January 30, 1980

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SECY-79-653A

INFORMATION REPORT

For: The Commissioners

Thru: Executive Director for Operations

From: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Subject: WASHINGTON POST ARTICLE ON NUCLEAR REACTOR SAFETY DATED NOVEMBER 11, 1979

Purpose: To inform the Commissioners regarding our preliminary analysis of the Wyhl Report.

Discussion: In an interim Commission information paper dated December 10, 1979* we provided you with some background information on a Washington Post article entitled, "Are Nuclear Plants Unsafe--Even Without a Mishap?" This article, which was based primarily on a report entitled, "Radioecological Assessment of the Wyhl Nuclear Power Plant" (Wyhl Report), alleged that the NRC may be substantially underestimating doses to individuals in the environs of nuclear power plants. In our interim Commission paper, we indicated that the staff was completing a draft review of the Wyhl Report. Enclosed for your information is a copy of the revised translation of the Wyhl Report (Enclosure 1), and our first complete draft of the Review of the Wyhl Report (Enclosure 2). A brief summary of the results of our draft review of the Wyhl Report follows.

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Although the Wyhl Report's assessment is based largely on environmental models described in NRC's Regulatory Guide, the Wyhl Report uses values for some model parameters that are much higher than the values NRC uses. As a result, the Wyhl Report estimates doses that are from 10 to 10,000 times higher than the doses calculated using NRC's values for Regulatory Guide parameters.

Comparison of the Wyhl Report's dose to the maximum individual from various pathways and radionuclides indicates that a large fraction of the total dose estimates in the Wyhl Report is due to the air-food ingestion pathway for Cs-137 and Sr-90. Values for the following parameters are in most disagreement with those of Regulatory Guide 1.109, and ultimately have the greatest effect on the Wyhl Report's dose estimates: (1) soil to plant transfer factors (B_{iv}) for cesium and strontium that are 7 to 1500 times larger than NRC values, (2) ingestion dose conversion factors (DCFs) for Sr-90 (bone) and Cs-137 (kidney) that are 12 to 40 times larger, respectively, than NRC values, and (3) forage to meat transfer factors (F_f) that are from 5 to 65 times higher, depending on nuclide and type of meat, than the values used by NRC.

Based on an indepth review of the references in the Wyhl Report it is concluded that the Wyhl Report uses unrealistically large values for soil to plant transfer of cesium and strontium; and ingestion dose conversion factors for Cs-137 (kidney), and Sr-90 (bone). In addition, the Wyhl Report predicts concentration of Cs-137, the most crucial nuclide to the Wyhl Report's analysis, and I-131 in vegetation, meat and/or milk that are much greater than the lower limit of detection of these nuclides. However, review of the environmental monitoring data of about 20 nuclear power plants operating in the U.S. in the year 1977 indicates that concentrations of Cs-137 and I-131 in vegetation, meat and/or milk are much lower than the Wyhl Report's predictions. Consequently, the Wyhl Report's estimated dose from vegetation, meat and milk ingestion is not a realistic dose for the hypothetical maximum individual living near nuclear power plants in the U.S.

Since the Wyhl Report includes many references with higher average soil to plant transfer factors for cesium and strontium than current Regulatory Guide 1.109 values, we are considering increasing the current values for soil to plant transfer of these nuclides in future revisions of Regulatory Guide 1.109. The proposed values for soil to plant transfer of cesium and strontium would only slightly increase (by less than 10%) our total dose estimates from all radioactive effluents from a nuclear power reactor.

Harold Denton

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Enclosures: Commissioners, SECY, PE & GC only.
*1. Revised Translation of "Radioecological Assessment of the Wyhl Nuclear Power Plant"
*2. Draft "Review of the Wyhl Report"

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* Copies of enclosures may be obtained from Edward Branagan, NRR, Ext. 27895.

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REVIEW OF THE

WYHL REPORT

ABSTRACT

This report reviews the technical basis for the dose estimates in a report entitled "Radioecological Assessment of the Wyhl Nuclear Power Plant" (Wyhl Report). Although the Wyhl Report's assessment is based largely on environmental models described in NRC's Regulatory Guide, the Whyl Report uses values for some model parameters that are much higher than the values NRC uses. As a result, the Wyhl Report estimates doses that are from 10 to 10,000 times higher than the doses calculated using NRC's values for Regulatory Guide parameters. A large fraction of the total dose estimates in the Wyhl Report is due to Cs137 and Sr-90. Based on an indepth review of the Wyhl Report it is concluded that the Wyhl Report uses unrealistically large values for the following parameters: (1) soil to plant transfer of cesium and strontium; and (2) ingestion dose conversion factors for Cs-137 (kidney), and Sr-90 (bone). In addition, the Wyhl Report predicts concentrations of Cs-137, the most crucial nuclide to the Wyhl Report's analysis, and I-131 in vegetation, meat and/or milk that are much greater than the lower limit of detection of these nuclides. A review of the environmental monitoring data of about 20 nuclear power plants operating in the U.S. in the year 1977 does not substantiate the Wyhl Report's predictions. Consequently, the Wyhl Report's estimated dose from vegetation, meat and milk ingestion is not a realistic dose for the hypothetical maximum individual living near nuclear power plants in the U.S.

Since the Wyhl Report includes many references with higher average soil to plant transfer factors for cesium and strontium than current Regulatory Guide 1.109 values, NRC is considering increasing the current values for soil to plant transfer of these nuclides in future revisions of Regulatory Guide 1.109. The proposed values for soil to plant transfer of cesium and strontium would only slightly increase total dose estimates from all radioactive effluents from nuclear power reactors.

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

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I. INTRODUCTION

The Department of Environmental Protection of the University of Heidelberg has published a report entitled "Radioecological Assessment of the Wyhl Nuclear Power Plant" (Wyhl Report).[1] The Wyhl Report assesses the environmental impact of a proposed nuclear reactor to be built near Wyhl, Germany. The Wyhl reactor is a pressurized water reactor (PWR). The assessment is based largely on environmental models that are used by the U.S. Nuclear Regulatory Commission (NRC) in licensing reactors.

Several Regulatory Guides (Regulatory Guides 1.109, 1.111, 1.112 and 1.113) were developed by NRC to implement Appendix I of Title 10, Code of Federal Regulations, Part 50 (i.e., 10 CFR Part 50).[2,3,4,5] Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low As Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," provides numerical guidance for radioactive effluent design objectives and technical specification requirements for limiting conditions of operation for light-water-cooled nuclear power plants.

- Regulatory Guide 1.112, "Calculation of Released Radioactive Materials in Gaseous and Liquid Effluents from Light-Water-Cooled Power Reactors," provides methods for calculating releases of radioactive effluents (liquid and gaseous) from light water reactors.

- Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Release from Light-Water-Cooled Reactors," provides methods for calculating dispersion of airborne effluents.

- Regulatory Guide 1.113, "Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I," provides methods for calculating dispersion of liquid effluents.

- Regulatory Guide 1.109, "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, provides methods for calculating doses (both maximum hypothetical individual, and population) from both liquid and airborn releases.

The procedures and models provided in these guides are subject to continuing review by the staff.

One of the main conclusions of the Wyhl Report is that the radiological impacts from a proposed reactor are much greater than the Federal Republic of Germany's Regulatory Agency responsible for licensing the reactor, Hessisches Ministerium fur Wirtschaft und Technic, estimates. The Wyhl Report estimates individual doses that are from 10 to 10,000 times higher than the doses calculated using NRC's Regulatory Guide parameters.

Some of the reasons for the large differences in dose estimates between the Wyhl Report's assessment and the German Regulatory Agency's assessment are given in the Summary section (Ch. 11) of the Wyhl Report. These reasons include:

1. "The meteorological long-term dispersion factor assumed in the GRS assessment was about 2.5 times too low, so that the meteorological attenuation was about 2.5 times too high."
2. "The assumed nuclide spectrum for radioactive aerosols was not conservative. In particular, the percentage of cesium-137 that was used was too small."
3. "The enrichment factors for the passage of radionuclides from the soil into crop plants were between 10 and 1000 times too low in the most critical cases . . . ."
4. "The transfer coefficients for the passage of radionuclides from forage into beef, pork and milk were between 10 and 100 times too low in the most critical cases . . . ."
5. "The transfer factors for the passage of radionuclides from foodstuffs into the bloodstream via the gastrointestinal tract were between 10 and 20,000 times too low (see, for example, plutonium on p. 91)."
6. "The value assigned for the biological half-lives of radionuclides in the human organism were too low for some radionuclides."
7. "The nuclide composition of the radioactive noble gases was totally unrealistic. Consequently, the calculated radiation exposure from radioactive noble gases was about 5 times too low."

1.1 PURPOSE OF REVIEW OF WYHL REPORT

Since the Wyhl Report refers to some documents that have been published after publication of the documents which are cited in some of the relevant NRC Guides, we have reviewed the Wyhl Report to:

1. Write a review of the report that would be useful in licensing hearings and responding to petitions for rulemaking.

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2. Determine the need to incorporate this more recent data in future revisions of the Regulatory Guides relating to the radiological assessment of routine releases from nuclear power plants.

1.2 METHOD OF REVIEW OF WYHL REPORT

Since the Wyhl Report primarily criticizes the SSK and only indirectly criticizes NRC's environmental models, we have reviewed the Wyhl Report for generic criticisms of our models rather than site specific criticisms of the Wyhl nuclear power plant. Since the Wyhl Report questions the models and many of the values for model parameters used by NRC in radiological assessments of routine release from nuclear power plants, we have limited our review to the most significant differences in models and model parameters.

Chapter 2 - Critique of Source Terms

This chapter is divided into an introductory section and several sections that compare the Wyhl Report's source term with typical NRC source term estimates. The introductory section briefly describes the overall importance of source term models to radiological assessments. It indicates, in general terms, that the basis for NRC models is nuclear plant operating experience and that the source term for a particular plant is dependent upon these generic NRC models, as well as the specific treatment systems proposed for a nuclear plant. The later sections compare the Wyhl Report's source terms with both general NRC models described in NUREG-0017 and actual data from semi-annual effluent release reports.[8]

Chapter 3 - Critique of Dispersion Models

This chapter includes three sections: (1) Introduction; (2) Critique of Wyhl's Dispersion models; and (3) General Description and Basis for NRC Models. The introductory section briefly describes the overall importance of dispersion models to radiological assessments. Important input parameters for dispersion models are identified. The second section, "Critique of Wyhl's Dispersion Models," discusses the general methodology, including atmospheric dispersion models, assumptions and input data used in making the assessment of the Wyhl site. Dispersion models used in the Wyhl Report are compared with models used in NRC reactor licensing hearings. The last section, "General Description and Basis for NRC Models," describes the physical basis for NRC at[illegible]eric dispersion models and important NRC input parameters.

Chapter 4 - Pathway Analysis

This chapter identifies the major reasons why the Wyhl Report's dose estimates are higher (by several orders of magnitude) than those typically estimated by NRC in reactor licensing hearings. The chapter analyzes several of the pathways in Wyhl for airborne releases: (1) gamma submersion, (2) external exposure from contaminated ground, and (3) food ingestion. Since Wyhl's dose estimates for liquid releases are small (less than 15% for most body organs) compared with dose estimates for airborne releases, the liquid pathway is not analyzed in detail. The dose estimates in this chapter are based on the source terms and dispersion models used in the Wyhl Report. Doses to the maximum individual are estimated with variations of the models described in NRC Regulatory Guide 1.109. The Wyhl Report's dose calculations were analyzed with NRC's computer program GASPAR. GASPAR calculates doses from airborne effluents using the models in Regulatory Guide 1.109. GASPAR was run several times with each run incorporating progressively more of the Wyhl Report's values for model parameters. The Wyhl Report's air-food ingestion doses are also analyzed from a radionuclide viewpoint. Values of parameters critical to the Wyhl Report's dose estimates are identified.

Chapter 5 - Critical Parameters in Radiological Assessment Models

This chapter reviews in detail the basis for large differences between the Wyhl Report's values and NRC's values for critical parameters in assessing offsite doses to the maximally exposed adult. The parameters that are reviewed are those that were identified, in Chapter 4, as accounting for major differences between the Wyhl Report's and NRC's adult dose estimates. This chapter is divided into four major sections: (1) Soil to Plant Transfer of Cesium; (2) Soil to Plant Transfer of Strontium; (3) Ingestion Dose Conversion Factors for Cs-137 and Sr-90; and (4) Summary and Conclusions of Critical Parameters for Cs-137 and Sr-90. The first two sections review and summarize papers on soil to plant transfer of cesium and strontium referenced in the Wyhl Report and the main reference in Regulatory Guide 1.109 (Y. C. Ng, 1968).[7] An appendix to this chapter reviews references cited in a recent paper by Y. C. Ng (1979).[8] The technical basis for the Wyhl Report's ingestion dose conversion factors (DCFs) for Cs-137 (kidney) and Sr-90 (bone) is analyzed. The Wyhl Report's DCFs for Cs-137 (kidney) and Sr-90 (bone) are compared with the corresponding DCFs in Regulatory Guide 1.109. The Wyhl Report's DCFs are also compared with preliminary results from an NRC contract with Oak Ridge National Laboratory (ORNL).[9]

Chapter 6 - Comparison of Wyhl Report's Radiological Model with Environmental Monitoring Data

This chapter compares the Wyhl Report's estimate of radionuclide concentrations in the environment with measured concentrations around nuclear power plants in the United States.

Chapter 7 - Summary and Conclusions

The chapter summarizes the finuings from the review of the Wyhl Report and other recent literature. Se eral changes in future revisions of Regulatory Guide 1.109 values for soil-to-plant transfer of cesium and strontium are proposed. Use of these proposed values in the interim should result in a slightly more conservative estimate of the food ingestion dose near nuclear power plants.

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2. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, Revision 1, "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," Washington, DC, October 1977.

3. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.111, Revision 1, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Washington, DC, July 1977.

4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.112, Revision 0-R, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Light-Water-Cooled Power Reactors," Washington, DC, April 1976.

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.113, Revision 1, "Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I," Washington, DC, April 1977.

6. U.S. Nuclear Regulatory Commission, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors (PWR-GALE Code)," NUREG-0017, Washington, DC, April 1976.

7. Y. C. Ng, C. A. Burton, S. E. Thompson, R. K. Tandy, H. K. Kretner, and M. W. Pratt, "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Releases to the Biosphere," USAEC Report UCRL-50163, Part IV (with October 22, 1968 insert), May 1968.

8. Y. C. Ng, "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products," International Symposium on Biological Implications of Radionuclides Released from Nuclear Industries, Vienna, Austria, March 1979.

9. G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities," prepared by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission, NUREG/CR-0150, June 1978.

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2. CRITIQUE OF SOURCE TERMS

2.1 INTRODUCTION

Determination of radiation exposures to maximum individuals and populations living in the vicinity of a nuclear power plant first requires a knowledge of the quantity of radioactive materials released from the plant. The average quantity of radioactive material released to the environment from a nuclear power plant during normal operation, including anticipated operational occurrences, is called the "source term" since it is the source or initial number used incalculating the environmental impact of radioactive releases. The impacts are directly related to the magnitude of the source term.

During the operation of a nuclear power reactor plant, small quantities of radioactive materials are expected to be present in the liquid and gaseous effluents released to the environment. Federal regulations[1, 2] in the U.S. require the release of radioactive materials from nuclear power stations to be "as low as is reasonably achievable" (ALARA).

Most of the radioactive materials originate in and are retained within the reactor fuel elements, although a small fraction of the radioactive materials may escape from the fuel through small defects in the cladding into the primary coolant. In addition, radioactive materials may be present in the primary coolant due to the neutron activation of corrosion products, chemical additives and hydrogen and oxygen in the primary coolant. Radioactive materials are transported from the primary system to auxiliary liquid systems through process operations, equipment drains, or equipment leakage. System venting, gas stripping, and fluid leakage to ventilated areas provide a means for radioactive materials that are present in liquid and gaseous streams that leak from, or are withdrawn from, the primary system that constitute the radioactive waste requiring treatment prior to release to the environment or recycling within the plant. Figures 2.1 and 2.2 present general descriptions of gaseous effluent pathways and liquid effluent pathways for pressurized water reactors. These figures also show potential effluent treatment equipment.

The NRC has developed calculational models to provide estimates of the source terms from nuclear power plants. For pressurized water reactors (PWRs), these models are discussed in detail in NUREG-0017[3]. These models provide values for the levels of radioactivity formed in the plant and transported to effluent systems in the plant and also provide values for the amount of treatment or cleanup that can be performed on these wastes before they are released to the environment. These models are based on data generated at operating reactors, on field tests, on laboratory experiments and on performance of equipment designed to reduce releases.

Therefore, the evaluation of the source term for a particular reactor being considered is dependent upon the generic models developed in NUREG-0017 and upon the specific provisions incorporated into the reactor plant design to reduce effluent releases so as to conform to the "as low as is reasonably achievable" release criteria.

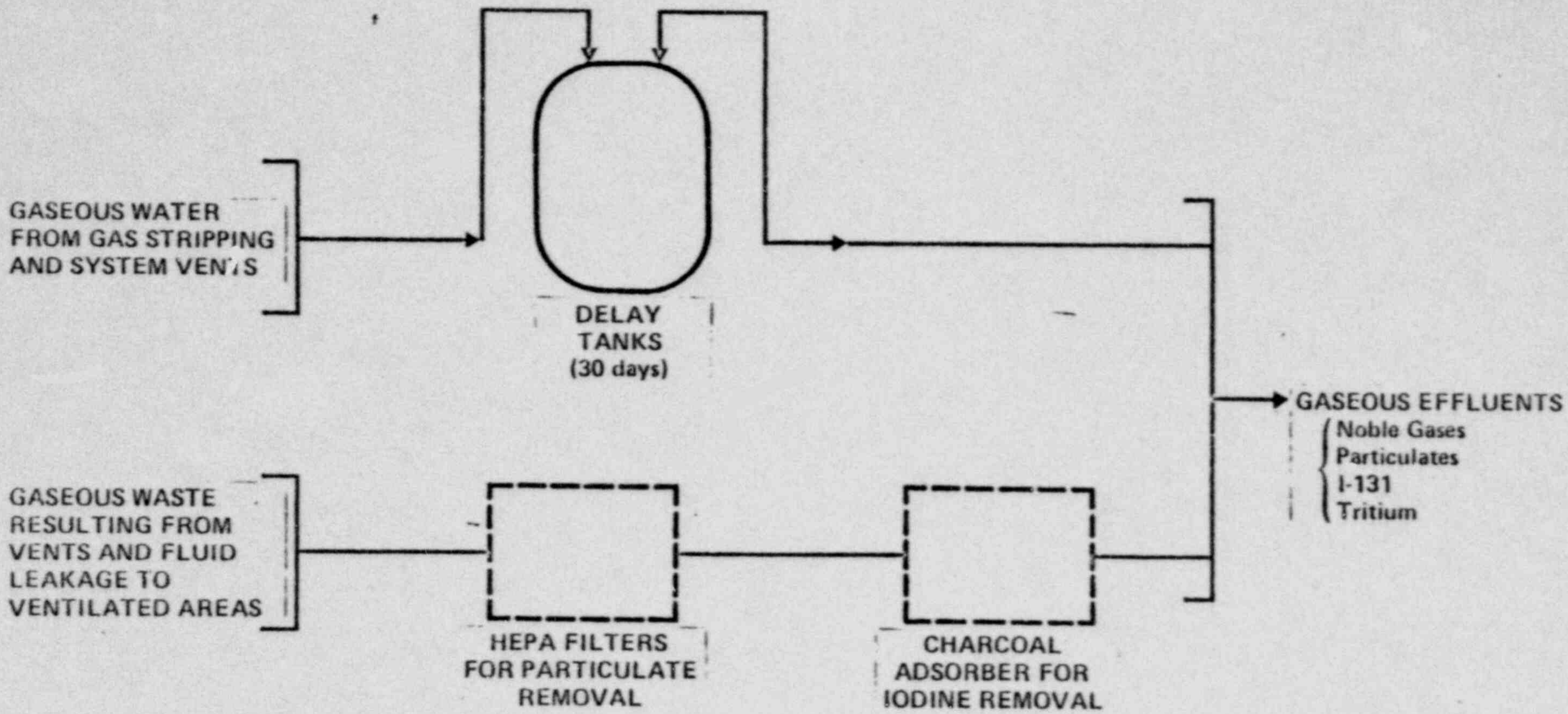

Figure 2.1 General Description of Gaseous Effluent Pathways and Potential Treatment Equipment in a Pressurized Water Reactor.

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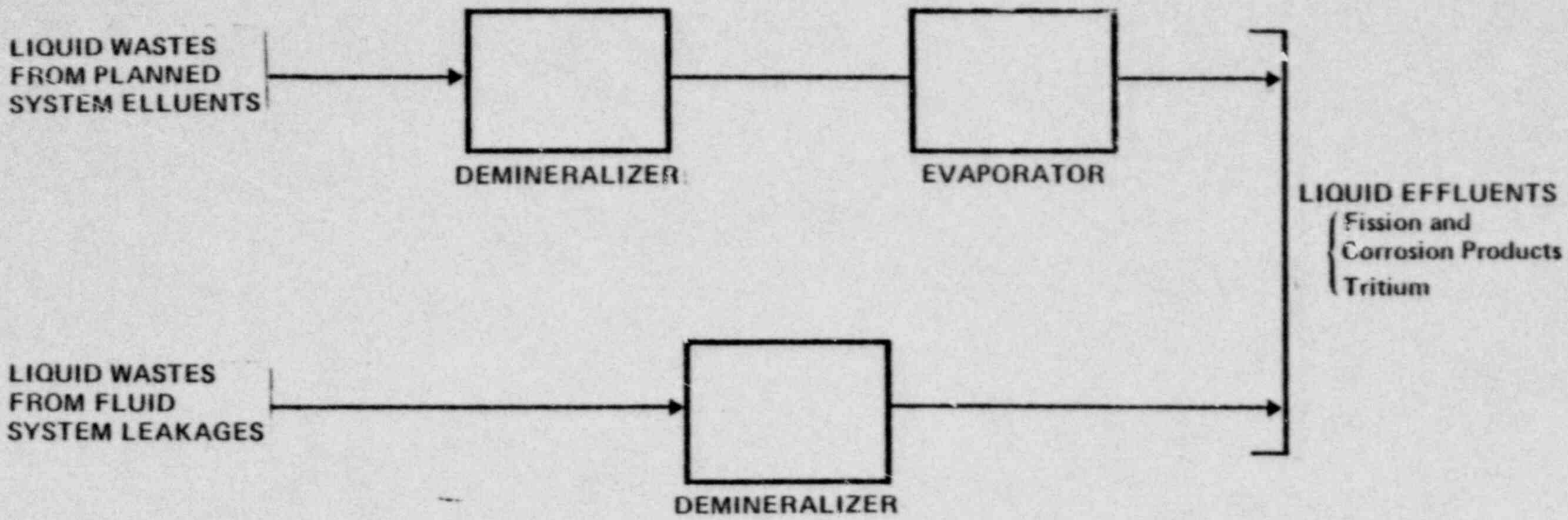

Figure 2.2 General Description of Liquid Efflents Pathways and Potential Treatment Equipment in a Pressurized Water Reactor

2.2 COMPARISON OF WYHL'S SOURCE TERMS WITH NRC SOURCE TERM FOR A BASE CASE PWR

Sections 2, 3 and 4 of the Wyhl Report present a discussion of the source terms assumed for the Wyhl nuclear power plant for both liquid and gaseous effluents. There is no specific information listed in the Wyhl Report as to the bases for the values presented, the amount of treatment equipment provided for the Wyhl plant, or the level of the release limits which must be met.

Thus, it is impossible to come to a conclusion regarding the appropriateness of the values in the Wyhl Report for the Wyhl plant and it is very difficult to make any definitive comparisons between the data in the Wyhl Report and NRC source term models.

One comparison which can be made to get an approximation of differences is to compare the Wyhl Report numbers to a NRC source term, assuming a realistic treatment system design, designated as a "base case."

Table 2.1 presents a listing of the source terms in the Wyhl Report and a comparison of those releases to NRC source term estimates for a PWR. The NRC values for the base case PWR are based on the models of NUREG-0017 for 3400 MWt reactor and were calculated to represent realistic values. This means that the source terms presented for the release of iodine-131, particulates and ventilation system noble gases are for releases with no treatment provided since PWRs do not always provide treatment for these release pathways. However, the values [illegible]ed for the realistic base case PWR for noble gases from the waste gas system and for liquid releases of fission and corrosion products consider the presence of treatment equipment since, in the USA, all

TABLE 2.1: COMPARISON OF WYHL REPORT RELEASES WITH BASE CASE NRC RELEASES

Airborne Releases	Wyhl Report (Ci/yr)[a]	NRC-PWR (Ci/yr)[b]
Noble Gases	80,000	12,000
I-131	0.3	0.24
Particulates	1.0	0.4
Tritium	NV	680
Liquid Releases		
Tritium	1,600	680
Other Fission and Corrosion Products	10	1.0

[a]Wyhl Report estimates are taken from Section 2.1 and 2.2 of the Wyhl Report.

[b]These values were derived from data in NUREG-0017 and assumed the following: no treatment of particulate and I-131 releases with a continuous containment purge; 30 days holdup for noble gases; and for liquid wastes evaporation and demineralization of shim bleed wastes and demineralization of floor drain wastes.

reactors have had to add treatment equipment on these release pathways in order to meet the ALARA criteria of the Federal Regulations. Thus, the noble gas release is based on a 30-day holdup in the waste gas system and the liquid release is based on evaporation and demineralization. We will see in the next comparison table the validity of using this realistic base case for noble gas and liquid releases.

Referring back to Table 2.1, one can see quite clearly that the Whyl Report and NRC-PWR estimates are in fairly good agreement for the release of iodine-131 and particulates. For noble gases and liquid releases, the presence of the realistic base case treatment systems result in NRC-PWR estimates somewhat below the Wyhl Report estimates. These comparisons can not be carried much beyond this point since, as was discussed in the introduction, effluent treatment methods incorporated into the design of the Wyhl plant are unknown. If the Whyl plant includes treatment systems comparable to those assumed in our calculation of the source term estimate, then reasonable agreement can be seen. If Wyhl treatment systems are different from those in our assumption, then valid comparisons can not be made.

2.3 EFFECT OF TREATMENT EQUIPMENT ON SOURCE TERMS

Consideration must also be given to the type of process treatment at an individual plant before source terms can be calculated. The most common type of treatment available for the removal of iodine-131 and particulates from effluent streams are charcoal adsorbers and HEPA (High Efficiency Particulate Air) filters, respectively. These processes can reduce iodine levels by as much as a factor of 100 depending on the amount of charcoal used and can also reduce particulate releases by a factor of 100. In addition, PWRs can reduce their noble gas releases by keeping primary coolant gas levels low by routing greater quantities of gas to the waste gas system where additional storage tanks for delay can be provided. Also, liquid releases can be reduced by additional demineralizers and evaporators in the system. Since in many cases a particular PWR will have to treat one or all of the gaseous effluent pathways with additional equipment such as charcoal adsorption or HEPA filtration, the NRC-PWR estimates in Table 2.1 would be correspondingly reduced for those cases providing treatment. In order to illustrate the effect of actual plant treatment equipment, Table 2.2 presents a comparison of the NRC base case values with the average of the calculated estimates made [illegible] 20 operating PWRs based on specific plant design. Since these plants are currently in operation and effluent release data have been reported, Table 2.2 also presents an averafe pf operating experience to date at these reactors. A review of Table 2.2 shows that when the effect of additional treatment equipment is considered, the source term from the average plant is reduced below the base case.

Table 2.2 also shows that, on the average, the calculated estimate based on the generic models of NUREG-0017 and the specific plant system agrees will with the release experience currently being obtained. This provides confidence in the generic models of NUREG-0017.

2.4 CONCLUSION

In summary, it is difficult to come to any definitive conclusion concerning the validity of the Wyhl Report numbers without more knowledge of the treatment systems employed and the bases for their release estimates. Based on

TABLE 2.2: COMPARISON OF NRC BASE CASE SOURCE TERM ESTIMATES TO ESTIMATES FOR ACTUAL PLANT DESIGNS

Airborne Releases	Base Case[a]	Average of Estimated Release for 20 PWRs[b]	Average of Actual Release for 20 PWRs[c]
Noble Gases	12,000	5,200	7,500
I-131	0.24	0.063	0.05
Particulates	0.4	0.023	0.02
H-3	680	550	100
<u>Liquid Releases</u>			
Mixed Fission and Corrosion Products	1.0	0.7	1.2
H-3	680	460	400

[a]From Table 2.1

[b]Values obtained from computer code runs made using NUREG-0017 models and parameters for specific plants.

[c]Values obtained from semiannual effluent release reports for specific plants.

the above discussions, the values presented in the Wyhl report may well be valid for that particular power plant given its reactor design and treatment system design. However, the source terms of the Wyhl Report can not be generically applied to all PWRs since there is not a fixed source term applicable to all plants. The source term is a variable from plant to plant depending on the plant design proposed by the specific reactor to meet the limiting dose guideline present in Federal Regulations.

REFERENCES

1. Code of Federal Regulations, Title 10, Chapter 1, Part 20, "Standards for Protections Against Radiation" (10 CFR Part 20).

2. Code of Federal Regulations, Title 10, Chapter 1, Part 50, "Licensing of Production and Utilization Facilities" (10 CFR Part 50).

3. NUREG-0017, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors (PWR)," April 1976.

3. CRITIQUE OF DISPERSION MODELS

3.1 INTRODUCTION

In order to determine the maximum radiation exposure (dose) from airborne releases to individuals, and populations living in the vicinity of a nuclear power plant, an assessment of the dilution characteristics of the atmosphere in the site vicinity must be made. The vehicle for extension of the source term though the various pathways and ultimately, to the doses is generally a transport and diffusion model.

Federal regulations[1,2,3] in the U.S. establish site suitability, limits on concentrations of radioactive material in effluents to unrestricted areas, the requirements for operating procedures to meet the "as low as reasonably achievable" (ALAR) release criteria, and provide numerical guidance for design objectives and limiting conditions for operation.

Calculational procedures used by utility applicants in the U.S. to determine design objectives should address the following five points:

(1) An applicant should be free to use as realistic a model for characterizing natural phenomena, including plant performance as he considers useful. An applicant may take into account situations not adequately characterized by such standardized models as may be available with respect to specific features of plant design, proposed modes of plant operation, or local natural environmental features which are not likely to change significantly during the term of plant operation.

(2) Where selection of data is strictly a matter of interpreting experimental evidence, both the applicant and the Regulatory Staff should use prudent scientific expertise to select those values which would be expected to yield estimates nearest the real case.

(3) If approximations implicit in a model can produce a deviation from the true result the direction of which is either uncertain or would tend to underestimate dosage or if available experimental information leaves a substantial range of uncertainty as to the best estimate of some parameter values, or both, data should be chosen so as to make it unlikely, with all such deviations and uncertainties taken into account together, that the true dose would be underestimated substantially.

(4) The models used in describing effluent releases should take into account all real sources and pathways within the plant; and the estimated releases should be characteristic of the expected average releases over a long period of time, with account taken of normal operation and anticipated operational occurrences over the lifetime of the plant.

(5) The model of the exposed individual and the assumed characteristics of the environs with respect to human occupancy and to land and water use should be determined in each case in accordance with the intent indicated below for each particular category of effluent for which design-objective guidelines are given.

(a) For design objectives affected by assumptions as to consumption of water or food (other than milk) produced in the environs, one should consider the model individual exposed with account taken only of such potential occupancies and usages as could actually be realized during the term of plant operation.

(b) For design objectives affected by exposure as a direct result of human occupancy (immersion exposure), the model individual should be the hypothetical individual maximally exposed with account taken only of such potential occupancies, including the fraction of time an individual would be exposed, as could actually be realized during the term of plant operation.

(c) For design objectives relative to thyroid dose as affected by consumption of milk, the iodine pathway through the environs of a plant and the characteristics of the model receptor should be essentially as they actually exist at the time of licensing.

The transport and diffusion of radioactive materials in the form of aerosols, vapors, or gases released into the atmosphere from a nuclear power plant are a function of the state of the atmosphere along the plume path, the topography of the region, and the characteristics of the effluents themselves. For a routine airborne release, the concentration of radioactive material in the surrounding region depends on the source term; the height of the release; the momentum and buoyancy of the emitted plume; the windspeed, atmospheric stability, and airflow patterns of the site; and various effluent removal mechanisms. Geographic features such as hills, valleys, and large bodies of water greatly influence dispersion and airflow patterns. Surface roughness, including vegetative cover, affects the degree of turbulent mixing. Sites with similar topographical and climatological features can have similar dispersion and airflow patterns, but detailed dispersion patterns are usually unique for each site.

It has been the practice in the U.S. to implement an onsite meteorological program[4] in order to provide meteorological information with which dilution factors can be estimated. Various provisions allow for justification of data sets of lesser degree of detail. However, prior to the issuance of a permit to construct, one year or more of meteorological data are required to be collected and prior to the issuance of a permit to operate an addition two years or more are required. These data are to be evaluated in response to the requirements for the preparation of Safety Analysis Reports, Environmental Reports, or Early Site Reviews.

Onsite or representative offsite information when used judiciously can provide useful information regarding dilution characteristics in the site vicinity. A multitude of evaluations can be performed with such data bases, however, such information can prove misleading if not applied properly.

It was not evident from the objectives statement of the Wyhl Report that the experts relate the various release conditions, to appropriate meteorological conditions. The results of any atmospheric dispersion calculation have merit only when used in its proper context. Dilution estimates can only be as worthwhile as the assumptions made with regard to transport and diffusion, the plant engineering and operational configuration, and the meteorological conditions, that could be experienced. The implication is that the user ensures that the meteorology and the model are appropriate for the objective.

POOR ORIGINAL

Three release conditions are generally considered in addressing the various U.S. regulations: normal (routine), intermittent (purge), and abnormal (accident). There are three attendant philosophies for estimation purposes as well. Added measures of conservatism are incorporated into the selection of actual meteorological conditions and the model as the time frame decreases. Likewise, different methodologies are used to calculate dilution estimates that account for planned or unplanned releases and short- or long-term variability in meteorology.

The position established in the Wyhl Report was that short-term meteorological data was necessary, but unavailable, and that projecting coincident release/dose calculations was impossible. On these bases, adjustments were made to the dilution factors to reflect perceived errors inherent in the inadequate meteorological information.

3.2 CRITIQUE OF THE ATMOSPHERIC TRANSPORT AND DIFFUSION MODEL USED IN THE WYHL REPORT

In the discussions that follow, the atmospheric transport and diffusion model, the meteorological input, and assumptions made will be dealt with in varying degrees of detail. At the outset, it should be noted that the information provided does not meet the minimum level of specificity regarding selection of appropriate meteorological data and proficiency in model applications, and presentation of results which are acceptable in the U.S.[6]

The least sophisticated model acceptable to the USNRC will be used in the comparison of methodologies. The methodologies as outlined in various regulatory guides[7,8,9,10] and other documents[11,12] have a common derivative with the model[13] referred to in the Wyhl Report; 13, Gaussian. At that common point is where the similarity ends.

The meteorological information used in the Wyhl Report leaves much to be desired. To compensate for inadequacies, an attempt was made in the Wyhl Report to introduce unsubstantiated error functions.

3.2.1 METEOROLOGICAL DATA

It is extremely difficult to perform a diffusion calculation and retain any credible sense of realism in the estimate if the meteorological data are inadequate. Considerable effort was made in the Wyhl Report to demonstrate that the conditions prevailing at one location can only be approximated by conditions at another.

Meteorological data in one form or another were presented for five stations (Freiburg, Karlsruhe, Breisach, Bremgarten, and Strassburg) for five meteorological factors (atmospheric stability, wind direction, weather phenomena, wind speed, and inversion). No single station was considered to adequately represent Wyhl on all accounts, further, no single station record was presented for each of the three parameters mandatory for an adequate assessment.

(atmospheric stability, wind direction and speed)

POOR ORIGINAL

An undefined statistical measure of error was attributed to the variability between two station location records. Meteorological data are not [illegible] documented as to the period of record, representativeness of the period, representativeness of the location, exposure of equipment, and accuracies quality of data records, etc.

The information that was presented would be considered inadequate in the U.S. to discuss climatology much less diffusion at a power reactor site. Whereas the Wyhl experts concluded that erroneous assumptions were made in the construction of the model with regard to the interdependency of meteorological parameters, no support was given to indicate coincident data were used to estimate dilution factors.

Without dwelling on one of the major inadequacies of the entire report, there appears to be a misconception of the use of meteorological data in models. This includes not only the manner in which they are to be applied in the model, but the selection of the data base as well. Data synthesized from multiple locations for different time periods and for different parameters hardly provides anything useful. Providing a statistical measure of error, which went undefined, to ensure that the true dose would unlikely be underestimated substantially is avoiding the issue. As was stated in the introduction, the data should be chosen such that the coincident deviations, variability, and uncertainty are taken into account together to provide the best estimate.

The implication of summation of the estimation error is that Wyhl experts violated the diffusion calculation procedure by not considering dependence among wind direction and speed and atmospheric stability. Clearly [illegible]ated in the referenced document describing the model and understood by any diffus[illegible] specialist, the basic requirement to use the diffusion models is that a three parame[illegible] statistic be available rather than separate statistics for three parameters. For such a comparison, consider wind direction in twelve 30 degree sectors, wind speed in seven classes, and atmospheric stability in six classes; the requirement should provide 504 unique pieces of information, the misapplication would provide only 25. Several factors lead us to believe that the Wyhl expert could have erred in this fashion.

3.2. TRANSPORT AND DIFFUSION MODELS

The atmospheric transport and diffusion models referenced in the Whyl Report analyses were given in detail in the Interior Ministry document[13]. Strict adherence to the procedures of the guide was implied to the degree that it appeared superfluous to present or repeat the content. Unfortunately, the component applications of the model were never presented.

The guide has a basic premise that is generally acceptable. In later sections of this chapter, the development of the models common to US and FRG regulatory guides are presented. Given the starting point of the Ministry guide, the basic diffusion equation assumes a Gaussian distribution in the horizontal (crosswind) and vertical plane with total reflection off the ground. This model is referenced from Slade[11] and given in the form:

$$\bar{\chi}_{(x,y,z)} = \frac{\bar{Q}}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-h_e)^2}{2\sigma_z^2}\right]\exp\left[-\frac{(z+h_e)^2}{2\sigma_z^2}\right]\right\} \quad (3\text{-}1)$$

where

$\bar{\chi}_{(x,y,z)}$	is the time averaged concentration at location (x,y,z)
$\bar{Q}$	is the rate of material being released
σ_y, σ_z	are the plume spread parameters or the standard deviation of the distribution of material in the y- and z-directions.
$\bar{u}$	is the mean wind speed in the along wind direction, x.
h_e	is the effective height of release above the ground

The guide continues in the development of short-term dilution factor as a ground level concentration along a plume centerline of the form:

$$\bar{\chi}_{(x,0,0)} = \frac{\bar{Q}}{\pi\sigma_y\sigma_z\bar{u}} \exp\left(\frac{-h_e^2}{2\sigma_z^2}\right) \quad (3\text{-}2)$$

Likewise, the guide continues in the development of long-term dilution factor as as a ground level concentration with uniform lateral mixing; this form is commonly referred to as the sector spread equation:

$$\bar{\chi}_{(x,0)} = \frac{\left(\frac{2}{\pi}\right)^{1/2}\bar{Q}}{\frac{2\pi x}{N_s}\sigma_z\bar{u}} \exp\left(\frac{-h_e^2}{2\sigma_z^2}\right) \quad (3\text{-}3)$$

where

N_s	is the number of sectors considered in 360 degrees (2π radians), in the Wyhl Report this was 12.

The short-term model and the long-term model described as being used in the Wyhl Report are identical in theory to the basic models in the U.S. but that is where the similarity stops.

The application of the component elements of the two sets of models are unique from each other. Considerable differences can exist between the two applications of the same model; these differences are not cosmetic but rather require detailed investigation to determine sensitivity for various combinations of meteorological conditions.

POOR ORIGINAL

3.2.3 ASSUMPTIONS

The diffusion calculations performed in the Wyhl Report were in strict accordance with guidelines presented in the Ministry of the Interior document. This was the basis for excluding the procedure in the Report. The experts embodied a limited mixing adjustment to the procedure, but otherwise accepted the recommendations of the guidline document. The experts proceeded to criticize the model in a fashion which sheds considerable doubt on their attempt for realistic or conservative evaluations. Specifically, the assumptions with which they take issue are:

1. Gaussian distribution
2. Independence of meteorological parameters
3. Exclusion of turbulence factors

Within the introduction of the Ministry document exist several points which appear to have been ignored:

1. The guide represents the state of the art which can be readily applied
2. Allowance is made so that local feature characteristics can be incorporated
3. Flexibility to deviate from guide recommendations when position is substantiated.

The referenced document was intended for use as a guide, just as are the USNRC Regulatory Guide Series and IAEA Safety Guide Series.

