APPENDIX 15B

ACCIDENT DOSE MODEL DESCRIPTIONS

15B.1 OFFSITE DOSE MODEL

This discussion describes the models used to calculate offsite radiological doses that would result from releases of radioactivity due to various postulated accidents.

The following assumptions are used for offsite dose evaluations:

a) The direct dose contribution offsite from any post-accident onsite source point is negligible compared with the direct dose due to immersion in the post-accident effluent cloud.

b) All radioactivity releases are treated as ground level releases regardless of the point of discharge.

c) Isotopic data including decay constants and dose conversion factors are listed in Table 15B-2. The isotopic data listed in Table 15B-2 is obtained from the RADTRAD (Reference 15B-4) computer code which is used to evaluate the radiological consequences of accidents. These dose conversion factors are used to calculate immersion and inhalation doses and are derived from Federal Guidance Report Nos. 11 and 12 (References 15B-6 and 15B-7).

The acceptance criteria for the offsite doses is in terms of Rem TEDE. The determination of TEDE doses takes into account the committed effective dose equivalent (CEDE) dose resulting from the inhalation of airborne activity (the long-term dose accumulation in the various organs) as well as the effective dose equivalent (EDE) dose resulting from immersion in the cloud of activity. The definition of these doses is given in 10CFR20.1003.

The models used to evaluate offsite doses for accidents are as follows:

Immersion Dose (Effective Dose Equivalent)

Assuming a semi-infinite cloud, the immersion doses are calculated using the equation:

$$D_{im} = \sum_i DCF_i \sum_j R_{ij} (\chi / Q)_j \qquad \text{(EQ. 15B-1)}$$

where:

D_{im} = Immersion (EDE) dose (rem)

DCF_i = EDE dose conversion factor for isotope i (rem-m^3/Ci-sec)

R_{ij} = Amount of isotope i released during time period j (Ci)

$(\chi/Q)_j$ = Atmospheric dispersion factor during time period j (sec/m^3)

Inhalation Dose (Committed Effective Dose Equivalent)

The CEDE doses are calculated using the equation:

$$D_{CEDE} = \sum_i DCF_i \sum_j R_{ij} (BR)_j (\chi/Q)_j \qquad \text{(EQ. 15B-2)}$$

where:

D_{CEDE} = CEDE dose (rem)

DCF_i = CEDE dose conversion factor (rem per curie inhaled) for isotope i

R_{ij} = Amount of isotope i released during time period j (Ci)

$(BR)_j$ = Breathing rate during time period j (m^3/sec)

$(\chi/Q)_j$ = Atmospheric dispersion factor during time period j (sec/m^3)

Total Dose (Total Effective Dose Equivalent)

The TEDE doses are the sum of the EDE and the CEDE doses.

15B.2 CONTROL ROOM HABITABILITY ENVELOPE DOSE MODEL

This discussion describes the models used to calculate control room habitability envelope (CRHE) radiological doses that would result from releases of radioactivity due to various postulated accidents.

The acceptance criteria for CRHE doses is in terms of Rem TEDE. The determination of TEDE doses takes into account the committed effective dose equivalent (CEDE) dose resulting from the inhalation of airborne activity (the long-term dose accumulation in the various organs) as well as the effective dose equivalent (EDE) dose resulting from immersion in the cloud of activity. The definition of these doses is given in 10CFR20.1003. The total CRHE TEDE dose is the sum of the EDE and the CEDE doses for all CRHE post-accident radiation sources.

The design basis for the CRHE is to provide adequate radiation protection to permit access to and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem total effective dose equivalent (TEDE) for the duration of the accident. This basis is consistent with 10CFR50.67. Radiation protection for the CRHE is provided by radiation shielding and by an emergency ventilation system.

The CRHE radiation shielding is designed to reduce gamma radiation shine from both normal and post-accident radiation sources to levels consistent with the requirements of 10CFR20 or 10CFR50.67.

The post-accident emergency ventilation system is designed to preclude entrance of unfiltered air to the control room and to maintain outleakage of air from this zone with respect to other plant ventilation zones and the air outside the plant.

Details of control room emergency ventilation system design and instrumentation are discussed in Subsection 9.4.1 and Section 6.4.

