U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

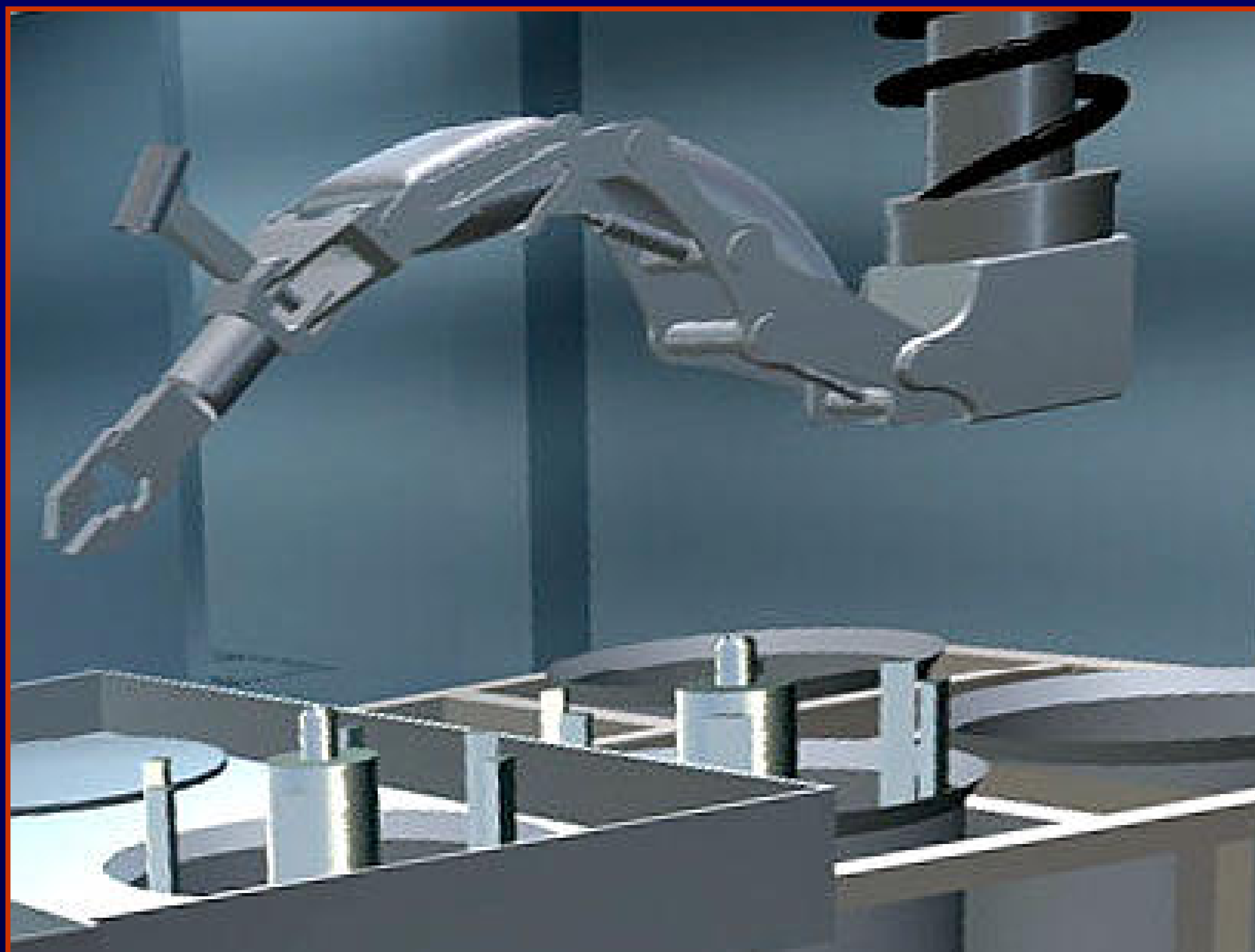
HRTD Human Resources Training & Development

SAMPLE DOSE CALCULATION PROBLEMS

Exposure Pathways to People

- Direct radiation from waste handling
- Inhalation dose from waste handling
- Doses from accidents
- Dose from drinking groundwater

