Attachment B

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February 11, 1997

Mr Michael LaFronza, Radiation Specialist
Nuclear Materials Inspection, Section
U.S. Nuclear Regulatory Commission
Region III
801 Warrenville Road
Lisle, IL 60532-4351

fax: 630-515-1259
voice: 630-829-9865

Re. Effluent Releases to the Sewer

Dear Mr. LaFronza:

Based on our recent telephone conversations, I request your approval to release our collected liquid effluent and our near term continuation as discussed below. This is for both our chemical process and our fume scrubber liquids. Longer term solutions will be discussed as we develop our plans.

The following qualifications apply:

Qualifications for Release:

1. It is sufficient to demonstrate compliance with 10 CFR 20.2003(a)(1) regarding solubility of material released to the sanitary sewer by passing all liquid effluent in question through a 0.45μ or smaller filter.

2. Total activity levels of material released to the sewer will be within release limits. In the short term, we will sample every drum until we have an agreed-upon sampling and testing protocol.

   (As an example, the attached spreadsheet output represents typical activity and percent of limit for a 55-gallon drum of process water. If a sample of a 55-gallon drum has on the order of 3×10^{-5} μCi/ml or less of total activity, its release represents about 1% of our monthly limit assuming all activity is due to Th-232, which is a conservative assumption. If you assume the activity is half from each of Th-232 and Th-228, the number becomes approximately 0.6%. Including activity from any other isotopes reduces this number further.)

3. For short term verification of filter integrity, we will:

a) Change the 0.45μ filter at least once per month (represents about 600-1000 gallons)

b) or more often if determined necessary (e.g. after we process the drums we have collected)

c) or as we change process streams. For example, process water is typically pH of 8 or higher and scrubber water is about pH of 1-2. We would change filters before filtering one after the other.

d) As an additional safety measure, we will put a 0.20μ filter after the 0.45μ filter and pass all liquids through it as well. This 0.20μ filter will be changed whenever the 0.45μ filter is changed

I look forward to your quick reply on this matter.

Sincerely,

Dr. Mitchell C. Colton
Radiation Safety Officer

Calculations for RAM water disposal

3E-07 uCi/ml Th-232 monthly average release to sewer
10 CFR, pg 447, 1/1/93 (most restrictive)

6E-07 uCi/ml U-232 monthly average release to sewer
10 CFR, pg 447, 1/1/93 (most restrictive)
3E-06 is for U-nat

6E-07 uCi/ml Ra 226 monthly average release to sewer
10 CFR, pg 447, 1/1/93

1.110E-01 uCi/g Th-nat activity
6.77E-01 uCi/g U-nat activity, depleted is less
3.60E-01 uCi/g, specific activity for depleted U

water results:
pCi/l x 1E-6 = uCi/ml

each drum =	55	gal	216,216
or	208.191.81	ml	

water from:	2190	cuf
4/93-7/93	1,638,120	gal
	6.20E+09	ml
low estimate	2.07E+09	ml/month-avg

recent months have been higher

g/month allowable	
Th	U
5586.293	1831.842

208191.808 ml process water/barrel (=55 gal)
2.0669E+09 ml sewer water/month

Conc/Activity	Units	uCi/ml/mont	% of monthly limit
3E-05	uCi/ml	3.0218E-09	1.01%
		per 55 gal barrel	

Attachment C

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
WASHINGTON, D.C. 20555

January 28, 1994

NRC INFORMATION NOTICE 94-07: SOLUBILITY CRITERIA FOR LIQUID EFFLUENT RELEASES TO SANITARY SEWERAGE UNDER THE REVISED 10 CFR PART 20

Addressees

All byproduct material and fuel cycle licensees with the exception of licensees authorized solely for sealed sources.

Purpose

The U.S. Nuclear Regulatory Commission is issuing this information notice to emphasize the changes in 10 CFR Part 20 with respect to liquid effluent releases to sanitary sewerage and to encourage you to prepare for these revisions. It is expected that licensees will review this information for applicability to their operations, distribute it to appropriate staff, and consider actions to prepare for, and incorporate, these changes. Suggestions contained in this information notice are only recommendations; therefore, no specific action nor written response is required.

Background

On December 21, 1984, NRC released an information notice documenting several instances of reconcentration of radionuclides released to sanitary sewerage (IN No. 84-94, "Reconcentration of Radionuclides Involving Discharges into Sanitary Sewage Systems Permitted under 10 CFR 20.303"). Several other instances have since occurred in Portland, Oregon; Ann Arbor, Michigan; Erwin, Tennessee; and Cleveland, Ohio. The primary contributors, in some of these cases, appear to have been insoluble materials released as dispersible particulates or flakes. This issue was addressed again on May 21, 1991, by NRC, when it published its revision of Part 20 in the Federal Register (56 FR 23360), which removed insoluble non-biological material from the types of material that may be released to sanitary sewerage. Relative to this issue, the NRC Office of Nuclear Regulatory Research is conducting a study to clarify the mechanisms underlying reconcentration in sanitary sewerage and sewage treatment facilities.

* Sanitary sewerage is defined by 10 CFR 20.1003 as "a system of *public sewers* for carrying off waste water and refuse, but excluding sewage treatment facilities, septic tanks, and leach fields owned or operated by the licensee [emphasis added]."

Description of Circumstances

To help prevent further reconcentration incidents at public sewage treatment facilities, 10 CFR 20.2003(d)(1), effective January 1, 1994, was written as follows:

> §20.2003 Disposal by release into sanitary sewerage
> (d) A licensee may discharge licensed material into sanitary sewerage if each of the following conditions is satisfied:
> (1) The material is readily soluble (or is readily dispersible biological material) in water; and...

However, this revision to Part 20 did not contain an operational definition of solubility, and this precipitated many questions, from licensees, concerning how the solubility of a material may be demonstrated. Without the ability to demonstrate compliance, these licensees were unable to determine whether new procedures should be developed, new treatment systems installed, or whether they should apply for an exemption, based on the principle of maintaining all doses as low as is reasonably achievable (ALARA).

Discussion

In some of the known reconcentration incidents, the greatest reconcentrations appear to have been due to compounds released to sanitary sewerage that were not soluble. There are many approaches that may be used to determine a chemical compound's solubility in water. The following discusses two of the more common approaches:

1. Direct Determination of Compound Solubility Class, Formal Solubility, or Solubility Product (K_{sp})

   This approach would be applicable whenever there is sufficient knowledge of the chemical form of all materials contained in the liquid effluent at the point of release. With this knowledge, it would be possible to use one (or more) of the following methods:

   (a) Solubility Class Determination:

   The solubility class of the compound to be released could be determined directly from common literature data (e.g., *Handbook of Chemistry and Physics* - CRC Press, and *Lange's Handbook of Chemistry* - McGraw- Hill Book Company). If a compound is classified as "v s" (very soluble) or "s" (soluble), this would indicate the compound is "readily soluble." On the other hand, if it is classified as "i" (insoluble), "sl s" (slightly soluble), or "v sl s" (very slightly soluble), this would indicate materials that are "not readily soluble." Certain compounds are designated as class "d" (decompose). If the decomposed species of these compounds are classified as either "v s" or "s," this would indicate that the parent compound is "readily soluble." If these decomposed species are simple ions, such compounds (class "d") should be considered "readily soluble."

(b) Solubility Product (K_{sp}) Determination:

The solubility product constant of the compound could also be used to determine if a compound is readily soluble in water. The solubility product constant, K_{sp}, for a strong electrolyte M_mA_a, is expressed as:

$$K_{sp} = [M]^m [A]^a$$

where [M] and "m" are the ionic concentration (mole/liter) and the number of moles, respectively, of the dissolved cation; and [A] and "a" are the ionic concentration and the number of moles, respectively, of the dissolved anion.

For a simple electrolytic compound, with one mole of a dissolved cation species and one mole of a dissolved anion species, a K_{sp} greater than 1.00 E-05 mole^2/liter^2 would indicate that a compound is "readily soluble." For other compounds with more complex dissolution reactions (i.e., more than one mole dissolved for each species and/or more anionic or cationic species present in the dissolved products), the K_{sp} constant would increase exponentially, based on the number of moles and/or the number of dissociated species. For example, if three moles are present (two for the anion and one for the cation), the unit of K_{sp} would be mole^3/liter^3, and the corresponding K_{sp} would be $(1\ E\text{-}05)^{3/2}$ or 3.2 E-08 mole^3/liter^3; the same principle could be applied for more complex dissolution reactions.

(c) Formal Solubility Determination:

Compound solubilities (g/100 ml or mole fraction per 100 ml) are also listed in the chemical literature. From a review of general scientific literature, "formal solubilities"** greater than 0.003 mole/liter would indicate that a compound is "readily soluble."

** The general relation between the formal solubility, S_f, and the solubility product, K_{sp}, of a strong electrolyte M_mA_a in water is given by:

$$S_f = \sqrt[m+a]{\frac{K_{sp}}{m^m a^a}},$$

where K_{sp} is the solubility product, [M] is the molar concentration of the metal ion (cation), [A] is the molar concentration of the anion, "m" is the number of moles of dissolved cation per mole of dissolved substance, and "a" is the number of moles of the dissolved anion per mole of dissolved substance.

For further discussion on the determination of solubility products and formal solubility, refer to Chapter 6, "Precipitation and Dilution," from Water Chemistry, by Vernon L. Snoeyink and David Jenkins (John Wiley and Sons: 1983) or texts relating to physical and/or analytical chemistry.

Formal solubilities less than 0.003 molc/liter would indicate compounds that are "not readily soluble."

It should be pointed out that all values mentioned above (e.g., solubility class, formal solubility, and solubility product) correspond to measurements taken under standard conditions (e.g., 25°C, 101.3 kPa, pH of 7, and E_h of 0.

2. Filtration and Radiometric Analysis of Suspended Solids

This approach may be used if knowledge of the chemical form of all materials contained in the liquid effluent at the point of release is incomplete. It is most applicable when releases are made in a batch mode. This approach involves the use of standard laboratory procedures to test representative samples of the waste stream for the presence of suspended radioactive material.

The following two laboratory procedures were developed specifically to determine the suspended solids content of water: ASTM Method D 1888-78, "Standard Test Methods for Particulate and Dissolved Matter, Solids, or Residue in Water," and the American Public Health Association's Method 7110, "Gross Alpha and Gross Beta Radioactivity (Total, Suspended, and Dissolved)" from Standard Methods for the Examination of Water and Wastewater. It should be noted that ASTM Method D 1888-78 was developed to measure the total suspended solids content of water, not just the radioactive portion. In either case, activity in the suspended solids portion of effluent greater than that found in similarly processed background water samples would indicate the presence of insoluble radioactive material.

Whether one of the above approaches or a self-developed alternative is used, it is a good health physics practice to document this approach in the form of a procedure. Procedures such as these usually include provisions for the documentation of any models, calculations, analytical measurements, and/or quality control measures used. This information is usually maintained with the applicable release records, to demonstrate that the developed procedure will ensure compliance with the regulations.

If material to be released would not qualify as being "readily soluble," 10 CFR 20.2003(a)(1) would prohibit release to sanitary sewerage unless an exemption has been granted. Exemptions will be judged on a case-by-case basis, when it is demonstrated that release to sanitary sewerage is in accordance with the ALARA principle, consistent with applicable regulations, and in the public interest.

It is expected that licensees will review this information for applicability to their operations, and consider actions, as appropriate to their licensed activities. However, suggestions contained in this information notice are not NRC requirements; therefore, no specific action nor written response is required.

If you have any questions about the information in this information notice, please contact one of the technical contacts listed below or the appropriate regional office.

Robert F. Burnett, Director
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Attachments:
1. List of References
2. List of Recently Issued NMSS Information Notices
3. List of Recently Issued NRC Information Notices

REFERENCES

Annual Book of ASTM Standards. Volume 11.01, "Water (I)." American Society for Testing and Materials, Easton, MD, 1989.

CRC Handbook of Chemistry and Physics. CRC Press, Inc., Boca Raton, FL, 65th ed, 1984.

Lange's Handbook of Chemistry. McGraw-Hill, Inc., New York, NY, 13th ed, 1985.

Snoeyink, Vernon L. and David Jenkins, Water Chemistry. John Wiley & Sons, Inc., New York, NY, 1980.

Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC, 17th ed, 1989.

Attachment D

Designation: D 1888 – 78[1]

Standard Test Methods for PARTICULATE AND DISSOLVED MATTER, SOLIDS, OR RESIDUE IN WATER[1]

This standard is issued under the fixed designation D 1888; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

These test methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

[a] NOTE—Section 2 was added editorially and subsequent sections renumbered in January 1985.

1. Scope

1.1 These test methods cover the determination of particulate, dissolved, and total matter, sometimes referred to as the suspended, dissolved, and total solids, in water. Two procedures consistent with the total matter content, are provided as follows:

	Sections
Method A—Particulate and Dissolved Matter in Water with More Than 25 ppm of Total Matter	7 to 13
Method B—Particulate and Dissolved Matter in Water with 25 ppm or Less of Total Matter (Automatic Evaporation)	14 to 20

1.2 The test methods actually cover the determination of (*1*) the constituents of water that can be removed by filtration, and (*2*) the residue on evaporation to dryness of either filtered or unfiltered samples; as a result, they do not always measure water components as defined. Separation of particulate matter by filtration requires precise definition of the filtering medium since some materials that are in no sense dissolved, for example, certain colloids, may not be removed by the filter used. Secondly, an evaporation residue will usually differ in composition from the particulate and dissolved matter present in the water.

1.3 When particulate matter is determined separately (the sample is filtered and the residue quantitatively assessed), provision is made for the use of either a membrane filter that will remove all particles over 0.45 μm in size or an asbestos fiber medium in a Gooch crucible. However, unless otherwise specified when results are reported, use of the membrane filter shall be assumed. It is further provided that all buoyant floating particles or large particulate agglomerations that cannot be dispersed throughout the sample by vigorous shaking need not be considered as fundamental constituents of the water under examination and may be excluded, therefore, from the test portion.

1.4 The test methods include steps for the determination of volatile matter in the dry residue from either filtration or evaporation. They do not, however, cover water constituents that are (*1*) volatile at the boiling temperature, or (*2*) normally classified as "oily matter," which is extractable with organic solvents or volatile at the drying temperature of filtration residues. For the determination of the latter, refer to Test Method D 2778.

2. Applicable Documents

2.1 *ASTM Standards:*

D 1066 Practice for Sampling Steam[2]

D 1129 Definitions of Terms Relating to Water[2]

D 1192 Specification for Equipment for Sampling Water and Steam[2]

D 1193 Specification for Reagent Water[2]

D 2778 Test Method for Solvent Extraction of Organic Matter from Water[3]

D 3370 Practices for Sampling Water[2]

[1] These test methods are under the jurisdiction of ASTM Committee D-19 on Water and are the direct responsibility of Subcommittee D19.05 on Inorganic Constituents in Water.

Current edition approved April 28, 1978. Published August 1978. Originally published as D 1888 – 61 T. Last previous edition D 1888 – 67 (1974).

[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] Discontinued; see *1983 Annual Book of ASTM Standards*, Vol 11.02.

Definitions

3.1 The terms *particulate matter*, *dissolve atter*, *total matter*, and others related to water nstituents determined in these test methods, e defined in accordance with Definitions 1129 as follows:

3.1.1 *particulate matter*—that matter, exclusive of gases, existing in the nonliquid state which dispersed in water to give a heterogeneous ixture.

3.1.2 *dissolved matter*—that matter, exclusive gases, which is dispersed in water to give a ngle phase of homogeneous liquid.

3.1.3 *total matter*—the sum of the particulate d dissolved matter.

3.1.4 *volatile matter*—that matter that is anged under conditions of the test from a solid a liquid state to the gaseous state.

3.1.5 *fixed matter*—residues remaining after nition of particulate or dissolved matter, or th.

3.2 For definitions of other terms used in these st methods, refer to Definitions D 1129.

Interferences

4.1 Some evaporation residues readily absorb oisture; rapid weighing is essential to this t method. Some residues contain materials, ch as ammonium carbonate, that decompose low 103°C; others contain liquids, such as glyc- l and sulfuric acid, that will remain as a liquid idue at 103°C with or without solution of salts at might also be present.

4.2 Rapid weighing of ignited residues, also, mportant because of possible moisture absorp- n. Furthermore, there is likelihood of interfer- ce from carbonates, organic matter, nitrite and rate nitrogen, water of hydration, chlorides, d sulfates which may be decomposed either mpletely or in part when ignited at 600°C. No gle temperature is known that will eliminate these interferences. Reasonably reproducible ults should be obtained, however, at the pre- ibed 600°C.

4.3 Because the water being sampled is of ressity in contact with the sample container l tubing, it is important, especially in the case glass, that the possible precipitation of cations the absorption of substances originally present the water, on these surfaces, be recognized.

Purity of Reagents

5.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[4] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D 1193. Referee grade reagent water shall be used for Method A and the nonreferee grade for Method B.

5.3 Except for concentrated hydrochloric acid (HCl, sp gr 1.19), reagents including reagent water should be membrane-filtered prior to use.

6. Sampling

6.1 Collect the sample in accordance with the applicable ASTM standard, as follows: Practice D 1066, Specification D 1192, and Practices D 3370.

6.2 Because of the low concentration of total matter in some waters and the possible effects of aeration on others, sampling shall be carried out in a matter which reduces atmospheric exposure to a minimum. The type and size of the container shall be consistent with the nature of the water being sampled (see 16.1 and 19.1).

6.3 Samples containing 25 ppm or less of total matter on which only the total matter content is to be determined shall be immediately acidified with 0.2 mL of concentrated HCl (sp gr 1.19)/L of water to prevent iron deposition on the walls of the container. If particulate matter is to be separately determined, the sample, regardless of total matter content, shall be filtered as soon as possible (see 18.3) and then acidified.

METHOD A—PARTICULATE AND DISSOLVED MATTER IN INDUSTRIAL WATER WITH MORE THAN 25 PPM OF TOTAL MATTER

7. Scope

7.1 This method is primarily applicable to water that will yield a residue on evaporation at 103°C of at least 25 mg/L.

[4] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."

8. Summary of Method

8.1 Total matter is determined by evaporation of an appropriate aliquot, or the particulate and dissolved matter are separated by filtration and individually assessed. The particulate matter is dried and weighed. The dissolved matter is determined by weighing the residue obtained after evaporating the filtered sample. Volatile matter and fixed matter under any of the above classifications are determined by weighing the residues remaining after ignition at a temperature of 600°C.

9. Apparatus

9.1 *Sample Reservoir*—A chemical-resistant container of 1 to 4-L capacity.

9.2 *Membrane Filter Assembly*—See 16.4.

9.3 *Glass Petri Dish*, 150-mm diameter.

9.4 *Filter Crucible*—See 16.6.

9.5 *Evaporating Dish*—A straight-wall or round-bottom platinum dish of 80 to 100-mm diameter and approximately 200-mL capacity. A porcelain dish may be substituted for the platinum dish if the residue is not to be analyzed.

9.6 *Heater*—A controlled electric hot plate, infrared lamp, or steam bath for maintaining the temperature of the evaporating sample near the boiling point.

10. Reagents

10.1 *Chloroform or Benzene*, purified or USP grade.

10.2 *Ethyl Alcohol* (95 %).

NOTE 1—Specially denatured ethyl alcohol conforming to Formula 3A or 30 of the U.S. Bureau of Internal Revenue may be substituted for ethyl alcohol (95 %).

10.3 *Hydrochloric Acid* (sp gr 1.19)—Concentrated hydrochloric acid (HCl).

11. Procedure

11.1 Weigh a quantity of sample sufficient to yield on evaporation approximately 25 mg of residue if only the amount is to be determined, or at least 100 mg if this residue is to be analyzed. The sample shall be well shaken before removing the aliquot and inclusion of floating material or agglomerates that cannot be dispersed shall be avoided. If only total matter is to be determined, without classification, proceed in accordance with 11.3. If both particulate and dissolved matter are to be determined, proceed in accordance with 11.2.

11.2 *Particulate Matter*—This determination shall preferably be made using a membrane filter following the procedure given in 18.3.1, except that a 0.2-mg residue from the solvent washings shall be permissible. The less desirable alternative use of an asbestos fiber medium is described in 18.3.2. In either case the filtrate shall be immediately acidified with 0.2 mL of HCl (sp gr 1.19)/L of water unless the sample contains significant amounts of alkaline chemicals, for example, sodium hydroxide (NaOH), whose composition would be affected by the acid; acidification will prevent deposition of iron on the sample container.

11.3 *Total Matter and Dissolved Matter*—Transfer the sample aliquot provided for total matter determination (11.1) or the filtrate obtained from the particulate matter separation (11.2) to a sample reservoir having a valve-controlled outlet. Fill an evaporating dish that previously has been ignited at 600 ± 25°C for 1 h cooled in a desiccator, and weighed, to within approximately ¼ in. (6.3 mm) of the top with the sample from the reservoir. Heat the dish to evaporate the sample, but do not allow the sample to boil. Periodically add sample from the reservoir to the dish to prevent drying until the reservoir is empty. Rinse the reservoir several times with water, adding the rinsings to the contents of the evaporating dish. Then evaporate the remainder of the material in the dish to near dryness. Transfer to a 103°C oven and complete the evaporation. Dry the dish and its contents for 1 h (see 4.1), cool in a desiccator, and weigh. Repeat the cycle of drying (1-h periods), cooling and weighing until loss in weight is no more than 4 % of the previous weight. Record the weight of residue as "weight of total matter" (or, if the sample had been filtered, "dissolved matter"). Ignite the dish contents for 30 min at 600 ± 25°C, cool in a disiccator, and reweigh (see 4.2). Record the loss in weight as "weight of volatile matter" (or "volatile dissolved matter") and the weight of the ignited residue as "weight of fixed matter" (or "fixed dissolved matter").

12. Calculation

12.1 Calculate the result of each specific determination in parts per million, as follows:

$$\text{Matter, ppm} = (W_x/V) \times 1000$$

where:

W_x = W_1 = grams of total matter found,

W_2 = grams of particulate matter found,

W_3 = grams of dissolved matter found,
W_4 = grams of volatile matter found,
W_5 = grams of volatile particulate matter found,
W_6 = grams of volatile dissolved matter found,
W_7 = grams of fixed matter found,
W_8 = grams of fixed particulate matter found, or
W_9 = grams of fixed dissolved matter found, and
= litres of sample used.

12.2 When particulate and dissolved matter have been separately determined, total matter, volatile matter, and fixed matter can be calculated by adding the two appropriate values.

