associates Engineering Corporation (See Appendix A - Dehmel & Rogers, May 1993, hereinafter called the "NORM document"). The Committee has responded to six specific questions asked by ORIA and also has provided more general comments and suggestions.

The NORM document is the latest draft in a series that spans several years and reflects the responsiveness of ORIA staff to comments by EPA internal reviewers, by the public, and by the Radiation Advisory Committee (RAC, or "the Committee"). The Agency appears to have accessed and summarized most of the information about diffuse NORM that was generally available at the time the document was prepared. However, the 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 for regulatory initiatives. The following discussion summarizes the Committee's responses to the six specific issues raised by ORIA in its charge to the RAC.

Issue 1. <u>NORM sources</u>. ***Does the information in the document present an adequate characterization of processes and sources of NORM, including the adequacy of the data?***

Findings

The information in the document does not present an adequate characterization of sources of NORM to the extent required to conduct a useful screening analysis of the risks associated with these sources. In some cases, the presentation of available data is inadequate while in other cases the basic data that are needed are lacking.

The volume of the source of NORM and the radionuclide concentrations in the source are key parameters for a risk assessment. The adequacy of this information varies for the different sources of NORM considered in the document. In general, the volumes of the sources are better characterized than are the radionuclide concentrations. For most sources, a wide range of radionuclide concentrations is noted, and a single value is selected for the assessment. In some cases the selected value appears to be conservative[1], i.e., it is more likely to be biased high than low; but in other cases it is not known whether the selected value is likely to be biased high or low. Furthermore, for cases in which the radionuclide concentration in a given source of NORM spans more than an order of magnitude, it may be inappropriate to adopt a single value to characterize the radioactivity of wastes from that sector in risk assessment calculations.

Recommendations

1a. Information in the NORM document does not provide an adequate basis for omitting particular sources because of negligible risk, nor for identifying particular sources for regulatory initiatives. The RAC recommends that EPA re-evaluate the literature on volumes and radionuclides concentrations in sources of NORM, with attention given to comments in the RAC report as well as to comments received from the public, and make needed corrections to the NORM document. Publications since the last literature search should also be considered in the re-evaluation.

Issue 2. Model parameters. ***Are parameters used in the risk assessment reasonable? Are the references and justifications adequate? Does the presentation properly reflect the best available scientific information?***

Findings

In most cases, the references and justifications for the parameters used in the risk assessment have not been provided in the reviewed NORM document, making it difficult to determine whether or not the adopted values are reasonable. In fact, the procedure used to select parameter values is not clearly articulated. Moreover, some of the parameters represent highly aggregated constructs, requiring substantial effort to trace them back to their experimental or theoretical basis. To a limited extent, the RAC was able to compare the adopted values to the range of values published in the literature in order to judge the degree to which the adopted values are reasonable or conservative estimates. Some of the adopted parameter values (e.g., food uptake factors) appear to fall outside the range of measured values, in the direction of non-conservatism. While many of the choices are consistent with standard risk assessment practices, the parameter

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[1] A "conservative" risk analysis is one in which the parameter values used in the risk models are biased so as not to underestimate the true risk, and to provide an upper bound estimate of the risk. In an "anti-conservative" analysis, parameter values are biased so as to intentionally underestimate the true risk, and to provide a lower bound estimate of the risk. A "non-conservative" analysis is designed so as not to over-estimate the true risk, but may not necessarily underestimate it.

values for food uptake factors may be anticonservative in the sense of potentially underestimating risk.

Recommendations

2a. The RAC recommends that the original data sources and justifications for the selection of representative values for all parameters be incorporated into the NORM document (or in an appendix thereto).

2b. The RAC recommends that a complete list of terms be added to the appendix to the NORM document, that would clearly define each parameter used and that would cite the mathematical expression used to derive any lumped parameters.

2c. The RAC recommends that EPA document the reasons for the discrepancies between the dose and risk conversion factors used in the NORM document and those recommended by the ICRP.

Issue 3. Scenarios. ***Does the preliminary risk assessment adequately identify and characterize the key scenarios needed for evaluating individual and population risks from the sources characterized?***

Findings

In general, the list of pathways is reasonably comprehensive and may even include some pathways that are very unlikely to contribute substantially to total risk. However, it does not include at least one pathway that is commonly assessed in EPA programs covering hazardous wastes (Superfund and RCRA): soil ingestion by humans and by grazing animals. The NORM document also does not appear to have considered leaching of potassium-40 from waste piles; the consequences for risk of this omission are not clear. The list of receptors is reasonable, and the matrix of pathways vs. receptors is reasonably complete.

Recommendations

3a. The RAC recommends that the list of pathways to be considered include, to the extent appropriate, those pathways used in other programs of the EPA (e.g., Superfund). In particular, the soil ingestion pathway seems relevant.

Issue 4. Model formulations. ***Does the PATHRAE methodology presented in this document adequately quantify risks from the sources and scenarios characterized?***

Findings

With the exception of the radon transport model, the models and their submodels appear to be reasonably complete formulations for developing preliminary scoping estimates of doses and risks, with inclusion of an appropriate choice of generic site parameters (although not necessarily of parameter values; see issue 2 above). Underlying assumptions for the models are for the most part clearly stated. Detailed documentation for the models is apparently to be found in other EPA documents which presumably describe the mathematical basis of the models; in some cases, as discussed in the main text of the Committee's review, this basis is not sufficiently clear.

Recommendations

4a. The RAC recommends that advective flow be incorporated into the scenarios having to do with exposures to radon; its omission from these scenarios probably leads to underestimates of exposure for radium in the waste.

4b. The choice of computer models for assessing NORM risks may have been driven by existing software, rather than by the needs of the document. The Agency should consider using more flexible and transparent modern programming tools in future work.

Issue 5. Uncertainty analysis of risk estimates. ***Risk estimates calculated using the PATHRAE methodology are estimated to be within a factor of three of calculations made with more detailed codes. Given this error band, the methodology employed, and the lack of knowledge associated with the waste streams; is the Agency's characterization of uncertainty and sensitivity adequate for the purposes of this scoping study?***

Findings

The NORM document claims that risk estimates using the PATHRAE methodology are estimated to be within a factor of three of those obtained using more sophisticated codes, but does not support that assertion with calculations. In fact, in the single very limited comparison between the simplified methodology and the results from PRESTO-CPG-PC, the dose estimates were significantly different, by as much as a factor of 50 in one case.

However, the magnitude of the uncertainties introduced by model formulations for many scenarios and pathways may be exceeded by uncertainties that are inherent in the parameter estimates themselves. Uncertainties in source volumes, average radionuclide concentrations, transport parameters and dose-to-risk conversions may each be on the order of a factor of ten or more. As a result, for some pathways, the RAC would estimate that dose and risk estimates may be uncertain by several orders of magnitude. Some of these pathways (e.g., consumption of vegetables grown in soil upon which contaminated dust has settled) are often relatively minor contributors to overall risk, such that uncertainties associated with these doses are somewhat less important than those for major pathways (e.g., direct gamma radiation and radon) where uncertainties should generally be less.

Because the NORM document is neither consistently conservative nor consistently nonconservative, the Agency's characterization of uncertainty and sensitivity is not adequate, even for the purposes of this scoping study. Concentrations of radionuclides in NORM materials are typically estimated with conservative assumptions, but the same may not be true for the source volumes, and many of the pathway and risk assumptions are probably nonconservative. The document's qualitative uncertainty analysis, while informative about the professional judgments made by the authors, does not permit the reader to conclude that one source is definitely of more concern than another, that some sources can be dismissed as posing negligible risks, or that some sources clearly need further attention.

Recommendations

5a. The RAC recommends that the EPA better document its assertion that risk estimates calculated using the PATHRAE methodology are within a factor of three of calculations made with more detailed codes.

5b. The RAC recommends that the EPA revise its screening risk analysis for NORM sources by consistently using either conservative or nonconservative assumptions about exposure and risk coefficients. These revisions should be included in any risk estimates appearing in the final version of the NORM.

Issue 6. Priorities for additional work. ***In what areas does the SAB's RAC recommend the greatest priority be given for developing additional information?***

The RAC believes that the issue of NORM deserves substantial attention within EPA, and is concerned that timely resolution of this issue will require an increased commitment of resources. Despite its shortcomings, the NORM document nonetheless provides indications that some categories of NORM may produce risks that exceed those of concern from other sources of radiation. The RAC recommends that greatest priority be given to two aspects:

6a. First priority should be given to revising the NORM document to address the more demanding of the RAC's comments: the inclusion of more recent information on source volumes and concentrations, disaggregation and updating of food uptake factors and dose/risk conversion factors, documentation and justification of parameter selection, and consideration of advective flow as a means for radon transport. The revised NORM document could then serve as a useful and much-needed compilation of information for the public on NORM source terms and potential exposure pathways. However, any language suggesting that the present NORM document could be used to justify regulatory decisions should be removed from that document.

6b. To go beyond this limited use and to meet the goal of serving as a screening tool for identifying those categories that may or may not require further attention and possible regulatory action, it would be necessary for the Agency to conduct its risk assessment analysis using a consistent approach in addressing uncertainties, such as the methodology suggested by the RAC in this review report.

2. INTRODUCTION AND MAJOR CONCLUSIONS

The Radiation Advisory Committee (RAC, or "the Committee") has had a keen interest in the scientific issues surrounding the assessment of NORM materials and welcomes this opportunity to review ORIA's draft document on diffuse NORM (Dehmel and Rogers, May 1993, see Appendix A for full citation). The RAC is mindful that NORM is a "federal orphan," falling outside the Nuclear Regulatory Commission's (NRC's) mandate to regulate Atomic Energy Act materials and not having attracted significant levels of staff attention or research funding within EPA. Therefore, the intent of the NORM document, to serve as a scoping document that could support the EPA's need to make informed decisions about further research or regulation, is laudable.[2]

The RAC believes that the issue of NORM as a potential environmental problem deserves substantial attention within EPA, and is concerned that the issue may not be resolved in a timely manner without increased resources being devoted to it. Despite the shortcomings that are described in this RAC report, the NORM document nonetheless provides indications that some categories of NORM may produce risks that exceed those of concern from other sources of radiation. It is therefore advisable that EPA move forward toward a decision on the necessity to regulate NORM.

The RAC is of the opinion that the NORM document in its current form is insufficient to provide a basis for such a decision. If the EPA addresses the deficiencies identified in the RAC responses to the charge, then the revised NORM document could serve as a useful and much-needed compilation of information for the public on NORM source terms and potential exposure pathways. However, to go beyond this limited use and to meet the stated goal of serving as a screening tool for identifying those categories that may or may not require further attention and possible regulatory action, it would be necessary for the Agency to conduct its risk assessment analysis using a consistent approach in addressing uncertainties, such as the methodology suggested by the RAC in this review report. Any

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2 Unfortunately, the actual uses that EPA envisioned for the NORM document are not as clear as they might be, and the RAC's review is influenced by the Committee's notion of what the intent should be. On page ES-1 of the NORM document, it is stated that the document "was prepared as an initial step to help determine if standards governing the disposal and reuse of NORM waste and material are warranted" and that "(i)f EPA decides regulation is warranted, a much more detailed and complete risk analyses (sic) and waste characterization will be developed and presented in a Background Information Document that will accompany proposed regulations. This preliminary risk assessment will not be used as the primary source of information for developing such regulations."

language suggesting that the present NORM document could be used to justify regulatory decisions should be removed from that document.

A risk analysis appropriate for screening the NORM categories so as to determine those that definitely should (or definitely should not) be candidates for regulatory attention would need to take an approach that was either consistently conservative[3] (which would serve to identify categories of NORM that definitely would not require regulatory attention) and/or consistently nonconservative (which would serve to identify categories that might require regulatory attention).

In its documentation of the results of its risk analysis, EPA should also be careful to draw the reader's attention to the differences between those categories of NORM that may be rated high with respect to individual risk (where a few people may be exposed to estimated risks ordinarily thought to deserve EPA attention) and those that may be rated high with respect to population risk (where estimated risks to even the maximally exposed persons are relatively low but many people are exposed). A discussion of the policy implications of these two categories of risks, particularly with respect to the issues involved in imposing regulatory controls on the latter, would be useful.

The remainder of this report is organized to follow the six specific questions that the RAC was asked by ORIA to address in its review of the NORM document, followed by a section containing additional comments.

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3 The term "conservative" is used in the same sense as is commonly employed in risk assessment, i.e., implying the use of assumptions and procedures designed with a bias to ensure that the true risk will not be underestimated (instead of toward overestimating risk) so that health-protective decisions can be made. Compound conservative assumptions are therefore very likely to overstate risk, and a NORM category that ranks low in risk even with conservative methods is not a candidate for regulation. Categories that rank high in risk after conservative screening are not necessarily worthy of regulation, however, and more realistic evaluation is required to make the ultimate regulatory decisions.

3. NORM SOURCES

Issue 1: **NORM sources**
Does the information in the document present an adequate characterization of processes and sources of NORM, including the adequacy of the data?

The information in the document does not present an adequate characterization of sources of NORM to the extent required to conduct a useful screening analysis of the risks associated with these sources. In some cases, the presentation of available data is inadequate while in other cases the basic data that are needed are lacking.

