Sequoyah Nuclear Plant
Offsite Dose Calculation Manual
Dates of Revisions

Original ODCM	2/29/80*
Revision 1	4/15/80**
Revision 2	10/7/80**
Revision 3	11/3/80, 2/10/81 4/8/81 and 6/4/81**
Revision 4	11/22/82 (10/22/81, 11/28/81 and 4/29/82**
Revision 5	10/21/82**
Revision 6	1/20/83**
Revision 7	3/23/83**
Revision 8	12/16/83**
Revision 9	3/7/84**

*Low Power license for Sequoyah unit 1
**RARC Meeting date

$$X_i = \sum_{j=1}^{9} \sum_{k=1}^{7} (2/\pi)^{1/2} \frac{f_{jk} Q_i P}{\Sigma_{zk} u_j \ (2\pi x/n)} \exp(-\lambda_i \ x/u_j) \quad (1.1)$$

where

X_i = air concentration of radionuclide i, μ Ci/m³.

f_{jk} = joint relative frequency of occurrence of winds in windspeed class j, stability class k, blowing toward this exposure point, expressed as a fraction.

Q_i = average release rate of radionuclide i, μCi/s.

p = fraction of radionuclide remaining in plume, Figure 1.1.

Σzk= vertical dispersion coefficient for stability class k which includes a building wake adjustment,

$\Sigma zk = (\sigma_{zk}2 + cA/\pi)^{1/2}$, where σ_{zk} is the vertical dispersion coefficient for stability class k (m), c is a building shape factor (c=0.5), and A is the minimum building cross-sectional area (1800 m²), m. 9

u_j= midpoint value of wind speed class interval j, m/s.

x = downwind distance, m.

n = number of sectors, 16.

λ_i = radioactive decay coefficient of radionuclide i, s@-1#.

2 πx/n = sector width at point of interest, m.

For determining the total body dose rate

$$D_{TB} = \sum_i X_i \ DFB_i \quad (1.2)$$

where

D_{TB} = total body dose rate, mrem/y.

X_i = air concentration of radionuclide i, μCi/m³.

DFB_i = total body dose factor due to gamma radiation, mrem/y per μCi/m³ (Table 1.5).

For determining the skin dose rate

$$D_s = \sum_i X_i \ (DFS_i + 1.11 \ DF_{\gamma i}) \qquad (1.3)$$

where

D_s = skin dose rate, mrem/y.

X_i = air concentration of radionuclide i, $\mu Ci/m^3$.

DFS_i = skin dose factor due to beta radiation, mrem/y per $\mu Ci/m^3$ (Table 1.5).

1.11 = the average ratio of tissue to air energy absorption coefficients, mrem/mrad.

DF^{γ}_i = gamma-to-air dose factor for radionuclide i, mrad/y per $\mu Ci/m^3$ (Table 1.5).

B. Equations and assumptions for calculating doses from radioiodines and particulates are as follows:

Assumptions

1. Dose is to be calculated for the critical organ, thyroid, and the critical age group, infant.
2. Exposure pathways from iodines and particulates are milk ingestion, ground contamination, and inhalation.
3. The radioiodine and particulate mix is based on the design objective source term given in Table 1.1.
4. Basic radionuclide data are given in Table 1.2.
5. All releases are treated as ground-level.
6. Meteorological data are expressed as joint-frequency distributions (JFD's) of wind speed, wind direction, and atmospheric stability for the period January 1972 to December 1975 (Table 1.3).
7. Raw meteorological data for ground-level releases consist of wind speed and direction measurements at 10m and temperature measurements at 9m and 46m.
8. Dose is to be evaluated at the potential offsite exposure point where maximum concentrations are expected to exist.
9. Real cow locations are not considered.

This section of the ODCM describes the methodology that will be used to perform these monthly calculations.

Doses will first be calculated by a simplified conservative approach (step 1). If these exceed the specification limits, a more realistic calculation will be performed (step 2).

1.2.1 Noble Gases

Step 1

Doses will be calculated using the methodology described in this step. If any limits are exceeded, step 2 will be performed.

Equations and assumptions for calculating doses from releases of noble gases are as follows:

Assumptions

1. Doses to be calculated are gamma and beta air doses.
2. The highest annual-average X/Q based on licensing meteorology for ground level releases for any offsite location will be used.
3. No credit is taken for radioactive decay.
4. For gamma doses, releases of Xe-131m, Xe-133, Xe-135, Ar-41, and Kr-88 are considered.
5. For beta doses, releases of Xe-131m, Xe-133, Xe-135, Kr-85, and Ar-41 are considered. 3
6. Dose factors are calculated using data from TVA's nuclide library.
7. The calculations extrapolate doses assuming that only 90 percent of total dose was contributed.
8. A semi-infinite cloud model is used.
9. Building wake effects on effluent dispersion are considered.

