INTERSTATE NUCLEAR SERVICES
A SUBSIDIARY OF UNIFIRST CORPORATION

June 10, 1994

Ms. Betsy Ullrich
Senior Health Physicist
U.S. Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, PA 19406

Dear Betsy,

It was good to hear from your again. Enclosed is the pathway analysis for the INS Royersford, PA facility which was completed last summer. Please accept my apology for not sending it to you sooner. If you recall, one of the reasons for the analysis was to anticipate the need for a petition to allow higher discharge limits. However, based on a careful review of our existing effluent concentrations, I believe that we can comply with current Table 2 values. Therefore, I never sent the pathway analysis because I did not feel the need to challenge the new limits.

In conducting the study, we tried to employ realistic assumptions and actual data wherever possible, although were we did have to make a guess, it was always in the conservative direction. Thus, I believe that the results provided are "conservatively realistic".

I hope that you find the analysis to be useful and informative. Thank you for your interest.

Sincerely,

Michael J. Bovino, CHP
Manager, Health Physics and Engineering

enclosure
cc: 079 file

295 Parker Street • P.O. Box 51957 • Springfield, Massachusetts 01151 • (413) 543-6911 • FAX: (413) 543-6989

INS INTERSTATE NUCLEAR SERVICES

TAKE A CLEAN STEP FORWARD

TAKE A CLEAN STEP FORWARD WITH INS

INS is the nuclear services division of UniFirst Corporation, a leading nationwide service company listed on The New York Stock Exchange. INS has been providing total protective clothing programs to the U.S. nuclear industry since 1957, and it is the nation's largest protective clothing decontamination service. INS serves all parts of the country through its nationwide network of licensed cleaning facilities. The company offers clothing and respirator decontamination, protective clothing rental, garment reclamation, respirator filter recertification, on-site labor and mobile on-site cleaning services.

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

ROYERSFORD, PENNSYLVANIA

Sherry C. Wu
August 1993

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

ROYERSFORD, PENNSYLVANIA

AUGUST 1993

ORIGINATOR: Sherry Wu
Corporate Health Physics and Engineering Dept.

TECHNICAL REVIEW: [signature], CHP
Manager, Health Physics and Engineering

APPROVED BY: George J Bakerich
General Manager

TABLE OF CONTENTS

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."[4]

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/INS 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, ($C_{Co-60}^A = 4.31\text{E-}14\ \mu Ci/m\ell$). (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, ($DFA_{Co\text{-}60,\ Total\ Body,\ adult} = 1.85\text{E-}6$ mRem/pCi). (6.1.g)
7. Fifty year inhalation committed dose effective for total body $DCF_{50,T}$ in Table 9.5, ($DCF_{50,T\ Co\text{-}60} = 5.91\text{E-}8$ Sv/Bq). (6.1.h)

Calculational model:

The fifty year committed dose is given as:

$$H_{50,T} = Q_i\, DCF_{50,T} \qquad (6.1.1)$$

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:

$$D_{ja}^{A}(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \tag{6.1.2}$$

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:

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

Where:

Q_i^A 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:

$$Q_i^A = C_i^A F^A \tag{6.1.4}$$

Where:

C_i^A 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.

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

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

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

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

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

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, ($\left[\frac{\chi}{Q}\right](r,\theta) = 4.58\text{E-4 s/m}^3$).
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. Decay constant in Table 9.10, ($\lambda_{Co-60} = 1.32\text{E-1 yr}^{-1}$). (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, ($DFG_{Co\text{-}60,\ Total\ Body} = 1.7\text{E-8 mRem/hr per pCi/m}^2$). (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:

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

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/m^2; and
DFG_{ij}	is the open field ground plane dose conversion factor for organ j from radionuclide i, in mRem-m^2/pCi-hr.

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

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

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.