During emergency operation, 5810 +/- 10% cfm filtered outside air is supplied to the control structure. In addition to the intake of air through the filter system, some air will enter the control building due to ingress/egress of personnel and via infiltration from other identified leakage paths. An infiltration rate of 10 scfm has been assumed for ingress/egress and 600 cfm for the other unidentified leakage. Credit for operation of the CRHE emergency ventilation system is only taken for the DBA-LOCA and fuel handling/equipment handling accidents. Note that for analyses that do not credit operation of the CRHE emergency ventilation system, 6901 cfm (5810 + 10% cfm + 10 cfm + 500 cfm) of unfiltered inleakage is assumed.

Under accident conditions, radiation doses to control room personnel may result from several sources. While in the control room, personnel are exposed to beta and gamma radiation from gaseous fission products that enter after an accident via the ventilation system or from unfiltered air entering the control room. In addition, personnel may be subject to gamma shine dose from fission products in the containment and reactor building, from contained system sources and from fission products in the atmosphere outside the control room.

To evaluate the capability of the control room ventilation system and radiation shielding to keep doses within the specified criteria, control room doses are evaluated for each of these dose contributors. This analysis includes control room doses from the following radiation sources:

- Contamination of the control room atmosphere by the intake or infiltration of the radioactive material contained in the radioactive plume released from the facility,
- Radiation shine from the external radioactive plume released from the facility,
- Contamination of the control room atmosphere by the intake or infiltration of airborne radioactive material from areas and structures adjacent to the control room envelope,
- Radiation shine from radioactive material in buildings adjacent to the control structure; includes containment, reactor building and turbine building,
- Radiation shine from radioactive material in systems and components inside or external to the control room envelope, e.g., piping, components and radioactive material buildup in HVAC filters.

The short term accident χ/Q's for the SSES Control Room Habitability Envelope (CRHE) were calculated using the methodology provided in NUREG/CR-6331 - ARCON96 (Reference 15B-1) and Regulatory Guide 1.194 (Reference 15B-3). The ARCON96 code uses hourly meteorological data and recently developed methods for estimating χ/Q's in the vicinity of buildings to calculate relative concentrations at control room air intakes that would be exceeded no more than five percent of the time. These concentrations are calculated for averaging periods ranging from one hour to 30 days in duration.

The specific locations requiring ARCON96 χ/Qs for use in the applicable radiological evaluations were:

Turbine Building Unit 1 exhaust vent.
Turbine Building Unit 2 exhaust vent.
Standby Gas Treatment System exhaust vent.
Reactor Building Unit 2 Exhaust Vent

The atmospheric dispersion factors (χ/Q) used in the accident control room dose evaluation are listed in Table 15B-1.

The models used to evaluate CRHE doses for accidents are as follows:

15B.2.1 CRHE IMMERSION DOSES - IN-LEAKAGE OF RADIOACTIVITY

The dose to an individual in the Control Room Habitability Envelope (CRHE) from the in-leakage of radioactivity is calculated based on the time integrated concentration in the control room compartment. The determination of TEDE doses takes into account the committed effective dose equivalent (CEDE) dose resulting from the inhalation of airborne activity (the long-term dose accumulation in the various organs) as well as the effective dose equivalent (EDE) dose resulting from immersion in the cloud of activity.

CRHE immersion doses are calculated using the RADTRAD computer code (Reference 15B-4) and the control room atmospheric dispersion factors given in Table 15B-1. The dose models and methodology are as follows:

Immersion Dose (Effective Dose Equivalent)

Due to the finite volume of air contained in the CRHE, the immersion dose for an operator occupying the main control room is substantially less than it is for the case in which a semi-infinite cloud is assumed. The finite cloud doses are calculated using the geometry correction factor from Murphy and Campe (Reference 15B-6).

The equation is:

$$D_{im} = \frac{1}{GF} \sum_i DCF_i \sum_j (IAR)_{ij} O_j \qquad \text{(EQ. 15B-3)}$$

where:

D_{im} = Immersion (EDE) dose (rem)

GF = Geometry factor = $1173/V^{0.338}$

V = Volume of the CRHE (ft^3)

DCF_i = EDE dose conversion factor for isotope i (rem-m^3/Ci-sec)

$(IAR)_{ij}$ = Integrated activity for isotope i in the main control room during time period j (Ci-sec/m^3)

O_j = Fraction of time period j that the operator is assumed to be present Table 15B-1

Inhalation Dose (Committed Effective Dose Equivalent)

The CEDE doses are calculated using the equation:

$$D_{CEDE} = \sum_i DCF_i \sum_j (IAR)_{ij} (BR)_j O_j \qquad \text{(EQ. 15B-4)}$$

where:

