Revision 1
March 1974

U.S. ATOMIC ENERGY COMMISSION
REGULATORY GUIDE
DIRECTORATE OF REGULATORY STANDARDS

withdrawn

REGULATORY GUIDE 1.42

INTERIM LICENSING POLICY ON AS LOW AS PRACTICABLE FOR GASEOUS RADIOIODINE RELEASES FROM LIGHT-WATER-COOLED NUCLEAR POWER REACTORS[1/]

A. INTRODUCTION

Paragraph 20.1(c) of 10 CFR Part 20 provides that AEC licensees should make every reasonable effort to keep radiation exposures and releases of radioactive material in effluents to unrestricted areas as low as practicable. Consistent with this objective, §50.34a of 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that construction permit applications include design objectives and that technical specifications include operating conditions for the purpose of maintaining the release of radioactive material in effluents from nuclear power reactors as low as practicable. On June 9, 1971, the Atomic Energy Commission published in the Federal Register (36 F.R. 11113) for public comment proposed amendments that would, if adopted, supplement 10 CFR Part 50 by adding an Appendix I. Appendix I would, if adopted, provide numerical guides for design objectives and technical specification requirements for limiting conditions of operation for light-water-cooled nuclear power reactors (LWR) to keep radioactive material in effluents as low as practicable. On February 20, 1974, the Regulatory staff issued its "Concluding Statement of Position"[2/] based on

[1/] In this revision, Sections A, B, and C and Appendices C and D are almost completely rewritten and Appendices A and B are moderately revised.

[2/] Concluding Statement of Position of the Regulatory Staff Public Rulemaking Hearing on: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low As Practicable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactors, USAEC, February 20, 1974, Docket N. RM-50-2.

the record of the rule making hearing that was concluded in December 1973. The Concluding Statement included Regulatory staff recommendations on a modified Appendix I and five draft regulatory guides which provide models and parameters acceptable to the Regulatory staff for calculating average expected releases of radioactive materials in liquid and gaseous effluents from normal operations, and calculational models and parameters used to estimate doses for purposes of implementing the guidance on design objectives and limiting conditions of operation in Appendix I. Those five guides will be issued by the Regulatory staff at some time following the adoption of a final rule by the Commission. At that time Regulatory Guide 1.42 will be withdrawn.

Pending conclusion of the proposed Appendix I rule making proceeding and the Commission's decision on an effective rule, Regulatory Guide 1.42, Revision 1, provides interim guidance to aid applicants in implementing §§20.1(c), 50.34a, and 50.36a of the Commission's regulations with respect to keeping radioactive iodine releases in gaseous effluents from LWR plants as low as practicable. The revision of this guide reflects the position of the Regulatory staff with respect to radioiodine released in gaseous effluents as presented in its Concluding Statement of Position in the rule making proceeding. This guide may be used for LWR plants currently in the construction permit and operating licensing review stages as well as plants for which construction permit applications are received in the immediate future.

B. DISCUSSION

The experience of the Regulatory staff in administering §§20.1(c), 50.34a, and 50.36a of 10 CFR Parts 20 and 50 has shown that, in most cases, the calculated limiting dose in achieving as low as practicable releases of radioactive material in gaseous effluents from LWR plants is the potential dose to a child's thyroid due to radioactive iodine taken into the body of the child by ingestion of locally produced milk. Features of the five draft guides appended to the Concluding Statement of Position which are germane to guidance for radioactive iodine in gaseous effluents have been abstracted and presented as appendices of this interim guide. The calculational models with selected parametric values contained in the appendices to this guide are acceptable to the staff in evaluating LWR stations for compliance with §20.1(c) of 10 CFR Part 20 and §§50.34a and 50.36a of 10 CFR Part 50.

C. REGULATORY POSITION

The guidance presented below on radioactive iodine in gaseous effluents from light-water-cooled nuclear power reactors has been extracted from the Regulatory staff's Concluding Statement of Position.[2/]

1. Guidance on Design Objectives for Radioactive Iodine in Gaseous Effluents. For radioactive iodine above background[3/] releases to the atmosphere in LWR gaseous effluents:

   a. The calculated annual total quantity of all radioactive iodine from all LWRs at a site should not result in an annual dose or dose commitment to the thyroid of an individual in an unrestricted area from all pathways of exposure in excess of 15 millirems. In determining the dose or dose commitment, the portion thereof due to intake of radiaoctive iodine via the food pathways may be evaluated at the locations where the food pathways actually exist.

   b. The calculated annual total quantity of iodine-131 in gaseous effluents should not exceed 1 curie for each LWR at a site.

[3/] "Background" means the quantity of radioactive materials in the effluent from LWRs at a site that did not originate in the reactors.

c. Notwithstanding the guidance in C.1.a and C.1.b for a particular site, if an applicant for a permit to construct an LWR has proposed baseline in-plant control measures[4/] to reduce the possible sources of radioactive iodine releases and the calculated annual quantities, taking into account such control measures, exceed the design objective quantities set forth in C.1.a and C.1.b, the requirements for design objectives for radioactive iodine in gaseous effluents may be deemed to have been met provided the calculated annual total quantity of all radioactive iodine that may be released in gaseous effluents does not exceed four times the quantity calculated pursuant to C.1.a. (See C.2 for limiting conditions for operation.)