Robotic Arm for Safe Handling of SNF/HLW



Worker Protection – DOE SNF Handling

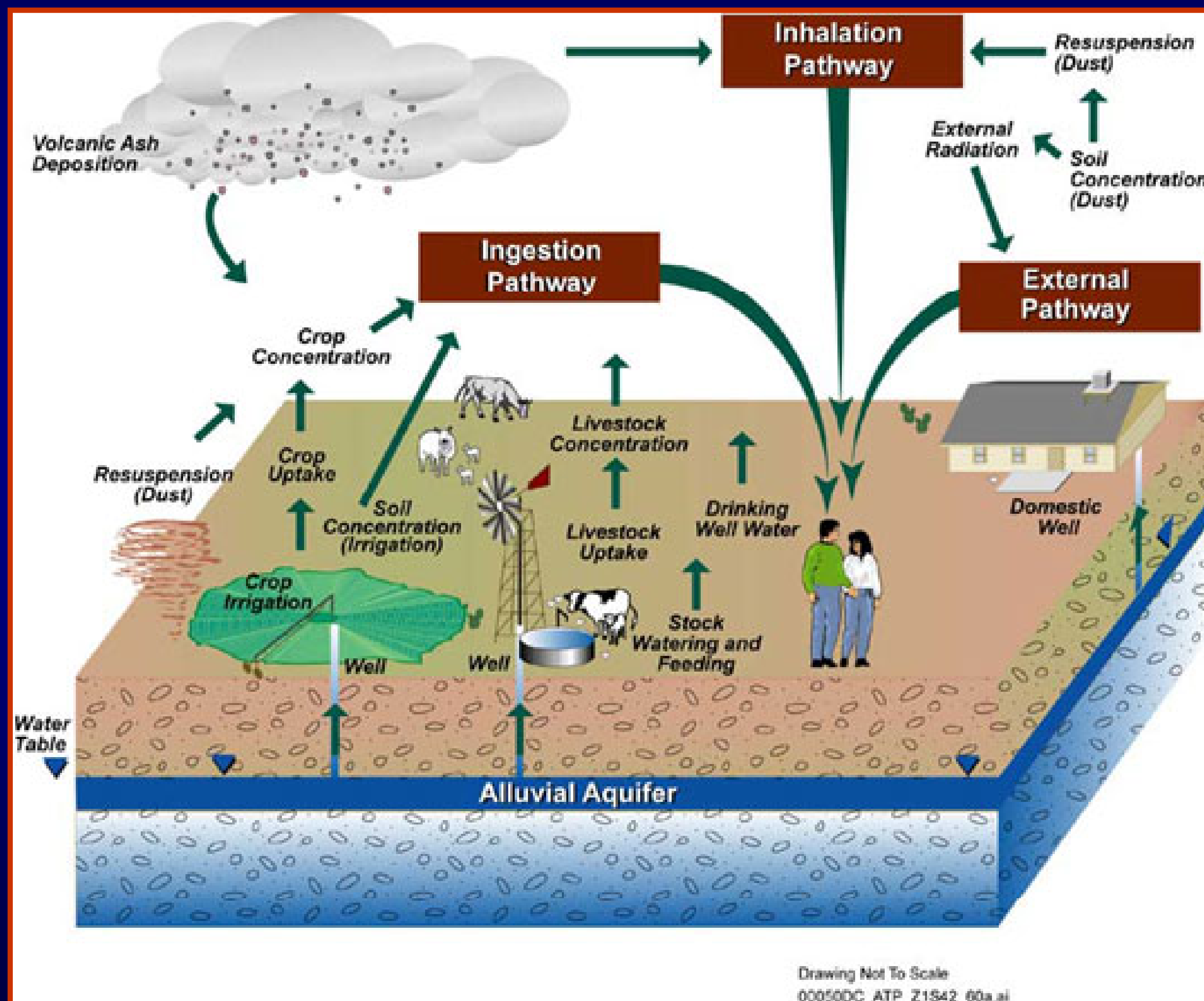
Remote closure welding Seals DOE SNF canister

