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Docket No. 030-20934

License No. 37-23341-01

Interstate Nuclear Services
ATTN: Michael J. Bovino, CHP
Manager, Health Physics and Engineering
295 Parker Street
P.O. Box 51957
Springfield, Massachusetts 01151

Dear Mr. Bovino:

Subject: "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services, Morris, Illinois"

This refers to your letter dated May 29, 1992, in response to our letter dated May 13, 1992.

Thank you for submitting a copy of your document "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services, Morris, Illinois" for our review. As agreed during our February 25, 1992 meeting, we will review the document and provide comments for your preparation of a similar pathway analysis for releases from the Interstate Nuclear Services facility in Royersford, Pennsylvania to the Royersford Wastewater Treatment Facility.

Your cooperation with us is appreciated.

Sincerely,

Original Signed By:
Francis M. Costello

Francis M. Costello, Chief
Research, Development &
Decommissioning Section
Division of Radiation Safety
and Safeguards

cc:
Public Document Room (PDR)
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Region I Docket Room (w/concurrences)

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07/10/92	07/8/92

INTERSTATE NUCLEAR SERVICES
A DIVISION OF UNIFIRST CORPORATION

May 29, 1992

Mr. Ronald R. Bellamy, Chief
Nuclear Materials Safety Branch
Division of Radiation Safety and Safeguards
US NRC Region I
475 Allendale Road
King of Prussia, Pennsylvania 19406-1415

Docket No. 030-20934   License No. 37-23341-01

Dear Mr. Bellamy,

As requested in your May 13, 1992 letter, enclosed is a copy of a pathway analysis performed for our facility in Morris, Illinois. The document, "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services", was prepared in May, 1991 using generally accepted models. We do not require the document be withheld from public disclosure. The analysis examined twelve possible pathways to the maximally exposed human receptor and incorporated site-specific data wherever possible. For conservatism, all doses were calculated using the most limiting dose conversion factor for each nuclide studied.

As agreed at the meeting held on February 25, 1992, your staff will review the analysis and provide comments to us so that we may apply the model to future pathway analyses. We are especially anxious to receive those comments as we will likely perform a pathway analysis in conjunction with a direct discharge NPDES permit that we are currently seeking for the Royersford location.

We appreciate you cooperation in this matter. If there are any questions concerning the pathway analysis, please contact either Ira Turner of my staff or myself at the number below.

Sincerely,

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

cc: G. Bakevich
file

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

MORRIS, ILLINOIS

Ira M. Turner
May 21, 1991

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

MORRIS, ILLINOIS

PREPARED FOR:

AMERICAN NUCLEAR INSURERS

MAY, 1991

ORIGINATOR: 5/21/91
Health Physicist

TECHNICAL REVIEW: CHP 5/22/91
Manager, Health Physics and Engineering

APPROVED BY: George J Balcewicz 5/22/91
General Manager

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

1.0 EXECUTIVE SUMMARY

A study was conducted for the American Nuclear Insurers on air and water effluent pathways of the Interstate Nuclear Services Corporation Morris, Illinois facility. Twelve possible pathways were examined using established regulatory guidance and actual data. Results indicate the dose to the maximally exposed individual, with ranges from one-hundred to one-hundred thousand times below the federally imposed limits. Based on these results, impact on the environment and human receptor from operation at the Morris site has been determined to be minimal.

2.0 INTRODUCTION AND SITE HISTORY

Interstate Nuclear Service Corporation (INS) of Morris, Illinois operates a laundry facility under Illinois Department of Nuclear Safety (IDNS) licence Number IL-01008-01, 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 released from the plant is filtered, monitored and released on a continuous basis. Liquid wastes from laundering operations are accumulated in a large liquid waste primary equalization pit. This wastewater is gravitationally drained to the pit via a drain trough. Overflow from the washers is drained by the same route to this pit.

filtered to remove suspended solids and held in tanks prior to release. The liquid in the pits is sampled, and once concentrations are determined to be within regulatory limits, is discharged to the sanitary sewer. INS's Morris operations typically release 10,000 gallons of wastewater each day, five days per week to the sewer. Water is 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.

The Morris Sewage Treatment Plant (STP), handles approximately 1.5 million gallons of wastewater per day including the discharge from INS. Wastewater received at the STP enters in parallel into two primary tanks with combined volume of 370,000 gallons. Wastewater of two (2) to two and a quarter (2.25) percent sludge solids flows from the two primary (aerobic digesting) tanks into a thickener tank. The thickener tank (capacity 193,000 gallons) is stirred up and allowed to settle. Water is pumped off the top and recycled back to the two primary tanks for reprocessing. Clarified water from the two primary tanks is released into the Illinois river. Settled sludge from the thickening tank is periodically drained. The frequency of this operation is dependant upon STP operations. Drainage of the tank can be delayed up to three months during the winter months to accommodate for freezing. Sludge removed from the thickener is primarily disposed of via landfilling, but a small portion is used for land farming (for crops to be consumed by farm animals). INS samples sludge activity concentrations from the thickener tank monthly as part of its environmental sampling program.

This pathway analysis provides a reasonable dosimetric model of Interstate Nuclear Services' operational effects upon the offsite 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 and actual data was incorporated where possible. All doses were calculated to the maximally exposed individual using the most limiting dose conversion factor.

3.0 SITE DESCRIPTION

The Interstate Nuclear Services Corporation of Springfield Massachusetts operates its Morris laundry services at 1006 Third Avenue, Morris, Illinois. At the INS site, potentially contaminated laundry items are water-washed in commercial laundry units, dried, surveyed for residual radioactivity then folded.

4.0 DATA COLLECTION

For this study, calculations and models were based on actual INS effluent records for 1990, INS facility design data, site visits and 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 11.0. The data assembled is 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, 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 the most limiting dose conversion factors were selected from the tables within Regulatory Guide 1.109 (the most limiting dose correction factor is based upon nuclide, and age group for each target organ, refer to Section 9.0). Due to this approach, one set of calculations has been iterated for each pathway. The dose commitment estimated for each pathway is thus conservatively higher than any individual receptor would realize. Sources for other dose conversion factors are listed in Section 11.0.

The fifty year dose commitments were calculated by use of conversion factors based on ICRP 30 models, which are found in NUREG/CR- 3332, entitled "Radiological Assessment - A Textbook on Environmental Dose Analysis".

6.0 SELECTED PATHWAY ANALYSES

Several exposure pathways were identified for this study. Other pathways outlined by Regulatory Guide 1.109 were not examined due to their minimal relative contribution and/or the absence of a credible pathway. In accordance with Regulatory Guide 1.109, "A pathway is considered significant if a conservative evaluation yields an additional dose increment equal to or more than ten percent of the total from all pathways considered." For the purposes of this study, twelve 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 exposure to ground deposition of airborne contaminants,
- Case 6.3 — Dose from ingestion of airborne contaminated green leafy vegetables,
- Case 6.4 — Dose from ingestion of beef fed upon airborne contaminated green leafy vegetables,
- Case 6.5 — Dose from ingestion of green leafy vegetables irrigated with contaminated water,
- Case 6.6 — Dose from ingestion of beef fed upon green leafy vegetables irrigated with contaminated water,
- Case 6.7 — Dose from ingestion of contaminated milk,
- Case 6.8 — Dose from inhalation of contaminated sludge-borne dust,
- Case 6.9 — Dose to the Sewage Treatment Plant worker from direct exposure to contaminated sludge,
- Case 6.10 — Dose from ingestion of water downstream from the sewage treatment plant,
- Case 6.11 — Dose from ingestion of aquatic foods taken from contaminated water supplies,
- Case 6.12 — Dose to Sewage Treatment Plant personnel from exposure to the sludge thickening tank,

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: 500 meters.
2. All releases considered ground level.
3. E stability class (moderately stable) all year.
4. Average wind speed: 2 meters/second.
5. Chronic intakes (extended over a single year) may be treated as acute for fifty year committed dose calculations (1 year intake = 1 acute intake) (6.1.a)

Data:

1. Plant stack flow rate: 1450 cubic feet per minute.
2. Airborne activity concentrations in Table 1.
3. Sigma y(σy) = 26.3 meters, Sigma z(σ_z) = 13.2 meters.
4. Plant stack operation estimated at 17 hours/day, 5 days/week, 52 weeks/year (1.59E7 seconds/year), (6.1.b)
5. Adult breathing rate = 8000 meters^3 / year. (6.1.c)

Calculational model:

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

$$\chi_i(r,\theta) = Q_i^A[\frac{\chi}{Q}](r,\theta) \quad (6.1.1)$$

Where:

Q_i^A is the release rate of nuclide i in air, in Ci/yr.

$[\frac{\chi}{Q}](r,\theta)$ is the average annual gaseous dispersion factor at distance r (500 meters) and sector θ, in seconds/m^3. It is further defined as:

$$\frac{1}{\pi \ \sigma_y \ \sigma_z \ \overline{\mu}} \quad (6.1.2)$$

Where:

π is the constant pi (3.14159),
σ_y is the lateral plume spread in meters,
σ_z is the vertical plume spread in meters,
$\overline{\mu}$ is the average wind speed in meters/second.

The annual dose associated with the inhalation of all radionuclides to organ j of the receptor, is given as:

$$D_j^A(r,\theta) = R_a \sum_i \chi_i(r,\theta) \; DFA_j \qquad (6.1.3)$$

Where:

R_a is the adult breathing rate, in m^3/year,

DFA_j is the inhalation dose factor for radionuclide i and organ j in mRem/pCi (based on most limiting inhalation dose factors, Section 9.0).

The fifty year committed dose was calculated using:

$$H_{50,T} = (Q_i)(DCF_{50,T})\,k \qquad (6.1.4)$$

Where:

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

k is a conversion that assumes one year of steady intake can be equated to a single acute intake.

All further calculations of fifty year committed dose follow this model.

Sample Calculation:

The sample calculation has been performed for Co-60.

$$[\frac{\chi}{Q}](r,\theta) = \frac{1}{\pi\ (26.3 \text{ meters})\ (13.2 \text{ meters})\ (2 \text{ meters / second})}$$

$$= 4.6E\text{-}4 \text{ seconds / meter}^3$$

$$Q_i^A = \left(\frac{7.65E\text{-}13\ \mu Ci}{cm^3}\right)\left(\frac{1450\ ft^3}{min}\right)\left(\frac{28317\ cm^3}{ft^3}\right)\left(\frac{2.65E5\ min}{\text{operation year}}\right)\left(\frac{Ci}{1E6\ \mu Ci}\right)$$

$$Q_i^A = \frac{8.32E\text{-}6\ Ci}{year}$$

$$\chi_i(r,\theta) = \left(\frac{8.32E\text{-}6\ Ci}{year}\right)\left(\frac{4.6E\text{-}4\ sec}{m^3}\right)\left(\frac{year}{1.59E7\ sec}\right)\left(\frac{1E12\ pCi}{Ci}\right)$$

$$\chi_i(r,\theta) = \left(\frac{2.41E\text{-}4\ pCi}{m^3}\right)$$

For this calculation, the most limiting dose conversion factor for the Total Body Committed Dose Equivalent was used.

$$D_j^A(r, \theta) = \left(\frac{8000\ m^3}{year}\right)\left(\frac{2.38E\text{-}4\ pCi}{m^3}\right)\left(\frac{9.10E\text{-}5\ mRem}{pCi\ inhaled}\right)$$

$$= \quad 1.75E\text{-}4\ mRem\ /\ year.$$

$$H_{50,T} = \left(\frac{2.41E\text{-}4\ pCi}{m^3}\right)\left(\frac{8000\ m^3}{year}\right)\left(\frac{1\ year}{1\ acute\ intake}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{7.28E\text{-}9\ Sv}{Bq}\right)\left(\frac{100\ Rem}{Sv}\right)\left(\frac{1000\ mRem}{Rem}\right)$$

$H_{50,T}$ = 3.79E-2 mRem.