2. Guidance on Technical Specifications for Limiting Conditions of Operation. The guidance on limiting conditions of operation for light-water-cooled nuclear power reactors (LWRs) set forth below may be used by an applicant for a license to operate an LWR as guidance in developing technical specifications under §50.36a(a) to keep levels of radioactive iodine in gaseous effluents to unrestricted areas as low as practicable. Paragraph 50.36a(b) provides that licensees be guided by certain considerations in establishing and implementing operating procedures specified in technical specifications that take into account the need for operating flexibility and at the same time assure that the licensee

[4/] Such in-plant control measures may include treatment of steam generator blowdown tank exhaust, clean steam supplies for turbine gland seals, condenser vacuum systems, containment purging exhaust and ventilation exhaust systems, and special design features to reduce contaminated steam and liquid leakage from valves and other sources such as sumps and tanks, as appropriate for the type of reactor.

will exert his best effort to keep levels of radioactive iodine in gaseous effluents as low as practicable. The following paragraphs provide additional specific guidance to licensees in this respect.

In using the guidance provided in this section, it is expected that the annual releases of radioactive iodine in gaseous effluents from LWRs can generally be maintained within the levels set forth as numerical guidance for design objectives in C.1.a and C.1.b.

a. If the quantity of radioactive iodine actually released in gaseous effluents during any calendar quarter exceeds one-half the design objective annual quantity derived pursuant to C.1.a and C.1.b, the licensee should:

   (1) Make an investigation to identify the causes for such release rates;

   (2) Define and initiate a program of action to reduce such release rates to the design objective levels; and

   (3) Report these actions in writing to the Commission within 30 days[5/] from the end of the quarter during which the release occurred.

[5/] Paragraph 50.36a(a)(2) requires the licensee to submit certain reports to the Commission with regard to the quantities of the principal radionuclides released to unrestricted areas. It also provides that, on the basis of such reports and any additional information the Commission may obtain from the licensee and others, the Commission may from time to time require the licensee to take such action as the Commission deems appropriate.

b. If the quantity of radioactive iodine actually released in gaseous effluents during any calendar quarter exceeds twice the design objective annual quantity or, during any period of 12 consecutive months, exceeds four times the design objective annual quantity derived pursuant to C.1.a and C.1.b, the Commission will take appropriate action to assure that such release rates are reduced.[5/]

c. The licensee should establish an appropriate surveillance and monitoring program to:

(1) Provide data on quantities of radioactive iodine released in gaseous effluents to assure that the guidance of C.1.a and C.1.b is met;

(2) Provide data on measurable levels of radioactive iodine in the environment to evaluate the relationship between quantities of radioactive iodine released in gaseous effluents and resultant radiation doses to individuals from principal pathways of exposure; and

(3) Identify changes in the use of unrestricted areas (e.g., for agricultural purposes) to permit modifications in monitoring programs for evaluating doses to individuals from principal pathways of exposure.

d. If the data developed in the surveillance and monitoring program described in C.2.c or from other monitoring programs show that the relationship between the quantities of radioactive iodine released in gaseous effluents and the dose to individuals in unrestricted areas is significantly different from that assumed in the calculations used to determine design objectives pursuant to C.1, the Commission may modify the quantities in the technical specifications defining the limiting conditions for operation in a license authorizing operation of an LWR.

APPENDIX A

PRINCIPAL PARAMETERS USED IN SOURCE TERM CALCULATIONS

A. Principal Parameters Used in PWR Source Term Calculations

1. Thermal Power Level - The maximum thermal power level (MWt) evaluated for safety considerations in the Safety Analysis Report.

2. Plant Capacity Factor - 80%

3. Fraction of Fuel Releasing Fission Products to the Primary Coolant

Zircaloy-clad fuel	0.25%
Stainless-steel-clad fuel	0.10%

4. Equilibrium Primary Coolant Radioiodine Concentration
   Escape Rate Coefficient - 1.3×10^{-8} sec^{-1}

5. Primary to Secondary Leakage Rate - 110 lb/day
   If the technical specifications limit the leakage rate to less than 110 lb/day (i.e., limitation on tritium activity in steam generator blowdown stream), calculate a leakage rate based on the specifications.

6. Containment Building Leakage Rate - 240 lb/day hot primary coolant with a partition factor of 0.1 for radioiodine.

7. Auxiliary Building Leakage Rate - 160 lb/day primary coolant with a partition factor (PF) of 0.005 for radioiodine. If the letdown heat exchangers are located within the containment building, assume that all of the leakage is cold and use a PF of 0.001.

8. Turbine Building Steam Leakage Rate (gaseous source term only)

   a. If no special design features are provided to reduce the leakage from steam line valves, use a leakage rate of 1700 lb/hr and a PF of 1 for radioiodine.

   b. If special design features are provided to reduce the leakage from "Stop, Control, and Bypass" valves 24 inches and larger, use a leakage rate of 1350 lb/hr and a PF of 1 for radioiodine.

   c. If special design features are provided to reduce the leakage rate from all steam line valves 2-1/2 inches and larger, use a leakage rate of 340 lb/hr and a PF of 1 for radioiodine.

9. Frequency of Containment Building Purge - 4 purges/yr

10. Primary System Volumes Degassed Per Year - Sum of a and b below.

   a. The number of coolant volumes consistent with two cold shutdowns per year, plus

   b. Total number of volumes degassed per year due to continuous stripping based on information in the Safety Analysis Report.