The volume of the source of NORM and the radionuclide concentrations in the source are key parameters for a risk assessment. Individual and population risks are related to the radionuclide concentration, but only the population risk is affected by the volume or distribution of the source. The adequacy of this information varies for the different sources of NORM considered in the NORM document. In general, the volumes of the sources are better characterized than are the radionuclide concentrations. For most sources, a wide range of radionuclide concentrations is noted, and a single value is selected for the assessment. In some cases the selected value appears to be conservative, that is, it is more likely to be high than low, but in other cases it is not known whether the selected value is likely to be biased high or low. Furthermore, for cases in which the radionuclide concentration in a given source of NORM spans more than an order of magnitude, it may be inappropriate to adopt a single value to characterize the radioactivity of wastes from that sector in risk assessment calculations.

The RAC recommends that EPA re-evaluate the literature on volumes and radionuclides concentrations in sources of NORM, with attention given to comments in the RAC report as well as to comments received from the public (e.g., See Appendix B), and make needed corrections to the NORM document. Publications since the last literature search should also be considered in the re-evaluation.

3.1 Uranium Mine Overburden

This section of the NORM document provides a good overview of the subject. However, the adoption of one set of risk assessment parameters "for representative disposal of uranium mining overburden" (p. B-1-23)[4] is too sweeping and will result in misleading and not very useful risk assessments.

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[4] Page numbers throughout this report refer to those in the NORM document (Dehmel and Rogers, May 1993).

The range of radioactivity levels in uranium mining overburden is very large -- for instance, the NORM document cites a range of Ra-226 concentrations from three to several hundred picocuries per gram. The range of uranium values is not cited. The NORM document should cite the full range of values for both the uranium and thorium decay chains. At secular equilibrium, uranium activity levels would be double those of Ra-226, with half coming from U-238 and half from U-234, and this is presumably the case for uranium overburden, according to the average values shown in Table B.1-5 (p. B-1-23). It would be useful to cite available data on U-238/Ra-226 and U-238/Th-230 ratios in overburden to determine the extent to which differential solubility may have affected the equilibrium ratios and how these ratios might be expected to evolve with time in an unremediated pile.

The use of a 5% figure for the U-235 decay chain in the absence of data is reasonable (p. B-1-17), and can be applied to all uranium calculations in this NORM document. It is not clear whether all decay products of U-235 have been included; they should be. The coefficients for radon and radon daughters discussed in the top half of page B-1-17 appear reasonable. However, these ratios would appear to depend on the physical configuration of the tailings and the NORM document should discuss the range of values to be expected.

On p. B-1-10, the RAC notes that, although it is true that surface mining dominates the overburden, the problem of overburden from underground mines could be very important locally, depending on radionuclide concentrations and the likelihood that the area may be used for residential, commercial, or agricultural purposes in the future.

3.2 Phosphate/Fertilizer Materials

3.2.1 Phosphate Industry Wastes

Although the mining and processing of phosphate rock is a large industry (the fifth largest mining industry in the U.S.), the activities that surround it are concentrated in the southeast U.S., mostly Florida and Tennessee, and in the west, primarily in southeast Idaho, Utah, Wyoming, and Montana. This focused industry is well understood and represented by organizations familiar with process rates and production rates of products containing phosphate. The NORM document mirrors the data from these organizations and major studies of the industry, and thus presents a responsible compilation of the amount of product and waste produced over the past few decades for elemental phosphorous and phosphoric acid, the two principal products.

Mining, beneficiation, and processing of the ore to produce phosphoric acid (the wet process) and elemental phosphorous (the thermal process) are adequately described in terms of how radioactive material distributes in the products and wastes. These estimated distributions are based on fairly extensive measurements made by EPA and others. In particular, a series of studies by EPA's Office of

Radiation Programs in the 1970's and 80's provided much of the data for these estimates. Thus, the NORM document presents estimates based on good measurements, which is very desirable. Nonetheless, consideration of the huge volumes of materials requires extrapolation from this data set, and the inevitable uncertainties that accompany such extrapolation are not adequately presented. For example, one extrapolated statistic for phosphoric acid production that perpetuates throughout the analysis is that about 80% of the Ra-226 in the original phosphate rock goes into the phosphogypsum wastes while about 86% of the uranium and 70% of the thorium remain in the phosphoric acid (and presumably about 20% of the Ra-226). This statistic is based on measurements for the wet process only; no such statistic is presented for the thermal process. Since 70-80% of the elemental phosphorous produced is used in fertilizers, which become widely distributed sources of NORM, data for both the wet and thermal processes are needed. The mix of thermal phosphorus production versus the wet process is already changing due to increasing energy costs for thermal process plants.

The NORM document is deficient in its description of the distribution of beneficiation wastes, primarily the slimes and tailings. Beneficiation waste control practices have changed over the years, and the risk assessment needs to recognize current trends and their implications for ways in which diffuse NORM from this sector could affect the general public. For example, the slimes produced during ore beneficiation contain appreciable amounts of Ra-226 and, when used as shallow fill, they can produce elevated radon levels in structures built on filled areas. Recent practices of restricting slime use have reduced these circumstances.

Waste production rates are reasonably described for the phosphogypsum; however, the phosphate slag inventory is estimated to range between 224 and 424 million metric tons (MT)(three significant figures appear out of place for such a wide-ranging estimate). More recent data on slag production should be obtained, if available (the NORM document references 1975 production data).

The NORM document describes the production of concentrated radioactivity in scale deposits (primarily Ra-226) and then dismisses it because the volume is low. EPA should assure that these NORM wastes are properly managed - perhaps the practice of emplacing scale in phosphogypsum piles is appropriate if it occurs; perhaps not. Ferrophosphorus is reported (page B-2-9) to be a product of the thermal process. The radioactivity content appears to be low as shown in Table B.2-4 of the document.

Phosphate Slag is described as a fused matrix that minimizes radon emanation, an assumption which appears to be reasonable considering the experience with basement fills in Soda Springs and Pocatello, Idaho. The assumption of an emanation fraction of 0.01 for radon is noted as arbitrary; however, data are presented from Montana slag that suggest it was calculated from these measurements. Measurement of a few samples would confirm this estimate and/or support the use of the Montana data. It is further reported that radionuclides can be leached from slag, but no more is said of it. It should be stated whether or not, and why, this may be a significant pathway of exposure. Furthermore, the document neglects another potential pathway, that of suspension of slag dust in precipitation.

3.2.2 Radionuclide Concentrations

In the NORM document, most of the radionuclide concentration data for the phosphate industry are based on measured data or extrapolations of these data to other matrices and forms using assumed fractions. The original measurements were done primarily by EPA using state-of-the-art laboratories and reported in well documented studies. A few inconsistencies can be noted.

An informative statistic is that about 80% of the Ra-226 in phosphate ore goes to phosphogypsum waste while 86% of the uranium goes into the phosphoric acid. These data are based on Florida phosphate ore deposits and are useful for establishing potential exposure pathways for NORM in phosphate ore. Yet, Table B.2-4, which is based on measured data, shows that the Ra-226 in the ore is somewhat less than 80% of the Ra-226 concentration in the phosphogypsum. Perhaps this apparent discrepancy is due to density changes in the processing, but it should be reconciled.

Extrapolations for phosphogypsum are generally based on concentrations in Florida phosphate ore which is generally higher than other ores; thus, these estimated values are probably conservative for phosphogypsum wastes overall.

Decay products of uranium and Ra-226 are calculated based on radiological equilibrium conditions for a selected source term which is usually chosen near the high end of measured values. Assumed ingrowth periods appear reasonable, and the calculated values are correct for these periods. Decay products of U-235 are reasonably calculated to be 5% of the U-238 activity (the actual value is 4.6%). These ingrowth radionuclides are adjusted for radon emanation fractions which are assumed to be 0.2 for phosphogypsum and 0.3 for fertilizer applications, respectively. The difference is presumably to account for differences in soil conditions, but it is not explained. Average concentrations of U-238, Ra-226, U-235, and Th-232 in phosphogypsum are estimated to be 6.0, 33, 0.30, and 0.27 pCi/g, respectively.

Phosphogypsum Concentrations are based on measured data and appear to have been extrapolated correctly both for direct disposal in stacks and reuse in fertilizers and soil conditioners. The reuse scenarios also appear reasonable.

The largest deficiencies in the radionuclide concentration data are the absence of concentrations of key radionuclides in elemental phosphorus, phosphoric acid manufactured from it that may be used in fertilizers, and phosphoric acid from the wet process. These data would be useful for assessing the risks associated with the widespread application of these materials as products.

Phosphate Slag Concentrations (Table B.2-6) appear to be conservative because a value near the upper end of measured concentrations for Ra-226 was used for the exposure estimates. Average concentrations of U-238, Ra-226, U-235, and Th-232 in phosphate slag are estimated to be 25, 35, 1.3, and 0.77 pCi/g, respectively. The radon emanation from slag is expected to be very low because of its vitrified matrix. Decay products of the above nuclides are also present in the phosphogypsum and phosphate slag.

3.3 Phosphate Fertilizers and Potash

Processes for production of fertilizers that contain phosphoric acid and potash are described in section B.3 of the NORM document. These processes and consumption rates are reasonable descriptions -- there is obviously widespread application of radioactive substances in these materials in U.S. agriculture. The two major issues to be resolved are: 1) whether the distribution of uranium and radium in fertilizers leads to exposure pathways that represent significant population impacts, and 2) whether current understanding of the sources of fertilizer components is sufficient to determine the cost-effectiveness of procedures that might reduce the potential radiological consequences to the population.

Radionuclide Concentration data in section B-3.4.1 of the NORM document are not consistent with the data in Table B.2-4 for Florida phosphate rock, which is the major source of fertilizer components and hence entrained radioactivity. It is interesting that the process of making phosphoric acid eliminates 80% of the Ra-226 and its decay products, only to have some of it reintroduced by mixing the phosphoric acid with crushed phosphate rock to produce a bag of marketable product. Nonetheless, the data in Table B.3-3 are based on measured values and appear to be the most appropriate for use in exposure scenarios. The NORM document emphasizes that most of the uranium goes with the product and most of the Ra-226 goes to the waste, yet the concentration of Ra-226 is about equal to that of U-238 in normal and triple superphosphate. (The concentrations of uranium and radium in other forms of phosphate are closer to what would be forecast from this statistic). Because normal and triple superphosphate are produced in quantities that are smaller than that for phosphoric acid, the average fertilizer (Table B.3-4) contains considerably more radioactivity from uranium than from radium.

3.4 Fossil Fuels - Coal Ash

3.4.1 Coal Ash Generation

The NORM document, on page B-4-1, states that there are over 1,300 coal-fired boilers operated by electric utilities and nearly 60,000 industrial boilers in the U.S., and that about 889 million MT of coal were consumed in 1989. Table B.4-1, on page B-4-2, indicates that 889 million MT of coal were produced in 1989 and that 800 million MT were consumed. The difference in the data presented on pages B-4-1 and B-4-2 is only about 10%, but this difference in production vs. consumption raises concern about the attention to details in the preparation of the NORM document.

The NORM document states that coal production has increased by about 60% from 1970 to 1989. The NORM document also states that the coal production rate has been assumed to rise at 1.3% per year during the 1990s and at 2.8% per year into the next century.

It is reported that in 1985 the representative ash content of coals used by utilities ranged from 5.9% to 29.4%, with a national average of 10.5%. The average ash content of coal burned has decreased from about 14% in 1975 to the 1985 value of about 10%. The NORM document quotes an EPA prediction that the ash content will remain at about 10% until the end of the century.

The NORM document notes that the ash content of coal can be reduced by as much as 50% to 70% by washing the coal. Washing the coal could also remove some of the radioactive material, but the NORM document indicates that no data could be located to support this contention.

An estimate presented of the relative fractions of the different types of ash produced in modern furnaces that burn pulverized coal is: fly ash: 74%, bottom ash: 20%, boiler slag: 6%. These values are based on 1984 data and it is stated that the data are believed to be typical of the ash distribution for currently operating furnaces and those that will operate for the next decade (EPA, 1988a; EPA, 1988b). The NORM document did not provide an estimate of the percentage of furnaces that use pulverized coal.

Citing data from the American Coal Ash Association , Inc. (ACAA), the NORM document states that in 1990 the combustion of coal in utility and industrial boilers generated 61.6 million MT of coal ash and slags and 17.2 million MT of sludges. These were broken down into 45.6 million MT of fly ash, 12.3 million MT of bottom ash, 3.7 million MT of boiler slag, and 17.2 million MT of sludges (flue gas desulfurization sludges). The ACAA data show that the yearly ash production rate almost tripled between 1966 and 1990.

The NORM document notes that, although the demand for electricity has increased an overall average of 2.7% per year, over the "past 10 years" the annual production rate of ash has remained relatively stable, ranging from 57.9 to 65.2 million MT. The NORM document does not explain why the yearly ash production rate has remained relatively stable.

The NORM document states that the yearly ash generation rate (including bottom ash and boiler slags) is predicted to be 109 to 136 million MT by the turn of the century (EPA, 1988b; EEI, 1988). The bases for this prediction are not presented and, because the ash generation rate did not increase much during the period 1980-1990, it is not clear why the rate would be expected to increase this much by the turn of the century.