12.3 If asbestos fiber filtration was used for the removal of particulate matter, it is mandatory that this be stated when reporting either particulate or dissolved matter. Otherwise, use of a membrane medium shall be assumed.

13. Precision

13.1 No statement can be made concerning the precision of this method. The precision is influenced by both the nature and the amount of entrained matter and by the effects of drying and ignition on its actual composition.

METHOD B—PARTICULATE AND DISSOLVED MATTER IN INDUSTRIAL WATER WITH 25 PPM OR LESS OF TOTAL MATTER (AUTOMATIC EVAPORATION)

14. Scope

14.1 This method is intended primarily for steam condensate and distilled or demineralized water that contains 5 ppm or less of total matter. Because of the automatic evaporation feature, the method is desirable for use, however, on all waters containing up to 25 ppm of total matter, particularly if a large residue is desired for chemical analysis.

15. Summary of Method[1]

15.1 Total matter is determined by evaporation, or the particulate and dissolved matter are separated by filtration and individually evaluated. The particulate matter is dried, freed of oily matter by extraction, dried again, and weighed. The solution of dissolved matter is evaporated to dryness using a dish provided with a constant-level control. Sufficient sample is evaporated to give the desired accuracy for the measurement and provide ample material for other analytical requirements. The residue is dried and weighed. Volatile matter in any of the three classifications is subsequently removed by ignition. The total, particulate, dissolved, volatile, or fixed matter are then calculated from the various weights obtained.

16. Apparatus

16.1 *Sample Reservoir*—A covered, 20-L (5-gal) container of corrosion-resistant metal, suitable plastic, or chemical-resistant glass with necessary tubular connections. Most waters with very low total matter exhibit a pH in the range from 6 to 9. For samples of such waters, containers of TFE-fluorocarbon, block tin, polyethylene, or chemical-resistant glass shall be selected with that order of preference, depending upon the purity.

16.2 *Automatic Evaporation Assembly*—A dust shield, constant-level device, heater, and evaporation dish. Typical assemblies are described in 16.2.1 and 16.2.2.

16.2.1 *Evaporation Assembly A* (Fig. 1):

16.2.1.1 *Dust Shield*—A heat-resistant cover glass enclosing the Monel-sheathed ring heater, platinum evaporating dish, antenna, and electrical terminal posts, with provision for introducing the water sample through the base. Minimum practicable enclosed space is necessary to prevent condensation on the cover. The top of the dust shield is covered with a "dunce cap" to prevent foreign material from dropping into the dish while permitting free passage for the moisture-laden air. An open-bottom aluminum platform supporting two filter cylinders and having an opening under the glass cover is provided to supply filtered inlet air. Either a seal must be provided or filter material used between glass cover and the platform as well as between chassis and platform.

16.2.1.2 *Evaporator Assembly*, as shown under the glass cover—The Monel-sheathed ring heater is suspended over the platinum evaporating dish by two stainless steel arms which are connected through the electronic control system to a power circuit containing a timer. The platinum dish is supported by an aluminum plate provided with leveling screws so that the distance from the dish to the heater can be adjusted. A stainless steel inlet tube is used for addition of sample at the pouring spout of the platinum vessel.

16.2.1.3 *Electronic Control Circuit*—Control of the water level in the platinum dish is effected by a capacitance-type electrode or antenna which can be made conveniently of a flat coil of platinum wire (16 to 20-gage). The antenna is suspended from a stainless steel arm which makes contact with the electric control circuit[3] through a terminal post. A change of the water level activates the shut-off valve[4]; if the water level in the platinum dish does not return to the upper level control within 45 s after reaching this lower level of capacitance control, the current to the ring heater is broken by means of a time interlock. The purpose of this interlock is to prevent the drying of the dish at a temperature above the specified 103°C (217°F) level, should additional sample fail to reach the dish. Since the 45-s timer automatically turns off the heater when sample flow is interrupted, an additional timer is incorporated which may be used upon completion of evaporation to keep the heater on for a specified time period to lower the water level in the dish and thus facilitate its removal from the test assembly. An overflow device is incorporated in the assembly, also. A platinum wire electrode is positioned so that its tip is suspended slightly above the normal water level in the platinum dish. This electrode serves as an additional upper-water level control should a failure occur in the capacitance system.

16.2.2 *Evaporation Assembly B* (Figs. 2, 3 and 4).

16.2.2.1 *Dust Shield*—The dust shield compartment consists of a heat-resistant glass bell jar equivalent to that used on assembly "A" and is contained in an enclosed dust-shielded compartment. Air is provided through an external filter source into this shielded sample compartment.

16.2.2.2 *Evaporator Assembly*—The evaporator assembly as shown schematically in Fig. 4 consists of a balance,[5] one arm of which extends into the dust shield compartment. The balance arm extending into the dust shield holds a platinum sample dish. Also extending into this compartment from the balance base and mounted in the dust shield compartment is a heater connection consisting of the necessary wiring connections and a Monel-sheathed ring heater similar to that used in evaporator assembly A. In addition, a solenoid water sample valve[6] is provided with a ⅛-in. (3.2-mm) outside diameter stainless steel tubing connection feeding into the shielded sample compartment and then to the platinum sample dish. Automatic sample addition is accomplished by a level switch on the counter balance arm and this actuates the water sample valve. Control effected by counter balance arm can be dampened by a dash pot. If desired, a timer mechanism can be installed to record the volume of water evaporated. Calibration of this assembly is accomplished by using a calibrated sample reservoir and timing the addition and evaporation rate. This calibration will have to be carried out under atmospheric conditions similar to those pertaining at the actual sampling location.

16.2.2.3 *Wiring Diagram*—The wiring diagram for this assembly is also shown in Fig. 3.

16.3 *Sampling Device* (see Fig. 5)—A cooling coil with overflow pipe and solenoid valve suitable for sampling from a water source to a continuous sample evaporator. (The cooling coil is, of course, necessary only when sample is above room temperature.)

16.4 *Membrane Filter Assembly*—A borosilicate glass or stainless steel funnel with a flat, fritted base of the same material, and membrane filters (0.45-μm pore size) to fit.[8]

16.5 *Glass Petri Dish*—150-mm diameter.

16.6 *Filter Crucible*—A Gooch crucible containing an evenly distributed filter mat approximately 5-mm thick and composed of divided asbestos fiber, produced by pouring a slurry of acid-washed asbestos into the crucible under slight suction.

16.7 *Evaporating Dish*—A straight-walled or round-bottom platinum dish of 80 to 100-mm diameter and approximately 200-mL capacity.

17. Reagents

17.1 See Section 10.

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[3] The RCA Thermocap Relay Unit manufactured by the Niagara Electron Laboratories, Niagara Falls, NY, or equivalent, has been found satisfactory for this purpose.

[4] The electrically operated valve (No. 5004141312) sold by Diamond Power Specialty Corp., Lancaster, OH, or an air-operated valve (No. 1000A 2-way Demi G 303 with No. 5049 stainless diaphragm) manufactured by the G. W. Dahl Co., Inc., Bristol, RI, have been found satisfactory for this purpose. The Dahl valve must be coupled with a solenoid air valve such as the Skinner Electric Valve, 3-way, vented, No. V5D4200 manufactured by Skinner Electric Valve Div., The Skinner Chuck Co., 100 Edgewood Ave., New Britain, CT, or its equivalent. It is imperative that new valves be tested to determine that contamination does not occur from mechanical wear on materials of construction.

[5] The balance manufactured by the Fisher Scientific Co., Catalog No. 2-035, or its equivalent, has been found satisfactory for this purpose.

[6] Suitable membrane filter holder and filters, HAW-PO4700, are available from Millipore Co., Bedford, MA.

18. Procedure

18.1 Select a volume of sample sufficient to yield an evaporation residue of approximately 25 mg if only the matter content is to be determined, or approximately 100 mg if the evaporation residue is to be analyzed.

18.2 If both particulate and dissolved matter are to be determined, proceed in accordance with 18.3; if only total matter is desired, follow the procedure starting with 18.4.

18.3 *Particulate Matter*—This water component is preferably separated by filtration using a membrane having a pore size of 0.45 µm (see 18.3.1); an alternative procedure using an asbestos fiber medium, generally considered to have a 5-µm pore size, is described in 18.3.2.

18.3.1 *Membrane Filtration*—Place *n* + 1 plain, white filter disk of the prescribed pore size in a 150-mm petri dish, where *n* equals the number of tests to be run. Place the dish and filters in a drying oven at 103°C for 15 min or in a vacuum desiccator for 30 min. If oven-dried, allow the filters to cool to room temperature while exposed to the air. Weigh each filter to the nearest 0.1 mg. With most balances it is desirable to have a polonium alpha emitter source to dispel effects of static electricity. Label filters with ball point pen and mark the extra filter *C* for "control." Proceed with the filtration in accordance with 18.3.1.1 through 18.3.1.5.

18.3.1.1 Place a weighed filter on the fritted base of the filter holder, and clamp the funnel portion of the apparatus in place on top of the filter. Place the filtration assembly on a filter flask of appropriate size and with the aid of a vacuum from a vacuum-pressure pump or water aspirator, pour the sample into the funnel and draw through the filter into the filter flask. Where sample bottles are employed for collection of the sample, the entire contents of a sample bottle should be filtered. Wash the bottle with an appropriate quantity of filtered water (may be obtained from the filter flask) and pour this also to the filter funnel. Transfer sample and washings to sample reservoir. Dry the membrane by drawing air through the filter and wash with chloroform or benzene until 10 mL of the washings leave not more than 0.1 mg of residue on evaporation at 103°C. Air-dry the sediment for several minutes. Discard the washings. Release the vacuum and with flat-bladed forceps, remove the filter from the fritted base and place in the petri dish.

18.3.1.2 Wet the control filter (*C*) with the sample water from the filter flask, and place it also in the petri dish.

18.3.1.3 Place the petri dish in the drying oven at 103°C for 30 min; allow the filters to cool to room temperature and equilibrate to ambient humidity after removing from the oven, and reweigh.

18.3.1.4 Record the weight of particulate matter adjusted for the difference between final and initial weight of the test filter as "weight of particulate matter." Make a positive or negative adjustment in the event of any weight change occurring in the "control" filter.

18.3.1.5 Place the filter used in the particulate matter determination in a clean, ignited, small, porcelain crucible, which has been weighed, after ignition and cooling, to the nearest 0.1 mg. Add approximately 1 mL of ethyl alcohol and ignite with a match when the filter is fully wetted. After the alcohol has burned off, place the lid on the crucible and ignite it in the furnace at 600 ± 25°C for at least 30 min. Remove the crucible from the furnace and allow it to cool to room temperature in a desiccator. Remove the crucible cover and weigh the crucible to the nearest 0.1 mg (see 4.2). Record the loss in weight as "weight of volatile particulate matter" and the weight of the ignited residue as "weight of fixed particulate matter."

18.3.2 *Asbestos Fiber Filtration* (Note 2)—Filter the selected volume of sample through a filter crucible (see 16.6) that previously has been dried for 1 h at 103°C, cooled in a desiccator, and weighed. After filtration, wash the filter crucible contents twice with water, transferring the filtrate and washings to the sample reservoir for subsequent determination of dissolved matter as described in 18.4. Dry the crucible contents by drawing air through the crucible for several minutes; then wash the crucible contents with chloroform or benzene until 10 mL of the washings leave not more than 0.1 mg of residue on evaporation at 103°C. Discard the washings. Air-dry the sediment for several minutes; then place the crucible in an oven at 103°C for 1 h, cool in a desiccator, and weigh. Record the weight of the residue as "weight of particulate matter." Ignite the crucible contents for 30 min at 600 ± 25°C, cool in a desiccator, and reweigh (see 4.2). Record the loss in weight as "weight of volatile particulate matter" and the weight of the ignited residue as "weight of fixed particulate matter."

NOTE 2—Since asbestos fiber filters are generally considered to have a pore size of 5 µm, no process of coagulation shall be employed that will alter the content of either dissolved or particulate matter.

18.3.3 Immediately acidify the filtrate and washings with 0.2 mL of HCl (sp gr 1.19)/L of water.

18.4 *Total Matter and Dissolved Matter*—Weigh a platinum dish that has been dried for 1 h at 103°C and cooled in a desiccator. Using Evaporation Assembly A or B, start the evaporation of the selected volume of sample for total matter only or the filtrate and washings from the particulate matter removal (see 18.3), as follows:

18.4.1 *Evaporation Assembly A*—With the current off, insert the clean, weighed platinum dish (previously ignited at 600 ± 25°C) in the evaporator assembly and adjust the dish height by use of the leveling screws in the aluminum base. Antenna adjustments, if necessary, may also be made at this time, using the set screw provided at the end of the antenna arm. Turn on the circuit and heater switches and set the control knob on the relay to allow water to rise to the proper level with respect to the antenna and the desired water level in the dish. It is advisable to operate the relay with the water level as close to the antenna as possible. Observe the evaporator for a period of time to ascertain the satisfactory operation of the relay and assure the absence of boiling in the dish.

18.4.2 *Evaporation Assembly B*—Adjust the apparatus to the most rapid rate feasible without boiling. The adjustment is accomplished by the addition of 7 to 10-g weights to the tare weight of the evaporating dish on the counter weight arm of the balance. With the top of the shielded compartment removed, manually trip the level switch on the counter balance arm several times to actuate the water sample valve and flush out the sampling line. Then place a carefully cleaned and weighed platinum dish on the balance pan in the shielded compartment. Place a clean bell jar carefully on the seal mounted on the support plate in the dust shielded compartment (Fig. 4). Close the shield compartment leaving the vent open. Turn on the heater current and observe the operation long enough to assure satisfactory performance.

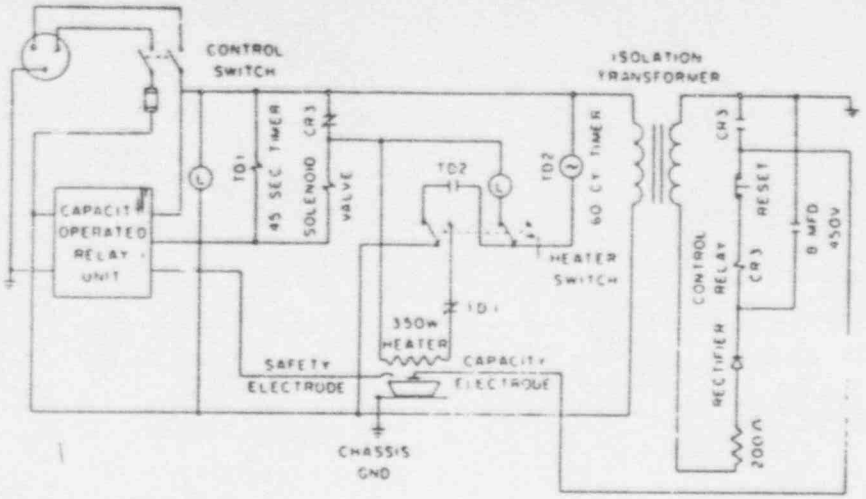
18.4.3 When evaporation is almost complete, remove the dish from the assembly, transfer to a 103°C oven, and heat to dryness. Continue heating for 1 h, cool in a desiccator, and weigh (see 4.1). Record the weight of the residue as "weight of total matter" (or, if sample had been filtered, "dissolved matter"). Ignite the dish and contents for 1 h at 600 ± 25°C, cool in a desiccator, and reweigh (see 4.2). Record the loss in weight as "weight of volatile matter" (or "volatile dissolved matter"), and the weight of the ignited residue as "weight of fixed matter" (or "fixed dissolved matter").

19. Calculation

19.1 See Section 12.

20. Precision

20.1 See Section 13.



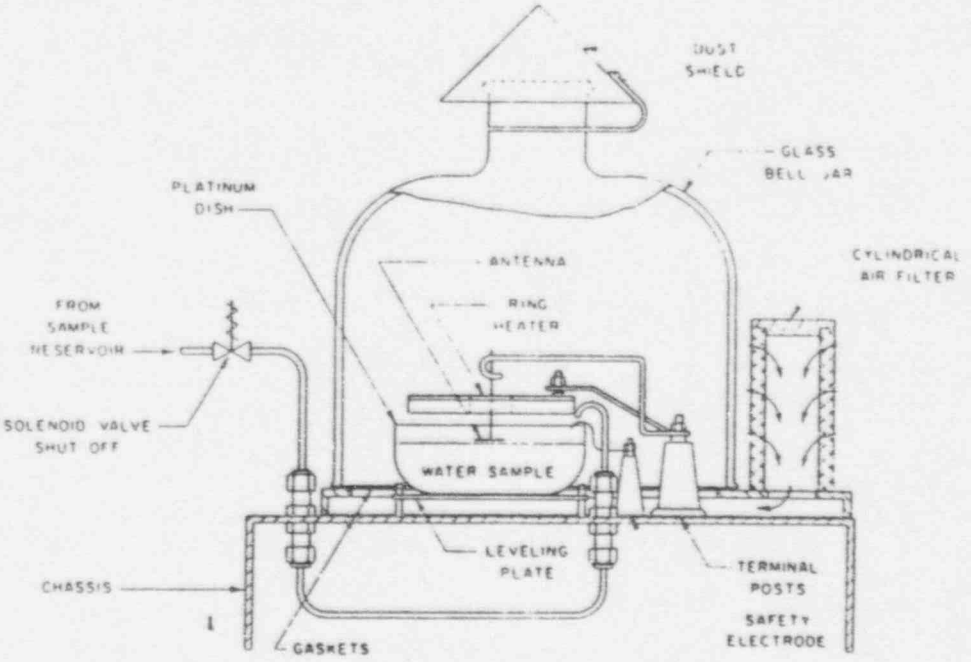


FIG. 1 Evaporation Assembly A

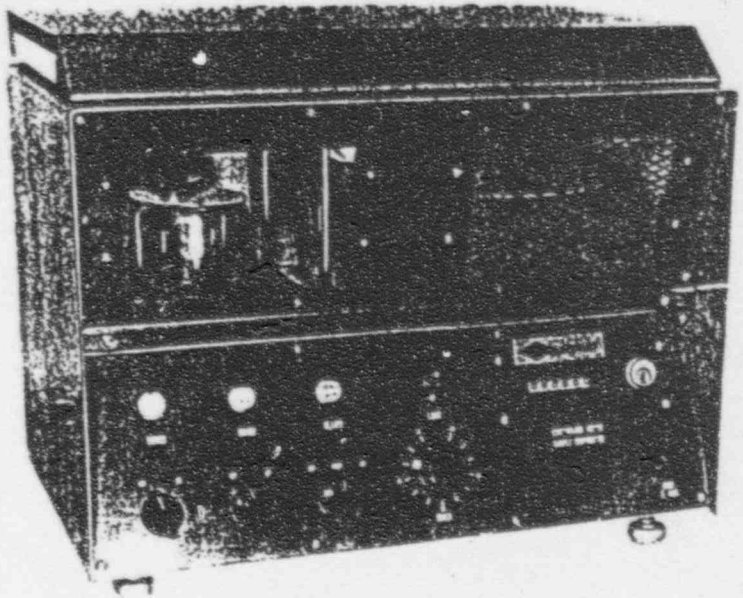


FIG. 2 Evaporation Assembly B

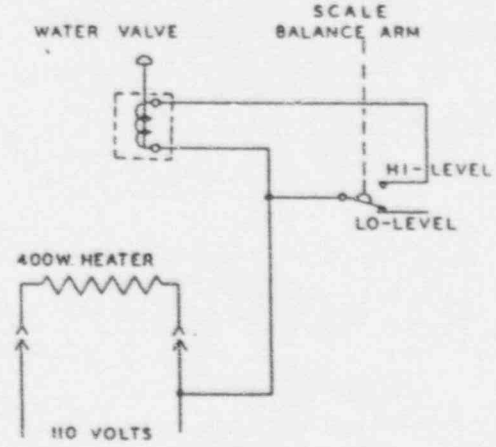


FIG. 3 Automatic Evaporation Circuit

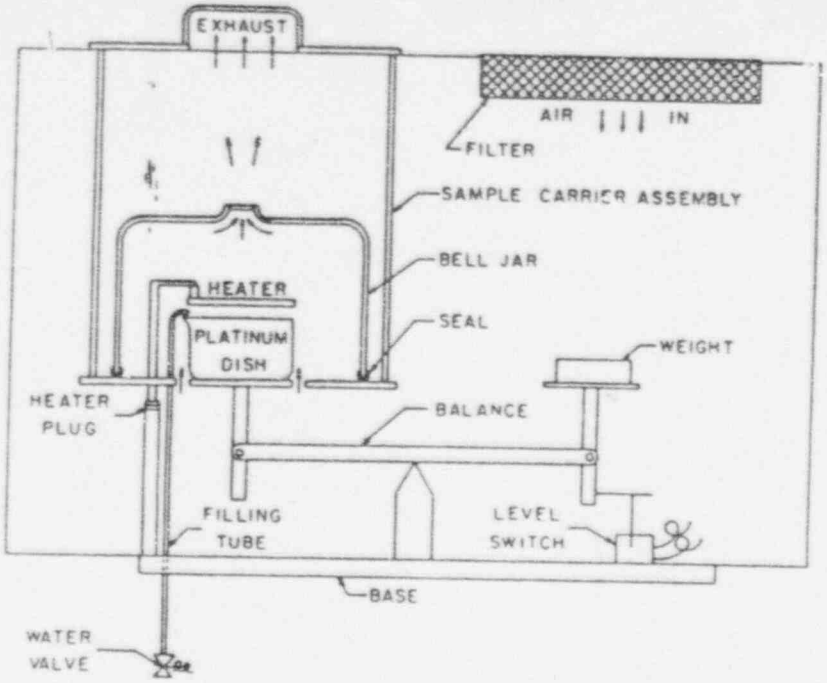


FIG. 4 Automatic Evaporation Assembly

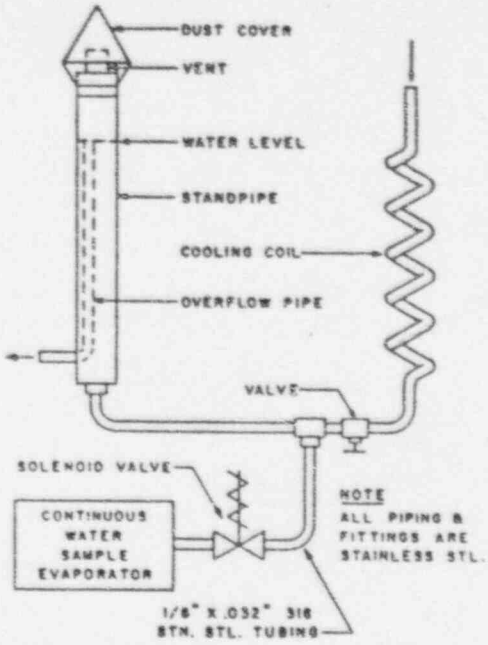


FIG. 5 Automatic Evaporator Sampling Equipment

RADIOLOGICAL IMPACTS OF EFFLUENT RELEASES TO THE ATMOSPHERE AND SANITARY SEWER FROM INTERSTATE NUCLEAR SERVICES

ROYERSFORD, PENNSYLVANIA

Sherry C. Wu
August 1993

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ROYERSFORD, PENNSYLVANIA

AUGUST 1993

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9.0 Data Tables

RADIOLOGICAL IMPACTS OF EFFLUENT RELEASES TO THE ATMOSPHERE AND SANITARY SEWER FROM INTERSTATE NUCLEAR SERVICES ROYERSFORD, PENNSYLVANIA

1.0 EXECUTIVE SUMMARY

A study was conducted on air and water effluent pathways of the Interstate Nuclear Services Corporation Royersford, Pennsylvania facility. Thirteen possible pathways were examined using established regulatory guidance and actual data. Results indicate the dose to the maximally exposed individual is approximately 2.86E-1 mRem per year for the general public and approximately 20.8 mRem per year for a wastewater treatment plant worker. Based on these results, impact on the environment and human receptor from operation at the Royersford site has been determined to be within regulatory guidance levels.