11. Waste Gas Storage Tanks - Holdup Time

Calculate the holdup time by the following equations:

$T_f = VP/140$

$T_h = VP(n-2)/140$

where

T_f is the time required to fill one tank, days

T_h = holdup time, days

V = volume of each tank, ft^3

P = storage pressure, atmospheres (absolute)

n = total number of storage tanks

(n-2) = correction to subtract the tank being filled and the tank held in reserve

140 = average waste gas flow rate per reactor to the storage tanks, ft^3/day (STP)

12. Steam Generator Blowdown Rate - 0.06% of steam flow

13. Partition (PF) and Decontamination Factors (DF) for Radioiodine

	PF
Steam Generator, Internal Partition	
a. Recirculating U-Tube	0.01
b. Once Through	1
Steam Generator Blowdown Tank Vent	0.05
	DF
Steam Generator Blowdown Tank Vent Separate Condenser*	100
Charcoal Adsorber	10
Main Condenser Air Ejector	2000
Internal Cleanup System (Kidney)	**

14. Decontamination Factors (DF) for Demineralizers

Note: For two demineralizers in series, the DF for the second demineralizer is given in parentheses.

*If the steam generator blowdown tank is vented to the turbine condenser, the source term is zero.

**Assume the internal cleanup system will operate for 16 hours prior to purging at a DF of 10 for radioiodine and a mixing efficiency of 70%.

	DF (Anion)
Mixed Bed (Li_3BO_3)	10
Mixed Bed (H^+ OH^-)	
Condensate	10^3
Radwaste	10^2(10)
Cation Bed (H^+)	1(1)
Anion Bed (OH^-)	10^2(10)
Powdex (any system)	10(10)
Reverse Osmosis	1.5 per stage for all radionuclides

15. Decontamination Factors (DF) for Evaporators

	DF
Miscellaneous Radwaste Evaporators	10^3
Boric Acid Evaporators	10^2
Separate Evaporator for Detergent Wastes	10^2

16. Flow Through Charcoal Delay System - Negligible release of iodine-131 ($<10^{-4}$ Ci/yr).

17. Guidelines for Rounding Off Numerical Values
In calculating the estimated annual release of radioactive materials in gaseous waste, round off all numerical values to two significant figures.

B. Principal Parameters Used in BWR Source Term Calculations

1. Thermal Power Level - The maximum thermal power level (MWt) evaluated for safety considerations in the Safety Analysis Report.

2. Plant Capacity Factor - 80%.

3. Equilibrium Primary Coolant Radioiodine Concentration - The I-131 concentration in the primary coolant is assumed to be 5×10^{-3} μCi/g, independent of power level.

4. Reactor Building Leakage Rate (gaseous source term only) Use 500 lb/hr at primary coolant activity and a PF of 0.001 for radioiodine.

5. Radwaste Building (gaseous source term only) - The release of radioiodine in gaseous effluent is negligible ($<10^{-4}$ Ci/yr of iodine-131).

6. Turbine Building Steam Leakage Rate (gaseous source term only)
   a. If no special design features are provided to reduce the leakage from steam line valves, use a leakage rate of 1700 lb/hr and PF of 1 for radioiodine.

   b. If special design features are provided to reduce leakage from the "Stop, Control, and Bypass" valves (24 inches and larger) and no others, use a leakage rate of 1350 lb/hr and a PF of 1 for radioiodine.

   c. If special design features are provided to reduce the leakage from all steam line valves 2-1/2 in. and larger, use a leakage rate of 340 lb/hr and a PF of 1 for radioiodine.

7. Turbine Gland Seal Steam Leakage Rate (gaseous source term only) Use 0.1% of the main steam flow and a decontamination factor (DF) of 100 for radioiodine across the turbine gland seal steam condenser. If clean steam is supplied to the gland seal, the radioiodine source term is negligible ($<10^{-4}$ Ci/yr). If sealing steam

is supplied from the condensate storage tanks, 1×10^{-6} times the main steam flow should be used.

8. Partition (PF) and Decontamination Factors (DF) for Radioiodine

	PF
Reactor Vessel, Internal Partition	0.01
	DF
Main Condenser Air Ejector	200
Recombiner/Condenser	100
Charcoal Adsorber	10

9. Decontamination Factors (DF) for Demineralizers

Note: For two demineralizers in series, the DF for the second demineralizer is given in parentheses.

	DF (Anion)
Mixed Bed (H^+ OH^-)	
Reactor Coolant	10
Condensate	10^3
Clean Waste	10^2(10)
Dirty Waste (Floor Drains)	10^2(10)
Cation Bed (H^+)	
Dirty Waste	1(1)
Powdex (any system)	10(10)
Reverse Osmosis	1.5 per stage for all radionuclides

10. Decontamination Factors (DF) for Evaporators

	DF
Miscellaneous Radwaste Evaporators	10^3
Separate Evaporator for Detergent Waste	10^2

11. <u>Flow Through Charcoal Delay Systems</u>

The release of radioiodine in gaseous effluent is negligible ($<10^{-4}$ Ci/yr of iodine-131).

12. <u>Decontamination Factor (DF) for Cryogenic Distillation</u>

Use a DF of 1×10^4 for radioiodine.

13. <u>Guidelines for Rounding Off Numerical Values</u>

In calculating the estimated annual release of radioactive materials in gaseous waste, round off all numerical values to two significant figures.

APPENDIX B

PROCEDURE FOR CALCULATION OF ANNUAL AVERAGE RELATIVE CONCENTRATIONS IN AIR

Annual average relative concentration (χ/Q) may be estimated from onsite meteorological data or suitable offsite data in the form of joint frequency distributions of wind direction and wind speed by atmospheric stability class. Wind direction should be based on 22-1/2 degree sectors representing the 16 compass points, and wind speed classes based on the Beaufort wind scale or other suitable class divisions. Wind directions and speeds should represent conditions at the release point for stack releases and at the 10-meter level for rooftop vent and building releases. Wind speeds may be adjusted downward (but not upward) to represent conditions at appropriate release heights, using a standard power law extrapolation procedure (Ref. 1) if data from the appropriate levels are not available. Atmospheric stability may be divided into seven classes to represent Pasquill stability classes A (extremely unstable) through G (extremely stable) based, preferably, on onsite vertical temperature gradient measurements as presented in Regulatory Guide 1.23 (Safety Guide 23) or other suitable methods.