For the near field evaluation, such as the distance to the peak projected at Wyhl (500 meters), there are over 25 years of tracer studies conducted in the field and wind tunnel studies conducted in the laboratory that support Gaussian concepts; various summary documents are available to show the progression of development 11,14,15,16,17. The staff presenting the Wyhl Report had every opportunity to develop or use any other modeling procedure that would be defensible. From a technical viewpoint, the Gaussian treatment is perhaps most appropriate with the limited meteorological data and skills identified. Local characteristics that may demonstrate that steady state conditions are inappropriate can be accomodated with adjustment factors for stagnation and recirculation that should be developed for the site they are to represent. Variable trajectory and other time dependent models are generally available, however, they are at the mercy of inadequate meteorological data bases.

The meteorological parameters incorporated in the diffusion calculation relate a condition or state of the atmosphere representative of the time scale sampled. If the time scale is one minute or one hour, there are representative values of wind direction and speed and estimates of atmospheric stability for that time frame. A diffusion calculation is based on the joint occurrence of these three parameters. Adjustments are accepted to vary sampling time and impact not only the measured variables, but the dispersion coefficients as well.

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Turbulence, whether thermally or mechanically induced, is implicit in the diffusion calculation. The determination of atmospheric stability is a function of the interaction between surface heating or cooling and ambient wind conditions. The existence of thermal turbulence or thermal stability is dependent on the vertical structure of the atmosphere and its ability to enhance or constrain the growth of a parcel of air. Mechanical turbulence is a function of wind speed and localized features which deforms uniform flow. These factors are expressly incorporated in a steady state model by virture of the plume spread parameters assigned by stability class determinations.

At a minimum, a diffusion calculation however short term or long term, must have appropriate meteorological data. Without the ability to represent the flow of the effluent (direction), the rate of transport of the effluent (speed), and the growth or dispersal of the effluent (plume spread a function of stability), in concert, there is no calculation.

3.2.4 DISCUSSION OF RESULTS

The concern raised by the Wyhl experts regarding the independent treatment of meteorological parameters is warranted. We express the same concerns. The short-term and long-term models of the Ministry of the Interior document can [illegible] be applied with meteorological data that represents the coincidence of the various parameters. From the information presented we can only conclude that this information was unavailable and consequently directed the Wyhl experts to use the gross approximation presented in the Ministry document.

In an attempt to do more than just state that there is insufficient information to evaluate the Wyhl Report methodology, for that is truly the case, the following is based on conjecture. Until direct interrogation of the expert (we cannot determine the diffusion specialist from the contribution list) can be accomplished or merely a detailed synopsis of the application of the model is obtained, we can only, at best, conject as to the source of their estimate of 1.4×10^{-6} s/m^3.

The simplified determination of the long-term diffusion factor outlined in the Ministry document is based only on a wind direction distribution. An assumed stability and windspeed that is representative of the long-term concentration can be reconstructed in this fashion. For example, from Appendix 13 of the Ministry document, reproduced here in Figure 3-1, for a release height of 100 meters and a downwind distance of 500 meters, the relati[illegible] concentration was estimated as 2.2×10^{-6} s/m^3. Given the following equati[illegible] based on 12 sector segmentation:

$$\bar{\chi}_{(x,0)} [illegible] \frac{\left(\frac{2}{\pi}\right)^{1/2}}{\frac{2\pi x}{12}} \frac{\bar{Q}}{\sigma_z \ \bar{u}} \exp\left(\frac{-h_e^2}{2\sigma_z^2}\right) \qquad (3-4)$$

with the σ_z [illegible]ermined form information provided from Appendix 11 (σ_z = 43 meters for [illegible] 25 meters for E), reproduced here in Table 3-1, the $\left(\frac{\chi u}{Q}\right)$ for D stability is $4.7 \times 10^{-6} m^{-2}$ and for E stability $4.1 \times 10^{-8} m^{-2}$. Attendant wind speeds to relate this to the $\left(\frac{\bar{\chi}}{Q}\right)_{(500,0)}$ of 2.2×10^{-6} s/m^3 yield speeds of 2.1 m/sec for D stability and 0.[illegible] m/sec for E stability. This presumes the wind direction for the enitre year is univariate; ie, 100% within a single 30° sector. These wind speed/stability class combinations are rather conservative when considering the anticipated wind frequency distribution and stability class frequency distribution that could be experienced in the site area. It is also of note that these speeds would be representative of the 100 meters release height not that of the surface level (~10 meters).

A complicating factor which could not be resolved during the review, is the source of the estimate at the point of maximum radiation load (1.41 x 10-6 s/m³). It was concluded that the meteorological data were inadequate to perform a rigorous diffusion calculation, therefore, strictly following the Ministry guide, it should have been assumed that this simplified method was adopted. It was not.

As discussed in Section 3.2.1, the meteorological data was unavailable in the form needed for the calculation. However, there are several factors that imply that the Wyhl expert attempted to calculate relative concentration using the independent statistics for the three parameters: atmospheric stability, wind direction, and speed. It is reiterated again that this approach is in error.

The factors providing this conclusion are:

1. their conclusion that the diffusion calculation was based on independent parameter statistics

2. the pattern of the concentration isopleths with a relative secondary peak

The NRC attempted to perform a calculation which reproduced these estimates based on the 12 class wind direction frequency at Bremagarten with an isotropic treatment of calms, the 6 stability class distribution at Freiburg, and the 6 wind speed class distribution at Bremgarten. The dispersion coefficients of Vogt, the wind speed class midpoints of .75, 2.5, 4.4, 6.7, 9.4, and 12.1 meters/second adjusted to a 100 meter release height by stability class, and no plume rise were considered in the calculation. The estimated peak and location were comparable to that presented in the Whyl Report. Differences could have resulted from the stratification of the wind speed classes and other assumptions that were not presented.

The peak X/Q in the Wyhl Report of 1.4×10^{-6} sec/m³ cannot be related to an appropriate X/Q for the site. The high frequency (27.39%) of wind direction within a single sector is disturbingly high. Sites in the U.S. rarely have as much as a 20% frequency within a single 22.5° sector. The uniform application of wind speed frequency and atmospheric stability across this sector provides misleading information. Should a X/Q be calculated correctly, the peak value in the Wyhl Report could not have been remotely approached.

Should the following discussion be representative of the procedure that the Wyhl Experts followed, the review must conclude that the X/Q estimates are worthless. In effect, the treatment of parameter independence provides sufficient latitude to simulate extremely stable or unstable atmospheres with wind speeds in excess of 10 m/s or a neutral atmosphere (considerable mechanical turbulence) in a calm environment. The atmosphere just does not function this way.

Just considering the incidence of the most frequently occurring condition (wind direction and speed and atmospheric stability) if in fact the parameters were independent: wind direction from 210° for 27.39%, wind speed less than 1.5 m/sec 41.7% and atmospheric stability class D 29.0%. This element of the matrix (210, <1.5, D) has a "joint" frequency of 3.3%. The stability categorization scheme of Pasquill indicates that D stability can occur during the daytime only with winds in excess of 5 m/s and during the nighttime with winds in excess of 3 m/s. The likelihood of the joint occurrence of the three parameters by definition is 0.

The two tables in the Wyhl Report identifying stability and wind speed frequency of occurrence (see Table 3-2) are difficult to reconcile. Since the maximum wind speed of A, B, E, and F stability are 2, 5, 5, and 3 m/s, respectively, Beaufort class 4 and above windspeeds (5.5 m/s or greater) must be stability classes C and D. Classes C and D comprise 45.6% of the stability frequency; Beaufort 4 and greater make up only 19.2% of the frequency at Bremgarten and
13.8% at Freiburg. Adding in Beaufort 3 yields only 37.1%
and 28.5%. Surely, some understanding of diffusion concepts could have eliminated the impossible combinations.

The Wyhl expert resolved that the low wind speed frequency of occurrence coincided with the frequency of inversion conditions. For a stack release of the order of 100 meters, the location of the peak concentration of conditions with D stability is of the order of 5 x 10^2m, for E stability it is of the order of 2 x 10^3m, and for F stability of the order of 5 x 10^3m. The peak hourly $\left(\frac{\chi u}{Q}\right)$, relative concentration normalized by wind speed, are of the order of 10^{-5} to 10^{-6} m^{-2} or less; given that the frequency of hours for which a small fraction of the 8760 hours in a year could occur with the same meteorological conditions, the χ/Q could only be of the order of 10^{-7} to 10^{-8} s/m^3. The peak value could be overestimated by an order of magnitude or more.

3.3 GENERAL DESCRIPTION AND TECHNICAL BASIS FOR THE NRC ATMOSPHERIC TRANSPORT AND DIFFUSION MODELS

To simplify the discussion of atmospheric transport and diffusion models which are generally acceptable to the NRC, the least complex model will be discussed. (ie, derivatives of the Gaussian distribution) Realizing that the time dependent models would require a sophisticated set of meteorological information that was apparently unavailable for use in the Wyhl Report, it would be fruitless to discuss them in great detail. The Gaussian models generally provide reasonable estimates of concentration in flat and gently rolling terrain with a minimum amount of meteorological data. Incorporating factors to represent local stagnation and recirculation characteristics of valley and coastal locations, the model assures conservatism. The characteristic building shapes and dimensions and different release points representative of nuclear power plants have influenced the selection, development, or acceptance of several modeling concepts. The derivation of the generic formulation is presented first, followed by the calculational procedures of various elements of the long- and short-term models, and, finally, the application of modeling results to address the objectives of the calculation.

3.3.1 GENERIC DIFFUSIONS EQUATIONS

The traditional Gaussian formulation or distribution forms the basis for the simplistic short- and long-term transport and diffusion models. Several assumptions are incorporated into the Gaussian version to yield the versions considered for the evaluation of dilution factors. A consolidated outline of this derivation follows which clearly defines the assumptions. The development of the model is found in many other locations.[11,12]

The initial Gaussian formulation under consideration is that for an instantaneous point source release; i.e., single discrete puff. This is given in the form:

$$\chi_{(x,y,z)} = \frac{Q\,(2\pi)^{-3/2}}{\sigma_x \sigma_y \sigma_z} \exp\left\{-\left[\frac{(x-\bar{u}t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right]\right\} \quad (3\text{-}5)$$

where

$\chi(x,y,z)$ is the instantaneous concentration at a point at or along wind (axial) distance, x, cross wind distance, y, and vertical distance, z,

Q is the total amount of material released,

$\sigma_x\ \sigma_y\ \sigma_z$ are the plume spread parameters or standard deviation of the distribution of material in the x-, y-, z-directions,

$\bar{u}$ is the mean wind speed in the along wind direction, x,

t is time.

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In order to obtain the continuous point source formulation, the plume is presumed to be composed of an infinite number of overlapping puffs along the x-axis, transported by the mean wind, $\bar{u}$. By incorporating a simplifying assumption that diffusion can be neglected along the plume axis and by integrating with respect to t from 0 to ∞, given that $t = \frac{x}{\bar{u}}$, the continuous point source formulation is derived:

$$\bar{\chi}_{(x,y,z)} = \frac{\bar{Q}}{2\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right)\right] \qquad (3\text{-}6)$$

where

$\bar{\chi}_{(x,y,z)}$ is the time averaged concentration at location (x, y, z)

$\bar{Q}$ is the release rate of material

In this steady-state formulation a Gaussian relationship is still apparent in the crosswind and vertical directions. In order to accomodate the effect of a barrier afforded by the earth's surface, the assumption is made that the plume is reflected at the surface yielding the form:

$$\bar{\chi}_{(x,y,z)} = \frac{\bar{Q}}{2\pi \sigma_y \sigma_z \bar{u}} \exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-h_e)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+h_e)^2}{2\sigma_z^2}\right]\right\} \qquad (3\text{-}7)$$

where h_e is the effective height of release above the ground

The objective of these calculations is to provide estimates of concentration at ground level, i.e., when z=0. This yields:

$$\bar{\chi}_{(x,y,0)} = \frac{\bar{Q}}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{h_e^2}{2\sigma_z^2}\right)\right] \qquad (3\text{-}8)$$

At this point, the derivation diverges to present the development of the short-term model and long-term model. The initial discussion deals with the short-term model development and the final discussion with the long-term.

The present form of the equation when considered for the short-term application assumed the wind direction within a sector, 22.5° for U.S. and 30° for the Wyhl Report, is directed along the centerline. This is a conservative assumption in that the probability that the receptor will be on the centerline when the flow is toward the sector is rather small. A centerline concentration; i.e., y=0; estimated from an elevated continuous point source would be of the form:

$$\bar{\chi}_{(x,0,0)} = \frac{\bar{Q}}{\pi \sigma_y \sigma_z \bar{u}} \exp\left(-\frac{h_e^2}{2\sigma_z^2}\right) \qquad (3\text{-}9)$$

Similarily, should the centerline concentration be estimated from ground based source, the calculation would be made using a form of the following equation:

$$\bar{\chi}_{(x,0,0)} = \frac{\bar{Q}}{\pi \sigma_y \sigma_z \bar{u}} \quad (3\text{-}10)$$

Additional concepts incorporating the building wake effects, plume spread, and topography are considered in the evaluation of short-term concentrations.

Returning for the derivation of the long-term model, to incorporate the variance of mean wind conditions within the area of interest, the objective was to uniformly spread the plume over an arc of a given width. This concept incorporates the meander of the plume centerline within the sector of concern. The formulation is referred to as the crosswind integrated diffusion equation and is obtained by integrating with respect to y from $+\infty$ to $-\infty$ which yields:

$$\bar{\chi}_{(x,0)} = \frac{\left(\frac{2}{\pi}\right)^{1/2} \bar{Q}}{\sigma_z \bar{u}} \exp\left(-\frac{h_e^2}{2\sigma_z^2}\right) \quad (3\text{-}11)$$

To segment the calculation for evaluation on a sector basis at a given distance, x, from the source, the length of the arc or width of the sector at distance x is incorporated:

$$\bar{\chi}_{(x,0)} = \frac{\left(\frac{2}{\pi}\right)^{1/2} \bar{Q}}{\frac{2\pi x}{N_s} \sigma_z \bar{u}} \exp\left(-\frac{h_e^2}{2\sigma_z^2}\right) \quad (3\text{-}12)$$

where,

N_s is the number of sectors considered in 360 degrees (2π radians), in the U.S. This is generally 16, in the Wyhl Report this was 12.

The Gaussian characteristic has been removed from the crosswind plane, but still remains in the vertical. In this form the entire sector width is assumed to experience a uniform concentration in the average incorporating wind variability within the sector. This form of the model is similar to the form addressed in the USNRC Regulatory Guides; that is:

$$\bar{\chi}_{(x,0)} = \frac{2.032 \, \bar{Q}}{x \, \Sigma_z \, \bar{u}} \exp\left(-\frac{h_e^2}{2\sigma_z^2}\right) \quad (3\text{-}13)$$

where

Σ_z is the verical plume spread parameter adjusted for source configuration.

Source characteristics and plant configuration should be considered in the practical application of this model. These concepts include building wake effects, plume rise, stack downwash, plume spread, topography, and removal mechanisms.

In any application of these models it is incumbent that the quality of the meteorological data be assured. Guidelines for acceptable onsite meteorological data collection programs are provided in the USNRC regulatory guides[4], ANSI standards,[8] and IAEA Safety Guides.[9] Locations not having this level of sophistication are generally advised on alternative sources of data or acceptable adjustments to provide a margin of safety on the estimates. As the quality and representativeness of the information decrease, so the usefulness and applicability of the estimates decrease.

3.3.2 LONG TERM MODEL

The long-term diffusion model[9] presented is the constant mean wind direction model. The version presented in section 3.3.1 is that which is appropriate for use when the meteorological data are in the form of hourly data. In the event only joint frequency information is available, the formulation presented in USNRC Regulatory Guide 1.111 is generally accepted.

The equation for this model is:

$$(\overline{\chi/Q'})_D = 2.032 \sum_{ij} \frac{n_{ij}}{N \times \Sigma_{zj}(x)\, \bar{u}_i} \exp\left[\frac{-h_e^2}{2\sigma_{zj}^2(x)}\right] \qquad (3\text{-}14)$$

h_e is the effective release height

n_{ij} is the length of time (hours of valid data) weather conditions are observed to be at a given wind direction, windspeed class, i, and atmospheric stabiliti class, j;

N is the total hours of valid data

$\bar{u}_i$ is the mid point of wind speed class, i, at a height representative of release;

x is the distance down wind of the source;

$\sigma_{zj}(x)$ is the vertical plume spread without volumetric correction at distance, x, for stability class, j;

$\Sigma_{zj}(x)$ is the vertical plume spread with volumetric correction for a release within the building wake cavity, at a distance, x, for stability class, j; otherwise $\Sigma_{zj}(x) = \sigma_{zj}(x)$;

$(\overline{\chi/Q'})_D$ is the average effluent concentration, $\bar{\chi}$, normalized by source strength, Q', at distance, x, in a given downwind direction, D; and

2.032 is $(2/\pi)^{1/2}$ divided by the width in radians of a 22.5^0 sector.

Effects of spatial and temporal variations in airflow in the region of the site are not described by the constant mean wind direction model. Unlike the variable trajectory models, the constant mean wind direction model can only use meteorological data from a single station to represent diffusion conditions within the region of interest. If the constant mean wind direction model is to be used, airflow characteristics in the vicinity of any site should be examined to determine the spatial and temporal variations of atmospheric transport and diffusion conditions and the representativeness of single station meteorological data at receptors considered.

$$E_t = 2.58 - 1.58\,R \quad \text{for} \quad 1 < R \leq 1.5 \tag{3-16}$$

and

$$E_t = 0.3 - 0.06\,R \quad \text{for} \quad 1.5 < R \leq 5.0 \tag{3-17}$$

The release should be considered to be elevated $100(1-E_t)$ percent of the time, and 100 E_t percent of the time it should be considered to be ground based. For the meteorological conditions, both calculations should be performed, adjusted by the fraction of release mode and summed to represent the contribution at the receptor point.

Other methods or relationships[21] that may represent a given facility more appropriately should be presented with justification for the alternate approaches.

3.3.2.1 BUILDING WAKE EFFECTS

For ground level releases an adjustment to model identified in the previous section can be made that takes into account the initial dispersion in the wake of a solid structure. This adjustment could be in the form

$$\Sigma_z = \left(\sigma_z^2 + \frac{H^2}{2\pi}\right)^{1/2} \tag{3-18}$$

where

Σ_z is the vertical plume spread parameter adjusted for source configuration

H is the maximum solid adjacent structure height.

This adjustment is limited to a maximum of $\sqrt{3}$ or:

$$\Sigma_z \leq \sqrt{3}\,\sigma_z \tag{3-19}$$

3.3.2.2 PLUME RISE AND AERODYNAMIC EFFECTS

Effluents released from stack sources generally have sufficient vertical velocity or potential for rise, i.e., a positively buoyant plume, to warrant a plume rise consideration. Most releases from nuclear power stations have effluent temperatures comparable to that of the ambient air. The practice generally followed is based on the Briggs formulation for momentum induced plume rise.[22]

For neutral or unstable atmospheric conditions the equation considered is of the form:

$$\Delta h = 1.44 \left(\frac{w_o}{\bar{u}_h}\right)^{2/3} \left(\frac{x}{D}\right)^{1/3} D \qquad (3\text{-}20)$$

where

- Δh is the plume rise (meters)
- w_o is the effluent exit velocity (meters/second)
- $\bar{u}_h$ is the mean wind speed at the height of release (meters/second)
- x is the downwind distance (meters)
- D is the internal stack diameter (meters)

When the effluent exit velocity to ambient wind speed ratio is less than 1.5, the effects due to aerodynamic stack downwash are incorporated into the plume rise estimation in the form:

$$c = 3 \left(1.5 - \frac{w_o}{\bar{u}_h}\right) D \qquad (3\text{-}21)$$

where

- c is the downwash substracted from Δh above

The plume rise estimated and adjusted, if necessary, is compared with the following equation and the lesser of the two estimates are used:

$$\Delta h = 3 \left(\frac{w_o}{\bar{u}_h}\right) D \qquad (3\text{-}22)$$

For stable atmospheric conditions, the same procedure is followed, however, the lesser of yet two more formulations results in the estimate of plume rise. These formulations follow:

$$\Delta h = 4 \left(\frac{F_m}{s}\right)^{1/4} \qquad (3\text{-}23)$$

and

$$\Delta h = 1.5 \left(\frac{F_m}{\bar{u}_h}\right)^{1/3} s^{-1/6} \qquad (3\text{-}24)$$

where

$$F = \left(\frac{w_o D}{2}\right)^2 \qquad (3\text{-}25)$$

and

$$s = \frac{g}{T} \frac{\partial \theta}{\partial z} \qquad (3\text{-}26)$$

where

F_m is the momentum flux parameter (meters^4/seconds^2)

s is the restoring acceleration per unit vertical displacement for adiabatic motion in a stratified atmosphere (seconds^{-2})

g is the gravitational acceleration (meters/seconds^2)

T is the ambient air temperature (^oK)

$\frac{\partial\theta}{\partial z}$ is the vertical potential temperature gradient (^oK/meter)

In an unstable atmosphere s is negative, however, for the various stable stability classes, s can be held constant. The values assumed are 0.87 x 10^{-3} for E stability, 1.75 x 10^{-3} for F, and 2.45 x 10^{-3} for G.

There are numerous other plume rise formulations that have been proposed and more closely reflect conditions at a elected number of locations. However, no other set of formulations have gained the general acceptance in the community as those detailed. Should a more representative method be identified and supported for a given location, the flexibility exists to accomodate a more appropriate technique.

3.3.2.3 PLUME SPREAD

The traditional Pasquill-Gifford dispersion coefficients for σ_z are given in Figure 3-2 . Should the selected model be other than the constant mean wind direction model additional curves to represent lateral dispersion may be needed. Likewise in unique environs alternate curves may be deemed more appropriate. The applicant would be expected to demonstrate the applicability of any deviation from the traditional set of curves.

3.3.2.4 TERRAIN EFFECTS

The treatment of terrain effects an the effective stack height provides opportunities to consider plume deformation and deflection when encountering significant terrain displacements. The effective stack height is determined from:

$$h_e = h_s + \Delta h - c - h_t \qquad (3\text{-}27)$$

where

h_s is the physical stack height

h_t is the terrain height adjustment

Δh and c are the plume rise and aerodynamic stack downwash considered earlier.

The NRC treatment considers the most conservative case in its calculations; this assumption presumes that the terrain at the receptor is represented by the maximum elevation between the source and the receptor. At the elevation where $h_t = h_s + \Delta h - c$, the calculation reverts to a nonwake adjusted ground level sector spread calculation. This may produce extremely conservative estimates in the near field with rapid rises in elevation. Likewise, with the presence of a single ridge followed by lowlying areas, the ridge height would be used for estimation purposes. This treatment is illustrated in Figure 3-3 .

Alternative acceptable methods include that of the half height terrain concept[23] during unstable and neutral conditions and the "valley" concept[24] during stable conditions. These two methods are illustrated in Figures 3-4 and 3-5 , respectively.

In simple terms, the half height concept minimizes the effective stack height to one half the value of the equilibrium effective stack height in flat terrain when the terrain height is above the computed equilibrium height. In those cases where the terrain height is below the equilibrium height, the effective stack height is the equilibrium stack height minus ½ the terrain height. All heights are considered relative to the stack base elevation. Following this concept the centerline height may after impacting terrain increase in height above terrain back to a maximum of the equilibrium height. It is assumed that under unstable and neutral conditions the plume remains a minimum of one half of the equilibrium plume height over flat terrain away from the surface.

The valley concept is a bit more complex, but represents a concept more appropriate than direct plume impaction with no deflection. The underlying concepts of valley assure that under stable conditions the plume will have a tendency to be deflected upward and to the side. Deflection of the plume by terrain during stable conditions is accomplished by the attenuation of concentration with height in the affected sector. This is accomplished by applying a factor based on the receptor elevation and the equilibrium height of the plume over flat terrain. The factor assumes the entire plume will be attenuated at a 400 meter displacement above the initial centerline height. On the leeward side of the hill, the NRC will consider the plume to reform as terrain decreases to the point where the centerline may lift off the 10 meter minimum to impact terrain again.

It should be noted that the valley treatment may result in discontinuties in concentration isopleth patterns where significant terrain displacements are located almost resembling what would be expected in a variable trajectory or time dependent model. Therefore, the applicant would have to demonstrate the applicability of these concepts to ensure that the dilution factors are not substantially underestimated; viz, box canyon.

3.3.2.5 REMOVAL MECHANISMS

3.3.2.5.1 Deposition

Dry deposition of elemental radioiodines and other similar releases are incorporated into the NRC model. The remaining material considered to be suspended in a depleted plume is determined by extracting the material deposited from the undepleted plume. The assumptions and simplifications incoporated in this aspect of the model were summarized earlier and are included in Enclosure E1. To incorporate these two factors into the model a series of curves were prepared which relate plume travel distance to relative deposition rate and plume depletion on a stability class basis.

To obtain the relative deposition per unit area at a given point in a given sector, the relative deposition rate must be adjusted by the arc length of the sector at the point being considered. Thus, the sector averaged deposition rate is determined as:

$$\frac{\overline{D}}{Q} = \frac{\left(\frac{\overline{D}}{Q}\right)_R}{\frac{2\pi x}{N_s}} \qquad (3\text{-}28)$$

where

$\overline{D}/Q$ is the sector averaged deposition rate

$(\overline{D}/Q)_R$ is the relative deposition rate obtained from the curves

x is the downwind distance from the source

Depletion factors can be taken directly from the curves with no adjustment as above as it would have been incorporated in the calculation of the relative concentration $\overline{X}/Q$.

The curves are given for release heights of 100, 60, 30, and 0 meters which are generally used to represent releases at greater than 80 meters, 45 to 80 meters, 15 to 45 meters, and less than 15 meters, respectively. The NRC treatment of topography assumes that after the equilibrium plume height is reached, the plume cannot get higher from the ground; it is assumed that the plume centerline height will either remain level to the ground, or it will approach it. Other approaches to the treatment of topography allow for adjustments in either direction based on atmospheric stability class. Because topography does change with distance, and likewise the vertical separation distance between the plume centerline and the ground will change, it is usually necessary to read from more than one deposition and depletion curve as the plume travels with distance.

The actual depletion to a point depends on the depletion rate based on the plume history prior to reading the point. Thus, an adjustment of depletion and deposition estimates must be made to account for this change in plume centerline height above ground and the plume's prior history.

To approximate the adjustment for deposition rate in changing terrain, the adjustment factor is determined for the crossover point (the point at which a new curve is read) as the ratio of the fraction remaining (depletion) from the old height curve to the fraction remaining from the new height curve. The deposition values beyond this point are multiplied by this ratio. As terrain changes continue, this ratio is adjusted to reflect the existing ratio leading to the crossover point and the two curves involved.

To approximate the adjustment for depletion of the plume, the adjustment factor is determined for the crossover point as the difference in value between the fraction remaining from the old height curve to the new height curve. This factor is then added to the value at the common distance for the new height curve.

Caution should be exercised when considering the adjustment to the deposition values when the deposition curves are at or near their peak. Discontinuities can arise which may distort the anticipated deposition rates.

In those areas that have a well defined rainy season or high incidence of fog corresponding to the grazing season (radioiodine pathways), the effects of wet deposition and attendant plume depletion should be evaluated for releases other than ground level.

Wet deposition or washout of the plume results in considerable depletion of the plume. The efficiency of removal of plume material during precipitation or fogging conditions is greater than that from settling in a dry atmosphere. However, most sites experience precipitation and fogging for a small portion of a long-term period and would result in a small additional fraction of the dry deposition.

3.3.2.5.2 DECAY

To incorporate radioisotope decay into the estimation procedure, an exponential decay factor can be determined from the isotope hal life under consideration. Conservative estimates of 2.26 days for noble gases and 8 days for radioiodines can be incorporated into the model. This takes the form:

$$D_h = \exp\left(\frac{-.69315\,x}{t_h\,\bar{u}}\right) \qquad (3\text{-}29)$$

where

D_h	is the decay factor applied to the relative concentration or depleted relative concentration (nondimensional)
x	is the downwind distance to the point being considered
$\bar{u}$	is the wind speed at release height
$\frac{x}{\bar{u}}$	is the time required to transport effluent to the point being considered
t_h	is the radioisotope half life
-.69315	is equivalent to ln(.50), therefore, if $\frac{x}{\bar{u}} = t_h$ the plume is expected to contain only half the material at the point of calculation that is started with at the source.

The appropriate X/Q or depleted X/Q is multiplied by the appropriate decay factor to consider the noble gases or radioiodines, respectively.

3.3.2.6 METEOROLOGICAL DATA

The appropriate meteorological data to be used in the long-term model are wind direction, wind speed, and a measure of atmospheric stability. The wind conditions must be representative of the release height. In the case of a ground level release, the data should be represenative of the 10 meter level. In the case of an elevated release the wind speed may have to be adjusted to the height of release. This may be accomplished using a power law relationship of the form:

$$\bar{u}_h = \bar{u}_m \left(\frac{h_s}{h_m} \right)^P \qquad (3\text{-}30)$$

where

$\bar{u}_h$	is the mean wind speed at the height of release
$\bar{u}_m$	is the mean wind speed measured at height, h_m
h_s	is the stack height of release above the ground.

In the case of calms, the wind direction should be assigned in proportion to the wind direction frequency of the lowest noncalm wind speed class by the atmospheric stability class. The wind speed should be assigned as one half the threshold speed of the anenometer or vane, which ever is higher, if the system conforms to a USNRC Regulatory Guide 1.23 system. Otherwise a value of 0.1 m/sec should be assigned as the wind speed for the observation.

3.3.3 SHORT-TERM MODEL

The short term diffusion models[7,8,10] presented in Section 3.3.1 are the generic version of the ground release mode and actual version for the elevated release. The ground release mode incorporates a factor for initial mixing of the plume in the wake of the reactor building; this factor can be considered an enhanced $\sigma_y \sigma_z$. Recently, this model has also incorporated the lateral meander characteristics observed under low wind speed neutral and stable conditions; this adjustment incorporates both the lateral meander (enhanced σ_y) with the building wake as the two factors are inseparable. The ground release models are presented in the section dealing with building wake.

3.3.3.1 BUILDING WAKE EFFECTS

The short-term model for a ground based centerline consideration was given in Section 3.3.1. This equation assumes that the plume material is release from a point and into an area that is hom--enously undisturbed. Most releases at nuclear power plants are through other building aperatures. These type releases would occur within an area affected by the plant complex.

The approach to accomodate the behavior of the plume through the wake cavity is to adjust the dispersion coefficients to simulate rapid mixing in the wake of buildings. Depending on the height of the release, the effluent can be mixed upward, if released near the ground, or downward, if released near the roof, or a combination of these factors. A formula was offered that estimated the enhanced mixing as a function of the building dimensions of the form:

$$\overline{\chi}_{(x,0,0)} = \frac{\overline{Q}}{(\pi \sigma_y \sigma_z + cA)\,\overline{u}} \qquad (3\text{-}31)$$

where

c   is a building shape factor

A   is the minimum cross-sectional area of the structure providing the displacement.

Intuitively, this shape factor was considered to be in the range of values between ½ and 2. Ultimately, wind tunnel tests supported this range of values. The ½ factor is used to be conservative.

The concern for the near field calculation of the order of tens of meters provided an inequity in this calculation for tracing back to the source the equation would reduce to:

$$\bar{\chi}_{(0,0,0)} = \frac{\bar{Q}}{cA\bar{u}} \qquad (3\text{-}32)$$

Based on observations and the facts in the literature, it is confirmed that the effluent does not mix immediately throughout the wake.

Based on dilution observations at the NRTS under comparable meteorological conditions, roughly a maximum of 3 times more dilution occurred in the building wake area than occurred in open terrain. A second equation was formulated to act as a limit on the first. This took the form:

$$\bar{\chi}_{(x,0,0)} = \frac{\bar{Q}}{3\pi \sigma_y \sigma_z \bar{u}} \qquad (3\text{-}33)$$

These two forms of the wake adjusted ground release model are used exclusively in the calculation under unstable conditions. The estimated relative concentration is taken to be the maximum of the two estimates.

For neutral and unstable conditions the same steps as above are followed, however, this maximum value is compared to yet another estimate and the minimum of the two estimates is used as that which represents the meteorological conditions.

This last representation incorporates the plume meander observed under low wind speed stable conditions. It is used to estimate the relative concentration for stable and neutral conditions when the wind speed is less than 6 m/sec. It is given in the form:

$$\bar{\chi}_{(x,0,0)} = \frac{\bar{Q}}{\pi \Sigma_y \sigma_z \bar{u}} \qquad (3\text{-}34)$$

where

Σ_y is the lateral plume spread parameter with meander and building wake effects.

Σ_y is a function of atmospheric stability, wind speed, and distance from the source.

3.3.3.2 PLUME SPREAD

The traditional Pasquill-Gilford dispersion coefficients for σ_z and σ_y as given in Figure 3-2 and Figure 3-6 are appropriate for most locations. Other diffusion curves may apply at sites under certain conditions. The applicant would be expected to demonstrate the applicability of any deviation from the traditional curves.

The adjustment factors for neutral and stable conditions to incorporate the combined effect of plume meander and building wake are given in Figure 3-7 as a function of atmospheric stability, wind speed, and distance from the source. For distances of 800 meters or less Σ_y is the product of σ_y and the meander correction factor, M. For distances greater than 800 meters,

$$\Sigma_y = (M-1)\,\sigma_{y_{(800)}} + \sigma_y \qquad (3\text{-}35)$$

3.3.3.3 TERRAIN EFFECTS

The treatment of terrain effects on the effective stack height is straight forward.. With no plume rise credit, the treatment is the most conservative method available. Essentially, the terrain height that represents the maximum elevation between the source and the receptor is substracted from the physical stack height. This application is illustrated in Figure 3-8. Once the terrain displacement equals or exceeds the physical stack height, a ground release equation is achieved but the wind speed at release height is still used.

The effects of an elevated release can exceed the effects of a ground release in the vicinity of a dramatic rise in terrain since plume meander and building wake factors are not experienced.

3.3.3.4 METEOROLOGICAL DATA

The appropriate meteorological data to be used in the short-term model are wind direction, wind speed, and a measure of atmospheric stability. The wind conditions must be representative of the release height. In the case of a ground level release, the data should be representative of the 10 meter level. In the case of an elevated release the wind speed may have to be adjusted to the height of release. This may be accomplished using a power law relationship of the following:

$$\bar{u}_h = \bar{u}_m \left(\frac{h_s}{h_m}\right)^p \qquad (3\text{-}36)$$

where

$\bar{u}_h$ is the mean wind speed at the height of release

$\bar{u}_m$ is the mean wind speed measured at height, h_m

h_s is the stack height of release above the ground

In the case of calms, the wind direction for the time period (i.e., 1 hour) should be assigned in proportion to the wind direction frequency of the lowest non calm wind speed class by the atmospheric stability class. The wind speed should be assigned as the threshold speed of the anemometer or vane, whichever is higher, if the system conforms to a USNRC Regulatory Guide 1.23 system. Otherwise, a conservative assignment of speed as a function of the equipment should be made.

3.3.4 APPLICATION OF DILUTION ESTIMATES

Arriving at the point of calculating a relative concentration does not in itself provide a result. The objective of the calculation must be established to ensure the representation of appropriate levels of conservatism have been applied to meet this objective. The application of results of diffusion calculations may be straightforward, such as the average, others may require significant manipulation to arrive at a level sufficiently conservative based on the safety implicaitons of the objective.

3.3.4.1 NORMAL (ROUTINE) RELEASES

The routine release calculation is outlined in considerable detail in the USNRC Regulatory Guide 1.111; portions of these procedures were abstracted and presented in the discussion of the long-term model. Essentially, there are three release modes that can be considered depending on the plant operation and configuration, mixed mode, and ground level. The form of the meteorological data (hourly or joint frequency table) can produce results that differ slightly due to the wind speed class stratification for summarizing the data and, in the mixed mode case, the level of met orological data used to represent the release.

Essentially the hourly or summary table matrix location (wind direction X wind speed X atmospheric stability class) is considered one value at a time based on the three joint parameter values for the impact at a receptor point. This calculation is repeated for every receptor location (direction and distance from the source) for either every hour, in which case the relative concentrations accumulate at each receptor through the end of the data record, or for every matrix location, in which case the relative concentration is multiplied by the frequency of occurrence of that 3 parameter event and then the values accumulate through the end of the data matrix. At the conclusion of this calculation the receptor matrix (distance X direction) is then divided by the total number of valid hours for the data record yielding the undepleted relative concentration.

Other factors are applied to this calculation after each hourly or matrix location relative concentration value is determined. These include:

1. Stagnation/Recirculation Factor

s. Deposition Factor

3. Depletion Factor

4. Decay Factor

It is also appropriate to consider multiple factor relationship such as a decayed and depleted relative concentration.

Essentially the values represent the total integrated relative concentration divided by the valid period of record.

POOR ORIGINAL

3.3.4.2 INTERMITTANT (PURGE) RELEASES

The purge release calculation is based on a two component evaluation using the long-term model. First, for those receptor locations to be considered calculate the routine release calculation as above and second, develop an hourly frequency distribution of relative concentration for the period during which the receptor location experiences the plume.

From the frequency distribution, the 15th percentile highest relative concentration is selected. The justification for the choice of the 15 percentile value is given in Enclosure E-2 . This value and the recirculation corrected average relative concentration are considered to form a relationship to provide intermittant release values for any purge release period. The relation ip assumes the average condition to represent
the average annual condition based on 8760 hours. A time vs concentration straight line curve on a log-log scale is then prepared basing the hourly value at the one hour position and the annual average at the 8760 hour position. As the averaging time increases, the recirculation factor gradually is introduced. This method is summarized and an example is presented in Enclosure E-3 . To approximate the appropriate depletion and deposition associated with the purge release period, the ratios between these values and the annual average are determined and applied to the relative concentration value.

3.3.4.3 ABNORMAL (ACCIDENTAL) RELEASES

The accidental release calculation is outlined in considerable detail in the USNRC Regulatory Guide 1.145, portions of these procedures were abstracted and presented in the discussion of the short-term model. The restrictions placed on using the elevated version of the short-term model, release point higher than nearest adjacent structure by a factor of 2.5, make it highly unlikely that the elevated mode would be used frequently. The discussion, therefore, will be geared toward the application for a ground level release.

The model outlined is a departure from the previous regulatory position provided in USNRC Regulatory Guides 1.3 and 1.4 which assumed a circular site boundary and omnidirectional 5 percentile highest relative concentration for the 0-2 hour accident condition. For the exclusion area boundary the model presently considers a direction dependent site boundary distance which is the minimum distance of the sector centerline plus and minus 1/2 sector to reflect the plume meander concept.

A frequency distribution of one hour relative concentrations using the methods

provided in section 3.3.3 at the adjusted site boundary distances should be constructed for each sector. From each of these distributions the relative concentration which is exceeded 0.5% of the time should be determined. The justification for the selection of the .5 percentile value is given in enclosures 4 and 5. This can be accomplished by developing a curve of probability vs relative concentration on a receptor/sector basis by taking the value associated with the esceedance probability level as below:

$$P_d\left(\frac{\bar{\chi}}{Q}\right) = \frac{N}{N_d} \cdot 0.005 \qquad (3\text{-}37)$$

where

$P_d\left(\frac{\bar{\chi}}{Q}\right)$ is the exceedance probability of the receptor/sector value representing the .5% value of the total time.

N is the number of valid hours in the data record

N_d is the number of hours the wind direciton was into the sector of interest.

one hour

An alternative to this method is to serially list the highest N*.005 values in each sector computed at the adjusted site boundary distance. Extracting the one value corresponding to this level presents the value of concern i.e., with 8760 valid hours, one must select the value corresponding to the 44th highest hour value. These values are termed the sector χ/Q values and the highest of these is considered the maximum sector χ/Q.

For the low population zone (LPZ) the concern is for accident periods of longer duration than the 0-2 hour period. Essentially, the calculation to determine the sector χ/Q values is identical as above, however, these values are related to their annual average counter_part at the same location, computed using the long-term model. The two hour values are graphed with the counter_part 8760 hour values for each sector location as a straight time on a log-log time vs χ/Q plot. Selected from these curves are the 8, 16, 72 and 624 hour values for each receptor point.

It should be noted that this treatment is similar for the elevated (nonfumigation) case. However, when relating the short-term estimates to the long-term the plume rise credit of the long-term model is not incorporated into the calculation of effective stack height.

The last procedure prior to establishing the limiting relative concentration at the exclusion area boundary and low population zone is the determination of the overall 5% χ/Q. For the exclusion area boundary, the ranked serial listing or distribution of all sector hourly relative concentrations (i.e., all 8760 hours in the year) is constructed to select the χ/Q value that is exceeded no more than 5% of the time. For the low population zone, the same procedure is followed, however, the χ/Q value selected is then related to the maximum of the annual average χ/Q's around the LPZ by a log-log time-vs-concentration plot to select the 8, 16, 72, and 624 hour χ/Q's that are exceeded no more than 5% of the time. These values are then compared with the maximum sector χ/Q values, the higher of the two values is then considered for the accident evaluations.