The production and utilization of ash varies by region throughout the United States and Table B.4-4 presents data on the production and utilization by region. Table B.4-5 presents a breakdown of ash and sludge utilization by type of utilization. The table indicates that the utilization is a percentage of production, but the data appear more likely to be a percentage of utilization rather than of production.

In summary, data are presented for yearly ash production rates from 1966 to 1990 based on ACAA yearly data sheets. These data sheets have not been reviewed by the RAC, but are assumed to be reliable. It appears that the annual production rates from these data were used with the estimates of the relative fractions of the different types of ash produced to estimate the annual quantities of fly ash, bottom ash, and boiler slag. As previously stated, these estimates of the relative fractions are based on 1984 data for "modern furnaces that burn pulverized coal," and it is assumed in the NORM document that these data are typical of the ash distribution for currently operating furnaces and those that will operate for the next decade. The EPA report referenced for this assumption has not been reviewed by the RAC. The NORM document quotes EPA and EEI projections that the yearly ash generation rate will vary from 109 to 136 million MT by the turn of the century (compared to 61.6 million MT in 1990). The bases for these projections are not presented and it is not clear why the ash generation rate would increase this much by the turn of the century when there was so little increase between 1980 and 1990.

3.4.2 Radionuclide Concentrations

The NORM document notes that coal contains naturally occurring uranium and thorium, as well as their radioactive decay products. It is also noted that the radioactivity of coal varies over two orders of magnitude depending on the type of coal and the region from which it is mined. On page B-4-20, it is stated that the concentrations of U-238 and Th-232 in coal range from 0.08 to 14 pCi/g and 0.08 to 9 pCi/g, respectively (UNSCEAR, 1982). U-238 and Th-232 concentrations are 0.6 and 0.5 pCi/g, respectively, calculated as arithmetic means, and 0.34 and 0.26 pCi/g, respectively, calculated as geometric means (Beck et al., 1980; Beck and Miller, 1989).

On page B-4-21, the U-238 and Th-232 concentrations in coal ash are stated to range from 1.5 to 8.6 pCi/g and 0.4 to 7.5 pCi/g, respectively (Beck et al., 1980; Beck and Miller, 1989). The NORM document references a 1982 UNSCEAR report for U-238 and Th-232 average concentrations in fly ash of 5.4 and 1.9 pCi/g, respectively (UNSCEAR, 1982). Thus, it is noted that the radioactivity of fly ash is typically higher than that of coal and that the enrichment is dependent upon the type of coal used, the ash content, and the type of boiler in which the coal is used. It is also noted that the enrichment ratio is dependent upon the radionuclide and that higher enrichment ratios have been observed for Ra-226, Po-210, and Pb-210 than for U-238 and Th-232.

Page B-4-21 contains a statement that a limited review of the published literature was conducted to identify commonly reported radionuclides and their respective concentrations. It is not clear whether the radionuclide concentrations used in this NORM document were based on the literature review or on UNSCEAR (1982) alone. If the concentrations are based on data other than those from UNSCEAR, the data are not presented and discussed.[5]

On page B-4-21, it is stated that radionuclide distributions and concentrations were grouped in two categories, fly ash and bottom ash, and it was assumed that ash materials were comprised of 80% fly ash and 20% bottom ash, which includes boiler slags. Then weighted average radionuclide concentrations in coal ash were estimated (page B-4-22). The values given for U-238 and Th-232 are 3.3 pCi/g and 2.1 pCi/g, respectively. (This weighted concentration would not necessarily be applicable to reuse scenarios since the use of coal ash is not necessarily in an 80:20 mix.) Values of the concentrations of the various radionuclides in fly ash and in bottom ash that were used to compute the weighted concentrations are not presented, and it is not clear how the values used were determined. Thus the adequacy of the concentrations of radionuclides in coal ash used in this NORM document cannot be evaluated.

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5 William Russo of ORIA determined, for the RAC, that the values used for the radionuclide concentrations were "engineering judgments," by the contractor, based on the review of the literature noted. The values were not taken from the UNSCEAR report cited, nor from any other single reference.

3.5 Oil and Gas Production

3.5.1 Summary

A fundamental flaw of the source term analysis for this sector is that none of the risks from NORM containing more than 2,000 pCi/g have been included because they have been assigned to the "discrete" NARM (Naturally-Occurring and Accelerator-Produced Material) category. This action has eliminated from consideration in the source-term analysis a portion of NORM waste that may represent the largest risks to exposed individuals. As a result of imposing this arbitrary threshold of 2,000 pCi/g, which is based on a transportation standard (49 CFR 173.403) and not on risk assessment considerations, the risks from NORM for this sector are not adequately characterized. The RAC recommends that either these wastes be included in the risk analysis or else that the rationale for and consequences of their omission from the analysis be explicitly stated.

3.5.2 Waste Volume Characterization

From the data presented in the NORM document one can obtain the following:

Oil production dropped in the USA from 9.6 million barrels per day (mbd) to 8.2 mbd in the period from 1970-1977. It then increased up to 9.0 mbd by 1985, and dropped again to 7.6 mbd by 1989. This was due to worldwide economic fluctuations.

Gas production declined steadily from 22 trillion ft^3 to 17 trillion ft^3 between 1970 and 1983. It was steady from 1983 to 1989 at 17-18 trillion ft^3.

Oil and gas production are a regional activity in the USA. Eight states (Alaska, California, Kansas, Louisiana, New Mexico, Oklahoma, Texas, and Wyoming) accounted for 92% of all oil production and 70% of all producing wells in 1989. The same eight states accounted for 92% of all natural gas production and 48% of the wells in 1989.

Calculations of scale and sludge NORM volumes are based on a 'generic' oil production facility incorporated into the NORM document from the 'Louisiana Report' (Rogers & Associates, 1993). A full evaluation of the adequacy of the calculations and underlying assumptions would require a thorough review of the Louisiana Report. As a minimum, however, the RAC recommends that the Agency revise the NORM document so as to emphasize that NORM source-term data in the Louisiana Report may not be representative of oil and gas producing facilities elsewhere in the U.S., and that the Agency evaluate the possible consequences for the risk assessment.

An important assumption is that only 30% of all wells generate elevated NORM levels. Although a reasonable assumption at face value, it should be noted that various references quoted have this value ranging from 0 to 90%, depending on the region or age of the wells.

Based on the above, an annual production rate of NORM/scale waste of 25,000 MT/yr is calculated (p. B-5-16; also note that 17,900 MT would be located in the aforementioned eight states). However, using a production rate of 6×10^{-4} MT of scale per barrel produced, based on a survey of U.K. facilities (SC&A, Inc. 1988), a NORM/scale annual production rate of 1,500 MT/yr is calculated. It is stated in the NORM document that this lower value is more reasonable and expected. The NORM document justifies the lower number for present-day scale production rates because "newer facilities produce less entrained water in the crude oil," citing a 1992 report by Rogers & Associates (p. B-5-16) (Rogers & Associates, 1992).

Finally, the NORM document estimates total production of about 1,000,000 MT of NORM/scale over the 40-yr period 1949-89. This calculation was based on the 25,000 MT/yr production rate, despite the statement that the lower value is expected. For this calculation, the RAC assumed that the Agency considered the lower value to be appropriate for estimating present-day and future rates of NORM production, and not for historic rates. No uncertainty range is given. It is difficult to evaluate the validity of that estimate, but the reader can calculate reasonable upper and lower bounds of 20,700,000 MT to 60,000 MT of stockpiled NORM/scale in the USA between 1949-89[6].

The same 'generic' facility and assumptions were used to model NORM/sludge volumes. An annual rate of production of 225,000 MT/yr of NORM/sludge was calculated ($\approx$160,000 MT/yr in the eight states mentioned).

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[6] For calculation of a reasonable upper bound for NORM scale waste (refer to Appendix A - Diffuse NORM Wastes: Waste Characterization and Preliminary Risk Assessment by Dehmel, J-C, and V. Rogers, May 1993, pg. B-5-16). Assume 115 billion barrels produced in the USA from 1949-1989; 6×10^{-4} MT scale/barrel produced; 30% of scale contains NORM.

The Reasonable Upper Bound (UB) is then the product of the above numbers as follows:

UB = (1.15×10^{11} barrels produced) x (6×10^{-4} MT scale/barrel produced) x (0.30% of scale containing NORM)
= 20.7 million MT NORM containing scale produced in the USA between 1949 and 1989

The reasonable Lower Bound (LB) is calculated as follows:

LB = (40 years) x (1,500 MT NORM scale/year)
= 60,000 MT NORM containing scale produced in the USA between 1949 and 1989

The NORM document estimates that ≈10,000,000 MT of NORM/sludge have accumulated in the USA in the 1949-89 period. No uncertainty data were shown for this calculation.

In summary, a total annual production of ≈250,000 MT/yr of NORM in the form of sludge and scale in oil production is calculated in the NORM document, with a total stockpile of ≈11,000,000 MT of NORM for the period of 1949-89. No data were presented that addressed uncertainty issues.

3.5.3 Radionuclide Concentrations

According to the NORM document, radium is the main concern in NORM wastes from this sector, and Ra-226 and Ra-228 and their progenies are the main sources of risk. A 3:1 ratio of Ra-226:Ra-228 is assumed (p. B-5-9, citing Rogers & Associates, 1988) without further justification. The assumption of secular equilibrium with respect to Ra-226 and its decay products seems reasonable if radon does not diffuse quickly out of the scale or sludge. However, the RAC was confused by the discussion in the NORM document about the 3:1 ratio because Ra-226 is a daughter product of U-238 decay, while Ra-228 is a daughter product of Th-232 decay. One would not expect these two nuclides to vary systematically; the discussion of this issue on p. B-6-3 is much more reasonable.

An average concentration of 480 pCi/g for radium in scale is quoted from the Louisiana Report (Rogers & Associates, 1993); and, using the 3:1 ratio, 360 pCi/g and 120 pCi/g concentrations are assigned to Ra-226 and Ra-228 (and their progenies), respectively. The validity of these concentrations cannot be fully evaluated without a thorough review of the Louisiana Report. It is important to note that these concentrations were not measured. Rather, the exposure rate was measured and was then transformed to pCi of radium using a 'standard formula'. The data were then log-transformed, and the distribution of values was 'censored' for those below the detection limit. Finally, applying linear least squares line fitting procedures to the various censored data sets (which in some cases only included two points), a log-normal distribution was constructed. The concentrations used in the NORM document being reviewed are the medians of that distribution. A range of uncertainty of 10 pCi/g to 100,000 pCi/g can be gleaned from the NORM document based on various references quoted.

For sludge the same assumptions and arguments apply, except that the average concentration for radium in sludge is given as 75 pCi/g, and for Ra-226 and Ra-228 (and their progenies) values of 56 pCi/g and 19 pCi/g are derived as described in the previous paragraph. A range of uncertainty of 1 pCi/g to 1,000 pCi/g can also be obtained as a reasonable approximation based on references quoted.

Radon emanation coefficients of 0.05 for scale and 0.22 for sludge are assumed due to lack of knowledge regarding the true but unknown value.

External exposure rates of 30-70 μR/hr are assumed, but can range from background to several mR/hr (API, 1989).

3.5.4 Other Issues

Although the RAC agrees with some of the conclusions drawn in the NORM document (E-2-1 through E-2-4), it finds that the one-page qualitative uncertainty analysis shown (E-2-7 to E-2-8) is inadequate, and disagrees with the description of this source term as well-characterized (a ranking of '2').

3.6 Water Treatment Sludges

3.6.1 Waste Volume Characterization

The NORM document does not address any of the risks associated with selective-sorbent technologies, such as ion exchange resins, or with spent Granular Activated Carbon (GAC). These omissions result in an incomplete and inaccurate source term characterization.

The NORM document states throughout this section that only 700 facilities are expected to have significant problems with NORM/sludge production (out of 60,000 utilities in the USA). These data are relatively old and should be updated with more recent EPA reports. The numbers presented deal only with radium, because no projections exist for the impact of the proposed radon and uranium standards. Furthermore, waste generation and disposal practices related to the use of selective sorbent technologies such as radium-selective complexers are not addressed in the NORM document, because it is assumed that their radioactivity will be sufficiently high as to require disposal as low-level radioactive waste (p. B-6-10). Consequently, a major portion of NORM risks (i.e., NORM waste that may represent higher risks to exposed individuals) from water treatment is absent from the exposure estimates. In addition, no attempt has been made to characterize the historical production of NORM by water treatment facilities, which would have been a daunting endeavor given the lack of reliable information.

Based on two surveys by the American Water Works Association (AWWA, 1986, 1987), and the assumption that only 700 systems have waters with high NORM levels, an annual production rate of 260,000 MT/yr is calculated. Underlying assumptions for this value are that the annual generation of sludge per water utility is 2,140 MT, that only 28% of water treatment processes have the capability to remove radionuclides (and hence have the potential to create NORM-contaminated sludge), that 700 water utilities in the U.S. process water with elevated radionuclide concentrations, and that only 60% of these 700 utilities actually produce sludge (p. B-6-17 to -18). No discussion of uncertainties or variabilities is presented. No attempt is made to tie this analysis to the Radionuclides in Drinking Water Criteria Documents (See Appendix A - EPA/SAB Letter Report EPA-SAB-RAC-LTR-92-018, September 30, 1992 and references cited therein, including the 1991 Proposed Rules for Drinking Water).