2.0 INTRODUCTION AND SITE HISTORY

Interstate Nuclear Service Corporation (INS) of Royersford, Pennsylvania operates a laundry facility under Nuclear Regulatory Commission (NRC) license Number 37-23341-01, authorizing the collection and laundering of clothing and other items potentially contaminated with low-level radioactive material. INS receives items for laundering from customers engaged in the production of nuclear energy and the use and/or disposal of radioactive materials. Air from the plant is filtered, monitored, and released on a continuous basis. Liquid wastes from laundering operations are filtered to remove suspended solids and held in two 5000-gallon tanks prior to release. The liquid in the hold-up tanks are sampled, and once concentrations are determined to be within regulatory limits, is discharged to the sanitary sewer. INS typically releases 20.5 thousand gallons of wastewater each day, five days per week to the sewer. Water is also collected each month as a composite sample and is analyzed. Analysis of the water released from the plant has identified a variety of radionuclides including mixed fission products and activation products.[2.0]

The Royersford Wastewater Treatment Facility (RWTF) produces approximately 350,000 to 400,000 gallons of wet sludge per year including the discharge from INS. The wastewater, which is 6 to 8 percent solid, may be processed by several methods before it is discharged into the Schuylkill River or transported to Pottstown Landfill in Montgomary County, Pennsylvania. The capacity of the mechanical dewatering system is 775,000 gallons, and RWTF uses grinding, settling, trickling filters, anaerobic digestor pumping, chlorine contact tanks, and sludge holding tanks in this process. The plant discharges an average of 0.3722 MGD of processed water in the summer and 0.3355 MGD in the winter into the Schuylkill. Of the 400,000 gallons of sludge dewatered each year, 100,000 gallons are dewatered through reed-bed processing. RWTF has two reed-beds, one is 28 by 50 square feet and the other is 70 by 50 square feet, and they are designed for a life of 5 to 7 years before sludge removal. TLD's are placed at various locations around the wastewater plant.[2.1]

This pathway analysis provides a reasonable model of Interstate Nuclear Services' operational effects upon the off-site human receptor. Calculational methods were based primarily on 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" (Refer to Section 9.0 for the Dose Conversion Factors used). Additional models were developed using standard health physics and engineering principles. ICRP-30 methods were used for estimation of the fifty year committed dose. In all cases conservative assumptions were made, but actual data were incorporated where possible. All doses were calculated to the theoretical maximally exposed adult individual.

3.0 SITE DESCRIPTION

The Interstate Nuclear Services Corporation of Springfield, Massachusetts operates its Royersford laundry services at 401 North Third Avenue in Royersford, Pennsylvania. At the INS site, potentially contaminated laundry items are water-washed in commercial laundry units, dried, surveyed for residual radioactivity, and folded before being returned to the customers.

4.0 DATA COLLECTION

For this study, calculations, models, and written correspondence were based on actual INS effluent records for 1992, INS facility design data, phone calls to key wastewater treatment plant personnel, landfill operations personnel, engineering personnel, and other personnel in state agencies. These sources are identified in Section 10.0. The data assembled are considered accurate and reliable considering the many conservative assumptions employed in the calculations. Refer to Section 9.0 for INS plant effluent data.

5.0 EXAMINATION OF DOSE COMMITMENT ESTIMATE TECHNIQUES

Each exposure pathway was examined using established guidelines and actual data. To illustrate the methods employed for each pathway, examples are presented. For the examples, Co-60 was selected to illustrate the calculational bases and assumptions. Every effort was taken to realistically model the conditions with actual data. To complete the calculational process for each target organ and for each nuclide, calculations were iterated using a spreadsheet program.

Calculations were performed for annual and fifty year committed doses. To ensure a conservative estimate, dose conversion factors for adults were selected from the tables within Regulatory Guide 1.109. The dose commitment estimated for each pathway is assumed to be conservative for any individual receptor. The fifty year dose commitments were calculated by use of conversion factors based on ICRP 30 models, which are found in NUREG/CR-3332, entitled "Radiological Assessment - A Textbook on Environmental Dose Analysis."

6.0 SELECTED PATHWAY ANALYSES

Several exposure pathways were identified for this study. Other pathways outlined by Regulatory Guide 1.109 were not examined due to their minimal relative contribution and/or the absence of a credible pathway. In accordance with Regulatory Guide 1.109, "A pathway is considered significant if a conservative evaluation yields an additional dose increment equal to or more than ten percent of the total from all pathways considered." For the purposes of this study, thirteen pathways were examined although some were less than ten percent of the total. This was done to ensure a comprehensive evaluation of both the air and water pathways. The pathways examined were:

Case 6.1	Dose From Inhalation of Radionuclides in Air,
Case 6.2	Dose From Direct Exposure to Ground Deposition of Airborne Contaminants,
Case 6.3	Dose From Ingestion of Water Downstream From the Wastewater Treatment Plant/TNS Direct Discharge,
Case 6.4	Dose From Ingestion of Aquatic Foods Taken From Contaminated Water Supplies,
Case 6.5	Dose From Ingestion of Airborne Contaminated Green Leafy Vegetables,
Case 6.6	Dose From Ingestion of Beef Fed Upon Airborne Contaminated Green Leafy Vegetables,
Case 6.7	Dose From Ingestion of Green Leafy Vegetables Irrigated With Contaminated Water,
Case 6.8	Dose From Ingestion of Beef Fed Upon Green Leafy Vegetables Irrigated With Contaminated Water,
Case 6.9	Dose From Ingestion of Milk,
Case 6.10	Dose From Direct Exposure to Contaminated Reed-bed Sludge,
Case 6.11	Dose From Inhalation of and Direct Exposure to Contaminated Reed-bed Sludge During Sludge Removal,
Case 6.12	Dose From Direct Exposure to Mechanical Dewatered Sludge,
Case 6.13	Dose From Inhalation of Contaminated Sludge-borne Dust.

Case 6.1
Dose From Inhalation of Radionuclides in Air

This pathway was examined to investigate the effect of airborne plant effluent on doses received downwind from direct inhalation of airborne contaminants.

Assumptions:

1. Nearest receptor to the plant, ($r = 500$ m).
2. All releases are considered ground level.
3. Meteorological condition is E stability class (moderately stable) all year.
4. Average wind speed, ($\bar{\mu} = 2$ m/s). (6.1.a)
5. All wind blows to the receptor 100% of the time.
6. Chronic intakes (extended over a single year) may be treated as acute for fifty year committed dose calculations (1 yr intake = 1 acute intake) (6.1.b)
7. The most limiting dose conversion factor is usually the Total Body Committed Dose Equivalent, so this was used in all further sample calculations.

Data

1. Sigma y, ($\sigma_y = 26.3$ m), Sigma z, ($\sigma_z = 13.2$ m). (6.1.c)
2. Airborne activity concentrations C_i^A in Table 9.1, ($C^A_{Co-60} = 4.31E\text{-}14$ $\mu Ci/m\ell$). (6.1.d)
3. Plant stack flow rate for 1992, ($F^A = 32000$ ft^3/min). (6.1.e)
4. Plant stack operation is estimated at 8 hours per day, 5 days per week, and 50 weeks per year.
5. Adult breathing rate, ($R_a = 8000$ m^3/yr). (6.1.f)
6. Inhalation dose factor for radionuclide i, organ j, and age group adult DFA_{ija} in Table 9.3, ($DFA_{Co\text{-}60,\ Total\ Body,\ adult} = 1.85E\text{-}6$ mRem/pCi). (6.1.g)
7. Fifty year inhalation committed dose effective for total body $DCF_{50,T}$ in Table 9.5, ($DCF_{50,T\ Co\text{-}60} = 5.91E\text{-}8$ Sv/Bq). (6.1.h)

Calculational model:

The fifty year committed dose is given as:

$$H_{50,T} = Q_i\, DCF_{50,T} \qquad (6.1.i)$$

Where:

Q_i is the release rate of nuclide i, in Ci/yr;

$DCF_{50,T}$ is the fifty year committed dose conversion factor for nuclide i, for target organ T, used in this report as the whole body; and

All further calculations of fifty year committed dose follow this model, in mRem delivered in 50 years.

The annual dose from inhalation of radionuclides in air to organ j of an individual is given as:

$$D^{A}_{ja}(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \qquad (6.1.2)$$

Where:

R_a is the annual air intake for adults, in m^3/yr;

$\chi_i(r,\theta)$ is the annual average concentration of radionuclide i in air at location (r,θ), in pCi/m^3; and

DFA_{ija} is the inhalation dose factor for radionuclide i, organ j, and age group a, in mRem/pCi.

The annual average airborne concentration of radionuclide i at location (r,θ), with respect to the release point may be determined by:

$$\chi_i(r,\theta) = Q^{A}_i \left[\frac{\chi}{Q}\right](r,\theta) \qquad (6.1.3)$$

Where:

Q^{A}_i is the release rate of nuclide i to the atmosphere, in Ci/yr; and

$\left[\frac{\chi}{Q}\right](r,\theta)$ is the annual average gaseous dispersion factor in the sector at angle θ and at the distance r from the release point, in s/m^3.

The release rate of nuclide i in air is given as:

$$Q^{A}_i = C^{A}_i F^{A} \qquad (6.1.4)$$

Where:

C^{A}_i is the concentration of radionuclide i in air from INS plant, in $\mu Ci/m\ell$; and

F^{A} is the flow rate of air from INS plant, in ft^3/min.

The annual average gaseous dispersion factor from ground level release point is given as:

$$\left[\frac{\chi}{Q}\right](r,\theta) = \frac{1}{\pi\sigma_y\sigma_z\bar{\mu}} \qquad (6.1.5)$$

Where:

π	is the constant pi = 1.14159;
σ_y	is the lateral plume spread, in m;
σ_z	is the vertical plume spread, in m; and
$\bar{\mu}$	is the average wind speed at ground level release height, in m/s.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$\left[\frac{\chi}{Q}\right](r,\theta) = \frac{1}{\pi(26.3\text{m})(13.2\text{m})(2\text{m/s})}$$
$$= 4.58\text{E-}4\ \text{s/m}^3$$

$$Q_i^A = \left(\frac{4.31\text{E}-14\mu\text{Ci}}{\text{m}\ell}\right)\left(\frac{3.2\text{E}4\,\text{ft}^3}{\text{min}}\right)\left(\frac{2.83\text{E}4\,\text{m}\ell}{\text{ft}^3}\right)\left(\frac{60\,\text{min}}{\text{hr}}\right)\left(\frac{8\text{hr}}{\text{day}}\right)\left(\frac{5\text{day}}{\text{wk}}\right)\left(\frac{50\text{wk}}{\text{yr}}\right)\left(\frac{\text{Ci}}{1\text{E}6\mu\text{Ci}}\right)$$
$$= 4.69\text{E-}6\ \text{Ci/yr}$$

$$\chi_i(r,\theta) = \left(\frac{4.69\text{E}-6\text{Ci}}{\text{yr}}\right)\left(\frac{4.58\text{E}-4\text{s}}{\text{m}^3}\right)\left(\frac{\text{yr}}{3.15\text{E}7\text{s}}\right)\left(\frac{1\text{E}12\text{pCi}}{\text{Ci}}\right)$$
$$= 6.82\text{E-}5\ \text{pCi/m}^3$$

$$D_{\mu s}^A(r,\theta) = \left(\frac{8000\text{m}^3}{\text{yr}}\right)\left(\frac{6.82\text{E}-5\text{pCi}}{\text{m}^3}\right)\left(\frac{1.85\text{E}-6\text{mRem}}{\text{pCi}}\right)$$
$$= 1.01\text{E-}6\ \text{mRem/yr}$$

$$H_{50,T} = \left(\frac{6.82\text{E}-5\text{pCi}}{\text{m}^3}\right)\left(\frac{8000\text{m}^3}{\text{yr}}\right)\left(\frac{5.91\text{E}-8\text{Sv}}{\text{Bq}}\right)\left(\frac{\text{Bq}}{27.027\text{pCi}}\right)\left(\frac{1\text{E}5\text{mRem}}{\text{Sv}}\right)$$
$$= 1.19\text{E-}4\ \text{mRem delivered in 50 years}$$

Case 6.2
Dose From Direct Exposure to Ground Deposition of Airborne Contaminants

This pathway was examined to investigate the effect of airborne plant effluent on doses received downwind from deposition of airborne contaminants on the ground plane.

Assumptions:

1. Assumptions made in Case 6.1 apply.
2. The maximally exposed individual is constantly exposed (never leaves home).
3. Meteorological condition is E stability class (moderately stable) all year.
4. Deposition constant, (V_d = 0.01 m/s). (6.2.a)
5. Duration of accumulation of deposited nuclides approximate plant operational life at 1992 concentrations, (t_b = 17 yr). (6.2.b)

Data:

1. Same $\left[\frac{\chi}{Q}\right](r,\theta)$ as used in Case 6.1, ($\left[\frac{\chi}{Q}\right](r,\theta)$ = 4.58E-4 s/m³).
2. Same Q_i^A for each nuclide i as used in Case 6.1, (Q^A_{Co-60} = 4.69E-6 Ci/yr).
3. Decay constant in Table 9.10, (λ_{Co-60} = 1.32E-1 yr^{-1}). (6.2.c)
4. Shielding factor, (S_F = 0.7). (6.2.d)
5. External dose factor for standing on contaminated ground for radionuclide i and organ j DFG_{ij} in Table 9.6, ($DFG_{Co-60,\ Total\ Body}$ = 1.7E-8 mRem/hr per pCi/m²). (6.2.e)

Calculational model:

The annual dose from direct exposure to ground deposition of airborne contaminants to organ j of an individual is given as:

$$D_j^G(r,\theta) = 8760\, S_F \sum_i C_i^G(r,\theta) DFG_{ij} \qquad (6.2.1)$$

Where:

8760	is the number of hours in a year;
S_F	is a shielding factor that accounts for the dose reduction due to shielding provided by residential structures during occupancy, dimensionless;
$C_i^G(r,\theta)$	is the ground plane concentration of radionuclide i at distance r in sector θ, in pCi/m²; and
DFG_{ij}	is the open field ground plane dose conversion factor for organ j from radionuclide i, in mRem-m²/pCi-hr.

The ground plane concentration of radionuclide i at location (r,θ), with respect to the release point may be determined by:

$$C_i^G(r,\theta) = \frac{[1E12][\delta_i(r,\theta)Q_i^A]}{\lambda_i}\left[1-e^{-(\lambda_i t_b)}\right] \qquad (6.2.2)$$

Where:

1E12	is the number of pCi per Ci;
$\delta_i^A(r,\theta)$	is the annual average relative deposition of effluent species i at location (r,θ), considering depletion of the plume during transport, in m^{-2};
Q_i^A	is the annual release rate of nuclide i to the atmosphere, in Ci/yr;
λ_i	is the radioactive decay constant for nuclide i, in yr^{-1}; and
t_b	is the time period over which the accumulation is evaluated, in yr.

The annual average relative deposition of effluent species i at location (r,θ), considering depletion of the plume during transport, may be determined by:

$$\delta_i^A(r,\theta) = V_d\left[\frac{\chi}{Q}\right](r,\theta) \qquad (6.2.3)$$

Where:

V_d	is the deposition constant, in m/s; and
$\left[\frac{\chi}{Q}\right](r,\theta)$	is the annual average gaseous dispersion factor in the sector at angle θ and at the distance r from the release point, in s/m^3.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body

$$\delta_i^A(r,\theta) = \left(\frac{0.01m}{s}\right)\left(\frac{4.58E-4s}{m^3}\right)$$
$$= 4.58E\text{-}6\ m^{-2}$$

$$C_i^G(r,\theta) = \frac{\left(\frac{1E12\,pCi}{Ci}\right)\left(\frac{4.58E-6}{m^2}\right)\left(\frac{4.59E-6Ci}{yr}\right)}{1.32E-1yr^{-1}}\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]$$
$$= 1.46E2\ pCi/m^2$$

$$D_j^G(r,\theta) = \left(\frac{8760hr}{yr}\right)(0.7)\left(\frac{1.46E2pCi}{m^2}\right)\left(\frac{1.7E-8mRem-m^2}{hr-pCi}\right)$$
$$= 1.52E\text{-}2\ mRem/yr$$

Case 6.3
Dose From Ingestion of Water Downstream From the Wastewater Treatment Plant/INS Direct Discharge

This pathway was examined to investigate the effect on doses received if an individual were to directly ingest water from the Schuylkill River, downstream of Royersford Wastewater Treatment Facility (RWTF). The Suburban Water Company services several communities with water from the Schuylkill downstream of INS effluents. Because of modeling assumptions, this case can also apply to direct discharge of INS effluent into the Schuylkill River. INS had applied for a permit to the Pennsylvania Department of Environmental Resources to make releases directly from the Royersford facility to the Schuylkill River.

Assumptions:

1. Dilution factor D_p is calculated as the ratio of the Schuylkill River flow rate to the INS liquid effluent flow rate.
2. Transport time of nuclide between the release from INS and the ingestion by the receptor, (t_p = 12 hr). (6.3.a)
3. Annual consumption of water for an individual, (U_a^w = 730 ℓ/yr). (6.3.b)
4. All of the radionuclides in the INS effluent end up in the wastewater effluent (none is retained in the sludge).

Data:

1. Flow rate of INS effluent, (F^W = 5,107,425 gal/yr). (6.3.c)
2. Average flow rate of Schuylkill River , (F^R = 1899 ft^3/s). (6.3.d)
3. Water activity concentrations C_i^W in Table 9.2, (C^W_{Co-60} = 6.01E-7 $\mu Ci/m\ell$). (6.3.e)
4. Ingestion dose factor for radionuclide i, organ j, and age group adult DFI_{ija} in Table 9.4, ($DFI_{Co\text{-}60,\ Total\ Body,\ adult}$ = 4.72E-6 mRem/pCi). (6.3.f)
5. Fifty year ingestion committed dose effective for total body $DCF_{50,T}$ in Table 9.5, ($DCF_{50,T\ Co\text{-}60}$ = 7.28E-9 Sv/Bq). (6.3.g)

Calculational model:

The annual dose from ingestion of water downstream from the wastewater treatment plant to organ j of an individual is given as:

$$R_{aj} = \frac{U_a^w M_p}{F^w} \sum_i Q_i^w \, DFI_{ija} \, e^{-(\lambda_i t_p)} \qquad (6.3.1)$$

Where:

U_a^w is the usage factor of water, in ℓ/yr;
M_p is the mixing ratio at the point of exposure, dimensionless;
F^w is the flow rate of liquid effluent from INS, in gal/yr;
Q_i^w is the release rate of nuclide i in water, in Ci/yr;
DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;
λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and
t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

The release rate of nuclide i in water is given as:

$$Q_i^w = C_i^w F^w \qquad (6.3.2)$$

Where:

C_i^w is the concentration of radionuclide i in water from INS plant, in μCi/mℓ; and
F^w is the flow rate of liquid effluent from INS, in gal/yr.

The mixing ratio at the point of exposure is given as:

$$M_p = \frac{1}{D_p} \qquad (6.3.3)$$

Where:

D_p is the dilution factor at the point of exposure, dimensionless.

The dilution factor at the point of exposure is given as:

$$D_p = \frac{F^R}{F^w} \qquad (6.3.4)$$

Where:

F^R is the flow rate of the Schuylkill River, in ft^3/s; and
F^w is the flow rate of liquid effluent from INS, in gal/yr.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$D_p = \frac{\left(\frac{1892\,ft^3}{s}\right)}{\left(\frac{5.11E6\,gal}{yr}\right)}\left(\frac{3.15E7\,s}{yr}\right)\left(\frac{7.48\,gal}{ft^3}\right)$$
$$= 8.76E4$$

$$M_p = \frac{1}{8.76E4}$$
$$= 1.14E\text{-}5$$

$$Q_i^w = \left(\frac{6.01E-7\,\mu Ci}{m\ell}\right)\left(\frac{5.11E6\,gal}{yr}\right)\left(\frac{3785\,m\ell}{gal}\right)\left(\frac{Ci}{1E6\,\mu Ci}\right)$$
$$= 1.07E\text{-}2\ Ci/yr$$

$$R_{aj} = \frac{\left(\frac{210\ell}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6\,gal}{yr}\right)}\left(\frac{1.07E-2\,Ci}{yr}\right)\left(\frac{4.72E-6\,mRem}{pCi}\right)e^{-(1.50E-5\,hr^{-1})(12\,hr)}\left(\frac{1E12\,pCi}{Ci}\right)\left(\frac{gal}{3.785\ell}\right)$$
$$= 2.17E\text{-}5\ mRem/yr$$

$$H_{50,T} = \left(\frac{2.17E-5\,mRem}{yr}\right)\left(\frac{pCi}{4.72E-6\,mRem}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Bq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$
$$= 1.24E\text{-}4\ mRem$$

Case 6.4
Dose From Ingestion of Aquatic Foods Taken From Contaminated Water Supplies

This pathway was examined to investigate the effect on doses received from sport fish, which are assumed to have been taken from the Schuylkill River, downstream of Royersford Wastewater Treatment Facility.