Equations

For determining the gamma dose to air:

$$D\gamma = \frac{(X/Q)}{0.9} \quad \frac{10^6}{3.15 \times 10^7} \sum_i Q_i \; DF\gamma_i \qquad (1.12)$$

5

where:

$D\gamma$ = gamma dose to air, mrad.

X/Q = highest annual-average relative concentration, 5.12×10^{-6} s/m^3. 9

0.9 = fraction of total gamma dose expected to be contributed by these nuclides. 3

10^6 = µCi/Ci conversion factor

3.15×10^7 = s/yr conversion factor

Q_i = monthly release of radionuclide i, Ci.

$DF\gamma_i$ = gamma-to-air dose factor for radionuclide i, mrad/yr per µCi/m^3 (Table 1.5).

This equation then reduces to

$$D\gamma = 1.81 \times 10^{-7} \sum_i Q_i \; DF\gamma_i \qquad (1.13)$$ 1 5

For determining the beta dose to air:

$$D\beta = \frac{(X/Q)}{0.9} \; \frac{10^6}{3.15 \times 10^7} \sum_i Q_i \; DF\beta_i \qquad (1.14)$$ 5

where:

$D\beta$ = beta dose to air, mrad.

X/Q = highest annual-average relative concentration, 5.12×10^{-6} s/m^3. 9

0.9 = fraction of total beta dose expected to be contributed by these nuclides. 3

10^6 = µCi/Ci conversion factor

3.15×10^7 = s/yr conversion factor

Q_i = monthly release of radionuclide i, Ci. 1

$DF\beta_i$ = gamma-to-air dose factor for radionuclide i, mrad/yr per µCi/m^3 (Table 1.5).

This equation then reduces to:

$$D\beta = 1.81 \times 10^{-7} \sum_i Q_i \; DF_{\beta i} \qquad (1.15)$$ 5

Step 2

This methodology is to be used if the calculations in Step 1 yield doses that exceed applicable limits.

Equations and assumptions for calculating doses to air from releases of noble gases are as follows:

Assumptions

1. Doses to be calculated are gamma and beta air doses.
2. Dose is to be evaluated at the nearest site boundary point in each sector.
3. Historical onsite meteorological data from the period 1972-1975 will be used. 9
4. All measured radionuclide releases are considered.
5. A semi-infinite cloud model is used.
6. Radioactive decay is considered.
7. Building wake effects on effluent dispersion are considered.
8. Dose factors are calculated using data from TVA's radionuclide library.

Equations

Equations for calculating air concentration, X, is the same as in Section 1.1.1, step 1, part A. Air concentrations are calculated for the site boundary in each sector.

For determining the gamma dose to air

$$D_{\gamma n} = t_m \sum_i X_{ni} \, DF\gamma_i \qquad (1.16)$$ 5

where:

$D_{\gamma n}$ = gamma dose to air for sector n, mrad.

X_{ni} = air concentration of radionuclide i in sector n, $\mu Ci/m^3$

$DF_{\gamma i}$ = gamma-to-air dose factor for radionuclide i, mrad/yr per $\mu Ci/m^3$ (Table 1.5). 1

t_m = time period considered, yr

For determining the beta dose to air:

$$D\beta_n = t_m \sum_i x_{ni} \cdot DF\beta_i \qquad (1.17)$$

where:

$D\beta_n$ = beta dose to air for sector n, mrad.

X_{ni} = air concentration of radionuclide i in sector n, $\mu Ci/m^3$

$DF\beta_i$ = beta to air dose factor for radionuclide i, mrad/yr per $\mu Ci/m^3$

t_m = time period considered, yr

The sector having the highest total dose is then used to check compliance with specification 3.11.2.2.

1.2.2 Iodines and Particulates

Step 1

Doses will be calculated using the methodology described in this step. If any limits are exceeded, step 2 will be performed.

Equations and assumptions for calculating doses from releases of iodines and particulates are as follows:

Assumptions

1. Doses are to be calculated for the infant thyroid from milk ingestion and for the child bone and teen g.i. tract from vegetable ingestion. 7

2. Real cow locations are considered for the milk pathway and nearest resident-locations with home-use gardens are considered for the vegetable pathway.