Case 6.2
Dose from 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. No cross wind component, Case I meteorological conditions apply,
2. Duration of accumulation of deposited nuclides approximate plant operational life (t_b = 3 years) at 1990 concentrations,
3. The maximally exposed individual is constantly exposed (never leaves home),
4. 1 Rem is equal to 1 R for gamma exposure.

Data:

1. Same Q and χ/Q for each nuclide i as used for Case 6.1.
2. Shielding factor, $S_f = 0.7$ (6.2.a)

Calculational model:

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

$$C_i^G(r,\theta) = \left[\frac{\left[\frac{1E12\ pCi}{Ci}\right]\gamma(r,\theta)\,Q_i}{\lambda_i}\right]\left(1 - e^{-(\lambda_i t_b)}\right) \quad (6.2.1)$$

Where:

$\gamma(r,\theta)$ is the annual average relative deposition of effluent species at location (r,θ), considering plume depletion during transport, in m^{-2}. From Regulatory Guide 1.111, the relative deposition is 4E-5 m^{-1}. For a 22.5° sector (1/16 of 360°), assume a maximum deposition (no cross wind), over an arc one meter wide:

$$\gamma(r,\theta) = \left(\frac{4E\text{-}5}{meter}\right)\left(\frac{1}{16}\right)\left(\frac{1}{1\ meter}\right) = \frac{2.5E\text{-}6}{meter^2} \quad (6.2.2)$$

Q_i = Annual release, in Ci/year.
λ_i = Decay constant of nuclide i, in years^{-1}.
t_b = Time of accumulation, in years.

$$D_i = S_f \sum_i C_i^G\, DFG_i \quad (6.2.3)$$

S_f Shielding factor, 0.7,
DFG_i Dose conversion factor, in mR • m^2/hr • pCi.

Sample Calculation:

The sample calculation has been performed for Co-60.

$$Q_i = \left(\frac{7.65E\text{-}13\ \mu Ci}{cc}\right)\left(\frac{28316.8\ cc}{ft^3}\right)\left(\frac{1450\ ft^3}{min}\right)\left(\frac{60\ min}{hr}\right)\left(\frac{17\ hr}{day}\right)\left(\frac{260\ day}{work\ year}\right)\left(\frac{Ci}{1E6\ \mu Ci}\right)$$

$$Q_i = 8.33E\text{-}6\ Ci\ /\ year.$$

$$C_i^G = \frac{\left[\left(\frac{2.5E\text{-}6}{m^2}\right)\left(\frac{8.33E\text{-}6\ Ci}{yr}\right)\left(\frac{1E12\ pCi}{Ci}\right)\right]}{\left(\frac{1.32E\text{-}1}{yr}\right)}\left(1 - e^{-\left(\frac{1.32E\text{-}1}{yr}\right)(3\ yr)}\right)$$

$$C_i^G = \left(\frac{51.61\ pCi}{m^2}\right)$$

$$D_i = \left(\frac{51.61\ pCi}{m^2}\right)\left(\frac{2000\ hr}{yr}\right)\left(\frac{1.7E\text{-}8\ mR\ m^2}{hr\ pCi}\right)\left(\frac{mRem}{mR}\right)(0.7)$$

$$D_i = \left(\frac{1.2E\text{-}3\ mRem}{year}\right)$$

Case 6.3
Dose from ingestion of airborne contaminated green leafy vegetables (consumed directly by humans)

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

Assumptions:

1. A plant neighbor grows and eats his own GLVs.
2. 100 % of deposited material is retained on the crops, (r=1).
3. Crops are exposed for 5 month growing season,(te = 3360 hrs).
4. Productivity yield,(Yv) = 2 Kg/m^2.
5. Time deposits remain on GLVs = 14 days, (l_w) = (0.0021/hr).
6. Hold up time between harvest and consumption, (t_h = 24 hrs or 1 day). (6.3.a)

Data:

1. Same Q and χ/Q for each nuclide i as used for Case 6.1.

Calculational model:

The dose received from ingestion of green leafy vegetables contaminated by airborne deposition is calculated by:

$$D_j^D(r,\theta) = U^{veg} \sum_i DFI_j \; C_i^v \qquad (6.3.1)$$

Where:

U^{veg}	is the Usage Factor, (190 kg/yr),
DFA_j	is the dose conversion factor specific to organ j,
C_i^v	is the concentration of nuclide i in the green leafy vegetable,

The concentration of radionuclide i deposited on green leafy vegetables and the surrounding soil with corresponding uptake, at the location (r,θ), with respect to the release point may be determined as:

$$C_i^v = d_i(r,\theta)\left[\frac{r\left[1-e^{-(\lambda_{Ei} t_e)}\right]}{Y_v \lambda_{Ei}} + \frac{B_{iv}\left[1-e^{-(\lambda_i t_b)}\right]}{P \; \lambda_i}\right] e^{-(\lambda_i t_h)} \qquad (6.3.2)$$

Where:

C_i^v	concentration of nuclide i in pCi/kg,
$d_i(r,\theta)$	is the annual average relative deposition rate of effluent species at location (r,θ), considering plume depletion during transport, in pCi / m^2 hr,
λ_{Ei}	Effective removal rate, in 1/days (Co^{60} = 4.99E-2),
λ_i	Radioactive decay constant, in 1/days (Co^{60} = 3.6E-4),

B_{iv}	Transfer rate, vegetation/soil, dimensionless (Co^{60} = 9.4E-3),
t_e	Growing season (120 days),
t_h	Holdup time between harvest and consumption, (1 day),
t_b	Time for buildup in soil (3 years = 1095 days),
Y_v	Crop productivity (kg/m^2)
P	Surface density of soil (240 kg/m^2) (6.3.b)
r	Fraction of deposited activity retained on crops, dimensionless,

Sample Calculation:

The sample calculation has been performed for Co-60.

Using previously calculated annual average relative deposition of 2.5E-6 / m^2:

$$d_{Co^{60}}(r,\theta) = \left(\frac{2.74E9\ pCi\ yr}{Ci\ day}\right)\left(\frac{8.33E\text{-}6\ Ci}{yr}\right)\left(\frac{2.5E\text{-}6}{m^2}\right)$$

$$d_{Co^{60}}(r,\theta) = \left(\frac{5.7E\text{-}2\ pCi}{m^2\ day}\right)$$

For concentrations of airborne ^{60}Co depositions in and on the green leafy vegetables:

$$C^{v}_{Co^{60}} = \left(\frac{5.7E\text{-}2\ pCi}{m^2\ day}\right)\left[\frac{1.0\left(1 - e^{-\left(\left(\frac{4.99E\text{-}2}{day}\right)(120\ day)\right)}\right)}{\left(\frac{2\ kg}{m^2}\right)\left(\frac{4.99E\text{-}2}{day}\right)} + \frac{(9.4E\text{-}3)\left(1 - e^{\left(\frac{3.6E\text{-}4}{day}\right)(1095\ day)}\right)}{\left(\frac{240\ kg}{m^2}\right)\left(\frac{3.6E\text{-}4}{day}\right)}\right]\left(e^{\left(\frac{3.6E\text{-}4}{day}\right)(1)}\right)$$

$$C^{v}_{Co^{60}} = \left(\frac{0.57\ pCi}{kg}\right)$$

$$D^{D}_{j}(r,\theta) = \left(\frac{1.21E\text{-}4\ mRem}{pCi}\right)\left(\frac{190\ kg}{year}\right)\left(\frac{0.57\ pCi}{kg}\right) = \left(\frac{1.3E\text{-}2\ mRem}{year}\right)$$

$$H_{50,T} = \left(\frac{0.57\ pCi}{kg}\right)\left(\frac{190\ kg}{year}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{7.28E\text{-}9\ Sv}{Bq}\right)\left(\frac{100\ Rem}{Sv}\right)\left(\frac{1000\ mRem}{Rem}\right)$$

$$H_{50,T} = (2.13\ mRem)$$

Case 6.4
Dose from ingestion of beef fed upon airborne contaminated green leafy vegetables (consumed by beef cattle, in turn consumed by humans)

This pathway was examined to investigate the effect of airborne plant effluent on doses received downwind. Specifically, from cattle ingesting green leafy vegetables (GLVs) subjected to deposition and uptake of airborne contaminants, and in turn the cattle are consumed by humans.

Assumptions:

1. Assumptions made in Case 6.3 apply,
2. All beef consumed is contaminated, and raised on 100 % contaminated green leafy vegetables,
3. Annual consumption of beef (U^l) is 95 kg/yr,
4. Time from slaughter to consumption (t_s) 1 day, (6.4.a)

Data:

1. Same Q and χ/Q for each nuclide i as used for Case 6.1.

Calculational model:

The annual dose to organ j of an individual is given by:

$$D_j^D(r, \theta) = \sum_i DFI_j \, U^l \, C_i^F(r, \theta) \qquad (6.4.1)$$

Where:

DFI_j is the dose conversion factor for organ j, in mRem/year,
U^l is the consumption rate of beef, in kg/year,

The concentration of contaminant by airborne deposition in the beef is calculated by:

$$C_i^F(r, \theta) = F_f \, C_i^V(r, \theta) \, Q_f \, e^{-(\lambda_i t_s)} \qquad (6.4.2)$$

Where:

F_f is the fraction of feed that is contaminated, (1, dimensionless),
Q_f is the amount of contaminated feed consumed by the animal, in kg/day,
t_s is the time from slaughter to consumption,
other terms previously defined.

Sample Calculation:

The sample calculation has been performed for Co-60.

C_i^v determined in Case 6.3 for ^{60}Co,

$$C_i^F(r,\theta) = \left(\frac{1.3E\text{-}2\ kg}{day}\right)\left(\frac{0.57\ pCi}{kg}\right)\left(\frac{50\ kg}{day}\right) e^{-\left(\left(\frac{3.6E\text{-}4}{day}\right)(1\ day)\right)}$$

$$C_i^F(r,\theta) = \left(\frac{3.70E\text{-}1\ pCi}{kg}\right)$$

$$D_i^F(r,\theta) = \left(\frac{95\ kg}{yr}\right)\left(\frac{0.37\ pCi}{kg}\right)\left(\frac{1.21E\text{-}4\ mRem}{pCi}\right)$$

$$D_i^F(r,\theta) = \left(\frac{4.3E\text{-}3\ mRem}{year}\right)$$

$$H_{50,T} = \left(\frac{0.37\ pCi}{kg}\right)\left(\frac{95\ kg}{year}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{7.28E\text{-}9\ Sv}{Bq}\right)\left(\frac{100\ Rem}{Sv}\right)\left(\frac{1000\ mRem}{Rem}\right)$$

$$H_{50,T} = (6.92E\text{-}1\ mRem)$$

Case 6.5
Dose from ingestion of green leafy vegetables irrigated with contaminated water (consumed directly by humans)

This pathway was examined to investigate the doses received from consumption of green leafy vegetables irrigated with contaminated water.