The best evaluation of the validity of this analysis comes from the NORM document itself (p. B-6-18):

> "It is also not clear from past survey data what number of utilities have passed the EPA Drinking Water Standards for finished water, but may still generate water treatment sludges at concentrations that are of concern in the context of this assessment. Although in those cases the radionuclide concentrations may be relatively low, the wastes may be generated in much larger quantities."

It is the opinion of the RAC that the analysis underestimates present and future volumes of NORM/sludge wastes from this sector.

3.6.2 Radionuclide Concentrations

Radionuclides of concern are radium, uranium, radon, and their progeny. Almost all calculations are for radium. Ra-226 concentrations are said to vary from 0.5 pCi/L to 25 pCi/L. The NORM document estimates that for every pCi/L in water, 2 pCi/g would be found in sludge. The critical assumptions are a 90% removal efficiency (which is reasonable based on the available technologies), and a sludge generation rate of 3.1 m^3 per million gallons (or 0.82 cm^3/L) of treated water (Hahn, 1988).

Table B.6-7 of the NORM document presents a set of concentrations that are to be used for the risk assessment model waste pile. These are based on the upper value of the radium concentration range. Pb-210 and Po-210 are calculated assuming a radon emanation coefficient of 0.30. Uranium and thorium concentrations are assumed without further justification. Because no justification is provided for most of the parameter values, the RAC cannot evaluate the validity of the concentrations chosen except for radium. The radium concentrations are high, but may be representative of utilities treating waters with elevated NORM levels. No analysis is given of the uncertainty inherent in the calculated values. Such an analysis should address the likelihood that these values vary from location to location.

Radon fluxes were assumed to be similar to those of typical soils due to lack of information.

External exposure rates of 86 μR/hr were calculated based on the concentrations from Table B.6-7. Given that no data were presented, the validity of this value is questionable.

3.6.3 Other Issues

The RAC finds that the one-page qualitative uncertainty analysis shown (E-2-7 to E-2-8) is inadequate, and disagrees with the description of this source term as well-characterized (a ranking of '2').

3.7 Metal Mining and Processing Wastes

3.7.1 Rare Earths

The NORM document states (p. B-7-24) that in 1985 the U.S. produced about 20,800 MT of crude rare-earth concentrates and that these crude concentrates typically consist of titanium and zirconium minerals and 1 to 20% monazite. It is further stated that the rare-earth oxide content is about 55% in monazite, which also contains about 6% ThO_2 and 0.4% U_3O_8 (Hedrick and Templeton, 1985). The NORM document contains the assumption that the rare-earth waste production rate is about equal to the annual crude concentrate consumption rate of 20,800 MT and that this waste contains 20% monazite. No reference or basis is given for this assumption. The activities in the waste are given as 3,900 pCi/g for thorium and 18,000 pCi/g for uranium.

On page B-7-38, it is stated that rare-earth elements are recovered primarily from mineral types such as bastnasite, monazite, and xenotime. Monazite ores are stated to contain the highest concentrations of thorium and uranium, which range from 3-10% ThO_2 and 0.1-0.5% U_3O_8 equivalent. It is stated that, assuming monazite ores average about 4% ThO_2, the activity from ThO_2 in U.S. rare earths is about 3,900 pCi/g. The activity from natural uranium in the same ore type at 0.3% U_3O_8 is given as about 1,800 pCi/g. Pages B-7-24 and B-7-25 present relative activities of 3,900 pCi/g for thorium and 18,000 pCi/g for uranium, apparently corresponding to 6% ThO_2 and 0.4% U_3O_8. Thus the same activity is given for two somewhat different percentages of thorium, and the difference in the activity stated for uranium is an order of magnitude, which may be a typographical error.

On page B-7-53, for the generic rare earth site, the assumption is stated that the ores are "composed of 50% monazite sands". No reference or basis for this assumption is presented. For this generic site, the source term is based on a Th-232 activity of 2,000 pCi/g and a U-238 activity of 900 pCi/g.

In summary, the NORM document, on page B-7-24, refers to a 1-20% range of monazite in rare-earth concentrates and states an assumption of 20% monazite in rare-earth waste. On page B-7-52, there is a statement that the ores are assumed to be composed of 50% monazite sands for the generic site. A single reference is presented for the 1-20% range and no basis is presented for the 20% and 50% assumptions. Thus, it is not clear what the appropriate fraction of monazite should be. In addition, there are inconsistencies in the activities of the U-238 and Th-232 reported.[7]

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[7] William Russo of ORIA determined, for the RAC, that the compositions of ThO_2 and U_3O_8 used in the analyses were 4% and 0.3%, respectively. He also determined that the concentration of 18,000 pCi/g stated for uranium was a typographical error and that the value of 1,800 pCi/g is high by a

3.7.2 Zirconium, Hafnium, Titanium, and Tin

Zirconium, hafnium, titanium, and tin are grouped together for consideration in the NORM document. The estimated annual waste generated from production of these metals is given as 50,000 MT for zirconium and hafnium, 4,000 MT for tin, and 414,000 MT for titanium (p. B-7-26; Hedrick and Templeton, 1989; EPA, 1990).

The source term used to assess risk from a generic zirconium, hafnium, titanium, and tin waste site is given in Tables B.7-21 and B.7-22 of the NORM document. (Table B.7-21 is mislabeled; the term "rare earth" in the table title should be replaced by "Zr, Hf, Ti and Sn.") It is stated that the generic source term is representative of radionuclide concentrations for titanium and tin waste. The NORM document states that the source term is based on a conservative Ra-226 activity of 43 pCi/g, based on tin slag (Conference of Radiation Control Program Directors, 1981) and also typical of measurements in chloride process waste, solids, and leachate for titanium tetrachloride production (EPA, 1990). Pb-210 and Po-210 concentrations were estimated by assuming a radon emanation coefficient of 0.3.

The reports by the Conference of Radiation Control Program Directors (1981) and by the EPA (1990) have not been reviewed by the RAC, making it difficult to comment on the adequacy of the radionuclide source terms used to assess risk from these wastes. Data presented on pages B-7-40 through B-7-42 show that elevated NORM concentrations are associated with zirconium, titanium, and tin mining and processing and that, in some cases, the concentrations exceed 1,000 pCi/g.

3.7.3 Large Waste Volume Processes

For the risk assessment, a generic site is assumed for aluminum, copper, iron, zinc, lead, and precious metal mining and processing waste. Table B.7-10 presents estimated amounts of waste generated by the extraction and beneficiation of these metal ores in 1980. The amounts vary from 280 million MT for copper and 200 million MT for iron to 1 million MT for lead and zinc.

The NORM document presents limited data on radionuclide concentrations in waste from aluminum mining and processing that show these wastes can contain elevated levels of U-238 and Th-232. The NORM document also notes that several studies have reported uranium and thorium concentrations in various copper mining and processing materials. The NORM document notes (page B-7-50) that

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factor of 2. The statement on page B-7-52 that the ores are assumed to be composed of 50% monazite sands for the generic site was determined to mean that it was assumed that there was a 50% dilution of the ore with sand and other materials.

"it is difficult to characterize the radiological properties of overburden and tailings associated with the mining and processing of copper ores" and recommends "a more detailed survey of wastes and tailings, especially from the copper mines and mills of Arizona and New Mexico". The NORM document states that it is conservatively assumed that the large waste volume metal mining and processing waste industry exhibit waste sites with radionuclide concentrations equal to the screening criteria values used in the EPA Report to Congress on Special Wastes from Mineral Processing (EPA, 1990) of 10 pCi/g for U-238 and Th-232 and 5 pCi/g for Ra-226 (p. B-7-62). The use of source terms corresponding to screening levels appears indicative of the uncertainty in the characterization of the radionuclide concentrations.

3.8 Geothermal Energy Waste

The NORM document notes that there is a lack of data on which to base estimates of overall waste generation from geothermal energy sources. The 50% escalation factor for going from an estimate of 20,000 m^3 for liquid dominated wastes to 30,000 m^3 for the whole sector is rather arbitrary (p. B-8-15). The Sonoma vapor generation stations are the largest in this NORM sector and thus a better attempt should be made to characterize its waste generation. The station operators are likely to have some record of solid waste generation that would enable a more justifiable estimate to be made.

It is understandable that these radionuclide concentrations have been used to make risk estimates in the absence of adequate data. However, a theoretical analysis of the geological and solubility factors at the Sonoma sites relative to the Imperial Valley sites might enable a more refined estimate to be made.

4. MODEL PARAMETERS

Issue 2: **Model parameters**
Are parameters used in the risk assessment reasonable? Are the references and justifications adequate? Does the presentation properly reflect the best available scientific information?

In most cases, the references and justifications for the parameters used in the risk assessment have not been provided in the reviewed NORM document, making it difficult to determine whether or not the adopted values are reasonable. To a limited extent, as discussed below and in Appendices B and C, the RAC was able to compare the adopted values to the range of values published in the literature in order to judge the extent to which the adopted values are reasonable or conservative estimates. Some of the adopted parameter values appear to fall outside the range of measured values, in the direction of non-conservatism (e.g., food uptake factors; see discussion in section 4.2 below). In addition, the dose and risk conversion factors in the NORM document differ substantially from those currently endorsed by ICRP and NCRP (section 4.3 below). The reasons for these discrepancies should be discussed.

4.1 Documentation of Parameter Selection Process

Supporting rationale for the selection of "representative" parameter values is often found only in other documents. For example, the selection process used to adopt representative values for hydrologic parameters (Tables D.2-1 and -3 of the NORM document) is not found elsewhere in the document, but rather in a series of handwritten letter reports prepared by R.F. Weston, Inc., for Rogers & Associates (Madonia, 1989a, 1989b, 1989c, 1989d). Some of these letter reports were examined in a cursory manner by the RAC, which found the quality of data to be quite variable and the explicit justification for representative values to be generally inadequate. For example, no data source or discussion could be found for any of the distribution coefficients (K_d), which govern the rate of leaching of the radionuclides from the source material, and its subsequent transport through the subsurface. The RAC recommends that the original data sources and justifications for the selection of representative values for all parameters be incorporated into the NORM document (or in an appendix thereto).

Documentation of the meaning of parameter values is sometimes mystifying. For example, two terms that need explanation are the "humid impermeable default values" and the "humid impermeable value" that serve as the basis for the water uptake factors and the river flow rate q_r. Similarly, the appendix containing the spreadsheet calculations is welcomed, but the parameters in these tables often differ from those defined in the main body of the NORM document. Presumably, some values are lumped together to form new parameters. Consequently, one cannot easily double check or reconstruct model results from these appendix tables. The RAC recommends that a complete list of terms be added to the appendix that would clearly define each parameter used, and that would cite the mathematical expression used to derive any lumped parameters.

4.2 Parameter Selection for Specific Pathways

Even with recourse to the original references (see above), it is difficult to assess the underlying rationale and validity of many of the adopted parameter values, although in some cases it is possible to compare the values to those in the literature. A related problem is inadequate definition of what is included in a particular parameter. For example, it is difficult to review the food chain pathway calculations in the draft NORM document because the entire food chain is subsumed into an aggregated parameter called the food uptake factor, U_F, in units of kg/yr. Comparison with values derived from other references (Appendix Table C-1) shows that the U_F values used in the document are not necessarily conservative (Appendix Table C-2), because they are exceeded substantially by values derived from the other three references. The most glaring discrepancies are observed for the ingestion of vegetables by humans for Pb, Po, and Ra.

The NORM document not only fails to justify the selection of default values for most parameters, but also fails to provide any explanation when adopted parameter values vary substantially from one type of NORM source to another. For example, selected values for saturated hydraulic conductivity (K_{sat}) and for distribution or sorption coefficients (K_d) range over several orders of magnitude among the various NORM sources for the hydrologic pathways. This aspect of the assessment is sufficiently critical that documentation within the text or an appendix is warranted.

Additional questions and comments on some of the parameter values included in other pathway scenarios are presented in Appendix D.

4.3 Dose Conversion Factors

Discrepancies appear in comparisons between the dose and risk conversion factors used in the draft NORM document and those in ICRP Publication 60 (ICRP, 1991) and in revisions to ICRP Publication 56 (ICRP, 1989; ICRP, in press). Appendix Tables C-3 and C-4 compare the risk conversion factors for ingestion and inhalation between values listed in Table D.2-4 of the NORM document and those obtained from ICRP 60 (Phipps et al., 1991). Appendix Table C-5 shows the same comparison for a few selected radionuclides that are considered in a recent revision to ICRP Publication 56 (ICRP, in press).

The apparent reason for the above discrepancy is EPA's own analysis of the risk of radiogenic bone cancer in which Puskin et al. (1992) have asserted that ICRP 60 (ICRP, 1991) confused the average skeletal dose with that of the bone surface. The result is a bias in ICRP 60 towards overestimation of the effective dose by about a factor of 4 to 5 for radionuclides that deposit primarily on the bone surface. This bias has been acknowledged by Bair and Sinclair (1992) to have existed for at least 15 years. Appendix Tables C-3 through C-5, however, show discrepancies for Th-230, Th-232, Th-228, Ra-228, and Po-210 that greatly exceed a factor of 5, with the EPA's values being substantially lower than the values derived using the ICRP revisions to its Publication No. 56 (ICRP, 1989; ICRP, in press). The reasons for these large discrepancies should be investigated and discussed by EPA. If EPA has risk coefficients that are more defensible than those recommended by NCRP and ICRP, every effort should be made to ensure wide dissemination of the rationale for EPA's estimates.