3.4 RECOMMENDED REVISIONS TO THE USNRC ATMOSPHERIC TRANSPORT AND DIFFUSION MODEL

There are no justified changes to the present [illegible] to the NRC nor recommendations for same as a result of information presented in the Wyhl Report. The development of techniques presented in the regulatory guides are issued to provide acceptable methods of implementing the Commission's regulations; regulatory guides are not regulations. The NRC staff maintains a flexible stature on evaluating applications on their own merits. As improvements in the state of the art become evident and warranted, the guides will be revised to accomodate advancements and suggestions on improvement.

The bases for the models referenced in the Wyhl Report are identical to those of the basic models generally acceptable to the NRC. However, the evaluation of the components are different. These differences may result in significantly differing results under given combinations of meteorological conditions. A comparative summary of the model components is given in Table 3-3.

With respect to the traditional Gaussian applications as dealt with in this review, advances are not radical nor fast tracked. Field and wind tunnel tests are providing more diverse information regarding mesoscale and microscale effects; as each case warrants, consideration will be given to upgrade the guide's recommendations.

With respect to the Wyhl Report, there is sufficient information pre ented herein for their experts to consider reevaluating the approach taken.

TABLE 3-1

Diffusion coefficients p_y, q_y, p_z and q_z as a function of diffusion category and emission height

The diffusion coefficients for 50 m shall be used for emission heights < 75 m, those for 100 m for emission heights ≥ 75 m.

$$\sigma_y = p_y \cdot x^{q_y}$$
$$\sigma_z = p_z \cdot x^{q_z}$$

Emission Height	Diffusion Category	Diffusion Coefficient			
		p_y	q_y	p_z	q_z
50 m	A	0.369	0.810	0.222	0.968
	B	0.369	0.810	0.222	0.968
	C	0.718	0.734	0.215	0.944
	D	0.625	0.767	0.205	0.936
	E	1.691	0.621	0.162	0.809
	F	5.382	0.578	0.396	0.618
100 m	A	0.229	1.003	0.097	1.158
	B	0.227	0.970	0.155	1.024
	C	0.224	0.938	0.247	0.890
	D	0.222	0.905	0.398	0.765
	E	1.691	0.621	0.162	0.809
	F	5.382	0.578	0.396	0.618

TABLE 3-2 3-29
METEOROLOGICAL INFORMATION FROM
THE WYHL REPORT

Distribution of the diffusion categories in the upper Rhine Valley (relative proportions at each station)

Diffusion Type	Very unstable	Slightly unstable	Indiff. Unstable	Indiff. stable	Stable	Very stable	Total
After Pasquill	A	B	C	D	E	F	
After Klug	V	IV	III 2	III 1	II	I	
Freiburg	0.021	0.150	0.166	0.290	0.191	0.182	1.000
Karlsruhe	0.022	0.074	0.139	0.397	0.218	0.150	1.000
Breisach	0.075		0.588		0.337		1.000

Comparison of the wind speeds according to the Beaufort wind scale. Frequency of occurrence per Beaufort force in %.

wind speed	in Beaufort	0, 1	2	3	4	5	6
	in m/sec	up to 1,5	1,6-3,3	3,4-5,4	5,5-7,9	8,0-10,7	>10,7
Bremgarten		41,7	21,2	17,9	12,8	5,1	1,3
Freiburg		41,2	30,3	14,7	9,5	3,3	1,0

Comparison of the wind roses of Breisach and Bremgarten in %

Wind Direction			East			South			West			North
sector	30	60	90	120	150	180	210	240	270	300	330	360
Brem-garten	9,35	2,97	2,84	1,09	3,94	12,19	25,98	6,22	2,85	1,52	5,50	8,62
Brei-sach	20,1		4,4		6,3	30,6	14,2		4,5		5,7	14,0

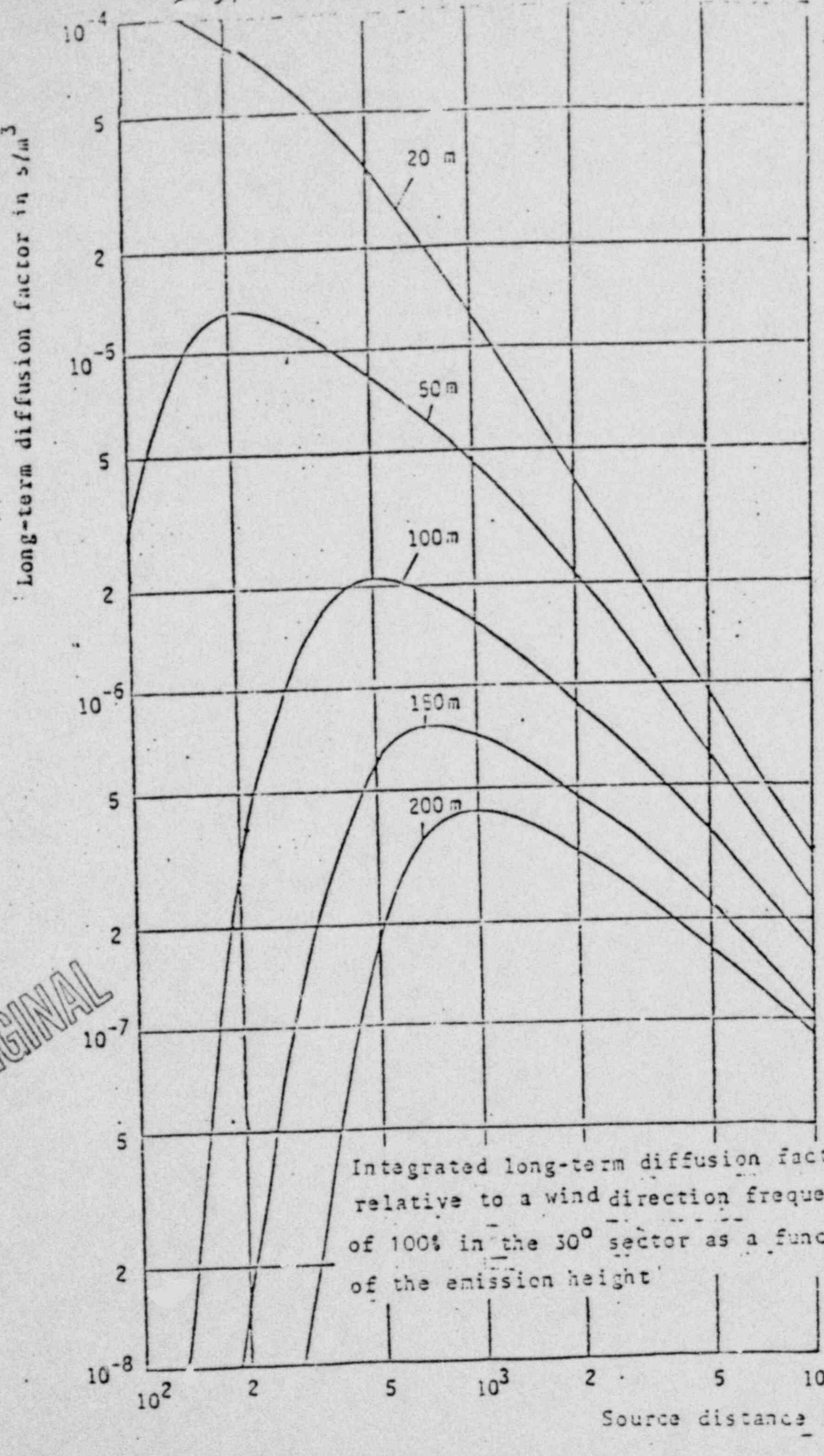
POOR ORIGINAL

TABLE 3-3

Summary of Model Components

		Wyhl	US
1.	Short-term Model	Centerline	Centerline
	a. Plume Rise	yes	no
	b. Fumigation	no	yes
	c. Building Wake	no	yes
	d. Plume Spread	Vogt - release height dependent	Pasquill-Turner
	e. Topography	unknown	yes
	f. Plume Meander	no	yes-neutral & stab
	g. Velocity Profile	power law	power law
2.	Long-Term Model	Sector Spread	Sector Spread
	a. Plume Rise	yes	yes
	b. Building Wake	no	yes
	c. Aerodynamic Stack Downwash	no	yes
	d. Plume Spread	Vogt - release height dependent	Pasquill-Turner
	e. Topography	unknown	yes
	f. Mixed Mode Release	no	yes
	g. Sector Width	30^0	22.5°
	h. Velocity Profile	power law	power law

3-31



Integrated long-term diffusion factor relative to a wind direction frequency of 100% in the 30° sector as a function of the emission height

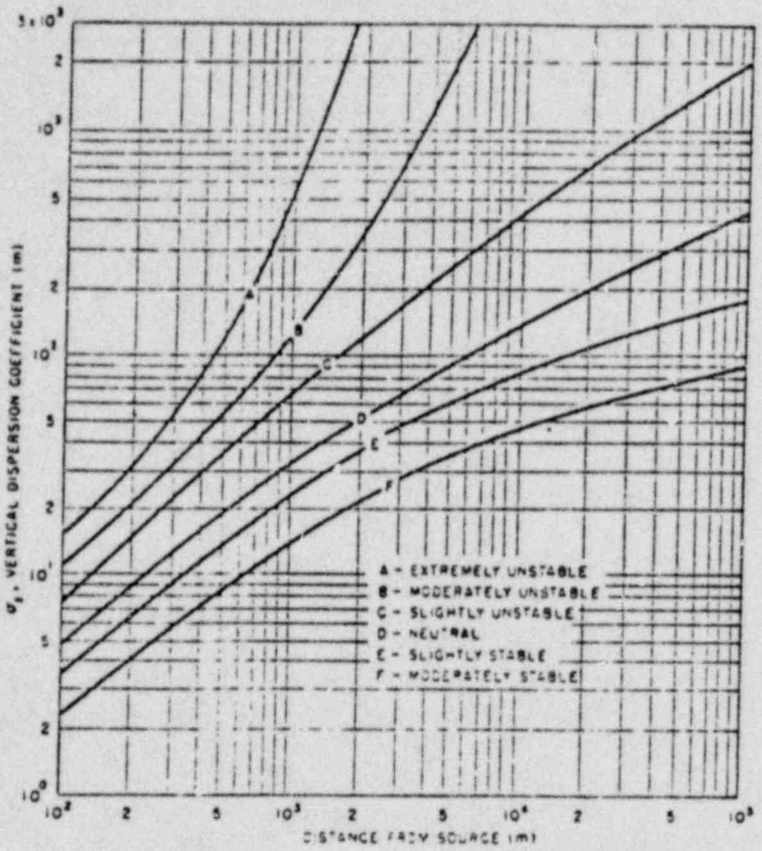


Figure 3-2 Vertical diffusion without meander and building wake effects, σ_z, vs. downwind distance from source for Pasquill's turbulence types (atmospheric stability)

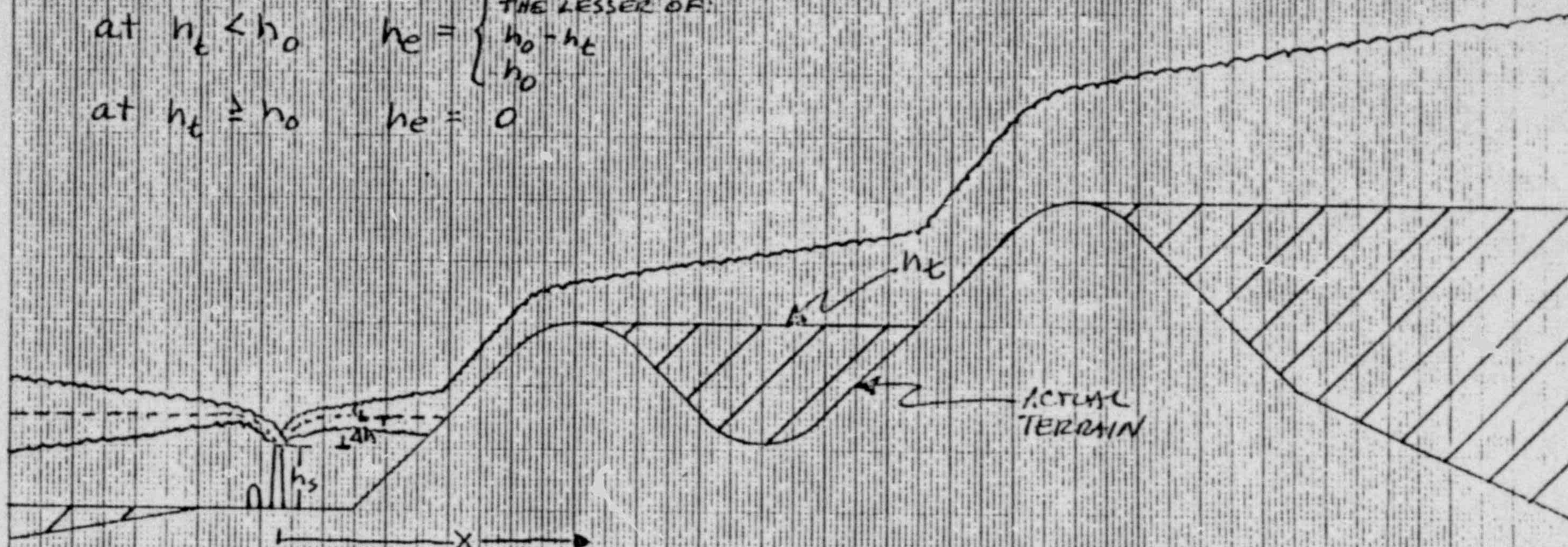
For purposes of estimating σ_z during extremely stable (G) atmospheric stability conditions, the following approximation is appropriate:

$$\sigma_z(G) = \frac{3}{5}\sigma_z(F)$$

$h_o = h_s + \Delta h$

at $h_t < h_o$ $\quad h_e = \begin{cases} \text{THE LESSER OF:} \\ h_o - h_t \\ h_o \end{cases}$

at $h_t \geq h_o$ $\quad h_e = 0$



h_e - effective stack height at X (℄)
h_o - equilibrium (flat terrain) effective stack height
h_s - physical stack height
Δh - plume rise
h_t - maximum terrain height between source and X

LONG - TERM MODEL
NRC TERRAIN TREATMENT
ALL STABILITY CONDITIONS

FIGURE 3-3

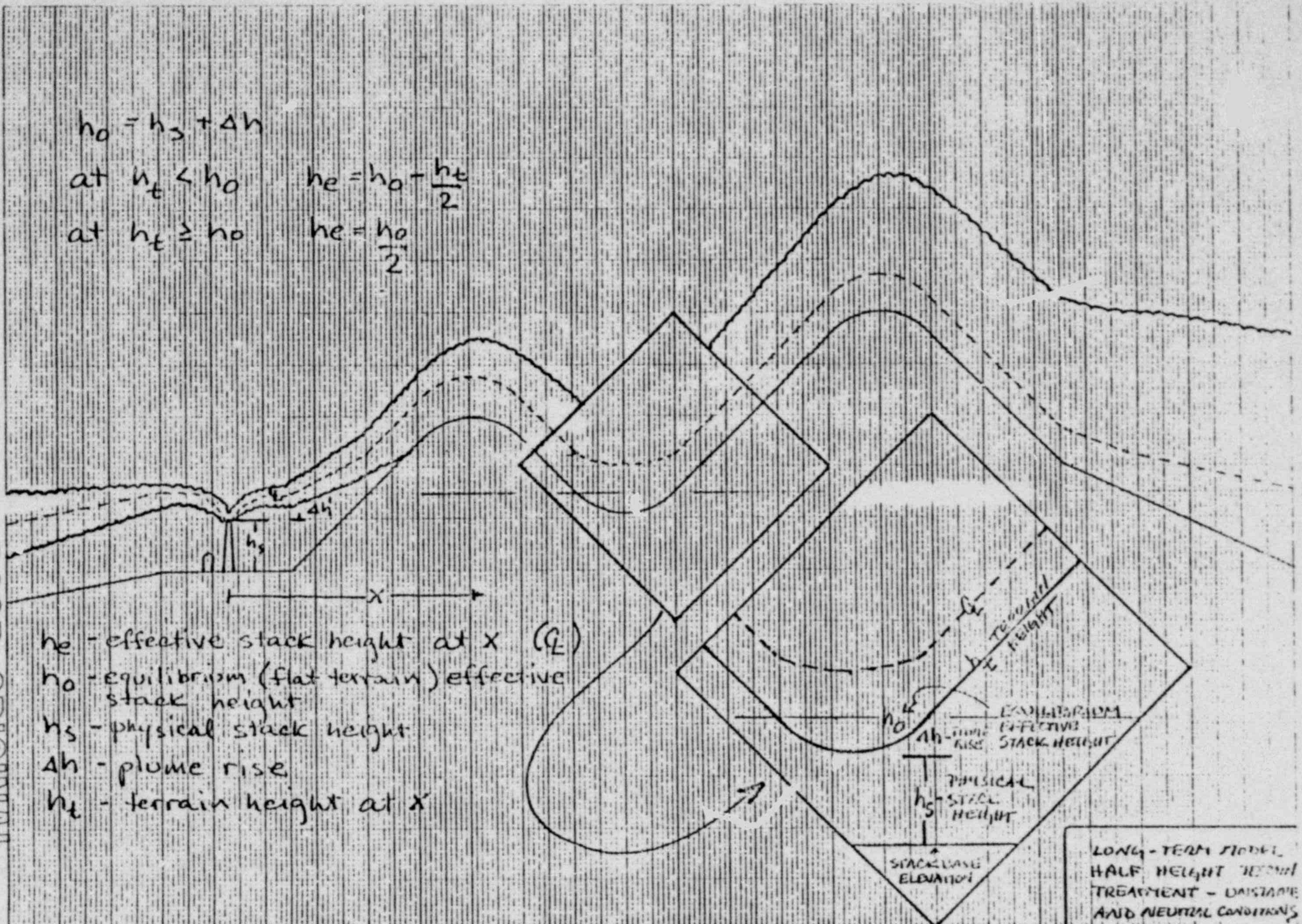
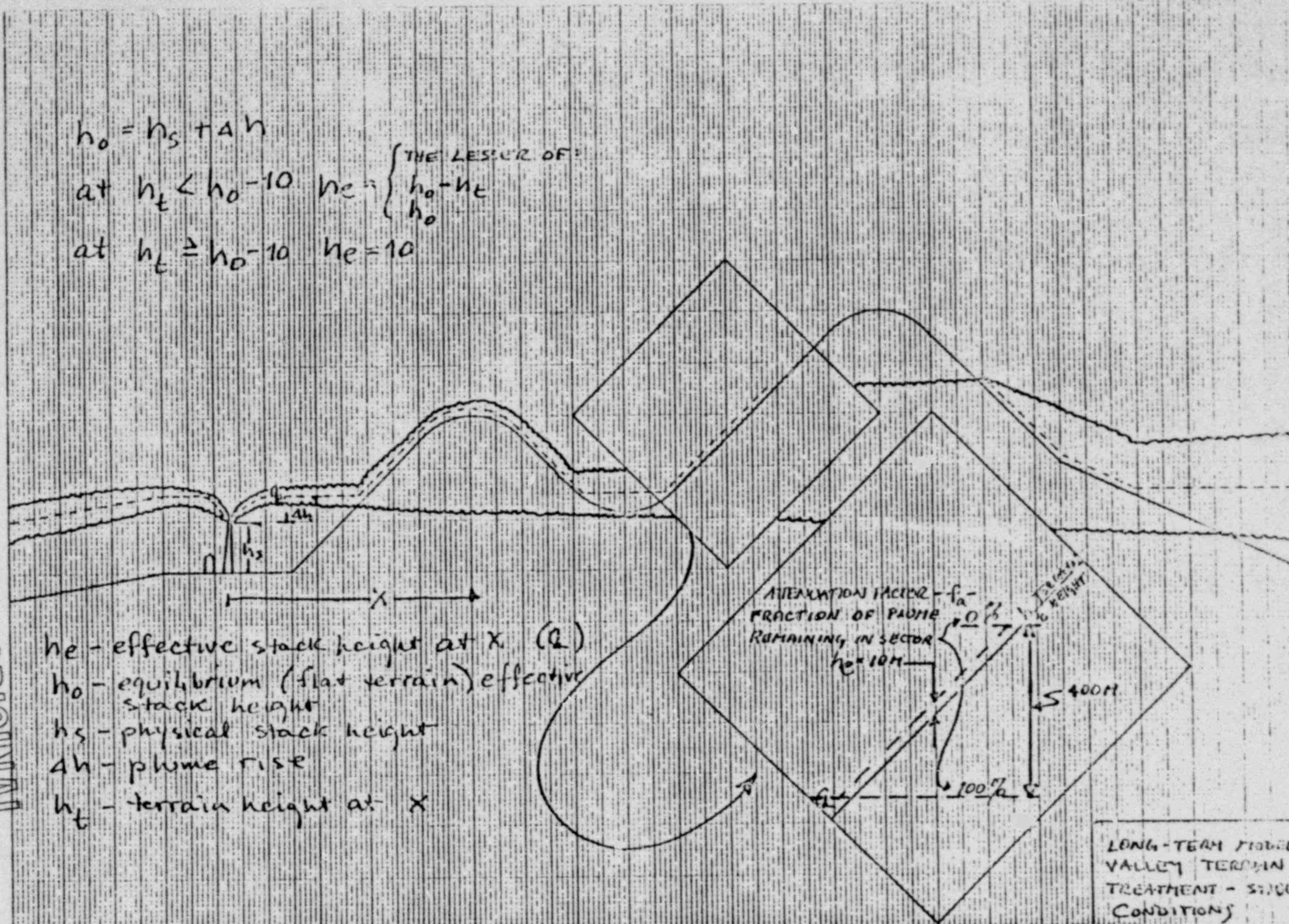

$h_o = h_s + \Delta h$
at $h_t < h_o$ $h_e = h_o - \frac{h_t}{2}$
at $h_t \geq h_o$ $h_e = \frac{h_o}{2}$
h_s
Δh
X
h_e - effective stack height at X (℄)
h_o - equilibrium (flat terrain) effective stack height
h_s - physical stack height
Δh - plume rise
h_t - terrain height at X
h_e
h_t TERRAIN HEIGHT
h_o EQUILIBRIUM EFFECTIVE STACK HEIGHT
Δh PLUME RISE
h_s PHYSICAL STACK HEIGHT
STACK BASE ELEVATION
LONG-TERM MODEL HALF HEIGHT TERRAIN TREATMENT - UNSTABLE AND NEUTRAL CONDITIONS

FIGURE 3-4



$h_o = h_s + \Delta h$
at $h_t < h_o - 10$ $h_e =$ THE LESSER OF: $h_o - h_t$, h_o
at $h_t \geq h_o - 10$ $h_e = 10$
h_s
Δh
X
ATTENUATION FACTOR - f_a - FRACTION OF PLUME REMAINING IN SECTOR
$h_e = 10M$
0%
100%
400M
f_a
h_e - effective stack height at X (R)
h_o - equilibrium (flat terrain) effective stack height
h_s - physical stack height
Δh - plume rise
h_t - terrain height at X
LONG-TERM MODEL VALLEY TERRAIN TREATMENT - STABLE CONDITIONS

FIGURE 3-5

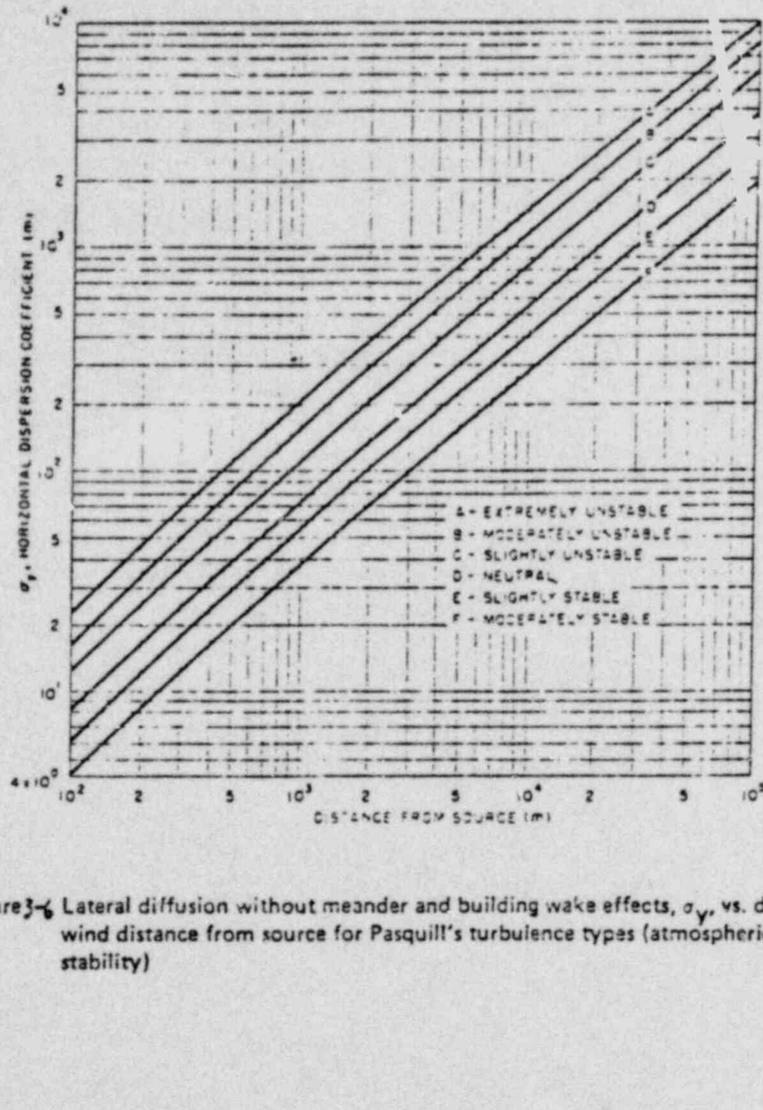


Figure 3-6 Lateral diffusion without meander and building wake effects, σ_y, vs. downwind distance from source for Pasquill's turbulence types (atmospheric stability)

For purposes of estimating σ_y during extremely stable (G) atmospheric stability conditions, without plume meander or other lateral enhancement, the following approximation is appropriate:

$$\sigma_y(G) = \frac{2}{3}\sigma_y(F)$$

POOR ORIGINAL

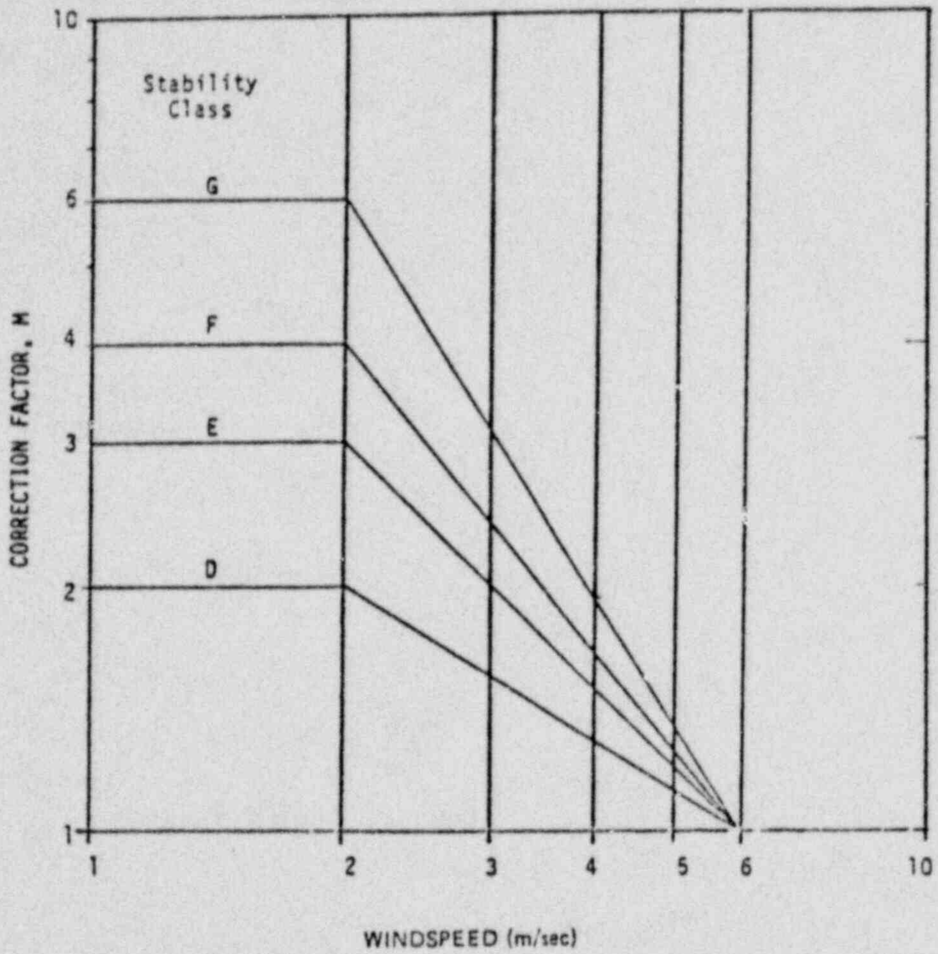


Figure 3-7 Correction factors for Pasquill-Gifford σ_y values by atmospheric stability class incorporating plume meander and building wake effects

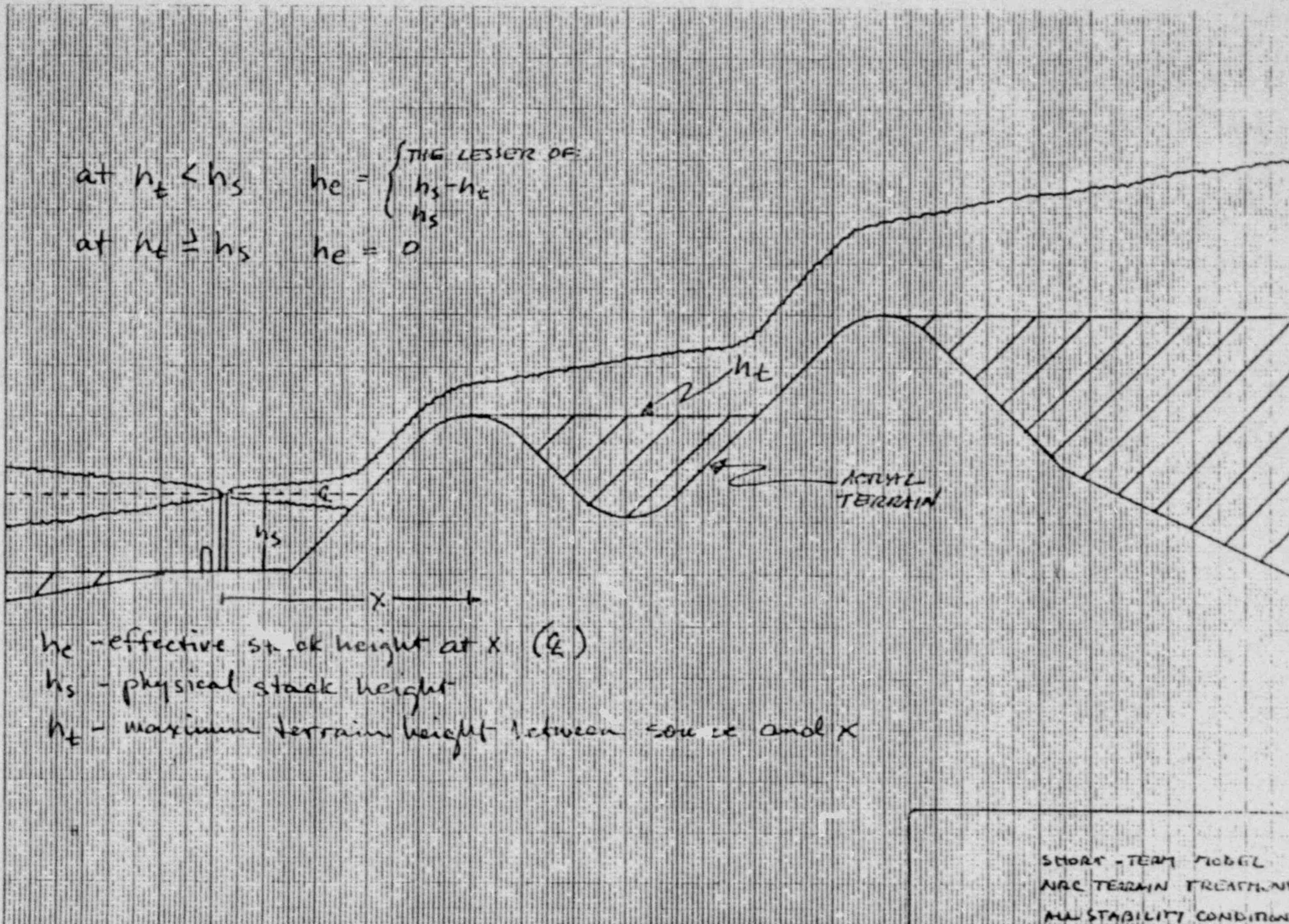

at $h_t < h_s$ $h_e = \begin{cases} \text{THE LESSER OF:} \\ h_s - h_t \\ h_s \end{cases}$
at $h_t \geq h_s$ $h_e = 0$
h_t
ACTUAL TERRAIN
h_s
x
h_e - effective stack height at x (℄)
h_s - physical stack height
h_t - maximum terrain height between source and x
SHORT - TERM MODEL
NRC TERRAIN TREATMENT
ALL STABILITY CONDITIONS

FIGURE 3-8

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CHAPTER 4

PATHWAY ANALYSIS

4.1 INTRODUCTION

In this chapter doses to the maximum individual for atmospheric releases were estimated by models described in NRC Regulatory Guide 1.109 with data values given in the Wyhl report. All of the dose estimates in this chapter are based on the source terms and dispersion models presented in the Wyhl Report. The dose estimates are made here to discern the relative significance of data values in the Wyhl report to the overall results and thereby determine the cause of the large values of doses presented in the report. The NRC models gave essentially the same results as those presented in the Wyhl report when all the Wyhl data values were used. This indicated that the models were essentially the same as those of NRC Regulatory Guide 1.109 and that the differences were a result of input data values.

In this chapter calculations and analyses are presented only for the air emission pathways. This is because the most significant differences between results we would expect and those presented by the authors are for the air emission pathways. The authors' results for the water emission pathways also appear significantly larger than what we would expect, but are small in comparison to the air emission pathway results. Table 4.1 shows this quantitatively. The air emission contribution

Table 4.1: Comparison of Wyhl Report's Doses to Maximum Hypothetical Individual from Different Pathways[a]

Source/Pathway	Dose (mrem/ry)			
	Whole Body	Bone	Kidney	Thyroid
Liquid Effluents Ingestion [c]	100.	2,000.	1,000.	100.
Airborne Effluents				
Noble gas immersion	31.	--	--	--
External exposure from contaminated ground	14.	--	--	--
Ingestion[b,c]	800.	6,000.	10,000.	900.

[a]The above dose estimates are to an adult located offsite where the doses are expected to be highest (maximum exposed individual).

[b]The food ingestion dose includes consumption of vegetables (leafy and root), potatoes, grains, pork, beef, milk and wine. All of the food eaten is assumed to be grown or raised at the point offsite where the doses are expected to be highest.

[c]Values rounded off to one significant figure.

accounts for an average of 85% of the doses listed in Table 4.1, and the water emission pathways account for the remaining 15%.

This chapter is organized as follows: The first section (4.2) deals with the exposure that is received by standing on contaminated ~~ground~~. The second section deals with the dose adults receive from ingestion of food that is contaminated with radioactive material and is divided into a section on vegetable consumption and a section on beef consumption (4.3). The third section deals with the dose infants receive via the iodine-131 air-milk-thyroid pathway (4.4). ~~The fourth, and final section, summarizes the results of these calculations.~~ (4.5)

4.2 EXPOSURE BY STANDING ON CONTAMINATED GROUND

This section provides estimates of the dose received by the maximum exposed individual ~~from~~ standing on contaminated ground. The results are used for comparison ~~for~~ with those of Section 7.1-2 of the Wyhl report.

The mathematical methods used for calculating gamma exposure by standing on contaminated ground D/Ndy by the authors is identical to that employed by NRC. It basically ~~consists~~ of multiplication of the source term, by the decayed and depleted meteorological dispersion factor, times the settling velocity, times the dose factor, times a term which accounts for the buildup of radioactive material on the soil during the life of the nuclear plant.

We used the source terms and the meteorological dispersion factor given in the report to calculate the contribution to total dose by this pathway at the maximum receiving point (500 m.) described in the report. The result that was obtained (4.91 mrem/yr-total body) was somewhat smaller than the authors' result of 14.6 mrem/yr. To determine the cause of this discrepancy, the authors' dose factors were incorporated into the calculation, resulting in a slight increase of 6.02 mrem/yr. Next the time period for buildup was changed from 15 years, which is used by NRC, to 50 years, the value used by the authors. This change had a fairly significant effect on the result as it increased it to 10.2 mrem/yr. In these calculations we used the authors' average settling velocity of 1.3 cm/sec. The authors do not describe the settling velocity they used, but in the section on deposition 5.1, they do suggest that it should be increased by 40% or so over the average value to account for atmospheric washout. Increasing the value we used by about that much would account for the difference between 10.2 mrem/yr we calculated and 14.6 mrem/yr calculated by the authors.

Our comparison of data in the Wyhl report with data in NRC Regulatory Guide 1.109 found that the dose factors used by the authors were all slightly larger than the ones used by NRC. We did not investigate the underlying cause for this discrepancy but are suspect of the authors' values as they are all consistently larger than those in 1.109. For example, the Wyhl values for Zn-65 and I-131 were 72% and 41% larger than the 1.109 values. The remaining Wyhl dose factor values were 15-27% larger. The authors' value for buildup of radionuclides on the ground surface of 50 years is equivalent to the duration of operation of the nuclear facility and represents the dose at the 50th year of operation. This is an overly conservative value from our standpoint as our plants are designed usually for 30 -40 years and selecting a value of half that period gives a better estimation of the average deposition. Furthermore, the average value would be expected to be somewhat less than that calculated by this method because weathering and soil washoff would tend to decrease the buildup by as it would disperse overtime. We feel that even in the authors' case the 15 year time value is a more realistic one. If the authors had used it, their result would have been smaller by 39%, or 8.9 mrem/yr.

4.3 DOSES TO ADULTS VIA THE AIR FOOD INGESTION PATHWAY

This section provides estimates of the dose received by the maximum exposed individual from the food ingestion pathway based on models of NRC Regulatory Guide 1.109. The calculations are made for comparison to those in Section 9.0 of the Wyhl report. The results of the Wyhl calculations were, in some cases, several orders of magnitude different than our results prior to inclusion of Wyhl values for the soil-plant transfer factor, fodder to meat transfer factor, and the dose commitment factor. While results of other sections of the Wyhl report are significantly different from ours, this section is important as the differences are greatest here.

For all the calculations here we utilized the authors' source terms* and meteorological deposition factor for the location where the maximum exposed individual would be located (D/Q = $2.55 \times 10^{-8}\ m^{-2}$). Also, the authors' site specific values for the vegetation period and the grazing period were used. The results of our calculations, as well as the authors', indicated that the very short-lived nuclides did not contribute much in these pathways as they decayed in transport of food goods to the consumer. The important nuclides for the authors' release spectrum are Co-58, Co-60, Zn-65, Sr-89, Sr-90, I-131, Cs-134, Cs-137, and Ce-144.

This section is divided into two parts. The first one deals with the air-plantfood-human pathway, and the second deals with the air-fodder-meat-human pathway.

4.3.1 Doses Due To Ingestion Of Vegetables

The following four tables (Tables 4.2 through 4.5) list the authors' dose estimates along with our dose estimates for several different computer runs, each incorporating progressively more of the authors' parameters. The authors' parameters are introduced in this stepwise manner in order to ascertain their relative importance. Our computer runs are indicated in the tables by NRC (A), NRC (B), and NRC (C). There is one table for

*Pu-234 was not included in the source term spectrum as our model was not set up to handle it. The rate of release of Pu-239 was small in comparison to other nuclides, hence the results are not much different by not including it.

each of the following: leafy vegetable consumption, root vegetable consumption, potato consumption, and cereal grain comsumption. The values for parameters that were used in each of the NRC runs are as follows: NRC(A) incorporates (1) the authors' value of 30 days for the transport time for holdup of vegetation after harvest (NRC value is 60 days); (2) the authors' value, 30 days, for holdup of leafy vegetation after harvest (NRC value is 1 day); (3) the authors' value, 30 days, for the exposure of man's vegetation to the plume (NRC value is 60 days); (4) the authors' value of 224 kg/m^2 for the effective surface density for soil (NRC value is 240 kg/m^2); (5) the authors' values of 1.5 kg/m^2 for leafy vegetable crop density, 4.0 kg/m^2 for root vegetable crop density, 1.8 kg/m^2 for potato crop density, and 0.34 kg/m^2 for cereal grain crop density (NRC value for all four crop densities is 2.0 kg/m^2); and (6) the authors' value of 50 years for the time period over which buildup of radionuclides in soil occurs. NRC (B) is similar to NRC (A) except it incorporates the authors' values for soil to plant transfer of radionuclides. NRC (C) is similar to NRC (B) except it incorporates the authors' values for the dose commitment factors. These are not the only parameters that are necessary for running the NRC Regulatory Guide 1.109 models, but represent the parameter values that were different from those generally used by NRC, hence it should be assumed that parameters that were not mentioned above were the same. It should also be noted that in calculating the radionuclide uptake by plants, either by direct aerosol deposition or by soil-plant-root uptake, the authors used a slightly different methodology than that of NRC. They multiply a factor for plant retention, times a factor for translocation, times a factor for preparation, whereas the NRC method relies on a single factor which characterizes ~~there~~ these three things. In all of the model runs we did we determined the values for these parameters from the authors' report (potato and root vegetables = 0.033; leafy vegetables and cereal grain = 0.132).