Assumptions:

1. Assumptions made in Case 6.3 apply.
2. Transport time of nuclide between the release from INS and the ingestion by the receptor, (t_p = 12 hr).
3. Annual consumption of fish for an individual, (U_a^f = 21 kg/yr). (6.4.a)

Data

1. Flow rate of INS effluent, (F^w = 5,107,425 gal/yr).
2. Same M_p as used in Case 6.3, (M_p = 1.14E-5).
3. Same Q_i^w for each nuclide i as used in Case 6.3, (Q_{Co-60}^w = 1.07E-2 Ci/yr).
4. Bioaccumulation factor for fish B_{ai} in Table 9.7, ($B_{a\,Co-60}$ = 50 ℓ/kg). (6.4.b)

Calculational model:

The annual dose from ingestion of aquatic foods taken from contaminated water supplies to organ j of an individual is given as:

$$R_{aij} = \frac{U_a^f M_p}{F^w} \sum_i Q_i^w B_{ai} DFI_{ija} e^{-(\lambda_i t_p)} \qquad (6.4.1)$$

Where:

U_a^f is the usage factor of fish, in kg/yr;

M_p is the mixing ratio at the point of exposure, dimensionless;

F^{ℓ} is the flow rate of liquid effluent from INS, in gal/yr;

Q_i^w is the release rate of nuclide i in water, in Ci/yr;

B_{ai} is the equilibrium bioaccumulation factor for nuclide i expressed as the ratio of the concentration in biota to the radionuclide concentration in water, in ℓ/kg;

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and

t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$R_{aj} = \frac{\left(\frac{21kg}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{1.07E-2Ci}{yr}\right)\left(\frac{50\frac{pCi}{kg}}{\frac{pCi}{l}}\right)\left(\frac{4.72E-6mRem}{pCi}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{1E12pCi}{Ci}\right)\left(\frac{gal}{3.785l}\right)$$

$$= 3.12E\text{-}5\ mRem/yr$$

$$H_{50,T} = \left(\frac{3.12E-5mRem}{yr}\right)\left(\frac{pCi}{4.72E-6mRem}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 1.78E\text{-}4\ mRem$$

Case 6.5
Dose From Ingestion of Airborne Contaminated Green Leafy Vegetables

This pathway was examined to investigate the effect of airborne plant effluent on doses received downwind from ingestion of green leafy vegetables subjected to deposition and uptake of airborne contaminants.

Assumptions:

1. Assumptions made in Case 6.1 apply.
2. A plant neighbor grows and eats his own green leafy vegetables.
3. 100% of deposited material is retained on the crops, ($r = 1$). (6.5.a)
4. Crops are exposed for 5 month growing season, ($t_e = 3360$ hr). (6.5.b)
5. Productivity yield, ($Y_v = 2$ kg/m^2). (6.5.c)
6. Duration of accumulation of deposited nuclides approximate plant operational life at 1992 concentrations, ($t_b = 17$ yr).
7. Surface density of soil, ($P = 240$ kg/m^2). (6.5.d)
8. 1 day holdup time between harvest and consumption, ($t_h = 24$ hr). (6.5.e)
9. Time that deposit remain on vegetable is 14 days, so the effective removal rate constant for radionuclide i from crops is $\lambda_w = \frac{\ln 2}{(14 \text{ days} \times 24 \text{ hr/day})} = 2.06\text{E-}3 \text{ hr}^{-1}$. (6.5.f)
10. Deposition constant, ($V_d = 0.01$ m/s).
11. Annual consumption of green leafy vegetables for a teen, most conservative case, ($U_a^v = 630$ kg/yr). (6.5.g)
12. 100% of vegetables neighbor eats is grown in his garden, ($f_g = 1$). (6.5.h)

Data:

1. Same $\left[\frac{\chi}{Q}\right](r,\theta)$ as used in Case 6.1, ($\left[\frac{\chi}{Q}\right](r,\theta) = 4.58\text{E-}4$ s/m^3).
2. Same Q_i^A for each nuclide i as used in Case 6.1, ($Q_{Co-60}^A = 4.69\text{E-}6$ Ci/yr).
3. The stable element transfer coefficient of green leafy vegetables B_{iv} in Table 9.7, ($B_{Co60,v} = 9.4\text{E-}3$ Veg/Soil). (6.5.i)

Calculational model:

The annual dose from ingestion of airborne contaminated green leafy vegetables to organ j of an individual is given as:

$$D_{ja}^{D}(r,\theta) = \sum_{i} DFI_{ija}\, U_{a}^{v}\, f_{g}\, C_{i}^{v}(r,\theta) \qquad (6.5.1)$$

Where:

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

U_{a}^{v} is the usage factor of vegetables, in kg/yr;

f_{g} is the fraction of the ingestion rate of vegetables that are produce in the garden of interest, dimensionless; and

$C_{i}^{v}(r,\theta)$ is the concentration of radionuclide i in vegetables at location (r,θ), in pCi/kg.

The concentration of radionuclide i in and on vegetation at the location (r,θ) is estimated as:

$$C_{i}^{v}(r,\theta) = d_{i}^{A}(r,\theta)\left\{\frac{r\left[1-e^{-(\lambda_{Ei}t_{e})}\right]}{Y_{v}\lambda_{Ei}} + \frac{B_{iv}\left[1-e^{-(\lambda_{i}t_{b})}\right]}{P\lambda_{i}}\right\}e^{-(\lambda_{i}t_{h})} \qquad (6.5.2)$$

Where:

$d_{i}^{A}(r,\theta)$ is the deposition rate of radionuclide i onto ground at location (r,θ), in pCi/m^2-s;

r is fraction of deposited activity retained on crops, dimensionless;

λ_{Ei} is the effective removal rate constant for nuclide i from crops, in hr^{-1};

t_{e} is the time period that crops are exposed to contamination during the growing season, in hr^{-1};

Y_{v} is the agricultural productivity (yield), in kg/m^2;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

λ_{i} is the radioactive decay constant for nuclide i, in hr^{-1} or yr^{-1};

t_{b} is the period of long-term buildup for activity in sediment or soil, in yr^{-1};

P is the effective surface density of soil, in kg(dry soil)/m^2; and

t_{h} is the time delay between harvest of vegetation and ingestion by man, in hr^{-1}.

The deposition rate from the plume may be determined by:

$$d_i^{\wedge}(r,\theta) = Q_i^{\wedge} V_d \left[\frac{\chi}{Q}\right](r,\theta) \qquad (6.5.3)$$

Where:

$Q_i^{\wedge}$ is the release rate of nuclide i to the atmosphere, in Ci/yr;

V_d is the deposition constant, in m/s; and

$\left[\frac{\chi}{Q}\right](r,\theta)$ is the annual average gaseous dispersion factor in the sector at angle θ and at the distance r from the release point, in s/m^3.

The effective removal rate constant for radionuclide i from crops is given as:

$$\lambda_{E_i} = \lambda_i + \lambda_w \qquad (6.5.4)$$

Where:

λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and

λ_w is the removal rate constant for physical loss by weathering, in hr^{-1}.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

λ_{E_i} = 1.50E-5 hr^{-1} + 2.06E-3 hr^{-1}
= 2.08E-3 hr^{-1}

$$d_i^{\wedge}(r,\theta) = \left(\frac{4.69E-6Ci}{yr}\right)\left(\frac{0.01m}{s}\right)\left(\frac{4.58E-4s}{m^3}\right)\left(\frac{yr}{3.15E7s}\right)\left(\frac{1E12pCi}{Ci}\right)$$
$$= 6.82E\text{-}7\ pCi/m^2\text{-}s$$

$$C_i^{v}(r,\theta) = \left(\frac{6.82E-7pCi}{m^2 s}\right)\left\{\frac{(1.0)\left[1-e^{-(2.08E-3hr^{-1})(3360hr)}\right]}{\left(\frac{2.0kg}{m^2}\right)(2.08E-3hr^{-1})} + \frac{(9.4E-3)\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]}{\left(\frac{240kg}{m^2}\right)(1.50E-5hr^{-1})}\right\} e^{-(1.50E-5hr^{-1})(24hr)}\left(\frac{3600s}{hr}\right)$$
$$= 5.96E\text{-}1\ pCi/kg$$

$$D_{\mu s}^{D}(r,0) = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{630kg}{yr}\right)(1.0)\left(\frac{5.96E-1pCi}{kg}\right)$$

$$= 1.77E\text{-}3\ mRem/yr$$

$$H_{50,T} = \left(\frac{5.96E-1pCi}{kg}\right)\left(\frac{630kg}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 1.01E\text{-}2\ mRem$$

Case 6.6
Dose From Ingestion of Beef Fed Upon Airborne Contaminated Green Leafy Vegetables

This pathway was examined to investigate the effect of airborne plant effluent on doses received downwind. Specifically, from ingestion of cattle that ingested green leafy vegetables subjected to deposition and uptake of airborne contaminants.

Assumptions:

1. Assumptions made in Case 6.5 apply.
2. All beef consumed is contaminated and raised on 100% contaminated green leafy vegetables.
3. Amount of contaminated feed consumed by animal, (Q_F = 50 kg/day). (6.6 a)
4. Amount of time from slaughter to consumption, (t_s = 1 day). (6.6 b)
5. Annual consumption of beef for an individual, (U_a^F = 110 kg/yr). (6.6 c)

Data:

1. The stable element transfer coefficient F_f that relates the daily intake rate by the animal to the concentration in beef in Table 9.7, ($F_{fCo\text{-}60}$ = 1.3E-2 day/kg). (6.6 d)
2. Same concentration of radionuclide i in the animal's feed $C_i^v(r,\theta)$ as used in Case 6.5, ($C_{iCo\text{-}60}^v(r,\theta)$ = 5.96E-1 pCi/kg).

Calculational model:

The annual dose from ingestion of beef fed upon airborne contaminated green leafy vegetables to organ j of an individual is given as:

$$D_{ja}^D(r,\theta) = \sum_i DFI_{ija}\, U_a^F\, C_i^F(r,\theta) \qquad (6.6.1)$$

Where:

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

U_a^F is the usage factor of beef, in kg/yr, and

$C_i^F(r,\theta)$ is the concentration of radionuclide i in beef at location (r,θ), in pCi/kg.

The concentration of radionuclide i in beef is estimated as:

$$C_i^F(r,\theta) = F_f\, C_i^v(r,\theta)\, Q_F\, e^{-(\lambda_i t_s)} \qquad (6.6.2)$$

Where:

F_f	is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of beef, in days/kg;
$C_i^v(r,\theta)$	is the concentration of radionuclide i in the animal's feed, in pCi/kg;
Q_F	is the consumption rate of contaminated feed by an animal, in kg/day (wet weight);
λ_i	is the radioactive decay constant for nuclide i, in day^{-1}; and
t_s	is the average time from slaughter to consumption, in day.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$C_i^F(r,\theta) = \left(\frac{1.3E-2\,day}{kg}\right)\left(\frac{5.96E-1\,pCi}{kg}\right)\left(\frac{50\,kg}{day}\right)e^{-(3.61E-4\,day^{-1})(1\,day)}$$
$$= 3.87E\text{-}1\ pCi/kg$$

$$D_{js}^D(r,\theta) = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{3.87E-1\,pCi}{kg}\right)$$
$$= 2.01E\text{-}4\ mRem/yr$$

$$H_{50,T} = \left(\frac{3.87E-1\,pCi}{kg}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Bq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$
$$= 1.15E\text{-}3\ mRem$$

Case 6.7
Dose From Ingestion of Green Leafy Vegetables Irrigated With Contaminated Water

This pathway was examined to investigate the effect of waterborne plant effluent on doses received downstream from ingestion of green leafy vegetables irrigated with contaminated water.

Assumptions:

1. Assumptions made in Case 6.3 apply.
2. A plant neighbor grows and eats his own green leafy vegetables.
3. Transit time required for nuclides before irrigation, (t_p = 12 hr).
4. Crops are irrigated with contaminated water (I = 1 in/wk).
5. 100% of deposited material is retained on the crops, (r = 1).
6. Crops are exposed for 5 month growing season, (t_e = 3360 hr).
7. Productivity yield, (Y_v = 2 kg/m^2).
8. 100% of the crops is irrigated with contaminated water, (f_1 = 1) (6.7.a)
9. Duration of accumulation of deposited nuclides approximate plant operational life at 1992 concentrations, (t_b = 17 yr)
10. Surface density of soil, (ρ = 240 kg/m^2).
11. 1 day holdup time between harvest and consumption, (t_h = 24 hr).
12. Annual consumption of green leafy vegetables for a teen, most conservative case, (U_a^v = 630 kg/yr).

Data

1. Flow rate of INS effluent, (F^W = 5,107,425 gal/yr).
2. Same M_p as found in Case 6.3, (M_p = 1.14E-5).
3. Same Q_i^W for each nuclide i as used for Case 6.3, (Q^W_{Co-60} = 1.07E-2 Ci/yr).
4. Same λ_{Ei} for each nuclide i as used in Case 6.5, ($\lambda_{E\,Co-60}$ = 2.08E-3 hr^{-1}).
5. The stable element transfer coefficient of green leafy vegetables B_{iv} in Table 9.7, ($B_{Co-60\,v}$ = 9.4E-3 Veg/Soil).

Calculational model:

The annual dose from ingestion of green leafy vegetables irrigated with contaminated water to organ j of an individual is given as:

$$R_{ja} = \sum_i DFI_{ija}\, U_a^v\, C_{iv} \qquad (6.7.1)$$

Where:

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

U_a^v is the usage factor of vegetables, in kg/yr, and

C_{iv} is the concentration of radionuclide i in the edible portion of the crop, in pCi/kg.

The concentration of radionuclide i on edible portion of the vegetation is estimated as:

$$C_{iv} = d_i^W \left\{ \frac{r\left[1 - e^{-(\lambda_{Ei} t_e)}\right]}{Y_v \lambda_{Ei}} + \frac{f_i B_{iv}\left[1 - e^{-(\lambda_i t_e)}\right]}{P\lambda_i} \right\} e^{-(\lambda_i t_h)} \qquad (6.7.2)$$

Where:

d_i^W is the deposition rate of radionuclide i from irrigated water, in pCi/m^2-s;

r is fraction of deposited activity retained on crops, dimensionless;

λ_{Ei} is the effective removal rate constant for nuclide i from crops, in hr^{-1};

t_e is the time period that crops are exposed to contamination during the growing season, in hr^{-1};

Y_v is the agricultural productivity (yield) in kg/m^2;

f_i is the fraction of the year crops are irrigated, dimensionless;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

λ_i is the radiological decay constant for nuclide, in hr^{-1} or yr^{-1};

t_b is the period of long-term buildup for activity in sediment or soil, in yr^{-1};

P is the effective surface density of soil, in kg(dry soil)/m^2; and

t_h is the time delay between harvest of vegetation and ingestion by man, in hr^{-1}.

The deposition rate from irrigated water is given as:

$$d_i^W = C_{iw} I \qquad (6.7.3)$$

Where:

C_{iw} is the concentration of radionuclide i in water used for irrigation, in pCi/ℓ; and

I is the average irrigation rate during the growing season, in in/wk.

The concentration of radionuclide i in the river is the same as that in water used for irrigation and may be determined by:

$$C_{iw} = \frac{M_p}{F^W} Q_i^W e^{-(\lambda_i t_p)} \qquad (6.7.4)$$

Where:

M_p is the mixing ratio at the point of exposure, dimensionless;

F^W is the flow rate of liquid effluent from INS, in gal/yr;

Q_i^W is the release rate of nuclide i in water, in Ci/yr;

λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and

t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$C_{iw} = \frac{(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{1.07E-2Ci}{yr}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{gal}{3785m\ell}\right)\left(\frac{1E12pCi}{Ci}\right)$$

$$= 6.29E\text{-}6\ pCi/m\ell$$

$$d_i^w = \left(\frac{6.29E-6pCi}{m\ell}\right)\left(\frac{1in}{wk}\right)\left(\frac{wk}{6.048E5s}\right)\left(\frac{m}{39.37in}\right)\left(\frac{1E6m\ell}{m^3}\right)$$

$$= 2.64E\text{-}7\ pCi/m^2\text{-}s$$

$$C_{iv} = \left(\frac{2.64E-7pCi}{m^2s}\right)\left\{\frac{(1.0)\left[1-e^{-(2.08E-3hr^{-1})(3300hr)}\right]}{\left(\frac{2.0kg}{m^2}\right)(2.08E-3hr^{-1})} + \frac{(1.0)(9.4E-3)\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]}{\left(\frac{240kg}{m^2}\right)(1.50E-5hr^{-1})}\right\}e^{-(1.50E-5hr^{-1})(24hr)}\left(\frac{3600s}{hr}\right)$$

$$= 2.31E\text{-}1\ pCi/kg$$

$$R_{si} = \left(\frac{4.72E-6mRem}{pCi}\right)\left(\frac{630kg}{yr}\right)\left(\frac{2.31E-1pCi}{kg}\right)$$

$$= 6.86E\text{-}4\ mRem/yr$$

$$H_{50,T} = \left(\frac{2.31E-1pCi}{kg}\right)\left(\frac{630kg}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 3.92E\text{-}3\ mRem$$

Case 6.8
Dose From Ingestion of Beef Fed Upon Green Leafy Vegetables Irrigated With Contaminated Water

This pathway was examined to investigate the effect of waterborne plant effluent on doses received downstream. Specifically, from ingestion of cattle that ingested green leafy vegetables irrigated with contaminated water.

Assumptions:

1. Assumptions made in Case 6.7 apply.
2. All beef consumed is contaminated and raised on 100% contaminated green leafy vegetables.
3. Amount of contaminated feed consumed by animal, (Q_F = 50 kg/day).
4. Amount of contaminated water consumed by animal, (Q_{Aw} = 50 ℓ/day). (6.8.a)
5. Annual consumption of beef for an individual, (U_a^F = 110 kg/yr).

Data:

1. The stable element transfer coefficient F_f that relates the daily intake rate by an animal to the concentration in beef in Table 9.7, ($F_{f\,Co\text{-}60}$ = 1.3E-2 day/kg).
2. Same concentration of radionuclide i in the animal's feed C_{iv} or C_{iF} as used in Case 6.7, ($C_{Co\text{-}60\,v}$ = 2.31E-1 pCi/kg).
3. Water activity concentration in the Schuylkill River based on INS waterborne effluent data C_{iAw} in Table 9.2 and as used in Case 6.7, ($C_{Co\text{-}60\,Aw}$ = 6.29E-6 pCi/mℓ). (6.8.b)

Calculational model:

The annual dose from ingestion of beef fed upon green leafy vegetables irrigated with contaminated water to organ j of an individual is given as:

$$R_{ja} = \sum_i DFI_{ija}\, U_a^F\, C_{iA} \qquad (6.8.1)$$

Where:

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

U_a^F is the usage factor of beef, in kg/yr; and

C_{iA} is the concentration of radionuclide i in beef, in pCi/kg.

The concentration of radionuclide i in beef is estimated as:

$$C_{iA} = F_f [C_{iF} Q_F + C_{iAw} Q_{Aw}] \qquad (6.8.2)$$

Where:

F_f	is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of beef, in days/kg;
C_{iF}	is the same as C_w in Case 6.7, the concentration of radionuclide i in the animal's feed, in pCi/kg;
Q_F	is the consumption rate of contaminated feed by an animal, in kg/day (wet weight);
C_{iAw}	is the concentration of radionuclide i in water consumed by animals, in pCi/ℓ; and
Q_{Aw}	is the consumption rate of contaminated water by an animal, in ℓ/day.

Sample Calculation

The sample calculation has been performed for Co-60 on the Total Body.

$$C_{iA} = \left(\frac{1.3E-2\,day}{kg}\right)\left[\left(\frac{2.31E-1\,pCi}{kg}\right)\left(\frac{50\,kg}{day}\right)+\left(\frac{6.29E-6\,pCi}{m\ell}\right)\left(\frac{50\,\ell}{day}\right)\left(\frac{1000\,m\ell}{\ell}\right)\right]$$

$$= 1.54E\text{-}1\ pCi/kg$$

$$R_{ai} = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{1.54E-1\,pCi}{kg}\right)$$

$$= 8.00E\text{-}5\ mRem/yr$$

$$H_{50,T} = \left(\frac{1.54E-1\,pCi}{kg}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Dq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$

$$= 4.56E\text{-}4\ mRem$$

Case 6.9
Dose From Ingestion of Milk

This pathway was examined to investigate the effect on doses received from consumption of contaminated milk. The contamination apparent in the milk is derived from the combination of airborne and waterborne deposition upon green leafy vegetables, which is considered the sole source of food for the dairy cow.

Assumptions:

1. Assumption made in Case 6.5 and Case 6.7 apply.
2. All milk consumed is contaminated.
3. All contamination in the milk is derived from the animal's consumption of green leafy vegetables.
4. Transit time required for nuclides before irrigation, (t_f = 12 hr).
5. 100% of deposited material is retained on the feeds, (r = 1).
6. Feeds are exposed for 5 month growing season, (t_e = 3360 hr).
7. Productivity yield, (Y_v = 2 kg/m²).
8. Duration of accumulation of deposited nuclides approximate plant operational life at 1992 concentrations, (t_b = 17 yr).
9. Surface density of soil, (P = 240 kg/m²).
10. 1 day holdup time between harvest and consumption of feed by the animal, (t_h = 24 hr).
11. Animal grazes in the pasture for half the year, (f_p = 0.5).
12. 100% of the animal's feed is pasture grass when it grazes on pasture, (f_s = 1.0).
13. Amount of contaminated feed consumed by animal, (Q_F = 50 kg/day).
14. Transport time of activity from the feed to the milk to the receptor, (t_f = 2 day). (6.9.a)
15. Annual consumption of milk for an individual, (U_a^m = 400 ℓ/yr) (6.9.b)

Data:

1. Same d_i^W for each nuclide i as used for Case 6.7, ($d^W_{Co\text{-}60}$ = 2.64E-7 pCi/m²s).
2. Same $d_i^A(r,\theta)$ for each nuclide i as used in Case 6.5, ($d^A_{Co\text{-}60}(r,\theta)$ = 6.82E-7 pCi/m²s).
3. Same λ_{E_i} for each nuclide i as used in Case 6.5, ($\lambda_{E\,Co\text{-}60}$ = 2.08E-3 hr⁻¹).
4. The stable element transfer coefficient F_m that relates the daily intake rate by the animal to the concentration in milk in Table 9.7, ($F_{m\,Co\text{-}60}$ = 1.0E-3 day/ℓ). (6.9.c)

Calculational model

The annual dose from ingestion of contaminated milk to organ j of an individual is given as

$$D_{ja}^{D}(r,\theta) = \sum_{i} DFI_{ija}\, U_{a}^{m}\, C_{i}^{m}(r,\theta) \qquad (6.9.1)$$

Where:

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;

U_{a}^{m} is the usage factor of milk, in ℓ/yr; and

$C_{i}^{m}(r,\theta)$ is the concentration of radionuclide i in milk at location (r,θ), in pCi/ℓ.