Assumptions:

1. A plant neighbor grows and eats his own GLVs.
2. Crops are exposed for 5 month growing season,(te) = 3360 hrs,
3. Productivity yield, (Yv) = 2 Kg/m^2.
4. Hold up time between harvest and consumption, (t_h) = 24 hrs or 1 day,
5. Annual consumption of GLVs, (Ua) = 190 kg/yr. (6.5.a)

Data:

1. Crops are irrigated with 1" of contaminated water per week, or 3.63 liters/m^2 day. (6.5.b)

Calculational model:

The annual dose to organ j of an individual is given by:

$$R_j = U^{veg} \sum_i d_i(r,\theta)\ DCF_j \left[\frac{r\left(1 - e^{-(\lambda_{Ei} t_e)}\right)}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}\left(1 - e^{-(\lambda_i t_b)}\right)}{P\ \lambda_i}\right] e^{-(\lambda_i t_h)} \quad (6.5.1)$$

Where:

U^{veg}	Usage factor, 190 kg/yr,
$d_i(r,\theta)$	deposition rate, in pCi/m^2 hr, based upon irrigation rate of 1 inch per week or 3.63 liters/m^2 day
DCF_j	is the dose conversion factor for organ j, in mRem/year,
r	fraction deposited that is retained on crops, dimensionless,
λ_{Ei}	is the effective removal rate constant for nuclide i, in 1/hours,
t_e	is the growing season, 120 days, (2880 hours),
Y_v	Vegetation yield (2 kg/m^2),
f_I	fraction of year crops are irrigated, (taken as 1.0 for 100 % use of contaminated water)
B_{iv}	transfer rate (plant concentration / soil concentration) for nuclide i,
λ_i	Decay constant, in 1/hours,
t_b	Period of time soil is exposed to contaminated water, based on plant operational life of 3 years, in hours, (26,280 hours, rounded to 3E4 hours),
P	Surface density of soil (240 kg/m^2)
t_h	Time of holdup between harvest and consumption (24 hours), (6.5.c)

Sample Calculation:

The sample calculation has been performed for Co-60.

$$d_i\ (r,\theta) = \left(\frac{3.63\ \text{liters}}{m^2\ \text{day}}\right)\left(\frac{4.39E\text{-}11\ \mu Ci}{cm^3}\right)\left(\frac{1E6\ pCi}{\mu Ci}\right)\left(\frac{1E6\ cm^3}{m^3}\right)\left(\frac{\text{day}}{24\ hr}\right)\left(\frac{m^3}{1E3\ \text{liter}}\right)$$

$$d_i\ (r,\theta) = 6.64E\text{-}3\ \frac{pCi}{m^2\ hr}$$

For clarity of fifty year dose commitment calculations, a portion of the calculation for R_j has been defined as 'x':

$$x = \left[\left(\frac{1\left(1 - e^{-\left(\frac{2.90E\text{-}3}{hr}\right)(2880\ hr)}\right)}{\left(\frac{2\ kg}{m^2}\right)\left(\frac{2.90E\text{-}3}{hr}\right)}\right) + \left(\frac{(1.0)(9.4E\text{-}3)\left(1 - e^{-\left(\frac{1.50E\text{-}5}{hr}\right)(3E4\ hr)}\right)}{\left(\frac{240\ kg}{m^2}\right)\left(\frac{1.5E\text{-}5}{hr}\right)}\right)\right]$$

$$x = 172.19\ \frac{m^2\ hr}{kg}$$

$$R_j = \left(\frac{190\ kg}{yr}\right)\left[\left(\frac{6.64E\text{-}3\ pCi}{m^2\ hr}\right)\left(\frac{1.21E\text{-}4\ mRem}{pCi}\right)\left[172.19\ \frac{m^2\ hr}{kg}\right]e^{\left(\frac{1.50E\text{-}5}{hr}\right)(24\ hr)}\right]$$

$$R_j = 2.63E\text{-}02\ mRem$$

$$H_{50,\ T} = \left(\frac{190\ kg}{yr}\right)\left(\frac{6.64E\text{-}3\ pCi}{m^2\ hr}\right)\left(\frac{172.19\ m^2\ hr}{kg}\right)\left(\frac{7.28E\text{-}9\ Sv}{Bq}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{100\ Rem}{Sv}\right)\left(\frac{1000\ mRem}{Rem}\right)$$

$$H_{50,\ T} = 4.28\ mRem$$

Case 6.6

Dose from ingestion of beef fed upon green leafy vegetables irrigated with contaminated water (consumed by cattle, in turn consumed by humans)

This pathway was examined to investigate the doses received from consumption of green leafy vegetables irrigated with contaminated water, which are consumed by humans.

Assumptions:

1. Assumptions in Case 6.5 apply.

Data:

1. Based on INS waterborne effluent data.

Calculational model:

The annual dose to organ j of an individual is given by:

$$R_j = U^{animal} \sum_i F_{iA}\, DCF_j \left[Q_F\, d_i\,(r,\theta) \left[\frac{r\left(1 - e^{-(\lambda_{Ei} t_e)}\right)}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}\left(1 - e^{-(\lambda_i t_b)}\right)}{P\, \lambda_i} \right] e^{-(\lambda_i t_h)} + C_{iw}\, Q_w \right] \quad (6.6.1)$$

Where:

U^{animal}	Usage factor, 110 kg/yr,
F_{iA}	Stable element transfer rate, in day/kg,
Q_F	Consumption rate of contaminated feed (beef cow is 50 kg/day),
C_{iw}	Concentration of nuclide i in water ingested (pCi/liter),
Q_{AW}	Consumption rate of contaminated water, (for beef cow 60 liters/day). (6.6.a)

Sample Calculation:

The sample calculation has been performed for Co-60.

For clarity of fifty year dose commitment calculations, a portion of the calculation for R_j has been defined as 'y':

$$y = \left[\left(\frac{50\ \text{kg}}{\text{day}}\right)\left(\frac{6.64\text{E-3 pCi}}{\text{m}^2\ \text{hr}}\right)\left(\frac{172.19\ \text{m}^2\ \text{hr}}{\text{kg}}\right) + \left(\frac{4.39\text{E-2 pCi}}{\text{liter}}\right)\left(\frac{60\ \text{liter}}{\text{day}}\right)\right]$$

$$y = \left(\frac{59.8\ \text{pCi}}{\text{day}}\right)$$

$$R_j = \left(\frac{110\ \text{kg}}{\text{yr}}\right)\left(\frac{1.3\text{E-2 day}}{\text{kg}}\right)\left(\frac{1.21\text{E-4 mRem}}{\text{pCi}}\right)\left(\frac{59.8\ \text{pCi}}{\text{day}}\right)$$

$$R_j = 1.04\text{E-02}\ \frac{\text{mRem}}{\text{year}}$$

$$H_{50,\,T} = \left(\frac{110\ \text{kg}}{\text{yr}}\right)\left(\frac{7.28\text{E-9 Sv}}{\text{Bq}}\right)\left(\frac{27.027\ \text{Bq}}{\text{pCi}}\right)\left(\frac{1.3\text{E-2 day}}{\text{kg}}\right)\left(\frac{59.8\ \text{pCi}}{\text{day}}\right)\left(\frac{100\ \text{Rem}}{\text{Sv}}\right)\left(\frac{1000\ \text{mRem}}{\text{Rem}}\right)$$

$$H_{50,\,T} = 1.68\ \text{mRem}$$

Case 6.7
Dose from ingestion of contaminated milk

This pathway examines the dose to an individual 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. All milk consumed is contaminated.
2. All contamination in the milk is derived from consumption of green leafy vegetables.

Data:

1. Concentrations of nuclides in respective media (air, water, green leafy vegetables) previously derived.

Calculational model:

$$D_{ij} = \sum_i DFI_j \, U_i^M \, C_i^M \qquad (6.7.1)$$

Where:

DFI_j	is the previously defined dose conversion factor, in mRem/pCi ingested,
U_i^M	is the usage factor for milk (teenager), 200 liter/year, (6.7.a)

The concentration of nuclide i in milk is determined by the relation:

$$C_i^M = F_i^M \, C_i^V(r,\theta) \, Q_f \, e^{-(\lambda_i t_f)} \qquad (6.7.2)$$

Where:

F_i^M	is the fraction of nuclide i appearing in milk, in day/liter,
$C_i^V(r,\theta)$	is the concentration within the food source, in pCi/kg,
Q_f	is the amount of feed consumed per day by the milk producer, in kg/day,
λ_i	is the decay constant of nuclide i, in 1/hours,
t_f	is the transport time, (48 hours) (6.7.b)

Sample Calculation:

$$C_i^V = \left(\frac{0.57\ \text{pCi}}{\text{kg}}\right) + \left(\frac{59.8\ \text{pCi}}{\text{day}}\right)\left(\frac{1.3\text{E-2 day}}{\text{kg}}\right) = 86.1\ \frac{\text{pCi}}{\text{kg}}$$

$$C_i^M = \left(\frac{1.0\text{E-3 day}}{\text{liter}}\right)\left(\frac{86.1\ \text{pCi}}{\text{kg}}\right)\left(\frac{50\ \text{kg}}{\text{day}}\right) e^{-\left(\frac{1.5\text{E-5}}{\text{hr}}\ (48\ \text{hr})\right)}$$

$$C_i^M = \frac{4.3\ \text{pCi}}{\text{liter}}$$

$$D_{ij} = \left(\frac{4.3\ \text{pCi}}{\text{liter}}\right)\left(\frac{200\ \text{liter}}{\text{year}}\right)\left(\frac{1.21\text{E-4 mRem}}{\text{pCi ingested}}\right)$$

$$D_{ij} = \frac{1.04\text{E-1 mRem}}{\text{year}}$$

$$H_{50,T} = \left(\frac{4.3\ \text{pCi}}{\text{liter}}\right)\left(\frac{200\ \text{liter}}{\text{year}}\right)\left(\frac{27.027\ \text{Bq}}{\text{pCi}}\right)\left(\frac{7.28\text{E-9 Sv}}{\text{Bq}}\right)\left(\frac{1\text{E5 mRem}}{\text{Sv}}\right)$$

$$H_{50,T} = (1.69\text{E1 mRem})$$

Case 6.8
Dose from inhalation of contaminated sludge-borne dust

This pathway examines the dose to landfill operators who may work around contaminated sludge. The following was modeled by Michael J. Bovino, and incorporates standard health physics and engineering principles. Most of the data were obtained by personal conversations with the Morris Wastewater Treatment Plant (MWTP) staff.

Assumptions:

1. Sludge is landfilled in a different location each day.
2. Radionuclides are evenly distributed throughout the sludge.
3. Mass loading of dust in air (M_L) is 100 $\mu g/m^3$. (6.8.a)
4. The worker averages 192 hours per year spreading sludge (2 days each month).
5. Sludge is continuously produced and removed from the MWTP, hence, no buildup of radionuclides in any particular load of sludge.
6. All of the radionuclides in the INS effluent end up in the sludge (no partitioning in the wastewater by soluble nuclides).
7. INS releases are treated as continuous.

