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ENVIRONMENTAL RADIOLOGICAL SURVEILLANCE IN PERSPECTIVE: THE RELATIVE IMPORTANCE OF ENVIRONMENTAL MEDIA AS A FUNCTION OF EFFLUENT PATHWAY AND RADIONUCLIDES

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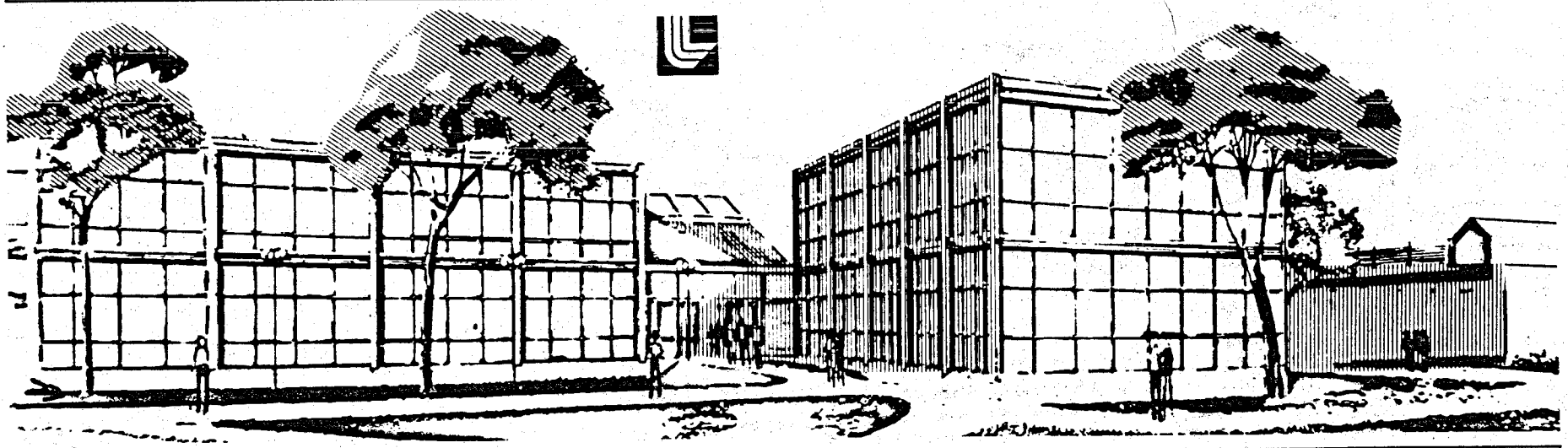

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ENVIRONMENTAL RADIOLOGICAL SURVEILLANCE IN PERSPECTIVE: THE RELATIVE IMPORTANCE OF ENVIRONMENTAL MEDIA AS A FUNCTION OF EFFLUENT PATHWAY AND RADIONUCLIDES*

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ABSTRACT

Most published guidelines for environmental surveillance emphasize the collection and analysis of specific media (e.g. air, water, milk, direct radiation) without total regard for the potential dose impact of the radionuclides expected in or actually present in the effluent streams from nuclear facilities. To determine the relative importance of medium/nuclide combinations in environmental surveillance, the experience at major ERDA sites and at operating nuclear power plants was reviewed. Typical release rates for nuclide groupings (tritium, noble gases, radioiodine, mixed fission or activation products, and transuranics) in those effluent streams were followed through various environmental pathways. By using this scheme the environmental medium which is most prominent in the critical dose pathway to man was determined. It was also possible to determine points of short-or long-term contaminant accumulation. Following these calculations, each medium was ranked for a given nuclide/effluent pathway combination providing the relative importance of sampling specific environmental media with emphasis on the radiation dose to a critical population group. Finally, the results of these environmental pathway studies are presented in tabular form to provide ready reference for environmental surveillance program design or evaluation.