Many of the parameters that were used by the authors that were different than that which would typically be used by the NRC may be justifiable as they represented site specific characteristics. However, we have not done a detailed analysis of the basis of these site parameters as they generally did not have a significant effect on the final results. The three parameters that were different and which the difference was not justified on the basis of site specificity were the period over which radionuclides build up and remain in the soil (discussed in the preceding section), the soil to plant transfer factors, and the dose commitment factors. By far, the latter two of these, and especially the soil to plant transfer factor, were the most important in terms of the final model results, and in the model calculations we made, we concentrate on determining which of the latter two is most important. This can be seen by examination of Tables 4.2 through 4.5.

The authors do not explain their methodology rigorously enough to allow exact duplication of their calculations. For some parameters such as the deposition velocity, we had to guess at the value the authors used, hence, our final results, after incorporating all of the authors' values, NRC (C), were not exactly the same as the authors'. The difference amounted to generally between 5% and 30%, with most of the value less than 10%, except for the bone-potato consumption pathway. For this pathway the difference was about 160%. The authors did not indicate that they handled bone any differently from other organs, and as we were able to reproduce their values for the other organs of the potato pathway, we concluded that the authors either actually used a different methodology in making this calculation, or the number they presented is erroneous. In general, as the Tables 4.1 through 4.4 indicate by comparison of NRC (C) results with the Wyhl results, we were able to closly reproduce the authors' results when their parameter values were used.

Table 4.2 lists the expected exposure for adults from the leafy vegetable ingestion pathway. It indicates that the most significant increases are due to the difference in the soil-plant transfer factor. For each organ there is at least an order of magnitude increase in going from NRC (A) to NRC (B). The importance of the dose commitment factor is ascertained in going from NRC (B) to NRC (C). Table 4.1 indicates it to have a fairly signficant effect, more than an order of magnitude, for bone and kidney pathways.

The nuclides which contribute most significantly to the dose in NRC (A) are Sr-90, Cs-134, and Cs-137. In NRC (B) the same nuclides contribute most significantly, except Sr-90 strongly dominates over both cesium isotopes, and Cs-134 becomes only marginally significant. NRC (C) is similar to NRC (B) except that Sr-90 becomes almost the sole contributor, 97%, to the bone pathway. On the average, the authors' soil-plant

Table 4.2. Leafy Vegetable Ingestion Doses

Mode 1	Wyhl Parameter values that are incorporated in model	Dose to Maximum Individual (mrem/yr)					
		Bone	Whole Body	Liver	Kidney	Lung	Thyroid
NRC (A)	Transport times for holdup at vegetation after harvest, exposure of vegetation to plume, surface density of soil, crop density, and time period for buildup of radionuclides in soil	0.6	0.3	0.3	0.0	0.0	0.0
NRC (B)	Same as NRC (A) except Wyhl soil-plant transfer factors	26	8.6	4.5	1.5	0.5	0.0
NRC (C)	Some as NRC (B) except Wyhl dose commitment factors	304.	11.	5.7	58.	0.6	3.9
WYHL	--	323.	10.	6.0	79.	0.6	6.4

transfer factors and dose commitment factors contributed an increase in the results by a factor of 293 over the first four pathways listed in the Table 4.2.

Table 4.3 lists the expected exposure for adults from the root vegetable ingestion pathway. The table indicates that, except for kidney, the most significant increases occur as a result of the authors' soil to plant transfer factors. For the bone and kidney pathway, a significant increase occurs when the authors' dose commitment factor is added, as well as their soil-plant transfer factor.

For NRC (A) over 98% of the dose was from Sr-90, Cs-134, and Cs-137 for whole body and bone. When the authors' soil-plant transfer factors were used, Sr-90 became the sole controlling nuclide and accounted for over 99% of the dose. Addition of the authors' dose commitment factors did not change this. For liver and kidney Cs-137, Cs-134, and Zn-65 were the controlling nuclides in NRC (A), listed in order of importance. When the authors' soil-plant transfer factors were used, Zn-65 lost its importance in that its contribution dropped from an average of 3.5% to an average of 0.7%. Introduction of the authors' dose commitment factors had a small effect and increased the Zn-65 importance to an average of 1.3%. The overall effect of incorporation of the authors' soil-plant transfer factors and dose commitment factors averaged over the first four pathways in the Table 4.3 was to increase the results by a factor of 4525.

Table 4.3. Root Vegetable Ingestion Doses

Model	Wyhl Parameter values that are incorporated in model	Dose to Maximum Individual (mrem/yr)					
		Bone	Whole Body	Liver	Kidney	Lung	Thyroid
NRC (A)	Transport time for holdup at vegetation after harvest, exposure of vegetation to plume, surface density of soil, crop density, and time period for buildup of radionuclides in soil	0.2	0.1	0.1	0.0	0.0	0.0
NRC (B)	Same as NRC (A) except Wyhl soil-plant tranfer factors	138.	34.	0.4	0.1	0.0	0.0
NRC (C)	Same as NRC (B) except Wyhl dose commitment factors.	1762.	42.	0.5	5.5	0.0	0.4
WYHL	--	1609.	39.	0.4	6.5	0.0	0.4

Table 4.4 lists the expected exposure for adults from the potato ingestion pathway. The data indicate that the most significant increases are due to the authors' soil to plant transfer factor, except for the kidney pathway where significant increases occurred as a result of the authors' dose commitment factor as well.

The most important nuclide contribution to NRC (A) was Sr-90, and Cs-137 in the total body and bone pathways with Sr-90 accounting for 42% and 75% respectively. When the authors' soil plant transfer factor was used, Cs-137 completely overwhelmed Sr-90, accounting for 94-97% of the dose. Addition of the dose commitment factor did not change this. In the liver and kidney pathway, Zn-65, Cs-134, and Cs-137 carried most of the contribution for NRC (A), in the reverse order of importance. When the author's soil-plant transfer factors were employed, the contribution of Zn-65 and Cs-134 was almost totally overshadowed by that of Cs-137. The authors' soil-plant transfer factors and dose commitment factors accuunted for an average increase of over a factor of 11,000 in the dose for the total body, liver, and kidney pathways.

Table 4.5 lists the expected exposure for adults from the cereal grain ingestion pathway. The table indicates that, except for kidney, the most significant increases occur as a result of the authors' soil-plant transfer factors. For the kidney pathway the effect of the dose commitment factor was also important.

Table 4.4. Potato Ingestion Doses

Model	Wyhl Parameter values that are incorporated in model	Dose to Maximum Individual (mrem/yr)					
		Bone	Whole Body	Liver	Kidney	Lung	Thyroid
NRC (A)	Transport time for holdup at vegetation after harvest, exposure of vegetation to plume, surface density of soil, crop density, and time period for buildup of radionuclides in soil	0.5	0.2	0.0	0.0	0.0	0.0
NRC (B)	Same as NRC (A) except Wyhl soil-plant tranfer factors	110.	101.	153.	52.	17.	0.0
NRC (C)	Same as NRC (B) except Wyhl dose commitment factors.	283.	130.	192.	2000.	17.6	130.
WYHL	--	463.	128.	145.	1925.	16.9	125.

Table 4.5. Cereal Grain Ingestion Doses

Model	Wyhl Parameter values that are incorporated in model	Dose to Maximum Individual (mrem/yr)					
		Bone	Whole Body	Liver	Kidney	Lung	Thyroid
NRC (A)	Transport time for holdup at vegetation after harvest, exposure of vegetation to plume, surface density of soil, crop density, and time period for buildup of radionuclides in soil	3.6	1.9	1.9	0.6	0.0	0.0
NRC (B)	Same as NRC (A) except Wyhl soil-plant tranfer factors	34.3	11.8	6.7	2.3	0.7	0.0
NRC (C)	Same as NRC (B) except Wyhl dose commitment factors.	390.	15.	8.7	86.	1.0	6.1
WYHL	--	415.	13.	7.0	72.	0.7	4.0

The most significant differences in nuclide contribution was in adding the soil-plant transfer factors in the whole body pathway. Prior to this, the main nuclide contributions were Cs-134 (22%), Cs-137 (44%), and Sr-90 (30%). When these transfer factors were incorporated, Sr-90 (61%) became the most important contribution, Cs-137 (32%) dropped a little, and Cs-134 (5%) became least important. Overall, the authors' soil-plant transfer factors and dose commitment factors resulted in an average increase in dose of a factor of 62 for the first four pathways.

The results of our study of the authors' parameter values for all four food sources can be briefly summarized. The most significant contribution to the increase came from the Sr-90 and Cs-137 nuclides and was due to the soil-plant transfer factors. The dose commitment factor had a lesser, but significant effect in the bone and kidney pathways due mainly to the Sr-90 and Cs-137 nuclides.

4.3.2 Doses Due To Ingestion Of Beef

Table 4.6 lists the authors' results along with our results for several different computer runs, each incorporating progressively more of the authors' parameters, for beef consumption. The values for parameters that were held constant in each of the NRC runs are as follows: (1) the authors' value of 224 kg/m^2 for the effective surface density for soil (NRC value is 240 kg/m^2); (2) a value of 0.75 kg/m^2 for the effective surface density of pasture grass (the authors do not give a value here, thus we used the standard NRC value); (3) the authors' value of 50 years for the time period over which buildup of radionuclides in soil occurs; and (4) the authors' value of 1.0 for translocation and 0.33 for retention (NRC value for this product is normally 0.2). NRC (A) was run with the above values and with typical NRC values for soil-grass transfer factors, fodder to meat transfer factors, and dose commitment and factors. NRC (B) is similar to NRC (A) except it incorporates the authors' values for the soil to grass transfer factors, NRC (C) is similar to NRC (B) except it incorporates the authors' fodder to meat transfer factors, and NRC (D) is similar to NRC (C) except it incorporates the authors' dose commitment factors. These paremeters mentioned above represent ones that the authors used which were different than those typically used by NRC, and are not all of the parameters necessary to run the model. It should be assumed that parameters that were not mentioned were the same.

As was discussed in the preceding section on vegetable consumption, many of the parameters here are similarly justifiable on a site specific basis. Ones that are not are the retention factor, the time period over which buildup of radioactive materials occurs in soil (previously discussed), the soil-grass transfer factors, the fodder meat transfer factors, and the dose commitment factors. The first two have an effect to increase the final result, but only marginally in comparison to the other three. Our basis for not agreeing with the authors' value for the buildup of radionuclides was previously given.

In this section, as in previous sections, we could not duplicate the authors' results exactly, as their methodology and numeric values, were not fully explained or given. For some parameters, such as deposition velocity and pasture grass density, we had to guess the value they used. For the purposes of this review we consider the values of "NRC (D)" to be adequate as the percent difference ranges from 8% to 24% with a mean and a mode of about 15%. Selection of a value for pasture grass density could have accounted for this by itself.

Averaging the relative increase over the five organs in Table 4.6 results in an increase of a factor of 33 for the soil-plant transfer factor, 23 for the fodder to meat transfer factor, and 6 for the dose commitment factor. Detailed analysis of output (not included here) indicated that dose commitment factor has a small effect on the whole body, liver, and lung pathway, and has its largest effect with the kidney pathway. Both the soil-plant transfer factor and the fodder-meat transfer factor have important effects in all pathways.

The most important nuclide contributors in NRC (A) are Cs-137, Cs-134, Co-60, Sr-90, and Zn-65, with the cesium isotopes dominating. Once these other factors are incorporated, the dose becomes almost totally dominated by Cs-137, with Cs-134 accounting for a few percent, and Sr-90 still have an effect on bone dose. The Co-60 and Zn-65 have no significant effect.

In summary, the authors' soil-plant transfer factors, fodder-meat transfer factors, and dose commitment factors multiplicatively inflate

Table 4.6. Beef Ingestion Doses

Model	Wyhl Parameter values that are incorporated in model	Dose to Maximum Individual (mrem/yr)				
		Bone	Whole Body	Liver	Kidney	Lung
NRC (A)	Soil surface density, time period for buildup of radionuclides, translocation and retention.	0.4	0.4	0.6	0.2	0.1
NRC (B)	Same as NRC (A) except authors' soil-plant tranfer factors incorporated	16.	13.	19.	6.3	2.1
NRC (C)	Same as NRC (B) except authors' fodder-meat transfer factor	349.	312.	464.	158.	52.
NRC (D)	Same as NRC (C) except authors' dose commitment factors is used	1002.	401.	587.	6083.	54.
WYHL	--	808.	368.	510.	5287.	47.

the dose estimate, with the principal contribution coming from Cs-137, Cs-134, and Sr-90, listed in order of importance.

4.3.3 Isotopic Analysis of Ingestion Doses

In the previous sections some comments were made regarding the importance of the various isotopes in contributing to dose within each food pathway. In this section the Wyhl dose calculations are compared to our dose calculations for the total dose for all food pathways. Table 4.7 lists the dose for 3 organs (W. body, bone, and kidney) calculated by the authors and by NRC. The NRC dose calculations are those described as NRC (A) in Table 4.2 through 4.6, hence they do not incorporate the Wyhl values for soil-plant transfer of radionuclides, dose commitment factors, and fodder-meat transfer factors. The food pathways represented in Table 4.7 are the vegetable (leafy and root), potato, cereal grain, and beef pathways. Only the results for ~~the~~ these food pathways are presented in the table because these were the ones we did calculations for.

Table 4.7 shows that, as indicated earlier, the Wyhl dose values are significantly higher than what we would expect. For the three organs listed, the total dose estimated by the Wyhl report is greater by a factor of 180 for whole body, 700 for bone, and 7000 for kidney than what we would estimate. The data in the table indicates that the authors' estimates are generally greater for all nuclides with the Cs-137 contribution being the greatest. The next chapter discusses the bases for the values used by the authors of the Wyhl report and by NRC.

Table 4.7. Isotopic Analysis of Wyhl Report's and NRC Ingestion Dose from Gaseous Effluents

Organ/Isotope	Wyhl[a] Dose mrem/yr	Wyhl[a] % of total dose	NRC[b] Dose mrem/yr	NRC[b] % of total dose
Whole Body				
Cs-134	26.	5	0.65	22
Cs-137	445.	83	1.36	45
Sr-90	61.	11	0.85	28
Other	5.	1	0.12	5
Total	537.	100	2.98	100
Bone				
Sr-90	~~27.~~ 2580.	68	3.45	64
Cs-134	~~989.~~ 27.	1	0.33	6
Cs-137	~~2580.~~ 989	26	1.52	28
Other	207.	5	0.10	2
Total	3800.	100	5.39	100
Kidney				
Cs-137	7036.	96	0.70	66
Cs-134	~~308.~~ stet	4	0.25	24
Zn-65	0	--	0.80	8
Other	3.	--	0.16	2
Total	7347.	100	1.05	100

[a]Dose estimates are taken from pp. ~~118-120~~ 99-102 of the Wyhl Report. Doses are to the adult maximum hypothetical individual. All of the food that the adult eats is assumed to be given or raised at the point maximum exposure. The ingestion dose includes ingestion of vegetables (leafy and root), potatoes, grains, and meat (beef only). Doses have been rounded off to the nearest whole number of mrem/yr.

[b]Similar to "a" above, except NRC Regulatory Guides 1.109 values used for soil-plant transfer factors, dose commitment factors, and fodder to beef transfer factors.

4.4 DOSES TO INFANTS VIA THE IODINE-131 AIR THYROID PATHWAY

This section presents our results of infant thyroid dose estimates from the milk pathway for comparision with the Wyhl estimates contained in Chapter 11 of the Wyhl Report. The authors' calculations resulted in a thyroid dose to infants from the cow milk consumption pathway of 753 mrem per year and from the goat milk plus cow milk consumption pathway of 2,204 mrem per year. The above thyroid doses are much larger than our current standards permit (e.g., 40 CFR 190 limits the thyroid dose to 7.5 mrem/yr.). We have analyzed the infant thyroid dose from the milk pathway, rather than adult doses, because the infant thyroid dose estimates in the Wyhl Report are from 4 to 12 times greater than the corresponding dose for the adult, depending on the type of milk (i.e., cow, goat, or sheep).

The calculations we made utilized the authors' source term, 0.3 Ci/yr for I-131 and a meteorological deposition factor of $1.82 \times 10^{-8}\ m^{-2}$ for the nearest point of exposure to the population (500 m) in an attempt to duplicate the authors' result of 753 mrem/yr cow, and 2204 mrem/yr cow plus goat. The first calculation that was made incorporated the authors' suggested grazing periods for cows and goats, and resulted in 45 mrem/yr for the cow pathway and 58 mrem/yr for the cow plus goat pathway. Table 4.8 lists the remaining parameters that were different in the authors' calculation compared to ours:

Table 4.8. Parameter Values for Calculating Infant Thyroid Doses

Parameter	NRC value	Authors' value	Difference ratio
Cow ingestion rate	50 kg/day	75 kg/day	+1.5
Crop productivity	2.0 kg/m^2	2.4 kg/m^2	+1.2
Storage time for fodder	90 days	182 days	+2.0
Dose commitment factor	1.4×10^{-2}	2.8×10^{-2}	+2.0
Cow milk transfer factor	6.0×10^{-3}	1.0×10^{-2}	+1.6
Goat milk transfer factor	6.0×10^{-2}	4.7×10^{-1}	+7.8

The authors' values for the first three parameters of this table were next incorporated into the calculations. This had small effect on the results, increasing the cow pathway to 69 mrem/yr and increasing the cow plus goat pathway to 71 mrem/yr. Next the authors' dose commitment factor was incorporated and this roughly increased the values two-fold, as would be predicted by observation of the difference ratio, to 138 mrem/yr for the cow pathway and 143 mrem/yr for the cow plus goat pathway. Finally, the cow and goat milk transfer parameters of the authors were used and this increased the resultant values to 230 mrem/yr for cow and 640 mrem/yr for cow plus goat.

Beyond differences in parameter values in the authors' model compared to ours, as close as we can tell, the authors neglected to include the decay of I-131 from animal feeding to receptor (about 2 days) and transport time to the population (about 4 days). This may be legitimate however as it may reflect food and fodder building differences in Germany and the United States. When these holdup times were excluded from our calculations, the results increase to 386 mrem/yr for cow and 1075 mrem/yr for cow plus goat. Both of these values are approximately a factor of 2 smaller than the results of the authors. The authors described the settling rate of iodine on clover to be about twice that of iodine on grass. We used the authors average settling velocity of 1.3 cm/sec in this calculation. If this value of settling velocity is increased 40% for fog deposition, and another 50% to take into consideration clover deposition, a settling velocity of about 2.6 cm/sec would result, accounting for the factor of 2 discrepancy.

The first two parameters in the table represent site specific values and should be used in the calculations as long as they represent average values rather than maximum ones. The authors' values for storage time for fodder is probably more reasonable than ours as the growth period is during one half of the year and the consumption period is during the other half of the year, with an effect of decreasing the end result. The authors' use of the high value for the settling velocity is conservatively unrealistic for two reasons. First, increasing the value to allow for fog is based on results obtained from fog and snow observations and is largely unrealistic because if not fog certainly snow conditions are not likely to frequently occur during the grazing season; and second, increasing the value to allow for clover deposition may be unrealistic as clover may not amount to a significant portion of the pasture grass. Finally, the values of the milk transfer factors we feel are overly conservative. While we have observed larger values of them in the literature we have not adopted their use because comparisons of actual field measurements of iodine in milk to model predictions indicate that the model is conservative. For example, in a presentation to the Health Physics Society (22nd Annual Meeting) in July, 1977, J. Steward Bland compared I-131 concentrations in milk from several dairies around a nuclear plant to results of the NRC Regulatory Guide 1.109 model. The Table 4.9 lists some of his results.

The results indicate that on the average, the model is conservative by a factor of approximately 9. Because the actual measured results consistently indicate that the models are conservative, we are reluctant

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Table 4.9: Comparisons of Measured and Calculated ^{131}I Levels in Milk

Location	^{131}I Milk Concentration pCi/l Calculated	Measured
Farm A	5.3	1.2
Farm B	10.0	0.4
Farm C	7.9	0.6
Farm D	0.9	0.5

to make adjustments on parameters without being sure that they do not radically alter the overall results. On this basis, it is concluded that the authors' results are unrealistic, caused by a poor choice of model parameter values.

5. CRITICAL PARAMETERS IN RADIOLOGICAL ASSESSMENTS MODELS

This chapter reviews the Whyl Report's references on resium and strontium soil to plant transfer factors (B_{iv}) and dose conversion factors (DCF) for Cs-137 and Sr-90[1]. The chapter focuses on these model parameters because, as was shown in chapter 4, they are the parameters which are in most disagreement with those of Regulatory Guide 1.109, and ultimately have the greatest effect on the resulting estimated dose calculations.[2]

For the most part this chapter reviews the author's references to assess their use of these references in generating soil to plant transfer factors and the dose conversion factors. This chapter is divided into four major sections: (1) Soil to Plant Transfer of Cesium; (2) Soil to Plant Transfer of Strontium; (3) Dose Conversion Factors for Cs-137 and Sr-90; and (4) Summary and Conclusions.

5.1 SOIL TO PLANT TRANSFER OF CESIUM

There are two major pathways for airborne radionuclides to get into vegetation: (1) direct aerosol deposition, and (2) soil to plant uptake. These major pathways are illustracted in Figure 5.1. The B_{iv} values used in the Wyhl Report for cesium lead to the conclusion that the soil to plant pathway accounts for the majority (from 76% for cereal grains to over 95% for potatoes, root vegetables, grass and clover) of the cesium activity in vegetation. The remainder is due to direct aerosol deposition. Based on NRC values in Regulatory Guide 1.109, the aerosol deposition pathway is the major contributor to cesium activity in vegetation. The soil to plant pathway is a

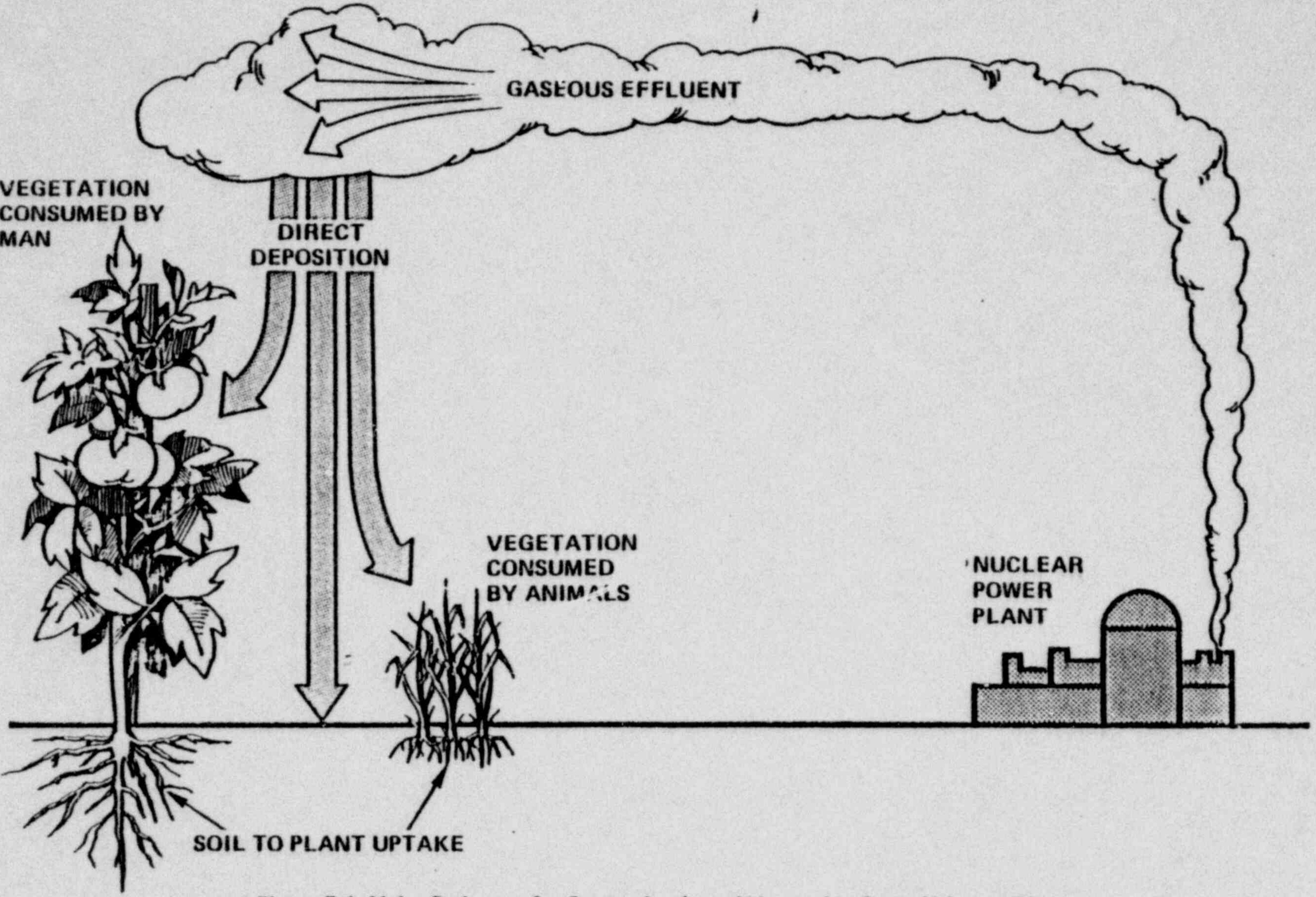

Figure 5.1 Major Pathways for Contamination of Vegetation from Airborne Effluents.

relatively minor pathway for NRC's models. Less than 10% of the cesium activity in food is due to the soil to plant pathway using NRC values. The Wyhl Report's and NRC's models estimate aerosol deposition components that are roughly comparable in magnitude. Since the soil to plant pathway dominates the cesium activity in vegetation, according to the Wyhl Report, this parameter not only leads to higher doses from humans consuming fruits and vegetables, but it also leads to higher doses from milk and meat pathways.

This section contains a brief review of: (1) factors influencing soil to plant transfer of cesium; (2) the basis for the Wyhl Report's soil to plant transfer factors for cesium; and (3) the basis for NRC's soil to plant transfer factors for cesium.

5.1.1 Factors Influencing Soil to Plant Transfer of Cesium

Many studies have been done on the uptake of cesium by plants. These studies include both greenhouse experiments and field studies. While most of the studies have used radioactive tracers techniques, there have been a few studies that have measured concentrations of stable cesium in soils and plants. At least two fairly extensive reviews have been made of soil to plant transfer of cesium: (1) Radioactivity and Human Diet by R. Scott Russell[3]; and (2) Transfer of Radioactive Materials from the Terrestrial Environment to Animals and Man by R. J. Garner.[4] Since these reviews are readily available and fairly extensive, we will only briefly discuss the major factors influencing soil to plant transfer of cesium.

There are many factors that influence the soil to plant transfer of cesium. Some of the factors that have been identified as significantly influencing the uptake of cesium into plants include: (1) the potassium concentration of soil; (2) the organic content of soil; and (3) the clay content of soil. Fredricksson et al. (1958) has shown that the cesium uptake from soils decreases as the potassium concentrations in soils increases.[5] This is thought to occur because of the similar chemical properties of cesium and potassium and the competition of cesium and potassium in the absorption process. Barber (1964) has shown that cesium uptake is greater for soils with a high concentration of organic material.[6] Soils with a high clay content tend to entrap cesium ions and limit plant absorption.[3] Consequently soils with a high clay content typically show low soil to plant uptake of cesium.

5.1.2 Basis for the Wyhl Report's Values for Soil to Plant Transfer of Cesium

The Wyhl Report gives soil to plant transfer values for cesium for six types of vegetation. The soil to plant transfer values on a fresh weight basis (FW) range from 0.07 for root vegetables to 15 for potatoes. These values are based on 13 references listed in the section on cesium transport factors (i.e. Section 6.2.3). We have obtained and reviewed 10 of the 13 references. The Wyhl Report references have been divided into two groups (1) greenhouse experiments, and (2) field studies. Since most references report plant radionuclide concentrations on a dry weight basis (DW), rather than a fresh weight basis (FW), it was necessary to assume a FW/DW ratio to convert plant radionuclide concentrations to a fresh weight basis. The basis for the FW/DW conversion factors, used in this review, is described in Appendix A. The method of reviewing the Wyhl Report's references is more fully described in Appendix B.

5.1.2.1 Greenhouse Experiments

1. Studies on Soil-Plant-Animal Interrelationships with Respect to Fission Products - Fredriksson et al. (1958)[5]

The purpose of this study was "to study under specific Swedish conditions the influence of: (1) liming on the uptake of Sr-90 from soils by different crops, (2) strontium carrier on plant uptake of Sr-90, (3) soil texture and potassium content in soil on plant uptake of Cs-137, (4) caesium carrier on uptake of caesium from soils by different plants."

As part of this study, Fredriksson et al. measured the uptake of Cs-137 in red clover for eleven different soils. The eleven soils represented the more important arable soils in Sweden. Experiments were conducted by adding 0.2 mCi of Cs-137 to pots containing from about 4 to about 6 kg of soil. Cs-137 activity per gram of dry matter was reported. The effect of different levels of Cs carrier in soil on the Cs-137 concentration in plants was investigated over a range of 0 to 500 mg of Cs carrier added per pot. The effect of different potassium levels in soil on the Cs-137 concentration in plants was investigated over a range of 0 to 2500 mg of potassium.

Fredriksson et al. found that the cesium concentration in soil has a large effect on the cesium concentration in red clover. Fredriksson et al. also found that the potassium content of soils has a significant effect on the cesium concentration in red clover.

In an attempt to derive B_{iv} values for typical soils, we have used B_{iv} values for the 9 soil types with their natural amounts of cesium and potassium (i.e. no added cesium or potassium) in Table 5.1. The soil to plant transfer factors for the cesium carrier experiment ranged from about 0.02 for the high density clay soil to 0.17 for the low density soil with a relatively high organic content. The average B_{iv} (FW) for soils with natural amounts of cesium in the cesium carrier experiment was 0.06 ± 0.05.

The soil to plant transfer factors for the potassium added experiment range from 0.09 for the very high density clay soil to 1.21 for the low density soil with a relatively high organic content. The average B_{iv} (FW) for soils with natural amounts of potassium in the added potassium experiment was 0.37 ± 0.34. The soils and plants used in the cesium and potassium experiments were the same. However, the average B_{iv} (DW) values from the potassium experiment are higher than the respective values from the cesium experiment. The cause for this discrepancy is not due to different plant yields per pot, or different levels of cation uptake for Ca, Mg or K.

The Wyhl Report uses a B_{iv} for clover (8.5) that is more than 7 times larger than the highest value derived from Fredriksson et al for natural soils. (1.2) The Wyhl value of 8.5 is based on soils in which significant quantities of cesium carrier were added to soil. The addition of cesium carrier leads to transfer factors that are much larger than those for the natural soils investigated. The Wyhl Report ignores one of the main conclusions of Fredriksson et al. that "The experiments with caesium show that this element, when applied to the soil in a carrier-free form, is so powerfully adsorbed that it cannot be taken up by the plants to any important extent."

TABLE 5.1: Cesium Soil to Plant Transfer Values for Red Clover

Soil Origin	Soil Concentration,[b] nCi/g	Cs Carrier Experiment[a] Plant Conc. (DW), nCi/g	Cs Carrier Experiment[a] B_{iv} (FW)[c]	K Level Experiment[a] Plant Conc. (DW), nCi/g	K Level Experiment[a] B_{iv} (FW)[c]
Kopparslagargarden, Skaraborgs lan	37.0	30.7	0.17	224.7	1.21
Skurups Lantmannaskola, Malmohus lan	32.8	11.3	0.07	73.5	0.45
Bronnestad, Malmohus lan	33.9	4.3	0.03	25.3	0.15
Jockelsta, Vastmanlands lan	35.7	14.3	0.08	65.3	0.37
Skottlandshus, Kristianstads lan	40.0	3.7	0.02	66.4	0.33
Ultuna, Uppsala lan	35.7	3.2	0.02	17.4	0.10
Vasterbygard, Uppsala	38.5	8.1	0.04	42.6	0.22
Gorsingeholm, Sodermanlands lan	55.6	27.6	0.10	123.5	0.44
Stensfalt, Skaraborgs lan	38.5	6.1	0.03	17.5	0.09
Average ± s	38.6 ± 6.8	12.1 ± 10.3	0.06 ± 0.05	72.9 ± 66.2	0.37 ± 0.34

[a]The B_{iv} (FW) values are for the natural amounts of cesium and potassium in 9 soil types in Tables 19 and 20 of Fredriksson et al. (1958).

[b]Soil concentrations were calculated from 0.2 mCi of Cs-137 added to each pot, and the soil weights given in Table 1.

[c]B_{iv} (FW) values are based on a FW/DW ratio of 5 for grass.

2. Release of Sr-90 and Cs-137 from Vina Loam Upon Prolonged Cropping - Nishita et al. (1958)[7]

Nishita et al. measured Sr-90 and Cs-137 activity concentrations in Ladino clover. The objective of this study was "to study the release of Sr-90 and Cs-137 from contaminated soils as a function of intensive and prolonged cropping." Carrier-free Cs-137 was mixed with Vina loam to give an activity concentration of 170 dps/g of soil. Exchangeable cesium levels were measured at the beginning of the experiment. About 25% of the Cs-137 initially added to the soil was in an exchangeable form at day zero. Plants were grown in 600 g of soil in 4 inch clay pots. Fertilizer was added to the pots at the beginning of the experiment and after the fifth harvest (day 286). Plant activity was reported in dps/gram of dry soil.

Derived B_{iv}(DW) values for clover tops varied from about 0.05 for plants harvested after 74 days to about 0.3 for plants harvested after 516 days (i.e., the ninth blooming stage of growth). Derived B_{iv} (DW) values for clover roots were about two to three times higher than the corresponding values for clover tops. The average B_{iv} (DW) was 0.11 ± 0.11 and 0.38 ± 0.15 for clover tops and clover roots, respectively. The above B_{iv} values are based on the total amount of Cs-137 added to the soil. Based on a FW/DW ratio of 5 for grass, then the average B_{iv} (FW) would be 0.02 for clover tops, and 0.08 for clover roots.

The Wyhl Report uses a B_{iv} for clover (8.5) that is more than 100 times larger than the highest value derived from Nishita et al for clover tops (0.06).

3. Influence of Soil Organic Matter on the Entry of Cesium-137 into Plants - Barber (1964)[6]

Barber measured concentrations of Cs-137 in ryegrass for six soil types. Five of the six soils were taken from pastures in Britain where Cs-137 had been observed in milk. The sixth soil was a tropical soil. Soils were analyzed for clay content, organic matter, cation exchange capacity, and exchangeable potassium. Soils were uniformly contaminated with Cs-137 prior to sowing ryegrass.

Experimental procedures were described very briefly. Based on the data given B_{iv} (FW) values can be derived ranging from about 0.02 for a soil containing predominantly kaolia clay (13.2%) to about 0.6 for a soil containing predominantly mica clay (12.8%). The unweighted average B_{iv} (FW) for all soil types is 0.16 ± 0.17. The above values are based on a FW/DW ratio of 5 for forage grass. The Wyhl Report uses a B_{iv} for grass (5.9) that is about 10 times larger than the highest value derived from Barber.

4. Absorption and Distribution of Cs-137 by Trifolium Pratense - Bergamini et al. (1971)[8]

Bergamini et al. measured the absorption and distribution of Cs-137 in a forage clover grown on one soil type. Plants were grown in large wooden boxes. Solutions of Cs-137 (SO_4), at three different concentrations, were added to plants in a manner simulating irrigation and contamination through radioactive rain. Plants were contaminated for three different phases of plant development: (1) seedling stage; (2) shooting stage; and (3) flowering stage.

Bergamini et al. report maximum and minimum values of concentration factors on a dry weight basis. Average values for concentration factors were not reported. For aerial plant parts, the concentration factor varied from 0.01 to 166.22. Based on a FW/DW ratio of 5 for forage grass, the above concentration factors, on a fresh weight basis, range from 0.002 to 33 (the latter value being reported in the Wyhl Report).

It is unlikely that the concentration factors reported by Bergamini are equivalent to NRC's soil to plant transfer factor for two reasons:

1. The harvest time for the maximum concentration factors is not reported. It is probable that some of the high values correspond to immature stages of growth when plants are unlikely to be eaten by grazing animals.

2. Bergamini reports soil concentrations as a function of depth; however, the average soil concentration is not given. If Bergamini used average soil concentrations that were different than the soil concentrations that NRC would calculate for the top 15 cm of soil, then the concentration factors reported by Bergamini would not be equivalent to NRC's B_{iv} values. In addition, Bergamini reports soil concentrations in units (cpm/g) that are different than the units for plant concentrations (pCi/g). Since the counting efficiency of the instrument is not given, it is difficult to convert soil concentration units to plant concentration units. This conversion is needed to check the basis for Bergamini's concentration factors.

The Wyhl Report uses a B_{iv} for clover (8.5) that would correspond to the <u>maximum</u> values given in Bergamini's tables.

5. Accumulation of Cs-137 and Sr-85 by Florida Forages in a Uniform Environment - Garrett et al. (1971)[9]

Garrett et al. measured the ratio of soil to plant radionuclide content for both Cs-137 and Sr-85 in nine forage species that are common to Florida. Following periods of radioactive fallout, the Cs-137 level in Florida milk was consistently higher than the national average. This study was designed to identify the causes of the higher than average Cs-137 levels in Florida milk. Carrier-free $^{137}CsCl$ (4 microcuries) was thoroughly mixed with 2500 grams of soil (Leon series soil). Forage was grown in shallow (4 cm deep) containers about 2 liters in volume. Leon series soil is a typical Florida soil representing about 26% of the Florida land area. A number of soil parameters for Leon series soil are given; however, the potassium concentration of the soil was not given. Soil moisture was controlled to about 15% moisture content by daily watering. Samples were oven-dried and analyzed by gamma spectroscopy. Soil to plant transfer factors are given in Table 5.2. The ratio of plant to soil radionuclde content (FW) for Cs-137 varied from about 4.6 for pangolagrass to about 8.5 for white clover. The unweighted average ratio of plant to soil radionuclide content (FW) for Cs-137 for the nine grasses was 5.9 $\pm$ 1.3. The Wyhl Report uses a B_{iv} of 8.5 for clover, and 5.9 for grass. The Wyhl values correspond to the values derived from Garrett et al for a soil with high soil to plant transfer characteristics for cesium.

TABLE 5.2: Cs Soil to Plant Transfer Factors for Florida Forages[a]

Forage	B_{iv} (DW)	B_{iv} (FW)
White Clover	42.6	8.5
Crabgrass	27.1	5.4
Pangolagrass	22.8	4.6
NK-37 Bermudagrass	24.7	4.9
Common bermudagrass	28.9	5.8
Oats	24.7	4.9
Dallisgrass	27.3	5.5
Coastal bermudagrass	29.6	5.9
Bahiagrass	36.2	7.2
Average ± s	29.3 ± 6.3	5.9 ± 1.3

a B_{iv} (DW) values are taken from Garrett et al. (1971).[9]

B_{iv} (FW) values are based on a FW/DW ratio of 5 for grass.

6. Factors of Transfer of Cs-137 from Soils to Crops - Marckwordt et al. (1971)[10]

Marckwordt et al. estimated upper bound for the soil to plant transfer of Cs-137 in four types of vegetation. The authors state in the introduction to their paper:

> "In consequence of the low mobility of Cs-137 in the soil, contamination of crops by this radioelement has proved via the soil, to be mostly of little importance compared with the direct contamination due to radioactive fallout. There are, however, cases, depending on the soil type, where an appreciable indirect contamination might occur."

Since the amount of cesium measured in plants is more dependent on the amount of exchangeable cesium in soils rather than the total cesium content of soils, the extractable cesium content of soil was measured. The percentage of magnesium extractable cesium was determined from experiments with Cs-134 labeled soil. Multiple regression analysis was used to relate the Mg extractable cesium to percent organic matter and percent clay. Soils that represented a range of soil types found in Italy, France and Germany were used. The organic content of soils ranged from 1.3 to 63.0%. The clay content of soils ranged from 1.7 to 61.8%. The equation relating Mg extractable cesium to organic matter and clay content is as follows:

$$Y = 0.9874 + 0.2099\, X_1 - 1.1479\, X_2,$$

Where Y = log % Mg extractable Cs;

X_1 = log % organic matter and

X_2 = log % clay content.

Cesium concentrations in plants were then estimated by first comparing the Cs/K ratio in plants with the "available" Cs/K ration in soils. An upper bound for this ratio was estimated to be about 0.5 for most soils.