The Gaussian plume model for long-period averages (Eq. 3.144 of Ref. 2) may be used to determine the annual average relative concentrations (χ/Q) at appropriate distances and directions from the source. The joint frequency distribution data should be used as input to these calculations. Vertical plume spread (σ_z) should be estimated at appropriate distances for each stability class using the curves presented in Reference 2, Figure 3.11.

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

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

For rooftop vent and building emissions, a ground-level release may be assumed, and the vertical plume spread adjusted in accordance with Eq. 3.142 of Ref. 2, where A should be defined as the maximum adjacent building height either upwind or downwind from the release point. The adjusted spread should be limited to a reduction of up to a factor of $\sqrt{3}$ of the relative concentration calculated for a ground-level point source. For stack releases, plume rise due to momentum based on the formula in Reference 3 is added to the height of the stack above plant grade, and topographical elevations higher than plant grade along the effluent trajectory are subtracted from the stack height.

References

1. Smith, M. (ed.), 1968, Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, American Society of Mechanical Engineers, New York, N.Y.

2. Slade, D. H. (ed.), Meteorology and Atomic Energy-1968, TID-24190, USAEC Division of Technical Information Extension, Oak Ridge, Tennessee.

3. Briggs, G. A., 1969, Plume Rise, TID-25075, USAEC Critical Review Series, USAEC Division of Technical Information Extension, Oak Ridge, Tennessee.

APPENDIX C

CALCULATIONAL MODELS FOR OFFSITE THYROID DOSES TO MAN VIA MILK AND LEAFY VEGETATION PATHWAYS

Annual average values of the relative concentration* (χ/Q) should be calculated as a function of distance from plant release points in 16 equiangular directions from potential sources. The estimates of χ/Q and the quantities of radioiodines released from the plant sources allow calculation of annual average air concentrations of radioiodine effluent in each of the 16 directions examined. The annual average concentration of gaseous radioiodine effluent species i at the location (r, θ_j) from the (0,0) release point may be determined from

$$C_{ij}(r,\theta_j) = \frac{Q_i\ R(r,h)\ \exp\left[-\lambda_i(r/\bar{v}_j)\right]}{3.15 \times 10^7}\,(X/Q)_j. \qquad (1)$$

In Equation 1:

$C_{ij}(r, \theta_j)$ is the annual average air concentration of radioiodine i as I_2 at the distance r and in the j^{th} sector from the source (curies per cubic meter),

Q_i is the quantity of radioiodine i annually released from the source as I_2 (curies per year),

r is the distance from the source to the location where χ/Q is determined (meters),

θ_j is the wind direction angle from the source to the location of interest in the j^{th} sector,

* Concentration normalized to a unit release rate.

$\bar{v}_j$ is the annual average wind speed for winds directed into the j^{th} sector (meters per second),

λ_i is the radiological decay constant of the radioiodine species i (inverse seconds),

$(\chi/Q)_j$ is the annual average relative concentration at the distance r meters from the source in the j^{th} sector (seconds per cubic meter), and

R(r, h) is a dimensionless iodine cloud depletion factor which is dependent upon distance from the source, r, and the height of release at the source, h. The value of the depletion factor may be determined using Equation 2, which is a function fitted to conform to plume depletion estimates as provided in the Final Environmental Statement on "as low as practicable".[1] This function is given by

$$R(r,h) = (4.47 \times 10^{-3}h + 0.618)[\exp\{-(1.06 \times 10^{-5}r)\} - \exp\{-(1.06 \times 10^{-4}r)\}] + \exp\{-(1.06 \times 10^{-4}r)\}; h \leq 100. \quad (2)$$

In Equation 2, h is the height of radioiodine release and r is the distance from the source, both in meters.

Radioiodine present as molecular iodine in the gaseous effluent is deposited from the effluent gases on surfaces via a transfer mechanism with the dimensions of velocity. This is termed deposition velocity, V, and is here given in units of meters per second. Deposition velocities of molecular iodine are reported[2] to have been observed to range from approximately 0.01 to 0.03 meter per second. A value of deposition velocity for molecular iodine of 0.015 meter per second has been stated[3] to lie within a factor of 5 for most reported observations exclusive of those influenced largely or in part by the airborne presence of methyl iodide. The value of 0.015 meter per second has been chosen, therefore, to represent an appropriate deposition velocity for molecular iodine.

The iodine deposited on surface vegetation is not completely retained immediately following deposition. The fraction of deposited iodine that remains on vegetation shortly after deposition is termed the vegetation retention factor and is denoted here as k_1. Experiments have been conducted to establish the value of this parameter under a variety of conditions. Observed values of this parameter range from 0.07 to 0.85.[4-15] The value of the vegetation retention factor, k_1, selected for use in this guide is 0.3.

In addition to the rapid loss of iodine immediately following its deposition, it has been observed that the subsequent rate of removal of the remaining radioiodine from vegetation is greater than that attributable to radiological decay alone. The rate of change of radioiodine on vegetation due to weathering has been shown to be represented adequately by a first order rate law[3,10,12,13,16] with a recommended[16] weathering half-life of 13 days. The model presented here assumes the adequacy of the first order law in calculation and accepts a weathering half-life, T_w, of 13 days.