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INTRODUCTION

Evaluation of radiation doses from the "as low as reasonably achievable" viewpoint has created pressure for increasingly sensitive environmental radiation measurement and evaluation techniques. As a result, many commercial laboratories, nuclear power plant sites, and ERDA installations have reduced radioanalytical detection levels, but not necessarily with a common goal--other than to drive detection sensitivities continually downward. Part of that problem stems from the fact published guidelines (EPA72, NRC75c or NRC75d) for environmental surveillance emphasize the collection and analysis of specific media (e.g. air, water, foodstuffs, and direct radiation), without regard for the actual or potential impact of the radiation or radioactivity to be measured. Hence, the limiting factors in environmental dose assessment are the detection sensitivities. If they are not based on a common lower dose (dose rate) limit, the resulting dose evaluations can be orders of magnitude apart because of the detection sensitivities alone.

Many statements of the objectives for environmental surveillance programs have been expressed (ICRP65, IAEA66, EPA72, NRC75c, NRC75d, NCRP76, and ERDA77). Several of these objectives are paraphrased below:

- evaluate adequacy of (ERDA77)...or verify in-plant controls (NRC75d)

- detect rapid changes...and evaluate long-term trends (ERDA77)
- public information (EPA72, NRC75c)
- detect radioactivity from off-site sources (ERDA77)
- provide data on measurable levels...in site environs (NRC75b)
- evaluate <u>principal</u> pathways of exposure (ICRP65, NRC75d)
- establish correlations between environmental levels and releases from plant operations (NRC75c)
- maintain a data base (ERDA77)

Two of the early publications (ICRP65 and IAEA66), both from internationally recognized bodies, provided the bases for the U.S. guides which have followed in the 1970s. These latter reports have emphasized environmental surveillance programs for light water reactors, reflecting the growth in nuclear power plants in the U.S. In reviewing the referenced publications and the objective statements paraphrased above, some common bases exist, although the ranking of objectives varies. From this input, four primary purposes are suggested and are listed below in order of importance:

- To assess the actual or potential radiation dose to persons in the site environs.

- To test the compliance or non-compliance of observed data with standards and regulations expressed in annual doses.
- To verify that effluent controls are adequate and have not deteriorated.
- To check for long-term buildup and to predict environmental trends from plant-released radioactivity.

The published guides referred to above suggest radiological environmental surveillance programs with a minimum number of samples, providing reasonable criteria for tailoring to any type of nuclear facility. With this background, the balance of this report is focused on 1) program planning, including a critical look at detection levels, 2) the relative importance of nuclide/media combinations on a dose basis, and 3) practical guidelines for minimum levels of surveillance.

PROGRAM PLANNING AND CRITICAL PATHWAY ANALYSIS

The necessity of adjusting environmental surveillance techniques to meet established objectives is a widely recognized, yet seldom followed principle. Often the program is planned to meet several objectives, but without explicity stating the rationale for any of these several objectives. As noted above, one of the primary objectives for environmental surveillance is to measure

or evaluate radiation doses to people. Yet, what is a "significant" or "important" dose is not clear.

Annual whole body equivalent radiation doses* were calculated for ingestion or inhalation of specific media contaminated with radionuclides at the lower limits of detection given in Regulatory Guide 4.8 (NRC75d) and are presented in Table 1. Although this particular set of values is only applicable for the detection limits given in that Regulatory Guide, equally disparate values would apply using the limits given in the EPA Guide (EPA72), etc. Why should the ingestion or inhalation of a particular nuclide at a concentration corresponding to the lower limit of detection (LLD) result in a "dose" varying by orders of a magnitude, depending on the medium and nuclide in question? One might ask an even more important question, why should the potential intake route for a given nuclide result in doses several orders of magnitude apart, as we note for ^{90}Sr? Similar discrepancies are true for other radionuclide/media combinations.

If dose is the most important parameter to determine from environmental surveillance, then it would seem logical to set minimum detection levels (or lower limits of detection) based on dose.