The concentration of radionuclide i in milk at location (r,θ) is estimated as:

$$C_{i}^{m}(r,\theta) = F_{m}\, C_{i}^{v}(r,\theta) Q_{f}\, e^{-(\lambda_{i} t_{f})} \qquad (6.9.2)$$

Where:

F_{m} is the average fraction of the animal's daily intake of radionuclide i which appears in each liter of milk, in day/ℓ;

$C_{i}^{v}(r,\theta)$ is the concentration of radionuclide i in the animal's feed at location (r,θ), in pCi/kg;

Q_{f} is the consumption rate of contaminated feed by an animal, in kg/day (wet weight);

λ_{i} is the radioactive decay constant for nuclide i, in day^{-1}; and

t_{f} is the average transport time of the activity from the feed into the milk and to the receptor, in day.

The concentration of radionuclide i in the animal's feed at location (r,θ) is estimated as:

$$C_{i}^{v}(r,\theta) = f_{p} f_{s} C_{i}^{p}(r,\theta) + (1 - f_{p}) C_{i}^{s}(r,\theta) + f_{p}(1 - f_{s}) C_{i}^{s}(r,\theta) \qquad (6.9.3)$$

Where:

f_{p} is the fraction of the year that animals graze on pasture, dimensionless;

f_{s} is the fraction of daily feed that is pasture grass when the animal grazes on pasture, dimensionless;

$C_{i}^{p}(r,\theta)$ is the concentration of radionuclide i on pasture grass (calculated using Equation (6.5.2) with t_{h} = 0 day), in pCi/kg; and

$C_{i}^{s}(r,\theta)$ is the concentration of radionuclide i in stored feeds (calculated using Equation (6.5.2) with t_{h} = 90 day), in pCi/kg.

The concentration of radionuclide i on pasture grass may be determined by:

$$C_i^P(r,\theta) = [d_i^A(r,\theta) + d_i^W]\left\{\frac{r\left[1-e^{-(\lambda_{Ei}+\lambda_i)t_e}\right]}{Y_v\lambda_{Ei}} + \frac{B_{iv}\left[1-e^{-(\lambda_i+\lambda_b)t_b}\right]}{P\lambda_i}\right\}e^{-(\lambda_i)(0day)} \quad (6.9.4)$$

Where:

$d_i^A(r,\theta)$ is the deposition rate of radionuclide i onto ground at location (r,θ), in pCi/m^2-s;

d_i^W is the deposition rate of radionuclide i from irrigated water, in pCi/m2-s;

r is fraction of deposited activity retained on crops, dimensionless;

λ_{Ei} is the effective removal rate constant for nuclide i from crops, in hr^{-1};

t_e is the time period that crops are exposed to contamination during the growing season, in hr^{-1};

Y_v is the agricultural productivity (yield), in kg/m^2;

f_i is the fraction of the year crops are irrigated, dimensionless;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

λ_i is the radioactive decay constant for nuclide i, in hr^{-1} or yr^{-1};

t_b is the period of long-term buildup for activity in sediment or soil, in yr^{-1}, and

P is the effective surface density of soil, in kg(dry soil)/m^2

The concentration of radionuclide i in stored feeds may be determined by

$$C_i^S(r,\theta) = [d_i^A(r,\theta) + d_i^W]\left\{\frac{r\left[1-e^{-(\lambda_{Ei}+\lambda_i)t_e}\right]}{Y_v\lambda_{Ei}} + \frac{B_{iv}\left[1-e^{-(\lambda_i+\lambda_b)t_b}\right]}{P\lambda_i}\right\}e^{-(\lambda_i)(90day)} \quad (6.9.5)$$

$$= C_i^P(r,\theta)e^{-(\lambda_i)(90day)}$$

Where:

All variables are defined under Equation (6.9.4).

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$C_i^P(r,0) = \left[\left(\frac{6.82E-7pCi}{m^2 s}\right) + \left(\frac{2.64E-7pCi}{m^2 s}\right)\right]\left\{\frac{(1.0)\left[1-e^{-(3.08E-3hr^{-1})(3360hr)}\right]}{\left(\frac{2.0kg}{m^2}\right)(2.08E-3hr^{-1})} + \frac{(1.0)(9.4E-3)\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]}{\left(\frac{240kg}{m^2}\right)(1.50E-5hr^{-1})}\right\}(1)\left(\frac{3600s}{hr}\right)$$

$$= 8.27E\text{-}1\ pCi/kg$$

$$C_i^*(r, \quad \left(\frac{8.27E-1pCi}{kg}\right)e^{-(3.61E-4day^{-1})(90day)}$$

$$= 8.00E\text{-}1\ pCi/kg$$

$$C_i^v(r,0) = (0.5)(1.0)\left(\frac{8.27E-1pCi}{kg}\right) + (1-0.5)\left(\frac{8.00E-1pCi}{kg}\right) + (0.5)(1-1.0)\left(\frac{8.00E-1pCi}{kg}\right)$$

$$= 8.13E\text{-}1\ pCi/kg$$

$$C_i^m(r,0) = \left(\frac{1.0E-3day}{\ell}\right)\left(\frac{8.13E-1pCi}{kg}\right)\left(\frac{50kg}{day}\right)e^{-(3.61E-4day^{-1})(2day)}$$

$$= 4.06E\text{-}2\ pCi/\ell$$

$$D_{ja}^{\alpha}(r,0) = \left(\frac{4.72E-6mRem}{pCi}\right)\left(\frac{400\ell}{yr}\right)\left(\frac{4.06E-2pCi}{\ell}\right)$$

$$= 7.67E\text{-}5\ mRem/yr$$

$$H_{50,T} = \left(\frac{4.06E-2pCi}{\ell}\right)\left(\frac{400\ell}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 4.38E\text{-}4\ mRem$$

Case 6.10
Dose From Direct Exposure to Contaminated Reed-bed Sludge

This pathway was examined to investigate the effect on doses received from contaminated reed-bed sludge at Royersford Wastewater Treatment Facility by a RWTF worker. Reed bed processing is a method to separate the solid sludge sent to landfills from the water portion. This processing involves reeds growing in beds of sludge, which removes water via transpiration and evaporation. Data are available for 1992 TLD direct radiation environmental monitoring at the reed-bed location.

Assumptions:

1. New sludge is added on top of the reed bed every day.
2. All of the radionuclides in the INS effluent end up in the sludge.
3. Employees at RWTF apply sludge to the reed beds t_a for 1 hour every 2 weeks during the summer and 1 hour every 3 weeks during the winter, which is approximately 20 hours per year. (6.10.a)

Data:

1. Net exposure recordings from the TLD at RWTF are averaged for the reed-bed work area. (X_r = 7.85E-2 mRem/hr). (6.10.b)

Calculational model:

The annual dose from direct exposure to contaminated reed-bed sludge to whole body of an individual may be determined by:

$$X_y = X_r t_a \qquad (6.10.1)$$

Where:

X_r is the average TLD recordings at reed bed area, in mRem/hr; and
t_a is the amount of time worker spends applying sludge to the reed beds, in hr/yr.

Sample Calculation:

The sample calculation has been performed on the Total Body.

$$X_r t_a = \left(\frac{7.85E-2\,mRem}{hr}\right)\left(\frac{20\,hr}{yr}\right)$$
$$= 1.57\ mRem/yr$$

$$X_y = 1.57\ mRem/yr$$

Case 6.11
Dose From Inhalation of and Direct Exposure to Contaminated Reed-bed Sludge During Sludge Removal

This pathway was examined to investigate the effect on doses received from contaminated reed-bed sludge at Royersford Wastewater Treatment Facility by a RWTF worker. Specifically, workers are removing the sludge from the reed beds for transport to landfill site after a certain number of years of accumulation. Most of the data were obtained from key people involved with waste handling.

Assumptions

1. All of the radionuclides in the INS effluent end up in the sludge.
2. Sludge has accumulated at the same reed bed each year, so buildup of radionuclides may have occurred.
3. Sludge is removed from the reed bed to be transport to public landfill every 5 years. (6.11.a)
4. Radionuclides are evenly distributed throughout the sludge.
5. In consideration of radioactive decay of nuclides, the model is that one layer of sludge of the same radioactivity is added on top of the reed bed sludge each year.
6. Concentration (activity per mass) of the reed bed sludge at the time of removal C_i^{Sim} is the average of the decay of each layer since all the sludge would be mixed during removal.
7. Mass loading of dust in air (M_l = 500 μg/m^3). (6.11.b)
8. Employees at RWTF remove sludge from the reed beds t_y for 8 hours per day, 5 days per week, and 2 weeks per 5 years.
9. Density of dry sludge is about that of aluminum, (ρ_s = 2.70 g/cm^3). (6.11.c)
10. Linear attenuation of sludge μ_s is about that of aluminum, ($\mu_{s,Co\text{-}60}$ = 1.62E-1 cm^{-1}). (6.11.d)
11. Sludge thickness, (x_s = 6 in).
12. If nuclide i has more than one peak of photon energy, then its energy is the most averaged one.
13. 1 Rem is equal to 1R for gamma exposure.

Data

1. The activity per mass in the reed bed sludge before decay C_{oi}^{Sim} is in Table 9.8, ($C_o^{Sim}{}_{Co\text{-}60}$ = 69.5 pCi/g). (6.11.e)
2. Adult breathing rate, (R_a = 8000 m^3/yr).
3. Specific gamma ray constant Γ_i in Table 9.11, ($\Gamma_{Co\text{-}60}$ = 13.2 R-cm^2/hr-mCi). (6.11.f)
4. Buildup factor of the sludge as its own shield B_i, which depends on the linear attenuation factor μ_s, the sludge thickness x_s, and the photon energy of the nuclide i is given in Table 9.9, ($B_{Co\text{-}60}$ = 3.25). (6.11.g)
5. Values for μ_s and B_i were interpolated from existing data.

Calculational model:

The annual dose from sludge removal from reed beds after a 5 year accumulation period may be determined by:

$$D_{ja}^{SR} = D_{ja}^{SI} + X_{sa} \qquad (6.11.1)$$

Where:

D_{ja}^{SI} is the annual dose from inhalation of contaminated reed-bed sludge during sludge removal, in mRem/yr; and

X_{sa} is the annual dose from direct exposure to contaminated reed-bed sludge during sludge removal, in mRem/yr.

The annual dose from direct exposure to contaminated reed-bed sludge of an individual may be determined by:

$$X_{sa} = \dot{X}_{si} t_r \qquad (6.11.2)$$

Where:

$\dot{X}_{si}$ is the exposure rate to the sludge for nuclide i, in R/hr; and

t_r is the amount of time worker spends removing the sludge from the reed beds, in hr/yr.

The exposure rate of sludge of radionuclide i of an individual may be determined by:

$$\dot{X}_{si} = \frac{\Gamma_i B_i C_i^{Slv}}{2\mu_s} \qquad (6.11.3)$$

Where:

Γ_i is the specific gamma ray constant for nuclide i, in R-cm^2/hr-mCi;

B_i is the buildup factor of the sludge as its own shield for nuclide i, dimensionless;

C_i^{Slv} is the average concentration or activity per volume of radionuclide i at time of sludge removal, in pCi/g; and

μ_s is the linear attenuation coefficient of sludge.

The average concentration (activity per volume) of radionuclide i at time of sludge removal to organ j of an individual may be determined by:

$$C_i^{Slv} = C_i^{Slm} \rho_s \tag{6.11.4}$$

Where:

C_i^{Slm} is the average concentration or activity per mass of radionuclide i at time of sludge removal, in pCi/g; and

ρ_s is the density of sludge, in g/cm^3.

The annual dose from inhalation of contaminated reed-bed sludge to organ j of an individual may be determined by:

$$D_{ja}^{Sl} = R_a M_l t_r \sum_i C_i^{Slm} DFA_{ija} \tag{6.11.5}$$

Where:

R_a is the annual air intake for adults, in m^3/yr;

M_l is the mass loading of dust for dusty work, in μg/m^3;

t_r is the amount of time worker spends removing the sludge from the reed beds, in hr/yr;

C_i^{Slm} is the average concentration or activity per mass of radionuclide i at time of sludge removal, in pCi/g; and

DFA_{ija} is the inhalation dose factor for radionuclide i, organ j, and age group a, in mRem/pCi.

The average concentration (activity per mass) of radionuclide i at time of sludge removal after 5 years to organ j of an individual may be determined by:

$$C_i^{Slm} = Ave\left(\sum_i C_{oi}^{Slm} e^{-(\lambda_i t_s)}\right)$$

$$= C_{oi}^{Slm} \frac{\left[e^{-(5\lambda_i)} + e^{-(4\lambda_i)} + e^{-(3\lambda_i)} + e^{-(2\lambda_i)} + e^{-(1\lambda_i)}\right]}{5} \tag{6.11.6}$$

Where:

C_{oi}^{Slm} is the original concentration or activity per mass of nuclide i before decay, in pCi/g;

λ_i is the radiological decay constant for nuclide, in yr^{-1}; and

t_s is the time passed since last sludge removal, in yr.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body

$$C_i^{Slm} = \left(\frac{69.5\,pCi}{g}\right)\frac{\left[e^{-(1.32E-1\,yr^{-1})(5yr)} + e^{-(1.32E-1\,yr^{-1})(4yr)} + e^{-(1.32E-1\,yr^{-1})(3yr)} + e^{-(1.32E-1\,yr^{-1})(2yr)} + e^{-(1.32E-1\,yr^{-1})(1yr)}\right]}{5}$$

$$= 4.76E1\ pCi/g$$

$$D_{ja}^{Sl} = \left(\frac{8000m^3}{yr}\right)\left(\frac{500\mu g}{m^3}\right)\left(\frac{8hr}{day}\right)\left(\frac{5day}{wk}\right)\left(\frac{2wk}{5yr}\right)\left(\frac{4.76E1pCi}{g}\right)\left(\frac{1.85E-6mRem}{pCi}\right)\left(\frac{yr}{8760hr}\right)\left(\frac{g}{1E6\mu g}\right)$$

$$= 6.44E-7\ mRem/yr$$

$$H_{sol,T} = \left(\frac{4.76E1pCi}{g}\right)\left(\frac{500\mu g}{m^3}\right)\left(\frac{8000m^3}{yr}\right)\left(\frac{5.91E-8Sv}{Bq}\right)\left(\frac{g}{1E6\mu g}\right)\left(\frac{8hr}{day}\right)\left(\frac{5day}{wk}\right)\left(\frac{2wk}{5yr}\right)\left(\frac{yr}{8760hr}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E3mRem}{Sv}\right)$$

$$= 7.61E-5\ mRem$$

$$C_i^{Slv} = \left(\frac{4.76E1pCi}{g}\right)\left(\frac{2.70g}{cm^3}\right)\left(\frac{Ci}{1E12pCi}\right)$$

$$= 1.29E-10\ Ci/cm^3$$

$$\dot{X}_{sa} = \frac{\left(\frac{1.32E-1m^3}{hr\cdot mCi}\right)(3.25)\left(\frac{1.29E-10Ci}{cm^3}\right)}{2\left(1.62E-1cm^{-1}\right)}\left(\frac{1E3mCi}{Ci}\right)$$

$$= 1.70E-5\ R/hr$$

$$X_{sa} = \left(\frac{1.70E-5R}{hr}\right)\left(\frac{8hr}{day}\right)\left(\frac{5day}{wk}\right)\left(\frac{2wk}{5yr}\right)\left(\frac{Rem}{R}\right)\left(\frac{1E3mRem}{Rem}\right)$$

$$= 2.73E-1\ mRem/yr$$

$$D_{ja}^{SR} = \left(\frac{6.44E-7mRem}{yr}\right) + \left(\frac{2.73E-1mRem}{yr}\right)$$

$$= 2.73E-1\ mRem/yr$$

Case 6.12
Dose From Direct Exposure to Mechanical Dewatered Sludge

This pathway was examined to investigate the effect on doses received from contaminated mechanical dewatered sludge at Royersford Wastewater Treatment Facility by a RWTF worker. Data are available for 1992 TLD direct radiation environmental monitoring at the dewatering processes location and general areas around the wastewater treatment facility. Some data were obtained from key people involved with waste handling.

Assumptions:

1. All of the radionuclides in the INS effluent end up in the sludge.
2. Radionuclides are evenly distributed throughout the sludge.
3. Employees at RWTF work near mechanical dewatered sludge for 4 hours per week and 48 weeks per year.
4. Employees at RWTF work in general area for 35 hours per week and 48 weeks per year.

Data

1. Net exposure recordings from the TLD at RWTF are average for the mechanical dewatered sludge area and the general area. ($\dot{X}_m$ = 1.14E-2 mRem/hr and $\dot{X}_g$ = 8.65E-3 mRem/hr). (6.12.a)
2. The types of mechanical methods to process watewater include grinding, settling, trickling filters, anaerobic digestor pumping, chlorine contact tanks, and sludge holding tanks. (6.12.b)
3. RWTF contracts some of the dewatering work. (6.12.c)

Calculational model:

The annual dose from direct exposure to mechanical dewatered sludge to whole body of an individual may be determined by:

$$X_m = \dot{X}_m t_m + \dot{X}_g t_g \qquad (6.12.1)$$

Where:

- X_m is the average TLD recordings at mechanical dewatering processes area, in mRem/hr;
- t_m is the amount of time worker spends at mechanical, in mechanical dewatering processes area, in hr/yr; and
- $\dot{X}_g$ is the average TLD recordings in general work areas, in mRem/hr; and
- t_g is the amount of time worker spends in general areas around the facility, in hr/yr.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$\dot{X}_m t_m = \left(\frac{1.14E-2\,mRem}{hr}\right)\left(\frac{4\,hr}{wk}\right)\left(\frac{48\,wk}{yr}\right)$$

$$= 2.18\ mRem/yr$$

$$X_g t_g = \left(\frac{8.65E-3\,mRem}{hr}\right)\left(\frac{35\,hr}{wk}\right)\left(\frac{48\,wk}{yr}\right)$$

$$= 14.54\ mRem/yr$$

$$X_m = \left(\frac{2.18\,mRem}{yr}\right)+\left(\frac{14.54\,mRem}{yr}\right)$$

$$= 16.72\ mRem/yr$$

Case 6.13
Dose From Inhalation of Contaminated Sludge-borne Dust

This pathway was examined to investigate the effect on doses received from contaminated sludge at landfill by a worker. The following was modeled by Michael J. Bovino, and incorporates standard health physics and engineering principles. Most of the data were obtained from key people involved with waste handling. The individual from this model would not be the same individual from Case 6.10, Case 6.11, and Case 6.12.

Assumptions:

1. Assumptions made in Case 6.11 apply.
2. Sludge is landfilled in a different location each time.
3. Mass loading of dust in air (M_1 = 500 $\mu g/m^3$).
4. Employees at RWTF remove sludge from the reed beds t_r for 8 hours per day, 1 day per week, and 1 week per 5 years.

Data:

1. Adult breathing rate, (R_a = 8000 m^3/yr).
2. Same concentration (activity per mass) of the sludge C_i^{Slm} as used in Case 6.11, (C_{Co-60}^{Slm} = 4.76E1 pCi/g).

Calculational model:

The annual dose from inhalation of contaminated sludge-borne dust to organ j of an individual may be determined by:

$$D_{ja}^{Sl} = R_a M_1 t_r \sum_i C_i^{Slm} DFA_{ija} \qquad (6.13.1)$$

Where:

R_a	is the annual air intake for adults, in m^3/yr;
M_1	is the mass loading of dust for dusty work, in $\mu g/m^3$;
t_r	is the amount of time worker spends at the landfill site, in hr/yr;
C_i^{Slm}	is the average concentration or activity per mass of radionuclide i of sludge, in pCi/g; and
DFA_{ija}	is the inhalation dose factor for radionuclide i, organ j, and age group a, in mRem/pCi.

Sample Calculation:

The sample calculation has been performed for Co-60 on the Total Body.

$$D_{\mu s}^{Si} = \left(\frac{8/000m^3}{yr}\right)\left(\frac{500\mu g}{m^3}\right)\left(\frac{8hr}{day}\right)\left(\frac{1day}{wk}\right)\left(\frac{wk}{5yr}\right)\left(\frac{4.76E1pCi}{g}\right)\left(\frac{1.85E-6mRem}{pCi}\right)\left(\frac{yr}{8760hr}\right)\left(\frac{g}{1E6\mu g}\right)$$

$$= 6.44E\text{-}8\ mRem/yr$$

$$H_{SI,T} = \left(\frac{4.76E1pCi}{g}\right)\left(\frac{500\mu g}{m^3}\right)\left(\frac{8000m^3}{yr}\right)\left(\frac{5.91E-8Sv}{Bq}\right)\left(\frac{g}{1E6\mu g}\right)\left(\frac{8hr}{day}\right)\left(\frac{1day}{wk}\right)\left(\frac{1wk}{5yr}\right)\left(\frac{yr}{8760hr}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 7.61E\text{-}6\ mRem$$

7.0 DISCUSSION

The approach taken for each of the above examinations is conservative. Assumptions have been made that force conservatism:

a. Use dose factors of adults, which is usually the most limiting,
b. Partitioning never occurs in any of the pathways, i.e. all effluent enters into the pathway examined,
c. Gradual buildup and decay of nuclides does not occur in many cases,
d. Environmental conditions are stable throughout the year,
e. All food consumed is contaminated,
f. Transport times are less than those listed in Regulatory Guide 1.109, in order to ensure for local consumption.
g. Amount of time in direct exposure situations is excessive for anticipated operations,
h. Consumption rates reflect the most conservative age group,
i. Conservative geometry was selected for buildup factors (point isotropic source used instead of planar).

The above limitations were imposed to ensure compensation for any inadequacies due to a limited quantity of data, and to simplify calculations. Some of the inadequacies in the data:

a. Buildup factors was a point isotropic source since ones for a planar source were not available for Aluminum,
b. Dose Conversion Factors for a few nuclides were not included in guidance documents,
c. Inability to correlate data collected at the wastewater treatment plant to actual pathway data.