Soil to plant transfer factors (P_d) were reported in units of pCi/Kg product per mCi/Km^2. The upper limit estimates of P_d were as follows: wheat, 3; lucerne, 9; lettuce, 15; and grass, 22. Based on an effective surface density of 240 Kg/m^2, and the FW/DW ratios in Appendix A, these P_d values convert to the following maximum B_{iv} (FW) values: wheat, 0.65; lucerne, 0.54; lettuce, 0.19; and grass, 1.06. The average B_{iv} (FW) of the four types of vegetation is about 0.6 ± 0.4.

The Wyhl Report uses the following B_{iv} values: cereal grains, 0.48; grass, 5.9; and leafy vegetables 0.75. For all items except cereal grain the Wyhl values are 4 or more times greater than the upper limit values estimated by Marckwordt et al.

5.1.2.2 Field Studies

1. Distribution of Radiostrontium and Radiocesium in the Organic and Mineral Fraction of Pasture Soils and Their Subsequent Transfer to Grasses - D'Souza et al. (1971)[11]

D'Souza et al. measured the transfer of Sr-85 and Cs-134 to grasses. Soils were taken from four permanent pastures in Belgium. The four soil types, with their percent clay content in parenthesis, were as follows: (1) Sandy (2.2)· (2) Brown-acid alluvial (15.8); (3) Schisty (8.8); and (4) Brown-acid (6.0).

Four experimental pastures (1 m x 10 m) were set up by placing the soil organic fraction on a 15 cm layer of sand on polyester sheets. Plants were watered regularly, and excess water was drained. Soil was sprayed with Cs-134 at a rate of 1 mCi/m^2. Pasture grass activity was reported in pCi/g DW for the four soils over a period of two years.

Based on their results, B_{iv} values can be derived. The average B_{iv} (FW) value for the four soils was as follows for different times after spraying: 2 months, 1.8 ± 0.6; 5 months, 0.6 ± 0.6; 12 months, 0.3 ± 0.3; and 15 months, 0.3 ± 0.3. The highest value of any soil for any time was about 2.5 The above values are based on a FW/DW ratio of 5 for grass.

The Wyhl Report uses a B_{iv} for grass (5.9) that is more than 2 times larger than the highest value derived from D'Souza et al.

2. Radioactive Fission Product Cs-137 in Mushrooms in W. Germany during 1963-1970 - Grueter (1971)[12]

Grueter measured the Cs-137 activity in mushrooms grown on different German soils. Mushrooms were collected at the same places in the months of September and October over the years 1963 to 1970. Rough soil contamination was removed prior to drying and ashing. Investigations were carried out in connection with fallout from nuclear weapons tests.

Grueter reports mushroom concentrations of cesium on a fresh weight basis. Cesium-137 concentrations in mushrooms ranged from about 0.29 to 30.6 pCi/g. Soil concentrations of Cs-137 are not reported. One value is given for the ratio of plant to soil concentrations (16.5) for the year 1966. It is probable that this value includes a significant amount of activity incorporated by direct deposition because plant concentrations for latter years,

years in which aerosol deposition is much less, are much lower. Soil to plant transfer cf Cs-137 in mushrooms is probably a factor of 3 or more below the value of 16.5; however, more data on soil concentrations is needed to obtain a more precise value for B_{iv} (FW) for mushrooms.

The Wyhl Report references Grueter for a transport factor of 16.5 for cesium. However, the Wyhl Report fails to note that the plant to soil concentration factor of 16.5 for the year 1966 probably includes a significant amount of activity from direct deposition in addition to the activity from root uptake.

3. Environmental Radioactive Pollution and Man - A. N. Marei (1973)[13]

This article is contained as Chapter 7 in a book entitled Radioecology edited by V. M. Klechkovskii and G. G. Polikarpov. The chapter is mainly concerned with the migration of Sr-90 and Cs-137 from the environment to man. The chapter contains a brief summary of the migration of Sr-90 and Cs-137 from soils into grass and milk. The chapter also discusses human intake and metabolism of these isotopes. The author states that there is an opinion that the concentration of Cs-137 in plants is mainly due to aerial contamination, and that soil to plant transfer of Cs-137 is slight. The author points out that for some soils the soil to plant pathway is the dominant pathway for Cs-137 in food. Values are given for the migration of Cs-137 from soil to grass for several soil types: (1) loamy sod-podzolic soil, 1.62; (2) sandy-loamy sod-podzolic soil, 7.95; and (3) sandy sod-podzolic soil, 23.6. It is not clear whether these migration values are for fresh weight or dry weight. If Marei's values are based on dry weight, then the average B_{iv} (FW) would be 2.2 ± 2.3 assuming a FW/DW ratio of 5 for grass. The values reported in this

Chapter are extracted from other references. The procedures and methods used in determining the above soil to plant transfer factors are not described.

The Wyhl Report references this paper for the migration values given above without substantiating the experimental basis for the values.

4. Uptake of Radiocesium from Contaminated Floodplain Sediments by Herbaceous Plants - Sharitz et al. (1975)[14]

Sharitz et al. measured radiocesium concentrations in two herbaceous plant species native to a delta region near the Savannah River Plant in South Carolina. Concentrations of radiocesium in soil (primarily kaolinite clays) were also measured. The original source of the radiocesium in soil samples was from heat exchange cooling water discharged from two nuclear production reactors between 1954 and 1968. Both plant and soil samples were dried prior to counting by gamma spectroscopy. Although no attempt was made to distinguish between Cs-137 and Cs-134 activity, the amount of Cs-134 was estimated to be small (less than 5%) compared with Cs-137. The authors found that the average concentration of cesium in plants was fairly constant (i.e., about 200-700 pCi/g dry weight, depending on species, and plant part), while soil concentrations fit a bimodal distribution. Soils classified as low level had an average cesium concentration of about 25 pCi/g (DW), while soils classified as high level had an average cesium concentration of about 540 pCi/g (DW). Based on the authors' results, derived B_{iv} (FW) values for cesium range from about 2 to 6, depending on species and plant, for low level soils. For high level soils, derived B_{iv} (FW) range from about 0.1 to 0.2. The unweighted average B_{iv} (FW) was 3.9 for low level soils and 0.15 for high level soils. The above B_{iv} (FW) values are based on a FW/DW ratio of 4.

The authors conjectured that the relative independence of plant concentrations to soil concentrations may be due to soil differences. Soils with high concentrations might contain more clay and silt sediment, and consequently more potassium. Since potassium and cesium have similar chemical properties, high concentration of potassium would lead to low soil to plant transfer of cesium.

The Wyhl Report references Sharitz et al. for similar transport factors.

5.1.2.3 Summary and Conclusions of Review of Wyhl References for Soil to Plant Transfer of Cesium

1. The papers that were reviewed contained a large range of soil to plant transfer factors. The range of B_{iv} values reported by the various authors is given in Tables 5.3 and 5.4 for greenhouse experiments and field studies, respectively.

2. The majority of the Wyhl Report's references (6 out of 10) that were reviewed are greenhouse experiments, as opposed to field studies. While greenhouse experiments allow better control of variables, they often suffer from a fundamental disadvantage in that they may not simulate field conditions as well as field studies. The amount of soil in which plants grew ranged from 0.6 kg/pot for Ladino clover (Nishita et al.)[7] to 6 kg/pot for red clover (Fredriksson et al.).[5] Larger pots allow more room for roots to develop in normal field conditions. None of the papers discussed root cramping.

3. In most cases the B_{iv} values for cesium used in the Wyhl Report are based on soil and plant characteristics that tend to maximize the transfer of cesium from soils to plants. For example:

- The Wyhl Report's value for B_{iv} for leafy vegetables (0.75) is about 4 times greater than the upper limit value (0.19) derived from Marckwordt et al.[10]
- The Wyhl Report's B_{iv} for clover (8.5) is based on the largest B_{iv} for forage reported by Garrett et al.[9] The B_{iv} values derived from Garrett et al. are based on a Florida soil with high soil to plant transfer characteristics for cesium. Soil characteristics that would lead to high B_{iv} values should also result in increased downward movement of cesium into soils. As the cesium moves deeper into soils, B_{iv} values should decrease because the cesium should move beyond the root zone with time. The Wyhl Report ignores the much lower B_{iv} values for clover obtained by Fredriksson et al and Nishita et al (1958). (see Table 5.3).
- The Wyhl Report's B_{iv} for grass (5.9) is based primarily on the data reported by Garrett and Marei. The Wyhl Report ignoes the much lower average values for grass obtained by Barber (0.2), d'Souza (0.9), and even Marckwordt's upper limit estimate (0.6). The Wyhl Report value for grass is more than 2 times higher than the highest values measured by Barber (0.6), d'Souza (2.5) and Marckwordt (1.1). The B_{iv} values derived from Garrett et al. (1971) are based on plants grown on Florida soil.[9] Roessler et al (1969) have shown that the Cs-137 content in Florida foods, and the Cs-137 body burden in Florida residents is among the highest in the nation. As stated by Roessler et al.

TABLE 5.3: Range in Cesium Soil to Plant Transfer Factors Reported by Various Papers Cited in Wyhl Report - Greenhouse Experiments

Reference	B_{iv} (FW)			Parameters Examined
	Low	High	Unweighted Avg. ± s	
Fredriksson et al. (1958)[a]	0.02	1.2	0.22 ± 0.22	Red clover grown on 9 typical Swedish soils.
Nishita et al. (1958)	0.01	0.12	0.05 ± 0.04	Clover tops and roots for harvest times up to 1.5 years.
Barber (1964)	0.02	0.6	0.16 ± 0.17	Rye grass grown on 6 common soils.
Bergamini et al. (1970)[b]	0.002	33	-	A forage clover contaminated with 3 concentrations of 137$CsSO_4$ for three phases of plant development
Garrett et al. (1971)	4.6	8.5	5.9 ± 1.3	Nine types of forage grown on a Florida soil with high soil to plant transfer characteristics for cesium.
Marckwordt et al. (1971)	0.2	1.1	0.6 ± 0.4	Common food crops grown on a hypothetical soil with high soil to plant transfer characteristics.

[a] The B_{iv} values derived from Fredriksson et al. are based on the natural amounts of cesium and potassium in 9 of the more important arable soils in Sweden.

[b] Bergamini reported only maximum and minimum values. It is likely that some of the maximum values for B_{iv} correspond to immature stages of harvest.

TABLE 5.4: Range in Cesium Soil to Plant Transfer Factors Reported by Various Papers Cited in Wyhl Report - Field Studies

Reference	B_{iv} (FW) Low	High	Unweighted Avg.	Parameters Examined
D'Souza et al. (1971)	0.08	2.5	0.9 ± 0.8[a]	Grasses grown on 4 soils for harvest times up to 15 months
Grueter (1971)	-	-	16.5[b]	Mushrooms grown on German soils over the years 1963 to 1970
Marei (1973)	0.32	4.7	2.2 ± 2.3[c]	Grass grown on 3 soils with high soil to plant transfer characteristics.
Sharitz et al. (1975)	0.1	6.0	2.0 ± 10.5[d]	Two herbaceous plants grown on soils with different cesium concentrations

a The average B_{iv} values are based on average for four soil types and four harvest times.

b Since this value includes a significant amount of activity incorporated by direct deposition, it is probably high by a factor of 3 or more.

c These values were obtained by dividing the values reported by Marei by a FW/DW ratio of 5.

d Based on the unweighted average of B_{iv} for low level soils (N25pCi/g) and B_{iv} for high level soils (N540 pCi/g).

"The primary factor affecting levels in animal products in Florida appears to be radiocesium levels in locally grown forages.(35) One explanation for the elevated ^{137}Cs levels in Florida vegetations is an unusually high uptake of this nuclide from soils which have a low clay content and in which there is a rapid turnover of organic material."[16]

The physical basis for the values from Marei is not described in enough detail to be given much weight.

. The Whyl Report's B_{iv} for potatoes (15) is about 100 times higher than the largest value referenced for potatoes in Section 6.2.3 of their report (0.16).

4. All of the reviewed references had higher <u>average</u> soil to plant transfer of cesium than NRC's current value of 0.01. All of these refereces, except for two (Marckwordt et al., and Grueter) are limited to vegetation (grass and clover) consumed by animals rather than vegetation directly consumed by man. Marckwordt et al. estimated maximum rather than average B_{iv} values. The mushroom contamination reported by Grueter is not suitable for estimating soil to plant transfer because it includes significant quantities of contamination from the direct deposition pathway.

5.1.3 Basis for NRC Values for Soil to Plant Transfer of Cesium

The soil to plant transfer values used in Regulatory Guide 1.109 are derived from a report entitled "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere." (USAEC Report UCRL-50163, Part IV, October, 1968) by Y. C. Ng et al.[15] Ng gives average concentrations of 100 elements in typical argicultural soil, and portions of the human diet derived from plants. The average cesium concentration in soil (5 ppm) is derived from a book entitled "The Geochemistry of Rare and Dispersed Elements in Soils" by Vinogradov (1959).[17] Ng derived the average cesium concentration in plants (0.05 ppm on a fresh weight basis) from four references: (1) Trace Elements in Biochemistry - Bowen (1966)[18]; (2) "Comparative Elemental Analyses of A Standard Plant Material" - Bowen (1967)[19]; (3) "Trace Analysis of Biological Materials by Mass Spectrometry and Isotope Dilution" - Morrison (1967)[20]; and (4) "The Different Distribution of Rubidium and Cesium in Natural Plants - Yamagata (1959).[21] Dry weight literature values for plant concentrations were converted to wet weight values by assuming the water concentration to be 75%. The soil to plant transfer factor for cesium, used in Regulatory Guide 1.109, was obtained by dividing the average plant concentration (0.05 ppm, FW) by the average soil concentration (5 ppm) to get a value of 0.01. The physical basis upon which this value is based is presented in brief summaries of the 5 references cited by Ng. (See Appendix C.)

Since the NRC periodically reviews the models in Regulatory Guide 1.109, we have also included in this report a recent paper by Y. C. Ng. In March of 1979, Y. C. Ng presented a paper at the International Atomic Energy Agency's (IAEA) Symposium on Biological Implications of Radionuclides Released from Nuclear Industries.[22] Ng's paper was entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products." In this paper Ng presented updated values for transfer of radionuclides to plants, milk and other animal products. Ng referred to six additional papers on soil to plant transfer of cesium and strontium. Since these papers were very briefly summarized in Ng's IAEA paper, we have reviewed these papers and included a summary of them in Appendix D.

Table 5.5 is a reproduction of Table VIII from Ng's IAEA paper. For most plants grown on most soils, the B_{iv} values for cesium in Table 5.5 are less than NRC's B_{iv} value for cesium (0.01). A B_{iv} of 0.01 would slightly underestimate cesium transfer for some plants (e.g., potato ιt, bean fruit, and wheat grain) grown on coarse soils.

Since an individual's diet consists of many tyes of vegetation, NRC's B_{iv} value should be based on an average value of vegetation grown on a soil type. Doubling NRC's B_{iv} value for cesium would lead to a realistically conservative value for fine, medium and coarse soil textures. Since aerosol deposition dominates the air to plant transfer of cesium, a B_{iv} value of 0.02 slightly increases the estimate of activity in vegetation (by less than 10%).

5.2 SOIL TO PLANT TRANSFER OF STRONTIUM

As stated earlier in the section on cesium (i.e., Section 5.1) there are two basic pathways for airborne radionuclides to get into vegetation: (1) direct aerosol deposition, and (2) soil to plant uptake. The B_{iv} values used by in the Wyhl Report for strontium lead to the conclusion that the soil to plant pathway accounts for over 90% of the Sr-90 activity in all types of vegetation considered. The remainder is due to aerosol deposition. Based on NRC values in Regulatory Guide 1.109, the aerosol deposition pathway is the major contributor to Sr-90 activity in vegetation. The soil to plant pathway is a relatively minor pathway for NRC's models. Less than 15% of the Sr-90 activity in flood is due to the soil to plant pathway using NRC values. The Wyhl Report's and NRC's models estimate aerosol deposition components that are roughly comparable in magnitude. Since the soil to plant pathway dominates

NOTE: Ng's permission is needed to include this table in our final paper.

Table 5.5 Concentration Factors in Forage, Produce, and Grains Grown in Coarse-, Medium-, and Fine-Textured Soils[a,b]

Range of CF (pCi/kg wet plant matter ' pCi/kg dry soil)		
Soil Texture	Sr	Cs
Coarse	0.02 - 1.7	9.5(-4)[c] - 0.031
Medium	1.6(-3) - 0.43	5(-5) - 2.6(-3)
Fine	7.8(-3) - 0.38	9(-4) - 0.013
B_{iv} Veg/soil[d]	0.017	0.01

[a]This table is taken from Table VIII of Y. C. Ng's IAEA paper entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products," Vienna, March 26-36, 1979.

[b]Based on references summarized in Appendix D.

[c]9.5(-4) denotes 9.5×10^{-4}.

[d]From Table E-1 of Regulatory Guide 1.109 [2].

the strontium activity in vegetation according to the Wyhl Report, this parameter not only leads to higher doses from humans consuming fruits and vegetables, but it also leads to higher doses from the milk and meat pathways.

This section contains a brief review of (1) factors influencing soil to plant transfer of strontium; (2) the basis for the Wyhl Report's soil to plant transfer factors for strontium; and (3) the basis for NRC's soil to plant transfer factors for strontium.

5.2.1 Factors Influencing Soil to Plant Transfer of Strontium

Many studies have been done on the uptake of strontium into plants. These studies include both greenhouse experiments and field studies. While most of the studies have used radioactive tracers, there have been a few studies that have measured concentrations of stable strontium in soils and plants. At least two fairly extensive reviews have been made of soil to plant transfers of strontium:

1. Radioactivity and Human Diet - R. Scott Russel (1966)[3]; and

2. Transfer of Radioactive Materials from the Terrestrial Environment to Animals and Man - R. J. Garner (1972).[4]

Since these reviews are readily available and fairly extensive, we will only briefly discuss the major factors influencing soil to plant transfer of strontium.

While there are many factors that influence soil to plant transfer of strontium, some are more significant than others. Garner has stated that, "The availability of Sr 90 to plants is determined mainly by the exchangeable calcium content of the soil, the degree of calcium base saturation and the total base exchange capacity."[4] Calcium and strontium have similar chemical properties. The amount of strontium that is transferred from the soil solution to plants is partially determined by the amount of calcium in the soil solution. Many authors have studied the ratio of Sr-90 to calcium in plants and the ratio of Sr-90 to calcium in soil solutions. In general, the ratio of Sr-90 to calcium in plant shoots is about equal to the ratio of Sr-90 to calcium in soil solutions. Some plant parts have higher concentrations of strontium than others. In general, the lowest concentrations of strontium from root absorption are found in plant reproductive organs, while the highest concentrations are found in foliage.

5.2.2 Basis for the Wyhl Report's Values for Soil to Plant Transfer of Strontium

The Wyhl Report gives soil to plant transfer values for strontium for six types of vegetation. The soil to plant transfer values (FW) range from 0.75 for potatoes to 15 for root vegetables. These values are based on 12 references listed in the section on strontium transport factors (i.e, Section 6.2.7). We have obtained and reviewed 10 of the 12 references. The Wyhl Report references have been divided into two groups: (1) greenhouse experiements and (2) field studies. The methodology used in reviewing these references is more fully described in Appendix B.

5.2.2.1 Greenhouse Experiments

1. Plant Uptake of Sr-90, Ru-106, Cs-137 and Ce-144 from Three Different Types of Soils - Romney et al. (1954)[23]

Romney et al. measured the concentration of several fission products, including Sr-90 and Cs-137, in three common food crops grown on three different types of soils. Plants were grown in 1.6 Kg of soil in plastic-lined clay pots. Watering of plants was carefully controlled. Activity was measured in the following plant species and plant parts: (1) barley - forage and grain, (2) bean - leaves, stems and fruit, and (3) radish - top and root. Plants were grown on three agricultural soils which had a wide range of chemical properties: (1) Sassafras sandy loam, (2) Hanford sandy loam, and (3) Sorrento fine sandy loam.

Strontium soil to plant transfer factors (FW) were derived from the reported soil and plant concentrations. Strontium soil to plant transfer factors are given in Table 5.6. Plant parts are classified into two groups: (1) the edible plant part eaten by humans; and (2) the edible plant part that could be eaten by animals. Soil to plant transfer factors (FW) for plant parts eaten by humans ranged from 0.2 for bean fruit grown on Sorrento soil to about 5.4 for radish roots grown on Sassafras soil. Soil to plant transfer factors (FW) varied by about an order of magnitude for different soils. The average B_{iv}(FW) for human edible plant parts grown on the three soils was 1.6 ± 1.8.

Table 5.6. Sr-90 Soil to Plant Transfer Factors (FW) for Common Food Crops[a]

Edible Plant Part	Soil Type: Sassafras	Soil Type: Hanford	Soil Type: Sorrento
Humans			
Barley/Grain	-	1.73	-
Bean/Fruit	1.94	0.54	0.20
Radish/Root	5.36	0.41	0.21
Average ± s	3.65 ± 2.42	0.89 ± 0.73	0.21 ± 0.01
Animals			
Barley/Forage	21.1	5.75	2.49
Bean/Leaves & Stems	7.35	3.05	1.56
Radish/Top	17.3	5.05	2.28
Average ± s	15.3 ± 7.1	4.62 ± 1.40	2.11 ± 0.49
Humans & Animals			
Average ± s	9.5 ± 8.2	2.8 ± 2.6	1.2 ± 1.3

[a] B_{iv} (FW) values were derived from Romney et al. (1954) by dividing the reported plant concentrations by the reported soil concentration (100 dps/g of soil), and using the following FW/DW ratios: barley/grain, 1.1; bean/fruit, 9.0; radish/root, 15.6; barley/forage, 1.1; bean/leaves and stems, 4; and radish/top, 4.

Soil to plant transfer factors (FW) for plant parts that may be eaten by animals ranged from 1.6 for bean leaves grown on Sorrento soil to 21.1 for barley forage grown on Sassafras soil. Soil to plant transfer factors varied by about an order of magnitude for different soils. The average B_{iv}(FW) for animal edible plant parts grown on the three soils was 7.3 ± 7.0.

The Wyhl Report uses a B_{iv} for root vegetables (15) that is about 3 times higher than the largest value derived from Rmoney et al for radish roots (5.4). The Wyhl Report's B_{iv} for cereal grain (1.67) is about equal to the value derived from Romney et al for barley (1.7).

2. Release of Sr-90 and Cs-137 from Vina Loam upon Prolonged Cropping - Nishita et al. (1958)[7]

Nishita et al. measured Sr-90 and Cs-137 activity concentrations in Ladino clover. The objective of this study was "to study the release of Sr-90 and Cs-137 from contaminated soils as a function of intensive and prolonged cropping." Carrier-free Sr-90 was mixed with Vina loam to give an activity concentration of 99.4 dps/g of soil. Exchangeable strontium levels were measured at the beginning of the experiment. About 90% of the Sr-90 initially added to the soil was in an exchangeable form at day zero. Plants were grown in 600 g of soil in 4-inch clay pots. Fertilizer was added to the pots at the beginning of the experiment and after the fifth harvest (day 286). Plant activity was reported in dps/gram of dry soil.

Derived B_{iv}(FW) values for clover tops varied from about 1.0 for plants harvested after 74 days to about 1.3 for plants harvested after 516 days (i.e., the ninth blooming stage of growth). Derived B_{iv}(FW) values for clover roots were about 25% lower than the corresponding values for clover tops. The average B_{iv} (FW) was $\bar{1.0} \pm 0.1$ and 0.75 ± 0.05 for clover tops and clover roots, respectively. The above B_{iv} values are based on the total amount of Sr-90 added to the soil and a FW/DW ratio of 5 for forage grass. The amount of exchangeable strontium in soil gradually decreased from about 90% at day 0 to about 65% at day 516. The Wyhl Report's B_{iv} for clover (7.2) is about 5 times higher than the largest value reported by Nishita et al (1.3)

3. Influence of Stable Sr on Plant Uptake of Sr-90 from Soils - Romney et al. (1959)[24]

Romney et al. investigated the effect of different concentrations of stable strontium in soil on the soil to plant uptake of a strontium tracer. The purpose of the experiment was "to determine to what extent the addition of stable Sr to Sr-90 contaminated soils might reduce plant uptake of Sr-90." Two plant species (i.e. bean plants and Ladino clover) were grown on three soil types. The three soil types were selected because of their wide differences in chemical properties. The three soils used were (1) Sassafras sandy loam, (2) Hanford sandy loam, and (3) an alkaline - calcareous sandy loam from Yucca Flat, Nevada. The soils contained exchangeable native strontium in the following concentrations (meg./100g of air-dry soil): (1) Sassafras sandy loam, 0.002; (2) Hanford sandy loam, 0.032; and (3) Yucca Flat sandy loam, 0.172.

Bean plants were grown in 1.6 Kg of soil per pot for the three soil types. Clover was grown in 20 Kg lots for only one soil type - Hanford sandy loam. The concentration of Sr-90 in equilibrium with Y-90 was 100 dis./sec/g of soil.

The strontium uptake of bean tops varied for different soils by a factor of about 20. For the control case (i.e., the case in which stable strontium was not added to the soil) the following B_{iv}(FW) values were derived for bean tops: (1) Sassafras sandy loam, approximately 2.2; (2) Hanford sandy loam, approximately 1; and (3) Yucca Flat sandy loam, approximately 0.1. The above B_{iv} values are based on an FW/DW ratio of 9 for bean tops. The average B_{iv} (FW) is 1.1 ± 1.1.

The strontium uptake of clover grown on Hanford soil for the control case decreased with the age of harvest. For the control case the following B_{iv}(FW) values were derived for different harvest times: (1) 252-day cutting, 3.9; (2) 304-day cutting, 3.6; (3) 329-day cutting, 3.7; (4) 423-day cutting, 3.2; and (5) 551-day cutting, 2.6. The above B_{iv} values are based on an FW/DW ratio of 5 for forage grass. The Wyhl Report's B_{iv} for clover (7.2) is about twice as large as the average value derived from Romney et al for clover (3.4).

4. Uptake of Strontium by Pasture Plants and its Possible Significance in Relation to the Fall-out of Strontium-90 - Vose and Koontz (1959)[25]

Vose and Koontz investigated the soil to plant uptake of stable strontium for different forage species and different soil types. Forage species were classified as grasses or legumes. Eight grass species and eight legume species were grown in 1-gallon stone crocks. Plants were grown in the following soil types (1) Nord fine sandy loam; (2) Yolo fine sandy loam; and (3) Sacramento fine sandy loam. The strontium content of plants and soils was determined by X-ray spectrograph. Soils were extracted with ammonium acetate - ammonia at pH 9.0. Plants were harvested at eight weeks when the plants were beginning to flower or reach maximum vegetative growth.

Strontium plant concentrations and strontium soil to plant transfer factors are reported in Table 5.7. The average B_{iv}(FW) for grasses ranged from 0.43 for Nord fine sandy loam to 0.98 for Sacramento fine sandy loam. The average B_{iv}(FW) for grasses for all soil types was 0.67 ± 0.28. The average B_{iv}(FW) for legumes for all soil types (2.4 ± 1.2) was about 3.5 times greater than for grasses.

The author does not discuss the relation between extractable strontium from soils and total strontium in soils. If the total strontium soil concentration is significantly greater than the extractable strontium concentration, then the above soil to plant transfer factors would be too high.

The Wyhl Report's B_{iv} for grass (3.2) is about 2 times greater than the highest value reported by Vose and Koontz for grass (1.4). The Wyhl Report's B_{iv} for clover (7.2) is larger than the highest value reported by ose and Koontz for legumes (4.8)

5. Comparative Sr-90 Content of Agricultural Crops Grown in a Contaminated Soil - Evans et al. (1962)[26]

Evans et al. measured the Sr-90 content of 36 species of plants grown on Greenville loam obtained from Ontario, Canada. The plant species used in this study represent cereal, forage, and vegetable species important to Canadian agriculture. Plants were grown in 2.5 kg of soil in 5-pint plastic pots. Strontium-90 (51.6 mCi) was mixed with the soil prior to planting.

Strontium-90 concentration and soil to plant transfer factors (FW) of various species are given in Tables 5.8, 5.9, and 5.10 for cereal crops, forage crops, and vegetable crops, respectively. Soil to plant transfer factors (FW) for cereal crops vary from about 0.03 for corn grains to about 2.2 for flax straws. The average B_{iv}(FW) for cereal crops is about 0.7 $\pm$ 0.8. The above B_{iv} values are based on an FW/DW ratio of 1.1. Soil to plant transfer factors (FW) for forage crops and tobacco vary from about 0.2 for wheat grass to about 1.0 for sweet clover, erector. The average B_{iv}(FW) for forage crops and tobacco is about 0.9 $\pm$ 1.1. Soil to plant transfer factors (FW) for vegetable crops vary from about 0.01 for tomato fruit to about 2.6 for cucumber tops. The average B_{iv}(FW) for vegetable crops is about 0.5 $\pm$ 0.6.

The range of B_{iv} for all crops extends from about 0.01 for tomato fruit to about 2.6 for cucumber tops. The average B_{iv}(FW) of cereal crops (0.7), forage crops (0.9), and vegetable crops (0.5) is 0.7$\pm$ 0.2.

Table 5.7 Stable Strontium Soil to Plant Transfer Factors for Forage Species Grown on Three Soil Types[a]

Species	Nord fine sandy loam		Yolo fine sandy loam		Sacramento fine sandy loam	
	Plant Sr (meq/g)	B_{iv}(FW)	Plant Sr (meq/g)	B_{iv}(FW)	Plant Sr (meq/g)	B_{iv}(FW)
Grasses						
Bromus inermis, Manchar	1.49	0.56	0.83	0.70	1.25	1.42
Lolium perenne, Oregon Commercial	1.31	0.50	0.74	0.62	0.89	1.01
Lolium perenne, S.101	1.19	0.45	0.71	0.60	0.89	1.01
Festuca elatior, Late Otofte	1.19	0.45	0.65	0.55	0.89	1.01
Festuca arundinacea, Alta	1.07	0.41	0.71	0.60	0.89	1.01
Phleum pratense, American Commercial	1.01	0.38	0.59	0.50	0.59	0.67
Phalaris puberosa, Harding-grass	0.95	0.36	0.71	0.60	0.71	0.81
Dactylis glomerata, Potomac	0.93	0.35	0.65	0.55	0.77	0.88
Average ± s		0.43 ± 0.07		0.59 ± 0.06		0.98 ± 0.22
Legumes						
Trifolium subterraneum, Tallarook	4.70	1.78	3.99	3.35	4.22	4.80
Medicago sativa, Caliverde	3.81	1.44	2.44	2.05	2.65	3.01
Trifolium fragericum, Salinas	3.57	1.35	2.20	1.85	2.74	3.11
Trifolium repens, S.100	3.51	1.33	1.96	1.65	2.62	2.98
Trifolium repens, Dutch White	3.27	1.24	2.84	2.39	3.45	3.92
Trifolium pratense, Kenland	3.20	1.21	2.47	2.08	3.99	4.53
Trifolium repens, Landino	3.09	1.17	2.74	2.30	3.57	4.06
Lotus corniculatus, Los Banos	2.53	0.96	1.67	1.40	2.38	2.70
Average ± s		1.31 ± 0.24		2.13 ± 0.59		3.63 ± 0.79

[a]Soil to plant transfer factors were derived from the plant concentrations in Vose et al. (1959) using the following soil extractable strontium soil concentrations (meq/g) reported by the authors:[26] (1) Nord fine sandy loam, 0.528; (2) Yolo fine sandy loam, 0.238; and (3) Sacramento fine sandy loam, 0.176. A FW/DW ratio of 5 was used to convert to FW values.

The Wyhl Report's B_{iv} values exceed (by factors ranging from 2 to 65) the maximum values reported in Evans as follows: grass - Wyhl, 3.2, Evans, 0.36; clover - Wyhl, 7.2, Evans 1.0, (Sweetclover) and 3.5 (alfalfa); leafy vegetables - Wyhl, 2.5, Evans 1.3 (pea tops); potatoes - Wyhl, 0.75, Evans, 0.03; root vegetables - Wyhl, 15, Evans, 0.23 (onion); and cereal grains - Wyhl, 1.67, Evans, 0.11 (barley grain).

6. Influence of Liming and Mineral Fertilization on Plant Uptake of Radiostrontium from Danish Soils - A. J. Anderson (1963)[27]

The purpose of this study was to determine the uptake of strontium by rye grass and red clover, and to investigate the effect of moderate liming and mineral fertilization on strontium uptake. Plants were grown in a greenhouse for 11 months during which period six harvests were made. Typical Danish agricultural soils were used. Carrier free ^{89}Sr or ^{90}Sr were mixed with soil samples. Rye grass and red clover were grown in PVC pots, each containing 800 g air-dried soil.

Plant and soil concentrations were reported in this paper for plants grown under a number of growth conditions. Based on the plant and soil concentrations, B_{iv} values were derived for the control case (i.e., no added lime or fertilizer). Derived B_{iv}(FW) values for rye grass grown on 20 different soils ranged from 0.2 to about 0.9. The average B_{iv}(FW) for rye grass grown on 20 soils was about 0.5 $\pm$ 0.2. Average soil to plant transfer factors (FW) for red clover (1.4 $\pm$ 0.6) were about three times higher than for rye grass. Soil to plant transfer factors for red

Table 5.8 Strontium Soil to Plant Transfer Factors for Cereal Crops, Flax and Corn

Plant Sample	Plant Sr-90 (nCi/g.)	B_{iv}(FW)[1]
Oat straw	28.41	1.25
Oat grain	2.18	0.10
Rye straw	31.97	1.40
Rye grain	1.65	0.07
Wheat straw	22.33	0.98
Wheat grain	1.25	0.05
Barley straw	34.61	1.53
Barley grain	2.50	0.11
Flax straw	50.77	2.24
Flax seed	14.28	0.63
Corn stalks	15.56	0.18
Corn grain	0.55	0.03
Average $\pm$ s	17.2 $\pm$ 16.6	0.71 $\pm$ 0.75

[1] B_{iv}(FW) was obtained by dividing the plant concentrations given in Evans et al. (1962) by the soil concentration (20.64 nCi/g).[26] B_{iv}(FW) values are based on a FW/DW ratio of 1.1 for grains and straw.

Table 5.9 Strontium Soil to Plant Transfer Factors for Forage Crops and Tobacco

Plant Sample	Plant Sr-90 (nCi/g.)	$B_{iv}(FW)$[a]
Brome grass	31.26	0.30
Timothy	19.11	0.19
Crested wheat grass, Fairway	19.36	0.19
Crested wheat grass, Summit	29.45	0.29
Creeping red fescue	36.94	0.36
Reed canary grass	30.37	0.29
Green needle grass	24.05	0.23
Alfalfa	80.01	3.53
Sweet clover, Erector	107.45	1.04
Sweet clover, Arctic	94.73	0.92
Red clover	91.30	0.88
Alsike clover	70.94	0.69
White clover	75.86	0.74
Birdsfoot trefoil	76.44	0.93
Soybean, straw	99.16	4.36
Soybean, seed	10.82	0.47
Sugar beet, tops	83.63	1.01
Sugar beet, root	23.47	0.29
Tobacco	79.66	0.97
Average $\pm$ s	57.1 ± 32.8	0.9 ± 1.1

[a]$B_{iv}(DW)$ was obtained by dividing the plant concentrations in Evans et al. (1962) by the reported soil concentration (i.e., 20.64 nCi/g).[26] $B_{iv}(FW)$ values are derived from $B_{iv}(DW)$ values using the following FW/DW ratios: (1) all grasses, 5.0; (2) alfalfa is assumed to be in the form of a hay (1.1) rather than a grass (5.0); (3) clover, 5.0; (4) birdsfoot trefoil, 4; (5) soybean straw and seed, 1.1; and (6) sugarbeets and tobacco, 4.

Table 5.10 Strontium Soil to Plant Transfer Factors for Vegetable Crops

Plant Material	Plant Sr-90 (nCi/g.)	B_{iv}(FW)[1]
Cabbage, outer leaves	89.51	0.33
Cabbage, head	19.54	0.07
Cauliflower, leaves	79.47	0.32
Cauliflower, head	9.52	0.03
Lettuce, tops	43.82	0.11
Spinach, tops	77.58	0.27
Pea, tops	102.94	1.28
Pea, seed (green shelled)	4.41	0.05
Bean, tops	115.43	0.62
Bean, seed (green shelled)	17.18	0.09
Carrot, tops	108.29	1.31
Carrot, root	25.56	0.15
Turnip, tops	145.16	0.74
Turnip, root	30.32	0.13
Potato, tops	77.45	0.94
Potato, tuber	3.09	0.03
Onion, bulb and tops	38.54	0.23
Cucumber, tops	215.43	2.61
Cucumber, fruit	21.47	0.04
Tomato, tops	67.77	0.82
Tomato, fruit	4.92	0.01
Celery, tops	98.73	0.30
Average ± s	63.5 ± 54.1	0.48 ± 0.62

[1]B_{iv}(DW) was obtained by dividing the reported plant concentrations in Evans et al. (1962) by the reported soil concentration (i.e., 20.64 nCi/g).[26]

clover grown on the 20 soils ranged from about 0.3 to 2.9. The average B_{iv}(FW) for the two plant species grown on 20 types of soils was about 1.0 ± 0.6. The above B_{iv} values are based on an FW/DW ratio of 5 for rye grass and clover. The effect of liming and fertilizer on B_{iv} was small in comparison with the range of B_{iv} values for different plant species grown on different soils.

The Wyhl Report's B_{iv} for grass (3.2) and clover (7.2) is more than 2.5 times higher than the largest values (0.9 and 2.9 for grass and clover respectively) reported by Anderson for the control case.

7. Soil-Plant Relationships of Radioactive Elements - Menzel (1965)[28]

Menzel estimated values for soil to plant transfer (DW) of 40 elements. Elements were grouped into one of five categories ranging from strongly concentrated to strongly excluded. Strontium was listed in the slightly concentrated category (i.e., B_{iv}(DW) from 1 to 100).

Menzel references six papers as the basis for this classification for strontium. The materials and procedures of the referenced papers is not described in detail. However, only papers in which water soluble forms of strontium were added to soil were considered in obtaining references. Menzel does not state whether the classification of strontium is based on field or greenhouse experiments. Since most of the strontium references cited by Wyhl are greenhouse experiments, we have somewhat arbitrarily included this paper in this section. Based on an FW/DW ratio of 4, then B_{iv}(FW) ranges from 0.25 to 25 with a midpoint of about 12.6 ± 17.5.

The Wyhl Report's B_{iv} values for strontium are within the range given by Menzel.

8. Accumulation of Cs-137 and Sr-85 by Florida Forages in a Uniform Environment - Garrett et al. (1971)[9]

Garrett et al. measured the ratio of soil to plant radionuclide content for both Cs-137 and Sr-85 in nine forage species that are common to Florida. Following periods of radioactive fallout, the Cs-137 level in Florida milk was consistently higher than the national average. This study was designed to identify the causes of the higher than average Cs-137 levels in Florida milk. Uptake of strontium was investigated to determine if there were interspecie differences in soil to plant uptake of other nuclides than Cs-137.

Aqueous high specific activity ^{85}Sr Cl (1 mCi) was thoroughly mixed with 2500 grams of soil (Leon series soil). Forage was grown in shallow (4 cm deep) containers about 2 liters in volume. Leon series soil is a typical Florida soil representing about 26% of the Florida land area. A number of soil parameters for Leon series soil are given; however, neither the potassium nor calcium concentration of the soil was given. Soil moisture was controlled to about 15% moisture content by daily watering. Samples were oven-dried and analyzed by gamma spectroscopy. The ratio of plant to soil radionuclide content (FW) for Sr-85 varied from a 0.8 for bahiagrass to 3.0 for white clover. The unweighted average ratio of plant to soil radionuclide content (FW) for Sr-85 for the nine grasses was about 1.7 $\pm$ 0.6. The above B_{iv} values are based on a FW/DW ratio of

5 for forage grass. The Wyhl Report's B_{iv} for grass (3.2) and clover (7.2) is more than 1.5 times higher than the largest values (2.1 and 3.0 respectively) reported by Garrett et al.

5.2.2.2 Field Studies

1. Isotopes and Radiation in Soil-Plant Relationships Including Forestry - D'Souza et al (1972)[11]

D'Souza et al. studied the distribution of the radionuclides in grass growing in four typical Belgium pasture soils. Soils were artificially contaminated with radiostrontium and radiocesium under both field and greenhouse conditions. Soils were sprayed with Sr-85 in amounts ranging from 10 to 100 mCi/m^2. The time of spraying grass with Sr-85 was not given, and its is not clear whether decay has been taken into account in the reported soil surface contaminations.

Plant concentrations (pCi/g (DW)) ranged from about 250 pCi/g to about 4000 pCi/g for soils sprayed with 10 mCi/m^2. Assuming the effective surface density of 240 kg/m^2 in Regulatory Guide 1.109, then the surface concentration of 10 mCi/m^2 converts to a soil concentration of 41.7 pCi/g. Based on this assumption, then B_{iv}(FW) values ranged from 1 to 19. The average B_{iv}(FW) for grass grown on four soils and sampled for two time periods was 5.3 $\pm$ 1.6. The above B_{iv} values are based on an FW/DW ratio of 5 for grasses. The Wyhl Report's B_{iv} for grass (3.2) is about one-half of the average value obtained from d'Souza et al.