Reference: National Spent Nuclear Fuel Program (NSNFP)

Yucca Mountain Surface Facilities

Stack emissions a potential source of radiation exposure from waste handling facility

Public Exposure Pathways



DOSE EQUATIONS

Direct Radiation Doses to Workers

Dose (mrem/yr) = Exposure Rate (mrem/hr) x Occupancy Time (hr/yr)

Worker Doses from Inhalation

Dose (mrem/yr) =

Air Concentration (Ci/m^3) x
Breathing Rate (m^3/yr) x
Dose Conversion Factor (mrem/Ci inhaled)

Dose to Public from Inhalation

Dose (mrem/yr) =

Source Term - Q (Ci/yr) x
Dispersion Term - (χ/Q) (sec/m^3) x
Dose Factor - DF (mrem/hr per pCi/L) x
Breathing Rate (m^3/hr) x
Exposure Period (hr/yr) x
Unit Conversion Factors - pCi/Ci , m^3/L and sec/yr

Dose to Public from Drinking Contaminated Groundwater

Dose (mrem/yr) =

Groundwater Concentration (Ci/L) x
Consumption Rate (L/yr) x
DCF (mrem/Ci ingested)

Sample Problem

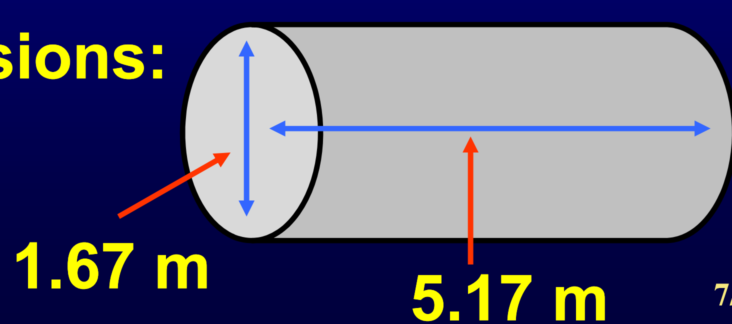
Direct Dose From Waste Package

Assumptions

The following information relative to the 44-BWR Waste Package was obtained from the Yucca Mountain Science and Engineering Report:

- Surface dose rate - 1,405 rem/hr (page 3-33)
- % of total waste in this waste package - 32% (table 3-3)
- Total BWR assemblies - 124,532 (table 3-8)
- MTHM of waste per assembly - 0.177 (table 3-8)
- Assemblies per waste package - 44 (table 3-2)
- Handling pool depth - 15 meters (page 2-47)

44-BWR Package Dimensions:
(Table 3-7 & Fig 3-5)



Assumptions

Doses from waste packages (obtained from the DOE FEIS):

Worker Population	Table	MEI Dose* (rem)	Collective Dose (person-rem)*
Surface	F-46 (operations)		
Involved		15 - 20	4,400 - 11,000
Non-Involved		0	0
Subsurface	F-49 (emplacement)		
Involved		18 - 24	230 - 340
Non-Involved		0.3 - 0.41	4.9 - 7.4

* High/low temperature operating mode – not annual doses

NOTE: Table F-49 is based on Table F-6 which is based on Tables G-4 & G-6 of DIRS 150941 which is not publicly available for review due to Homeland Security concerns

Assumptions

Table F-6. Estimated annual subsurface worker exposures to radiation emanating from waste packages.[a]