3. The highest annual-average D/Q based on 1972 to 1975 meteorological data for ground level releases will be used for ingestion pathway doses. 6 7

4. No credit is taken for radioactive decay.

5. Releases of I-131 are considered for the milk pathway. Sr-90 releases are considered for the vegetable pathway to the child bone. Co-58 releases are considered for the vegetable pathway to the teen g.i. tract. 7

6. The calculations extrapolate doses assuming that only 90 percent of the total dose was contributed.

7. The cow is assumed to graze on pasture grass for the whole year.

Equations

For determining the thyroid dose from milk ingestion of I-131:

$$DTH_{131} = \frac{Q_{131} \cdot DF_{131} \cdot D/Q}{(0.9)\ 3.15 \times 10^7} \times 10^6 \qquad (1.18)$$ 5

where:

DTH_{131} = thyroid dose from I-131, mrem.

Q_{131} = monthly release of I-131, Ci.

DF_{131} = I-131 milk ingestion dose factor to infant, 7.24×10^{11} mrem/yr per $\mu Ci/m^2$-s (Table 1.7)

D/Q = relative deposition rate, $2.96 \times 10^{-9} m^{-2}$. 9

0.9 = fraction of dose expected to be contributed by I-131.
3.15×10^7 = s/yr.
10^6 = µCi/Ci

Equation 1.18 then reduces to:

$$DTH_{131} = 75.6 \cdot Q_{131}$$ 9

For determining the bone dose from vegetable ingestion:

$$DBC_s = \frac{Q_s\ DF_s\ D/Q \cdot 10^6}{3.15 \times 10^7 (0.9)} \qquad (1.19)$$

where: 5

DBC_s = bone dose to child from Sr-90, mrem.

Q_s = monthly release of Sr-90, Ci.

DF_s = Sr-90 vegetable ingestion dose factor to child,

1.36×10^{13} mrem/yr per $\mu Ci/m^2$-s. (As per Regulatory Guide 1.109 and NUREG/CR-1004 methodologies).

D/Q = relative deposition rate, $7.10 \times 10^{-9} m^{-2}$. 9

3.15×10^7 = s/yr.

10^6 = µCi/Ci.

0.9 = fraction of total bone dose expected to be contributed by Sr-90.

Equation 1.19 then reduces to

$$DBC_s = 3406 \cdot Q_s$$ 9

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For determining the gastrointestinal (g.i.) tract dose from vegetable ingestion:

$$DGI_T = \frac{Q_c \, DF_c \, D/Q \cdot 10^6}{(0.9)\ 3.15 \times 10^7} \qquad (1.20)$$

Where:

DGI_T = teen g.i. tract dose from Co-58, mrem

Q_c = monthly release of Co-58, Ci

DF_c = Co-58 vegetable ingestion dose factor for the teen g.i. tract, 3.87×10^9 mrem/yr per $\mu Ci/m^2$-s. (Regulatory Guide 1.109 and NUREG/CR-1004 methodologies.) 7

D/Q = relative deposition rate, $7.10 \times 10^{-9}\ m^{-2}$ 9

3.15×10^7 = s/yr

10^6 = µCi/Ci

0.9 = fraction of total g.i. tract dose expected to be contributed by Co-58

Equation 1.20 then reduces to

$$DGI_T = 0.97\ Q_c$$ 9

Step 2

This methodology is to be used if the calculations in step 1 yield doses that exceed applicable limits.

Doses for releases of iodines and particulates shall be calculated using the methodology in Section 1.1.1, step 1, part B, with the following exceptions:

1. All measured radionuclide releases will be used.

2. Dose will be evaluated at real cow locations and will consider actual grazing information.

The receptor having the highest total dose is then used to check compliance with specification 3.11.2.3.

Calendar quarter doses are first estimated by summing the doses calculated for each month in that quarter. Calendar year doses are first estimated by summing the doses calculated for each month in that year. However, if the annual doses determined in this manner exceed or approach the specification limits, doses calculated for previous quarters with the methodology of section 1.4 will be used instead of the doses estimated by summing monthly results. 8

1.3 Dose Projections

In accordance with specification 3.11.2.4, dose projections will be performed. This will be done by averaging the calculated dose for the most recent month and the calculated dose for the previous month and assigning that average dose as the projection for the current month.

1.4 Quarterly and Annual Dose Calculations

A complete dose analysis utilizing the total estimated gaseous releases for each calendar quarter will be performed and reported as required in Specifications 6.9.1.8 and 6.9.1.9. Methodology for this analysis is the same as that described in Section 1.1.1, except that real pathways and receptor locations (Table 1.4) are considered. In 9
addition, meteorological data representative of a ground level release for each corresponding calendar quarter will be used. This analysis will replace the estimates in Section 1.2.