4.4 Substantial Bias in Risk Estimates

The combined effect of revisions to the dose factors in ICRP Publication 56 (ICRP, 1989; ICRP, in press) and the use of the "detriment" risk conversion factor of 0.073 per Sv as recommended by ICRP 60 (ICRP, 1991) and NCRP Publication 116 (NCRP, 1993) results in substantial discrepancies with respect to the factors listed in Table D.2-4 of the draft NORM document in the estimate of health risk per unit intake of a radionuclide (Appendix Table C-5). The sources of the discrepancy should be discussed in the NORM document, particularly because the direction of bias is in many cases towards underestimation when the risk estimates are combined with values assumed for U_F. The RAC also notes that the EPA risk values refer only to cancer fatality, while the ICRP values include weighted values for morbidity and severe hereditary disorders.

5. SCENARIOS

Issue 3: Scenarios

Does the preliminary risk assessment adequately identify and characterize the key scenarios needed for evaluating individual and population risks from the sources characterized?

5.1 Identification of Pathways

In general, the list of pathways is reasonably comprehensive and may even include some pathways that are very unlikely to contribute substantially to total risk. However, it does not include at least one pathway that is commonly assessed in EPA programs covering hazardous wastes (Superfund and RCRA): soil ingestion by humans and by grazing animals. EPA risk assessments commonly assume that residentially exposed persons ingest 100 mg/day soil as adults and 200 mg/day as young children. Radionuclide concentrations in the ingested soil would probably be the same as used for dust lofting or leaching by infiltration of rainfall. For secondary deposition of wind-blown dust, the hazardous waste programs assume mixing into the top 1 cm of soil for soil ingestion purposes, because not all soil is tilled. The RAC recommends that the list of pathways to be considered include, to the extent appropriate, those pathways used in other programs of the EPA (e.g., Superfund).

For radon and radon progeny, two pathways not assessed include dermal absorption and volatilization of radon from potable water. However, exclusion of these pathways from the risk assessment appears warranted. Dermal absorption from soil or water is probably insignificant, because inorganic substances typically are not easily absorbed through the skin. Radon doses associated with volatilization are also likely to be negligible relative to those from all radionuclides via ingestion.

5.2 Identification of Receptors

The list of receptors is reasonable. Many hazardous waste assessments would not include an on-site worker scenario, arguing that such would be included under OSHA provisions. In that case, the workers would be monitored for exposure (at least for the gamma component), and exposures would be limited to 5 rem/yr. Both the on-site resident and the nearest off-site resident downwind (which the NORM document calls the Critical Population Group (CPG)) might easily be included in a hazardous waste assessment, depending upon the plausibility of releasing the waste site for unlimited use.

Scenarios for dose calculations always contain speculative elements. However, the rationale for using a particular assumption or for selecting a particular parameter value should be explicitly explained so far as possible. For instance, the assumption that a house will be 100 meters from the boundary of a disposal site (p. B-1-20) appears to be quite arbitrary.

EPA hazardous waste assessments typically would not examine anything akin to the general population scenario. However, this focus on a more widespread population risk appears quite appropriate as a basis for establishing general priorities and public policies, and is a consideration in the air programs of EPA and the State of California.

5.3 Matrix of Pathways vs. Receptors

The matrix of pathways vs. receptors is reasonably complete. EPA hazardous waste programs might well argue that the full list of pathways assessed for the CPG should also be assessed for the on-site resident, but simply adding the risk from these pathways for the CPG to the risks of direct exposure for the on-site residents is sufficient to indicate that the indirect pathways are generally negligible sources of risk for the on-site resident.

5.4 Source Term vs. Scenario

The RAC has identified some issues that overlap questions 1 (on sources) and 3 (on scenarios and pathways). While many of the pathways and scenarios are common to most of the NORM waste source types, the application of a scenario or its parameters to a specific source type is sometimes in question.

The assumptions for exposures of individuals and populations due to phosphogypsum disposal are reasonable because the number, design, and location of stacks are well known and they do not appear destined for relocation. The reuse of phosphogypsum, especially in fertilizers, is more uncertain.

Most of the exposure scenario data for phosphate slag were taken from the EPA studies of southeastern Idaho (EPA, 1990). The RAC believes that these data do not provide an adequate basis for remedial action decisions where slag has been used, because of concerns raised by the RAC in its review of the Idaho Radionuclide Study (EPA/SAB, 1992). This review identified concerns about the method used to estimate doses to the average individual and to the maximally exposed individual (reported in Table B.2-7 of the NORM document). However, the approximate and average nature of these data may be adequate for providing a broad overview of the NORM content of slag which could provide a basis for considering whether or not future uses of slag should be controlled.

The reuse scenario for phosphate slag in highway and street paving appears reasonable; however, an analysis is not given for its use in building materials and as fill material in a way that would allow population impacts to be broadly determined. The data provided are based on EPA's Idaho Radionuclide Study report. Until the Agency addresses the RAC's concerns on calculated exposures for average and maximally exposed individuals, the RAC would doubt the accuracy of projected impacts of slag uses in building and fill materials. Reuse of slag as a fill material around buildings or in construction material for buildings is an important potential exposure pathway because of long exposure times for homemakers and children; the NORM document should analyze the risks associated with such a reuse scenario.

In the fertilizer application scenario, concentrations of K-40 in soil would increase due to applications of potash containing an average of 420 pCi per gram of potash (which contains 696 pCi/g-K_2O). Because K-40 is very soluble, it is leached from the soil. From the data in the NORM document, about 2/3 of that applied to soil is leached away. This pathway does not appear to be analyzed; it should be addressed. The soil concentrations of K-40 are calculated on the basis of a leach rate assuming 20 years of application to a typical Illinois field using equation B-1 (p. B-3-15). It would appear more realistic to base the calculations on a saturation condition in which the K-40 application rate and the K-40 leach rate are in equilibrium with one another, a condition that would be achieved (99+%) in 30 years. The calculated soil buildup by equation B-1 is highly dependent on the leach rate fraction that is calculated from equation D-13. The calculations of soil buildup by equation D-13 depend on an equilibrium distribution coefficient. Values for these are listed in Table B.3-6 for the radionuclides considered, and they appear reasonable, although they are all derived from the same reference.

Table B.3-6 also contains risk assessment parameters reflective of the discussions in Section B.3.2 of the NORM document and other assumptions for radon emanation and respirable fraction of resuspended NORM. The latter fraction appears high, but conservative.

The underlying basis for the radiation exposure rate determinations appears weak. Whereas it is true that increases in the exposure rate would be proportional to the added concentration of gamma emitters, the actual exposure rate due to the application of fertilizer containing NORM is not really determined, only asserted to be only about 0.25% of that from soil that has not received fertilizer containing NORM (NORM document, p. E-3-12). The RAC recommends that the Agency support this contention by referencing actual measurements collected during aerial surveys of gamma radiation.

The exposure rate due to leached materials is not provided, as pointed out earlier for K-40.

6. MODEL FORMULATION

Issue 4: Model formulations

Does the PATHRAE methodology presented in this document adequately quantify risks from the sources and scenarios characterized?

6.1 General Overview

Following a cursory overview, all of the models and their submodels appear to be reasonable formulations for developing preliminary scoping estimates of doses and risks, with inclusion of an appropriate choice of generic site parameters (although not necessarily of parameter values; see discussion of issue 2 in Section 4 of this report). Underlying assumptions for the models are for the most part clearly stated. Detailed documentation for the models is apparently to be found in other EPA documents which presumably describe the mathematical basis of the models.

6.2 Radon Transport Model

Five exposure pathways or scenarios for radon and radon progeny are analyzed in the NORM document:

1. worker exposure to indoor radon, under the assumption that there is an office on the NORM storage/disposal site. The exposure time is assumed to be 2,000 hours per year. A 75% "occupancy factor" is incorporated in the risk factor used (p. D-1-10).

2. individual exposure to indoor radon in a house built on a NORM storage/ disposal site. The exposure time is assumed to be all year, with a 75% occupancy factor.

3. member of the critical population group (CPG) (defined as living 100 m downwind of the edge of the NORM storage/disposal site), exposed to indoor radon, again with a 75% occupancy factor. In this case, the indoor radon pathway is from the outdoor air.

4. same individual, but exposed to indoor radon produced by NORM in building materials used in the house. This scenario is restricted to the use of coal ash in making concrete blocks for basement walls or in the concrete used for the floor slab.

5. general population (defined as living in the area within 50 miles of the NORM storage/disposal site) exposed to radon in an unspecified location (presumably the relevant exposure condition is to ambient air concentrations, although the

risk factor used in the equation still contains the correction for a 75% indoor occupancy factor).

A number of issues are raised by the analysis of these exposure pathways, probably the most significant of which is the use of only diffusive transport of radon in scenarios 1 and 2. The dominant transport process for houses with elevated indoor radon concentrations is the advective flow of radon-bearing soil gas into the house. Diffusion alone cannot account for elevated indoor levels, with the possible exception of some of the extreme radium concentrations assumed in the NORM source term scenarios (e.g., rare earth wastes with assumed radium concentrations of 900 pCi/g). If advective flow were also incorporated in this analysis, potential radon exposures would be significantly higher, or conversely, the radium concentration in the waste materials needed to produce indoor radon concentrations of concern would be substantially lower.[8]

Analysis of an advective transport pathway requires knowledge about the characteristics of the soil or waste pile medium, particularly the air permeability (or the parameters that affect it, such as soil moisture). The PATHRAE code is not equipped to estimate advective transport, although there are several codes now available to perform such analyses. One such code, RAETRAD (Nielsen et al., 1992), is reasonably adaptable and is currently being used by the EPA to make estimates of radon transport as part of the waste criteria effort also being conducted by ORIA and is also being used by the State of Florida as part of a radon "potential" mapping project. Because radon exposures are potentially among the most important risks attributable to NORM wastes , a more realistic assessment approach is needed than is provided by a simple diffusion model.

Although less important overall, the present NORM document does not assess the exposures to outdoor radon for the individuals in scenarios 1 and 2. Presumably the outdoor radon concentrations on-site are much higher than those off-site, even though the latter concentrations are the basis for the assessment of scenarios 3 and 5. For the sake of consistency and comparison, these exposure pathways should also be analyzed as part of scenarios 1 and 2.

The release of radon into the outdoor air from a NORM waste pile is largely based on diffusive transport through the soil cover, although the equations used for scenarios 3 and 5 appear to be based on the assumption that the NORM waste materials are exposed (uncovered). However, the reference disposal pile parameters shown in Table D.2.1 (p. D-2-2) list a cover thickness assumed for some of the NORM waste categories. The estimated radon release rates do not appear to take these cover materials into account.

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[8] In a memo to Bill Russo, Vernon Rogers (one of the authors of the NORM document) argued that the diffusive transport assumptions were sufficiently conservative to cover the contribution of advective flow (Rogers, 1993), but the RAC was unable to evaluate the validity of that assertion.

6.3 Other Individual Models

Comments on individual models are provided in Appendix D to this review.

6.4 Choice of Software

The RAC notes that the PATHRAE spreadsheet method for estimating NORM risks is derived from the PATHRAE code in the PRESTO family that was originally developed to deal with risks from the disposal of low-level waste in unregulated sanitary landfills[9]. As a readily available tool, it has been attractive to EPA contractors. Since that original development, the PRESTO code has been modified in many ways to deal with a variety of issues not originally considered in its design. As a readily available tool, it has been attractive to EPA contractors because of precedent and economy. However, it does not contain some of the more recently recognized pathways of exposure (e.g., advective flow of radon) and it aggregates some parameters (e.g., food uptake factors) in such a way that it is difficult even to evaluate them, let alone to update them with more recent findings. While the RAC appreciates the difficulty of developing a whole new risk assessment tool when schedules are tight, it recommends that EPA explore other software options when assessing an important issue such as NORM.

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[9] The PATHRAE and PRESTO family codes are developed in FORTRAN; however, the FORTRAN code was not used by the Agency in the analysis. Rather, its equations were simplified and placed into spreadsheets where the calculations were performed. One advantage of this approach is that it would allow sensitivity and uncertainty analyses to be conducted using commercially available software, such as Crystal Ball® or @ Risk®.

7. UNCERTAINTY ANALYSIS

Issue 5: Uncertainty analysis

Risk estimates calculated using the PATHRAE methodology are estimated to be within a factor of three of calculations made with more detailed codes. Given this error band, the methodology employed, and the lack of knowledge associated with the waste streams; is the Agency's characterization of uncertainty and sensitivity adequate for the purposes of this scoping study?