Considering the preceding, the rate of change of radioiodine i on green fodder at the location of interest is given by

$$d\rho_{ij}/dt = k_1 C_{ij} V - (\lambda_i + \lambda_w)\rho_{ij} \qquad (3)$$

In Equation 3,

ρ_{ij} is the average quantity of radioiodine i present on green fodder (curies per square meter),

k_1 is the vegetation retention factor (dimensionless),

C_{ij} is the average air concentration of radioiodine i as I_2 (curies per cubic meter),

V is the deposition velocity of iodine as I_2 (meters per second),

λ_i is the radiological decay constant of radioiodine i (inverse seconds), and

λ_w is the weathering decay constant of iodine (inverse seconds).

Integration of Equation 3 with respect to time yields

$$\rho_{ij} = \frac{k_1 C_{ij} V}{\lambda_i + \lambda_w} [1 - \exp\{-(\lambda_i + \lambda_w) t\}] \tag{4}$$

In Equation 4, t represents the time in seconds since the start of radioiodine release. It is here assumed that equilibrium conditions exist and, as a consequence, the exponential term in Equation 4 goes to zero. The average equilibrium areal density of radioiodine i is then given by

$$\rho_{ij} = \frac{k_1 C_{ij} V}{\lambda_i + \lambda_w} \tag{5}$$

where ρ_{ij} is the quantity of radioiodine i in curies per square meter on vegetation at the location of interest.

Annual Infant Thyroid Dose Via Cows Milk

Milk cattle pastured on green fodder containing iodine secrete a portion of the iodine ingested into their milk. Several authors[3,5,6,12,14,15,17-20] have measured or calculated (using the measurements of others) the concentration of radioiodine in milk of cattle pastured on forage with measured areal activity densities. Based on this information, an iodine transfer coefficient, k_2, was found to range from 0.014 to 1.54 curies/liter per curie/square meter, with average values ranging from 0.09 to 0.40 for I-131. A value of 0.20 has been selected as appropriate to represent the I-131 transfer coefficient, k_2, for purposes of this model. Upon application of appropriate parameters and relationships[21], the value of the iodine transfer coefficient for I-133 has been calculated to be 0.09 curie/liter per curie/square meter.

The values assigned to iodine transfer coefficients are, of course, dependent upon the quantities of green fodder ingested per unit time by the cow. However, given free access to pasture, cows have been shown[22] to ingest a nearly constant weight of grass per day over a large weight range of daily concentrate intakes. As a consequence of this, no allowance is provided for iodine concentration reduction in milk due to supplemental feeding of cows that are allowed to graze freely.

It might also be expected that the addition of inactive iodine to the diet of a cow could provide some reduction of radioiodine concentration in milk. This is true, but the iodine intake requirements of the cow must be quite large to affect the iodine transfer coefficients.

It has been reported[21] that as much as 2 grams of iodine per day results in only a 50% reduction in milk radioiodine concentration and that, within a rather large range, the iodine content of a cow's diet has little effect on the radioiodine concentration in milk. It is concluded that under normal agricultural practices, the quantities of iodine ingested by cows have little effect on the iodine transfer coefficients. No allowance is, therefore, provided here to adjust the coefficients based upon this mechanism.

The average equilibrium concentrations of radioiodine-131 and -133 may then be calculated using

$$m_{131,j} = \frac{0.20k_1V}{\lambda_{131} + \lambda_w} C_{131,j} \tag{6}$$

and

$$m_{133,j} = \frac{0.09k_1V}{\lambda_{133} + \lambda_w} C_{133,j} \tag{7}$$

Under the above considerations, the milk radioiodine equilibrium concentrations of I-131 and I-133 relative to air radioiodine equilibrium concentrations are

$$m_{131,j} = 5.58 \times 10^2 \, C_{131,j} \tag{8}$$

$$m_{133,j} = 4.10 \times 10^1 \, C_{133,j} \tag{9}$$

The milk ingestion rate for a child is assumed to be 1 liter per day. The breathing rate used in defining the MPC air values for radioiodine in air is 3 cubic meters per day. Using the fractional thyroid deposition values from human ingestion and inhalation as 0.30 and 0.23, respectively, the daily depositions of radioiodine within the thyroid by milk ingestion and air inhalation are given by:

$$\text{Daily Thyroid Deposit (milk)} = (0.30)(1)m_{ij} \text{ and}$$
$$\text{Daily Thyroid Deposit (inhalation)} = (0.23)(3)C_{ij}.$$

The ratio of milk to air thyroid doses for the same air concentration is

$$S_i = \frac{(0.30)(1)\ m_{ij}}{(0.23)(3)\ C_{ij}} \tag{10}$$

These ratios for I-131 and I-133 are then 243 and 17.8, respectively.

Thus, the calculation of infant thyroid dose via the cow milk pathway may be related directly to those air concentration values provided in 10 CFR Part 20 that correspond to air doses of 1500 millirem per year to an infant's thyroid. These are given below:

Nuclide	Annual Infant Thyroid Dose Via Cows Milk (mrem)
I-131	$(243)\left(\frac{C_{131,j}}{MPC_a}\right)(1500)$
I-133	$(17.8)\left(\frac{C_{133,j}}{MPC_a}\right)(1500)$.

Alternative representations of the above are:

$$D_{131}(\text{mrem/yr}) = 1.15 \times 10^8 (\chi/Q)_j Q_{131} R \tag{11}$$

and

$$D_{133}(\text{mrem/yr}) = 2.12 \times 10^6 (\chi/Q)_j Q_{133} R \tag{12}$$

In Equations 11 and 12, $(\chi/Q)_j$ is given in seconds per cubic meter, Q_i is given in curies per year, and R (from Equation 2) is dimensionless.