Data:

1. MWTP produces an average of 10.8 m^3 of sludge per day.
2. Average adult breathing rate (B_R) is 8000 m^3 / year.

Calculational model:

The annual dose to organ j of an individual is given by:

$$D_j^s = B_r M_l \sum_i C_i^s DFA_{ij} \qquad (6.8.1)$$

Where:

B_r	is the average adult breathing rate,
M_l	is the mass loading of dust in air for dusty work (100 $\mu gm/m^3$),
DFA_{ij}	is the dose conversion factor for nuclide i, organ j, in mRem/year,

The Activity concentration of sludge for nuclide i is given by:

$$C_i^s = \frac{Q_i^w}{M_s}$$

Where:

Q_i^w	is the INS annual release rate of nuclide i into the sewer, in Ci/yr,
M_s	is the mass of sludge produced annually by MWTP, provided all effluent constitutes sludge.

Calculate B_R for th[illegible]ork year:

$$B_R = \left(\frac{8000\ m^3}{yr}\right)\left(\frac{yr}{8760\ hours}\right)\left(\frac{1E3\ liter}{m^3}\right) = \left(\frac{913.2\ liters}{hour}\right)$$

$$B_R = \left(\frac{913.2\ liters}{hour}\right)\left(\frac{8\ hour}{work\ day}\right)\left(\frac{192\ work\ day}{year}\right) = \left(\frac{1.40E6\ liters}{work\ year}\right)$$

Sample Calculation:

$$M_s = \left(\frac{520{,}000\ gal}{6\ months}\right)\left(\frac{12\ months}{yr}\right)\left(\frac{0.134\ ft^3}{gal}\right)\left(\frac{28316\ cm^3}{ft^3}\right)\left(\frac{1.3\ gm}{cm^3}\right)$$

$$M_s = \left(\frac{5.13E9\ gm}{yr}\right)$$

The sample calculation has been performed for Co-60.

$$C_i^s = \left(\frac{0.0896\ Ci}{yr}\right)\left(\frac{yr}{5.13E9\ gm}\right)\left(\frac{1E12\ pCi}{Ci}\right)$$

$$C_i^s = \left(\frac{17.5\ pCi}{gm}\right)$$

$$D_j^S = \left(\frac{1.40E6\ liter}{yr}\right)\left(\frac{100\ \mu gm}{m^3}\right)\left(\frac{gm}{1E6\ \mu gm}\right)\left(\frac{17.5\ pCi}{gm}\right)\left(\frac{m^3}{1E3\ liter}\right)\left(\frac{9.10E\text{-}5\ mRem}{pCi\ inhaled}\right)$$

$$D_j^S = \left(\frac{2.23E\text{-}4\ mRem}{yr}\right)$$

$$H_{50,T} = \left(\frac{17.5\ pCi}{gm}\right)\left(\frac{100\ \mu gm}{m^3}\right)\left(\frac{gm}{1E6\ \mu gm}\right)\left(\frac{1.40E6\ l}{yr}\right)\left(\frac{m^3}{1000\ l}\right)\left(\frac{8.94E\text{-}9\ Sv}{Bq}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{1E5\ mRem}{Sv}\right)$$

$$H_{50,T} = 5.91E\text{-}02\ mRem$$

Case 6.9
Dose from direct exposure to contaminated sludge

This pathway examines the dose (external exposure) from contaminated sludge to a landfill worker. This pathway was modeled by Michael J. Bovino and incorporates standard health physics and engineering principles. Most of the data was based on personal conversations with key people involved with waste handling. The method used is for a shielded infinite plane source.

Assumptions:

1. Same assumptions as in Case 6.8,
2. The exposure rate from the previous day's deposit is negligible due to soil cap, due to a six inch cap of clean fill each day.
3. 1 R is approximately equal to 1 Rem for gamma exposure,
4. For selection of buildup factors, the density of soil is approximately equivalent to that of Aluminum, 2.7 g/cm^3,
5. Based on volume produced daily, the sludge is spread over an area 3.3 meters, by 3.3 meters, by 1 meter.

Data:

1. The MWTP produces 520,000 gallons of sludge every 6 months,
2. Values for μ_s and B_i were interpolated from existing data., using an unweighted exponential fit. (6.9.a)

Calculational model:

The exposure rate is determined by:

$$\dot{X} = \sum_i \frac{\Gamma_i B_i C_i^{Sv}}{2 \mu_s} [E_2 b_1 - E_2 b_3] \qquad (6.9.1)$$

Where:

Γ_i	is the specific gamma ray constant for nuclide i, in R-m2/Ci-hr,
B_i	is the buildup factor of the sludge as its own shield for nuclide i,
μ_s	is the linear attenuation coefficient of sludge,
E_2	is the shielding function. Found as: E2 function of b1 = 6 E-2; E2 function of b3 = 2E-7, (6.9.b)
b_1	is the relaxation length of the soil cap $(\mu_s x)_{soil}$
b_3	is the relaxation length of the soil cap plus the sludge $(\mu_s x)_{soil} + (\mu_s x)_{sludge}$,

The Activity per Unit Volume of Sludge is given as:

$$C_i^{Sv} = \frac{Q_i^W}{V_s}$$

Where:

Q_i^W is the annual release rate of nuclide i into the wastewater (sewer) system, in Ci/yr,

V_s is the volume of the sludge landfilled, in m3/day,

$$V_s = \left(\frac{520{,}000\ \text{gal}}{6\ \text{months}}\right)\left(\frac{12\ \text{months}}{\text{year}}\right)\left(\frac{0.134\ \text{ft}^3}{\text{gal}}\right)\left(\frac{28316\ \text{cm}^3}{\text{ft}^3}\right)\left(\frac{\text{m}^3}{1\text{E}6\ \text{cm}^3}\right)$$

$$V_s = \left(\frac{10.8\ \text{m}^3}{\text{day}}\right)$$

Sample Calculation:

The sample calculation has been performed for Co-60.

$$C_i^{Sv} = \left(\frac{0.089\ \text{Ci}}{\text{yr}}\right)\left(\frac{\text{day}}{10.8\ \text{m}^3}\right)\left(\frac{\text{yr}}{365\ \text{day}}\right) = \left(\frac{2.27\text{E-5}\ \text{Ci}}{\text{m}^3}\right)$$

$$b_1 = \left(\frac{0.0724}{\text{cm}}\right)\left(\frac{2.54\ \text{cm}}{\text{in}}\right)(6\ \text{in}) = 1.10$$

$$b_3 = \left(\frac{0.0724}{\text{cm}}\right)\left(\frac{2.54\ \text{cm}}{\text{in}}\right)(36\ \text{in}) + 1.10 = 7.72$$

$$\dot{X} = \frac{\left(\frac{1.32\ \text{R-m}^2}{\text{Ci-hr}}\right)(4.43)\left(\frac{2.27\text{E-5}\ \text{Ci}}{\text{m}^3}\right)}{2\left(\frac{0.0724}{\text{cm}}\ \frac{100\ \text{cm}}{\text{m}}\right)}[(6\ \text{E-2})(1.10) - (2\ \text{E-7})(7.72)]$$

$$\dot{X} = \left(\frac{6.05\text{E-7}\ \text{R}}{\text{hr}}\right)$$

$$X = \left(\frac{1.69\text{E-6}\ \text{R}}{\text{hr}}\right)\left(\frac{192\ \text{hr}}{\text{yr}}\right)\left(\frac{\text{Rem}}{\text{R}}\right)\left(\frac{1000\ \text{mRem}}{\text{Rem}}\right)$$

$$X = \left(\frac{1.16\text{E-1}\ \text{mRem}}{\text{yr}}\right)$$

Case 6.10
Dose from ingestion of water downstream from the sewage treatment plant

This pathway was examined to investigate the possibility of direct ingestion of water by the population. The Illinois Department of Transportation Division of Water Resources indicated that the only community using the Illinois River as a water supply is Peoria (approximately 60 miles downstream).

Assumptions:

1. Transport time (tp), between release from INS and ingestion by the receptor is assumed to be 12 hours.
2. Dilution factor Mp is calculated as 5.68E6, 2.64E6 (INS discharge) :1.5E13 (Illinois River flow). (6.10.a)

Data:

1. Flow rate of INS effluent (F), = 2.64E6 liters/yr.
2. The usage factor (U), intake rate for an individual is given as 370 liters of water per year consumed. (6.10.b)

Calculational Model:

The annual dose to organ j, from all of the nuclides i, from drinking contaminated water is given as:

$$R_j = \frac{U M_p}{F} \sum_i Q_i D_{ij} e^{-(\lambda_i t_p)} \qquad (6.10.1)$$

Where:

U	is the usage factor, 370 liters/year,
M_p	is the dilution factor, calculated above,
F	is the annual flow from INS, 2.64E6 liters/year,
t_p	transport time from INS to consumption, (2 days),
Q_i	is the release rate of nuclide i, in Ci/year,
D_{ij}	Ingestion dose conversion factor for nuclide i, organ j, in mRem/pCi,
λ_i	Decay constant for nuclide i.

Sample Calculation:

The sample calculation has been performed for Co-60.

$$R_{ij} = \frac{\left(\frac{370\ l}{yr}\right)\left(\frac{1}{5.68E6}\right)}{\frac{2.64E6\ liters}{yr}} \left(\frac{0.089\ Ci}{yr}\right)\left(\frac{1.21E\text{-}4\ mrem}{pCi\ ingested}\right)\left(\frac{1\ E12\ pCi}{Ci}\right) e^{-\left(\frac{3.6\ E\text{-}4}{day}\ 2\ day\right)}$$

$$R_{ij} = \left(\frac{2.66E\text{-}4\ mRem}{yr}\right)$$

$$H_{50,\ T} = \left(\frac{2.66E\text{-}4\ mRem}{year}\right)\left(\frac{pCi}{1.21E\text{-}4\ mRem}\right)\left(\frac{7.28E\text{-}9\ Sv}{Bq}\right)\left(\frac{27.027\ Bq}{pCi}\right)\left(\frac{1E5\ mRem}{Sv}\right)$$

$$H_{50,\ T} = 4.32E\text{-}2\ mRem$$

Case 6.11
Dose from ingestion of aquatic foods taken from contaminated water supplies

This pathway was examined for sport fish which are assumedly taken from the Illinois River, downstream of the MWTP.

Assumptions:

1. Same assumptions as those for Case 6.4.
2. All of the radionuclides in the INS effluent end up in the wastewater effluent (none is retained in the sludge).
3. Transport time (tp), between release from INS and ingestion by the receptor is assumed to be 24 hours.

Data:

1. From Case 6.4.
2. The usage factor (U), intake rate for an individual is given as 6.9 kg of fish per year consumed. (6.11.a)

Calculational model:

The total annual dose to organ j from all of the nuclides i from eating sport fish is determined by:

$$R_j = \frac{U\,M_p}{F} \sum_i Q_i\,B_i\;DCF_j\,e^{-(\lambda_i\,t_p)} \qquad (6.11.1)$$

Where:

U	is the usage factor, 6.9 kg/year,
M_p	is the dilution factor, calculated above,
F	is the annual flow from INS, 2.64E6 liters/year,
t_p	transport time from INS to consumption, (1 day),
Q_i	is the release rate of nuclide i, in Ci/year,
B_i	is the bioaccumulation factor (Co^{60} 50 pCi/Kg per pCi/liter of activity in the water),
DCF_j	Ingestion dose conversion factor for organ j, in mRem/pCi,
λ_i	Decay constant for nuclide i.