*Here defined as the critical organ dose divided by 6 for bone and thyroid, by 1 for total body, and by 3 for all other critical organs.

However, this apparently has not been the rationale for establishing minimum detection sensitivities.

Hence, those responsible for the environmental program at a given site are faced with frequent decisions such as: 1) whether to base dose estimates on environmental or effluent measurements; 2) which media should be sampled realizing that the minimum sensitivities for different media could result in potential dose impacts varying by orders of magnitude (see Table 1) even for the same nuclide; and 3) which media within a given exposure pathway should be sampled to provide adequate dose sensitivity. In addition, environmental measurements included in the routine program for purposes other than dose estimation, e.g., trend evaluation or public interest, may be desired, yet must be clearly distinguished. Most environmental measurements will indeed serve more than one purpose, but seldom optimally.

A basic principle is that the effluents and the environment into which they are dispersed are dynamic, showing both spatial and temporal variations of nearly all constituents. The importance of individual radionuclides depends on the physical and chemical forms that determine their movement in the environment and eventual uptake, deposition, and retention by man, and on their differential metabolism by man. Therefore the underlying principle (and need) in environmental surveillance is flexibility--changing the program scope and intensity in response to changing facility processes,

environmental parameters, and program results. To achieve this end, a critical pathway analysis, the first step in developing or modifying any environmental surveillance program, must be performed. The essential elements for critical pathway analyses are:

- Site-specific source term (radionuclides, quantities, and respective effluent pathways).
- Local meteorology and site topography.
- Surface (and where appropriate, ground water) hydrology.
- Demography (population distribution, land and water use, recreational habits, diet).

The exposure pathway concept is sufficiently documented and understood that no extended treatment is given here. Various graphical illustrations of exposure pathways are available, such as in the EPA (EPA72) and ERDA (ERDA77) surveillance guides, and in the report for fuel fabrication plants by Corley et al (Co73). The procedure suggested here is the dose calculation matrix, Figure 3.2 in the ERDA guide (ERDA77), which was first prepared for the Year 2000 regional dose study (F171). The procedure shown in the ERDA guide is for a single radionuclide and must be reiterated for each nuclide released, with respective organ doses summed for all nuclides. For specific calculational details and lists of various standard parameters the reader is referred to the works of Soldat (So71) and others (So74), Killough and McKay (Ki76), and Regulatory

Guide 1.109 (NRC76).

Summation of respective organ doses and inter-comparison of calculated doses with fractions of dose criteria will indicate which of the nuclides released are the critical nuclides. For these nuclide(s), a retrace of the dose calculation procedure will reveal both the critical pathways and the possibilities for measurements, as well as those other nuclides and pathways which will not require routine measurement for dose evaluation. As noted in Regulatory Guide 4.1 (NRC75c), "Where practical, a suitable indicator medium or organism in each important pathway should be sampled and analyzed for the plant-contributed radionuclides released to the environment."

EFFLUENT PATHWAYS AND RADIONUCLIDES

To determine the relative importance of medium/nuclide combinations in environmental surveillance, the experience at major ERDA sites (De74) and at operating nuclear power plants of the light water type (LWR) (NRC75a, NRC77) was reviewed. Releases of radioactivity in effluents from the two types of facilities (ERDA and LWR) are governed by separate, yet essentially equal federal standards. The ERDA installations are governed by the Manual of Operations (ERDA74), while the LWRs are governed by Title 10, Code of Federal Regulations, Part 20 (10 CFR20) and by limits established in the technical specifications for each facility.

The effluent data summarized here is based on the values presented in the three summary documents noted above for the amount of radioactivity in airborne and liquid effluents released from the respective facility types. Although effluent release data were presented in different formats for the two pathways (airborne and liquid), the data here have been grouped into four categories (a fifth, noble gases, is included for the atmospheric releases)—tritium, radioiodine, mixed fission or activation products, and transuranics. Because of the differences in the effluents between LWR types, boiling water (BWR) and pressurized water (PWR), their releases are summarized separately. Typical release rates for each of the nuclide categories are summarized in Tables 2 and 3. The release values for the transuranics (alpha emitters with half-lives greater than 30 days) from LWRs are based on the calculations of Malaro and Essig (Ma75).