2. Environmental Radioactive Pollution and Man - A. N. Marei (1973)[13]

This article is contained as Chapter 7 in a book entitled Radioecology edited by V. M. Klechkovskii and G. G. Polikarpov. The chapter is mainly concerned with the migration of Sr-90 and Cs-137 from the environment to man. The chapter contains a brief summary of the migration of Sr-90 and Cs-137 from soils into grass and milk. The chapter also discusses human intake and metabolism of these isotopes.

Marei references a previous publication by the author for migration values of Sr-90 from three soil types to grass: (1) 0.72; (2) 2.34, and (3) 0.50. If it is assumed that these migration values are equivalent to B_{iv}(DW) values, then the average B_{iv}(FW) is about 0.2 $\pm$ 0.2. The procedures and methods used in determining the above migration values is not described in this paper. The Wyhl Report's B_{iv} for grass (3.2) exceeds the highest value reported by Marei.

5.2.2.3. Summary and Conclusions of Review of Wyhl References for Soil to Plant Transfer of Strontium

1. The papers that were reviewed contained a large range of soil to plant transfer factors. The range of B_{iv} values reported by the various authors is given in Table 5.11 and 5.12 for greenhouse experiments and field studies, respectively.

2. The majority of the Wyhl Report's references (8 out of 10) that were reviewed are greenhouse experiments. The other two references are field

studies. As noted earlier, greenhouse experiments are useful for comparing plant uptake in different soils and determining the relative effect of liming and fertilizer on plant uptake. However, greenhouse experiements are not as likely to provide good quantitative estimates of soil to plant uptake. Russell has stated, "However, even if large containers are used, the development of roots is likely to contrast with that where plants are grown under field conditions. If experiments are to provide reliable quantitative information for predicting the long-term consequences either of world-wide fallout or of possible discharges from nuclear reactors, they must be carried out under the field conditions of normal agriculture."[3]

3. The Wyhl Report uses the following B_{iv} values for estimating the Sr concentration in plants: grass, 3.2; clover, 7.2; leafy vegetable, 2.5; potatoes, 0.75; root vegetables, 15; and cereal grains, 1.67. In most cases the B_{iv} values for strontium used in the Wyhl Report are based on soil and plant characteristics that tend to maximize the transfer of strontium from soil to plants. For example:

- The Wyhl Report's B_{iv} for grass (3.2) is larger than the <u>highest</u> values derived from Vose and Koontz (1.4), Evans (0.36), Anderson (0.9), Garrett (2.1), and Marei (2.3) for grass. The only B_{iv} values for grass that are larger than those in the Wyhl Report are those contained in d'Souza.
- The Wyhl Report's B_{iv} for clover (7.2) is larger than the <u>highest</u> values derived from Nishita et al (1.3), Romney et al (3.4), Vose and Koontz (4.8), Evans (3.5), Anderson (2.9), and Garrett (3.0) for clover and Alfalfa.

- The Wyhl Report's B_{iv} for leafy vegetables is larger than the highest value derived from Evans et al (1.3) for leafy vegetables.
- The Wyhl Report's B_{iv} for potatoes (0.75) is 25 times larger than the value derived from Evans et al for potatoes (0.03).
- The Wyhl Report's B_{iv} for root vegetables is larger than the highest values derived from Romney et al (5.4) and Evans et al (0.23) for root vegetables.

4. The amount of soil in which plants grew ranged from 0.6 kg/pot for Ladino clover (Nishita et al.)[7] to 2.5 kg for 36 species of plants (Evans et al.).[26] Larger pots allow more room for roots to develop in normal field conditions. None of the papers discussed root cramping.

5. All of the reviewed references had higher average soil to plant transfer of strontium than NRC's current value of 0.017. The references included a variety of crops grown on many soil types.

5.2.3 Basis for NRC Values for Soil to Plant Transfer of Strontium

As stated earlier, the soil to plant transfer values used in Regulatory Guide 1.109 are derived from a report entitled, "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere," (USAEC Report UCRL-50163, Part IV, October 1968) by Y. C. Ng et al.[15] Ng gives average concentrations of 100 elements in typical agricultural soil and portions of the human diet derived from plants. The average strontium concentration in soil (300 ppm) is derived from a book entitled, "The

Geochemistry of Rare and Dispersed Elements in Soils" by Vinogradov (1959).[17] Ng derived the average strontium concentration in plants (5 ppm on a fresh weight basis) from two references: (1) Strontium and Barium in Plants and Soils - Bowen (AERE-SPAR-4, 1955);[29] and (2) Strontium-90 in the Australian Environment, 1957 to 1960 - Bryant (1962).[30] Dry weight literature values for plant concentrations were converted to wet weight values by assuming the water concentration to be 75%. The soil to plant transfer factor for strontium used in Regulatory Guide 1.109, was obtained by dividing the average plant concentration (5 ppm, FW) by the average soil concentration (300 ppm) to get a value of 0.017. The physical basis upon which this value is based is presented in Appendix C.

As part of our effort to periodically update the models in Regulatory Guide 1.109, we have also included in this report a recent paper by Y. C Ng entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products."[22] Soil to plant transfer factors, as a function of soil texture, are reproduced from Ng's paper in Table 5.5. This table shows that NRC's soil to plant transfer factors for strontium (i.e., 0.017) is low for a number of plants grown in three soils with different soil texture. Baker has suggested that NRC's current value for B_{iv} for strontium should be raised by about an order of magnitude to 0.2.[31] A value of 0.2 would be realistically conservative for most plants consumed by humans grown on most soils. However, B_{iv}(FW) values for crops normally eaten by animals are slightly higher than values for plants consumed by humans. A value of 1.0 would be realistically conservative for most plants consumed by animals on most soils (see Appendix C for a more thorough discussion of Ng's paper). B_{iv} values of 0.2 and 1.0 for crops consumed by humans and crops consumed by animals, respectively, would

Table 5.11 Range in Strontium Soil to Plant Transfer Factors Reported by Various Papers Cited in Wyhl Report - Greenhouse Experiments

Reference	B_{iv} (FW)			Parameters Examined
	Low	High	Unweighted Avg.	
Romney et al. (1954)	0.2	21.3	4.5 ± 4.0	Three common food crops grown on three soils with a wide range in chemical properties
Nishita et al. (1958)	0.7	1.3	0.9 ± 0.2	Clover tops and clover roots for times up to 1.5 years
Romney et al. (1959)	0.1	3.9	2.3 ± 1.6	Bean tops grown on three soil types, and clover harvested up to 1.5 years after planting
Vose and Koontz (1959)	0.3	4.8	1.5 ± 1.2	Sixteen forage species grown on three soil types
Evans et al. (1962)	0.01	2.6	0.7 ± 0.2	Thirty-six plant species that included cereal crops, forage crops, and vegetable crops.
Anderson (1963)	0.2	2.9	1.0 ± 0.6	Two forage species grown on 20 soil types
Menzel (1965)	0.25	25	12.6 ± 17.5	Derived B_{iv} values are based on a rough classification of elements according to their concentration factors.
Garrett et al. (1971)	0.8	3.0	1.7 ± 0.6	Nine forage species grown on a Florida soil with high soil to plant transfer characteristics for cesium

Table 5.12. Range in Strontium Soil to Plant Transfer Factors Reported by Various Papers Cited in Wyhl Report - Field Studies

Reference	B_{iv} (FW) Low	High	Unweighted Avg.	Parameters Examined
D'Souza et al. (1972)	1	19	5.3 $\pm$ 1.6	Grasses grown in covered and uncovered plots on four soil types
Marei (1973)	0.1	0.6	0.2 $\pm$ 0.2	Grass grown on three soils with high cesium soil to plant transfer characteristics

increase the estimate of activity in vegetation by a factor of about 2.6 to 5 for Sr-90, depending on vegetation type.

5.3 INGESTION DOSE CONVERSION FACTORS FOR CS-137 and SR-90

The Wyhl Report's ingestion dose conversion factors (DCFs) for Sr-90 and Cs-137 for the kidney and bone, respectively, are more than 10 times larger than the corresponding values used by NRC.

5.3.1 Basis for the Wyhl Report's Ingestion Dose Conversion Factor for Sr-90 and Cs-137

Chapter 8 of the Wyhl Report, "Examination of the Dose Factors," presents the ingestion dose conversion factors that were used in calculating doses to adults and children, and the technical basis for these DCFs.

The Wyhl Report's ingestion DCFs for Sr-90 (bone) and Cs-137 (kidney) are compared with NRC's and ORNL's corresponding DCFs in Table 5.13.

Strontium-90

The Wyhl Report's Sr-90 DCF for the bone (0.096 mrem/pCi) is more than 12 times greater than the value used by NRC (i.e., 0.0076 mrem/pCi). In their discussion of DCFs for strontium, the Wyhl Report states that the International Commission on Radiological Protection's (ICRP) transfer factor from the gastrointestinal tract to bone for Sr-90 is too low. ICRP uses a transfer factor from the gastrointestinal tract to bone of 0.09 for stable strontium and Sr-90, and a value of 0.21 for Sr-85, Sr-85m, Sr-89, Sr-91 and Sr-92.[32] Strontium-85, Sr-85m, Sr-89, Sr-91 and Sr-92 have effective half lives ($T_{1/2}$ less than 65 days) that are much shorter than Sr-90 ($T_{1/2}$ = 17.5 years) and stable strontium. Since the transfer factor of 0.09 for Sr-90 is based on "a personal communication (Durbin to Morgan 8/7/58)[33] which cannot be checked and which apparently is unpublishable," it is dismissed. However, even increasing the Sr-90 transfer factor by about 2.3 (i.e, from 0.09 to 0.21) does not explain a more than 12 fold increase in the DCF.

Cesium-137

The Wyhl Report uses a DCF of 0.00144 mrem/pCi in calculating the dose to the kidney from ingestion of Cs-137. This value for Cs-137 DCF for the kidney is about 40 times greater than the corresponding value used by NRC (i.e., 0.000037 mrem/pCi) to calculate the adult kidney dose. The Wyhl Report does not discuss the basis for their higher value.

5.3.2 Basis for NRC's Ingestion Dose Conversion Factors for Cs-137 and Sr-90

NRC's adult ingestion dose conversion factors (DCFs) are given in Table E-11 of U.S. NRC Regulatory Guide 1.109. The basis for the ingestion dose conversion factors in Regulatory Guide 1.109 is described in a document entitled "Age-Specific Radiation Dose Committment Factors For a One-Year Chronic Intake" (NUREG-0172).[34] The equations for calculating internal dose conversion factors in NUREG-0172 were derived from those given in ICRP Publication 2, "Report of ICRP Committee II on Permissible Dose for Internal Radiation."[32]

Table 5.13: Comparison of Wyhl Report's Ingestion Dose Conversion Factors for Sr-90 (Bone) and Cs-137 (Kidney)

Isotope/Organ	Adult Ingestion Dose Conversion Factors, mrem/pCi		
	Wyhl[a]	NRC[b]	ORNL[c]
Sr-90/Bone	9.6×10^{-2}	7.6×10^{-3}	1.2×10^{-3}
Cs-137/Kidney	1.44×10^{-3}	3.7×10^{-5}	7.73×10^{-5}

[a] Ingestion dose conversion factors (DCFs) are from Table 8-1 of the Wyhl Report.

[b] NRC's DCFs are from Table E-11 of Regulatory Guide 1.109.

[c] ORNL's DCFs are from p. 312 of NUREG/CR-0510, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities." The ingestion DCF for Sr-90 is based on a transfer fraction of 0.20 from the GI tract to blood. The DCFs in this document are presented primarily to compare the results of various methodologies. These DCFs have not been endorsed or recommended by ORNL.

As stated in our Regulatory Guides, the procedures and models in Regulatory Guides are subject to continuing review by the staff. Currently, NRC's Office of Regulatory Research has a contract with Oak Ridge National Laboratory (ORNL) entitled "Dosimetry and Biotransport Models to Implement ALARA." The objective of this contract is to assemble the latest data and models to calculate a unified set of internal dose conversion factors. ORNL has published three documents under this contract: (1) "SFACTOR: A Computer Code for Calculating Dose Equivalent to a Target Organ per Microcurie-Day Residence of a Radionuclide in a Source Organ" (ORNL/NUREG/TM-85); (2) "INREM II: A Computer Implementation of Recent Models for Estimating the Dose Equivalent to Organs of Man from an Inhaled or Ingested Radionuclide" (NUREG/CR-0114); and (3) "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities, Vol. 1" (NUREG/CR-0150).[35, 36, 37] The last document (NUREG/CR-0150) contains a set of DCFs that were calculated by ORNL primarily to compare the results of various methodologies. Although these DCFs have not been endorsed or recommended by ORNL, we include them here for illustrative purposes. Table 5.14 compares the Wyhl Report's ingestion DCFs for Sr-90 and Cs-137 with ORNL's DCFs. The Wyhl Report's Sr-90 ingestion DCF is 80 times greater than the value in NUREG/CR-0150. The Wyhl Report's CS-137 ingestion DCF is about 19 times greater than the corresponding value in NUREG/CR-0150.

5.4 SUMMARY AND CONCLUSIONS OF CRITICAL PARAMETERS FOR CS-137 and SR-90 IN RADIOLOGICAL ASSESSMENT MODELS

This chapter reviews the technical basis for several parameters for Cs-137 and Sr-90. These nuclides are critical to the Wyhl Report's ingestion dose estimates for the maximum individual. Most of the Wyhl Report's references for soil to plant transfer (B_{iv}) of Cs and Sr, as well as their basis for ingestion dose conversion factors (DCFs) for Cs-137 (Kidney) and Sr-90 (bone) have been reviewed. The technical basis for corresponding NRC values for Cs-137 and Sr-90 is given.

5.4.1 Soil to Plant Transfer of Cesium and Strontium

The Wyhl Report references over 20 papers for soil to plant transfer (B_{iv}) of cesium and strontium. Most of the Wyhl Report's references are greenhouse experiments as opposed to field studies. Greenhouse experiments are not as likely to provide good quantitative estimates of soil to plant uptake as field studies. In most cases the B_{iv} values for cesium and strontium are based on soil and plant characteristics that maximize transfer from soil to plants. For example:

- The Wyhl Report's B_{iv} for cesium exceeds or is about equal to the highest values derived from the reviewed references for 4 of the 6 vegetation categories (clover, leafy vegetables, potatoes and cereal grain). The Wyhl Report's B_{iv} for grass is larger than the highest value derived from 3 of the 5 references on soil to grass transfer. Only the Garrett et al and Marei references support the Wyhl Report's B_{iv} for grass. The B_{iv} values derived from Garrett et al are for a soil with high soil to plant transfer characteristics for cesium. The experimental basis for the B_{iv} values in Marei is not described in sufficient detail to give it much weight. Although the Wyhl Report's reference on root vegetables was not reviewed, the B_{iv} for root vegetables also appears to be based on the highest values observed.

. The Wyhl Report's B_{iv} for strontium exceeds the <u>highest</u> values derived from the references reviewed for four of the six vegetation categories (clover, leafy vegetables, potatoes, and root vegetables). The Wyhl Report's B_{iv} for grass is larger than the <u>highest</u> values derived from 5 of the 6 references concerning soil to grass transfer. The Wyhl Report's B_{iv} for cereal grains (1.67) exceeds the highest value reported by Evans (0.11); it is about equal to the highest value reported by Romney et al (1.7).

Consequently, the Wyhl Report's estimated doses from the air to food pathway are unrealistically high because of the use of unrealitic B_{iv} values for cesium and strontium. The use of high values for other parameters (e.g., feed to milk, feed to meat, and ingestion rates) in series with maximum B_{iv} leads to an even more unrealistic model. Chapter 6 compares results from the Wyhl Reports radiological model with measured concentrations of radionuclides in the environment around operating nuclear power plants.

NRC's soil to plant transfer values used in Regulatory Guide 1.109 are derived from a report entitled "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere." (USAEC Report UCRL-50163, Part IV, October, 1968) by Y. C. Ng et al.[15] NRC's B_{iv} values are based on soil to plant transfer of stable elements in soil. NRC values are based primarily on field studies as opposed to greenhouse experiments.

Since the Wyhl Report includes many references that have higher <u>average</u> soil to plant tranfer factors for cesium and strontium than NRC's current values of

0.01 and 0.017, respectively, we have taken this opportunity to update NRC's values for these factors.

As part of our effort to periodically update the models in Regulatory Guide 1.109, we have also included in this report a paper presented by Y. C. Ng at the International Atomic Energy Agency's (IAEA) Symposium on Biological Implications of Radionuclides Released from Nuclear Industries. Ng's paper was entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products."[22] In this paper Ng presented updated values for transfer of radionuclides to plants, milk and other animal products.

Based on our review of Ng's paper, the references cited in Ng's paper (see Appendix D), as well as the Wyhl Report, we are considering the following changes in values for soil to plant transfer (fresh weight (FW) basis) of cesium and strontium in future revisions of Regulatory Guide 1.109. These proposed valves would be used in the interim.

1. The B_{iv} value for Cs would be increased from 0.01 to 0.02. Doubling NRC's present value for cesium (0.01) would lead to a more conservative value for fine, medium, and coarse soil textures. Since aerosol deposition dominates the air to plant transfer of cesium, a B_{iv} value of 0.02 slightly increases the estimate of activity in vegetation (by less than 10%).

2. The B_{iv} value for strontium would be increased from 0.017 to 0.2 for plants consumed by humans and to 1.0 for plants consumed by animals. These B_{iv} values should be realistically conservative for most plants grown on fine

medium and coarse soil textures. Use of these values would result in an increase in previous estimates of activity in vegetation by a factor of about 2.6 to 5 for Sr-90, depending on vegetation type.

5.4.2 Ingestion Dose Conversion Factors for Strontium-90 and Cesium-137

The Wyhl Report's ingestion DCFs for Sr-90 and Cs-137 for the kidney and bone, respectively, are more than 10 times larger than the values used by NRC. The Wyhl Report's main criticism of the Sr-90 DCF for bone is that the transfer factor (0.09) used by the International Commission on Radiological Protection (ICRP) is based on "a personal communication (Durbin to Morgan 8/7/58) which cannot be checked and which is apparently unpublishable." However, the Wyhl Report does not reference any new documents that would discredit the ICRP's value of 0.09. The Wyhl Report's value for Cs-137 DCF for the kidney is about 40 times greater than the corresponding value used by NRC. The Wyhl Report does not provide any new references to support their use of this much higher number. Consequently, the Wyhl Report's estimated bone and kidney doses are unrealistically high because of the use of unrealistic DCFs for Sr-90 (bone) and Cs-137 (kidney).

The basis for the ingestion dose conversion factors in U.S. NRC Regulatory Guide 1.109 is described in a document entitled "Age-Specific Radiation Dose Committment Factors for a One-Year Chronic Intake" (NUREG-0172).[34] The equations for calculating internal dose conversion factors in NUREG-0172 were derived from those given in ICRP Publication 2, "Report of ICRP Committee II on Permissible Dose for Internal Radiation."[32]

As stated in NRC's Regulatory Guides, the procedures and models in Regulatory Guides are subject to continuing review by the staff. Currently, NRC's Office of Regulatory Research has a contract with Oak Ridge National Laboratory (ORNL) entitled "Dosimetry and Biotransport Models to Implement ALARA." The objective of this contract is to assemble the latest data and models to calculate a unified set of internal dose conversion factors. Results from NRC's contract with ORNL and similar studies will be incorporated into Regulatory Guide 1.109 in a timely fashion.

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6. COMPARISON OF WYHL REPORT'S RADIOLOGICAL MODEL WITH ENVIRONMENTAL MONITORING DATA

Earlier chapters in this review have analyzed individual components of the Wyhl Report's radiological model. A number of deficiencies in values of several parameters in the Wyhl Report's model have been identified. However, the ultimate test of a model is to compare its predictions with measured values. This chapter compares the Wyhl Report's estimate of radionuclide concentrations in the environment with measured concentrations around nuclear power plants in the United States.

6.1 <u>Environmental Concentrations of Radionuclides Predicted by the Wyhl Report</u>

Although the Wyhl Report does not give predicted values of radionuclides in environmental samples, these values can be derived from the Wyhl Report in the following manner. The Wyhl Report contains several tables listing expected radiation exposure to adults (see Chapter 9 of the Wyhl Report). Concentrations of radionuclides in foods were derived by dividing the expected dose by the product of the corresponding ingestion dose conversion factors and the annual consumption of the food. Concentrations of radionuclides due to airborne releases are listed in Tables 6.1, 6.2, and 6.3 for vegetation, meat, and milk, respectively.

10 CFR Parts 20 and 50 require that radiological environmental monitoring programs be established to provide data on measurable levels of radiation and radioactive materials in the site environs of nuclear power plants. NRC Regulatory Guide 4.1, Rev. 1, "Programs for Monitoring Radioactivity in the

Table 6.1: Concentration of Radionuclides in Vegetation Derived from Wyhl Report

Nuclide	Vegetation Concentrations, pCi/kg Wet Weight[a]			
	Leafy Vegetables	Potatoes	Root Vegetables	Cereal Grains
Co-58	7.4	0.3	0.1	2.1
Co-60	14.9	4.3	3.9	21.6
Zn-65	11.4	2.9	2.4	10.1
Sr-89	1.1	< 0.1	0.2	0.1
Sr-90	59.7	17.6	348.8	40.2
I-131	27.2	0.0	0.0	0.0
Cs-134	40.1	463.1	3.2	32.9
Cs-137	760.1	14340.0	7.0	516.1
Ce-144	6.7	0.9	0.6	7.2
Pu-239	0.1	0.1	0.1	0.1

[a]Radionuclide concentrations in vegetation were derived from the Wyhl Report by dividing the adult bone dose (Table 9-1) by the product of the corresponding ingestion dose conversion factor (Table 8-1) and the annual adult consumption of vegetation (Table 7.1.3-4).

Table 6.2: Concentration of Radionuclides in Meat Derived from Wyhl Report

Nuclide	Meat Concentrations, pCi/kg[a]	
	Beef	Pork
Co-58	15.5	0.2
Co-60	33.7	0.7
Zn-65	82.1	78.8
Sr-89	0.4	< 0.1
Sr-90	15.6	1.6
I-131	168.0	64.3
Cs-134	1476.0	761.4
Cs-137	35080.0	20600.0
Ce-144	1.5	0.1
Pu-239	< 0.1	< 0.1

[a]Radionuclide concentrations in meat were derived from the Wyhl Report by dividing the adult bone dose (Table 9-1) by the product of the corresponding ingestion dose conversion factor (Table 8-1) and the annual adult consumption of meat (Table 7.1.3-4).

Table 6.3: Annual Average Concentrations of Radionuclides in Milk Derived from Wyhl Report

Nuclide	Milk Concentrations, pCi/l		
	Cow[a]	Goat[b]	Sheep[b]
Co-58	1.19		
Co-60	2.59		
Zn-65	64.05		
Sr-89	0.38		
Sr-90	15.1		
I-131	84.0	246.0	279.0
Cs-134	177.2		
Cs-137	4210.0		
Ce-144	0.7		
Pu-239	< 0.0		

[a] Radionuclide concentrations in cow milk were derived from the Wynl Report by dividing the adult bone dose listed in Table 9-1 by the product of the corresponding ingestion dose conversion factors (Table 8-1) and the adult annual milk consumption (360 liters, Table 7.1.4-4).

[b] I-131 concentrations in goat and sheep milk were derived by dividing the infant thyroid dose listed in Chapter 11 of the Wyhl Report by the product of the infant thyroid dose conversion factor (2.8×10^{-2} mrem/pCi, Table 8-1) and the infant annual milk consumption (320 liters, Table 7.1.4-4). The Wyhl Report did not list doses due to infant milk consumption from other isotopes.

Environs of Nuclear Power Plants," provides an acceptable basis for the design of programs to monitor levels of radiation and radioactivity in the station environs.[1] The Radiological Assessment Branch's Branch Technical Position (as revised November 1979) sets forth an example of an acceptable minimum radiological monitoring program.[2] The radionuclide detection capabilities for analysis of food and milk samples are given in Table 6.4 as stated in the Branch Technical Position.

Comparison of Tables 6.1 through 6.3 with Table 6.4 indicates that the Wyhl Report's predicted concentrations of radionuclides in vegetation, meat, and milk exceed the lower limit of detection of several radionuclides. More specifically:

1. The Wyhl Report's concentrations of Cs-137 in leafy vegetables, potatoes, and cereal grains exceed the lower limit of detection of Cs-137 in food products (80 pCi/kg, wet) by a factor of 6 to 180 depending on the food.

2. The Wyhl Report's estimate of Cs-134 in potatoes exceeds the lower limit of detection of Cs-134 in food products (60 pCi/kg, wet) by a factor of about 8.

3. The Wyhl Report's estimate of I-131, Cs-134, and Cs-137 in meat exceeds the lower limit of detection of these isotopes in food products (60 to 80 pCi/kg, wet) by a factor of about 3 to about 440.

4. The Wyhl Report's estimate of I-131, Cs-134, and Cs-137 in milk exceeds the lower limit of detection of these isotopes in milk (1 to 18 pCi/l) by a factor of about 10 to over 200.

Table 6.4: Detection Capabilities for Environmental Sample Analysis[a]

Indicator Nuclide	Lower Limit of Detection (LLD)[b] Food Products (pCi/kg, wet)	Milk (pCi/l)
I-131	60	1
Cs-134	60	15
Cs-137	80	18
Ba-140		60
La-140		15

[a]This list does not mean that only these nuclides are to be detected and reported. Other peaks which are measurable and identifiable, together with the above nuclides, shall also be identified and reported.

[b]The LLD is defined as the smallest concentration of radioactive material in a sample that will yield a net count (above system background) that will be detected with 95 percent probability with only 5 percent probability of falsely concluding that a blank observation represents a "real" signal. The above LLDs are taken from Reference 2. The above LLDs for some nuclides are slightly lower than those that were in effect for the year 1977 (see Reference 3).

6.2 Comparison of Wyhl Report's Estimated Environmental Concentrations with Measurements

As stated in the Branch Technical Position on environmental monitoring, the NRC requires that numerous environmental samples be taken near nuclear power plants.[2] Environmental samples include water, airborne particulates, gas, fish, milk, food products, and sediment. Since the Wyhl Report predicts concentrations of Cs-137 and I-131 that exceed the lower limit of detection of these isotopes in vegetation, meat, and/or milk, we have reviewed the environmental monitoring data in environmental monitoring reports for the operating year 1977 to see how applicable the Wyhl Report model is to plants in the United States. These reports were submitted by the licensee to NRC. Individual licensee reports are available in the NRC Public Document Room, 1717 H Street, NW, Washington, DC, 20555, and in local public document rooms located near each licensed facility. Environmental monitoring reports of 18 plants were arbitrarily selected, by alphabetical order, for review out of a total of about 50 plants.[4-~~22~~ 23]

Ranges of measured concentrations of Cs-137 in vegetation, meat and poultry, and milk near nuclear reactors are given in Tables 6.5 through 6.7, respectively. Ranges of measured concentrations of I-131 in milk samples near nuclear power reactors are given in Table 6.8. The environmental monitoring data contained in Tables 6.5 through 6.9 include measurements from both indicator and control stations. The measured environmental concentrations, unlike the Wyhl Report's estimated concentrations, are the result of atmospheric bomb tests as well as operating reactors. Since the Peoples Republic of China conducted two nuclear tests in the fall of 1976 and one in September 1977, significant increases in environmental concentrations were measured. Typically, a number of fission

Table 6.5: Comparison of Wyhl Report's Estimates with Measurements of Cs-137 in Vegetation Near Nuclear Power Plants[a]

Nuclear Power Plant[e]	Type(s) of Vegetation Sampled[b]	Range of Cs-137 Concentration, pCi/kg[c]	
		Measured[d]	Wyhl Report
Arkansas 1	grass clippings	70 ~~[illegible]~~ - 280	7 - 14,000
Beaver Valley 1	feed, forage, and garden crops	< 20 - 70	7 - 14,000
Browns Ferry	tomatoes, potatoes green beans, peaches, cabbage, and soy beans	< 15 - 95	7 - 14,000
Brunswick	fodder, feed, food crop, and terrestrial vegetation	10 - 140	7 - 14,000
Calvert Cliffs	tobacco and corn	no range given, average = 50	7 - 14,000
Cook 1	grapes and grape leaves	all < 100	7 - 14,000
Cooper	vegetation, feed, forage, garden crops, and apples	< 3 - not available	7 - 14,000
Crystal River 3	green leafy vegetables, grass, citrus, and watermelon	19 - 1760	7 - 14,000
Davis Besse	cabbage, beets, grass, and feed	< 10 - 45	7 - 14,000
Dresden 1, 2, 3	grass, feed, hay, and vegetables	< 100 - 2800	7 - 14,000
Duane Arnold	alfalfa, lettuce, cabbage, oats, and corn	10 - 200	7 - 14,000
Fitzpatrick and Nine Mile Point	onions, lettuce, corn, tomatoes, cucumbers, squash, peppers, cabbage, apples, and pears	all < 80	7 - 14,000

Table 6.5 (Continued)

Nuclear Power Plant[e]	Type(s) of Vegetation Sampled[b]	Range of Cs-137 Concentration, pCi/kg[c]	
		Measured[d]	Wyhl Report
Fort Calhoun	cattle feed and vegetation	< 10 - 283	7 - 14,000
Haddam Neck	lettuce, peaches, swiss chard, cabbage, plums, and apples	3 - 20	7 - 14,000
Edwin I. Hatch	none		
LaCrosse	type not stated	all < 331	7 - 14,000
Maine Yankee	type not stated	100 - 320	
Millstone 1, 2	grass, strawberries, cabbage, peaches, broccoli, apples, and turnips	37 - 74	7 - 14,000

[a]All concentration measurements were taken from the environmental monitoring reports for the year 1977 submitted by the licensee to NRC.

[b]Although concentrations of Cs-137 were measured in these types of vegetation, not all types of vegetation were necessarily sampled at all locations.

[c]Concentrations are given on a fresh weight (FW) basis. For annual environmental reports that reported concentrations on a dry weight (DW) basis, a FW/DW ratio of 4 was used to convert DW concentrations to FW concentrations.

[d]A significant fraction of Cs-137 detected in vegetation samples is due to atmospheric bomb tests.

[e]The following plants, in alphabetical order, were not included in th~~at~~is review because either the 1977 report had not been written, or because the report was not readily available: Big Rock Point 1, R. E. Ginna, Humboldt Bay, Indian Point, and Kewaunee.

Table 6.6: Comparison of Wyhl Report's Estimates with Measurements of Cs-137 in Meat and Poultry Near Nuclear Power Plants[a]

Nuclear Power Plant[c]	Type(s) of Meat and/or Poultry	Range of Cs-137 Concentration, pCi/kg, wet	
		Measured[b]	Wyhl Report
Arkansas 1	none		20,600 - 35,080
Beaver Valley 1	none		
Browns Ferry	poultry	all < 40	20,600 - 35,080
Brunswick	none		
Calvert Cliffs 1	none		
Cook 1	none		
Cooper	rabbit muscle	54 -	20,600 - 35,080
Crystal River	meat and poultry	all < 37	20,600 - 35,080
Davis Besse	chicken, raccoon, goose, and turtle	all < 7	20,600 - 35,080
Dresden 1, 2, 3	none		
Duane Arnold	chicken, pork, and beef	all < 130	20,600 - 35,080
Fitzpatrick and Nine Mile Point	meat and poultry	all < 130	20,600 - 35,080
Fort Calhoun	none		
Haddam Neck	none		
Edwin I. Hatch	none		

Table 6.6 (Continued)

Nuclear Power Plant[c]	Type(s) of Meat and/or Poultry	Range of Cs-137 Concentration, pCi/kg, wet	
		Measured[b]	Wyhl Report
LaCrosse	none		
Maine Yankee			
Millstone 1, 2	none		

[a]All concentration measurements were taken from the environmental monitoring reports for the operating year 1977. These reports were submitted by the licensee to NRC.

[b]A significant fraction of the Cs-137 detected in meat and/or poultry samples is due to atmospheric bomb tests.

[c]The following plants, in alphabetical order, were not included in this review because either the 1977 report had not been written, or because the report was not readily available: Big Rock Point 1, R. E. Ginna, Humboldt Bay, Indian Point, and Kewaunee.

Table 6.7: Comparison of Wyhl Report's Estimates with Measurements of Cs-137 in Milk Near Nuclear Power Plants[a]

Nuclear Power Plant[c]	Range of Cs-137 Concentration, pCi/l[a]	
	Measured[b]	Wyhl Report
Arkansas 1	Range not given	4210
Beaver Valley 1	3 - 17	4210
Browns Ferry	10 - 15	4210
Brunswick	7 - 86	4210
Calvert Cliffs	none	
Cook 1	all < 10	4210
Cooper	< 3 -	4210
Crystal River	14 - 91	4210
Davis Besse	< 4 - 7	4210
Dresden 1, 2, 3	< 5 - 7	4210
Duane Arnold	< 5 - 16	4210
Fitzpatrick and Nine Mile Point	< 15 - 22	4210
Fort Calhoun	< 1.8 - 6.4	4210
Haddam Neck	4 - 64	4210
Edwin I. Hatch	none	
LaCrosse	not analyzed	

Table 6.7 (Continued)

Nuclear Power Plant[c]	Range of Cs-137 Concentration, pCi/l[b] Measured[d]	Wyhl Report
Maine Yankee	< 10 - 35	
Millstone Point 1	4 - 112	4210

[a]Concentrations of radionuclides in milk samples were taken from the environmental monitoring reports for the operating year 1977. These reports were submitted by the licensee to NRC.

[b]A significant fraction of the Cs-137 detected in milk samples is due to atmospheric bomb tests.

[c]The following plants, in alphabetical order, were not included in this review because either the 1977 report had not been written, or because the report was not readily available: Big Rock Point 1, R. E. Ginna, Humboldt Bay, Indian Point, and Kewaunee.

Table 6.8: Comparison of Wyhl Repo[illegible] Estimates with Measurements of I-131 in Milk Near [illegible]ear Power Plants[a]

Nuclear Power Plant[c]	Range of I-131 Concentration, pCi/l[a] Measured[b]	Wyhl Report
Arkansas 1	Range not given	84 - 279
Beaver Valley 1	0.2 - 38	84 - 279
Browns Ferry	0.7 - 117	84 - 279
Brunswick	0.2 - 59	84 - 279
Calvert Cliffs	none	
Cook 1	< 0.5 - 144	84 - 279
Cooper	< 0.2 -	84 - 279
Crystal River	all < 11	84 - 279
Davis Besse	< 0.5 - 24	84 - 279
Dresden 1, 2, 3	< 0.5 - 7	84 - 279
Duane Arnold	< 0.4 - 177	84 - 279
Fitzpatrick and Nine Mile Point	0.0 - 49	84 - 279
Fort Calhoun	< 0.5 - 286	84 - 279
Haddam Neck	0.0 - 26	84 - 279
Edwin I. Hatch	< 0.1 - 88	84 - 279
LaCrosse	< 1.0 - 270	84 - 279

Table 6.8 (Continued)

Nuclear Power Plant[c]	Range of I-131 Concentration, pCi/l[a] Measured[b]	Wyhl Report
Maine Yankee	0.1 - 24	84 - 279
Millstone Point 1, 2	-0.3 - 9	84 - 279

[a]Concentrations of radionuclides in milk samples were taken from the environmental monitoring reports for the operating year 1977. These reports were submitted by the licensee to NRC.

[b]A significant fraction of the I-131 detected in milk samples is due to atmospheric bomb tests.

[c]The following plants, in alphabetical order, were not included in this review because either the 1977 report had not been written, or because the report was not readily available: Big Rock Point 1, R. E. Ginna, Humboldt Bay, Indian Point, and Kewaunee.

Table 6.9: Comparison of Wyhl Report's Estimates with Measurements of I-131 in Milk at Highest Annual Mean Location for Nuclear Power Plants[a]

Nuclear Power Plant[c]	Highest Annual Mean I-131 Concentration for a Location, pCi/l	
	Measured[b]	Wyhl Report
Arkansas 1	60 (1/6)	84 - 279
Beaver Valley 1	16 (6/44)	84 - 279
Browns Ferry	17.5(7/51)	84 - 279
Brunswick	10.3(16/43)	84 - 279
Calvert Cliffs	None	84 - 279
Cook 1	144 (1/12)	84 - 279
Cooper	23.2(7/52)	84 - 279
Crystal River	< 11	84 - 279
Davis Besse	11 (5/19)	84 - 279
Dresden 1, 2, 3	12 (< 9/37)	84 - 279
Duane Arnold	34.5(10/36)	84 - 279
Fitzpatrick and Nine Mile Point	0.07(11/11)	84 - 279
Fort Calhoun	25.0(5/42)	84 - 279
Haddam Neck	2.9(10/10)	84 - 279
Edwin I. Hatch	29 (not given)	84 - 279

Table 6.9 (Continued)

Nuclear Power Plant[c]	Highest Annual Mean I-131 Concentration for a Location, pCi/l[a] Measured[b]	Wyhl Report
LaCrosse	130 (4/18)	84 - 279
Maine Yankee	11 (5/17)	84 - 279
Millstone Point 1, 2	10 (13/13)	84 - 279

[a]Concentrations of radionuclides in milk samples were taken from the environmental monitoring reports for the operating year 1977. These reports were submitted by the licensee to NRC.

[b]Means are based upon detectable measurements only. The fraction of samples with concentrations greater than the lower limit of detection for I-131 is given in parentheses. A significant fraction of the I-131 detected in milk samples is due to atmospheric bomb tests.

[c]The following plants, in alphabetical order, were not included in this review because either the 1977 report had not been written, or because the report was not readily available: Big Rock Point 1, R. E. Ginna, Humboldt Bay, Indian Point, and Kewaunee.

products (e.g., Sr-89, Sr-90, I-131, and Cs-137) are detected in air and milk samples following atmospheric testing.

Vegetation

The Wyhl Report estimates Cs-137 concentrations in vegetation (pCi/kg, FW) as follows: root vegetables, 7; cereal grains, 516; leafy vegetables, 760; and potatoes, 14340. Table 6.5 shows that the measured concentrations range from less than 3 to 2800 pCi/kg. The two plants reporting the highest concentrations were Crystal River (1760 pCi/kg) and Dresden (2800 pCi/kg).

The Crystal River value of 1760 pCi/kg is based on one measurement of the Cs-137 in leafy vegetables. A preliminary review of the data indicates that this high value is probably not due to plant operations for several reasons. First, the preoperational monitoring report reported a median concentration of Cs-137 in grass of 1363 pCi/kg with a standard deviation of about 2000. Consequently, the value of 1760 is within the 95 percent confidence interval for grass. Second, there were several Chinese nuclear weapons tests in the fall of 1976 and 1977. These tests could be responsible for the elevated concentrations. Third, the quantity of Cs-137 released from Crystal River (4.76×10^{-6} Ci) by the air pathway was very small compared with the Wyhl Report's estimated release (0.4 Ci) and the releases from a number of other reactors (e.g., Cook, 0.008 Ci; Cooper, less than 10^{-4} Ci; Calvert Cliffs, 1.1×10^{-3} Ci; and Brusnwick, 4.6×10^{-3} Ci). Consequently, it is unlikely that the one high value of 1760 pCi/kg in leafy vegetables is due to operation of the Crystal River plant.

The Dresden plants recorded several high values in vegetation. A preliminary review of the Dresden data indicates that the highest concentrations are probably not due to plant operations for the following reasons. First, the high measurements were recorded for only a few collection times. These collection times were in the fall when fallout from the Chinese nuclear tests was observed in the U.S. Second, the farm at which the highest concentration of Cs-137 was ~~were~~ measured was also the collection farm furthest away from the plant (i.e., more than 15 miles away). Consequently, it is unlikely that the high values of Cs-137 in grass is due to operation of the Dresden units.

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Meat

The Wyhl Report estimates Cs-137 concentrations in meat (pCi/kg, FW) as follows: beef, 35080; and pork, 20600. Table 6.6 indicates that the measured concentrations of Cs-137 in meat and/or poultry for all plants were less than 130 pCi/kg. The Wyhl Report's estimated concentrations of Cs-137 in meat are over 150 times greater than measured concentrations in the vicinity of nuclear power plants operating in the United States. Consequently, the Wyhl Report's estimated dose from meat ingestion is not a realistic dose for the hypothetical maximum individual living near nuclear power plants in the United States.

Milk

The Wyhl Report estimates concentrations of Cs-137 and I-131 in cows' milk of 4210 and 84 pCi/l, respectively. The highest measured Cs-137 concentration in milk (112 pCi/l) was more than a factor of 35 below the Wyhl Report's estimate. Iodine-131 concentrations in milk ranged from 0.0 to 270 pCi/l. The highest measured I-131 concentrations in milk for most power plants were of the same order of magnitude as the Wyhl Report's estimates. However, the annual average measured values of I-131 in milk are below the Wyhl Report's annual average of 84 pCi/l (see Table 6.9). Consequently, the Wyhl Report's estimated dose from milk ingestion is not a realistic dose for the hypothetical maximum individual living near nuclear power plants in the United States.