As indicated, each of the relations provided for the calculation of dose to an infant's thyroid assumes that the cattle from which milk is obtained are pastured throughout the year. For those areas without year-around grazing, doses calculated using these relations may be reduced by multiplying the calculated values by the fraction of the year that grazing commonly occurs in the area.

Annual Infant Thyroid Dose Via Goats Milk

Goats pastured on green fodder containing iodine secrete in their milk a substantially greater fraction of the iodine ingested than do cows. In general, a significant part of the diet of milk goats takes the form of whole oats[23] or processed feeds containing from about 13 to 16 percent protein.[24-26] It may be inferred, however, that milk goats consume approximately 1.2 kilograms dry weight of green fodder daily if fed only by pasture. Using the average dry weight per square meter of hay harvested in the United States,[27] 0.365 kilogram per square meter, the milk goat is estimated to graze about 3.3 square meters daily. A number of observations have indicated[25] that daily milk production ranges from 0.8 to 3.4 liters. A milk output of 2.3 liters per day[26] was chosen to represent typical output for this examination. Based upon the above information and observed transfer coefficients for iodine[28] normalized to milk output, the calculated iodine transfer coefficient, k_2, for I-131 is 1.44 curies/liter per curie/square meter. It is here assumed that this parameter is reduced for I-133 in the same ratio as for the cow. Consequently, it is assumed that the iodine transfer coefficient for I-133 is 0.65 curie/liter per curie/square meter. It is furthermore here assumed that over a large range of supplemental feeding, no substantial reduction occurs in the green fodder intake of goats. As a consequence, no allowance is made for supplemental feeding of goats.

As with the cow, the transfer of radioiodine to the milk of the goat is affected by the addition of stable iodine to its diet.[29] At low supplemental levels of stable iodine feeding (4 mg I/day), radioiodine transfer to milk appears to be enhanced; while at high levels of supplemental feeding (0.9 g I/day), the transfer of radioiodine to milk is substantially reduced. It is here assumed that normal agricultural practices will not significantly affect iodine transfer. Consequently, no allowance is made for this effect.

The average equilibrium concentrations of radioiodine-131 and -133 may then be calculated using:

$$n_{131,j} = \frac{1.44\ k_1 V}{\lambda_{131} + \lambda_w} C_{131,j} \tag{13}$$

$$n_{133,j} = \frac{0.65\ k_1 V}{\lambda_{133} + \lambda_w} C_{133,j} \tag{14}$$

Under the above considerations, the radioiodine equilibrium concentrations of I-131 and I-133 in goat milk relative to radioiodine equilibrium concentrations in air are given below:

$$n_{131,j} = 4.02 \times 10^3 C_{131,j} \tag{15}$$

$$n_{133,j} = 2.95 \times 10^2 C_{133,j} \tag{16}$$

The goat milk ingestion rate for a child is assumed to be 700 milliliters per day. The breathing rate used in defining the MPC values for radioiodines in air is 3 cubic meters per day. Using the fractional thyroid deposition values from human ingestion and inhalation as 0.30 and 0.23, respectively, the daily depositions of radioiodine within the thyroid by goat milk ingestion and air inhalation are given by:

Daily Thyroid Deposit (milk) = $(0.30)(0.70)\ n_{ij}$

and

Daily Thyroid Deposit (inhalation) = $(0.23)(3)\ C_{ij}$.

The ratio of goat milk to air thyroid doses for the same air concentration is

$$W_i = \frac{(0.30)(0.70)n_{ij}}{(0.23)(3)C_{ij}} \qquad (17)$$

These ratios for I-131 and I-133 are then 1220 and 90, respectively.

Thus, the calculation of infant thyroid dose via the goat milk pathway may be related directly to those air concentration values provided in 10 CFR Part 20 that correspond to air doses of 1500 millirem per year to an infant's thyroid. These are given below:

Nuclide	Annual Infant Thyroid Dose Via Goats Milk (mrem)
I-131	$(1220)(\frac{C_{ij}}{MPC_a})(1500)$
I-133	$(90)(\frac{C_{ij}}{MPC_a})(1500)$

Alternative representations of the above are:

$$D_{131}(\text{mrem/yr}) = 5.82 \times 10^8 (\chi/Q)_j Q_{131} R \qquad (18)$$

$$D_{133}(\text{mrem/yr}) = 1.07 \times 10^7 (\chi/Q)_j Q_{133} R \qquad (19)$$

In Equations 18 and 19, $(\chi/Q)_j$ is given in seconds per cubic meter, Q_i is given in curies per year, and R (from Equation 2) is dimensionless.

As indicated in the discussion of infant thyroid dose via the cow milk pathway, doses calculated per Equations 18 and 19 are annual doses and may be reduced by that proportion of the year that goats are actually pastured.

Annual Adult Thyroid Dose Via Leafy Vegetables

The equilibrium areal density of radioiodine i on vegetation is as given in Equation 5. The average United States production per unit area during 1971 of several leafy vegetables[27] is as follows:

Cabbage	2.47 kilograms per square meter
Lettuce	2.38 kilograms per square meter
Spinach	1.11 kilograms per square meter

Upon normalization of these yields to relative total production,[27] the average yield of leafy vegetables is estimated to be 2.34 kilograms per square meter. It is assumed that over a period of 3 months of a year the adult consumes 18 kilograms of fresh leafy vegetables. As a consequence, the rate of ingestion of radioiodine via this pathway during this period of 3 months is given by $8.53 \times 10^{-2} \rho_{ij}$ curies per day. Of that ingested, 30% is retained in the thyroid, or the daily thyroid deposition is $2.56 \times 10^{-2} \rho_{ij}$ curies per day.