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

$$C_i^G(r,\theta) = \frac{\left(\frac{1E12pCi}{Ci}\right)\left(\frac{4.58E-6}{m^2}\right)\left(\frac{4.69E-6Ci}{yr}\right)}{1.32E-1yr^{-1}}\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]$$
$$= 1.46E2\ pCi/m^2$$

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

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, ($U_a^w = 730\ \ell/yr$). (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, ($C_{Co-60}^W = 6.01E\text{-}7\ \mu Ci/m\ell$). (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:

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

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:

$$Q_i^W = C_i^W F^W \tag{6.3.2}$$

Where:

C_i^W	is the concentration of radionuclide i in water from INS plant, 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:

$$M_p = \frac{1}{D_p} \tag{6.3.3}$$

Where:

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

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

$$D_p = \frac{F^R}{F^W} \tag{6.3.4}$$

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.

$$D_p = \frac{\left(\frac{1899\,ft^3}{s}\right)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{3.15E7s}{yr}\right)\left(\frac{7.48gal}{ft^3}\right)$$
$= 8.76E4$

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

$$Q_i^W = \left(\frac{6.01E-7\mu Ci}{m\ell}\right)\left(\frac{5.11E6gal}{yr}\right)\left(\frac{3785m\ell}{gal}\right)\left(\frac{Ci}{1E6\mu Ci}\right)$$
$= 1.07E\text{-}2$ Ci/yr

$$R_{aj} = \frac{\left(\frac{730\ell}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{1.07E-2Ci}{yr}\right)\left(\frac{4.72E-6mRem}{pCi}\right)e^{-(1.50E-5hr^{-1})(12\,hr)}\left(\frac{1E12pCi}{Ci}\right)\left(\frac{gal}{3.785\ell}\right)$$
$= 2.17E\text{-}5$ mRem/yr

$$H_{50,T} = \left(\frac{2.17E-5mRem}{yr}\right)\left(\frac{pCi}{4.72E-6mRem}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$
$= 1.24E\text{-}4$ 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, ($B_{a\,Co\text{-}60}$ = 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:

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

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^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.

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

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

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

$= 1.78\text{E-}4$ 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 $\lambda_w = \frac{\ln 2}{(14\text{days})(24\text{hr/day})} = 2.06\text{E-3 hr}^{-1}$. (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, ($B_{Co\text{-}60\,v} = 9.4\text{E-3}$ 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:

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

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:

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

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:

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

Where:

Q_i^A 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:

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

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.

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

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

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

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

$= 1.77E\text{-}3$ 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, ($F_{f\,Co\text{-}60}$ = 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, ($C_{Co\text{-}60}^V(r,\theta)$ = 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:

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

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.

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

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

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

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_I = 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, ($P = 240\ kg/m^2$).
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_{Co-60}^W = 1.07E-2 Ci/yr).
4. Same λ_{Ei} for each nuclide i as used in Case 6.5, ($\lambda_{E\,Co\text{-}60}$ = 2.08E-3 hr^{-1}).
5. The stable element transfer coefficient of green leafy vegetables B_{iv} in Table 9.7, ($B_{Co\text{-}60\,v}$ = 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:

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

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:

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

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:

$$d_i^W = C_{iw} I \tag{6.7.3}$$

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:

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

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.

$$C_{iw} = \frac{(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{1.07E-2Ci}{yr}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{gal}{3785m\ell}\right)\left(\frac{1E12pCi}{Ci}\right)$$
$$= 6.29E\text{-}6 \text{ pCi/m}\ell$$

$$d_i^W = \left(\frac{6.29E-6pCi}{m\ell}\right)\left(\frac{1in}{wk}\right)\left(\frac{wk}{6.048E5s}\right)\left(\frac{m}{39.37in}\right)\left(\frac{1E6m\ell}{m^3}\right)$$
$$= 2.64E\text{-}7 \text{ pCi/m}^2\text{-s}$$