Operations phase	Higher-temperature	Lower-temperature: Long-term ventilation	Lower-temperature: Long-term ventilation (natural ventilation after 50 years)	Lower-temperature: Derated waste packages	Lower-temperature: Maximum spacing
Emplacement					
First 24 years (person-rem per year)[b]	6.0	6.0	6.0	8.3	6.0
Latter period of emplacement for aging cases (person-rem per year)[c]	N/A[d]	6.0	N/A	N/A	6.0
Monitoring (person-rem per year)[e]	3.7	3.7	3.7	3.7	3.7
Monitoring for natural ventilation period (person-rem per year)[f]	N/A	N/A	1.07	N/A	N/A
Closure (overall exposure in person-rem)[g]	270	300	300	330	460

a. Numbers are rounded to two significant figures.
b. Sources: Tables G-4 and G-6 of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).
c. For aging cases, it is assumed that 90 full-time equivalent workers are retained for emplacement. Annual exposure levels are assumed to be the same as for the first 24 years.
d. N/A = not applicable.
e. Source: Table G-6 of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).
f. It is assumed that the annual exposure from radiation emanating from the waste packages is reduced by the ratio of full-time equivalent workers for the forced ventilation period to those for the 250-year natural ventilation period. See Tables I-18 and I-18a for long-term ventilation in letter update to the Subsurface Engineering File (DIRS 155515-Williams 2001, all).
g. Values derived from Appendixes G and H of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).

(6.0 person-rem/year x 24 years) = 144 person-rem
(3.7 person-rem/year x 76 years) = 281 person-rem

Sample Problem

Dose to Workers from Radioactive Emissions from Spent Nuclear Fuel and HLW-Dry Handling Scenario

Assumptions

- Unloading and handling of commercial spent nuclear fuel/high level waste during the operation and monitoring periods produces routine radioactive emissions from repository facilities (DOE FEIS, pages G-32 and G-37)

- Radionuclides would be released from a small percentage of fuel elements with pinhole leaks in the cladding (DOE FEIS, page G-38)

Assumptions

- For dry handling, operations are conducted in a shielded, ventilated and filtered facility
- Radioactive particulates are released as well as noble gases such as Kr-85
- Important particulates released include Cs-137, as well as Co-60, Sr-90, and other radionuclides (DOE FEIS, Page A-8)

Assumptions

- For this problem, focus on Cs-137 - Dose calculation methodology is very similar for other radionuclides

- Percentage of failed fuel = 0.25%
  (DOE FEIS, Page G-38)

- For PWR fuel assemblies:
  - Cs-137 inventory = 5.2×10^4 Ci/assembly
  - Burnup = 41,200 MWd/MTHM
  - enrichment = 3.75%
  - decay time = 23 years

(DOE FEIS, Table A-12)

Assumptions

- **For BWR fuel assemblies:**
  - **Cs-137 inventory = 1.6×10^{4} Ci/assembly**
  - **Burnup = 33,600 MWd/MTHM**
  - **enrichment = 3.03%**
  - **decay time = 23 years**

  (DOE FEIS, Table A-13)

- **Total Cs-137 inventory in spent nuclear fuel/HLW = 4.8×10^{9} Ci for Proposed Action**

  (DOE FEIS, Page A-9)

Assumptions

- Proposed action duration = 24 years (DOE FEIS)
- HEPA filtration efficiency on the waste handling facility air exhaust duct = 99.97%
- Fraction of Cs-137 (i.e. volatiles) released due to spent fuel cladding breaches = 2×10^{-4} (NRC SFPO Interim Staff Guidance (ISG)-5, Revision 1, Table 7.1; based on NUREG/CR-6487)

Assumptions

- Workers in the waste handling facility are not exposed to radioactive emissions, due to remote operation (DOE FEIS, page G-30)
- Particulates (and noble gases) are released from a 60 m tall stack as an elevated release (DOE FEIS, page G-32)

Assumptions

- Maximum exposed worker (MEI) is a noninvolved worker at the South Portal
(DOE FEIS, page G-30)

- Neglect Cs-137 decay/deposition in transit from waste handling facility to South Portal
(Cs-137 half-life is 30 years)

- South Portal is about 1.6 miles from waste handling facility (at the North Portal)
(DOE FEIS, Figure 2-10, page 2-20)

Assumptions

- Workers (MEI) are exposed for a period of 2,000 hours/year
  (DOE FEIS, page G-30)

- GENII code used to calculate annual average atmospheric dispersion factors
  (DOE FEIS, page G-32)

Assumptions

- Workers are exposed internally via inhalation of Cs-137 (see supplemental analysis at the end of this problem, regarding air submersion dose from Cs-137)
- Worker breathing rate (Reference Man) = 1.2 m^3/hr
- Dose Conversion Factor (DCF) (CEDE) = 8.63×10^{-9} Sv/Bq for Class D (EPA Federal Guidance Report No. 11)
  NOTE: 6.7 E-09 Sv/Bq if ICRP 68 is used instead.