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6.3 Summary and Conclusions

C

The Wyhl Report estimates concentrations of Cs-137 and I-131 in vegetation, meat, and/or milk that exceed the lower limits of detection for these nuclides. In order to determine the applicability of the Wyhl Report's model to nuclear power plants operating in the United States, the Wyhl Report's estimated concentrations were compared with environmental monitoring data. Data was taken from environmental monitoring reports submitted by the licensee for the operating year 1977. The measured environmental concentrations of Cs-137 and I-131, unlike the Wyhl Report's estimated concentrations, are the result of atmospheric bomb tests as well as operating reactors. A significant fraction of Cs-137 and I-131 detected in samples is due to atmospheric bomb tests. In almost all cases, the Wyhl Report's estimated annual concentrations of Cs-137 in vegetation, meat, and milk, and of I-131 in milk exceeded the upper limit of the range of concentrations measured in the United States. For a few cases in which the upper limit of the measured range was comparable to the Wyhl Report's estimates, a preliminary review of the data indicates that the high values were due to causes other than routine emissions from the power plants. Consequently, the Wyhl Report's estimated dose from vegetation, meat, and milk ingestion is not a realistic dose for the hypothetical maximum individual living near nuclear power plants in the United States.

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23. Northeast Nuclear Enegy Company, "Millstone Point Site Radiological Environmental Monitoring Porgram, Annual Environmental Operating Report, Part B, January 1, 1977 - December 31, 1977," Docket Nos. 50-245 and 50-336, March 1978.

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7. SUMMARY AND CONCLUSIONS OF REVIEW OF THE WYHL REPORT

The purpose of this report was to review the technical basis for the dose estimates in a report entitled "Radioecological Assessment of the Wyhl Nuclear Power Plant" (Wyhl Report). Although the Wyhl Report's assessment is based largely on environmental models described in NRC's Regulatory Guides, the Wyhl Report uses values for some model parameters that are much higher than the values NRC uses. As a result, the Wyhl Report estimates doses that are from 10 to 10,000 times higher than the doses calculated using NRC's values for Regulatory Guide parameters.

Since the Wyhl Report primarily criticizes the German Regulatory Agency's assessment of the Wyhl power plant and only indirectly criticizes NRC's environmental assessment, we have reviewed the Wyhl Report for generic criticisms of our models rather than site-specific criticisms of the Wyhl nuclear power plant. Since the Wyhl Report questions the models and many of the values for model parameters used by NRC in radiological assessments of routine release from nuclear power plants, our detailed review has been limited to the most significant differences.

A chapter by chapter summary of our findings from this review follows.

Critique of Source Terms (Ch. 2)

It is difficult to come to any definitive conclusion concerning the validity of the Wyhl Report's estimate of source terms without more knowledge of the treatment systems employed and the bases for their release estimates. The source terms estimated in the Wyhl Report may well be valid for that particular power plant given its reactor design and treatment system design. However, the source terms of the Wyhl Report cannot be generically applied to all pressurized water reactors (PWRs) since there is not a fixed source term applicable to all plants. The source term is a variable from plant to plant depending on the plant design proposed by the specific reactor to meet the limiting dose guideline present in Federal regulations.

<u>Critique of Meteorological Dispersion Models</u> (Ch. 3)

While the theoretical basis of the atmospheric transport and diffusion model and the simplistic models acceptable to the USNRC share the identical form, the evaluation of the component parts are only remotely similar. The Wyhl Report does not contain sufficient supporting information relative to the estimate of dilution factors.

No definitive conclusions can be drawn from the information presented. An attempt to conjecture the approach taken could not reproduce the results presented. The meteorological factors critical in diffusion calculations were deemed unavailable and yet the Wyhl Report contained diffusion estimates. To further complicate the issue, the Wyhl Report uses an undefined statistical measure of error for various elements of their calculations; these errors were considered additive, implying independence between meteorological parameters. We conclude that the Wyhl Report does not adequately discuss the diffusion problem.

Pathway Analysis (Ch. 4)

Comparison of the Wyhl Report's dose to the maximum individual from various pathways indicates that airborne effluents, as opposed to liquid effluents, contribute the majority of the dose (over 75 percent of the dose to the whole body, thyroid, kidney, and bone). The air-food ingestion pathway contributes the largest fraction of the Wyhl Report's total dose estimate for most body organs. Radionuclide analysis of the Wyhl Report's air-food pathway indicates that cesium-137 and Sr-90 account for the majority of the ingestion dose to most body organs. Values for the following parameters are in most disagreement with those of Regulatory Guide 1.109, and ultimately have the greatest effect on the Wyhl Report's dose estimates: (1) soil to plant transfer factors (B_{iv}) for cesium and strontium that are 7 to 1500 times larger than NRC values, (2) ingestion dose conversion factors (DCFs) for Sr-90 (bone) and Cs-137 (kidney) that are 12 to 40 times larger, respectively, than NRC values, and (3) forage to meat transfer factors (F_f) that are from 5 to 65 times higher, depending on nuclide and type of meat, than the values used by NRC.

Review of Critical Parameters in Radiological Assessment Models (Ch. 5)

The Wyhl Report references over 20 papers for soil to plant transfer of cesium and strontium. Most of the Wyhl Report's B_{iv} values are based on greenhouse experiments as opposed to field studies. While greenhouse experiments allow better control of variables, they are not as likely to provide good quantitative estimates of soil to plant uptake as field studies. In most cases, the Wyhl Report's B_{iv} values for cesium and strontium are based on soil and plant characteristics that maximize transfer from soil to plants.

For example:

- The Wyhl Report's B_{iv} for cesium exceeds or is about equal to the highest value derived from the references reviewed for 4 of the 6 vegetation categories (clover, leafy vegetables, potatoes and cereal grain) investigated.

- The Wyhl Report's B_{iv} for strontium exceeds the highest value derived from the references reviewed for four of the six vegetation categories (clover, leafy vegetables, potatoes, and root vegetables) investigated.

Additional and more quantitative examples of this tendency to overestimate these parameters are given in Chapter 5.1.2.3 and Chapter 5.2.2.3.

Consequently, the Wyhl Report's estimated doses from the air to food pathway are unrealistically high because of the use of unrealistic soil to plant transfer values for cesium and strontium. The use of high values for other parameters (e.g., feed to milk, feed to meat, and ingestion rates) in series with maximum B_{iv} leads to an even more unrealistic model. These unrealistic doses from the air to food pathway result in total dose estimates from all sources (i.e., liquid and airborne effluents) that are unrealistic.

The Wyhl Report does not provide any new references to support their use of adult ingestion dose conversion factors for Cs-137 (kidney) and Sr-90 (bone) that are much greater than the values used in Regulatory Guide 1.109, which are based on an International Commission on Radiological Protection publication.[2] Consequently, the Wyhl Report's estimated bone and kidney doses are unrealistically high because of the use of unrealistic DCFs for Sr-90 (bone) and Cs-137 (kidney).

Since the Wyhl Report includes many references that have higher average soil to plant transfer factors for cesium and strontium than NRC's current values of 0.01 and 0.017, respectively, we have taken this opportunity to update NRC's values for these factors. We have also reviewed in this report a paper presented by Y. C. Ng entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products."[3] Based on our review of Ng's paper and the references cited in Ng's paper and the Wyhl Report, we are considering the following changes in values for soil to plant transfer of cesium and strontium in future revisions of Regulatory Guide 1.109. The values proposed below would be used in the interim.

1. The B_{iv} value for Cs would be increased from 0.01 to 0.02. Doubling NRC's present value for cesium (0.01) would lead to a more conservative value for fine, medium, and coarse soil textures. Since aerosol deposition dominates the air to plant transfer of cesium, a B_{iv} value of 0.02 slightly increases the estimate of cesium activity in vegetation (by less than 10 percent).

2. The B_{iv} value for strontium would be increased from 0.017 to 0.2 for plants consumed by humans and to 1.0 for plants consumed by animals. These B_{iv} values should be realistically conservative for most plants grown on fine, medium, and coarse soil textures. Use of these values would increase NRC's estimate of activity in vegetation by a factor of about 2.6 to 5 for Sr-90, depending on vegetation type. However, the total dose from all radioactive effluents would change only slightly.

Comparison of Wyhl Report's Radiological Model with Environmental Monitoring Data (Ch. 6).

The Wyhl Report estimates concentrations of Cs-137 and I-131 in vegetation, meat, and/or milk that exceed the lower limits of detection for these nuclides. However, the Wyhl Report does not provide any environmental monitoring data to support its predictions of high concentrations of power plant radionuclides in food. In order to determine the applicability of the Wyhl Report's model to nuclear power plants operating in the United States, the Wyhl Report's estimated concentrations were compared with environmental monitoring data for the year 1977. In almost all cases, the Wyhl Report's estimated annual concentrations of Cs-137 in vegetation, meat, and milk, and of I-131 in milk exceeded the upper limit of the range of concentrations measured in the United States. For a few cases in which the upper limit of the measured range was comparable to the Wyhl Report's estimates, a preliminary review of the data indicates that the high values were due to causes other than routine emissions from the power plant. Consequently, the Wyhl Report's estimated doses from vegetation, meat, and milk ingestion are not realistic doses for the hypothetical maximum individual living near nuclear power plants in the United States.

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APPENDIX A. FRESH WEIGHT TO DRY WEIGHT CONVERSION FACTORS FOR VEGETATION

Table 4.1: Fresh weight (FW) to dry weight (DW) ratios for common food crops[a]

Food Crop	FW:DW
Vegetables (edible portion)	
Bean	9.0
Cabbage	13.2
Carrots	8.5
Cauliflower	12.1
Celery	15.9
Corn	3.8
Cucumber	25.6
Lettuce	19.2
Mushroom	11.2
Onion	8.0
Peas	3.9
Potato	4.5
Radish	15.6
Spinach	13.7
Turnip roots	11.0
Turnip greens	9.5
Fruit (edible portion)	
Tomato	17.0
Grains and straw	1.1
Forage, hay, feed	
Grain (barley, corn, flax, oats, rye, soybean seed, wheat, Cottonseed meal)	1.1
Silage (alfalfa, corn, grass)	4.1
Hay (alfalfa, bluegrass, oats, grass, prairie, wheat)	1.1
Forage (grass)[b]	5.0

[a]Data presented in this table is from Handbook of Biological Data by W.S. Spector, 1956, unless otherwise indicated. A FW/DW ratio of 4 was used for vegetation that is not included in this table. This average value is taken from UCRL-50163, Part IV (October 1968) by Y.C. Ng.

[b]Healy, W. B., "Ingestion of Soil by Dairy Cows," N. Zealand J. Agric. Res. 11, 487-499 (1968).

APPENDIX B: METHOD FOR REVIEWING REFERENCES ON SOIL TO PLANT TRANSFER OF CESIUM AND STRONTIUM

References on soil to plant uptake factors were divided into two broad groups for this review. The first group, greenhouse references, contains references in which soil to plant transfer factors were measured by growing plants in pots and/or indoors. Greenhouse experiments have a potential advantage in that the aerosol component to activity concentrations in vegetation can either be controlled or eliminated. However, greenhouse experiments suffer from a fundamental disadvantage in that often they do not simulate field conditions very well.

The second group of experiments is called field experiments. The advantage of field experiments is that they simulate the real situation better than greenhouse experiments. The disadvantage of measuring soil to plant transfer factors by field experiments is that it is often difficult to isolate the soil to plant component of activity in food from the aerosol deposition component. Other factors that tend to obscure the measurement of B_{iv} by either greenhouse or field experiments include the resuspension of contaminated material from the ground and translocation of incorporated nuclides from one part of the plant to another.

The purpose of our review was not to criticize the techniques of individual authors since the stated objectives of papers varied widely. The purpose of our review was to make sure that when B_{iv} values were derived from the literature, the limitations of their use in Regulatory Guide 1.109 models was adequately discussed.[1]

In reviewing the results from both types of experiments, the following questions were addressed:

1. Could the author's calculation of B_{iv} be verified mathematically from the data given? If there were significant gaps in data or in calculations, then the results were not weighted very heavily in comparison with other studies.

2. Was the exterior of the plant washed prior to counting the activity in the plant? Failure to wash off aerosol deposition prior to counting plant activity would result in significant overestimates of B_{iv}.

3. If plants were washed prior to counting, was there any evidence that soluble radionuclides were removed? Harsh washing of plants might result in underestimates of B_{iv} for soluble radionuclides.

4. How were nuclides mixed into the soil? If nuclides were not thoroughly mixed in the soil, then erratic B_{iv} values might be encountered. If nuclides were injected in a highly soluble form into the soil (e.g., as a nutrient solution) then B_{iv} would be overestimated.

5. Were plants harvested at a mature stage (i.e., when they would most likely be eaten)? Premature harvesting of plants would lead to unrealistic B_{iv}s.

In reviewing the results from both types of experiments, the following questions were addressed:

1. Could the author's calculation of B_{iv} be verified mathematically from the data given? If there were significant gaps in data or in calculations, then the results were not weighted very heavily in comparison with other studies.

2. Was the exterior of the plant washed prior to counting the activity in the plant? Failure to wash off aerosol deposition prior to counting plant activity would result in significant overestimates of B_{iv}.

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4. How were nuclides mixed into the soil? If nuclides were not thoroughly mixed in the soil, then erratic B_{iv} values might be encountered. If nuclides were injected in a highly soluble form into the soil (e.g., as a nutrient solution) then B_{iv} would be overestimated.

5. Were plants harvested at a mature stage (i.e., when they would most likely be eaten)? Premature harvesting of plants would lead to unrealistic B_{iv}s.

6. Were B_{iv}s calculated on the basis of soil concentration before the plants were grown or at the time of harvest? Using soil concentrations at the time of harvest may lead to overestimates of B_{iv}.

7. Was the decay of the isotope properly taken into account in determining B_{iv}?

In reviewing greenhouse experiments the following questions were addressed in addition to the above questions:

1. How well did the greenhouse experiment simulate field conditions?

2. Were containers large enough to avoid root cramping?

3. Were containers properly drained? If soils were saturated with water, then nuclides might leach from the soils and be taken more readily up into the plant. This leaching could lead to unrealistically high B_{iv}s.

In reviewing field experiments, the following questions were addressed in addition to the general questions discussed above:

1. Was the foliar deposition component of the nuclide in vegetation either eliminated or subtracted from the experiment?

2. Was fallout measured during the study? If fallout were present, how was it subtracted from the plant activity measured? Failure to subtract fallout could lead to overestimates of B_{iv}.

3. Was resuspension of contaminated material by either wind or rain splashing eliminated from the study? Failure to eliminate the effect of resuspended activity could lead to overestimates of B_{iv}.

References

1. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109 Revision 1, "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," Washington, D.C., October 1977.

APPENDIX C

REVIEW OF BASIS FOR SOIL TO PLANT TRANSFER

OF CESIUM AND STRONTIUM

The soil to plant transfer values for cesium and strontium used in Regulatory Guide 1.109 are derived from a report entitled "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere" (USAEC Report UCPL-50163, Part IV, October 1968) by Y. C. Ng et al.[1,2]

This appendix contains a brief review of the physical basis upon which NRC's soil to plant transfer values (B_{iv}) are based.

Cesium Concentrations in Soils

1. The Geochemistry of Rare and Dispersed Chemical Elements in Soils - Vinogradov (1959)[3]

Chapter 8 of this book, "Lithium, Rubidium, and Cesium in Soils", is concerned with reporting concentrations of lithium and rubidium in the soils of the Russian Plain. The author concludes the chapter as follows:

"Finally, we must say a few words on the content of cesium in soils. We were unable to determine it quantitatively by spectroscopic analysis. From the sensitivity of the method, it can be concluded that the content of it in soils is not greater than $n \cdot 10^{-4}\%$, and that the Rb:Cs ratio is close to 50.

D. Ivanov found approximately 5 · 10^{-4}%Cs in soils of the Russian Plain, and Yamagata found approximately 10^{-4}%Cs in the soils of Japan. Using a spectroscopic method, G. Bertrand and D. Bertrand found from 3 · 10^{-5} to 2.5 · 10^{-3}%Cs (an average of about 5 · 10^{-4}%) in certain soils of France. In this work, the highest cesium content was found in soils on granites."

Cesium Concentrations in Plants

2. The Different Distribution of Rubidium and Cesium in Natural Plants - Yamagata et al. (1959)[4]

Yamagata et al. reported measurements of stable rubidium and cesium in plants. Native plants from various districts in Japan were analyzed by a spectrographic method using cathode-layer arc excitation. The leaves of sixty-one samples of fifty plant species were analyzed. The plant species consisted of 25 dicotyledons, 11 monocotyledons, 7 ferns, 5 gymnosperms, and two mosses. Rubidium and cesium contents of 15 soils in Japan were also measured. Cesium and rubidium concentrations in soil were determined by extracting these elements with hot hydrochloric acid. Distribution factors for Rb-K and Co-K were also reported for cucumbers, rice-plants and soybeans.

Stable cesium concentrations in plants (DW) are given in Table C.1. Yamagata et al. found that the stable cesium concentration in plants ranged from 0.002 to 1 ppm on a dry weight basis. The unweighted average cesium concentration of plants (DW) was 0.137 $\pm$ 0.212 ppm (n = 61). Based on the FW/DW ratio of 4 used by Ng, the average plant concentration is 0.034 $\pm$ 0.053 on a fresh weight basis.

Extractable cesium soil concentrations ranged from 0.01 to 3 ppm. An approximate average concentration for extractable cesium in soil was given as about 0.3 ppm. The paper did not relate extractable cesium concentrations in soil to total cesium concentrations in soil.

3. Trace Elements in Biochemistry - Bowen (1956)[5]

Trace Elements in Biochemistry contains two chapters related to the determination of soil to plant transfer factors: Chapter 3, "The Composition of the Soil," and Chapter 5, "Elementary Composition of Living Matter."

Chapter 5 contains a table that lists elemental composition of dry plant tissues. Elemental compositions in ppm are listed for 68 elements in 8 types of plant tissues. The plant tissues include plankton, brown algae, bryophytes, ferns, gymnosperms, angiosperms, bacteria and fungi. For the element cesium two entries are listed. Smales and Salmon (1955)[6] determined that the cesium content of brown algae was 0.067 ppm. Yamagata (1950) determined the cesium content of angiosperms was 0.2 ppm.[7] Based on the FW/DW ratio of 4 used by Ng, these concentrations convert to 0.017 and 0.050 ppm FW for brown algae and angiosperms, respectively.

Although Ng does not reference Bowen's book as his basis for cesium soil concentrations, Chapter 3 contains a list of elemental composition of soils. Chapter 3 contains a table that gives a range and a mean for 52 elements in soil. Soil compositions are reported for oven dried soils. Soils near mineral deposits are not included in computing ranges. The data is taken from work by Swaine (1955),[8] Vinogradov (1959),[3] Bear (1964),[9] and others.

TABLE C.1: Cesium Concentrations (DW) in Plants Reported by Yamagata et al. (1959)[4]

Plant Species	Cesium Conc., DW ppm	Plant Species	Cesium Conc., DW ppm
Usnea longissima	0.01	Skimmia japonica	0.2
"	0.004	Empetrum nigrum var. japonicum	0.05
Thelypteris Oligophlebia	0.05	Acer Tschonoskii	0.05
Lepisorus Thumbergianus	0.1	A. Mono	0.05
Dicranopteris glauca	0.01	Aesculus turbinata	0.02
Osmunda cinnamomea	0.1	Tilia japonica	0.03
"	0.3	Kalopanax pictus	0.07
Equisetum arvense	0.01	Phyllodoce aleutica	0.02
"	0.05	Rhododendron sp.	0.05
Abies Mariesii	0.05	R. Tchonoskii	0.05
Tsuga Sieboldii	0.03	R. Fauriae	0.05
Pinus densiflora	0.01	Andromeda Polifolia var. grandiflora	0.05
P. pumila	0.05	Arcterica nana	0.1
P. parvifolia	0.01	Menyanthes trifoliata	0.4
Myrica gale var. tomentosa	0.08	Adenophora nikoensis	1
Ostrya Japonica	0.02	"	0.1
Fagus japonica	0.05	Cirsium spicatum	0.3
Quercus crispula	0.02	"	0.04
"	0.4	Sasa paniculata	0.01
"	0.01	S. oseana	0.1
Reynoutria japonica	0.6	Miscanthus sinensis	0.1
Dianthus superbus var.	0.3	"	0.2
Nuphar pumilum var. ozeense	0.05	"	1
Nymphaea tetragona	0.05	Phragmites communis	0.5
Ranunculus nipponicus var.	0.3	Lisichiton camtschatcense	0.5
Magnolia obovata	0.02	Veratrum stamineum	0.01
"	0.004	"	0.05
Hydrangea hirta	0.3	Narthecium asiaticum	0.1
Saxifraga Fortunei	0.01	Iris laevigata	0.05
Sorbus commixta	0.002		
Sanguisorba sitchensis	0.03		
Sieversia pentapetala	0.05		

Stable cesium concentrations are reported to range from 0.3 to 25 ppm with a mean of 6 ppm.

4. Trace Analysis of Biological Materials by Mass Spectroscopy and Isotope Dilution - Morrison (1967)[10]

The purpose of this paper was to illustrate the use of mass spectroscopy and isotope dilution in detecting trace elements in biological materials. The author reported the concentration of 56 elements in 5 biological samples. The 5 biological samples that were examined were human whole blood, human kidney tumor, sheep lung, sheep bone and sugar beet leaves. Elemental concentrations were reported in ppm dry weight. Since the emphasis of the paper was on the use of mass spectroscopy and isotope dilution, the author does not discuss the selection or number of samples in any detail. The cesium concentration (DW) of sugar beet leaves was reported as 0.7 ppm.

5. Comparative Elemental Analyses of a Standard Plant Material - Bowen (1967)[11]

Bowen reported values for the elemental composition of a standard consisting of dried kale powder. The purpose of the paper was to assess the accuracy and precision of analytical techniques used in analytical measurements. A standard consisting of dried kale powder was submitted to 29 laboratories for analysis. Concentrations of 40 elements were measured in the standard by a variety of techniques. These techniques included: (1) activation analysis, (2) atomic-absorption spectroscopy, (3) catalytic technique, (4) colorimetry,

(5) flame photometry, (6) fluorescence analysis, (7) gravimetry, (8) polorography, (9) spectrometry, (10) turbidimety, and (11) volumetric analysis.

In general Bowen found that for most elements the reported concentrations were fairly consistent among laboratories and techniques. Concentrations in parts per million (ppm) were reported for 40 elements, one of which was cesium. The cesium concentration in the standard was 0.0688 $\pm$ 0.0071 ppm. This value was based on 6 determinations by one laboratory using activation analysis.

<u>Summary of Basis for NRC Values for Soil to Plant Transfer of Cesium</u>

The NRC value for soil to plant transfer of cesium (0.01 on a FW basis) is based on the soil to plant transfer of stable elements in soil. Over long time periods (e.g. 30 years of reactor operation) it is thought that radioactive effluents from reactors will be thoroughly bound to the soil similar to stable elements in soil. Garner has stated that "There is ample evidence to show that in many soils ^{137}Cs is firmly bound by clay minerals. Even in sandy soils, fixation appeared to be complete about three years after contamination.[212] The availability to plants from such soils is very small."[12] Papers that report the transfer of stable elements from soils to plants are based on more realistic conditions than most tracer experiments. Consequently, NRC B_{iv} values have been based on the transfer of stable elements from soil to plants.

The average concentration of cesium in soils and plants is based primarily on spectroscopic techniques. An average cesium soil concentration of about 5 ppm is found in both the Vinogradov reference[3] and the Bowen (1966) reference.[5]

Both references report values about an order of magnitude higher and lower than the average value.

The average cesium plant concentration (0.05 ppm, FW) given by Ng is based on four references. The unweighted average and range of cesium concentrations (DW) reported by the various authors is given in Table C.2. Soil to plant transfer factors are based on an average soil concentration of cesium (5 ppm).

Review of the 4 plant references indicates that more weight should be given to Yamagata et al. (1959)[4] and possibly Bowen (1966).[5] Morrison (1967) reports higher concentrations of cesium in plants, but only a very few samples were analyzed in his paper and in Bowen's paper (1967).[10,11] The emphasis of the Morrison (1967) and Bowen (1967) papers was on the analytical techniques used rather than on determining an average value for cesium concentrations in plants. Rounding off the unweighted average B_{iv} (FW) from Yamagata et al. (1959) and Bowen (1966) leads to an average B_{iv} (FW) of 0.01 for cesium.

<u>Strontium Concentrations in Soils</u>

1. The Geochemistry of Rare and Dispersed Chemical Elements in Soils - A. P. Vinogradov (1959).[3]

   This book concerns the geochemistry of rare and dispersed chemical elements in soils. The book is translated from the Russian edition. Chapter 9 is entitled "Strontium and Barium in Soils." Strontium concentrations in soil were determined spectrographically. Chapter 9

TABLE C.2: Cesium Concentrations in Plants

Reference	Cesium Concentrations (ppm, DW)			B_{iv} (FW)[a]			Methods
	Low	High	Unweighted Avg.	Low	High	Unweighted Avg.	
Yamagata et al. (1959)	0.002	1	0.137 ± 0.212	0.0001	0.050	0.007 ± 0.011	Spectrographic methods were used to analyze the leaves of 61 samples from 50 plant species
Bowen (1966)[b]	0.067	0.2	0.134 ± 0.094	0.003	0.010	0.007 ± 0.005	Results were obtained from Smales and Salmon (1955), and Yamagata (1950)
Morrison (1967)[b]	-	-	0.7	-	-	0.035	Mass spectroscopy was used to determine the concentrations of elements in sugar beet leaves
Bowen (1967)[c]	-	-	0.069 ± 0.007	-	-	0.004 ± 0.0004	Activation analysis was used to determine the cesium concentration in a standard consisting of dried kale powder

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a B_{iv} (DW) and B_{iv} (FW) values are based on the average cesium concentration for soils (5 ppm) reported by Vinagradov (1959). A FW/DW ratio of 4 has been used in converting values of B_{iv} (DW) to B_{iv} (FW).

b Bowen (1966) and Morrison (1967) do not report the number of plant samples analyzed. Morrison's value for cesium concentration in plants may be based on only one plant sample; however, the paper is not clear on this point.

c Bowen (1967) reports only the average and standard deviation of 6 determinations of the cesium content in a single plant samples.

reports Sr contents for seven types of Russian soils: Tundra soils, Podzolic, Grey forest, Chestnut, Serozems, Chernozems and Red soils.

The average Sr content for Russian soils ranges from a low of 30 ppm for red soils to a high of 1300 ppm for Tundra soils. The unweighted average soil concentration of strontium is about 350 ppm. Vinogradov compared the average Sr content of Russian soils to the soils of other countries. The average Sr content varied from about 270 ppm for Northern Scotland to 1000 ppm for Spain. The average concentration for U.S. soil is about 350 ppm. Based on data from five countries, the world average is about 510 ppm ± 280. It is not clear whether the Sr concentrations reported are total soil concentrations or only exchangable soil concentrations.

Strontium Concentrations in Plants

2. Strontium and Barium in Plants and Soils - Bowen et al. (1955)[13]

Bowen et al measured the stable strontium and barium content of plants and soils in England. Strontium and barium were chemically separated from soils and plants. Concentrations of strontium and barium in the chemically separated extracts from soil and plant samples were determined by activation analysis. The amount of strontium extracted from nine soils was measured as a function of pH of the extracting solution. For all soils examined, the amount of strontium extracted from soils increased with decreasing pH of the extracting solution. Even at the lowest pH values (pH = 3.9) reported, the amount of strontium extracted was still increasing for most of the soils tested.

Consequently, the strontium content of soils reported in this paper, for even the lowest pH, underestimate the total strontium content of soils and overestimate B_{iv}. The strontium content of the various soils using the lowest pH extractant is shown in Table C.3. The last two soils entered in the table (i.e., H and J) are classified as strontium rich soils.

The strontium content in 54 plant species was reported. For each soil type, the strontium concentration was measured for six types of plants. The average strontium concentration (DW) of the six plants grown on various soils is given in Table C.3. The strontium concentration (DW) of plants varies from about 14 ppm to 56 ppm for normal soils, and from about 400 to 7050 for strontium rich soils. The average strontium concentration (DW) of plants grown on normal soils is about 36 $\pm$ 13 ppm. Based on a FW/DW ratio of four, then the average strontium concentration (FW) of plants grown on normal soils is about 9 ± 3 ppm.

3. Strontium - 90 in the Australian Environment, 1957 to 1960 - Bryant et al. (1962)[14]

Bryant et al. measured the concentrations of stable strontium and Sr-90 in foods. Stable strontium concentrations were measured in whole grain wheat, and flour. Strontium-90 concentrations were measured in cabbages, whole grain wheat, flour and milk. Strontium-90 soil concentrations were reported for five coastal cities: Perth, Adelaide, Melbourne, Sydney and Brisbane. Soil concentrations of Sr-90 were reported for six time

Table C.3. Strontium Concentrations in Soils and Plants from Bowen et al.[13]

	Soil				Plants
Soil	Description	Humus Content	Soil pH	Sr Concentration[a] (ppm)	Avg. Sr Concentration (DW)[b] (ppm)
A	Coarse sand	V. high	4.67	0.918	35.25
B	Fine sand	V. low	5.59	0.627	14.31
C	Light Loam	High	7.50	7.52	27.52
D	Light loam	V. high	7.25	8.37	34.24
E	Mull from limestone cliff	High	7.43	198	43.70
F	Alluvial clay	Low	7.71	143	56.16
G	Light, chalky loam	V. low	8.30	215	42.42
H	Celestite rich loam	High	7.30	2840	403
J	Celestite rich clay	V. low	7.91	1490	7049

[a]Strontium concentrations of soils are based on the amount of strontium extracted at the lowest pH (pH = 3.94) of the extractant.

[b]Strontium concentrations for plants are based on the average concentration for the six plant species grown on each soil. Different plant types were grown on different soil types.

periods over the years 1957 to 1960. Strontium-90 dietary intakes and levels in human bone tissue were also reported.

Bryant et al. found that the stable strontium concentration in whole grain wheat ranged from 3.4 to 8 ppm. The average stable strontium concentration in whole grain wheat was 4.40 ± 0.97 ppm. Stable strontium concentrations in flour were about one-third of the concentration in whole grain wheat. Stable strontium concentrations in flour ranged from 1.3 to 2.4 with an average of 1.71 ± 0.23.

5.2.3.3 Summary of Basis for NRC Values for Soil to Plant Transfer of Strontium

The NRC value for soil to plant transfer of strontium (0.017 on a FW basis) is based on the soil to plant transfer of stable elements in soil. As noted earlier, over long time periods (e.g., 30 years of reactor operation) it is thought that radioactive effluents from reactors will be thoroughly bound to the soil similar to stable elements in soil. Papers that report the transfer of stable elements from soils to plants are based on more realistic conditions than most tracer experiments. Consequently, NRC B_{iv} values have been based on the transfer of stable elements from soil to plants.

The average concentration of strontium in soils and plants is based primarily on spectroscopic techniques. An average strontium soil concentration of about 350 ppm is found in the Vinogradov reference for the U.S soil.[3] Vinogradov reports average values from around the world about a factor of four higher and a factor of 10 lower than the average value for the U.S.

The average strontium plant concentration (5 ppm, FW) given by Ng is primarily based on two references. Bowen's average strontium concentration of plants (FW) grown on normal soils is about 9 ppm.[13] The average strontium concentration of plants grown on strontium rich soils (931 ppm, FW) is about two orders of magnitude higher than the comparable value for normal soils. Bryant's average strontium concentration (FW) in whole grain wheat, and flour is 4.4 and 1.7, respectively.[14] The unweighted average strontium plant concentration of the Bowen value for normal soils (i.e., 9 ppm) and the Bryant values for wheat and flour (i.e., 4.4 and 1.7, respectively) is about equal to the average value estimated by Ng (i.e., 5 ppm).[2]

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APPENDIX D. SUMMARY OF REFERENCES IN Y. C. NG'S PAPER ENTITLED "TRANSFER FACTORS FOR ASSESSING THE DOSE FROM RADIONUCLIDES IN AGRICULTURAL PRODUCTS"

In March of 1979, Y. C. Ng presented a paper at the International Atomic Energy Agency's (IAEA) Symposium on Biological Implications of Radionuclides Released from Nuclear Industries.[1] Ng's paper was entitled "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products." In this paper Ng presented updated values for transfer of radionuclides to plants, milk and other animal products. Ng referred to 6 additional papers on soil to plant transfer of cesium and strontium. Since these papers were very briefly summarized in Ng's IAEA paper, we have reviewed these papers. A summary of the 6 papers is given below. Papers are presented in chronological order. All of the papers except the paper by Hardy et al. (1977) are greenhouse experiments.

1. Transfer of Radioactive Fallout Debris From Soils to Human Investigated - Romney et al. (1960)[2]

Romney et al. measured the soil to plant transfer of several fission products, including Cs-137 and Sr-90, in six plants. Plants were grown in clay pots which contained a mixture of soil and radioisotopes. Romney et al. describe their procedures very briefly in this paper.

In general, Romney et al. found higher levels of Sr-90 in leaves than in other plant parts. The accumulation of Sr-90 in fruits and grain was relatively low compared with accumulation in other plant parts. In general, plant accumulati factors varied by about a factor of 10 for different soil types. Plants grown on acidic soils which had low calcium content had the highest Sr-90 uptake. Plants grown on clay type soils with calcium content had the lowest Sr-90 uptake. Calcium fertilizer (2 to 5 tons per acre) reduced Sr-90 accumulation factors by a factor of about five for plants grown on acidic soils.

Derived B_{iv} (dry weight (DW) and fresh weight (FW)) values are given in Table L.1. B_{iv} values for plant parts have been placed into one of two categories: (1) edible plant parts eaten by humans, and (2) edible plant parts that may be eaten by animals. For parts of plants eaten by humans, B_{iv}(FW) ranges from 0.16 for potato tubers to 1.73 for barley grain. The average B_{iv}(FW) for Sr-90 for human consumption is 0.57 ± 0.58. The average B_{iv}(FW) for animal consumption is about 5.5 times higher than the average value for human consumption.

TABLE D.1

Sr-90 Soil to Plant Transfer Factors

For Common Food Crops Romney et al.

Edible Plant Part	B_{iv}(DW)[a]	B_{iv}(FW)
Humans		
Barley/Grain	1.90	1.73
Bean/Fruit	3.20	0.36
Carrot/Root	2.97	0.35
Lettuce/Leaf	7.57	0.39
Radish/Root	6.47	0.41
Potato/Tuber	0.72	0.16
Unweighted average $\pm\sigma$	3.81 ± 2.66	0.57 ± 0.58
Animals		
Barley/Forage	6.32	1.26
Bean/Leaf	6.18	1.55
Carrot/Top	9.1	2.3
Lettuce/Stalk	4.24	1.06
Radish/Top	20.20	5.05
Potato/Top	31.36	7.84
Unweighted average $\pm\sigma$	12.9 ± 10.7	3.2 ± 2.7

[a] B_{iv}(DW) values are derived from a paper by Romney et al. (1960) by dividing the Sr-90 plant concentrations by the Sr-90 soil concentration (i.e., 100 dps/g).[2]

2. Comparative Sr-90 Content of Agricultural Crops Grown in a Contaminated Soil - Evans et al. (1962)[3]

This paper has already been summarized in section 5.2.2 of this report.

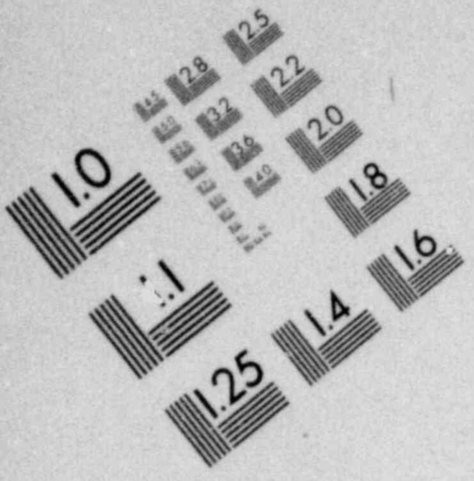
3. Fallcut Nuclide Solubility, Foliage Contamination, and Plant Part Uptake Contour Ratios - C. F. Miller (1963)[4]

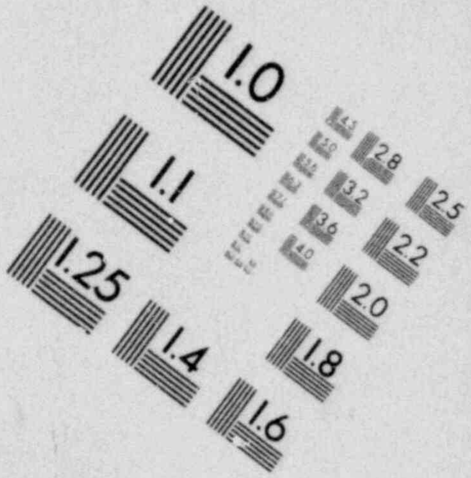
In this paper Miller summarizes so . of the data and mathematical models for food crop contamination. Miller notes that foliar deposition is the most important pathway for short-term plant contamination. However, he states that:

"The uptake of radionuclides by plants through their root system would be the major uptake path in the long-term period after a nuclear war."

This paper contains several tables which list values for soil uptake contamination factors (a_{su}). The soil uptake contamination factor has units of (atoms/gm of dry foliage) / (atoms/gm of soil). The a_{su} factor reported in this paper is equivalent to the B_{iv} factor used in Regulatory Guide 1.109. Values for a_{su} are reported for 6 radionuclides in 7 common food crops. These values were taken from a paper by Nishita, Romney, and Larson (1961). The materials and procedures used by Nishita et al. (1961) is only briefly reported in this paper. Table D.2 contains a_{su} values for Sr-90 and Cs-137.

For parts of plants eaten by humans, B_{iv}(FW) values for Sr-90 range from 0.001 for corn grain to about 0.36 for bean fruit. The average B_{iv}(FW) value for Sr-90 for parts of plants eaten by humans is 0.11 ± 0.17. The average B_{iv} (FW) for animal consumption (i.e., 1.02 ± 1.78) is about 9 times higher than the average value for human consumption.





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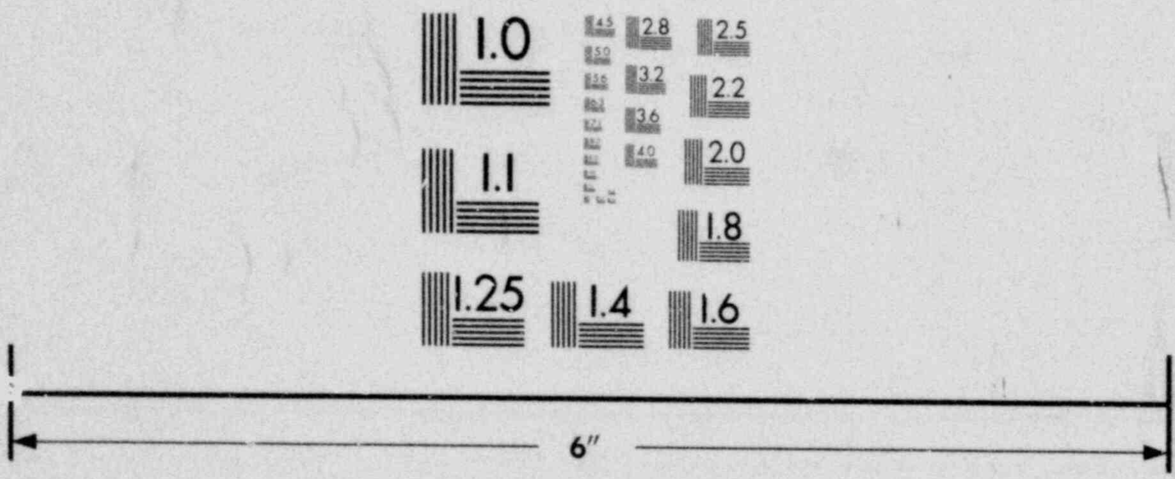

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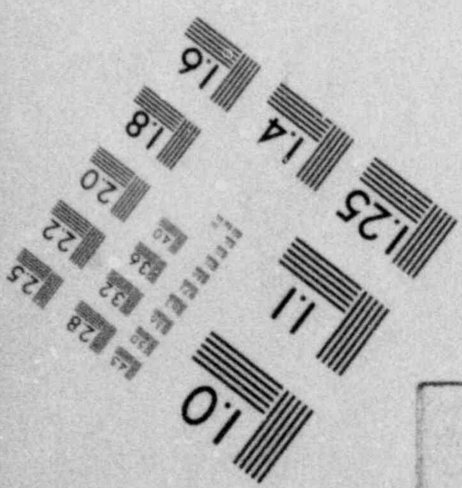

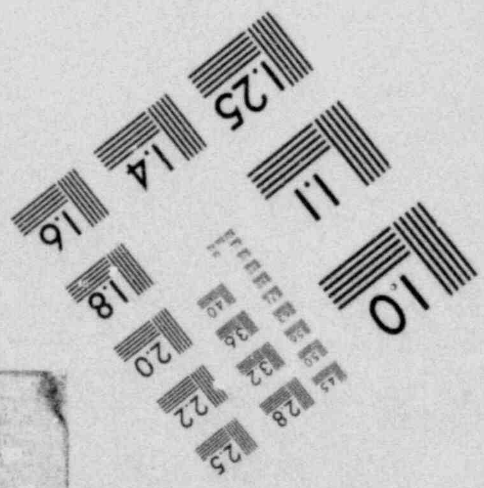

For parts of plant eaten by humans, Cs-137 B_{iv}(FW) values range from 0.0015 for wheat grain to 0.014 for bean/fruit. The average B_{iv}(FW) value for Cs-137 human consumption is 0.008 ± 0.009. The average B_{iv}(FW) for animal consumption (i.e., 0.01 ± 0.02) is about 2 times higher than the average value for human consumption.