$$C_{iv} = \left(\frac{2.64E-7pCi}{m^2s}\right)\left\{\frac{(1.0)\left[1-e^{-(2.08E-3hr^{-1})(3360hr)}\right]}{\left(\frac{2.0kg}{m^2}\right)(2.08E-3hr^{-1})} + \frac{(1.0)(9.4E-3)\left[1-e^{-(1.32E-1yr^{-1})(17yr)}\right]}{\left(\frac{240kg}{m^2}\right)(1.50E-5hr^{-1})}\right\}e^{-(1.50E-5hr^{-1})(24hr)}\left(\frac{3600s}{hr}\right)$$
$$= 2.31E\text{-}1 \text{ pCi/kg}$$

$$R_{aj} = \left(\frac{4.72E-6mRem}{pCi}\right)\left(\frac{630kg}{yr}\right)\left(\frac{2.31E-1pCi}{kg}\right)$$
$$= 6.86E\text{-}4 \text{ mRem/yr}$$

$$H_{50,T} = \left(\frac{2.31E-1pCi}{kg}\right)\left(\frac{630kg}{yr}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$
$$= 3.92E\text{-}3 \text{ mRem}$$

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, ($Q_{Aw} = 50\ \ell$/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:

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

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_{iv} 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.

$$C_{iA} = \left(\frac{1.3E-2\,day}{kg}\right)\left[\left(\frac{2.31E-1\,pCi}{kg}\right)\left(\frac{50\,kg}{day}\right)+\left(\frac{6.29E-6\,pCi}{m\ell}\right)\left(\frac{50\,\ell}{day}\right)\left(\frac{1000\,m\ell}{\ell}\right)\right]$$
$$= 1.54E\text{-}1\ pCi/kg$$

$$R_{aj} = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{1.54E-1\,pCi}{kg}\right)$$
$$= 8.00E\text{-}5\ mRem/yr$$

$$H_{50,T} = \left(\frac{1.54E-1\,pCi}{kg}\right)\left(\frac{110\,kg}{yr}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Bq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$
$$= 4.56E\text{-}4\ mRem$$

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, ($t_p = 12$ 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/m^2).
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/m^2).
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, ($U_a^m = 400\ \ell$/yr). (6.9.b)

Data:

1. Same d_i^W for each nuclide i as used for Case 6.7, ($d_{Co-60}^W = 2.64E\text{-}7$ pCi/m^{2}s).
2. Same $d_i^A(r,\theta)$ for each nuclide i as used in Case 6.5, ($d_{Co\text{-}60}^A(r,\theta) = 6.82E\text{-}7$ pCi/m^{2}s).
3. Same λ_{Ei} for each nuclide i as used in Case 6.5, ($\lambda_{E\,Co\text{-}60} = 2.08E\text{-}3$ 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, ($F_{m\,Co\text{-}60} = 1.0E\text{-}3$ day/ℓ). (6.9.c)

Calculational model:

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

$$D^D_{ja}(r,\theta) = \sum_i DFI_{ija}\, U^m_a\, C^m_i(r,\theta) \qquad (6.9.1)$$

Where:

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

U^m_a is the usage factor of milk, in ℓ/yr; and

$C^m_i(r,\theta)$ 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:

$$C^m_i(r,\theta) = F_m\, C^v_i(r,\theta) Q_F\, e^{-(\lambda_i t_f)} \qquad (6.9.2)$$

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;

$C^v_i(r,\theta)$ 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:

$$C^v_i(r,\theta) = f_p f_s\, C^P_i(r,\theta) + (1-f_p)\, C^s_i(r,\theta) + f_p(1-f_s)\, C^s_i(r,\theta) \qquad (6.9.3)$$

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;

$C^P_i(r,\theta)$ is the concentration of radionuclide i on pasture grass (calculated using Equation (6.5.2) with t_h = 0 day), in pCi/kg; and

$C^s_i(r,\theta)$ 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:

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

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:

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

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

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.