From Table 2 it is clear that noble gases are the largest annual source term in the airborne effluents for all 3 types of facilities, except that gaseous tritium (mostly as HT or T_2) releases from the major ERDA installations are of the same order of magnitude. Tritium releases from LWRs typically are several orders of magnitude less on an activity basis. The releases of noble gases from BWRs are two to three orders of magnitude greater than for PWRs, but the opposite is true for tritium released via the liquid effluent streams. Releases of mixed fission and activation products

(MF & AP), including radioiodines, are generally less than a few Ci/yr from all facility types both for air and water (liquid) pathways. The MF & AP are composed mostly of the shorter lived activation products such as ^{24}Na, ^{51}Cr and ^{58}Co, and the longer lived fission products, ^{134}Cs and ^{137}Cs. Releases of the more radiotoxic ^{90}Sr are typically a few orders of magnitude less. The differences in transuranics between ERDA facilities and LWRs may not be as great as shown, since the ERDA values include short-lived nuclides such as ^{239}Np. On the other hand, many of the ERDA installations handle and process very large quantities of transuranics, especially ^{239}Pu, and it is not surprising that up to mCi/yr quantities may be released.

Since the actual effluent releases from the diversity of installations within each facility type often varied over several orders of magnitude, the geometric mean release values were used for dose calculations. Using these geometric mean releases for each of the nuclide/pathway groupings discussed above, radiation doses (both internal and external) were calculated for individuals using the dose model of Soldat et al (So74) and the exposure parameters and dose factors in Regulatory Guide 1.109 (NRC76). To facilitate ranking, a "whole-body equivalent dose" was defined for ingestion and/or inhalation (see footnote on page 4). The whole-body equivalent dose for external pathways (e.g. shoreline sediment)

is the total body dose.

Secondarily, indirect dose pathways (e.g., soil, sediment, precipitation) were considered on a relative basis by comparing detection sensitivities for a given nuclide in the environmental media commonly sampled. This resulted in the nuclide/medium combination that provides the greatest measurement sensitivity (including both short- and long-term contaminant accumulation). Hence, by this scheme, it was possible to preferentially rank each point of measurement for a given effluent pathway.

RESULTS OF EFFLUENT PATHWAY CALCULATIONS

By using the scheme described above it was possible to determine on a generic basis the environmental media most important for nuclear facilities located at river sites. Only the most important (from a dose to man standpoint) medium or environmental measurement in each effluent pathway is shown in the following series of tables. The relative importance of environmental media within each table are ranked on a 1-5 scale, where the greatest importance of any combination is reflected by a rating of 1, while the least important are reflected by a rating of 5. Changing from a relative importance of 1 to 2 or 2 to 3, etc., indicates at least an order of magnitude decrease in dose.

The results for the above ranking for a major ERDA installation on a river site are presented in Table 4. Note that the three most important environmental measurements are direct radiation for noble gases, tritium in air and radioiodine in milk. Measurements of mixed fission or activation products in air particulates or fish, and tritium or iodine in potable water are at least an order of magnitude less important than the three previous measurements. And, of least importance is the measurement of transuranics in air particulates.

Table 5 shows the results of the same effluent pathway calculations for a typical BWR on a river site. Here, for dose assessment the critical measurements are direct radiation for noble gases and radioiodine in milk. An order of magnitude less important is the analysis of fish for fission and activation products (^{95}Nb, $^{134,137}Cs$, ^{32}P) from liquid releases to the river. All other pathways are orders of magnitude less important from a dose potential, especially the measurement of tritium and fission or activation products in air, which were so important for major ERDA installations.