Assumptions

- Annual average atmospheric dispersion factor (χ/Q) for MEI at South Portal = 1.9×10^{-5} s/m^3 (DOE FEIS, Table G-51)

- Proposed Action: lower temperature, maximum ventilation (DOE FEIS, Table G-51)

Calculation of Cs-137 Source Term

4.8×10^9 Ci x 0.0025 x 2×10^{-4} x 3×10^{-4} x (1/24yr) =

3×10^{-2} Ci/yr

Cs-137 released to the atmosphere outside the fuel handling facility

Calculation of Dose Due to Cs-137 Inhalation - MEI at South Portal

CEDE =

(0.03 Ci/yr) x (10^6 µCi/Ci) x (1.9 x 10^{-5} s/m^3) x
(1 yr/3.15 x 10^7 s) x (8.63 x 10^{-9} Sv/Bq) x
(3.7 x 10^9 mrem/µCi per Sv/Bq) x (1.2 m^3 /hr) x
(2,000 hr/yr) =

1.4 x 10^{-3} mrem/yr from inhalation of Cs-137

RADIOLOGICAL ACCIDENT SCENARIOS

DOE Accident Scenarios

(Information taken from DOE FEIS, Section 4.1.8.1)

Analyzed 10 accident scenarios (both internal and external initiating events)

Calculated consequences for 4 different receptors:

- **maximum exposed hypothetical member of public (MOP) on site boundary**
- **involved workers handling the waste**
- **noninvolved workers near the accident**
- **MOPs living within 80 km of the repository**

DOE Accident Scenarios

- Accidents ranged from relatively high frequency/low consequence (e.g., low level waste drum rupture)
- To low frequency/high consequence (e.g., transporter runaway and derailment)
- Frequency of accidents ranged from 0.59/yr (LLW drum failure in Waste Treatment Building) to 1.2×10^{-7}/yr (transporter runaway and derailment)
- However, dose consequence estimates (doses, latent cancer fatalities (LCFs)) do not appear to explicitly incorporate accident frequency

DOE Accident Scenarios

- drops involving:
  - baskets
  - unsealed disposal containers
  - unsealed shipping casks
  - low-level radwaste drums
    - highest frequency: 0.59/yr;
    - principal radionuclides: ^{60}Co & ^{137}Cs

Sample Problem

Low Level Waste Drum Rupture

Assumptions

- Use methodology in DOE DEIS*, Appendix H, Accidents (page H-26 through H-29)
- Rupture of a LLW drum due to dropping
- ^{60}Co drum inventory = 0.0035 Ci
- ^{137}Cs drum inventory = 0.0015 Ci
- Fraction of drum inventory released = 0.25
- Respirable airborne release fraction = 0.001 (Mueller et. Al., 1996)

* FEIS Appendix H not publicly available

Assumptions

- Dose is calculated to involved workers
- Worker is forklift operator 3 meters from the drum
- Dispersion volume (for inhalation intake) =
  3 m x 3 m x 3 m = 27 m^3
- Breathing rate for worker = 3.5 x 10^{-4} m^3/sec (about 1.2 m^3 per hour)

Assumptions

- Exposure time = 30 seconds
- Drum contents are dry waste form
- Effective DCF for ^{60}Co, Class Y = 5.9×10^{-8} Sv/Bq (EPA FGR No. 11 & ICRP 30)

NOTE: From ICRP 68, 7.1 E-09 Sv/Bq (Type M) or 1.7 E-08 Sv/Bq (Type S)

Assumptions

- Effective DCF for ^{137}Cs, Class D = 8.63×10^{-9} Sv/Bq (EPA FGR No. 11 & ICRP 30)

  NOTE: 6.7 E-09 Sv/Bq if ICRP 68 is used instead (only type F), a difference of only about 22%.