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

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

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

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

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

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

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

$= 4.06E\text{-}2$ pCi/ℓ

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

$= 7.67E\text{-}5$ 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, ($\dot{X}_r$ = 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:

$$X_r = \dot{X}_r t_a \tag{6.10.1}$$

Where:

$\dot{X}_r$ 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.

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

$$X_r = 1.57\ \text{mRem/yr}$$

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^{Slm} 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 ($M_l = 500\,\mu g/m^3$). (6.11.b)
8. Employees at RWTF remove sludge from the reed beds t_r 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}^{Slm} is in Table 9.8, ($C_o^{Slm}{}_{Co\text{-}60}$ = 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, (Γ_{Co-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:

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

Where:

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

X_{is} 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:

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

Where:

$\dot{X}_{is}$ 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:

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

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 $\mu g/m^3$;

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:

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

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

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.

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

= 4.76E1 pCi/g

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

= 6.44E-7 mRem/yr

$$H_{50,T} = \left(\frac{4.76\text{E1pCi}}{\text{g}}\right)\left(\frac{500\mu\text{g}}{\text{m}^3}\right)\left(\frac{8000\text{m}^3}{\text{yr}}\right)\left(\frac{5.91\text{E}-8\text{Sv}}{\text{Bq}}\right)\left(\frac{\text{g}}{1\text{E}6\mu\text{g}}\right)\left(\frac{8\text{hr}}{\text{day}}\right)\left(\frac{5\text{day}}{\text{wk}}\right)\left(\frac{2\text{wk}}{5\text{yr}}\right)\left(\frac{\text{yr}}{8760\text{hr}}\right)\left(\frac{\text{Bq}}{27.027\text{pCi}}\right)\left(\frac{1\text{E5mRem}}{\text{Sv}}\right)$$

= 7.61E-5 mRem

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

= 1.29E-10 Ci/cm³

$$\dot{X}_{is} = \frac{\left(\frac{13.2\text{R-cm}^2}{\text{hr-mCi}}\right)(3.25)\left(\frac{1.29\text{E}-10\text{Ci}}{\text{cm}^3}\right)}{2\left(1.62\text{E}-1\text{cm}^{-1}\right)}\left(\frac{1\text{E3mCi}}{\text{Ci}}\right)$$

= 1.70E-5 R/hr

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

= 2.73E-1 mRem/yr

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

= 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:

$\dot{X}_m$	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.

$$\dot{X}_m t_m = \left(\frac{1.14E-2\,\mathrm{mRem}}{\mathrm{hr}}\right)\left(\frac{4\,\mathrm{hr}}{\mathrm{wk}}\right)\left(\frac{48\,\mathrm{wk}}{\mathrm{yr}}\right)$$
$$= 2.18\ \mathrm{mRem/yr}$$

$$\dot{X}_g t_g = \left(\frac{8.65E-3\,\mathrm{mRem}}{\mathrm{hr}}\right)\left(\frac{35\,\mathrm{hr}}{\mathrm{wk}}\right)\left(\frac{48\,\mathrm{wk}}{\mathrm{yr}}\right)$$
$$= 14.54\ \mathrm{mRem/yr}$$

$$X_m = \left(\frac{2.18\,\mathrm{mRem}}{\mathrm{yr}}\right) + \left(\frac{14.54\,\mathrm{mRem}}{\mathrm{yr}}\right)$$
$$= 16.72\ \mathrm{mRem/yr}$$

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 ($M_l = 500\,\mu g/m^3$).
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:

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

Where:

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

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

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

$$H_{50,T} = \left(\frac{4.76E1pCi}{g}\right)\left(\frac{500\mu g}{m^3}\right)\left(\frac{8000m^3}{yr}\right)\left(\frac{5.91E-8Sv}{Bq}\right)\left(\frac{g}{1E6\mu g}\right)\left(\frac{8hr}{day}\right)\left(\frac{1day}{wk}\right)\left(\frac{1wk}{5yr}\right)\left(\frac{yr}{8760hr}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

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

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 empircally.