This series is continued in Table 6 for a PWR in which the most important measurements are radioiodine in milk and fission or activation products in fish. Direct radiation measurements for

noble gases, and the analysis of potable water for tritium and radioiodine are of secondary importance. One further note is that, on an absolute scale, the dose potential (relative importance =1) for the PWR case is approximately an order of magnitude less than those shown for the ERDA or BWR cases.

As we have seen in these tables, fish represent an important dose pathway to man for mixed fission and activation products released to rivers. Curiously, however, ^{32}P analyses in fish (one of the most important activation products from a dose standpoint (Bo75)) are generally missing from the routine environmental surveillance programs for most nuclear power plants. This may reflect the absence of a critical evaluation of pathways as shown above or the general practice of analyzing samples, especially fish, only for ^{90}Sr and gamma emitters, as emphasized in the published guides (EPA72, NRC75c, NRC75d). Unfortunately, these guides suggest the collection and analysis of samples falling within several category types—airborne, direct, waterborne, aquatic and ingestion—resulting in nearly identical routine environmental surveillance programs for a variety of installations with widely differing potential impacts. The fact that many surveillance programs are essentially identical, especially for LWRs, yet the potential dose pathways and impacts are not the same, emphasizes the need for a critical pathway analysis and tailoring the surveillance program to include collection and analysis of "suitable media... in each <u>important</u>

pathway... for the plant-contributed radionuclides released to the environment." (page 4.1-2 in NRC75c).

Independent assessments of the consequences of radionuclide releases from nuclear power plants have resulted in similar conclusions about the importance of fish, potable water and milk. Booth et al (Bo75) showed that the critical pathways for radionuclides discharged into freshwater from LWRs are consumption of fish and ingestion of water, confirming the results of the pathway calculations presented here for river sites. Boeri and Brofferio (Bo73) found that in some instances the ^{131}I contribution to dose, from fish consumption, was of the same order of that from milk, downstream of an Italian nuclear power station.

RECENT DEVELOPMENTS AND CONCLUSIONS

In an attempt to reduce some of the pitfalls and inconsistencies from earlier reports and guides, two recently published documents, one by the NCRP (NCRP76) and the other by ERDA (ERDA77), present techniques, methods, and criteria suitable for all types of nuclear facilities. Both documents contain comprehensive guidance with regard to the content of environmental monitoring programs and the interpretation of monitoring data. They have been under development for several years and have been subjected to extensive professional review. The Forward of the ERDA Guide suggests that it is an interim guide to be field tested by ERDA and its contractors prior

to finalizing the Guide after 1-2 years of scrutiny.

The ERDA Guide (ERDA77) lists a number of general program criteria with an emphasis on dose, but cautions that the proposed dose criteria do <u>not</u> define "as low as practicable" for environmental doses. However, it provides a framework within which a practical, minimal environmental surveillance program can be defined. A summary of the general criteria for ERDA Environmental Surveillance Programs follows:

- Environmental pathway analysis
- Measure each pathway contributing >0.1 mrem/yr when total dose exceeds
  - 1 mrem/yr to individuals
  - 100 person-rem/Yr per 10^6 population.
- Measurements on two media per pathway
- "Background" measurements required
- MDL equivalent to dose criteria

These criteria suggest that environmental sampling and measurements are only required for two media in each critical radionuclide/pathway combination (one of which may be the effluent stream) and only for those exposure pathways in which the annual dose (from plant-contributed nuclides) exceeds 0.1 mrem. They further suggest that minimum detectable levels (MDL) be based on those dose criteria and that "background" location measurements should be taken for

every critical nuclide/pathway combination for which environmental measurements are used in reporting annual dose estimates for site releases.