D_{CEDE} = CEDE dose (rem)

DCF_i = CEDE dose conversion factor (rem per curie inhaled) for isotope i

$(IAR)_{ij}$ = Integrated activity for isotope i in the main control room during time period j (Ci-sec/m^3)

$(BR)_j$ = Breathing rate during time period j (m^3/sec)

O_j = Fraction of time period j that the operator is assumed to be present

Total Dose (Total Effective Dose Equivalent)

The TEDE doses are the sum of the EDE and the CEDE doses. THE CRHE dose acceptance criteria is given as 5 Rem TEDE. The TEDE (total effective dose equivalent) is defined as the sum of the external dose equivalent (EDE) from external contamination plus the committed effective dose equivalent (CEDE) from internal contamination in NRC Regulatory Issue Summary 2003-04, Use of the Effective Dose Equivalent in Place of the Deep Dose Equivalent in Dose Assessments (Reference 15B-5).

In order to take credit for the radiation shielding effects of the control structure floors, the EDE portion of the TEDE is adjusted by the ratio of the geometry factor GF for 518,000 ft^3 (volume of CRHE) to the GF for 110,000 ft^3 (volume of control room) or

$GF = 1173. / (518{,}000)^{0.338} = 13.74$

$GF = 1173. / (110{,}000)^{0.338} = 23.19$

and the resulting ratio = 0.59.

15B.2.2 CRHE DIRECT SHINE DOSES

Unprotected doses outside the control room for a DBA-LOCA are calculated using the RADTRAD computer code (Reference 15B-4) and the control room atmospheric dispersion factors given in Table 15B-1. These results serve as input to evaluate the direct shine dose from the post-LOCA effluent cloud.

The direct shine to the control structure from the post-LOCA effluent cloud is evaluated by applying dose reduction factors for control structure radiation shielding to the unprotected whole body gamma dose outside the control room. The cloud shine dose is calculated as follows:

Cloud Shine Dose = D_γ^I (unprotected) X RF

where:

Cloud Shine Dose = Direct dose inside the control structure from the post-LOCA effluent cloud (rem)

D_γ^I (unprotected) = unprotected whole body gamma immersion dose outside the control room (rem)

RF = Direct dose reduction factor for control structure radiation shielding.

= $B\ e^{-\mu x}$

where:

B = buildup factor for shielding configuration

μ = total linear attenuation factor (cm^{-1})

x = thickness of concrete shielding provided by control structure (cm)

Conservatively assuming an average gamma energy of 1.0 Mev, for ordinary concrete:

μ(1.0 Mev) = 0.149 cm^{-1}

The control structure provides a minimum of 2.5 ft of concrete as radiation shielding for the control room from the post-LOCA effluent cloud. For 2.5' of concrete, $Be^{-\mu x} = 3.34 \times 10^{-4}$.

The direct shine CRHE doses from post-accident contained radiation sources are evaluated using source specific shielding design calculations. This includes radiation shine from radioactive material in buildings adjacent to the control structure (containment, reactor building and turbine building) and radiation shine from radioactive material in systems and components inside or external to the CRHE (e.g., piping, components and radioactive material buildup in HVAC filters). Dose rates are evaluated as a function of time post-accident using source terms based on activity transport and leakage assumptions and then are integrated to obtain an effective dose equivalent (rem EDE) for the duration of the accident. Direct shine doses results are combined with immersion and inhalation doses to obtain a total post-accident rem TEDE in the CRHE.

15B.3 REFERENCES

15B-1 NUREG/CR-6331, “Atmospheric Relative Concentrations In Building Wakes”, Revision 1, May 1997 (ARCON96 Computer Code).

15B-2 "Alternative Radiological Source terms For Evaluating Design Basis Accidents At Nuclear Power Reactors”, USNRC Regulatory Guide 1.183, Rev. 0 July 2000.

15B-3 “Atmospheric Relative Concentrations For Control Room Radiological Habitability Assessments At Nuclear Power Plants”, USNRC Regulatory Guide 1.194, June 2003.

15B-4 NUREG/CR-6604, “RADTRAD: A Simplified Model For RADionuclide Transport And Removal And Dose Assessment”, and Supplement 1, 6/8/99.

15B-5 NRC Regulatory Issue Summary 2003-04, “Use Of Effective Dose Equivalent In Place Of Deep Dose Equivalent In Dose Assessments”, 2/13/2003.