Source Term Calculation

^{60}Co release to air =

(0.0035 Ci) x (0.25) x (0.001) = 8.8×10^{-7} Ci

(DOE number is slightly different, 8.5×10^{-7} Ci)

^{137}Cs release to air =

(0.0015 Ci) x (0.25) x (0.001) = 3.8×10^{-7} Ci

^{60}Co Inhalation Intake Calculation

Intake = $(8.8 \times 10^{-7}\ \text{Ci}) \times (3.5 \times 10^{-4}\ \text{m}^3/\text{s}) \times (30\ \text{s})/(27\ \text{m}^3)$

$= (3.4 \times 10^{-10}\ \text{Ci}) \times (10^{6}\ \mu\text{Ci/Ci})$

$= 3.4 \times 10^{-4}\ \mu\text{Ci}$ of ^{60}Co

^{137}Cs Inhalation Intake Calculation

Intake = $(3.8 \times 10^{-7}\ \mathrm{Ci}) \times (3.5 \times 10^{-4}\ \mathrm{m^3/s}) \times (30\ \mathrm{s})/27\ \mathrm{m^3}$

= $(1.5 \times 10^{-10}\ \mathrm{Ci}) \times (10^{6}\ \mu\mathrm{Ci/Ci})$

= $1.5 \times 10^{-4}\ \mu\mathrm{Ci}$ of ^{137}Cs

Dose from inhalation of ^{60}Co

Dose (CEDE) = $(3.4 \times 10^{-4}\ \mu Ci) \times (5.9 \times 10^{-8}\ Sv/Bq) \times (3.7 \times 10^{9}\ mrem\ per\ \mu Ci\ per\ Sv/Bq)$

$= (7.4 \times 10^{-2}\ mrem) \times (10^{-3}\ rem/mrem)$

$= 7.4 \times 10^{-5}\ rem$

Dose from inhalation of ^{137}Cs

Dose (CEDE) = $(1.5 \times 10^{-4}\ \mu Ci) \times (8.63 \times 10^{-9}\ Sv/Bq) \times (3.7 \times 10^{9}\ mrem\ per\ \mu Ci\ per\ Sv/Bq)$

= $(4.8 \times 10^{-3}\ mrem) \times (10^{-3}\ rem/mrem)$

= $4.8 \times 10^{-6}\ rem$

Total Dose from LLW Drum Rupture

Total Dose (CEDE) = Inhalation dose from ^{60}Co + Inhalation dose from ^{137}Cs

= 7.4×10^{-5} rem + 4.8×10^{-6} rem

= 7.9×10^{-5} rem

Compare this value to DOE number of 7.0×10^{-5} rem on page H-29 of DEIS. Note: Difference may be due to roundoff.

Corresponding number in Table 4-36 of the DOE FEIS is 8.8×10^{-5} rem.

Sample Problem

Committed Dose Equivalent From Drinking Water Containing ^{129}I

Assumptions

- distance to exposed individual = 18 km
- maximum exposed organ = thyroid
- peak I-129 water concentration of 0.12 pCi/L
- water consumption rate = 2 L/day = 730 L/yr
- dose conversion factor (thyroid) = 2.48E-06 Sv/Bq (EPA FGR No. 11 & ICRP 30) 2.1E-06 Sv/Bq (ICRP 72)
- unit conversion factor = 3.7E+09 mrem/μCi per Sv/Bq (EPA FGR No. 11)
- 1 pCi = 1 E-06 μCi

Dose Calculation

CDE = (0.12 pCi/L) x (1 E-06 µCi/pCi) x
(730 L/yr) x (2.48 E-06 Sv/Bq) x
(3.7 E +09 mrem/µCi per Sv/Bq)

= 0.8 mrem/yr to the thyroid

NOTE: CEDE can be calculated using the above methodology and the effective DCF or estimated by (0.8 mrem/yr x 0.03) = 0.024 mrem/yr

THE END