Table D.2: Soil to Plant Transfer Factors for Common Food Crops - Miller

Edible Plant Part	Sr-90		Cs-137	
	B_{iv}(DW)	B_{iv}(FW)	B_{iv}(DW)	B_{iv}(FW)
<u>Humans</u>				
Corn/Grain	0.002	0.001	-	-
Wheat/Grain	0.11	0.10	0.0017	0.0015
Pea/Seeds	0.0081	0.002	-	-
Bean/Fruit	3.2	0.356	0.13	0.014
Average ± σ	0.83 ± 1.6	0.11 ± 0.17	0.0659 ± 0.09	0.008 ± 0.009
<u>Animals</u>[a]				
Corn/Leaves, Stems, Punicle, Husk, Cob	0.151	0.038	--	--
Wheat/Leaves, Stems	1.15	0.288	0.0071	0.002
Pea/Leaves, Stems, Pods, Roots	0.253	0.063	--	--
Bean/Leaves, Stems	14.700	3.68	0.100	0.025
Average ± σ	4.063 ± 7.11	1.02 ± 1.78	0.0536 ± 0.066	0.01 ± 0.02

[a]B_{iv} values for plant parts eaten by animals are based on an unweighted average of the B_{iv}(DW) for various plant parts from C. F. Miller (1963). A FW/DW ratio of 4 was used for converting B_{iv}(DW) values to B_{iv}(FW) values for plant parts that may be eaten by animals.

4. Uptake of Radionuclides by Plants - Sartor et al. (1966)

Sartor et al. measured the uptake of five radionuclides (Sr-85, Zr-95, Nb-95, Ru-106, Cs-137, and Ce-144) in seven common food crops. Crops were chosen from each important botanical family. Crops included a seed crop (beans), a root crop (carrots and radishes), a leafy crop (lettuce), a fruit crop (tomatoes), a grain crop (wheat), and an animal fodder crop (clover). Soil to plant transfer factors were measured for four types of soil that represent the major soil classes on a texture basis. The experimental procedures used in this study were designed to reproduce actual field conditions as close as possible. Plants were grown outdoors in large containers (three feet on each side).

Cesium

Cesium soil to plant transfer factors (FW) are given in Table D.3. For plant parts eaten by humans B_{iv}(FW) for various soils ranged from 2.7×10^{-5} for tomato fruit to 0.056 for wheat grain. For plant parts eaten by humans, the unweighted average B_{iv}(FW) of various plants ranged from 0.0004 for loam to 0.0173 for sandy soil. The unweighted average B_{iv}(FW) for all plant parts eaten by humans, grown on the 4 soils, was 0.006 ± 0.008. The average B_{iv}(FW) for animal consumption of clover (0.013 ± 0.006) is about 2.2 times higher than the average value for human consumption.

Strontium

Strontium soil to plant transfer factors (FW) are given in Table D.4. For plant parts eaten by humans B_{iv}(FW) for various soils ranged from 0.002 for bean and tomato fruit to 0.281 for wheat grain. For plant parts eaten by humans, the unweighted average B_{iv}(FW) ranged from 0.03 for plants grown on clay loam to about 0.16 for plants grown on sandy soil. The unweighted average B_{iv}(FW) for all plant parts eaten by humans, grown on the 4 soils, was 0.07 ± 0.06. The average B_{iv}(FW) for animal consumption of clover (0.52 ± 0.38) is about 7.6 times higher than the average value for human consumption.

Table D.3: Cs-137 Soil to Plant Transfer Factors for Common Food Crops
Sartor et al (1966)[a]

Edible Plant Part	Soil Type			
	Sand	Loam	Clay	Clay Loam
Humans				
Bean/Fruit	0.0051	0.0002	0.0015	-
Carrots/Roots	0.0098	0.0005	0.0022	0.0007
Lettuce/Leaves & Head	0.0259	0.0010	0.0053	-
Radish/Roots	0.0020	0.0003	-	-
Tomato/Fruit	0.0049	2.7×10^{-5}	0.0010	-
Wheat/Grain	0.0561	0.0006	0.0117	0.0011
Unweighted Average	0.0173	0.0004	0.0043	0.0009
Animals				
Clover/Tops	0.019	0.009	0.010	-

[a] B_{iv}(FW) values are derived from Tables 20 to 26 of Sartor et al. (1966) using the following FW/DW ratios: bean fruit, 9.0; carrot roots, 8.5; lettuce leaves and head, 19.2; radish roots, 15.6; tomato fruit, 17.0; wheat grain, 1.1; and clover, 5.0.

Table D.4: Sr-85 Soil to Plant Transfer Factors for Common Food Crops

Sartor et al (1966)[a]

Edible Plant Part	Soil Type			
	Sand	Loam	Clay	Clay Loam
Humans				
Bean/Fruit	0.027	0.002	0.012	-
Carrots/Roots	0.218	0.061	0.048	0.050
Lettuce/Leaves & Head	0.155	0.051	0.036	-
Radish/Roots	0.244	0.087	0.052	-
Tomato/Fruit	0.018	0.002	0.010	-
Wheat/Grain	0.281	0.100	0.059	0.009
Unweighted Average	0.157	0.051	0.036	0.030
Animals				
Clover/Tops	0.954	0.286	0.324	-

[a] B_{iv}(FW) values are derived from Tables 20 to 26 of Sartor et al. (1966) using the following FW/DW ratios: bean fruit, 9.0; carrot roots, 8.5; lettuce leaves and head, 19.2; radish roots, 15.6; tomato fruit, 17.0; wheat grain, 1.1; and clover, 5.0.

5. Experimental Investigation of Plant Uptake Contamination Factors - Sartor et al. (1968)

Sartor et al. measured the uptake of Sr-85, Ru-106, Ce-144 and Cs-137 for four plants species (wheat, tomatoes, corn and potatoes) grown in four different soil types. The soils used in the experiment are typical of agriculture soils in California. Extensive soil analysis was performed and plants were grown outdoors in large containers (3 x 3 x 3 cubic feet). Plant uptake contamination factors (A_{su}) were reported in units of (atoms/gm of dry plant) / (atoms/gm of soil). Values for A_{su} are equivalent to NRC Regulatory Guide 1.109 B_{iv}(DW) values.

Cesium

Soil to plant transfer factors for cesium are given in Table D.5 on a fresh weight basis. For plant parts eaten by humans, B_{iv}(FW) for various soils ranged from 0.0002 for corn kernels and tomato meat to about 0.02 for potato meat. For plant parts eaten by humans, the unweighted average B_{iv}(FW) for various plants ranged from 0.0006 for Pleasanton loam to 0.012 for Oakley Sandy loam. The unweighted average B_{iv}(FW) for all plant parts, eaten by humans, grown on the 4 soils was 0.005 ± 0.005. The unweighted average B_{iv}(FW) for animal consumption (0.012 ± 0.01) is about 2.4 times higher than the average value for human consumption.

Table D.5 Cs-137 Soil to Plant Transfer Factors for Common Food Crops[a]
Sartor et al. (1968)

Edible Plant Part	Soil Type: Oakley Sandy Loam	Pleasanton Loam	Clear Lake Clay	Hanford Sandy Clay Loam	Unweighted Average B_{iv}(FW)
Humans					
Tomato/Meat	0.010	0.0002	0.0028	--	0.0042
Potato/Meat	0.021	0.0008	0.0045	--	0.0088
Wheat/Grain	0.011	0.0013	0.0067	0.0053	0.0062
Corn/Kernel	0.007	0.0002	0.0016	0.0024	0.0029
Unweighted average	0.012	0.0006	0.0039	0.0039	0.005 ± 0.005[c]
Animals[b]					
Tomato/Leaves, Stem, Fruit, Peel, Root	0.0304	0.0188	0.0102	--	0.020
Potato/Leaves, Stem, Tuber, Peel, Root	0.0358	0.0034	0.0104	--	0.017
Wheat/Leaves, Stalk Head, Chaff	0.0105	0.0010	0.0041	0.0031	0.005
Corn/Leaves, Stalk, Cob Husk, Tassel, Silk	0.0250	0.0011	0.0061	0.0103	0.011
Unweighted average	0.025	0.006	0.008	0.007	0.012 ± 0.01[c]

[a] B_{iv}(FW) values are derived from Sartor et al. (1968).

[b] B_{iv}(FW) values for plant parts eaten by animals are based on an unweighted average of the B_{iv}(FW) for various plant parts. A FW/DW ratio of 4 was used for converting B_{iv}(DW) to B_{iv}(FW) values for plant parts that may be eaten by animals.

[c] The unweighted average B_{iv} for plants grown on all soils is based on the unweighted average value for individual soils.

Strontium

Soil to plant transfer factors for strontium are given in Table D.6 on a fresh weight basis. For plant parts eaten by humans, B_{iv}(FW) for various soils ranged from 0.002 for corn kernels to about 0.24 for wheat grain. For plant parts eaten by humans, the unweighted average B_{iv}(FW) for various plants ranged from about 0.04 for Camp Parks clay to 0.09 for Oakley Sandy loam. The unweighted average B_{iv}(FW) for all plant parts, eaten by humans, grown on the 4 soils was about 0.05 ± 0.03. The unweighted average B_{iv}(FW) for animal consumption (0.83 ± 0.73) is about 15.7 times higher than the average value for human consumption.

Table D.6: Sr-85 Soil to Plant Transfer Factors for Common Food Crops[a] - Sartor et al. (1968)

Edible Plant Part	Soil Type: Oakley Sandy Loam	Hanford Sandy Clay Loam	Yolo Silty Clay	Camp Parks Clay	Unweighted Average B_{iv}(FW)
Humans					
Tomato/Meat	0.029	0.020	0.007	--	0.019
Potato/Meat	0.077	0.061	0.032	--	0.057
Wheat/Grain	0.241	0.189	0.029	0.067	0.132
Corn/Kernel	0.011	0.010	0.005	0.002	0.007
Unweighted Average	0.090	0.070	0.018	0.035	0.053 ± 0.033[c]
Animals[b]					
Tomato/Peel, Root, Leaves Stem, Fruit	2.17	2.40	0.35	--	1.64
Potato/Leaves, Stem, Tuber, Peel, Root	2.60	2.48	0.53	--	1.87
Wheat/Leaves, Stalk, Head, Chaff	0.60	0.49	0.11	0.22	0.36
Corn/Leaves, Stalk, Cob, Husk, Silk, Tassel	0.53	0.38	0.05	0.07	0.26
Unweighted Average	1.48	1.44	0.26	0.15	0.83 ± 0.73[c]

[a] B_{iv}(DW) values are derived from Sartor et al. (1968).

[b] B_{iv}(DW) values for plant parts eaten by animals are based on an unweighted average of the B_{iv}(DW) for various plant parts. A FW/DW ratio of 4 was used for converting B_{iv}(DW) to B_{iv}(FW) values for animal consumption

[c] The unweighted average B_{iv} for plants grown on all soils is based on the unweighted average value for individual soils.

6. Radionuclide Uptake by Cultivated Crops - Hardy et al. (1977)

Hardy et al. measured the soil to plant uptake of Cs-137, Sr-90, and several transuranics in three common vegetables (potatoes, peas and corn). Crops were grown in Cape Cod, Massachusetts. Cape Cod soil is a moist and sandy loam soil. The soil had been exposed to global fallout as a source of radionuclides. Soil profiles were taken. The average Cs-137 soil concentration (DW) was about 405 fCi for the top 30 cm. of soil. The average Sr-90 soil concentration (DW) was about 59 fCi for the top 30 cm. of soil. Special attention was given to minimizing the foliar deposition component of activity in plants. Concentration ratios (C.R.) for edible portions of crops that had been shielded from direct deposition were reported. Concentration ratios were defined as (activity/ unit wt. of crop) / (activity/unit wt. of soil). The C.R. values reported are equivalent to B_{iv} values.

Derived B_{iv}(FW) values for Cs-137 and Sr-90 are reported in Table D.7. Values of B_{iv}(FW) for Cs-137 varied from 0.0057 for shelled peas to 0.0087 for potatoes. The average B_{iv}(FW) for Cs-137 was 0.0073 ± 0.0015. Values of B_{iv}(FW) for Sr-90 varied from 0.016 for potatoes to 0.093 for shelled peas. The average B_{iv}(FW) for Sr-90 uptake was 0.045 ± 0.042.

Table D.7 Soil to Plant Transfer Factors (FW) for Edible Portions of Common Food Crops - Hardy et al

Edible Plant Part	$B_{iv}(FW)^{a}$	
	Cs-137	Sr-90
Corn plus cob	0.0074 ± 0.0027	0.027 ± 0.006
Potatoes	0.0087 ± 0.0020	0.016 ± 0.004
Shelled Peas	0.0057 ± 0.0034	0.093 ± 0.024
Average ± σ	0.00727 ± 0.0015	0.0453 ± 0.0417

[a]Based on wet plant and dry soil weights reported in Hardy et al. (1977).

Summary and Conclusions of Review of Ng (1979) References for Soil to Plant Transfer of Cesium and Strontium

Cesium

Four of the six papers that were reviewed contained values for soil to plant transfer of cesium. Three of the four papers were greenhouse experiments. The fourth paper (Hardy et al.) was the only field study. The range of B_{iv}(FW) values derived from the various papers is given in Tables D.8 and D.9 for human consumption and animal consumption, respectively. For most plants grown on most soils the B_{iv}(FW) value is about equal to or less than the NRC value of 0.01. However, there were several crops grown on Oakley Sandy loam that were slightly higher (by a factor up to 5.6) than the NRC value of 0.01. Most of the crops with B_{iv}(FW) greater than 0.01 were crops which might be fed to animals. Potato meat, bean fruit and wheat grain were the only important crops for human consumption that had B_{iv}(FW) values greater than 0.01, and these values were higher (by a factor up to 5.6) for only one soil type.

Table D.8: Range in Cesium Soil to Plant Transfer Factors Reported in Various Papers Cited in Ng (1979) - Human Consumption

Reference	B_{iv}(FW) Low	High	Unweighted Avg.	Parameters Examined
Miller (1963)	0.0015	0.014	0.008 ± 0.009	Reports data from a paper by Nishita et al. (1961). Four common food crops were grown on one soil type.
Sartor et al. (1966)	0.0020	0.0561	0.017 ± 0.021	Six common food crops grown on sandy soil
Sartor et al. (1966)	2.7×10^{-5}	0.0010	0.0004 ± 0.0003	Six common food crops grown on loam
Sartor et al. (1966)	0.0015	0.0117	0.004 ± 0.004	Six common food crops grown on clay
Sartor et al. (1966)	0.0007	0.0011	0.0009 ± 0.0003	Six common food crops grown on clay loam
Sartor et al. (1968)	0.007	0.021	0.012 ± 0.006	Four common food crops grown on Oakley Sandy Loam
Sartor et al. (1968)	0.0002	0.0013	0.0006 ± 0.0005	Four common food crops grown on Pleasanton Loam
Sartor et al. (1968)	0.0016	0.0067	0.0039 ± 0.0022	Four common food crops grown on Clear Lake Clay
Sartor et al. (1968)	0.0024	0.0053	0.0039 ± 0.0021	Four common food crops grown on Hanford Sandy Loam
Hardy et al. (1977)	0.0057	0.0087	0.007 ± 0.002	Three common food crops grown outdoors on a moist and sandy loam (Cape Cod, Mass.).

Table D.9: Range in Cesium Soil to Plant Transfer Factors Reported by Various Papers Cited by Ng (1979) - Possible Animal Consumption

Reference	B_{iv}(FW) Low	High	Unweighted Avg.	Parameters Examined
Miller (1963)	0.002	0.025	0.01 ± 0.02	Reports data from a paper by Nishita et al. (1961). Four common food crops were grown on one soil type.
Sartor et al. (1966)	-	-	0.019	Clover grown on sandy soil
Sartor et al. (1966)	-	-	0.009	Clover grown on loam
Sartor et al. (1966)	-	-	0.010	Clover grown on clay
Sartor et al. (1968)	0.0105	0.0358	0.025 ± 0.011	Four common food crops grown on Oakley Sandy Loam
Sartor et al. (1968)	0.0010	0.0188	0.006 ± 0.009	Four common food crops grown on Pleasanton Loam
Sartor et al. (1968)	0.0041	0.0104	0.008 ± 0.003	Four common food crops grown on Clear Lake Clay
Sartor et al. (1968)	0.0031	0.0103	0.007 ± 0.005	Four common food crops grown on Hanford Sandy Loam

Strontium

All six papers that were reviewed contained values for soil to plant transfer of strontium. Five of the six papers were greenhouse experiments. The sixth paper (Hardy et al.) was the only field study. The range and unweighted average B_{iv}(FW) values derived from the various papers is given in Tables D.10 and D.11 for human and animal consumption, respectively. The unweighted average value reported for all papers is higher (by a factor up to about 100) than NRC's value of 0.017. The growth conditions reported in the paper by Sartor et al. (1966 and 1968) and Hardy et al. (1977) were more realistic than in most papers that were reviewed. Sartor et al. reported results from plants grown outdoors in large containers on four types of soil. Hardy reported results from field studies. Since plants were grown outdoors in cultivated plots, growth conditions were very similar to plants exposed to airborne effluents from reactors. The three other papers reported results for plants grown in much smaller containers.

As stated by Ng, Baker has suggested that NRC's current value of B_{iv} for strontium (0.017, FW) should be raised to 0.2. In the Sartor and Hardy papers all plants directly consumed by humans have a B_{iv}(FW) value less than 0.2 with the exception of wheat grain grown on Oakley Sandy loam. The B_{iv}(FW) of wheat grain grown on Oakley Sandy loam (0.24, FW) is only slightly greater than the proposed value of 0.2.

The average B_{iv}(FW) values for plant parts that might be eaten by animals is consistently higher (by a factor up to 20 for Oakley Sandy loam) than average values for human consumption. The average B_{iv}(FW) values for animal consumption in Table D.11 are artifically high because of the inclusion of a number of plant parts that are not normally consumed in large quantities. For example, if carrot tops, lettuce stalks, radish tops, and potato tops are excluded from Romney et al., then the average B_{iv}(FW) for Romney et al. decreases from 3.2 to 1.3. In a similar manner, we have calculated some new B_{iv}(FW) values for the various papers by excluding plant parts not normally consumed by animals. The B_{iv}(FW) values based only on crops normally eaten by animals are given in Table D.12. This table shows that for most forage species grown on most soils B_{iv}(FW) is 1.0 or less.

Table D.10: Range in Strontium Soil to Plant Transfer Factors Reported by Various Papers Cited by Ng (1979) - Human Consumption

Reference	B_{iv}(FW) Low	High	Unweighted Avg.	Parameters Examined
Romney et al. (1960)	0.16	1.73	0.57 ± 0.58	Six common food crops grown in clay pots which contained Hanford Sandy loam.
Evans et al. (1962)[a]	0.01	2.61	0.40 ± 0.58	Thirty-six plant species important to Canadian agriculture. Plants were grown in 5-pint pots which contained Greenville loam.
Miller (1963)	0.001	0.356	0.11 ± 0.17	Reports data from a paper by Nishita et al. (1961). Four common food crops were grown on one soil type.
Sartor et al. (1966)	0.018	0.281	0.16 ± 0.11	Six common food crops grown outdoors in large containers of sandy soil.
Sartor et al. (1966)	0.002	0.100	0.05 ± 0.04	Six common food crops grown outdoors in large containers of loam.
Sartor et al. (1966)	0.010	0.059	0.04 ± 0.02	Six common food crops grown outdoors in large containers of clay.
Sartor et al. (1966)	0.050	0.009	0.03 ± 0.03	Six common food crops grown outdoors in large containers of clay loam.
Sartor et al. (1968)	0.01	0.24	0.09 ± 0.10	Four common food crops grown outdoors in large containers of Oakley Sandy loam.
Sartor et al. (1968)	0.01	0.19	0.07 ± 0.08	Four common food crops grown outdoors in large containers of Hanford Sandy Clay loam.
Sartor et al. (1968)	0.005	0.032	0.02 ± 0.01	Four common food crops grown outdoors in large containers of Yolo Silty Clay.
Sartor et al. (1968)	0.002	0.067	0.03 ± 0.05	Four common food crops grown outdoors in large containers of Camp Parks Clay.
Hardy et al. (1977)	0.016	0.093	0.05 ± 0.04	Three common food crops grown outdoors on a moist and sandy loam (Cape Cod, Mass.).

[a]Entries are based on all vegetable values reported in Table 5.8 plus the values for grains (oat, rye, wheat, barley and corn) in Table 5.6.

Table D.11: Range in Strontium Soil to Plant Transfer Factors Reported by Various Papers Cited by Ng (1979) - PossiL : Animal Consumption

Reference	B_{iv}(FW) Low	High	Unweighted Avg.	Parameters Examined
Romney et al. (1960)	1.06	7.84	3.2 ± 2.7	Six common food crops grown in clay pots which contained Hanford Sandy loam.
Evans et al. (1962)[a]	0.18	4.36	1.0 ± 1.0	Thirty-six plant species important to Canadian agriculture. Plants were grown in 5-pint pots which contained Greenville loam.
Miller (1963)	0.038	3.68	1.02 ± 1.78	Reports data from a paper by Nishita et al. (1961). Four common food crops were grown on one soil type.
Sartor et al. (1966)	-	-	0.95	Clover grown outdoors in large containers of sandy soil.
Sartor et al. (1966)	-	-	0.29	Clover grown outdoors in large containers of loam.
Sartor et al. (1966)	-	-	0.32	Clover grown outdoors in large containers of clay.
Sartor et al. (1968)	0.53	2.60	1.5 ± 1.1	Four common food crops grown outdoors in large containers of Oakley Sandy loam.
Sartor et al. (1968)	0.38	2.48	1.4 ± 1.2	Four common food crops grown outdoors in large containers of Hanford Sandy Clay loam.
Sartor et al. (1968)	0.05	0.53	0.26 ± 0.22	Four common food crops grown outdoors in large containers of Yolo Silty Cl y.
Sartor et al. (1968)	0.07	0.22	0.15 ± 0.11	Four common food crops grown outdoors in large containers of Camp Parks Clay.

[a]Entries are based on all values reported in Tables 5.6 and 5.7 except for grains and tobacco. If grains were included then the unweighted average would be slightly lower (0.85 ± 0.98) than the values presented above.

Table D.12: Range in Strontium Soil to Plant Transfer Factors Reported by Various Papers Cited by Ng (1979) - Animal Consumption

Reference	B_{iv}(FW) Low	High	Unweighted Avg.	Parameters Examined
Romney et al. (1960)			1.26	Barley forage grown in clay pots which contained Hanford Sandy loam.
Evans et al. (1962)[a]	0.18	4.36	1.0 ± 1.0	Twenty-five species forage important to Canadian agriculture. Plants were grown in 5-pint pots which contained Greenville loam.
Miller (1963)	0.15	1.	0.65 ± 0.71	Reports data from a paper by Nishita et al. (1961). Corn and wheat plant parts grown on one soil type.
Sartor et al. (1966)	-	-	0.95	Clover grown outdoors in large containers of sandy soil.
Sartor et al. (1966)	-	-	0.29	Clover grown outdoors in large containers of loam.
Sartor et al. (1966)	-	-	0.32	Clover grown outdoors in large containers of clay.
Sartor et al. (1968)	0.53	0.60	0.57 ± 0.05	Corn and wheat plant parts grown outdoors in large containers of Oakley Sandy loam.
Sartor et al. (1968)	0.38	0.49	0.44 ± 0.08	Corn and wheat plant parts grown outdoors in large containers of Hanford Sandy Clay loam.
Sartor et al. (1968)	0.05	0.11	0.08 ± 0.04	Corn and wheat plant parts grown outdoors in large containers of Yolo Silty Clay.
Sartor et al. (1968)	0.07	0.22	0.15 ± 0.11	Corn and wheat plant parts grown outdoors in large containers of Camp Parks Clay.

[a]Entries are based on all values reported in Tables 5.6 and 5.7 except for grains and tobacco. If grains were included then the unweighted average would be slightly lower (0.85 ± 0.98) than the values presented above.

References

1. Y. C. Ng, "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products," International Symposium on Biological Implications of Radionuclides Released from Nuclear Industries, Vienna, Austria, March 1979.

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4. C. F. Miller, Fallout Nuclide Solubility, Foliage Contamination, and Plant Part Uptake Contour Ratios, Stanford Research Institute Rep. AD-417665 (1963).

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109 Revision 1, "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, Washington, D.C., October 1977.

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8. E. P. Hardy, B. G. Bennett, and L. T. Alexander, "Radionuclide uptake by cultivated crops," U.S. Health and Safety Laboratory Rep. HASL-321 (1977) I-19.

APPENDIX E: SUPPLEMENTAL INFORMATION ON METEOROLOGICAL MODELS

NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

Appendix E-1

MAY 12 1976

Files

PLUME DEPLETION AND RELATIVE DEPOSITION

Enclosed is a summary of the procedure used to estimate relative dry deposition rates and attendant plume depletion for elemental radioiodines in Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors.

Earl H. Markee, Jr.

Earl H. Markee, Jr., Leader
Meteorology Section
Hydrology-Meteorology Branch
Division of Site Safety and
Environmental Analysis

Enclosure:
As Stated

cc: J. Kastner
J. Hickey
R. Kornasiewicz
Meteorology Personnel

POOR ORIGINAL

[illegible] USED TO [illegible] AND
RELATIVE DEPOSITION ESTIMATES IN REGULATORY GUIDE 1.111

The procedure used to estimate relative deposition rates and attendant plume depletion presented in Regulatory Guide 1.111 was based on numerical solutions to the flux-gradient ("K-theory") diffusion equation described in Reference 1. The effluent was not allowed to diffuse beyond a height of 200m in stable condition and 1000m in neutral and unstable conditions. At the ground surface, a partial sink boundary condition involving the deposition velocity was assumed. The wind and eddy diffusivity profiles required as input to the diffusion equation were the same as those presented in Reference 1. Deposition velocity was allowed to vary with wind speed in accordance with the empirical equation presented in Reference 2 assuming an areal grass density of about $70g/m^2$. The resultant deposition velocities were 0.12, 1.20 and 0.38cm/sec for stable, neutral and unstable conditions, respectively.

Calculations were made representing ground level releases which are initially uniformly mixed through a 30m depth and elevated point sources releases at the 30, 60 and 100m levels. Since the estimates for ground level releases did not vary by more than a factor of two among the stability classes, single curves for relative deposition and depletion were drawn. However, for elevated releases significant variations among the stability classes would not allow the simplification to one curve for each release height. Other reasonable combinations of eddy diffusivity and wind profiles for each stability class and release height were used to provide deposition and depletion estimates allowing the deposition velocity to vary with wind speed in accordance with Reference 2. These estimates were quite similar to the original estimates in each stability class for elevated releases and for all stability classes assuming ground level releases. Since air concentration is inversely proportional to wind speed and deposition velocity is directly proportional to wind speed, the deposition rate is independent of wind speed. Therefore wind speed is not a factor in the estimation of deposition and depletion. Hence only atmospheric stability need be considered in making these estimates.

References:

1. E. H. Markee, Jr., "A Parametric Study of Gaseous Plume Depletion by Ground Surface Adsorption," in Proceedings of USAEC Meteorological Information Meeting, C. A. Mawson, Editor, AECL-2787, pp. 602-613, 1967.

2. C. A. Pelletier and J. D. Zimbrick, "Kinetics of Environmental Radioiodine Transport Through the Milk-Food Chain", in Environmental Surveillance in the Vicinity of Nuclear Facilities, W. C. Reinig, Editor, Charles C. Thomas Publishers, Springfield, Ill., 1970.

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

Appendix E-2

FEB 19 1976

Note to W. Gammill

Enclosed are specific responses to the questions raised by R. H. Vollmer in his note to you dated February 11, 1976. A copy of that note is also attached for your reference.

L. G. Hulman, Chief
Hydrologic and Meteorology Branch
Division of Site Safety and
Environmental Analysis

Enclosures:
As stated

cc w/encl:

R. Vollmer
J. Collins
W. Kreger
E. Markee
Meteorology Section
Personnel

POOR ORIGINAL

DISCUSSION OF SITE ANALYSIS TOPICS ON
AVERAGE ANNUAL X/Q COMPUTATIONS

2. Short term Releases

a. Item

Although at previous meetings on this subject SAB had agreed to use 50% meteorology for short term releases, we have learned that the model now in use by HMB uses a value closer to 15% meteorology.

b. Response

There appears to be a tendency to make shorter term releases during periods of poor diffusion conditions. Because of this tendency to make short term releases during periods of poor diffusion conditions, and the resulting order to magnitude differences in X/Q estimates that may result during such releases, we have elected to use the 15% meteorology for the one hour X/Q values. The 15% one hour X/Q value is approximately one standard deviation from the mean. The 15% one hour X/Q value is used to establish a power law relationship between one one-hour release and the annual average X/Q value (8760 hour release). The X/Q value for the appropriate number of hours of release from a given source is then calculated by extrapolation between the one hour value and the annual average value. Without the use of the 15% value as one point on the curve for cases where we do not know when short term releases will be made, we may substantially underestimate X/Q values. If we had better definition of when short term releases would be made, or when releases could be restricted, we would change the distribution we are presently using. We conclude that the use of the 15% one hour X/Q value to establish a X/Q distribution, at sites where we do not know when short term releases are to be made, precludes substantial underestimates of X/Q while at the same time preventing substantialy overestimates. If tech specs were available to control the time of short term releases we would modify our computational techniques.

Appendix E-3

CALCULATION OF INTERMITTENT (PURGE)
RELEASES WHEN USING JOINT FREQUENCY DATA

INPUTS: FOR EACH SET DISTANCE AND DIRECTION OF INTEREST.

1. $(X/Q)_{15}$ - 15-PERCENTILE UNDECAYED, UNDEPLETED X/Q, ASSUMING

   A) PART-TIME ELEVATED, PART-TIME GROUND LEVEL RELEASE (PER R.G. 1.111, C2)

   B) FOR RELEASE > 8 HOURS, OR MANY SHORT TERM RELEASES, THE EFFLUENT IS UNIFORMLY DISTRIBUTED IN THE HORIZONTAL WITHIN THE 22 1/2° SECTOR.

2. $(X/Q)_{AA}$ - UNDECAYED, UNDEPLETED ANNUAL AVERAGE X/Q, ASSUMING

   A) PART-TIME ELEVATED, PART-TIME GROUND LEVEL RELEASE (PER R.G. 1.111, C2)

   B) EFFLUENT IS UNIFORMLY DISTRIBUTED IN THE HORIZONTAL WITHIN THE 22 1/2° SECTOR.

3. TOTAL HOURS OF PURGE RELEASE PER YEAR.

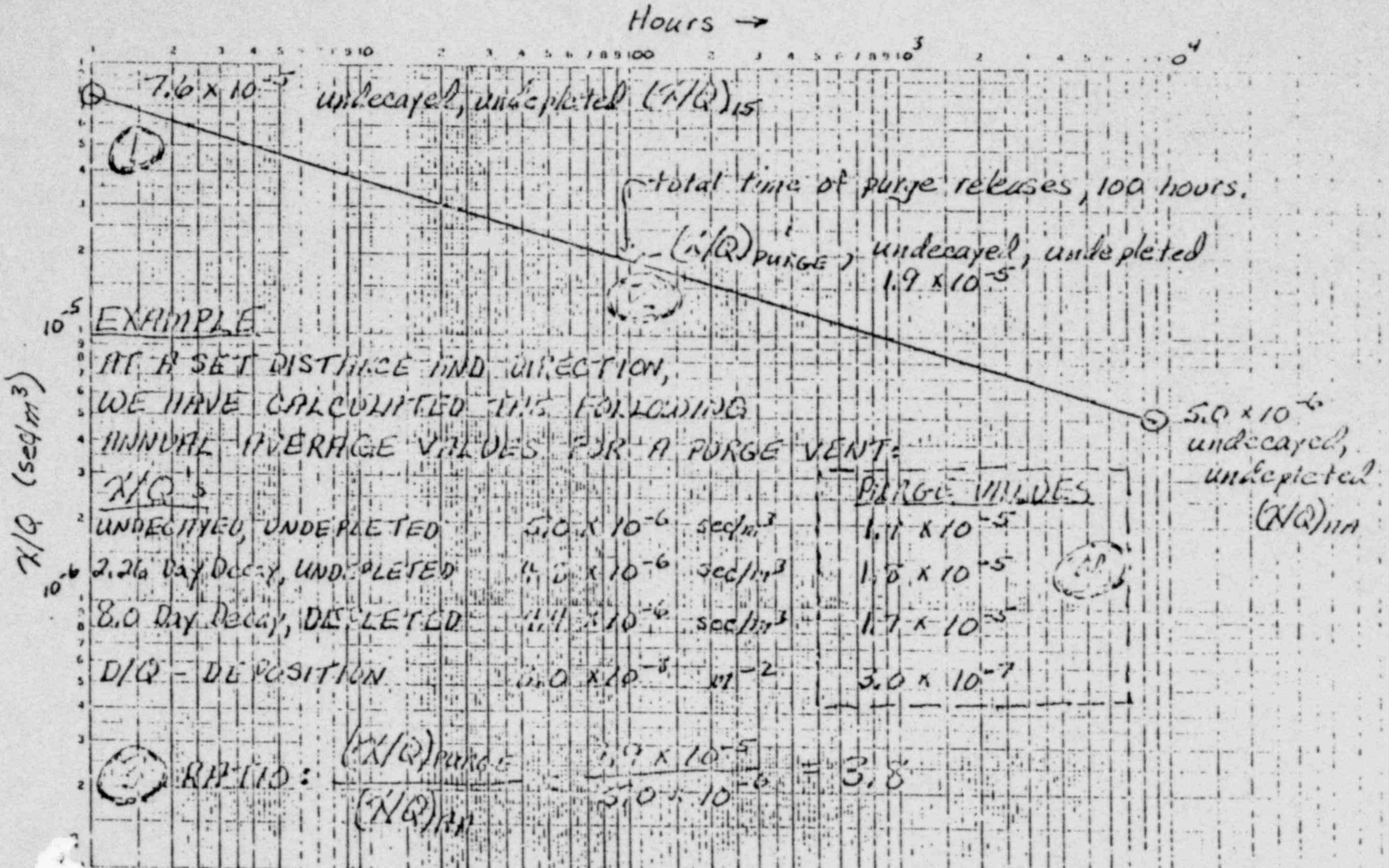
METHOD

STEP 1: ON LOG-LOG PAPER (X/Q VS. TIME), PLOT $(X/Q)_{15}$ AT ONE HOUR, AND $(X/Q)_{AA}$ AT 8760 HOURS AND CONNECT THESE POINTS WITH A STRAIGHT LINE.

STEP 2: READ THE UNDECAYED, UNDEPLETED X/Q, $(X/Q)_{PURGE}$, FOR THE PURGE RELEASE FROM THE GRAPH CORRESPONDING TO THE TOTAL TIME OF PURGE RELEASE PER YEAR.

STEP 3: DETERMINE THE RATIO: $\dfrac{(X/Q)_{PURGE}}{(X/Q)_{AA}}$

STEP 4: TO OBTAIN DEPLETED AND/OR DECAYED X/Q'S AND DEPOSITION VALUES FOR THE PURGE TIME PERIOD, MULTIPLY THE RESPECTIVE ANNUAL AVERAGE VALUES BY THE ABOVE RATIO.



CALCULATION OF INTERMITTENT (PURGE) RELEASES WHEN USING JOINT FREQUENCY DATA - EXAMPLE.

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUL 25 1978

Appendix E-4

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Daniel R. Muller, Acting Director
Division of Site Safety and Environmental Analysis

SUBJECT: METEOROLOGICAL MODEL FOR PART 100 EVALUATIONS

The Regulatory Requirements Review Committee (RRRC) has considered proposed revisions to the Meteorological Model for Part 100 evaluations on several occasions, specifically in February 1977, November 1977, and May 1978.

During the most recent meeting on this subject, May 2, 1978, the staff discussed several alternatives of sector and overall probabilities for use in the Regulatory Guide being developed. Historical approaches were discussed in some detail as bases for the selection of the probability of dispersion conditions in limiting sectors, and the overall limiting site probability level of 5% analogous to the SRP model was also discussed.

The staff presented information based on a parametric study of representative sites which indicated that the average of worst sector probabilities experienced in case review was about 0.6%. There was a considerable spread in the worst sector probability levels for the sites examined in the parametric study. In addition, the staff identified the relative contribution of both meander and variable exclusion area boundaries to anticipated changes in estimated dispersion conditions at the exclusion area boundary, and compared these changes to dispersion estimates produced by the SRP model.

At the conclusion of the RRRC meeting of May 2, 1978, the staff views on what had been accepted, recommended, or decided at the meeting varied, except that the staff should proceed with production of the standard and preparation of a Commission Information Paper.

Subsequent to the RRRC meeting, the staff of the Division of Site Safety and Environmental Analysis has further considered the sector average and the overall site probability level, concluding that the overall site probability specification was not necessary, and that detailed analysis of the parametric study results indicated a sector probability level of 0.5% would accurately reflect the average of the parametric study. These matters, and the numerous comments on the extensive and complex guide, have restrained, to some degree, progress in moving the guide into a more final form. Some major staff comments are included in memoranda from D. Bunch to H. Denton (dated June 19, 1978) and L. Hulman to H. Denton (dated June 26, 1978). The staffs of NRR and OSD have been proceeding with resolution of those comments which are within the context of the proposed guide. Detailed comments for final wording of the guide are ready for transmittal to OSD.

While progress in guide development is being made, the resolution of the sector probability level, and the question of whether the overall site probability level should be included, have not been fully resolved. I therefore request that you approve the following positions for NRR:

1. A limiting sector probability level of 0.5% be used in the new model (the basis for this is described in the memo from L. Hulman to H. Denton on 6/23/78).

2. An overall site probability limit of 5% be retained. It may well be that this factor has no influence in practice, but it will provide a limit for sites where adverse dispersion is non-directional.

These would apply to the standard being prepared and to the Hydrology-Meteorology Branch Technical Position on the sector dependent model.

Daniel R. Muller

Daniel R. Muller, Acting Director
Division of Site Safety and
Environmental Analysis
Office of Nuclear Reactor Regulation

cc: E. G. Case
R. P. Denise
L. Hulman

Appendix E-5

August 2, 1978

MEMORANDUM FOR: Daniel R. Muller, Acting Director, DSE

FROM: Harold R. Denton, Director, NRR

SUBJECT: PROPOSED NEW METEOROLOGICAL MODEL

By the memo of May 16, 1978, DSE was directed to allow applicants to use either the current model or the proposed new model (which was to be modified to include a 5% site X/Q criterion), pending the preparation and RRRC review of an Information Paper on the above subject. Your request for clarification has been considered and additional guidance is as follows:

1. The sector probability level to be used in connection with the interim position is 0.5%. I understand that this value represents the HMB's present judgment of the value that will normalize results from the new model to those from the old. Whether this value is ultimately adopted as a final position will rest first on the reviews of the Information Paper and secondly on the results of subsequent reviews of the proposed new model following its issuance for comment.

2. Since there remain substantive questions regarding the proposed model, you should include the staff's analyses supporting the 0.5% value, and a summary of key issues, as input to SD for inclusion in the "for comment" package. I would also suggest that any comments that you provide to SD not foreclose viable options such as retention of the current model, or alternative sector probability criteria (should information be developed that such alternatives are appropriate).

3. If it appears that a significant commitment of NRR resources will be required to address and resolve the issues surrounding the proposed new model, or to implement that model, that matter should be discussed in the Information Paper and at the next briefing before the RRRC.

H R Denton

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

POOR ORIGINAL

HMB-BTP-2 (REVISION I)
(AUGUST 2, 1978)
INTERIM BRANCH TECHNICAL POSITION
HYDROLOGY-METEOROLOGY BRANCH
ACCIDENT METEOROLOGY MODEL

It is our position that either the draft Regulatory Guide 1.XXX, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants" (dated September 23, 1977), or the procedures described in Standard Review Plan Section 2.3.4 may be used to evaluate atmospheric transport conditions for analysis of accidents with the following amendments to the draft regulatory guide model: (a) a limiting sector X/Q value at the 0.5% probability level be used*, (b) the accumulated frequency of the limiting sector X/Q or higher value in all sectors may not exceed 5% for the site, and; (c) normalization of individual sector probability distributions is not used.

*Amendment based on Memorandum from H. R. Denton to D. R. Muller, Subject: Proposed New Meteorological Model, dated August 2, 1978.