These very low discrimination levels (i.e., 0.1-1 mrem/yr) for environmental doses of site origin are still controversial, in part because of the impossibility of measuring them directly for some pathways and in part because of the questionable significance to individuals of an annual incremental dose of 1 mrem. Note that this recommendation does not define acceptable levels of radioactivity in the environment, but rather an acceptable discrimination level for environmental measurements. And it must be recognized that where the only source of exposure is direct or scattered radiation from either extremely high energy machines or airborne effluents, such a small radiation exposure is not distinguishable from the much larger and variable exposure from natural sources. For such sources, the environmental measurements may only serve as proof of nondetectability.

The criteria suggested in the ERDA Guide are not inconsistent with the conclusions given by Booth et al(Bo75) or the EPA (EPA76, EPA77). Booth et al adopted a criterion that a calculated annual dose of 0.01 - 1 mrem indicates a potentially important radionuclide, resulting in the following radionuclides released into freshwater as being "significant": ^{3}H (PWR), ^{32}P, ^{60}Co, ^{95}Nb,

^{131}I, $^{134,137}Cs$, and ^{182}Ta. The recently adopted environmental drinking water standard (EPA76) corresponds to a dose of 4 mrem/year, while the proposed guidance (EPA77) on dose limits for transuranics in the environs corresponds to doses of the order of a few mrad/year to the critical organ.

Table 7 presents the results of the critical pathway calculations for an atmospheric release from a major ERDA installation. All media with relative importance factors ranging from 1 to 4 have been included for the various radionuclides. These relative importance factors are the same as as those shown in Tables 4-6. The differences between media at a given relative importance factor are not considered significant, although the medium shown first in each column is considered to be the most important. When only one or two groups of media are shown for a particular effluent pathway/nuclide combination, all other media were considered to be relatively unimportant from a dose evaluation standpoint. Indicator media, such as animal thyroids and forage in the iodine column and deposition in the MF&AP column, tend to rank lower than others because they do not provide a good measure of dose to man, especially because of the uncertainties in environmental transfer factors.

With the help of supplementary data on the local environment and its population, the information presented in Table 7 establishes

relative pertinence of various environmental media, identifies potentially exposed populations and unusual exposure pathways. For the atmospheric pathways considered, this table shows the importance of direct radiation measurements and the sampling of air and milk or fresh leafy vegetables. It also points out the relative unimportance of analyzing milk for tritium or MF&AP and of collecting soil samples at all. As a matter of fact, applying the ERDA criteria summarized above, one would draw a horizontal line just above the relative importance factor of 3 in Table 7 and only sample (or be required to sample from a dose standpoint) up to two media for each of the four nuclide groupings. For this particular case, a combination of effluent monitoring for the nuclide groups plus an environmental surveillance program which includes direct radiation measurements, air sampling for tritium and MF&AP, and milk or leafy vegetable sampling for radioiodine would meet the suggested ERDA criteria.

Although this evaluation (Table 7) and those shown in Tables 4-6 have been done only for fresh water river sites, the method and tabular presentations are equally applicable to other types of sites. Indeed the method must be reapplied for other types of sites and effluent streams. This scheme of calculating doses and of ranking environmental media can be extremely beneficial in establishing or modifying existing surveillance programs. From tables such as those shown here it's easy to select the "best" combinations

of nuclides and media from the actual or expected facility effluent streams, to handle cost-benefit tradeoffs, and finally to select only those media required based on a given set of program criteria.

In conclusion, to plan and conduct environmental surveillance programs on a cost-effective basis, it is logical that media with the greatest contaminant-detection sensitivity and the most prominent role in the critical pathway should be the media routinely utilized. In fact, Regulatory Guide 4.1 (NRC75c) states that "...it may not be necessary to extensively sample and measure grazing plants and fodder to keep tract of iodine-131 cycling in the food chain, since sampling and measuring the milk produced by dairy cows in surrounding areas may be adequate," supporting the conclusions reached in the ERDA guide. One should not lose sight of the fact supplementary environmental measurements (beyond those required for dose evaluation) may be required to at least provide desirable benchmark data. Some compromises are inevitable, either because completely satisfactory measurement techniques are not available or because the best techniques are far too expensive for routine use over large geographical areas.