Each of the pathways uses maximal effluent values, and assumes that receptors are available for extended periods of time. For this reason, multiple exposures are seen, such as in the cases involving the wastewater treatment plant worker. In reality, these scenarios are not always practical. Many doses indicated by this analysis are, however, extremely low such that detection in the field offer questionable results and present difficulty when try to corroborate theoretical doses with those measured empirically.

Each of the cases above indicates dose to a maximally exposed individual. This individual, due to the approach employed in some calculations, is fictitious.

Table 9.25, Summation of Doses for General Public, indicates that annual dose a maximally exposed individual of the general population would receive from INS operations is low. The fifty year commitment is slightly higher. Table 9.26, Summation of Doses for Wastewater Treatment Plant Worker, still shows that the annual dose a maximally exposed wastewater treatment plant worker is relatively low. Given a total annual average effective dose equivalent of 360 to members of the U.S. population,[80] the relevance of the fifty year committed dose is diminished. As the BEIR V Committee discussed in its conclusions, low doses of radiation cannot be adequately associated with a numerical risk.[81] The committee has also pointed out that "...there may be no risk from exposures comparable to natural background."[82]

Given these conclusions, it is considered that the impact of INS operations on human receptors in the vicinity of the Royersford facility is minimal.

See Table 9.25 for the summation of all doses to the general receptor and Table 9.26 for the summation of all dose to the wastewater treatment plant receptor.

9.0 DATA TABLES*

Table 9.1
Concentration of Nuclides in INS Discharged Air (μCi/mℓ)

Nuclide	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Average
Cs-134		2.55E-15			6.37E-16
Cs-137	1.67E-14	3.63E-13	8.88E-15	5.47E-15	9.84E-14
Co-58	2.27E-14	1.40E-14			9.19E-15
Mn-54	2.90E-14	1.63E-14	1.65E-14	7.91E-15	1.74E-14
Co-60	6.03E-14	3.82E-14	5.00E-14	2.40E-14	4.31E-14
Zn-65		1.02E-14		1.36E-14	5.94E-15
Nb-95		2.10E-15			5.24E-16
Sr-90					

Table 9.2
Concentration of Nuclides in INS Wastewater (μCi/mℓ)

Nuclide	January	February	March	April	May	June
Cs-134					2.22E-07	1.25E-07
Cs-137	1.19E-06	5.49E-07	3.19E-07	4.72E-07	1.52E-06	1.40E-06
Co-58	4.97E-07	1.62E-07	1.81E-07		2.52E-07	
Mn-54			2.51E-07		4.00E-07	
Co-60	9.66E-07	2.36E-07	5.94E-07	2.02E-07	8.70E-07	
Zn-65						
Nb-95						
Sr-90	5.80E-09	5.80E-09	5.80E-09	1.80E-08	1.80E-08	1.80E-08

Nuclide	July	August	September	October	November	December
Cs-134	3.46E-07	1.33E-07		9.18E-08	1.41E-07	2.01E-07
Cs-137	1.75E-06	1.87E-06	3.10E-07	3.02E-07	7.11E-07	1.18E-06
Co-58	1.40E-07	7.10E-08				
Mn-54	9.84E-08	8.93E-08	3.10E-07	4.50E-07	1.01E-07	4.24E-07
Co-60	2.58E-07	3.10E-07	4.75E-07	5.80E-07	2.74E-07	1.85E-06
Zn-65	1.01E-07		4.66E-07	1.88E-06		4.39E-07
Nb-95						
Sr-90	1.69E-08	1.69E-08	1.69E-08	1.45E-08	1.45E-08	1.45E-08

Nuclide	Average from INS (uCi/ml)	Average in River (pCi/cc)
Cs-134	1.05E-07	1.20E-06
Cs-137	9.64E-07	1.10E-05
Co-58	1.09E-07	1.24E-06
Mn-54	1.77E-07	2.02E-06
Co-60	5.51E-07	6.29E-06
Zn-65	2.41E-07	2.74E-06
Nb-95		
Sr-90	1.38E-08	1.57E-07

*Note: Absence of data indicates nuclide was not present or in less than detectable quantity.

Table 9 3
Inhalation Dose Factors for Adults (mRem/pCi Inhaled)*

Nuclide	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI
Cs-134	4.66E-05	1.06E-04	9.10E-05		3.50E-05	1.22E-05	1.30E-06
Cs-137	5.98E-05	7.76E-05	5.35E-05		2.78E-05	9.40E-06	1.05E-06
Co-58		1.98E-07	2.60E-07			1.16E-04	1.33E-05
Mn-54		4.95E-06	7.87E-07		1.23E-06	1.75E-04	9.67E-06
Co-60		1.44E-06	1.85E-06			7.46E-04	3.56E-05
Zn-65	4.05E-06	1.29E-05	5.82E-06		8.62E-06	1.08E-04	6.68E-06
Nb-95	1.76E-06	9.77E-07	5.26E-07		9.67E-07	6.31E-05	1.30E-05
Sr-90	1.24E-02		7.62E-04			1.20E-03	9.02E-05

*Dose factors from USNRC Regulatory Guide 1.109 Table E-7

Table 9.4
Ingestion Dose Factors for Adults (mRem/pCi Ingested)*

Nuclide	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI
Cs-134	6.22E-05	1.48E-04	1.21E-04		4.79E-05	1.59E-05	2.59E-06
Cs-137	7.97E-05	1.09E-04	7.14E-05		3.70E-05	1.23E-05	2.11E-06
Co-58		7.45E-07	1.67E-06				1.51E-05
Mn-54		4.57E-06	8.72E-07		1.36E-06		1.40E-05
Co-60		2.14E-06	4.72E-06				4.02E-05
Zn-65	4.84E-06	1.54E-05	6.96E-06		1.03E-05		9.70E-06
Nb-95	6.22E-09	3.46E-09	1.86E-09		3.42E-09		2.10E-05
Sr-90	7.58E-03		1.86E-03				2.19E-04

*Dose factors from USNRC Regulatory Guide 1.109 Table E-11.

Table 9.5
Fifty Year Committed Dose Effective (Sv/Bq)*

Nuclide	Inhalation	Ingestion
Cs-134	1.25E-08	1.98E-08
Cs-137	8.63E-09	1.35E-08
Co-58	2.45E-09	3.20E-10
Mn-54	1.81E-09	7.48E-10
Co-60	5.91E-08	7.28E-09
Zn-65	5.51E-09	3.90E-09
Nb-95	1.57E-09	6.95E-10
Sr-90	3.51E-07	3.85E-08

*Data from NUREG/CR-3332 Table 7.19 and Table 7.21

Table 9.6
External Dose Factors for Standing on Contaminated Ground (mRem/hr per pCi/m^2)*

Nuclide	T. Body	Skin
Cs-134	1.2E-08	1.4E-08
Cs-137	4.2E-09	4.9E-09
Co-58	7.0E-09	8.2E-09
Mn-54	5.8E-09	6.8E-09
Co-60	1.7E-08	2.0E-08
Zn-65	4.0E-09	4.6E-09
Nb-95	5.1E-09	6.0E-09
Sr-90	7.1E-09	8.3E-09

*Dose factors from USNRC Regulatory Guide 1.109 Table E-6.

Table 9.7
Bioaccumulation Factor and Stable Element Transfer Data*

Nuclide	Fish Bai (pCi/kg per pCi/l)	Vegetable Biv (Veg/Soil)	Meat Ff (day/kg)	Milk Fm (day/l)
Cs-134	2.0E+03	1.0E-02	4.0E-03	1.2E-02
Cs-137	2.0E+03	1.0E-02	4.0E-03	1.2E-02
Co-58	5.0E+01	9.4E-03	1.3E-02	1.0E-03
Mn-54	4.0E+02	2.9E-02	8.0E-04	2.5E-04
Co-60	5.0E+01	9.4E-03	1.3E-02	1.0E-03
Zn-65	2.0E+05	4.0E-01	3.0E-02	3.9E-02
Nb-95	3.0E+04	9.4E-03	2.8E-01	2.5E-03
Sr-90	3.0E+01	1.7E-02	6.0E-04	8.0E-04

*Data from USNRC Regulatory Guide 1.109 Tables A-1 and E-1.

Table 9.8
Concentration of Nuclides in RWTF's Reed-Bed Sludge (pCi/g)*

Nuclide	Reed Bed 1	Reed Bed 2	Average
Cs-134			
Cs-137	5.0	11.0	8.0
Co-58	3.4		1.7
Mn-54	22.0	40.0	31.0
Co-60	46.0	93.0	69.5
Zn-65	12.0	15.0	13.5
Nb-95			
Sr-90			

*Data from actual analysis.

Table 9.9
Buildup Factor of Sludge in Reed-Bed*

Nuclide	Gamma Energy (MeV)	Mass Attenuation u/p (cm2/g)	Linear Attenuation u (cm-1)	Relaxation Length ux	Buildup Factor B
Cs-134	6.05E-01	8.0E-02	2.16E-01	3.29	5.88
Cs-137	6.62E-01	7.5E-02	2.02E-01	3.08	5.73
Co-58	8.10E-01	7.0E-02	1.89E-01	2.88	5.86
Mn-54	8.35E-01	6.5E-02	1.75E-01	2.67	5.48
Co-60	1.17E+00	6.0E-02	1.62E-01	2.47	3.25
Zn-65	1.12E+00	6.0E-02	1.62E-01	2.47	3.19
Nb-95	7.65E-01	7.0E-02	1.89E-01	2.88	5.70
Sr-90					

*Data from *Radiological Health Handbook* and *Atoms, Radiation, and Radiation Protection.*

Table 9.10
Decay Constant of Radionuclides

Nuclide	1/yr	1/day	1/hr
Cs-134	3.38E-01	9.26E-04	3.86E-05
Cs-137	2.31E-02	6.33E-05	2.64E-06
Co-58	3.55E+00	9.72E-03	4.05E-04
Mn-54	8.35E-01	2.29E-03	9.53E-05
Co-60	1.32E-01	3.61E-04	1.50E-05
Zn-65	1.03E+00	2.83E-03	1.18E-04
Nb-95	7.23E+00	1.98E-02	8.25E-04
Sr-90	2.47E-02	6.76E-05	2.82E-06

*Data from *Radiological Health Handbook*

Table 9.11
Specific Gamma Rav Constant (R-cm^2/hr-mCi)

Nuclide	Gamma
Cs-134	8.7
Cs-137	3.3
Co-58	5.5
Mn-54	4.7
Co-60	13.2
Zn-65	2.7
Nb-95	4.2
Sr-90	3.0

*Data from *Radiological Health Handbook*

Table 9.12
Case 6.1. Dose From Inhalation of Radionuclides in Air

Nuclide	Annual dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	3.76E-07	8.55E-07	7.34E-07		2.82E-07	9.84E-08	1.05E-08	3.73E-07
Cs-137	7.45E-05	9.66E-05	6.66E-05		3.46E-05	1.17E-05	1.31E-06	3.98E-05
Co-58		2.30E-08	3.02E-08			1.35E-05	1.55E-06	1.05E-06
Mn-54		1.09E-06	1.73E-07		2.71E-07	3.85E-05	2.13E-06	1.47E-06
Co-60		7.86E-07	1.01E-06			4.07E-04	1.94E-05	1.19E-04
Zn-65	3.04E-07	9.69E-07	4.37E-07		6.47E-07	8.11E-06	5.02E-07	1.53E-06
Nb-95	1.17E-08	6.47E-09	3.49E-09		6.41E-09	4.18E-07	8.62E-08	3.85E-08
Sr-90								
Total	7.52E-05	1.00E-04	6.90E-05		3.58E-05	4.79E-04	2.50E-05	1.64E-04

Table 9.13
Case 6.2. Dose From Direct Exposure to Ground Deposition of Airborne Contaminants (mRem/year)

Nuclide	T. Body	Skin
Cs-134	6.85E-05	8.04E-05
Cs-137	1.78E-02	2.07E-02
Co-58	5.54E-05	6.49E-05
Mn-54	3.69E-04	4.33E-04
Co-60	1.52E-02	1.79E-02
Zn-65	7.02E-05	8.08E-05
Nb-95	1.13E-06	1.33E-06
Sr-90		
Total	3.35E-02	3.92E-02

Table 9.14
Case 6.3. Dose From Ingestion of Water Downstream From the Wastewater Treatment Plant/INS Direct Discharge

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	5.44E-05	1.29E-04	1.06E-04		4.19E-05	1.39E-05	2.26E-06	6.40E-05
Cs-137	6.40E-04	8.76E-04	5.74E-04		2.97E-04	9.88E-05	1.70E-05	4.01E-04
Co-58		6.71E-07	1.50E-06				1.36E-05	1.07E-06
Mn-54		6.73E-06	1.28E-06		2.00E-06		2.06E-05	4.08E-06
Co-60		9.83E-06	2.17E-05				1.85E-04	1.24E-04
Zn-65	9.68E-06	3.08E-05	1.39E-05		2.06E-05		1.94E-05	2.89E-05
Nb-95								
Sr-90	8.71E-04		2.14E-04				2.52E-05	1.64E-05
Total	1.58E-03	1.05E-03	9.32E-04		3.62E-04	1.13E-04	2.83E-04	6.39E-04

Table 9.15
Case 6.4 Dose From Ingestion of Aquatic Foods
Taken From Contaminated Water Supplies

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	3.13E-03	7.44E-03	6.09E-03		2.41E-03	8.00E-04	1.30E-04	3.68E-03
Cs-137	3.68E-02	5.04E-02	3.30E-02		1.71E-02	5.69E-03	9.75E-04	2.31E-02
Co-58		9.65E-07	2.16E-06				1.96E-05	1.53E-06
Mn-54		7.74E-05	1.48E-05		2.30E-05		2.37E-04	4.69E-05
Co-60		1.41E-05	3.12E-05				2.65E-04	1.78E-04
Zn-65	5.57E-02	1.77E-01	8.01E-02		1.19E-01		1.12E-01	1.66E-01
Nb-95								
Sr-90	7.52E-04		1.85E-04				2.17E-05	1.41E-05
Total	9.64E-02	2.35E-01	1.19E-01		1.38E-01	6.48E-03	1.13E-01	1.93E-01

Table 9.16
Case 6.5 Dose From Ingestion of Airborne Contaminated Green Leafy Vegetables

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	3.39E-04	8.07E-04	6.60E-04		2.61E-04	8.67E-05	1.41E-05	4.00E-04
Cs-137	6.95E-02	9.50E-02	6.22E-02		3.23E-02	1.07E-02	1.84E-03	4.35E-02
Co-58		4.93E-05	1.10E-04				9.99E-04	7.83E-05
Mn-54		6.62E-04	1.26E-04		1.97E-04		2.03E-03	4.01E-04
Co-60		8.03E-04	1.77E-03				1.51E-02	1.01E-02
Zn-65	2.50E-04	7.95E-04	3.59E-04		5.32E-04		5.01E-04	7.45E-04
Nb-95	1.98E-08	1.10E-08	5.93E-09		1.09E-08		6.70E-05	8.20E-06
Sr-90								
Total	7.01E-02	9.81E-02	6.53E-02		3.32E-02	1.08E-02	2.05E-02	5.53E-02

Table 9.17
Case 6.6 Dose From Ingestion of Beef
Fed Upon Airborne Contaminated Green Leafy Vegetables

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	1.18E-05	2.82E-05	2.30E-05		9.11E-06	3.03E-06	4.93E-07	1.39E-05
Cs-137	2.43E-03	3.32E-03	2.17E-03		1.13E-03	3.74E-04	6.42E-05	1.52E-03
Co-58		5.54E-06	1.24E-05				1.12E-04	8.80E-06
Mn-54		4.62E-06	8.81E-07		1.37E-06		1.41E-05	2.80E-06
Co-60		9.11E-05	2.01E-04				1.71E-03	1.15E-03
Zn-65	6.53E-05	2.08E-04	9.39E-05		1.39E-04		1.31E-04	1.95E-04
Nb-95	4.75E-08	2.64E-08	1.42E-08		2.61E-08		1.61E-04	1.97E-05
Sr-90								
Total	2.50E-03	3.66E-03	2.50E-03		1.28E-03	3.77E-04	2.19E-03	2.91E-03

Table 9.18
Case 6.7. Dose From Ingestion of Green Leafy Vegetables
Irrigated With Contaminated Water

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134	1.69E-03	4.03E-03	3.29E-03		1.30E-03	4.33E-04	7.05E-05	1.99E-03
Cs-137	2.06E-02	2.82E-02	1.85E-02		9.58E-03	3.18E-03	5.46E-04	1.29E-02
Co-58		1.76E-05	3.94E-05				3.56E-04	2.79E-05
Mn-54		2.04E-04	3.89E-05		6.07E-05		6.25E-04	1.23E-04
Co-60		3.11E-04	6.86E-04				5.84E-03	3.92E-03
Zn-65	3.06E-04	9.75E-04	4.41E-04		6.52E-04		6.14E-04	9.14E-04
Nb-95								
Sr-90	2.85E-02		6.99E-03				8.23E-04	5.35E-04
Total	5.11E-02	3.38E-02	3.00E-02		1.16E-02	3.62E-03	8.88E-03	2.04E-02

Table 9.19
Case 6.8. Dose From Ingestion of Beef
Fed Upon Green Leafy Vegetables Irrigated With Contaminated Water

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134	6.07E-05	1.45E-04	1.18E-04		4.68E-05	1.55E-05	2.53E-06	7.15E-05
Cs-137	7.40E-04	1.01E-03	6.63E-04		3.43E-04	1.14E-04	1.96E-05	4.64E-04
Co-58		2.06E-06	4.61E-06				4.17E-05	3.27E-06
Mn-54		1.46E-06	2.80E-07		4.36E-07		4.49E-06	8.87E-07
Co-60		3.63E-05	8.00E-05				6.81E-04	4.56E-04
Zn-65	8.25E-05	2.62E-04	1.19E-04		1.75E-04		1.65E-04	2.46E-04
Nb-95								
Sr-90	1.53E-04		3.76E-05				4.42E-06	2.88E-06
Total	1.04E-03	1.46E-03	1.02E-03		5.66E-04	1.30E-04	9.19E-04	1.24E-03

Table 9.20
Case 6.9. Dose From Ingestion of Milk

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134	7.42E-04	1.77E-03	1.44E-03		5.72E-04	1.90E-04	3.09E-05	8.74E-04
Cs-137	3.42E-02	4.68E-02	3.07E-02		1.59E-02	5.28E-03	9.06E-04	2.15E-02
Co-58		1.49E-06	3.34E-06				3.02E-05	2.37E-06
Mn-54		6.22E-06	1.19E-06		1.85E-06		1.91E-05	3.77E-06
Co-60		3.48E-05	7.67E-05				6.54E-04	4.38E-04
Zn-65	6.10E-04	1.94E-03	8.77E-04		1.30E-03		1.22E-03	1.82E-03
Nb-95	9.02E-10	5.02E-10	2.70E-10		4.96E-10		3.04E-06	3.73E-07
Sr-90	7.21E-04		1.77E-04				2.08E-05	1.35E-05
Total	3.63E-02	5.06E-02	3.32E-02		1.78E-02	5.47E-03	2.89E-03	2.46E-02

Table 9.21
Case 6.10. Dose From Direct Exposure to Contaminated Reed-bed Sludge
(mRem/year)

Exposure per year	Annual Exposure
Application of sludge to reed bed dose	1.57
Total	1.57

Table 9.22
Case 6.11. Dose From Inhalation of and Direct Exposure to
Contaminated Reed-bed Sludge During Sludge Removal

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134								
Cs-137	3.26E-06	4.25E-06	2.92E-06		1.52E-06	5.13E-07	5.73E-08	1.74E-06
Co-58		1.46E-11	1.91E-11			8.54E-09	9.79E-10	6.67E-10
Mn-54		1.69E-07	2.03E-08		4.20E-08	5.98E-06	3.31E-07	2.29E-07
Co-60		5.01E-07	6.44E-07			2.60E-04	1.24E-05	7.61E-05
Zn-65	4.39E-06	1.40E-07	6.31E-08		9.35E-08	1.17E-06	7.24E-08	2.21E-07
Nb-95								
Sr-90								
Total	3.31E-06	5.04E-06	3.65E-06		1.65E-06	2.67E-04	1.28E-05	7.83E-05

Nuclide	Exposure Rate (R/hr)	Annual Exposure (mRem/year)
Cs-134		
Cs-137	9.41E-07	1.51E-02
Co-58	2.32E-09	3.71E-05
Mn-54	9.27E-07	1.48E-02
Co-60	1.70E-05	2.73E-01
Zn-65	1.07E-07	1.71E-03
Nb-95		
Sr-90		
Total	1.90E-05	3.04E-01

Nuclide	Total Annual Dose (mRem/year)
Cs-134	
Cs-137	1.51E-02
Co-58	3.71E-05
Mn-54	1.48E-02
Co-60	2.73E-01
Zn-65	1.71E-03
Nb-95	
Sr-90	
Total	3.04E-01

Table 9.23
Case 6.12. Dose From Direct Exposure to Mechanical Dewatered Sludge
(mRem/year)

Exposure per year	Annual Exposure
Mechical dewatering process dose	2.18
General area dose at RWTF	14.54
Total	16.72

Table 9.24
Case 6.13. Dose From Inhalation of Contaminated Sludge-borne Dust

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134								
Cs-137	3.26E-07	4.23E-07	2.92E-07		1.52E-07	5.13E-08	5.73E-09	1.74E-07
Co-58		1.46E-12	1.91E-12			8.54E-10	9.79E-11	6.67E-11
Mn-54		1.69E-08	2.69E-09		4.20E-09	5.98E-07	3.31E-08	2.29E-08
Co-60		5.01E-08	6.44E-08			2.60E-05	1.24E-06	7.61E-06
Zn-65	4.39E-09	1.40E-08	6.31E-09		9.35E-09	1.17E-07	7.24E-09	2.21E-08
Nb-95								
Sr-90								
Total	3.31E-07	5.04E-07	3.65E-07		1.65E-07	2.67E-05	1.28E-06	7.83E-06

Table 9.25
Summation of Doses for General Public
(mRem/year)

Pathways	Annual	50 Year
Case 6.1	6.90E-05	1.64E-04
Case 6.2	3.35E-02	
Case 6.3	9.32E-04	6.39E-04
Case 6.4	1.19E-01	1.93E-01
Case 6.5	6.53E-02	5.53E-02
Case 6.6	2.50E-03	2.91E-03
Case 6.7	3.00E-02	2.04E-02
Case 6.8	1.02E-03	1.24E-03
Case 6.9	3.32E-02	2.46E-02
Case 6.13	3.65E-07	7.83E-06
Total Body	2.86E-01	2.98E-01

Table 9.26
Summation of Doses for Wastewater Treatment Plant Worker
(mRem/year)

Pathways	Annual	50 Year
Case 6.10	1.57E+00	
Case 6.11	3.04E-01	7.83E-05
Case 6.12	1.67E+01	
Total Body	1.86E+01	7.83E-05

10.0 ENDNOTES

2.0 INS Corporation Royersford Radioactive Materials License

2.1 Written correspondence from the Royersford Wastewater Treatment Facility, July 11, 1993

6.1.a J. F. Sagendorf, J.T. Goll, and W. F. Sandusky, (eds). "Dispersion Coefficients as a Functin of Downwind Distance" computer printouts in *XOQDOQ: Computer Program for the Meterological Evaluation of Routine Effluent Releases at Nuclear Power Stations*. NUREG/CR-2919 United States Nuclear Regulatory Commission, Washington D.C., March 1981.