The ratios of vegetation ingestion to air doses over the course of a year for I-131 and I-133 are then

$$Y_{131} = \frac{(1/4)(2.56 \times 10^{-2})\rho_{131,j}}{(0.23)(20)C_{131,j}} = 3.9 \qquad (20)$$

$$Y_{133} = \frac{(1/4)(2.56 \times 10^{-2})\rho_{133,j}}{(0.23)(20)(C_{133,j})} = 0.64 \qquad (21)$$

Thus, the calculation of adult thyroid dose via the vegetation ingestion pathway may be directly related to those continuous air concentrations values provided in 10 CFR 20 that correspond to air doses of 1500 millirem per year to an infant's thyroid. The breathing rate of an adult is considered to be 20 cubic meters per day as compared with 3 cubic meters per day for an infant, the mass of the thyroid of an adult is 20 grams versus 2 for the infant, and the energy deposition per disintegration differs slightly from the adult to the infant thyroid. Dose corrections for the adult are provided in the table below:

Nuclide	Annual Adult Thyroid Doses Via Vegetation (mrem)
I-131	$(3.9)(\frac{C_{131,j}}{MPC_a})(0.84)(1500)$
I-133	$(0.64)(\frac{C_{133,j}}{MPC_a})(0.82)(1500)$

Alternative representations of the above are:

$$D_{131}(\text{mrem/yr}) = 2.1 \times 10^6 (\chi/Q)_j Q_{131} R \qquad (22)$$

$$D_{133}(\text{mrem/yr}) = 8.3 \times 10^4 (\chi/Q)_j Q_{133} R \qquad (23)$$

In Equations 22 and 23, $(\chi/Q)_j$ is given in seconds per cubic meter, Q_i is given in curies per year, and R (from Equation 2), is dimensionless. In the above adult thyroid dose relations, the duration of exposure per year (3 months) has been taken into account. In those areas where a greater or lesser time duration of consumption of leafy green vegetables normally occurs, the calculated dose values may be revised proportionately.

Infant and Adult Thyroid Dose Via Inhalation

The average annual concentration, $C_{ij}(r,\theta_j)$, of a gaseous radioiodine effluent species i at a location (r, θ_j) from the (0,0) release point is given in Equation 1 in curies per cubic meter. The thyroid dose via inhalation delivered to an infant present in this concentration environment during a year may be readily calculated by the use of the appropriate iodine air concentration values in column 1 of Table II in Appendix B of 10 CFR Part 20.

The concentration values provided there are those that would provide a resident infant with a 2-gram thyroid and a 3 cubic meter per day breathing rate, a thyroid dose of 1500 millirem per year. The annual dose that would be delivered to an infant residing in a radioiodine concentration of $C_{ij}(r,\theta_j)$ curies per cubic meter is then as given below:

Nuclide	Infant Annual Inhalation Thyroid Dose (mrem/yr)
I-131	$\frac{C_{131,j}}{MPC_a}(1500)$
I-133	$\frac{C_{133,j}}{MPC_a}(1500)$

The above alternative representations of infant dose relations are:

$$D_{131}(\text{mrem/yr}) = 4.8 \times 10^5 \, (\chi/Q)_j \, Q_{131} R \tag{24}$$

and

$$D_{133}(\text{mrem/yr}) = 1.2 \times 10^5 \; (\chi/Q)_j \; Q_{133}R \tag{25}$$

In Equations 24 and 25, $(\chi/Q)_j$ is given in seconds per cubic meter, Q_i is given in curies per year, and R, from Equation 2, is dimensionless.

In the calculation of inhalation thyroid dose to an adult residing in an environment containing the same radioiodine concentration, $C_{ij}(r,\theta_j)$, as the infant, the identical corrections are made for thyroid masses, inhalation rates, and energy depositions as in the treatment provided in the calculation of adult vegetation pathway thyroid dose. Consequently, the annual dose that would be delivered to an adult residing in a radioiodine concentration of $C_{ij}(r,\theta_j)$ curies per cubic meter is as given below:

Nuclide	Adult Annual Inhalation Thyroid Dose (mrem/yr)
I-131	$\frac{C_{131,j}}{MPC_a}(0.84)(1500)$
I-133	$\frac{C_{133,j}}{MPC_a}(0.82)(1500)$

Alternative representations of the above adult dose relations are:

$$D_{131}(\text{mrem/yr}) = 4.0 \times 10^5 \; (\chi/Q)_j \; Q_{131}R \tag{26}$$

and

$$D_{133}(\text{mrem/yr}) = 9.8 \times 10^4 \; (\chi/Q)_j \; Q_{133}R \tag{27}$$

In Equations 26 and 27, $(\chi/Q)_j$ is given in seconds per cubic meter, Q_i is given in curies per year and R, from Equation 2, is dimensionless.

References

1. "Final Environmental Statement Concerning Proposed Rule Making Action," Vol. I, Annex 6B, Directorate of Regulatory Standards, WASH-1258, U. S. Atomic Energy Commission, July 1973.

2. Beattie, J. R. and Bryant, P. M., "Assessment of Environmental Hazards from Reactor Fission Product Release," AHSB (S) R-135, 1970.

3. Peterson, H. T. and Smith, J. M., "Guides for Predicting Thyroid Dose from Environmental Measurements Following Radioiodine Releases. Environmental Surveillance in the Vicinity of Nuclear Facilities," (W.C. Reinig, ed.), Charles C. Thomas, 1970.