8.0 SUMMARY AND CONCLUSIONS

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,[8.0] 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.[8.1] The committee has also pointed out that "...there may be no risk from exposures comparable to natural background."[8.2]

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 Ray 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
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
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	6.89E-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
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
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 Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
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 Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
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 Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
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

	Annual Dose to each target organ (mRem/year)							50 year
Nuclide	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cs-134								
Cs-137	3.26E-06	4.23E-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	2.69E-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-08	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 Effective
	Bone	Liver	T.Body	Thyroid	Kidney	Lung	GI-LLI	
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.

6.1.1 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.

6.9.3 Regulatory Guide 1.109, p. 1.109-27.

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.

6.12.b Written correspondence from RWTF.

6.12.c Written correspondence from RWTF.

6.12.1 Standard conversion.

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.

8.2 Robert E. Alexander. "Radiation Limits in Perspective" in *The Health Physics Society's Newsletter* Volume XIX, Number 2, February 1991, p. 3.

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 DQT 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, ($U_a^w = 730\ \ell$/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, ($C^W_{Co-60} = 3E\text{-}5\ \mu Ci/m\ell$). (A.1.e)
4. Decay constant in Table A.5, ($\lambda_{Co-60} = 1.32E\text{-}1\ yr^{-1}$). (A.1.f)
5. Ingestion dose factor for radionuclide i, organ j, and age group adult DFI_{ija} in Table A.2, ($DFI_{Co\text{-}60,\ Total\ Body,\ adult} = 4.72E\text{-}6$ mRem/pCi). (A.1.g)
6. Fifty year ingestion committed dose effective for total body $DCF_{50,T}$ in Table A.3, ($DCF_{50,T\ Co\text{-}60} = 7.28E\text{-}9$ 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.

$$D_p = \frac{\left(\frac{1899\,ft^3}{s}\right)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{3.15E7s}{yr}\right)\left(\frac{7.48gal}{ft^3}\right)$$
$$= 8.76E4$$

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

$$Q_i^W = \left(\frac{3E-5\mu Ci}{m\ell}\right)\left(\frac{5.11E6gal}{yr}\right)\left(\frac{3785m\ell}{gal}\right)\left(\frac{Ci}{1E6\mu Ci}\right)$$
$$= 5.80E\text{-}1\ Ci/yr$$

$$R_{aj} = \frac{\left(\frac{730\ell}{yr}\right)(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{5.80E-1Ci}{yr}\right)\left(\frac{4.72E-6mRem}{pCi}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{1E12pCi}{Ci}\right)\left(\frac{gal}{3.785\ell}\right)$$
$$= 1.18E\text{-}3\ mRem/yr$$

$$H_{50,T} = \left(\frac{1.18E-3mRem}{yr}\right)\left(\frac{pCi}{4.72E-6mRem}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$
$$= 6.73E\text{-}3\ mRem$$

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, ($B_{a\,Co\text{-}60}$ = 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:

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

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.

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

= 1.70E-3 mRem/yr

$$H_{50,T} = \left(\frac{1.70E-3mRem}{yr}\right)\left(\frac{pCi}{4.72E-6mRem}\right)\left(\frac{7.28E-9Sv}{Bq}\right)\left(\frac{Bq}{27.027pCi}\right)\left(\frac{1E5mRem}{Sv}\right)$$

= 9.68E-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_I = 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 $\lambda_w = \frac{\ln 2}{(14\text{days})(24\text{hr/day})} = 2.06\text{E-3 hr}^{-1}$. (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_{Co-60}^W = 5.80E-1 Ci/yr).
4. The stable element transfer coefficient of green leafy vegetables B_{iv} in Table A.4, ($B_{Co\text{-}60\,v}$ = 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:

$$R_{aj} = \sum_i DFI_{ija}\, U_a^V\, C_{iv} \qquad (A.3.1)$$

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:

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

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_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:

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

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:

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

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:

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

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.