Sample Calculation:

The sample calculation has been performed for Co-60.

$$R_{ij} = \frac{\left(\frac{6.9\ \text{kg}}{\text{yr}}\right)\left(\frac{1}{3.64E6}\right)}{\frac{2.64E6\ \text{liters}}{\text{yr}}} \left(\frac{0.089\ \text{Ci}}{\text{yr}}\right)\left(\frac{1.21E\text{-}4\ \text{mrem}}{\text{pCi ingested}}\right)\left(\frac{50\ \text{pCi/Kg}}{\text{pCi/l}}\right)\left(\frac{1\ E12\ \text{pCi}}{\text{Ci}}\right) e^{-\left(\frac{1.5\ E\text{-}5}{\text{hr}}\ 24\ \text{hr}\right)}$$

$$R_{ij} = \left(\frac{3.89E\text{-}4\ \text{mRem}}{\text{year}}\right)$$

$$H_{50,\,T} = \left(\frac{3.89E\text{-}4\ \text{mRem}}{\text{year}}\right)\left(\frac{\text{pCi}}{1.21E\text{-}4\ \text{mRem}}\right)\left(\frac{7.28E\text{-}9\ \text{Sv}}{\text{Bq}}\right)\left(\frac{27.027\ \text{Bq}}{\text{pCi}}\right)\left(\frac{1E5\ \text{mRem}}{\text{Sv}}\right)$$

$$H_{50,\,T} = 6.33E\text{-}2\ \text{mRem}$$

Case 6.12

Dose to Sewage Treatment Plant personnel from exposure to the sludge thickening tank

This pathway was examined to consider the dose to personnel working in the office area near the sludge thickening tank. The sludge thickening tank is treated as a cylindrical source in this analysis. Simplifying assumptions have been made to facilitate calculations.

Assumptions:

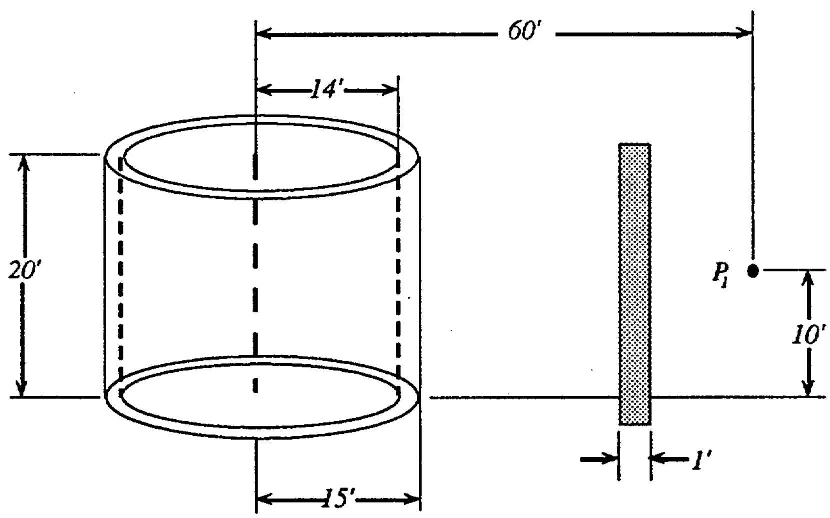
1. Personnel working in this area are exposed for 2000 hours annually,
2. All of the radionuclides in the INS effluent end up in the sludge thickening tank, remain in the tank for one year, and do not decay,
3. The tank wall is 1' thick concrete equivalent,
4. The office wall is 1' thick concrete equivalent,
5. Tank dimensions are 20' tall, by 15' radius,
6. The density of the sludge is 1.3 g/cm^3.

Data:

1. Activity concentration based on waterborne effluent.

Calculational Model:

The dose rate at a point (P_1) proximal to the cylinder source (sludge thickening tank) has been derived using a personal computer based shielding program[6.12.a]. This point is representative of the work area within the sewage treatment office. The geometry for the source is described in the graphic below:



The calculation for dose rate from the cylinder to point P_1 includes buildup based on the Taylor method. See Appendix A for results of the analysis.

7.0 DISCUSSION

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

a. Use of Most Limiting Dose Conversion Factors,
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. The amount of time in direct exposure situations is excessive for anticipated operations,
h. Consumption rates reflect the most conservative age group,
i. A 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 for a planar source were not available for Aluminum,
b. Dose Conversion Factors for a few nuclides were not included in guidance documents,
c. The inability to correlate data collected at the sewage treatment plant to actual pathway data. This was due to the erratic operational schedule of the sewage treatment plant.

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 Sewage Treatment Plant worker. In reality, these scenarios are not practical. Doses indicated by this analysis are, however, extremely low (such that detection in the field offer questionable results).

8.0 SUMMARY

Each of the Cases above indicate dose to a maximally exposed individual. This individual, due to the approach employed in some calculations, is fictitious. More specifically, this individual has a diet and radiosensitivity that is a corruption of the four age groups (Infant, Child, Teenager, Adult).

Table 9.17, Summation of Doses, indicates the annual dose a maximally exposed individual would receive from INS operations is low. The fifty year commitment seems considerably higher. Given a total annual average effective dose equivalent of 360 mrem/year 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 it's 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 Morris facility is minimal.

See Table 9.17 for the summation of all doses to the receptor.

9.0 DATA TABLES

Table 9.1
Airborne activity concentration (µCi/cc)

	1st	2nd	3rd	4th	Average	Annual Discharge (Ci/year)
Cr-51	2.76E-14				6.90E-15	7.51E-08
Cs-134			7.93E-14		1.98E-14	2.16E-07
Cs-137	2.01E-14	3.40E-14	2.86E-13		8.49E-14	9.24E-07
Co-58	7.42E-15	1.84E-14	4.02E-14		1.65E-14	1.80E-07
Mn-54	6.46E-14	1.30E-13	4.35E-13		1.57E-13	1.71E-06
Co-60	2.13E-13	3.42E-13	2.05E-12	4.53E-13	7.65E-13	8.32E-06
Nb-95			2.36E-14		5.90E-15	6.43E-08

Table 9.2
Concentrations of nuclides in INS wastewater (µCi/cc)

Month	Co-58	Co-60	Mn-54	Cs-134	Cs-137	Ag-110	Fe-55	Sb-125
January	0.00E+00	4.59E-06	6.13E-07	6.38E-07	1.66E-06	0.00E+00	0.00E+00	0.00E+00
February	0.00E+00	4.22E-06	1.23E-06	0.00E+00	1.37E-06	0.00E+00	0.00E+00	0.00E+00
March	5.64E-07	3.02E-06	0.00E+00	0.00E+00	1.30E-06	4.97E-07	0.00E+00	0.00E+00
April	4.55E-07	2.46E-06	0.00E+00	0.00E+00	7.68E-07	0.00E+00	0.00E+00	0.00E+00
May	4.19E-07	3.39E-06	1.23E-06	2.82E-07	1.08E-06	0.00E+00	0.00E+00	0.00E+00
June	6.27E-07	4.04E-06	1.04E-06	1.43E-07	1.34E-06	0.00E+00	0.00E+00	0.00E+00
July	8.99E-07	3.17E-06	1.58E-06	8.48E-07	8.74E-07	0.00E+00	0.00E+00	2.36E-07
August	8.29E-07	3.51E-06	1.06E-06	3.68E-07	7.63E-07	0.00E+00	0.00E+00	0.00E+00
September	6.02E-08	2.44E-06	5.05E-07	2.18E-07	1.11E-06	0.00E+00	0.00E+00	0.00E+00
October	3.99E-07	1.95E-06	5.68E-07	1.19E-07	1.03E-06	0.00E+00	9.01E-07	0.00E+00
November	5.21E-07	2.20E-06	7.81E-07	5.45E-07	1.62E-06	0.00E+00	9.01E-07	0.00E+00
December	2.68E-07	1.36E-06	2.56E-07	5.96E-07	2.15E-06	0.00E+00	9.01E-07	0.00E+00
INS (uCi/cc):	4.12E-07	2.83E-06	5.79E-07	2.89E-07	1.29E-06	5.47E-08	2.99E-07	1.23E-08
STP (uCi/cc):	6.40E-09	4.39E-08	9.00E-09	4.49E-09	2.00E-08	8.51E-10	4.64E-09	1.91E-10
INS (uCi/yr):	13068.5	89625.5	18375.5	9170.3	40803.9	1735.9	9474.5	389.6

Table 9.3
Most Limiting Inhalation Dose Conversion Factors - Page 1

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi inhaled - Infant						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	4.17E-08	4.11E-08	9.45E-09	9.17E-06	2.55E-07
	Cs-137	3.92E-04	4.37E-04	3.25E-05	No Data	1.23E-04	5.09E-05	9.53E-07
	Co-58	No Data	8.71E-07	1.30E-06	No Data	No Data	5.55E-04	7.95E-06
	Mn-54	No Data	1.81E-05	3.56E-06	No Data	3.56E-06	7.14E-04	5.04E-06
	Co-60	No Data	5.73E-06	8.41E-06	No Data	No Data	3.22E-03	2.28E-05
Second	Cs-137	3.92E-04	4.37E-04	3.25E-05	No Data	1.23E-04	5.09E-05	9.53E-07
	Co-58	No Data	8.71E-07	1.30E-06	No Data	No Data	5.55E-04	7.95E-06
	Mn-54	No Data	1.81E-05	3.56E-06	No Data	3.56E-06	7.14E-04	5.04E-06
	Co-60	No Data	5.73E-06	8.41E-06	No Data	No Data	3.22E-03	2.28E-05
Third	Cs-134	2.83E-04	5.02E-04	5.32E-05	No Data	1.36E-04	5.69E-05	9.53E-07
	Cs-137	3.92E-04	4.37E-04	3.25E-05	No Data	1.23E-04	5.09E-05	9.53E-07
	Nb-95	1.12E-05	4.59E-06	2.70E-06	No Data	3.37E-06	3.42E-04	9.05E-06
	Co-58	No Data	8.71E-07	1.30E-06	No Data	No Data	5.55E-04	7.95E-06
	Mn-54	No Data	1.81E-05	3.56E-06	No Data	3.56E-06	7.14E-04	5.04E-06
Fourth	Co-60	No Data	5.73E-06	8.41E-06	No Data	No Data	3.22E-03	2.28E-05

* Most limiting Dose factor (mRem/pCi inhaled) - Infant						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
3.92E-04	4.37E-04	5.32E-05	4.11E-08	1.36E-04	3.22E-03	2.28E-05

* Dose Factors from Table E-10, USNRC Regulatory Guide 1.109.

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi inhaled - Child						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	4.17E-08	2.31E-08	6.57E-09	4.59E-06	2.93E-07
	Cs-137	2.45E-04	2.23E-04	3.47E-05	No Data	7.63E-05	2.81E-05	9.78E-07
	Co-58	No Data	4.79E-07	8.55E-07	No Data	No Data	2.99E-04	9.29E-06
	Mn-54	No Data	1.16E-05	2.57E-06	No Data	2.71E-06	4.26E-04	6.19E-06
	Co-60	No Data	3.55E-06	6.12E-06	No Data	No Data	1.91E-03	2.60E-05
Second	Cs-137	2.45E-04	2.23E-04	3.47E-05	No Data	7.63E-05	2.81E-05	9.78E-07
	Co-58	No Data	4.79E-07	8.55E-07	No Data	No Data	2.99E-04	9.29E-06
	Mn-54	No Data	1.16E-05	2.57E-06	No Data	2.71E-06	4.26E-04	6.19E-06
	Co-60	No Data	3.55E-06	6.12E-06	No Data	No Data	1.91E-03	2.60E-05
Third	Cs-134	1.76E-04	2.74E-04	6.07E-05	No Data	8.93E-05	3.27E-05	1.04E-06
	Cs-137	2.45E-04	2.23E-04	3.47E-05	No Data	7.63E-05	2.81E-05	9.78E-07
	Nb-95	6.35E-06	2.48E-06	1.77E-06	No Data	2.33E-06	1.66E-04	1.00E-05
	Co-58	No Data	4.79E-07	8.55E-07	No Data	No Data	2.99E-04	9.29E-06
	Mn-54	No Data	1.16E-05	2.57E-06	No Data	2.71E-06	4.26E-04	6.19E-06
Fourth	Co-60	No Data	3.55E-06	6.12E-06	No Data	No Data	1.91E-03	2.60E-05

* Most limiting Dose factor (mRem/pCi inhaled) - Child						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
2.45E-04	2.23E-04	6.07E-05	2.31E-08	8.93E-05	1.91E-03	2.60E-05

* Dose Factors from Table E-9, USNRC Regulatory Guide 1.109.