6.1.b John E. Till and H. Robert Meyer, (eds). *Radiological Assessment: A Textbook on Environmental Dose Analysis*. NUREG/CR-3332. United States Nuclear Regulatory Commission. Washington D.C., September 1983, p. 7-5.

6.1.c Sagendorf, Goll, and Sandusky, p. 34

6.1.d INS Corp. Gamma Spec. Analysis of Discharged Air from First, Second, Third, and Fourth Quarter for 1992 Royersford.

6.1.e Design specification of the plant stack determines the air flow rate.

6.1.f "Calculation of Annual Doses to Man from Routine Releases Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I." USNRC Regulatory Guide 1.109. United States Nuclear Regulatory Commission, Washington D.C., October 1977, p. 1.109-40

6.1.g Regulatory Guide 1.109, pp. 1.109-44 to 1.109-45.

6.1.h Till and Meyer, pp. 7-77 to 7-82.

6.1.i Till and Meyer, p. 7-75.

6.1.2 Regulatory Guide 1.109, p. 1.109-7.

6.1.3 Till and Meyer, p. 2-8

6.1.4 "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routing Releases from Light-Water-Cooled Reactors." USNRC Regulatory Guide 1.111. United States Nuclear Regulatory Commission, Washington D.C., July 1977.

6.1.5 Till and Meyer, p. 2-8.

6.2.a Michael J. Bovino. "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services - Springfield, Massachusetts." Interstate Nuclear Services, September 1990, p. 7.

6.2.b Royersford plant manager, Harry Barnes, estimates the beginning of Royersford plant operation to be 1976. The exact year is not available since INS has bought the laundry facility from another corporation and does not have the original license.

6.2.c *Radiological Health Handbook*. U.S. Department of Health, Education, and Welfare, Washington D.C., January 1970, pp. 86 to 87.

6.2.d Regulatory Guide 1.109, p. 1.109-68.

6.2.e Regulatory Guide 1.109, pp. 1.109-41 to 1.109-42.

6.2.1 Regulatory Guide 1.109, p. 1.109-7.

6.2.2 Regulatory Guide 1.109, p. 1.109-24.

6.2.3 Regulatory Guide 1.111.

6.3.a Regulatory Guide 1.109, p. 1.109-69.

6.3.b Regulatory Guide 1.109, p. 1.109-40.

6.3.c Royersford 1992 Water Results.

6.3.d Pottstown Recording Station record of the Schuylkill River for 64 years.

6.3.e Royersford 1992 Water Results.

6.3.f Regulatory Guide 1.109, pp. 1.109-56 to 1.109-57.

6.3.g Till and Meyer, pp. 7-90 to 7-92.

6.3.1 Regulatory Guide 1.109, p. 1.109-2.

6.3.2 "Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I." USNRC Regulatory Guide 1.113. United States Nuclear Regulatory Commission, Washington D.C., April 1977.

6.3.3 Regulatory Guide 1.109, p. 1.109-3.

6.3.4 Regulatory Guide 1.113.

6.4.a Regulatory Guide 1.109, p. 1.109-40.

6.4.b Regulatory Guide 1.109, p. 1.109-13.

6.4.1 Regulatory Guide 1.109, p. 1.109-2.

6.5.a Regulatory Guide 1.109, p. 1.109-68.

6.5.b Regulatory Guide 1.109, p. 1.109-68.

6.5.c Regulatory Guide 1.109, p. 1.109-69.

6.5.d Regulatory Guide 1.109, p. 1.109-68.

6.5.e Regulatory Guide 1.109, p. 1.109-69.

6.5.f Regulatory Guide 1.109, p. 1.109-69.

6.5.g Regulatory Guide 1.109, p. 1.109-40.

6.5.h Regulatory Guide 1.109, p. 1.109-68.

6.5.i Regulatory Guide 1.109, p. 1.109-37.

6.5.1 Regulatory Guide 1.109, p. 1.109-7.

6.5.2 Regulatory Guide 1.109, p. 1.109-25.

6.5.3 Regulatory Guide 1.109, p. 1.109-26.

6.5.4 Regulatory Guide 1.109, p. 1.109-4.

6.6.a Regulatory Guide 1.109, p. 1.109-38.

6.6.b Regulatory Guide 1.109, p. 1.109-69.

6.6.c Regulatory Guide 1.109, p. 1.109-40.

6.6.d Regulatory Guide 1.109, p. 1.109-37.

6.6.1 Regulatory Guide 1.109, p. 1.109-7.

6.6.2 Regulatory Guide 1.109, p. 1.109-28.

6.7.a Regulatory Guide 1.109, p. 1.109-3.

6.7.1 Regulatory Guide 1.109, p. 1.109-3.

6.7.2 Regulatory Guide 1.109, p. 1.109-15.

6.7.3 Regulatory Guide 1.109, p. 1.109-15.

6.7.4 Regulatory Guide 1.109, p. 1.109-2.

6.8.a Regulatory Guide 1.109, p. 1.109-38.

6.8.b Royersford 1992 Water Results.

6.8.1 Regulatory Guide 1.109, p. 1.109-3.

6.8.2 Regulatory Guide 1.109, p. 1.109-16.

6.9.a Regulatory Guide 1.109, p. 1.109-68.

6.9.b Regulatory Guide 1.109, p. 1.109-40.

6.9.c Regulatory Guide 1.109, p. 1.109-37.

6.9.1 Regulatory Guide 1.109, p. 1.109-7.

6.9.2 Regulatory Guide 1.109, p. 1.109-27.

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6.9.4 Regulatory Guide 1.109, p. 1.109-27.

6.9.5 Regulatory Guide 1.109, p. 1.109-27.

6.10.a Correspondence from Royersford Wastewater Treatment Facility, August 27, 1993.

6.10.b TLD Direct Radiation Environmental Monitoring at the Royersford Wastewater Treatment Facility from January 7, 1992 to January 8, 1993.

6.10.1 Standard conversion.

6.11.a An estimate by Royersford Wastewater Treatment Facility engineer. The exact number of years of operation is not known since this is a relatively untried technology and is the first reed-bed at the facility.

6.11.b NUREG 5512 according to USNRC Comments on "Radiological Impacts of Effluent to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services - Morris, Illinois," June 1993, p. 2.

6.11.c *Radiological Health Handbook*, p. 65.

6.11.d James E. Turner. *Atoms, Radiation, and Radiation Protection*. New York: Pergamon Press, 1986, p. 126.

6.11.e Royersford Wastewater Treatment Plant nuclide concentration of reed-bed sludge for 1992.

6.11.f *Radiological Health Handbook*, p. 131.

6.11.g *Radiological Health Handbook*, p. 145.

6.11.1 Author determined that the total dose from reed-bed sludge removal is the summation of the inhalation of sludge dust and the direct exposure to sludge.

6.11.2 Standard conversion.

6.11.3 R. G. Jaeger, et al. *Engineering Compendium on Radiation Shielding Volume I*, Berlin: Springer-Verlag, 1968, p. 376.

6.11.4 Standard conversion.

6.11.5 Bovino, p. 13.

6.11.6 Modeled by Michael J. Bovino in discussion with the author, Interstate Nuclear Services.

6.12.a TLD Direct Radiation Environmental Monitoring from RWTF.

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6.12.c Written correspondence from RWTF.

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6.13.1 Bovino, p. 13.

8.0 "Health Effect of Exposure to Low Levels of Ionizing Radiation - BEIR V." National Research Council, National Academy Press, Washington D.C., 1990, p. 19.

8.1 National Research Council, p. 371.

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RADIOLOGICAL IMPACTS OF EFFLUENT RELEASES FROM DIRECT DISCHARGE TO THE SCHUYLKILL RIVER FROM INTERSTATE NUCLEAR SERVICES

ROYERSFORD, PENNSYLVANIA

Sherry C. Wu
August 1993

TABLE OF CONTENTS

1.0 INTRODUCTION

An appendix to "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services - Royersford, Pennsylvania" was prepared to demonstrate impact of INS to the general public if the plant were to release all of its wastewater at maximum permissible concentrations for expected nuclides* at levels outlined in 10 CFR 20, Appendix B, Table 3 ("sewer disposal"), effective January 1, 1994.

Due to political considerations, INS has applied for a National Pollutant Discharge Elimination System (NPDES) permit which will allow direct discharge of processed wastewater to the Schuylkill River and therefore bypass the Royersford Wastewater Treatment Facility. The direct discharge scenario mandates that INS follow 10 CFR 20, Appendix B, Table 2 (previously known as "unrestricted releases"), instead of Table 3, "sewer disposal" as is currently followed.

Recognizing that new effluent regulations have been significantly reduced, that Table 2 values are ten times more restrictive than Table 3, and that it may be economically unfeasible to meet impacts at Table 3 levels. As permitted under 10 CFR 20 §1301, this appendix has been prepared as a basis for a petition to the NRC to allow "unrestricted" direct-discharge releases from INS at "sewer disposal" maximum permissible concentration limits.

Four liquid pathways from the Royersford pathway analysis produce doses that mainly depend on wastwater from the plant. Results indicate that if INS were to directly discharge all of its liquid effluent at maximum permissible concentrations for expected nuclides, the dose to the theoretical maximally exposed individual is conservatively estimated to be 7.56 mRem per year. This is within the 100 mRem per year target dose limited stipulated in 10 CFR 20 §1301.

*Note: "expected nuclides" are those that have either been historically measured, appeared on DOT shipping papers, or been anticipated to be present in INS liquid effluent.

2.0 SELECTED PATHWAY ANALYSES

Several exposure pathways were identifies for this study of the effects on doses received if the maximum permissible concentration of nuclides in wastewater were released from INS plant. For the purposes of this study, the four pathways examined have doses that mainly depend on wastewater effluent from the plant. The pathways examined were:

Case A.1	Dose From Ingestion of Water Downstream From INS Direct Discharge,
Case A.2	Dose From Ingestion of Aquatic Foods Taken From Water Supplies With INS Direct Discharge,
Case A.3	Dose From Ingestion of Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge,
Case A.4	Dose From Ingestion of Beef Fed Upon Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge.

Case A.1
Dose From Ingestion of Water Downstream From INS Direct Discharge

This pathway was examined to investigate the effect on doses received if an individual were to directly ingest water from the Schuylkill River. The Suburban Water Company services several communities with water from the Schuylkill downstream of the Interstate Nuclear Services plant. INS had applied for a permit to the Pennsylvania Department of Environmental Resources to make releases directly from the Royersford facility to the Schuylkill River.

Assumptions:

1. Dilution factor D_p is calculated as the ratio of the Schuylkill River flow rate to the INS liquid effluent flow rate.
2. Transport time of nuclide between the release from INS and the ingestion by the receptor, (t_p = 12 hr). (A.1.a)
3. Annual consumption of water for an individual, (U_a^w = 730 ℓ/yr). (A.1.b)

Data

1. Flow rate of INS effluent, (F^W = 5,107,425 gal/yr) (A.1.c)
2. Average flow rate of Schuylkill River , (F^R = 1899 ft^3/s) (A.1.d)
3. Maximum water activity concentration allowed to be released from plant to sewers C_i^W in Table A.1, (C^W_{Co-60} = 3E-5 μCi/mℓ). (A.1.e)
4. Decay constant in Table A.5, (λ_{Co-60} = 1.32E-1 yr^{-1}). (A.1.f)
5. Ingestion dose factor for radionuclide i, organ j, and age group adult DFI_{ija} in Table A.2, ($DFI_{Co\text{-}60,\ Total\ Body,\ adult}$ = 4.72E-6 mRem/pCi). (A.1.g)
6. Fifty year ingestion committed dose effective for total body $DCF_{50,T}$ in Table A.3, ($DCF_{50,T\ Co\text{-}60}$ = 7.28E-9 Sv/Bq). (A.1.h)

Calculational model

The annual dose from ingestion of water downstream from INS to organ j of an individual is given as:

$$R_{aj} = \frac{U_a^w M_p}{F^w} \sum_i Q_i^w \, DFI_{ija} \, e^{-(\lambda_i t_p)} \qquad (A.1.1)$$

Where:

U_a^w is the usage factor of water, in ℓ/yr;
M_p is the mixing ratio at the point of exposure, dimensionless;
F^w is the flow rate of liquid effluent from INS, in gal/yr;
Q_i^w is the release rate of nuclide i in water, in Ci/yr;
DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;
λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and
t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

The release rate of nuclide i in water is given as:

$$Q_i^w = C_i^w F^w \qquad (A.1.2)$$

Where:

C_i^w is the maximum permissible concentration of radionuclide i in water to be released from plant to sewers, in $\mu Ci/m\ell$; and
F^w is the flow rate of liquid effluent from INS, in gal/yr.

The mixing ratio at the point of exposure is given as:

$$M_p = \frac{1}{D_p} \qquad (A.1.3)$$

Where:

D_p is the dilution factor at the point of exposure, dimensionless.

The dilution factor at the point of exposure is given as:

$$D_p = \frac{F^R}{F^w} \qquad (A.1.4)$$

Where:

F^R is the flow rate of the Schuylkill River, in ft^3/s; and
F^w is the flow rate of liquid effluent from INS, in gal/yr.

Sample Calculation

The sample calculation has been performed for Co-60 on the Total Body.

$$D_p = \frac{\left(\frac{1899.6\,ft^3}{s}\right)}{\left(\frac{5.11E6\,gal}{yr}\right)}\left(\frac{3.15E7\,s}{yr}\right)\left(\frac{7.48\,gal}{ft^3}\right)$$

$$= 8.76E4$$

$$M_p = \frac{1}{8.76E4}$$

$$= 1.14E\text{-}5$$

$$Q_i^w = \left(\frac{3E-5\,\mu Ci}{m\ell}\right)\left(\frac{5.11E6\,gal}{yr}\right)\left(\frac{3785\,m\ell}{gal}\right)\left(\frac{Ci}{1E6\,\mu Ci}\right)$$

$$= 5.80E\text{-}1\ Ci/yr$$

$$R_{aj} = \frac{\left(\frac{730\ell}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6\,gal}{yr}\right)}\left(\frac{5.80E-1\,Ci}{yr}\right)\left(\frac{4.72E-6\,mRem}{pCi}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{1E12\,pCi}{Ci}\right)\left(\frac{gal}{3.785\ell}\right)$$

$$= 1.18E\text{-}3\ mRem/yr$$

$$H_{50,T} = \left(\frac{1.18E-3\,mRem}{yr}\right)\left(\frac{pCi}{4.72E-6\,mRem}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Bq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$

$$= 6.73E\text{-}3\ mRem$$

Case A.2
Dose From Ingestion of Aquatic Foods Taken From Water Supplies With INS Direct Discharge

This pathway was examined to investigate the effect on doses received from sport fish, which are assumed to have been taken from the Schuylkill River, downstream of the Interstate Nuclear Services Royersford plant.

Assumptions:

1. Assumptions made in Case A.1 apply.
2. Transport time of nuclide between the release from INS and the ingestion by the receptor, (t_p = 12 hr).
3. Annual consumption of fish for an individual, (U_a^f = 21 kg/yr) (A.2.a)

Data:

1. Flow rate of INS effluent, (F^W = 5,107,425 gal/yr).
2. Same M_p as used in Case A.1, (M_p = 1.14E-5).
3. Same Q_i^W for each nuclide i as used in Case A.1, (Q_{Co-60}^W = 5.80E-1 Ci/yr).
4. Bioaccumulation factor for fish B_{ai} in Table A.4, ($B_{a\,Co-60}$ = 50 ℓ/kg). (A.2.b)

Calculational model:

The annual dose from ingestion of aquatic foods taken from contaminated water supplies to organ j of an individual is given as:

$$R_{aj} = \frac{U_a^f M_p}{F^W} \sum_i Q_i^W B_{ai} DFI_{ija} e^{-(\lambda_i t_p)} \qquad (A.2.1)$$

Where:

- U_a^f is the usage factor of fish, in kg/yr;
- M_p is the mixing ratio at the point of exposure, dimensionless;
- F^W is the flow rate of liquid effluent from INS, in gal/yr;
- Q_i^W is the release rate of nuclide i in water, in Ci/yr;
- B_{ai} is the equilibrium bioaccumulation factor for nuclide i expressed as the ratio of the concentration in biota to the radionuclide concentration in water, in ℓ/kg;
- DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;
- λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and
- t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

Sample Calculation

The sample calculation has been performed for Co-60 on the Total Body

$$R_{ai} = \frac{\left(\frac{21kg}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{5.80E-1Ci}{yr}\right)\left(\frac{50\frac{pCi}{kg}}{\frac{pCi}{l}}\right)\left(\frac{4.72E-6mRem}{pCi}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{1E12pCi}{Ci}\right)\left(\frac{gal}{3.785l}\right)$$

$$= 1.70E\text{-}3\ mRem/yr$$

$$H_{aiT} = \left(\frac{1.70E-3mRem}{yr}\right)\left(\frac{pCi}{4.72E-6mRem}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 9.68E\text{-}3\ mRem$$

Case A.3
Dose From Ingestion of Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge

This pathway was examined to investigate the effect of waterborne plant effluent on doses received downstream from ingestion of green leafy vegetables irrigated with contaminated water.

Assumptions

1. Assumptions made in Case A.1 apply.
2. A plant neighbor grows and eats his own green leafy vegetables.
3. Transit time required for nuclides before irrigation, (t_p = 12 hr).
4. Crops are irrigated with contaminated water, (I = 1 in/wk).
5. 100% of deposited material is retained on the crops, (r = 1). (A.3.a)
6. Crops are exposed for 5 month growing season, (t_e = 3360 hr). (A.3.b)
7. Productivity yield, (Y_v = 2 kg/m^2). (A.3.c)
8. 100% of the crops is irrigated with contaminated water, (f_l = 1) (A.3.d)
9. Duration of accumulation of deposited nuclides approximate plant operational life at 1992 concentrations, (t_b = 17 yr) (A.3.e)
10. Surface density of soil, (P = 240 kg/m^2). (A.3.f)
11. 1 day holdup time between harvest and consumption, (t_h = 24 hr) (A.3.g)
12. Time that deposit remain on vegetable is 14 days, so the effective removal rate constant for radionuclide i from crops is $\lambda_w = \frac{\ln 2}{(14 \text{ days} \times 24 \text{ hr/day})} = 2.06\text{E-}3 \text{ hr}^{-1}$ (A.3.h)
13. Annual consumption of green leafy vegetables for a teen, most conservative case, (U_a^v = 630 kg/yr). (A.3.i)

Data

1. Flow rate of INS effluent, (F^W = 5,107,425 gal/yr).
2. Same M_p as found in Case A.1, (M_p = 1.14E-5).
3. Same Q_i^W for each nuclide i as used for Case A.1, (Q^W_{Co-60} = 5.80E-1 Ci/yr).
4. The stable element transfer coefficient of green leafy vegetables B_{iv} in Table A.4, ($B_{Co-60\,v}$ = 9.4E-3 Veg/Soil). (A.3.j)

Calculational model

The annual dose from ingestion of green leafy vegetables irrigated with contaminated water to organ j of an individual is given as

$$R_{ja} = \sum_i DFI_{ija} U_a^v C_{iv} \qquad (A.3.1)$$

Where

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi,

U_a^v is the usage factor of vegetables, in kg/yr, and

C_{iv} is the concentration of radionuclide i in the edible portion of the crop, in pCi/kg.

The concentration of radionuclide i on edible portion of the vegetation is estimated as

$$C_{iv} = d_i^w \left\{ \frac{r\left[1 - e^{-(\lambda_{Ei} t_e)}\right]}{Y_v \lambda_{Ei}} + \frac{f_l B_{iv}\left[1 - e^{-(\lambda_i t_b)}\right]}{P\lambda_i} \right\} e^{-(\lambda_i t_h)} \qquad (A.3.2)$$

Where

d_i^w is the deposition rate of radionuclide i from irrigated water, in pCi/m^2-s;

r is fraction of deposited activity retained on crops, dimensionless;

λ_{Ei} is the effective removal rate constant for nuclide i from crops, in hr^{-1};

t_e is the time period that crops are exposed to contamination during the growing season, in hr^{-1};

Y_v is the agricultural productivity (yield), in kg/m^2;

f_l is the fraction of the year crops are irrigated, dimensionless;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

λ_i is the radiological decay constant for nuclide, in hr^{-1} or yr^{-1};

t_b is the period of long-term buildup for activity in sediment or soil, in yr^{-1};

P is the effective surface density of soil, in kg(dry soil)/m^2; and

t_h is the time delay between harvest of vegetation and ingestion by man, in hr^{-1}

The deposition rate from irrigated water is given as

$$d_i^w = C_{iw} I \qquad (A.3.3)$$

Where

C_{iw} is the maximum permissible concentration of radionuclide i in water used for irrigation, in pCi/ℓ; and

I is the average irrigation rate during the growing season, in in/wk.

The concentration of radionuclide i in the river is the same as that in water used for irrigation and may be determined by:

$$C_{iw} = \frac{M_p}{F^W} Q_i^W e^{-(\lambda_i t_p)} \qquad (A.3.4)$$

Where

M_p is the mixing ratio at the point of exposure, dimensionless;
F^W is the flow rate of liquid effluent from INS, in gal/yr;
Q_i^W is the release rate of nuclide i in water, in Ci/yr;
λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and
t_p is the average transit time required for nuclides to reach the point of exposure, in hr.

The effective removal rate constant for radionuclide i from crops is given as:

$$\lambda_{Ei} = \lambda_i + \lambda_w \qquad (A.3.5)$$

Where

λ_i is the radioactive decay constant for nuclide i, in hr^{-1}; and
λ_w is the removal rate constant for physical loss by weathering, in hr^{-1}.