The adequacy of an uncertainty analysis in a risk assessment and characterization study depends on the use to which the results and conclusions of the study will be put. In its description of the purposes of the NORM document, EPA variously describes the study as for scoping or as a basis for deciding on the need for regulation. The RAC views "scoping" as essentially synonymous with "screening," in the sense of separating sources of NORM on the basis of their priority for further study and possible regulation. The screen can be either *conservative* (i.e., is intended not to underestimate risk), which screens out low-priority areas from the need for further study, or *nonconservative* (i.e., is intended not to overestimate risk), which allows the identification of areas definitely in need of study and probably of regulatory attention. Unless uncertainties are relatively small, a conservative screen cannot reliably identify high priority sources, and a nonconservative screen cannot reliably identify low priority sources. Note that the degree of conservatism should be kept as small as feasible to avoid a useless screen; all that is required is to be able to assert with some confidence that the results are, on balance, conservative or nonconservative.

Because the document is neither consistently conservative nor consistently nonconservative, however, the Agency's characterization of uncertainty and sensitivity may not be adequate, even for the purposes of this scoping study. Concentrations of radionuclides in NORM materials are typically estimated with conservative assumptions, but the same may not be true for the source volumes, and many of the pathway and risk assumptions are probably nonconservative. The apparent degree of conservatism or non-conservatism in key parameters for the NORM assessment are shown in Table 7-1 on the following page. Table 7-1 was developed by the RAC to illustrate the points raised in this text. The document's qualitative uncertainty analysis, while informative about the professional judgments made by the authors, does not permit the reader to conclude that one source is definitely of greater concern than another, that some sources can be dismissed as posing negligible risks, or that some sources clearly need further attention.

Table 7-1 Direction of Conservatism in NORM Assessment Parameters

Parameters	**Conservative Bias Likely**	**Direction of Bias Uncertain**	**Non-Conservative Bias Likely**
Source volume		X	
Concentration	X		
Transport and fate		X	X (radon)
Receptor definition	X		
Food uptake factors			X
Other exposure factors		X	
Dose/risk conversion factors		X	
Overall risk estimates		X	

The NORM document claims overall accuracy to within a factor of three, but does not demonstrate that claim with calculations. For the source volume and concentration terms, the uncertainties are sometimes several orders of magnitude. For some pathways, it is clear from the RAC's review that uncertainties in the dose and risk estimates may be as much as one or two orders of magnitude, given the uncertainties in the estimated average parameter values and the simplistic models and assumptions. These pathways (e.g., consumption of vegetables grown in soil upon which contaminated dust has settled) are often relatively minor contributors to overall risk, such that uncertainties associated with these doses are somewhat less important than those for major pathways (e.g., direct gamma radiation and radon) where uncertainties should generally be less. Thus, the Agency's claim may be valid, but the RAC recommends further documentation of its assessment of uncertainty.

The Agency's characterization of uncertainty and sensitivity consisted of two parts: benchmarking the risk estimates against PRESTO and providing a qualitative ranking of uncertainties associated with parameter estimates for each scenario (Table E.2-1). Benchmarking the risk estimates against PRESTO begs the question of the validity of PRESTO and the parameters used for the NORM assessment.

Another concern is that estimates of risks averaged over all sites for a given source type may not be useful; if conducted on a site by site basis, then it may well be that a significant proportion of sites have risks that are well above the threshold of acceptable risk. Similarly, the aggregate risk calculated if one were to simulate the releases as time-dependent pulses (typical of arid regions) may not be the same as when calculated with steady annual rates, as in the NORM document. Consequently, the Agency might consider undertaking a preliminary uncertainty analysis to estimate the expected distribution of risks for each source and pathway for which the screening analysis suggests that the risks may possibly be significant. If requested, the RAC would be willing to provide additional suggestions to the Agency as to how such an analysis could be done.

8. PRIORITIES FOR ADDITIONAL WORK

Issue 6: Priorities for additional work

In what areas does the SAB's RAC recommend the greatest priority be given for developing additional information?

The RAC believes that the issue of NORM deserves substantial attention within EPA, and is concerned that the issue may not be resolved in a timely manner without increased resources being devoted to it. Despite its shortcomings, the NORM document nonetheless provides clear indications that some categories of NORM may produce risks that exceed those of concern from other sources of radiation. The RAC recommends that greatest priority be given to two aspects:

(a) First priority should be given to revising the NORM document to address the more demanding of the RAC's comments: the inclusion of more recent information on source volumes and concentrations, disaggregation and updating of food uptake factors and dose/risk conversion factors, documentation and justification of parameter selection, and consideration of advective flow as a means for radon transport. The revised NORM document could then serve as a useful and much-needed compilation of information for the public on NORM source terms and potential exposure pathways. However, any language suggesting that the present NORM document could be used to justify regulatory decisions should be removed from that document.

(b) To go beyond this limited use and to meet the stated goal of serving as a screening tool for identifying those categories that may or may not require further attention and possible regulatory action, it would be necessary for the Agency to conduct its risk assessment analysis using a consistent approach in addressing uncertainties, such as the methodology suggested by the RAC in this review report.

An ultimate goal of risk analysis appropriate for screening the NORM categories so as to determine those that are most likely (or not) to be candidates for regulatory attention would need to take an approach that was either consistently conservative (which would serve to identify categories of NORM that definitely would not require regulatory attention) and/or consistently nonconservative (which would serve to identify categories that might require regulatory attention).

(c) In its documentation of the results of its risk analysis, EPA should also be careful to draw the reader's attention to the differences between those categories of NORM that may be rated high with respect to individual risk (where a few people may be exposed to estimated risks ordinarily thought to deserve EPA attention) and those that may be rated high with respect to population risk (where estimated risks to even the maximally exposed persons are relatively low but many people are exposed). A discussion of the policy implications of these two categories of risks, particularly with respect to the issues involved in imposing regulatory controls on the latter, would be useful.

9. ADDITIONAL COMMENTS

In this section, the RAC provides additional comments that it believes to be relevant to the overall review of the NORM document, although outside the purview of specific charge provided by ORIA.

One stated purpose of the NORM document is to develop information from which EPA will make a determination of whether or not to control materials and/or wastes that contain NORM under the Toxic Substance Control Act (TSCA), the Resource Conservation and Recovery Act (RCRA), or other enabling legislation. The data and assumptions in the NORM document for many of the materials and wastes will, therefore, be of enormous importance in decisions affecting the general public and the industries that serve them. To this end, it is very important that the information on radionuclides and exposure/risk scenarios be as realistic as possible and address attendant uncertainties. Presentation of a conservative analysis to avoid missing potential exposure could be very costly to society in terms of potential future actions, as could an analysis that fails to take all potential impacts into account. The Introduction to the NORM document downplays this by pointing out that any regulatory action will need to be based on a much more extensive background document -- this may not be so; the important decision as to whether or not to control diffuse NORM might be based on this preliminary assessment. Thus, the Committee needs to be assured that the assessment is as rigorous as possible at this stage of the review of this important topic.

Members of EPA's Radiation Programs have been concerned that full consideration has not been given to the public implications (i.e., health effects) of radionuclides in such materials as phosphate deposits. There is (and has been) too much of a tendency to downplay its implications because it is diffuse, at low levels, and huge amounts of materials would need to be dealt with; a tone that comes through in the NORM document. On the other hand, the radionuclides in NORM materials have the potential to come into contact with large numbers of people and to expose some of them to significant levels of radiation due to usual practices. These usual practices appear to be taken as givens and not examined critically to determine if logical and justifiable procedures should be used that may significantly decrease public exposures. Two important situations come to mind:

a) greater production of phosphoric acid from elemental phosphorous would appear to reduce considerably the radioactivity applied to crops, yet the thermal process is thought to be a declining industry because of increasing energy costs; and

b) it is possible to remove uranium in the wet phosphoric acid process by installation of a separation loop, but this has not been actively pursued because the price of uranium would not make recovery of uranium by such a process cost-effective. Such processes could reduce the amount of NORM distributed in fertilizers, and even though it is dilute and individual exposures are low, the cumulative population effects due to uranium in fertilizers could possibly be reasonably diminished by use of technologies to remove uranium during the process of producing phosphoric acid. The NORM document should address this potential, and whether it could be justified in a broader context than just profitable uranium production.

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APPENDIX B
WRITTEN PUBLIC COMMENTS RECEIVED BY THE SAB/RAC

1) Alvarez, Joseph L., Ph.D., CHP , and John A. Auxier, Ph.D., CHP, Letter and report on diffuse NORM waste, Submitted on behalf of the phosphate industry, to Dr. Genevieve Matanoski, Chair of the SAB's Radiation Advisory Committee, September 17, 1993

2) API Briefing entitled "NORM OCCURRENCE," A Presentation by Mr. Kevin Grice of API (Texaco, Houston) to the SAB's Radiation Advisory Committee, February 23, 1994

3) James E. Gilchrest, Vice President, American Mining Congress, A Transmittal Letter to K. Jack Kooyoomjian, Ph.D., dated February 24, 1994 on Diffuse NORM, with attachment entitled "Review of EPA's Final Version -Diffuse NORM Wastes- Waste Characterization and Preliminary Risk Assessment, April 1993," Prepared for the American Mining Congress by SENES Consultants Ltd., Richmond Hill, Ontario, February 1994

4) Don W. Hendricks, C.H.P., A Letter dated February 12, 1994 to Dr. K. Jack Kooyoomjian, Designated Federal Official, Radiation Advisory Committee, Science Advisory Board (1400F), U.S. Environmental Protection Agency, with an enclosed executive summary from the final report documenting various radiological and non-radiological environmental contaminants in the environs of a uranium mill site. The report is entitled "Winter Baseline Investigation of Surface Media in the Vicinity of the Uravan Uranium Mill, Uravan, Colorado, Volume I, Results of January 1986 Field Investigation," Prepared for The State of Colorado, Department of Law, Office of the Attorney General, Prepared by ERI, Logan, Inc, Logan, UT, August 11, 1986

5) Jones, Ronald L., Vice President, American Petroleum Institute, Letter and attached report submitted to Dr. James E. Watson, Jr., Chair of the SAB's Radiation Advisory Committee, (five-page transmittal memo dated January 18, 1994, with a) Attachment A entitled "Critical Review of A Preliminary Risk Assessment of Management and Disposal Options for Oil Field Wastes and Piping Contaminated with NORM in the State of Louisiana"), Prepared for API by SENES Consultants, Ltd., Richmond Hill, Ontario, November 1993; and b) Attachment B from Morley Davis to Mike Loudermilk of API, entitled "Cumulative Distribution of Estimated Ra-226 Concentrations in Combined Sludges and Scales," a Memorandum from SENES Consultants Ltd., dated Jan 12 and 13, 1994)

6) Roewer, James R., Utility Solid Waste Activities Group (USWAG) Program Manager, a letter to Mr. William E. Russo, Jr. of the Office of Radiation and Indoor Air (ORIA), U.S. Environmental Protection Agency, Washington, D.C., in which he attached the Radian Report and the Comments presented by Jim Lingle of Wisconsin Electric Power Company on behalf of USWAG and the American Coal Ash Association (ACAA), March 4, 1994

7) Utility Solid Waste Activities Group (USWAG) and the American Coal Ash Association (ACAA), Comments on NORM Document by James W. Lingle, Senior Project Chemist, Wisconsin Electric Power Company, on behalf of the Utility Solid Waste Activities Group (USWAG) and the American Coal Ash Association (ACAA) Before the Radiation Advisory Committee of the Science Advisory Board, Washington, D.C., February 23, 1994

8) USWAG & ACAA, an additional submittal to the SAB/RAC by USWAG & ACAA entitled "Radian Review of EPA Report on Coal Ash Diffuse NORM Waste," dated February 21, 1994 (Originally presented by Richard G. Strickert of Radian Corporation, Austin, TX to Central and Southwest Services, Inc., Dallas TX, February 21, 1994)

APPENDIX C
EVALUATION OF FOOD UPTAKE FACTORS, AND DOSE AND RISK CONVERSION FACTORS USED IN THE NORM RISK ASSESSMENT

NOTE: The following five tables provide a comparison of the parameter values derived from other published references commonly used by the risk assessment community. The purpose of the comparison is to assess whether the values adopted in the NORM document are reasonable, or the extent to which they may be either conservative or nonconservative for the purposes of risk assessment. These tables are discussed in sections 4.2, 4.3 and 4.4 in the main body of this review.