Table 9.3
Most Limiting Inhalation Dose Conversion Factors - Page 2

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi inhaled - Teenager						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	1.69E-08	9.37E-09	3.84E-09	2.62E-05	3.75E-07
	Cs-137	8.38E-05	1.06E-04	3.89E-05	No Data	3.80E-05	1.51E-05	1.06E-06
	Co-58	No Data	2.59E-07	3.47E-07	No Data	No Data	1.68E-04	1.19E-05
	Mn-54	No Data	6.39E-06	1.05E-06	No Data	1.59E-06	2.48E-04	8.35E-06
	Co-60	No Data	1.89E-06	2.48E-06	No Data	No Data	1.09E-03	3.24E-05
Second	Cs-137	8.38E-05	1.06E-04	3.89E-05	No Data	3.80E-05	1.51E-05	1.06E-06
	Co-58	No Data	2.59E-07	3.47E-07	No Data	No Data	1.68E-04	1.19E-05
	Mn-54	No Data	6.39E-06	1.05E-06	No Data	1.59E-06	2.48E-04	8.35E-06
	Co-60	No Data	1.89E-06	2.48E-06	No Data	No Data	1.09E-03	3.24E-05
Third	Cs-134	6.28E-05	1.41E-04	6.86E-05	No Data	4.69E-05	1.83E-05	1.22E-06
	Cs-137	8.38E-05	1.06E-04	3.89E-05	No Data	3.80E-05	1.51E-05	1.06E-06
	Nb-95	2.32E-06	1.29E-06	7.08E-07	No Data	1.25E-06	9.39E-05	1.21E-05
	Co-58	No Data	2.59E-07	3.47E-07	No Data	No Data	1.68E-04	1.19E-05
	Mn-54	No Data	6.39E-06	1.05E-06	No Data	1.59E-06	2.48E-04	8.35E-06
Fourth	Co-60	No Data	1.89E-06	2.48E-06	No Data	No Data	1.09E-03	3.24E-05

• Most limiting Dose factor (mRem/pCi inhaled) - Teenager						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
8.38E-05	1.06E-04	6.86E-05	9.37E-09	4.69E-05	1.09E-03	3.24E-05

• Dose Factors from Table E-8, USNRC Regulatory Guide 1.109.

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi inhaled - Adult						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	1.25E-08	7.44E-09	2.85E-09	1.80E-06	4.15E-07
	Cs-137	5.98E-05	7.76E-05	5.35E-05	No Data	2.78E-05	9.40E-06	1.05E-06
	Co-58	No Data	1.98E-07	2.59E-07	No Data	No Data	1.16E-04	1.33E-05
	Mn-54	No Data	4.95E-06	7.87E-07	No Data	1.23E-06	1.75E-04	9.67E-06
	Co-60	No Data	1.44E-06	1.85E-06	No Data	No Data	7.46E-04	3.56E-05
Second	Cs-137	5.98E-05	7.76E-05	5.35E-05	No Data	2.78E-05	9.40E-06	1.05E-06
	Co-58	No Data	1.98E-07	2.59E-07	No Data	No Data	1.16E-04	1.33E-05
	Mn-54	No Data	4.95E-06	7.87E-07	No Data	1.23E-06	1.75E-04	9.67E-06
	Co-60	No Data	1.44E-06	1.85E-06	No Data	No Data	7.46E-04	3.56E-05
Third	Cs-134	4.66E-05	1.06E-04	9.10E-05	No Data	3.59E-05	1.22E-05	1.30E-06
	Cs-137	5.98E-05	7.76E-05	5.35E-05	No Data	2.78E-05	9.40E-06	1.05E-06
	Nb-95	1.76E-06	9.77E-07	5.26E-07	No Data	9.67E-07	6.31E-05	1.30E-05
	Co-58	No Data	1.98E-07	2.59E-07	No Data	No Data	1.16E-04	1.33E-05
	Mn-54	No Data	4.95E-06	7.87E-07	No Data	1.23E-06	1.75E-04	9.67E-06
Fourth	Co-60	No Data	1.44E-06	1.85E-06	No Data	No Data	7.46E-04	3.56E-05

• Most limiting Dose factor (mRem/pCi inhaled) - Adult						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
5.98E-05	1.06E-04	9.10E-05	7.44E-09	3.59E-05	7.46E-04	3.56E-05

• Dose Factors from Table E-7, USNRC Regulatory Guide 1.109.

Table 9.3
Most Limiting Inhalation Dose Conversion Factors - Page 3

• Most limiting Dose factor (mRem/pCi inhaled) - Infant						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
3.92E-04	4.37E-04	5.32E-05	4.11E-08	1.36E-04	3.22E-03	2.28E-05

• Most limiting Dose factor (mRem/pCi inhaled) - Child						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
2.45E-04	2.23E-04	6.07E-05	2.31E-08	8.93E-05	1.91E-03	2.60E-05

• Most limiting Dose factor (mRem/pCi inhaled) - Teenager						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
8.38E-05	1.06E-04	6.86E-05	9.37E-09	4.69E-05	1.09E-03	3.24E-05

• Most limiting Dose factor (mRem/pCi inhaled) - Adult						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
5.98E-05	1.06E-04	9.10E-05	7.44E-09	3.59E-05	7.46E-04	3.56E-05

• Most limiting Dose factor (mRem/pCi inhaled) - OVERALL						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
3.92E-04	4.37E-04	9.10E-05	4.11E-08	1.36E-04	3.22E-03	3.56E-05

The above values have been selected as the most limiting radionulcides from Regulatory Guide 1.109. The shaded value in each age group was selected as the most limiting conversion factor for each target organ. All age groups were combined to produce the Most Limiting Dose Factor - OVERALL.

Table 9.4
Most Limiting Ingestion Dose Conversion Factors - Page 1

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi ingested - Infant						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	1.41E-08	9.20E-09	2.01E-09	1.79E-08	4.11E-07
	Cs-137	5.22E-04	6.11E-04	4.33E-05	No Data	1.64E-04	6.64E-05	1.91E-06
	Co-58	No Data	3.60E-06	8.98E-06	No Data	No Data	No Data	8.97E-06
	Mn-54	No Data	1.99E-05	4.51E-06	No Data	4.41E-06	No Data	7.31E-06
	Co-60	No Data	1.08E-05	2.55E-05	No Data	No Data	No Data	2.57E-05
Second	Cs-137	5.22E-04	6.11E-04	4.33E-05	No Data	1.64E-04	6.64E-05	1.91E-06
	Co-58	No Data	3.60E-06	8.98E-06	No Data	No Data	No Data	8.97E-06
	Mn-54	No Data	1.99E-05	4.51E-06	No Data	4.41E-06	No Data	7.31E-06
	Co-60	No Data	1.08E-05	2.55E-05	No Data	No Data	No Data	2.57E-05
Third	Cs-134	3.77E-04	7.03E-04	7.10E-05	No Data	1.81E-04	7.42E-05	1.91E-06
	Cs-137	5.22E-04	6.11E-04	4.33E-05	No Data	1.64E-04	6.64E-05	1.91E-06
	Nb-95	4.20E-08	1.73E-08	1.00E-08	No Data	1.24E-08	No Data	1.46E-05
	Co-58	No Data	3.60E-06	8.98E-06	No Data	No Data	No Data	8.97E-06
	Mn-54	No Data	1.99E-05	4.51E-06	No Data	4.41E-06	No Data	7.31E-06
Fourth	Co-60	No Data	1.08E-05	2.55E-05	No Data	No Data	No Data	2.57E-05
	H-3	No Data	3.08E-07	3.08E-07	3.08E-07	3.08E-07	3.08E-07	3.08E-07
	Fe-55	1.39E-05	8.98E-06	2.40E-06	No Data	No Data	4.39E-06	1.14E-06
	C-14	2.37E-05	5.06E-06	5.06E-06	5.06E-06	5.06E-06	5.06E-06	5.06E-06

* Most limiting Dose factor (mRem/pCi ingested) - Infant						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
5.22E-04	7.03E-04	7.10E-05	5.06E-06	1.81E-04	7.42E-05	2.57E-05

* Dose Factors from Table E-14, USNRC Regulatory Guide 1.109.

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi ingested - Child						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	8.90E-09	4.94E-09	1.35E-09	9.02E-09	4.72E-07
	Cs-137	3.72E-04	3.13E-04	4.62E-05	No Data	1.02E-04	3.67E-05	1.96E-06
	Co-58	No Data	1.80E-06	5.51E-06	No Data	No Data	No Data	1.05E-05
	Mn-54	No Data	1.07E-05	2.85E-06	No Data	3.00E-06	No Data	8.98E-06
	Co-60	No Data	5.29E-06	1.56E-05	No Data	No Data	No Data	2.93E-05
Second	Cs-137	3.72E-04	3.13E-04	4.62E-05	No Data	1.02E-04	3.67E-05	1.96E-06
	Co-58	No Data	1.80E-06	5.51E-06	No Data	No Data	No Data	1.05E-05
	Mn-54	No Data	1.07E-05	2.85E-06	No Data	3.00E-06	No Data	8.98E-06
	Co-60	No Data	5.29E-06	1.56E-05	No Data	No Data	No Data	2.93E-05
Third	Cs-134	2.34E-04	3.84E-04	8.10E-05	No Data	1.19E-04	4.27E-05	2.07E-06
	Cs-137	3.72E-04	3.13E-04	4.62E-05	No Data	1.02E-04	3.67E-05	1.96E-06
	Nb-95	2.25E-08	8.76E-09	6.26E-09	No Data	8.23E-09	No Data	1.62E-05
	Co-58	No Data	1.80E-06	5.51E-06	No Data	No Data	No Data	1.05E-05
	Mn-54	No Data	1.07E-05	2.85E-06	No Data	3.00E-06	No Data	8.98E-06
Fourth	Co-60	No Data	5.29E-06	1.56E-05	No Data	No Data	No Data	2.93E-05
	H-3	No Data	2.03E-07	2.03E-07	2.03E-07	2.03E-07	2.03E-07	2.03E-07
	Fe-55	1.15E-05	6.10E-06	1.89E-06	No Data	No Data	3.45E-06	1.13E-06
	C-14	1.21E-05	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06

* Most limiting Dose factor (mRem/pCi ingested) - Child						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
3.72E-04	3.84E-04	8.10E-05	2.42E-06	1.19E-04	4.27E-05	2.93E-05

* Dose Factors from Table E-13, USNRC Regulatory Guide 1.109.