REFERENCES

Bo73 Boeri, G. and Brofferio, C., 1973, "Practical Reference levels for Radioactive Contamination in Environmental Surveillance," in Proc. of Symp. on Environmental Surveillance Around Nuclear Installations, Warsaw, Poland, IAEA.

Bo75 Booth, R. S., Kaye, S.V., and Rohwer, P.S,, 1975, " A Radiological Assessment of Radionuclides in Liquid Effluents of Light Water Nuclear Power Stations," ORNL-TM-4762, Oak Ridge National Laboratory, Tennessee.

Co73 Corley, J.P., Waite, D.A., Johnston, J.W., and Schwendiman, L.C., 1973, "Environmental Surveillance for Fuel Fabrication Plants," BNWL-1723, Battelle-Pacific Northwest Laboratories, Richland, Washington.

De74 Denham, D.H., Waite, D.A., and Corley, J.P., 1974, "Summary of Selected AEC Contractor Environmental Surveillance Techniques and Capabilities," BNWL-B-384, Battelle-Pacific Northwest Laboratories, Richland, Washington.

EPA72 U.S. Environmental Protection Agency (EPA), 1972, "Environmental Radioactivity Surveillance Guide," ORP/SID 72-2.

EPA76 U.S. EPA, 1976, "Drinking Water Regulations, Radionuclides," in the Federal Register, 41CFR133, pp28402-28409.

EPA77 U.S. EPA, 1977, "Guidance on Dose Limits for the Transuranic Elements in the General Environment," Office of Radiation Programs draft summary report.

ERDA74 U.S. Energy Research and Development Administration (ERDA), 1974, Manual of Operations, Chapter 0513, "Effluent and Environmental Monitoring and Reporting".

ERDA77 U.S. ERDA, 1977, "A Guide for Environmental Radiological Surveillance at ERDA Installations," ERDA 77-24.

Fl71 Fletcher, J.F. and Dotson, W.L., 1971, "HERMES--a Digital Computer Code for Estimating Regional Radiological Effects From the Nuclear Power Industry," HEDL-TME-71-168, Hanford Engineering Development Laboratory, Richland, Washington.

IAEA66 International Atomic Energy Agency, 1966, IAEA Safety Series No. 16: "Manual on Environmental Monitoring in Normal Operation," Vienna.

ICRP65 International Commission on Radiological Protection, 1965, (ICRP) Publication 7: "Principles of Environmental Monitoring Related to the Handling of Radioactive Materials," Pergamon Press, New York.

Ki76 Killough, G.G. and McKay, Larry R. (Compilers), 1976, "A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment," ORNL-4992, Oak Ridge National Laboratory, Tennessee.

Ma75 Malaro, James C. and Essig, Thomas H., 1975, "Doses from Radioactive Actinides Released in Liquid Effluents from Light-Water-Cooled Nuclear Power Reactors," NUREG-75/064, U.S. NRC, Washington, D.C.

NCRP76 National Council on Radiation Protection and Measurements, 1976, (NCRP) Report No. 50: "Environmental Radiation Measurements."

NRC75a U.S. Nuclear Regulatory Commission (NRC), 1975, "Summary of Radioactivity Released in Effluents from Nuclear Power Plants During 1973," NUREG-75/001.

NRC75b U.S. NRC, 1975, "Standards for Protection Against Radiation," 10CFR20.

NRC75c U.S. NRC, 1975, "Programs for Monitoring Radioactivity in the Environs of Nuclear Power Plants," Revision 1, Regulatory Guide 4.1.

NRC75d U.S. NRC, 1975, "Environmental Technical Specifications for Nuclear Power Plants," Regulatory Guide 4.8.

NRC76 U.S. NRC, 1976, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Regulatory Guide 1.109.