Table C-1 Comparison of food uptake factors (kg/yr) from various sources

Element	NORM	RESRAD*	NCRP	Miller*
Ac	0.18	0.61	0.20	0.49
K	113	---	230	---
Pa	0.25	0.61	2.0	0.49
Pb	0.013	11	1.0	0.80
Po	0.013	1.5	0.99	0.059
Ra	0.013	0.27	9.2	2.7
Th	0.013	0.92	0.21	0.068
U	0.022	0.65	0.69	0.064

* Modified to include the effects of soil uptake from grazing cattle

Data sources:
NORM : Dehmel and Rogers, 1993 (NORM document)
RESRAD : Gilbert et al. (1989)
NCRP : NCRP (in press)
Miller : Miller (1984)

Table C-2 Ratios (unitless) of food uptake factors (calculated from values in Table C-1)

Element	Ratio RESRAD/NORM	Ratio NCRP/NORM	Ratio Miller/NORM
Ac	3	1	3
K	-----	18	-----
Pa	2	8	2
Pb	846	77	62
Po	115	76	5
Ra	21	708	208
Th	71	16	5
U	30	31	3

Table C-3 Comparison of dose and risk conversion factors for ingestion from various sources

Radio-nuclide	Ingestion Dose Conversion Factor (DCF)			Ingestion Risk Conversion Factor (RCF), risk/pCi			Ratio ICRP to NORM	Ratio EPA to NORM
	ICRP 60 Sv/Bq	ICRP 60 mrem/pCi (Note A)	NORM mrem/pCi	ICRP 60 (Note D)	NORM (Note B)	EPA (Note C)		
U nat	3.8 E-02	1.4 E-04	5.3 E-04	1.0 E-10	1.5 E-10	4.4 E-11	0.68	0.29
Th-230	7.6 E-02	2.8 E-04	5.5 E-04	2.1 E-10	2.3 E-11	1.3 E-11	8.92	0.57
Th-232	3.7 E-01	1.4 E-03	2.7 E-03	1.0 E-09	2.1 E-11	1.2 E-11	47.57	0.57
Th-228	6.7 E-02	2.5 E-04	4.0 E-04	1.8 E-10	1.3 E-11	5.5 E-11	13.92	4.23
Pb-210	8.6 E-01	3.2 E-03	5.4 E-03	2.3 E-09	5.5 E-10	[illegible].6 E-10	4.22	1.20
Ra-228	2.7 E-01	1.0 E-03	1.4 E-03	7.3 E-10	7.0 E-11	1.0 E-10	10.41	1.43
Ra-226	2.2 E-01	8.1 E-04	1.3 E-03	5.9 E-10	9.4 E-11	1.2 E-10	6.32	1.28
Ra-224	8.0 E-02	3.0 E-04	-----	2.2 E-10	-----	3.8 E-11	-----	----
Po-210	2.1 E-01	7.8 E-04	1.9 E-03	5.7 E-10	1.4 E-10	1.5 E-10	4.05	1.07

Notes:

A ICRP 60 (ICRP, 1991) estimate of detriment per unit intake

B NORM document estimate of fatal cancers per unit intake (Dehmel and Rogers, 1993)

C EPA/Health effects assessment summary table (HEAST) estimate of excess total cancer risk per unit intake (EPA, 1993)

D ICRP 60 (ICRP, 1991) Risk Conversion Factors for ingestion were calculated using the following conversion:
DCF (Sv/Bq) x (1 Sv/1E+06 Sv) x (0.073 risk/Sv) x (1 Bq/27 pCi) = RCF (risk/pCi)

Table C-4 Comparison of dose and risk conversion factors for inhalation from various sources

Radio-nuclide	Inhalation Dose Conversion Factor (DCF)			Inhalation Risk Conversion Factor (RCF), risk/pCi			Ratio ICRP to NORM	Ratio EPA to NORM
	ICRP 60 Sv/Bq	ICRP 60 mrem/pCi (Note A)	NORM mrem/pCi	ICRP 60 (Note D)	NORM (Note B)	EPA (Note C)		
U nat	3.3 E+01	1.2 E-01	2.5 E-01	8.9 E-08	2.7 E-07	7.8 E-08	0.33	0.29
Th-230	5.1 E+01	1.9 E-01	3.3 E-01	1.4 E-07	2.9 E-08	2.9 E-08	4.75	1.00
Th-232	2.1 E+02	7.8 E-01	1.6 E+00	5.7 E-07	2.9 E-08	2.8 E-08	19.55	0.97
Th-228	8.6 E+01	3.2 E-01	3.4 E-01	2.3 E-07	7.2 E-08	7.8 E-08	3.23	1.08
Pb-210	2.2 E+00	8.1 E-03	1.4 E-02	5.9 E-09	1.4 E-09	4.0 E-09	4.24	2.86
Ra-228	1.1 E+00	4.1 E-03	4.8 E-03	3.0 E-09	5.8 E-10	6.9 E-10	5.12	1.19
Ra-226	2.1 E+00	7.8 E-03	8.6 E-03	5.7 E-09	2.8 E-09	3.0 E-09	2.03	1.07
Ra-224	8.2 E-01	3.0 E-03	-----	2.2 E-09	-----	1.2 E-09	-----	-----
Po-210	1.9 E+00	7.0 E-03	9.4 E-03	5.1 E-09	2.4 E-09	2.6 E-09	2.14	1.08

Notes:

A ICRP 60 (ICRP, 1991) estimate of detriment per unit intake

B NORM document estimate of fatal cancers per unit intake (Dehmel and Rogers, 1993)

C EPA/Health effects assessment summary table (HEAST) estimate of excess total cancer risk per unit intake (EPA, 1993)

D ICRP 60 (ICRP, 1991) Risk Conversion Factors for ingestion were calculated using the following conversion:

DCF (Sv/Bq) x (1 Sv/1E+06 Sv) x (0.073 risk/Sv) x (1 Bq/27 pCi) = RCF (risk/pCi)

Table C-5 Comparison of ingestion dose and risk conversion factors (using revised ICRP report)

Radio-nuclide	Ingestion Dose Conversion Factor (DCF)			Ingestion Risk Conversion Factor (RCF)			Ratio, ICRP/ NORM	Ratio, EPA/ NORM
	ICRP 56 Sv/Bq	ICRP 56 mrem/pCi (Note A)	NORM mrem/pCi	ICRP 56 risk/pCi (Note D)	NORM risk/pCi (Note B)	EPA risk/pCi (Note C)		
Pb-210	1.1 E+00	4.1 E-03	5.4 E-03	3.0 E-09	5.5 E-10	6.6 E-10	5.40	1.20
Ra-228	1.5 E+00	5.6 E-03	1.4 E-03	4.1 E-09	7.0 E-11	1.0 E-10	57.86	1.43
Ra-226	5.6 E-01	2.1 E-03	1.3 E-03	1.5 E-09	9.4 E-11	1.2 E-10	16.09	1.28
Ra-224	9.8 E-02	3.6 E-04	-----	2.6 E-10	-----	3.8 E-11	-----	-----
Po-210	2.3 E+00	8.5 E-03	1.9 E-03	6.2 E-09	1.4 E-10	1.5 E-10	44.36	1.07

Notes:

A Revisions to ICRP Publication No. 56 (ICRP, in press) [ICRP estimate of detriment per unit intake]

B NORM document estimate of fatal cancers per unit intake (Dehmel and Rogers, 1993)

C EPA/Health effects assessment summary table (HEAST) estimate of excess total cancer risk per unit intake (EPA, 1993)

D Revisions to ICRP 56 (ICRP, in press): Risk Conversion Factors for ingestion were calculated using the following conversion:

DCF (Sv/Bq) x (1 Sv/1E+06 Sv) x (0.073 risk/Sv) x (1 Bq/27 pCi) = RCF (risk/pCi)

APPENDIX D
VALUATION OF SPECIFIC PATHWAYS, MODEL FORMULATIONS, AND PARAMETERS USED IN THE NORM RISK ASSESSMENT

NOTE: The NORM risk assessment considers the pathways of exposure marked with alphanumeric codes in the table below. The codes refer to comments provided in the text of this appendix. These detailed comments are intended to augment discussions in Section 4 (Model Parameters), Section 5 (Scenarios), and Section 6 (Model Formulation) of this review.

PATHWAY	ON-SITE WORKER	ON-SITE RESIDENT	CRITICAL POPULATION GROUP (CPG)	GENERAL POPULATION
A. Direct gamma	A1	A2	A3	
B. Dust inhalation	B1	B2	B3	
C. Indoor radon	C1	C2	C3	
D. Outdoor radon			D1	D2
E. NORM in building materials			E1	
F. Radon in building materials			F1	
G. Drinking contaminated well water			G1	
H. Food contaminated by dust deposition			H1	
I. Food contaminated by irrigation water			I1	
J. Food from fertilized soil			J1	
K. Gamma from road pavement and aggregate			K1	
L. Dust from steel mill stack releases			L1	L2
M. Resuspended dust				M1
N. River water contaminated by ground water				N1
O. River water contaminated by surface runoff				O1

A. Direct Gamma Exposure

A1. On-site Worker

Model formulation appears reasonable. Parameter values appear reasonable, with the possible exception of DFG and the shielding factor f_{sh}. Does the DFG include self-shielding? What is the basis for assuming 25% shielding for a bulldozer?

A2. On-site Resident

Same comments as for on-site worker (comment A1). Additionally, gamma exposure indoors is assumed to be only one-third of that for outdoors. What is the basis for this assumption: does it, for example, assume that there is no waste under the house itself or that there is a basement? In contrast, when fallout radiation is involved, the assumed reduction is typically only about 25%.

Time spent outdoors is assumed to be 25% of the total, with 75% indoors. The latter can be easily supported with survey data, but the other 25% is more likely spent away from home than outdoors at home.

A3. CPG

What is the basis for the empirical attenuation with distance; what was the size of the pile observed? The use of 100 m as the distance to the nearest residence seems reasonable but is clearly arbitrary. How sensitive are results to this value? The average value would probably vary by waste type; for example, some people living in West Chicago are closer to the rare earths pile than 100 m, but to live that close to a mining waste pile is probably rare.

B. Dust Inhalation

B1. On-site Worker

The model uses 50 $\mu g/m^3$ as the total dust level and assigns a fraction of that load as respirable and formed of waste particles. The value of 50 $\mu g/m^3$ is the national ambient air quality standard for PM10 (Particulate Matter, 10 microns, most of which is respirable) (EPA, 1991), but the allowable dust levels for workplace exposures are much higher (up to 10 mg/m^3, depending upon silica content). Dust levels on construction sites probably exceed the ambient standard frequently, even if they do not approach the workplace standard.

The key parameter for this calculation is the fraction of the dust level that is respirable and consists of waste particles (as opposed to "clean" particles blowing across the waste area from upwind sources). Respirable fractions cited in the NORM document range from 0.05 to 0.7, with many of the values falling in the 0.2-0.5 range. These fractions are probably biased high, but perhaps not enough to offset the suspected low bias in the assumed total dust loading. This pathway also is the first to use the DF_{inh} that converts the inhaled pCi to effective dose equivalent, based upon distribution in and elimination from the body, target organ affinities, and other factors. These dose conversion factors, which are intended for protection decisions, may be inappropriate for risk assessments. They need to be updated to be consistent with new ICRP lung model (see Appendix Table C-4).

B2. On-site Individual

A lower dust level (10 $\mu g/m^3$) is used here than for the on-site worker. While it is reasonable to assume that dust levels would be lower in the absence of bulldozer activity, it may not be reasonable to assume that the levels would be quite this low. What are typical dust concentrations where no human activity is present? Would the respirable fraction be the same as in a construction area, as seems to be implied, or might it be higher? See also the comment about time spent outdoors at home (comment A2).

B3. CPG

Inadequate basis to comment on model formulation and adopted parameter values.

C. Indoor radon and radon daughter inhalation

C1. On-site Worker

C2. On-site Resident

C3. Critical Population Group

D. Outdoor radon

D1. CPG

How does the parameter V_a (average wind speed) enter the dose equation? It would appear that the dose would become infinite as V_a goes to zero; is this reasonable?

D2. General population

The general population living in the area within 50 miles of the NORM storage/disposal site) is exposed to radon in an unspecified location (presumably the relevant exposure condition is to ambient air concentrations, although the risk factor used in the equation still contains the correction for a 75% indoor occupancy factor).

E. External gamma radiation from NORM in building construction materials

E1. CPG

Documentation of the assumptions and equations for this scenario is very sketchy. It seems to assume residency in a room in which NORM is present in floors, walls and ceiling, a possibly extreme case. See also comments for pathway A.

F. Radon in building materials

F1. CPG

This scenario is restricted to the use of coal ash in making concrete blocks for basement walls or in the concrete used for the floor slab.

G. Drinking contaminated well water

G1. CPG

The following assumptions are stated in the NORM document and are reasonable for the stated purpose:

a) Constant release rate from the waste to the groundwater
b) Release rate is directly proportional to waste concentration. Question: Would the assumed leaching rate significantly deplete the wastes over 20 years?
c) Infiltration rate is 50% of annual precipitation
d) K_d in waste is same as for aquifer
e) 1-dimensional, porous media flow
f) Instantaneous transport through unsaturated zone to groundwater without decay or retardation. Question: Does this mean instantaneous depletion of surface materials, with reduction in potential for direct gamma and radon also? Given the amount of material moving to the groundwater, is there any double-counting?
g) Time to peak concentration in well is a function of the retardation factor, groundwater velocity, and distance to the well but is always $\leq$ 10,000 years
h) CPG obtains all water from well
i) Well is located 100 m from edge of waste pile
j) Short-lived radionuclides ^{227}Ac, ^{210}Po, and ^{210}Pb are in secular equilibrium with their parents at the point of water withdrawal for consumption

An additional assumption that is implied but not stated is that:

k) All water withdrawn through the well is recharged through the waste pile; no dilution of waste by water occurs other than that which has passed through the waste. This latter assumption is quite conservative; one would expect in most cases that the waste would be diluted to a large extent by water which entered the aquifer upgradient of the waste pile.

The dilution volume is annual rainfall times pile area; is this consistent with the assumption that half of the rainfall infiltrates?

Why is 481 L/yr used for drinking (730 at 2 L/day; 511 at 1.4 L/day)?