Table 9.4
Most Limiting Ingestion Dose Conversion Factors - Page 2

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi ingested - Teenager						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	3.60E-09	2.00E-09	7.89E-10	5.14E-09	6.05E-07
	Cs-137	1.12E-04	1.49E-04	5.19E-05	No Data	5.07E-05	1.97E-05	2.12E-06
	Co-58	No Data	9.72E-07	2.24E-06	No Data	No Data	No Data	1.34E-05
	Mn-54	No Data	5.90E-06	1.17E-06	No Data	1.76E-06	No Data	1.21E-05
	Co-60	No Data	2.81E-06	6.33E-06	No Data	No Data	No Data	3.66E-05
Second	Cs-137	1.12E-04	1.49E-04	5.19E-05	No Data	5.07E-05	1.97E-05	2.12E-06
	Co-58	No Data	9.72E-07	2.24E-06	No Data	No Data	No Data	1.34E-05
	Mn-54	No Data	5.90E-06	1.17E-06	No Data	1.76E-06	No Data	1.21E-05
	Co-60	No Data	2.81E-06	6.33E-06	No Data	No Data	No Data	3.66E-05
Third	Cs-134	8.37E-05	1.97E-04	9.14E-05	No Data	6.26E-05	2.39E-05	2.45E-06
	Cs-137	1.12E-04	1.49E-04	5.19E-05	No Data	5.07E-05	1.97E-05	2.12E-06
	Nb-95	8.22E-09	4.45E-09	2.51E-09	No Data	4.42E-09	No Data	1.95E-05
	Co-58	No Data	9.72E-07	2.24E-06	No Data	No Data	No Data	1.34E-05
	Mn-54	No Data	5.90E-06	1.17E-06	No Data	1.76E-06	No Data	1.21E-05
Fourth	Co-60	No Data	2.81E-06	6.33E-06	No Data	No Data	No Data	3.66E-05
	H-3	No Data	1.06E-07	1.06E-07	1.06E-07	1.06E-07	1.06E-07	1.06E-07
	Fe-55	3.78E-06	2.68E-06	6.25E-07	No Data	No Data	1.70E-06	1.16E-06
	C-14	4.06E-06	8.12E-07	8.12E-07	8.12E-07	8.12E-07	8.12E-07	8.12E-07

* Most limiting Dose factor (mRem/pCi ingested) - Teenager						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
1.12E-04	1.97E-04	9.14E-05	8.12E-07	6.26E-05	2.39E-05	3.66E-05

* Dose Factors from Table E-12, USNRC Regulatory Guide 1.109.

Quarter of 1990	Radionuclides identified in composite air sample	mRem/pCi ingested - Adult						
		Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
First	Cr-51	No Data	No Data	2.66E-09	1.59E-09	5.86E-10	3.53E-09	6.69E-07
	Cs-137	7.97E-05	1.09E-04	7.14E-05	No Data	3.70E-05	1.23E-05	2.11E-06
	Co-58	No Data	7.45E-07	1.67E-06	No Data	No Data	No Data	1.51E-05
	Mn-54	No Data	4.57E-06	8.72E-07	No Data	1.36E-06	No Data	1.40E-05
	Co-60	No Data	2.40E-06	4.72E-06	No Data	No Data	No Data	4.02E-05
Second	Cs-137	7.97E-05	1.09E-04	7.14E-05	No Data	3.70E-05	1.23E-05	2.11E-06
	Co-58	No Data	7.45E-07	1.67E-06	No Data	No Data	No Data	1.51E-05
	Mn-54	No Data	4.57E-06	8.72E-07	No Data	1.36E-06	No Data	1.40E-05
	Co-60	No Data	2.40E-06	4.72E-06	No Data	No Data	No Data	4.02E-05
Third	Cs-134	6.22E-05	1.48E-04	1.21E-04	No Data	4.79E-05	1.59E-05	2.59E-06
	Cs-137	7.97E-05	1.09E-04	7.14E-05	No Data	3.70E-05	1.23E-05	2.11E-06
	Nb-95	3.04E-08	9.75E-09	6.60E-09	No Data	1.53E-08	No Data	3.09E-05
	Co-58	No Data	7.45E-07	1.67E-06	No Data	No Data	No Data	1.51E-05
	Mn-54	No Data	4.57E-06	8.72E-07	No Data	1.36E-06	No Data	1.40E-05
Fourth	Co-60	No Data	2.40E-06	4.72E-06	No Data	No Data	No Data	4.02E-05
	H-3	No Data	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	No Data	No Data	1.06E-06	1.09E-06
	C-14	2.84E-06	5.68E-07	5.68E-07	5.68E-07	5.68E-07	5.68E-07	5.68E-07

* Most limiting Dose factor (mRem/pCi ingested) - Adult						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
7.97E-05	1.48E-04	1.21E-04	5.68E-07	4.79E-05	1.59E-05	4.02E-05

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

Table 9.4
Most Limiting Ingestion Dose Conversion Factors - Page 3

* Most limiting Dose factor (mRem/pCi ingested) - Infant						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
5.22E-04	7.03E-04	7.10E-05	5.06E-06	1.81E-04	7.42E-05	2.57E-05

* Most limiting Dose factor (mRem/pCi ingested) - Child						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
3.72E-04	3.84E-04	8.10E-05	2.42E-06	1.19E-04	4.27E-05	2.93E-05

* Most limiting Dose factor (mRem/pCi ingested) - Teenager						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
1.12E-04	1.97E-04	9.14E-05	8.12E-07	6.26E-05	2.39E-05	3.66E-05

* Most limiting Dose factor (mRem/pCi ingested) - Adult						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
7.97E-05	1.48E-04	1.21E-04	5.68E-07	4.79E-05	1.59E-05	4.02E-05

* Most limiting Dose factor (mRem/pCi ingested) - OVERALL						
Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI
5.22E-04	7.03E-04	1.21E-04	5.06E-06	1.81E-04	7.42E-05	4.02E-05

The above values have been selected as the most limiting radionulcides from Regulatory Guide 1.109. The shaded value in each age group was selected as the most limiting conversion factor for each target organ. All age groups were combined to produce the Most Limiting Dose Factor - OVERALL.

Table 9.5
Dose from inhalation of radionuclides in air

Nuclide	Annual Dose to each target organ (mRem/year)							50 year Effective
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	
Cr-51	6.82E-06	7.60E-06	1.58E-06	7.15E-10	2.36E-06	5.60E-05	6.19E-07	4.24E-06
Cs-134	1.96E-05	2.18E-05	4.54E-06	2.05E-09	6.79E-06	1.61E-04	1.78E-06	1.69E-03
Cs-137	8.39E-05	9.35E-05	1.95E-05	8.79E-09	2.91E-05	6.89E-04	7.62E-06	4.99E-03
Co-58	1.63E-05	1.82E-05	3.79E-06	1.71E-09	5.66E-06	1.34E-04	1.48E-06	6.65E-03
Mn-54	1.55E-04	1.73E-04	3.60E-05	1.63E-08	5.39E-05	1.28E-03	1.41E-05	1.94E-03
Co-60	7.55E-04	8.42E-04	1.75E-04	7.92E-08	2.62E-04	6.20E-03	6.86E-05	3.79E-02
Nb-95	5.83E-06	6.50E-06	1.35E-06	6.11E-10	2.02E-06	4.79E-05	5.29E-07	6.31E-05
Total	1.04E-03	1.16E-03	2.42E-04	1.09E-07	3.62E-04	8.57E-03	9.47E-05	5.32E-02

Table 9.6
Dose from exposure to airborne contaminated ground
(mRem / year)

Nuclide	Total Body	Skin
Cr-51	3.17E-12	3.74E-12
Co-58	1.94E-12	2.29E-12
Co-60	7.95E-09	9.40E-09
Mn-54	7.41E-10	8.75E-10
Nb-95	3.42E-12	4.04E-12
Cs-134	1.57E-10	1.85E-10
Cs-137	1.03E-09	1.22E-09
Total	9.89E-09	1.17E-08

Table 9.7
Dose ingestion of airborne contaminated green leafy vegetables

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cr-51	3.34E-04	4.50E-04	7.74E-05	5.88E-09	1.16E-04	4.74E-05	2.57E-05	1.56E-04
Cs-134	1.45E-03	1.95E-03	3.36E-04	2.55E-08	5.02E-04	2.06E-04	1.12E-04	9.37E-02
Cs-137	6.32E-03	8.51E-03	1.46E-03	1.11E-07	2.19E-03	8.98E-04	4.86E-04	2.82E-01
Co-58	1.02E-03	1.37E-03	2.36E-04	1.80E-08	3.53E-04	1.45E-04	7.85E-05	3.12E-01
Mn-54	1.12E-02	1.51E-02	2.59E-03	1.97E-07	3.88E-03	1.59E-03	8.62E-04	1.05E-01
Co-60	5.65E-02	7.61E-02	1.31E-02	9.96E-07	1.96E-02	8.03E-03	4.35E-03	2.13E+00
Nb-95	3.09E-04	4.16E-04	7.15E-05	5.44E-09	1.07E-04	4.39E-05	2.38E-05	2.51E-03
Total	7.71E-02	1.04E-01	1.79E-02	1.36E-06	2.67E-02	1.10E-02	5.94E-03	2.93E+00

Table 9.8
Dose from ingestion of beef fed upon airborne contaminated green leafy vegetables

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cr-51	1.95E-05	2.63E-05	4.53E-06	3.44E-10	6.77E-06	2.78E-06	1.50E-06	9.13E-06
Cs-134	1.38E-04	1.86E-04	3.21E-05	2.44E-09	4.80E-05	1.97E-05	1.07E-05	8.95E-03
Cs-137	6.32E-04	8.51E-04	1.46E-04	1.11E-08	2.19E-04	8.98E-05	4.86E-05	2.82E-02
Co-58	3.31E-04	4.46E-04	7.68E-05	5.84E-09	1.15E-04	4.71E-05	2.55E-05	1.01E-01
Mn-54	2.24E-04	3.01E-04	5.19E-05	3.94E-09	7.76E-05	3.18E-05	1.72E-05	2.10E-03
Co-60	1.84E-02	2.47E-02	4.26E-03	3.24E-07	6.37E-03	2.61E-03	1.41E-03	6.92E-01
Nb-95	2.16E-03	2.91E-03	5.01E-04	3.81E-08	7.49E-04	3.07E-04	1.66E-04	1.76E-02
Total	2.19E-02	2.95E-02	5.07E-03	3.85E-07	7.58E-03	3.11E-03	1.68E-03	8.51E-01

Table 9.9

Dose from ingestion of green leafy vegetables irrigated with contaminated water

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Co-58	1.44E-02	1.94E-02	3.35E-03	2.54E-07	5.00E-03	2.05E-03	1.11E-03	5.49E-01
Co-60	1.13E-01	1.53E-01	2.63E-02	2.00E-06	3.93E-02	1.61E-02	8.73E-03	4.28E+00
Mn-54	2.26E-02	3.04E-02	5.24E-03	3.98E-07	7.84E-03	3.21E-03	1.74E-03	8.77E-02
Cs-134	1.15E-02	1.55E-02	2.67E-03	2.03E-07	3.99E-03	1.64E-03	8.86E-04	1.18E+00
Cs-137	5.19E-02	6.98E-02	1.20E-02	9.14E-07	1.80E-02	7.37E-03	3.99E-03	3.63E+00
Ag-110	2.12E-03	2.85E-03	4.91E-04	3.73E-08	7.34E-04	3.01E-04	1.63E-04	3.21E-02
Sb-125	4.91E-04	6.61E-04	1.14E-04	8.65E-09	1.70E-04	6.97E-05	3.78E-05	1.92E-03
Fe-55	1.19E-02	1.61E-02	2.76E-03	2.10E-07	4.13E-03	1.69E-03	9.18E-04	1.01E-02
Total	2.14E-01	2.88E-01	4.96E-02	3.77E-06	7.41E-02	3.04E-02	1.65E-02	9.72E+00