Sample Calculation

The sample calculation has been performed for Co-60 on the Total Body.

$$\lambda_{Ei} = 1.50E\text{-}5\ hr^{-1} + 2.06E\text{-}3\ hr^{-1}$$
$$= 2.08E\text{-}3\ hr^{-1}$$

$$C_{iw} = \frac{(1.14E-5)}{\left(\frac{5.11E+9\ gal}{yr}\right)}\left(\frac{5.80E-1\ Ci}{yr}\right)e^{-(1.50E-5\ hr^{-1})(12\ hr)}\left(\frac{gal}{3785\ m\ell}\right)\left(\frac{1E12\ pCi}{Ci}\right)$$
$$= 3.42E\text{-}4\ pCi/m\ell$$

$$d_i^W = \left(\frac{3.42E-4\ pCi}{m\ell}\right)\left(\frac{1\ in}{wk}\right)\left(\frac{wk}{6.048E5\ s}\right)\left(\frac{m}{39.37\ in}\right)\left(\frac{1E6\ m\ell}{m^3}\right)$$
$$= 1.44E\text{-}5\ pCi/m^2\text{-}s$$

$$C_{iv} = \left(\frac{1.44E-5\ pCi}{m^2 s}\right)\left\{\frac{(1.0)\left[1-e^{-(2.08E-3\ hr^{-1})(3360\ hr)}\right]}{\left(\frac{2.0\ kg}{m^2}\right)(2.08E-3\ hr^{-1})} + \frac{(1.0)(9.4E-3)\left[1-e^{-(1.32E-1\ yr^{-1})(17\ yr)}\right]}{\left(\frac{240\ kg}{m^2}\right)(1.50E-5\ hr^{-1})}\right\}e^{-(1.50E-5\ hr^{-1})(24\ hr)}\left(\frac{3600\ s}{hr}\right)$$
$$= 12.6\ pCi/kg$$

$$R_{sj} = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{630kg}{yr}\right)\left(\frac{12.6pCi}{kg}\right)$$

$$= 3.73E\text{-}2\ mRem/yr$$

$$H_{SOT} = \left(\frac{12.6pCi}{kg}\right)\left(\frac{630kg}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 2.13E\text{-}1\ mRem$$

Case A.4
Dose From Ingestion of Beef Fed Upon Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge

This pathway was examined to investigate the effect of waterborne plant effluent on doses received downstream. Specifically, from ingestion of cattle that ingested green leafy vegetables irrigated with contaminated water.

Assumptions

1. Assumptions made in Case A.3 apply.
2. All beef consumed is contaminated and raised on 100% contaminated green leafy vegetables.
3. Amount of contaminated feed consumed by animal, (Q_F = 50 kg/day). (A.4.a)
4. Amount of contaminated water consumed by animal, (Q_{Aw} = 50 ℓ/day). (A.4.b)
5. Annual consumption of beef for an individual, (U_a^F = 110 kg/yr). (A.4.c)

Data

1. The stable element transfer coefficient F_f that relates the daily intake rate by an animal to the concentration in beef in Table A.4, ($F_{f\,Co\text{-}60}$ = 1.3E-2 day/kg). (A.4.d)
2. Same concentration of radionuclide i in the animal's feed C_{iv} or C_{iF} as used in Case A.3, ($C_{Co\text{-}60\,v}$ = 12.6 pCi/kg).
3. Water activity concentration in the river if the plant was to release the maximum permissible concentration of radionuclide i in its liquid effluent C_{iAw} in Table A.1, ($C_{Co\text{-}60\,Aw}$ = 3.42E-4 pCi/mℓ). (A.4.e)

Calculational model

The annual dose from ingestion of beef fed upon green leafy vegetables irrigated with contaminated water to organ j of an individual is given as:

$$R_{aj} = \sum_i DFI_{ija}\, U_a^F\, C_{iA} \qquad (A.4.1)$$

Where:

- DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, in mRem/pCi;
- U_a^F is the usage factor of beef, in kg/yr; and
- C_{iA} is the concentration of radionuclide i in beef, in pCi/kg.

The concentration of radionuclide i in beef is estimated as:

$$C_{iA} = F_f [C_{iF} Q_F + C_{iAw} Q_{Aw}] \qquad (A.4.2)$$

Where

F_f is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of beef, in days/kg;

C_{iF} is the same as C_{iv} in Case A.3, the concentration of radionuclide i in the animal's feed, in pCi/kg;

Q_F is the consumption rate of contaminated feed by an animal, in kg/day (wet weight).

C_{iAw} is the concentration of radionuclide i in water consumed by animals, in pCi/ℓ and

Q_{Aw} is the consumption rate of contaminated water by an animal, in ℓ/day.

Sample Calculation

The sample calculation has been performed for Co-60 on the Total Body

$$C_{iA} = \left(\frac{1.3E-2day}{kg}\right)\left[\left(\frac{12.6pCi}{kg}\right)\left(\frac{50kg}{day}\right) + \left(\frac{3.42E-4pCi}{m\ell}\right)\left(\frac{50\ell}{day}\right)\left(\frac{1000m\ell}{\ell}\right)\right]$$

$$= 8.38\ pCi/kg$$

$$R_{Ai} = \left(\frac{4.72E-6mRem}{pCi}\right)\left(\frac{110kg}{yr}\right)\left(\frac{8.38pCi}{kg}\right)$$

$$= 4.35E\text{-}3\ mRem/yr$$

$$H_{50,T} = \left(\frac{8.38pCi}{kg}\right)\left(\frac{110kg}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

$$= 2.48E\text{-}2\ mRem$$

3.0 SUMMARY

Each case indicates dose to a maximally exposed individual in addition to the maximum permissible concentration of radionuclides in the wastewater. Because of the approach employed in this and some other calculations, this individual is fictitious.

Table A 10, Summation of Doses for General Public From Liquid Effluent, indicates that the annual dose and the fifty year committed dose to a maximally exposed individual of the general population would receive from INS operations even if all releases were at maximum permissible concentrations are still relatively low.

Given these conclusions, it is proposed that direct discharge releases from INS to the Schuylkill River be permitted to be at levels outlined in Appendix B, Table 3 effective January 1, 1994.

4.0 DATA TABLES

Table A.1
Maximum Permissible Concentration of Nuclides in Wastewater From INS Plant*

Nuclide	From INS Plant (uCi/ml)	In River (pCi/cc)
Cs-134	9E-06	1.03E-04
Cs-137	1E-05	1.14E-04
Co-58	2E-04	2.27E-03
Mn-54	3E-04	3.42E-03
Co-60	3E-05	3.42E-04
Zn-65	5E-05	5.70E-04
Nb-95	3E-04	3.39E-03
Sr-90	5E-06	5.71E-05
H-3	1E-02	1.14E-01
Fe-55	1E-03	1.14E-02
Zr-95	2E-04	2.27E-03
I-129	2E-06	2.28E-05
I-131	1E-05	1.09E-04
U-235	3E-06	3.42E-05
U-238	3E-06	3.42E-05

*Data from USNRC 10 CFR Part 20 Table 3.

Table A.2
Ingestion Dose Factors for Adults (mRem/pCi Ingested)*

Nuclide	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI
Cs-134	6.22E-05	1.48E-04	1.21E-04		4.79E-05	1.59E-05	2.59E-06
Cs-137	7.97E-05	1.09E-04	7.14E-05		3.70E-05	1.23E-05	2.11E-06
Co-58		7.45E-07	1.67E-06				1.51E-05
Mn-54		4.57E-06	8.72E-07		1.36E-05		1.40E-05
Co-60		2.14E-06	4.72E-06				4.02E-05
Zn-65	4.84E-06	1.54E-05	6.96E-06		1.03E-05		9.70E-06
Nb-95	6.22E-09	3.46E-09	1.86E-09		3.42E-09		2.10E-05
Sr-90	7.58E-03		1.86E-03				2.19E-04
H-3		1.05E-07	1.05E-07	1.05E-07	1.05E-07	1.05E-07	1.05E-07
Fe-55	2.75E-06	1.90E-06	4.43E-07			1.06E-06	1.09E-06
Zr-95	3.04E-08	9.75E-09	8.60E-09		1.53E-08		3.09E-05
I-129	7.56E-07	2.23E-06	8.80E-07	1.89E-04	3.48E-06		1.92E-06
I-131	4.16E-06	5.36E-06	3.41E-06	1.95E-03	1.02E-05		1.57E-06
U-235	8.01E-04		4.86E-05		2.87E-04		7.81E-05
U-238	7.67E-04		4.54E-05		1.75E-04		5.50E-05

*Dose factors from NUREG-0172 Table 4.

Table A.3
Fifty Year Committed Dose Effective (Sv/Bq)*

Nuclide	Ingestion
Cs-134	1.98E-08
Cs-137	1.35E-08
Co-58	3.20E-10
Mn-54	7.48E-10
Co-60	7.28E-09
Zn-65	3.90E-09
Nb-95	6.95E-10
Sr-90	3.85E-08
H-3	1.70E-11
Fe-55	1.54E-10
Zr-95	1.02E-09
I-129	7.45E-08
I-131	1.44E-08
U-235	7.22E-09
U-238	6.42E-09

*Data from NUREG/CR-3332 Table 7.21

Table A.4
Bioaccumulation Factor and Stable Element Transfer Data*

Nuclide	Fish Bai (pCi/kg per pCi/l)	Vegetable Biv (Veg/Soil)	Meat Ff (day/kg)
Cs-134	2.0E+03	1.0E-02	4.0E-03
Cs-137	2.0E+03	1.0E-02	4.0E-03
Co-58	5.0E+01	9.4E-03	1.3E-02
Mn-54	4.0E-02	2.9E-02	8.0E-04
Co-60	5.0E-01	9.4E-03	1.3E-02
Zn-65	2.0E+03	4.0E-01	3.0E-02
Nb-95	3.0E+04	9.4E-03	2.8E-01
Sr-90	3.0E-01	1.7E-02	6.0E-04
H-3	9.0E-01	4.8E+00	1.2E-02
Fe-55	1.0E+02	6.6E-04	4.0E-02
Zr-95	3.3E+00	1.7E-04	3.4E-02
I-129	1.5E+01	2.0E-02	2.9E-03
I-131	1.5E+01	2.0E-02	2.9E-03
U-235	2.0E+00	2.5E-03	2.4E-04
U-238	2.0E+00	2.5E-03	2.4E-04

*Data from NUREG/CR-3585 Tables D-11, D-12, and D-14

Table A.5
Decay Constant of Radionuclides*

Nuclide	1/yr	1/hr
Cs-134	3.38E-01	3.86E-05
Cs-137	2.31E-02	2.64E-06
Co-58	3.55E+00	4.05E-04
Mn-54	8.35E-01	9.53E-05
Co-60	1.32E-01	1.50E-05
Zn-65	1.03E+00	1.18E-04
Nb-95	7.23E+00	8.25E-04
Sr-90	2.47E-02	2.82E-06
H-3	5.64E-02	6.43E-06
Fe-55	2.67E-01	3.04E-05
Zr-95	3.89E+00	4.44E-04
I-129	4.08E-08	4.65E-12
I-131	3.14E+01	3.59E-03
U-235	9.76E-10	1.11E-13
U-238	1.54E-10	1.75E-14

*Data from *Radiological Health Handbook*

Table A.6
Case A.1 Dose From Ingestion of Water Downstream From INS Direct Discharge

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134	4.66E-03	1.11E-02	9.07E-03		3.59E-03	1.19E-03	1.94E-04	5.49E-03
Cs-137	6.64E-03	9.08E-03	5.95E-03		3.08E-03	1.02E-03	1.76E-04	4.16E-03
Co-58		1.24E-03	2.77E-03				2.50E-02	1.96E-03
Mn-54		1.14E-02	2.18E-03		3.39E-03		3.49E-02	6.91E-03
Co-60		5.35E-03	1.18E-03				1.00E-02	6.73E-03
Zn-65	2.01E-03	6.41E-03	2.89E-03		4.28E-03		4.03E-03	6.00E-03
Nb-95	1.54E-05	8.56E-06	4.60E-06		8.46E-06		5.20E-02	6.36E-03
Sr-90	3.16E-01		7.75E-02				9.12E-03	5.93E-03
H-3		8.75E-03	8.75E-03	8.75E-03	8.75E-03	8.75E-03	8.75E-03	5.24E-03
Fe-55	2.29E-02	1.58E-02	3.69E-03			8.83E-03	9.08E-03	4.74E-03
Zr-95	5.04E-05	1.62E-05	1.09E-05		2.54E-05		5.12E-02	6.25E-03
I-129	1.26E-05	3.72E-05	1.47E-05	3.15E-03	5.80E-05		3.20E-05	4.59E-03
I-131	3.32E-04	4.75E-04	2.72E-04	1.56E-01	8.14E-04		1.25E-04	4.25E-03
U-235	2.00E-02		1.21E-03		4.67E-03		1.95E-03	6.68E-04
U-238	1.92E-02		1.13E-03		4.37E-03		1.37E-03	5.94E-04
Total	3.92E-01	6.49E-02	1.17E-01	1.67E-01	3.30E-02	1.98E-02	2.08E-01	6.99E-02

Table A.7

Case A.2 Dose From Ingestion of Aquatic Foods Taken From Water Supplies With INS Direct Discharge

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	2.68E-01	6.38E-01	5.22E-01		2.07E-01	6.86E-02	1.12E-02	3.16E-01
Cs-137	3.82E-01	5.22E-01	3.42E-01		1.77E-01	5.89E-02	1.01E-02	2.39E-01
Co-58		1.78E-03	3.98E-03				3.60E-02	2.82E-03
Mn-54		1.31E-01	2.50E-02		3.91E-02		4.02E-01	7.95E-02
Co-60		7.59E-04	1.70E-03				1.44E-02	9.68E-03
Zn-65	1.16E-01	3.69E-01	1.67E-01		2.46E-01		2.32E-01	3.45E-01
Nb-95	1.33E-02	7.39E-03	3.97E-03		7.30E-03		4.48E+01	5.49E+00
Sr-90	2.72E-01		6.69E-02				7.87E-03	5.12E-03
H-3		2.26E-04	2.26E-04	2.26E-04	2.26E-04	2.26E-04	2.26E-04	1.36E-04
Fe-55	6.59E-02	4.55E-02	1.06E-02			2.54E-02	2.61E-02	1.36E-02
Zr-95	4.78E-06	1.53E-06	1.04E-06		2.41E-06		4.86E-03	5.94E-04
I-129	5.44E-06	1.60E-05	6.33E-06	1.36E-03	2.50E-05		1.38E-05	1.98E-03
I-131	1.43E-04	2.05E-04	1.17E-04	6.71E-02	3.51E-04		5.41E-05	1.83E-03
U-235	1.15E-03		6.99E-05		2.69E-04		1.12E-04	3.84E-05
U-238	1.10E-03		6.53E-05		2.52E-04		7.91E-05	3.42E-05
Total	1.12E+00	1.72E+00	1.14E+00	6.87E-02	6.78E-01	1.53E-01	4.56E+01	6.51E+00

Table A.8

Case A.3 Dose From Ingestion of Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	1.45E-01	3.45E-01	2.82E-01		1.12E-01	3.71E-02	6.04E-03	1.71E-01
Cs-137	2.14E-01	2.93E-01	1.92E-01		9.93E-02	3.30E-02	5.66E-03	1.34E-01
Co-58		3.23E-02	7.25E-02				6.56E-01	5.14E-02
Mn-54		3.46E-01	6.60E-02		1.03E-01		1.06E+00	2.09E-01
Co-60		1.69E-02	3.73E-02				3.18E-01	2.13E-01
Zn-65	6.37E-02	2.03E-01	9.16E-02		1.36E-01		1.28E-01	1.90E-01
Nb-95	3.41E-04	1.90E-04	1.02E-04		1.87E-04		1.15E+00	1.41E-01
Sr-90	1.03E+01		2.53E+00				2.98E-01	1.94E-01
H-3		2.46E+00	2.46E+00	2.46E+00	2.46E+00	2.46E+00	2.46E+00	1.47E+00
Fe-55	7.13E-01	4.92E-01	1.15E-01			2.75E-01	2.83E-01	1.48E-01
Zr-95	1.30E-03	4.16E-04	2.82E-04		6.53E-04		1.32E+00	1.61E-01
I-129	4.18E-04	1.23E-03	4.87E-04	1.05E-01	1.93E-03		1.06E-03	1.53E-01
I-131	3.52E-03	5.03E-03	2.88E-03	1.65E+00	8.62E-03		1.33E-03	4.50E-02
U-235	6.36E-01		3.86E-02		1.49E-01		6.21E-02	2.12E-02
U-238	6.09E-01		3.61E-02		1.39E-01		4.37E-02	1.89E-02
Total	1.27E+01	4.20E+00	5.93E+00	4.22E+00	3.21E+00	2.81E+00	7.79E+00	3.32E+00

Table A.9

Case A.4 Dose From Ingestion of Beef Fed Upon Green Leafy Vegetables Irrigated By Water Supplies With INS Direct Discharge

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
Cs-134	5.21E-03	1.24E-02	1.01E-02		4.01E-03	1.33E-03	2.17E-04	6.13E-03
Cs-137	7.67E-03	1.05E-02	6.87E-03		3.56E-03	1.18E-03	2.03E-04	4.81E-03
Co-58		3.79E-03	8.50E-03				7.69E-02	6.03E-03
Mn-54		2.48E-03	4.74E-04		7.39E-04		7.61E-03	1.50E-03
Co-60		1.97E-03	4.35E-03				3.71E-02	2.48E-02
Zn-65	1.71E-02	5.45E-02	2.47E-02		3.65E-02		3.44E-02	5.11E-02
Nb-95	8.66E-04	4.82E-04	2.59E-04		4.76E-04		2.92E+00	3.58E-01
Sr-90	5.55E-02		1.36E-02				1.60E-03	1.04E-03
H-3		2.59E-01	2.59E-01	2.59E-01	2.59E-01	2.59E-01	2.59E-01	1.55E-01
Fe-55	2.56E-01	1.77E-01	4.12E-02			9.86E-02	1.01E-01	5.30E-02
Zr-95	3.98E-04	1.28E-04	8.64E-05		2.00E-04		4.04E-01	4.94E-02
I-129	1.09E-05	3.21E-05	1.26E-05	2.72E-03	5.00E-05		2.76E-05	3.96E-03
I-131	9.63E-05	1.38E-04	7.89E-05	4.51E-02	2.36E-04		3.63E-05	1.23E-03
U-235	1.37E-03		8.31E-05		3.20E-04		1.34E-04	4.57E-05
U-238	1.31E-03		7.76E-05		2.99E-04		9.41E-05	4.06E-05
Total	3.45E-01	5.22E-01	3.69E-01	3.07E-01	3.05E-01	3.60E-01	3.85E+00	7.16E-01

Table A.10

Summation of Doses From Liquid Effluent

Pathways	Annual	50 Year
Case A.1	1.17E-01	6.99E-02
Case A.2	1.14E+00	6.51E+00
Case A.3	5.93E+00	3.32E+00
Case A.4	3.69E-01	7.16E-01
Total Body	7.56E+00	1.06E+01

5.0 ENDNOTES

A 1 a "Calculation of Annual Doses to Man from Routine Releases Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I." USNRC Regulatory Guide 1.109. United States Nuclear Regulatory Commission, Washington D.C., October 1977, p. 1.109-69.

A 1 b Regulatory Guide 1.109, p. 1.109-40.

A 1 c Royersford 1992 Water Results.

A 1 d Pottstown Recording Station record of the Schuylkill River for 64 years.

A 1 e Royersford 1992 Water Results.

A 1 f Regulatory Guide 1.109, p. 1.109-68.

A 1 g G. R. Hoenes and J. K. Soldat. "Age-Specific Radiation Dose Commitment Factors For a One-Year Chronic Intake." NUREG-0172. United States Nuclear Regulatory Commission, Washington D.C., November 1977, p. 20 to 24.

A 1 h John E. Till and H. Robert Meyer, (eds). *Radiological Assessment: A Textbook on Environmental Dose Analysis*. NUREG/CR-3332. United States Nuclear Regulatory Commission, Washington D.C., September 1983, pp. 7-90 to 7-92.

A 1 i Regulatory Guide 1.109, p. 1.109-2.

A 1 2 "Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I." USNRC Regulatory Guide 1.113. United States Nuclear Regulatory Commission, Washington D.C., April 1977.

A 1 3 Regulatory Guide 1.109, p. 1.109-3.

A 1 4 Regulatory Guide 1.109, p. 1.113.

A 2 a Regulatory Guide 1.109, p. 1.109-40.

A 2 b O. I. Oztunali and G. W. Roles. "*De Minimis* Waste Impacts Analysis Methodology." NUREG/CR-3585. United States Nuclear Regulatory Commission, Washington D.C., February 1984, p. D-28.

A 2 1 Regulatory Guide 1.109, p. 1.109-2.

A 3 a Regulatory Guide 1.109, p. 1.109-68.

A 3 b Regulatory Guide 1.109, p. 1.109-68.

A 3 c Regulatory Guide 1.109, p. 1.109-69.

A 3 d Regulatory Guide 1.109, p. 1.109-3.

A 3 e Royersford plant manager, Harry Barnes, estimated the beginning of Royersford plant operation to be 1976. The exact year is not available since INS has bought the laundry facility from another corporation and does not have the original license.

A 3 f Regulatory Guide 1 109, p 1 109-68

A 3 g Regulatory Guide 1 109, p 1 109-68

A 3 h Regulatory Guide 1 109, p 1 109-69

A 3 i Regulatory Guide 1 109, p 1 109-40

A 3 j Oztunali and Roles, p D-25

A 3 1 Regulatory Guide 1 109, p 1 109-3

A 3 2 Regulatory Guide 1 109, p 1 109-15

A 3 3 Regulatory Guide 1 109, p 1 109-15

A 3 4 Regulatory Guide 1 109, p 1 109-2

A 3 5 Regulatory Guide 1 109, p 1 109-4

A 4 a Regulatory Guide 1 109, p 1 109-38

A 4 b Regulatory Guide 1 109, p 1 109-38

A 4 c Regulatory Guide 1 109, p 1 109-40

A 4 d Oztunali and Roles, p D-26

A 4 e Royersford 1992 Water Results

A 4 1 Regulatory Guide 1 109, p 1 109-3

A 4 2 Regulatory Guide 1 109, p 1 109-16