NCR77 U.S. NRC, 1977, "Radioactive Materials Released from Nuclear Power Plants (1975)," NUREG-0218.

So71 Soldat, J.K., 1971, "Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities," BNWL-SA-3939, Battelle-Pacific Northwest Laboratories, Richland, Washington.

So74 Soldat, J.K., Robinson, N.M., and Baker, D.A., 1974, "Models and Computer Codes for Evaluating Environmental Radiation Doses," BNWL-1754, Battelle-Pacific Northwest Laboratories, Richland, Washington.

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Table 1. Comparison of Annual Whole Body Equivalent Radiation Doses at Recommended Environmental Detection Limits

Nuclide	Media	Whole Body Dose Equivalent (mrem/yr)
^{3}H	water	0.019
^{60}Co	fish	0.031
^{90}Sr	air particulates	0.015
	fish	0.18
	milk	0.79
	water	1.1
^{131}I	air	0.22
	milk	0.29
	vegetation	0.55

Table 2. Radioactive Effluents (Ci/yr) From Selected Nuclear Facilities

EFFLUENT PATHWAY - AIR

Nuclear Facility Type	Radionuclides				
	Noble Gases	Tritium	Iodine	MF&AP*	TRU**
ERDA	10^{4}-10^{5}	10^{4}-10^{5}	1-5	1-5	10^{-3}
BWR	10^{5}-10^{6}	1-100	1-30	10^{-2}-3	10^{-8}
PWR	10^{2}-10^{4}	1-300	10^{-4}-1	10^{-3}-1	10^{-8}

* Mixed fission and activation products
** Transuranics

Table 3. Radioactive Effluents (Ci/yr) From Selected Nuclear Facilities

EFFLUENT PATHWAY - WATER

Nuclear Facility Type	Radionuclides			
	Tritium	Iodine	MF&AP*	TRU**
ERDA	10^3-10^5	1-5	1-10	0.1
BWR	1-100	10^{-3}-2	1-50	10^{-8}
PWR	10^2-10^4	10^{-3}-2	0.1-30	10^{-8}

* Mixed fission and activation products
** Transuranics

Table 4. Ranking of Environmental Media Based on Potential Radiation Dose

Major ERDA Installation

Effluent Pathway Radionuclide(s)	Air Noble Gas	Air Tritium	Air Iodine	Air MF&AP	Water Tritium/Iodine	Water MF&AP	Air TRU
1	Direct radiation	Air	Milk				
2				Air particulates	Potable water	Fish	
3							Air particulates
4							

Relative Importance of Environmental Media

Table 5. Ranking of Environmental Media Based on Potential Radiation Dose

Boiling Water Reactor (Nuclear Power Plant)

Relative Importance of Environmental Media	Effluent Pathway Radionuclide(s)	Air Noble Gas	Air Iodine	Air Tritium/MF&AP	Water Tritium	Water Iodine	Water MF&AP
1		Direct radiation	Milk				
2							Fish
3						Potable water	
4					Potable water		
5				Air			

Table 6. Ranking of Environmental Media Based on Potential Radiation Dose

Pressurized Water Reactor (Nuclear Power Plant)

Relative Importance of Environmental Media	Effluent Pathway Radionuclide(s)	Air Noble Gas	Air Tritium	Air Iodine	Air MF&AP/TRU	Water Tritium/Iodine	Water MF&AP
1				Milk			Fish
2		Direct radiation				Potable water	
3			Air				
4							
5					Air particulates		

Table 7. Ranking of Environmental Media Based on Potential Radiation Dose

Atmospheric Releases from a Major ERDA Installation

Relative Importance of Environmental Media	Noble Gases	Tritium	Iodine	MF&AP
1	Direct radiation Air	Air	Milk Vegetables	
2		Precipitation	Air Animal thyroids	Air particulates
3		Milk Vegetables Native grasses	Forage	Vegetables
4		Honey		Milk Deposition Direct radiation

NOTICE

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