Table 9.10

Dose from ingestion of beef fed upon green leafy vegetables irrigated with contaminated water

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Co-58	5.77E-03	7.77E-03	1.34E-03	1.02E-07	2.00E-03	8.20E-04	4.44E-04	2.18E-01
Co-60	4.47E-02	6.01E-02	1.04E-02	7.87E-07	1.55E-02	6.35E-03	3.44E-03	1.68E+00
Mn-54	5.49E-04	7.40E-04	1.27E-04	9.68E-09	1.91E-04	7.81E-05	4.23E-05	2.13E-03
Cs-134	1.40E-03	1.88E-03	3.23E-04	2.46E-08	4.84E-04	1.98E-04	1.07E-04	1.43E-01
Cs-137	6.28E-03	8.46E-03	1.46E-03	1.11E-07	2.18E-03	8.93E-04	4.84E-04	4.39E-01
Ag-110	1.09E-03	1.47E-03	2.54E-04	1.93E-08	3.80E-04	1.56E-04	8.43E-05	1.66E-02
Sb-125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe-55	1.45E-02	1.95E-02	3.35E-03	2.55E-07	5.01E-03	2.05E-03	1.11E-03	1.23E-02
Total	5.87E-02	7.90E-02	1.36E-02	1.03E-06	2.03E-02	8.34E-03	4.52E-03	2.48E+00

Table 9.11
Dose from ingestion of contaminated milk

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Cr-51	3.68E-05	5.21E-05	8.96E-06	6.81E-10	1.34E-05	5.49E-06	2.98E-06	7.48E-06
Co-58	5.66E-02	7.78E-02	1.34E-02	1.02E-06	2.00E-02	8.21E-03	4.45E-03	2.14E+00
Co-60	4.49E-01	6.05E-01	1.04E-01	7.92E-06	1.56E-01	6.39E-02	3.46E-02	1.69E+01
Mn-54	1.51E-03	2.05E-03	3.53E-04	2.68E-08	5.27E-04	2.16E-04	1.17E-04	5.86E-03
Nb-95	3.90E-05	5.47E-05	9.41E-06	7.15E-10	1.41E-05	5.77E-06	3.13E-06	1.40E-04
Cs-134	1.68E-01	2.27E-01	3.90E-02	2.97E-06	5.84E-02	2.39E-02	1.30E-02	1.72E+01
Cs-137	7.58E-01	1.02E+00	1.76E-01	1.34E-05	2.63E-01	1.08E-01	5.84E-02	5.30E+01
Ag-110	5.44E-01	7.37E-01	1.27E-01	9.65E-06	1.90E-01	7.78E-02	4.22E-02	8.23E+00
Total	1.98E+00	2.67E+00	4.60E-01	3.49E-05	6.87E-01	2.82E-01	1.53E-01	9.75E+01

Table 9.12
Dose from inhalation of contaminated sludge-borne dust

Nuclide	Annual Dose to each target organ (mRem/year)							50 year
	Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	Effective
Co-58	1.40E-04	1.56E-04	3.25E-05	1.47E-08	4.85E-05	1.15E-03	1.27E-05	8.62E-03
Co-60	9.59E-04	1.07E-03	2.23E-04	1.01E-07	3.33E-04	7.88E-03	8.71E-05	5.91E-02
Mn-54	1.97E-04	2.19E-04	4.56E-05	2.06E-08	6.82E-05	1.61E-03	1.79E-05	1.92E-03
Cs-134	9.81E-05	1.09E-04	2.28E-05	1.03E-08	3.40E-05	8.06E-04	8.91E-06	8.45E-03
Cs-137	4.37E-04	4.87E-04	1.01E-04	4.58E-08	1.51E-04	3.59E-03	3.96E-05	2.60E-02
Ag-110	1.86E-05	2.07E-05	4.31E-06	1.95E-09	6.44E-06	1.53E-04	1.69E-06	1.37E-03
Sb-125	4.17E-06	4.65E-06	9.68E-07	4.37E-10	1.45E-06	3.42E-05	3.79E-07	1.65E-05
Fe-55	1.01E-04	1.13E-04	2.35E-05	1.06E-08	3.52E-05	8.33E-04	9.20E-06	5.07E-04
Total	1.83E-03	2.04E-03	4.25E-04	1.92E-07	6.35E-04	1.50E-02	1.66E-04	1.04E-01

Table 9.13
Dose from direct exposure to contaminated sludges

Nuclide	Exposure rate (R/hr)	Annual Exposure (mRem)
Co-58	3.10E-08	5.95E-03
Co-60	6.08E-07	1.17E-01
Mn-54	3.83E-08	7.35E-03
Cs-134	4.88E-08	9.36E-03
Cs-137	8.54E-08	1.64E-02
Ag-110	1.19E-08	2.29E-03
Sb-125	6.93E-10	1.33E-04
Fe-55	1.28E-08	2.46E-03
Total	8.37E-07	1.61E-01

Table 9.14
Dose from ingestion of water downstream from the sewage treatment plant

Nuclide	Annual Dose to each target organ (mRem/year) Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	50 year Effective
Co-58	1.67E-04	2.25E-04	3.88E-05	2.95E-09	5.80E-05	2.38E-05	1.29E-05	6.31E-03
Co-60	1.15E-03	1.55E-03	2.67E-04	2.03E-08	4.00E-04	1.64E-04	8.88E-05	4.35E-02
Mn-54	2.36E-04	3.18E-04	5.47E-05	4.16E-09	8.19E-05	3.36E-05	1.82E-05	9.15E-04
Cs-134	1.18E-04	1.59E-04	2.73E-05	2.08E-09	4.09E-05	1.68E-05	9.08E-06	1.21E-02
Cs-137	5.25E-04	7.07E-04	1.22E-04	9.25E-09	1.82E-04	7.46E-05	4.04E-05	3.67E-02
Ag-110	2.23E-05	3.00E-05	5.17E-06	3.93E-10	7.73E-06	3.17E-06	1.72E-06	3.37E-04
Sb-125	5.01E-06	6.75E-06	1.16E-06	8.83E-11	1.74E-06	7.12E-07	3.86E-07	1.96E-05
Fe-55	1.22E-04	1.64E-04	2.82E-05	2.15E-09	4.23E-05	1.73E-05	9.38E-06	1.03E-04
Total	2.35E-03	3.16E-03	5.44E-04	4.14E-08	8.14E-04	3.34E-04	1.81E-04	9.99E-02

Table 9.15
Dose from ingestion of aquatic foods taken from contaminated water supplies

Nuclide	Annual Dose to each target organ (mRem/year) Bone	Liver	T. Body	Thyroid	Kidney	Lung	GI-LLI	50 year Effective
Co-58	1.93E-04	2.61E-04	4.48E-05	3.41E-09	6.71E-05	2.75E-05	1.49E-05	7.29E-03
Co-60	1.66E-03	2.24E-03	3.86E-04	2.93E-08	5.77E-04	2.36E-04	1.28E-04	6.27E-02
Mn-54	2.61E-03	3.51E-03	6.05E-04	4.60E-08	9.05E-04	3.71E-04	2.01E-04	1.01E-02
Cs-134	6.72E-03	9.05E-03	1.56E-03	1.18E-07	2.33E-03	9.55E-04	5.17E-04	6.89E-01
Cs-137	3.05E-02	4.11E-02	7.07E-03	5.38E-07	1.06E-02	4.34E-03	2.35E-03	2.13E+00
Ag-110	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb-125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe-55	3.49E-04	4.70E-04	8.08E-05	6.15E-09	1.21E-04	4.96E-05	2.69E-05	2.96E-04
Total	4.20E-02	5.66E-02	9.74E-03	7.41E-07	1.46E-02	5.98E-03	3.24E-03	2.90E+00

Table 9.16
Dose to the sewage treatment plant operator from the sludge thickening tank

The annual dose to the Sewage Treatment Plant worker is estimated at: 0.14 mRem.
See Appendix A for results of the computer analysis.

Table 9.17
Summation of doses

	Annual	50 Year
Total Body	8.57E-01	1.17E+02

(All doses reported in millirem)

Microshield 3.13

Page : 1
File : INSEVAL.MSH
Run date: May 20, 1991
Run time: 3:58 p.m.

File Ref:
Date: 5/20/91
By:
Checked:

CASE: INS Sludge Tank Calculation

GEOMETRY 9: Cylindrical source from side - combination shields

Distance to detector........................	X	1828.8	cm.
Source length................................	L	609.6	"
Dose point height from base..................	Y	304.8	"
Source cylinder radius.......................	T1	457.2	"
Thickness of second shield...................	T2	30.480	"
Thickness of third shield....................	T3	1320.8	"
Thickness of fourth shield...................	T4	20.320	"
Microshield inserted air gap.................	air	0.	"

Source Volume: 4.0032e+8 cubic centimeters

MATERIAL DENSITIES (g/cc):

Material	Source	Shield 2	Shield 3	Shield 4	Air gap
Air			.001220		.001220
Aluminum					
Carbon					
Concrete		2.350		2.350	
Hydrogen					
Iron					
Lead					
Lithium					
Nickel					
Tin					
Titanium					
Tungsten					
Urania					
Uranium					
Water	1.30				
Zirconium					

File: INSEVAL.MSH

CASE: INS Sludge Tank Calculation

BUILDUP FACTOR: based on TAYLOR method.
Using the characteristics of the materials in shield 1.

INTEGRATION PARAMETERS:

Number of lateral angle segments (Ntheta)..... 11
Number of azimuthal angle segments (Npsi)..... 11
Number of radial segments (Nradius)........... 11

SOURCE NUCLIDES:

Nuclide	Curies	Nuclide	Curies	Nuclide	Curies
Ag-110	1.7360e-03	Co-58	1.3068e-02	Co-60	8.9625e-02
Cs-134	9.1700e-03	Cs-137	4.0803e-02	Fe-55	9.4740e-03
Mn-54	1.8375e-02	Sb-125	3.9000e-04		

RESULTS:

Group #	Energy (MeV)	Activity (photons/sec)	Dose point flux MeV/(sq cm)/sec	Dose rate (mr/hr)
1	1.3363	3.329e+09	2.115e-02	3.816e-05
2	1.1795	3.326e+09	1.354e-02	2.517e-05
3	.8161	1.483e+09	1.977e-03	3.961e-06
4	.6024	3.398e+08	1.700e-04	3.517e-07
5	.5286	2.317e+08	7.354e-05	1.509e-07
6	.4273	4.474e+06	5.535e-07	1.133e-09
7	.2891	1.803e+05	2.663e-09	5.324e-12
8	.2139	1.006e+05	2.454e-10	4.605e-13
9	.1795	1.031e+06	7.895e-10	1.418e-12
10	.1172	3.767e+04	6.075e-13	9.589e-16
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
TOTALS:		8.715e+09	3.691e-02	6.779e-05

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