4. Peters, L. M. and Witherspoon, J. P., "Retention of 44-88 μ Simulated Fallout Particles by Grasses," Health Physics 22, 261, 1972.

5. Eckman, L. et al., "Studies on the Relationship between Iodine-131 Deposited on Pasture and its Concentration in Milk," Health Physics, 13, 701, 1967.

6. Booker, D. V., "Physical Measurements of Activity in Samples from Windscale," AERE HP/R 2607, 1958.

7. Cline, D. F. et al., "Effect of Physical and Biological Conditions on Deposition and Retention of I-131 on Plants," Health Physics, 11, 713, 1965.

8. Hull, A. P., "Vegetation Retention and Vegetation - Milk Ratio of Fallout ^{131}I," Health Physics, 9, 1173, 1963.

9. Barry, P. J. and Chamberlain, R. C., "Deposition of ^{131}I onto Plant Leaves from Air," Health Physics, 9, 1149, 1963.

10. Bunch, D. F., ed., "Controlled Environmental Radioiodine Tests," Progress Report Number Two, IDO-12053, 1966.

11. Hawley, C. A. et al., "Controlled Environmental Radioiodine Tests at the National Reactor Testing Station," IDO-12035, 1964.

12. Bryant, P. M., "Derivation of Working Limits for Continuous Release Rates of Iodine-131 to the Atmosphere in a Milk Producing Area," Health Physics, 10, 1964.

13. Garner, R. J. and Russell, R. S., "Isotopes of Iodine: Contamination of Plants with I-131", in "Radioactivity and Human Diet," R. S. Russell (ed.), Pergamon Press, Oxford, 1966.

14. Knapp, H. A., "Iodine-131 in Fresh Milk and Human Thyroids Following a Single Deposition of Nuclear Test Fallout," Health and Safety, TID-19266, 1963.

15. Bergstrom, S. O. and Gyllander, D., "Iodine-131 in Grass and Milk Correlated with Releases from the Studsvik Research Station," in "Environmental Contamination by Radioactive Materials," IAEA, Vienna, 1969.

16. Thompson, S. E. "Effective Half-life of Fallout Radionuclides on Plants with Special Emphasis on ^{131}I," UCRL-12388, 1965.

17. Chamberlain, A. C., "Deposition of ^{131}I in Northern England in October, 1957," Quarterly Journal of the Royal Meteorological Society, 85, 350, 1959.

18. Hansen, W. G., St. Louis Co. Health Dept., Radiological Research. Fallout Radiation Standards and Countermeasures. Hearing before the Subcommittee on Research, Development and Radiation; Joint Committee on Atomic Energy, 88th Congress; Washington, D. C. U. S. Government Printing Office, Part 2, pp. 519-527, 1963.

19. Garner, R. J., "An Assessment of the Quantities of Fission Products Likely to be Found in Milk in the Event of Aerial Contamination of Agricultural Land," Nature, 186, 1063, 1960.

20. Bryant, P. M., "Data for Assessments Concerning the Controlled and Accidental Releases of ^{131}I and ^{137}Cs to the Atmosphere," Health Physics, 17, 51, 1969.

21. Tamplin, A. R., "I-131, I-133, and Cow Milk," UCRL-14146, 1965.

22. Gjørup, H. L., Private Communication to F. O. Hoffman, Institut Für Reaktorsicherheit Der Technischen Überwachungs Vereine, e.V., reported in IRS-W-6, Köln, 1973.

23. Lengemann, F. W., "The Study of Iodine Secretion into the Milk of Dairy Animals," STI/PUB/90, IAEA, 1965.

24. Frigerio, N. A., Argonne National Laboratory, Private Communication to J. Kastner, USAEC, 1973.

25. Lengemann, F. W. and Wentworth, R. A., "Predicting the Total Intake of Radioiodine of Humans Consuming Goats' Milk", Health Physics, 12, 1955, 1966.

26. Rogers, A. L., "Goatkeeping in the United States," International Dairy Goat Conference, London, July 1964.

27. U.S. Bureau of the Census, Statistical Abstract of the United States, 1972 (93rd edition) Washington, D.C., 1972.

28. Lengemann, F.W., "Radioiodine in the Milk of Cows and Goats After Oral Administration of Radioiodate and Radioiodine," Health Physics, 17, 565, 1969.

29. Lengemann, F. W., "Metabolism of Radioiodide by Lactating Goats Given Iodine-131 for Extended Periods," Journal of Dairy Science, 53, 165, 1969.

APPENDIX D

Analysis of Milk for Iodine-131 at Levels Corresponding to a 15 mrem/year Dose to a Child's Thyroid Via the Air-Pasture-Cow-Milk Pathway

Based on the calculational models in Appendix C of this guide, a concentration of 2.4 pCi I-131 per liter in milk will result in a dose of 15 mrem to the thyroid (2 gm) of a child if the child were to consume one liter of that milk daily for a year. To assure that a child does not receive such a dose, it is necessary to know with a reasonable degree of certainty the actual I-131 concentration of the milk at these levels. Therefore, the milk should be sampled and analyzed for I-131 weekly with a sensitivity of 0.5 pCi/liter, with an overall error of $\pm$ 25%. This sensitivity and accuracy are readily attainable using a 4-liter sample of milk and state-of-the-art counting equipment, and such analyses are now offered on a routine commercially available basis. Analytical methods for achieving this sensitivity are described in Regulatory Guide 4.3, "Measurements of Radionuclides in the Environment - Analysis of I-131 in Milk," (September 1973).