Comments on distribution coefficients, K_d:

Uranium - Adopted values in the NORM document range from 45 to 450 ml/g, with no justification provided for the variation. The lower value appears reasonable, but justification for the highest value is needed. For comparison, apparent distribution coefficients measured at Los Alamos National Laboratory for the Yucca Mountain Project range from 0 to 30 ml/g for uranium in contact with tuff under oxidizing conditions (Barnard et al., 1992; Meijer, 1992). For these conditions, K_d values for pure minerals phases usually exceed 100 ml/g over a pH range of 6.5 to 8.0 (Meijer, 1992). U adsorption on hematite, goethite and silica is very sensitive to pH, showing sharp decreases for pH values outside of the range 6.5 to 8.0, and relatively insensitive to ionic strength. At high pH (> 8.0), U adsorption decreases sharply due to complexation of U by carbonate ions in solution.

Radium - Adopted values in the NORM document range from 45 to 2500 ml/g, with no justification provided for the variation. These values do not appear to be unreasonable. The distribution coefficient for radium should be similar to that for another divalent alkaline earth, barium (Thomas, 1987). For comparison, values for this chemical analog were measured by Los Alamos National Laboratory and found to range from 200 to 10^5 ml/g (Daniels and Wolfsberg, 1981; Erdal et al., 1981). The value is highly dependent upon the mineralogy of the media, with highest sorption ratios observed for clay-rich media.

Thorium - Adopted values in the NORM document are the highest among all of the radionuclides included in the NORM assessment, ranging from 3000 to 150,000 ml/g. Again, no justification is provided for the variation. The low end of this range is consistent with those measured at Los Alamos National Laboratory for thorium in contact with tuff, which exceeded several hundred ml/g (Thomas, 1987). Migration of this element is probably often controlled by solubility limits; a check should be made for model validity by comparing the peak Th concentrations in groundwater predicted by the model to the solubility limits for this element.

Protactinium - Adopted values in the NORM document range from 1500 to 15,000 ml/g. This element is known to be highly sorptive. For a first order comparison, sorption parameters are expected to be roughly comparable to those of Americium. Thomas (1987) reported that americium sorption showed no correlation with mineralogy and that, with two exceptions involving devitrified tuff, sorption coefficients exceeded 1000 ml/g in all samples.

The major problem in this pathway relates to inadequate justification provided for those parameter values -- and their variations from one NORM source term to another -- for which the range of observed values is several orders of magnitude: particularly, K_{sat} and sorption coefficients.

H. Ingestion of food contaminated by dust deposition

H1. CPG

This scenario includes plant uptake of radionuclides deposited on and tilled into the soil, but not direct deposition on edible above-ground fruits and vegetables, in contrast to the approach often taken for hazardous waste assessments. It also seems to exclude consumption of meat and milk products that might be affected by animals grazing on contaminated pasture and ingesting contaminated soil. However, these considerations may all be buried in the equivalent food uptake factor, a construct that seems designed to obfuscate rather than to enlighten. The validity of the model formulation cannot be evaluated until the meaning of the food uptake factor is clearly defined.

It is very difficult to review the food chain pathway calculations in the draft NORM document because the entire food chain is subsumed into an aggregated parameter called the food uptake factor, U_F, in units of kg/yr. Comparison with values derived from other sources (Appendix Table C-1) show that the U_F values used in the NORM document are not necessarily conservative (Appendix Table C-2) because they are exceeded substantially by values derived from the other three sources. The main source of these discrepancies are for the ingestion of vegetables by humans for Pb, Po, and Ra.

The time of deposition is arbitrarily set at 20 years; justification is needed for the assumption of cessation of deposition after this time. In some scenarios for high-level waste, deposition is assumed to occur forever, producing ever increasing risks for succeeding generations.

See also comment B2 about dust parameters. Also the comment about DF_{inh} factors applies to the DF_{ing} factors.

I. Ingestion of food contaminated by irrigation water

I1. CPG

The list of assumptions is identical to those stated for the groundwater pathway (comment G1), except h is replaced by the assumption that the CPG obtains all of its annual equivalent foodstuff consumption uptake from the contaminated well. A term that needs explanation is the "humid permeable default values" that serve as the basis for the water uptake factors used in the model.

J. Food from fertilized soil

J1. CPG

See comment H1.

The estimate of exposure from ingesting vegetables from fertilized soil appears at first to assume that concentrations in soil and vegetation are the same. Is this a case of parameters hidden in the uptake factors?

K. Gamma from road pavement and aggregates

K1. CPG

The CPG here is a police officer spending almost all his/her working hours on the highway, and in fact in the middle of the road. Such a scenario seems fairly extreme. Otherwise, the radiation transport formulations looks reasonable. See also comments for pathway A.

L. Dust from steel mill stack releases

L1. CPG

The general idea is the same as for dust blowing off of a waste pile, except the source term is different. The model formulation appears to include all the important variables.

The parameter selection is for a stack only 30 feet high and 10 feet in diameter. Is this typical for a steel mill using recycled feedstock?

L2. General population

The model integrates the CPG equations over distance. See comment L1 above.

M. Resuspended dust

M1. General population

This scenario averages the exposures as estimated for the CPG (comment B3) over the range from 100 m to 50 miles and applies a state-specific population density to obtain population dose. It includes direct inhalation of dust, ingestion of dust on plants, and gamma from deposited dust. See comment B3 on CPG dust pathway. The equation does not clearly deplete the plume by the amount of dust assumed to be deposited. How sensitive are the results to the maximum distance, which is arbitrary? Is it reasonable to use state-wide population density independent of the type of waste?

N. River water contaminated by ground water

N1. General population

The pathway for ingestion of river water contaminated by groundwater includes a parameter q_r, the river flow rate, which serves to dilute the radionuclide concentration introduced via groundwater. The NORM document states that the river flow rate q_r is assumed to be 1/3 of the "humid impermeable value" in EPA (1988a); what is the meaning of a "humid impermeable value"?

The population dose arises from consumption (as drinking water or from agricultural use) of river water contaminated by NORM migration through groundwater. Assumptions underlying the model are the same as assumptions a-g for the groundwater model (see comment G1). Additional assumptions are:

h) Rate of use of contaminated river water includes equivalent foodstuff consumption uptake (as a consequence of food irrigation) as well as direct water consumption

Additional assumptions that are implied but not stated:

i) Short-lived radionuclides ^{227}Ac, ^{210}Po, and ^{210}Pb are in secular equilibrium with their parents at the point of water use

j) The extent of dilution of waste is determined by the river volumetric flow rate. Dilution by groundwater is negligible.

O. River water contaminated by surface runoff

O1. General population

Assumptions are:

a) Constant release rate from the waste to surface runoff
b) Release rate is directly proportional to waste concentration
c) Infiltration rate is 50% of annual precipitation
d) K_d for soil is same as for aquifer
e) No time delay in runoff process

Question. We don't understand what this assumption means. Does it mean instantaneous transport from waste to river, with no radioactive delay or retardation along the surface path? Can't be this because retardation factor is included in model.

Additional assumptions that are implied but not stated include:

f) Exposed population obtains all drinking and irrigation water from the river immediately downstream of the entry point for the contaminated groundwater

g) Short-lived radionuclides ^{227}Ac, ^{210}Po, and ^{210}Pb are in secular equilibrium with their parents at the point of water withdrawal for use

h) Radionuclide concentration in runoff is same as in waste leachate in the unsaturated zone.

The rationale behind the selection of 0.1 as the dilution factor f_{dt} for surface water transport of waste is not clearly stated.

APPENDIX E - GLOSSARY OF TERMS AND ACRONYMS

Ac	Actinium, as an element or as an isotope of thorium or uranium alpha-decay chains (e.g., Ac-227)
ACAA	American Coal Ash Association
AWWA	American Water Works Association
API	American Petroleum Institute
Bq	Becquerel (1 disintegration per second)
CFR	Code of Federal Regulations
Ci	Curies ($3.7x10^{10}$ disintegration per second)
cm	Centimeter
cm^3	Cubic centimeter
CPG	Critical Population Group
DCF	Dose Conversion Factor
DF_{ing}	Dose Factor for Ingestion
DF_{inh}	Dose Factor for Inhalation
DFG	Dose Factor for Gamma
DOE	U.S. Department of Energy
E	Exponent (10^6)
EEI	Edison Electric Institute
EPA	U.S. Environmental Protection Agency (U.S. EPA, or "The Agency")
ES	Executive Summary
f_{dt}	Dilution factor for surface water transport of waste
f_{sh}	Shielding Factor
ft^3	Cubic feet
g	Gram
GAC	Granular Activated Carbon
HEAST	Health Effects Assessment Summary Table
Hf	Hafnium
hr	Hour
ICRP	International Commission on Radiological Protection
kg	Kilogram
K	Potassium
K_d	Distribution coefficient
K_{sat}	Saturated hydraulic conductivity
L	Liter
LB	Lower Bound
M	Mole
MT	Metric Tons
µ	Micro-, [10^{-6}] in combination with specific units
m	Milli-, [10^{-3}] in combination with specific units
m	Meter
m^3	Cubic meter
mbd	Million Barrels per Day
mg	Milli-gram

ml	Milli-liter
mR	Milli-Roentgens
mR/hr	Milli-Roentgens per Hour
NARM	Naturally-Occurring and Accelerator-Produced Radioactive Material
nat	Natural
NCRP	National Council on Radiation Protection and Measurements
NORM	Naturally-Occurring Radioactive Material
NRC	Nuclear Regulatory Commission
NRPB	National Radiological Protection Board
O	Oxygen
O_2	Oxide (Also oxygen; Oxide of a specific ores, such as ThO_2 or U_3O_8
ORIA	Office of Radiation and Indoor Air (U.S. EPA)
OSHA	Occupational Safety and Health Administration
PATHRAE (EPA)	Computer code used to assess the maximum annual dose to a critical population group resulting from waste disposal. It is a member of the PRESTO-EPA family of codes and emphasizes two areas: (1) the addition of exposure pathways pertaining to on-site workers during disposal operations, off-site personnel after site closure, and reclaimers and inadvertent intruders after site closure; and (2) the simplification of the sophisticated dynamic submodels to quasi-steady state submodels.
p	pico-, [10^{-12}] in combination with specific units
Pb	Lead, as an element or as an isotope of thorium or uranium alpha-decay chains (e.g., Pb-210)
PC	Personal Computer
pH	Negative log of hydrogen ion concentration
PM 10	Particulate Matter, 10 microns
Po	Polonium, as an element or as an isotope of thorium or uranium alpha-decay chains (e.g., Po-210)
PRESTO-CPG-PC	A PC version of PRESTO pertaining to the Critical Population Group (CPG) (a variant of PRESTO-EPA-CPG; See also EPA 1989 User Manual EPA 520/1-89-017, April 1989)
PRESTO (EMF)	A family of codes developed to evaluate doses resulting from the disposal of low-level radioactive waste. These codes include PRESTO-EPA-CPG (assesses annual effective dose equivalents to a critical population group), PRESTO-EPA-DEEP (assesses cumulative population health effects resulting from the disposal of low-level waste using deep geologic repositories), PRESTO-EPA-BRC (assesses cumulative population health effects to the general population residing in the downstream regional basin as a result of the disposal of low-level waste in an unregulated sanitary landfill), PRESTO-EPA-POP (assesses cumulative population health effects to the general population residing in the downstream regional basin on a low-level waste site), and PATHRAE (see above)

APPENDIX E - GLOSSARY OF TERMS AND ACRONYMS: CONTINUED:

q_r	River flow rate
R	Roentgen
Ra	Radium, as an element or as an isotope of thorium or uranium alpha-decay chains (e.g., Ra-223, Ra-224, Ra-226)
RAC	Radiation Advisory Committee (U.S. EPA/SAB/RAC)
RAETRAD	Radon Emanation and Transport into Dwellings, a computer code for radon risk assessment which was developed to provide a means of estimating the rates of radon gas entry into slab-on-grade dwellings from underlying soils and concrete components (See Appendix A - Nielsen et al., 1992)
RCF	Risk Conversion Factor
RCRA	Resource Conservation and Recovery Act
rem	roentgen equivalent man
RESRAD	Residual Radioactive Materials Guidelines (The DOE Model). This is a computer code developed by DOE to implement its guidelines for deriving guidelines for allowable concentrations of residual radioactive material in soil.
Rn	Radon, as an element or as an isotope of thorium or uranium alpha-decay chains (e.g., Rn-219, Rn-220, Rn-222)
SAB	Science Advisory Board (U.S. EPA)
Sn	Tin
Sv	Sievert (equal to 100 rem)
Th	Thorium, as an element or as an isotope (e.g., Th-228, Th-230, Th-232, Th-234)
Ti	Titanium
TSCA	Toxic Substances Control Act
TSPA	Total System Performance Assessment
U	Uranium, as an element or as an isotope (e.g., U-234, U-235, U-238)
U_F	Uptake factor for food ingestion
UB	Upper Bound
$\mu g/m^3$	micro-gram/cubic meter
U.K.	United Kingdom
μM	micro moles
U.N.	United Nations
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
$\mu R/hr$	micro-Roentgen per hour
U.S.	United States
U.S.A.	United States of America
USWAG	Utilities Solid Waste Activities Group
V_a	Average wind speed (average Velocity)
yr	Year
Zr	Zirconium

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