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

$$C_{iw} = \frac{(1.14E-5)}{\left(\frac{5.11E6gal}{yr}\right)}\left(\frac{5.80E-1Ci}{yr}\right)e^{-(1.50E-5hr^{-1})(12hr)}\left(\frac{gal}{3785m\ell}\right)\left(\frac{1E12pCi}{Ci}\right)$$
$$= 3.42E\text{-}4\ pCi/m\ell$$

$$d_i^W = \left(\frac{3.42E-4pCi}{m\ell}\right)\left(\frac{1in}{wk}\right)\left(\frac{wk}{6.048E5s}\right)\left(\frac{m}{39.37in}\right)\left(\frac{1E6m\ell}{m^3}\right)$$
$$= 1.44E\text{-}5\ pCi/m^2\text{-}s$$

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

$$R_{aj} = \left(\frac{4.72E-6\,mRem}{pCi}\right)\left(\frac{630\,kg}{yr}\right)\left(\frac{12.6\,pCi}{kg}\right)$$
$$= 3.73E\text{-}2\ mRem/yr$$

$$H_{50,T} = \left(\frac{12.6\,pCi}{kg}\right)\left(\frac{630\,kg}{yr}\right)\left(\frac{7.28E-9\,Sv}{Bq}\right)\left(\frac{Bq}{27.027\,pCi}\right)\left(\frac{1E5\,mRem}{Sv}\right)$$
$$= 2.13E\text{-}1\ mRem$$

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:

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

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:

$$C_{iA} = F_f \, [C_{iF} \, Q_F + C_{iAw} \, Q_{Aw}] \tag{A.4.2}$$

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.

$$C_{iA} = \left(\frac{1.3E-2\text{day}}{\text{kg}}\right)\left[\left(\frac{12.6\text{pCi}}{\text{kg}}\right)\left(\frac{50\text{kg}}{\text{day}}\right) + \left(\frac{3.42E-4\text{pCi}}{\text{m}\ell}\right)\left(\frac{50\ell}{\text{day}}\right)\left(\frac{1000\text{m}\ell}{\ell}\right)\right]$$
$$= 8.38 \text{ pCi/kg}$$

$$R_{aj} = \left(\frac{4.72E-6\text{mRem}}{\text{pCi}}\right)\left(\frac{110\text{kg}}{\text{yr}}\right)\left(\frac{8.38\text{pCi}}{\text{kg}}\right)$$
$$= 4.35E\text{-}3 \text{ mRem/yr}$$

$$H_{50,T} = \left(\frac{8.38\text{pCi}}{\text{kg}}\right)\left(\frac{110\text{kg}}{\text{yr}}\right)\left(\frac{7.28E-9\text{Sv}}{\text{Bq}}\right)\left(\frac{\text{Bq}}{27.027\text{pCi}}\right)\left(\frac{1E5\text{mRem}}{\text{Sv}}\right)$$
$$= 2.48E\text{-}2 \text{ mRem}$$

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-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
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	6.60E-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	5.95E-06	3.41E-06	1.95E-03	1.02E-05		1.57E-06
U-235	8.01E-04		4.86E-05		1.87E-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

	Annual Dose to each target organ (mRem/year)							50 year
Nuclide	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-04	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		7.69E-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.1.1 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.

RECEIVED-REGION I

'94 JUN 13 A9:38

INTERSTATE NUCLEAR SERVICES
A DIVISION OF UNIFIRST CORPORATION

INS Corporate Headquarters
295 Parker Street
P.O. Box 51957
Springfield, Massachusetts 01151
(413)543-6911
FAX: (413)543-6989

Other Plant Locations:

Royersford, Pennsylvania
Portsmouth, Virginia
Charleston, South Carolina
Columbia, South Carolina
Macon, Georgia
Vicksburg, Mississippi
Morris, Illinois
Osceola, Iowa
Santa Fe, New Mexico
Pleasanton, California
Honolulu, Hawaii
Bremerton, Washington