At the end of the year an annual dose analysis will be performed by calculating the sum of the quarterly doses to the critical receptors.

1.5 Gaseous Radwaste Treatment System Operation

The gaseous radwaste treatment system (GRTS) described below shall be maintained and operated to keep releases ALARA.

1.5.1 System Description

A flow diagram for the GRTS is given in Figure 1.3. The system consists of two waste-gas compressor packages, nine gas decay tanks, and the associated piping, valves, and instrumentation. Gaseous wastes are received from the following: degassing of the reactor coolant and purging of the volume control tank prior to a cold shutdown, displacing of cover gases caused by liquid accumulation in the tanks connected to the vent header, and boron recycle process operation.

1.5.2 Dose Calculations

Doses will be calculated monthly using the methodology described in Section 1.2. These doses will be used to ensure that the GRTS is operating as designed.

TABLE 1.4

SQN – RECEPTOR LOCATIONS

POINT	SECTOR	DISTANCE (M)	ELEVATION (M)	CHI-OVER-Q (S/M**3)	D-OVER-Q (1/M**2)
1 LAND SITE BOUNDARY	N	950.	-6.	5.12E-06	1.29E-08
2 LAND SITE BOUNDARY	NNE	2260.	-6.	1.93E-06	5.28E-09
3 LAND SITE BOUNDARY	NE	1910.	-6.	2.32E-06	6.33E-09
4 LAND SITE BOUNDARY	ENE	1680.	-6.	1.12E-06	2.64E-09
5 LAND SITE BOUNDARY	E	1570.	-6.	7.10E-07	1.46E-09
6 LAND SITE BOUNDARY	ESE	1460.	-6.	7.91E-07	1.58E-09
7 LAND SITE BOUNDARY	SE	1460.	-6.	9.14E-07	2.41E-09
8 LAND SITE BOUNDARY	SSE	1550.	-6.	1.34E-06	3.23E-09
9 LAND SITE BOUNDARY	S	1570.	-6.	2.37E-06	4.18E-09
10 LAND SITE BOUNDARY	SSW	1840.	-6.	4.51E-06	9.26E-09
11 LAND SITE BOUNDARY	SW	2470.	-6.	1.38E-06	2.63E-09
12 LAND SITE BOUNDARY	WSW	910.	-6.	2.93E-06	3.86E-09
13 LAND SITE BOUNDARY	W	670.	-6.	3.63E-06	3.74E-09
14 LAND SITE BOUNDARY	WNW	660.	-6.	2.49E-06	2.44E-09
15 LAND SITE BOUNDARY	NW	660.	-6.	2.85E-06	3.67E-09
16 LAND SITE BOUNDARY	NNW	730.	-6.	3.95E-06	6.59E-09
17 RESIDENT,GARDEN	N	1370.	0.	2.98E-06	7.10E-09
18 RESIDENT	NNE	2710.	0.	1.49E-06	3.88E-09
19 RESIDENT,GARDEN,BEEF	NE	3430.	15.	1.01E-06	2.33E-09
20 RESIDENT,GARDEN	ENE	2290.	0.	7.13E-07	1.57E-09
21 RESIDENT	E	1790.	8.	5.85E-07	1.18E-09
22 RESIDENT	ESE	1790.	46.	5.86E-07	1.14E-09
23 RESIDENT	SE	1680.	0.	7.42E-07	1.92E-09
24 RESIDENT,GARDEN,BEEF	SSE	2210.	46.	7.99E-07	1.79E-09
25 RESIDENT	S	2020.	0.	1.65E-06	2.75E-09
26 RESIDENT,GARDEN	SSW	2670.	0.	2.66E-06	4.92E-09
27 RESIDENT	SW	3010.	0.	1.04E-06	1.88E-09
28 RESIDENT,GARDEN	WSW	1140.	8.	2.09E-06	2.67E-09
29 RESIDENT,GARDEN	W	1750.	47.	8.53E-07	7.82E-10
30 RESIDENT,GARDEN,COW	WNW	1750.	12.	5.71E-07	4.98E-10
31 RESIDENT	NW	1140.	11.	1.25E-06	1.50E-09
32 RESIDENT	NNW	800.	0.	3.42E-06	5.67E-09
33 GARDEN,BEEF	NNE	3010.	0.	1.28E-06	3.24E-09
34 GARDEN	E	2630.	9.	3.38E-07	6.14E-10
35 GARDEN	ESE	1940.	29.	5.23E-07	9.91E-10
36 GARDEN	SE	3010.	47.	3.19E-07	7.16E-10
37 GARDEN	S	2290.	0.	1.38E-06	2.22E-09
38 GARDEN	SW	3320.	0.	9.10E-07	1.59E-09
39 GARDEN	NW	1180.	11.	1.19E-06	1.42E-09
40 GARDEN	NNW	1750.	17.	1.06E-06	1.59E-09
41 BEEF	ENE	2130.	14.	7.92E-07	1.77E-09
42 BEEF	E	2130.	17.	4.57E-07	8.78E-10
43 BEEF	ESE	3010.	53.	2.76E-07	4.69E-10
44 BEEF	SE	2630.	90.	3.88E-07	9.01E-10
45 BEEF	WSW	2060.	17.	8.78E-07	1.01E-09
46 BEEF	W	680.	0.	3.55E-06	3.65E-09
47 BEEF	WNW	670.	0.	2.43E-06	2.38E-09
48 BEEF	NW	670.	0.	2.78E-06	3.59E-09
49 MILK COW ADULT,BEEF	N	4120.	0.	6.18E-07	1.10E-09
50 MILK COW ADULT	NNE	4380.	0.	7.55E-07	1.69E-09
51 MILK COW ADULT	NE	5220.	47.	5.59E-07	1.12E-09
52 MILK COW ADULT,BEEF	SSW	3580.	6.	1.76E-06	2.96E-09
53 MILK COW ADULT	NW	1980.	5.	5.61E-07	6.09E-10
54 MILK GOAT ADULT	SSE	5340.	29.	2.28E-07	3.89E-10
55 MILK GOAT ADULT	S	5530.	37.	4.07E-07	4.81E-10
56 MILK GOAT TEEN	SE	2940.	61.	3.30E-07	7.46E-10

Table 1.4a Deleted by

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b. During any calendar year to $\leq$ 3 mrem to the total body and to $\leq$ 10 mrem to any organ.

To ensure compliance, cumulative dose calculations will be performed at least once per month according to the following methodology.

2.3.2 Monthly Analysis

Principal radionuclides will be used to conservatively estimate the monthly contribution to the cumulative dose. If the projected dose exceeds the above limits, the methodology in Section 2.3.3 will be implemented. 3

The 11 nuclides (listed below) contribute more than 95 percent of the dose to the total body and the three most critical organs for each pathway. The critical organs considered for fish ingestion are the gastrointestinal tract (GIT), bone, and liver. The critical organs for water ingestion are the GIT, bone, and thyroid. 9 7

H-3	Co-58	Sr-90	Cs-134
P-32	Co-60	Nb-95	Cs-137
Fe-55	Sr-89	I-131	

A conservative calculation of the monthly dose will be done according to the following procedure. First, the monthly operating report containing the release data will be obtained and the activities released of each of the above eleven radionuclides will be noted. This information will then be used in the following calculations. 3

2.3.2.1 Water Ingestion

The dose to an individual from ingestion of water is described by the following equation.

$$D_j = \frac{1}{.95} \sum_{i=1}^{11} (DCF)_{ij} \cdot I_{ij}, \text{ rem} \qquad (2.11)$$

5

where:

D_j = dose for the j^{th} organ from eleven radionuclides, rem

j = the organ of interest (bone GI tract and total body).

.95 = conservative correction factor, considering only eleven radionuclides.

DCF_{ij} = critical ingestion dose commitment factor for the j^{th} organ of adult or child from the i^{th} radionuclide rem/μCi, see attached as Table 2.1.

I_{ij} = monthly activity ingested of the i^{th} radionuclide by the critical age group for the j^{th} organ, μCi. 5

I_{ij} is described by

$$I_{ij} = \frac{A_i V_{ij} (30)}{Fd\,(7.34 \times 10^{10})} \quad ,\mu Ci \qquad (2.12)$$

where:

A_i = activity released of i^{th} radionuclide during the month, μCi.

V_{ij} = maximum individual's water consumption rate corresponding to the age group selected for the critical DCF_{ij} above (Adult: 2000 mL/d, Child: 1400 mL/d; Regulatory Guide 1.109) 5

30 = days per month 3

F = average river flow at Chickamauga Dam for the month (cubic feet per second)

d = fraction of river flow available for dilution (1/5)

7.34×10^{10} = conversion from cubic feet per second to milliliters per month.

The dose equation then becomes

$$D_j = \frac{2.15 \times 10^{-6}}{F} \sum_{i=1}^{11} (V \times DCF)_{ij} \times A_i, \text{ mrem} \qquad (2.13)$$ 5

considering the conversion factor from rem to mrem.