15B-6 K.G. Murphy and K.M. Campe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19," 13th AEC Air Cleaning Conference.

15B-7 Federal Guidance Report No. 11, “Limiting Values Of Radionuclide Intake And Air Concentration And Dose Conversion Factors For Inhalation, Submersion, And Ingestion”, 1988 (US Environmental Protection Agency).

15B-8 Federal Guidance Report No. 12, “External Exposure To Radionuclides In Air, Water, And Soil”, 1993 (US Environmental Protection Agency).

TABLE 15.B-1
CONTROL ROOM ATMOSPHERIC DISPERSION FACTORS FOR DESIGN BASIS ACCIDENTS
χ/Q (sec/m^3)

	CRHE χ/Q's (sec/m^3) without Occupancy Correction Factors (1)				
Time Period	0 to 2 hours	2 to 8 hours	8 to 24 hours	1 to 4 days	4 to 30 days
Release Point	RB Unit 2 CRHE Outside Air Intake Location (2)				
TB Unit 1 Exhaust Vent	1.09E-03	8.01E-04	2.89E-04	1.72E-04	1.50E-04
TB Unit 2 Exhaust Vent	1.21E-03	8.76E-04	3.16E-04	1.92E-04	1.61E-04
SGTS Exhaust Vent	1.16E-03	8.64E-04	3.09E-04	1.87E-04	1.60E-04
RB Unit 2 Exhaust Vent	2.29E-03	2.05E-03	8.56E-04	6.13E-04	4.77E-04
Release Point	Outside Control Building Location (3)				
TB Unit 1 Exhaust Vent	4.03E-03	3.61E-03	1.56E-03	1.12E-03	8.71E-04
TB Unit 2 Exhaust Vent	4.72E-03	4.25E-03	1.84E-03	1.32E-03	1.03E-03
SGTS Exhaust Vent	4.15E-03	3.61E-03	1.57E-03	1.12E-03	8.86E-04
RB Unit 2 Exhaust Vent	NA				

NOTES:

(1) Occupancy Correction Factors (Reference 15B-2
1.0 0-24 hrs
0.6 1-4 days
0.4 4-30 days

(2) Values to be used for dose internal to CRHE.

(3) Values to be used for dose external to CRHE. RB Unit Exhaust Vent not used for external cloud dose.

TABLE 15B-2
PHYSICAL DATA FOR ISOTOPES (1)

DOSE CONVERSION FACTORS

Isotope	Half Life (sec)	Whole Body DCF ($Sv\text{-}m^3/Bq\text{-}sec$)	Inhaled Thyroid DCF (Sv/Bq)	Inhaled Effective DCF (Sv/Bq)
Co-58	6.12E+06	4.76E-14	8.72E-10	2.94E-09
Co-60	1.66E+08	1.26E-13	1.62E-08	5.91E-08
Kr-85	3.38E+08	1.19E-16	0.00E+00	0.00E+00
Kr-85m	1.61E+04	7.48E-15	0.00E+00	0.00E+00
Kr-87	4.58E+03	4.12E-14	0.00E+00	0.00E+00
Kr-88	1.02E+04	1.02E-13	0.00E+00	0.00E+00
Rb-86	1.61E+06	4.81E-15	1.33E-09	1.79E-09
Sr-89	4.36E+06	7.73E-17	7.96E-12	1.12E-08
Sr-90	9.19E+08	7.53E-18	2.69E-10	3.51E-07
Sr-91	3.42E+04	4.92E-14	9.93E-12	4.55E-10
Sr-92	9.76E+03	6.79E-14	3.92E-12	2.18E-10
Y-90	2.30E+05	1.90E-16	5.17E-13	2.28E-09
Y-91	5.06E+06	2.60E-16	8.50E-12	1.32E-08
Y-92	1.27E+04	1.30E-14	1.05E-12	2.11E-10
Y-93	3.64E+04	4.80E-15	9.26E-13	5.82E-10
Zr-95	5.53E+06	3.60E-14	1.44E-09	6.39E-09
Zr-97	6.08E+04	4.43E-14	2.32E-11	1.17E-09
Nb-95	3.04E+06	3.74E-14	3.58E-10	1.57E-09
Mo-99	2.38E+05	7.28E-15	1.52E-11	1.07E-09
Tc-99m	2.17E+04	5.89E-15	5.01E-11	8.80E-12
Ru-103	3.39E+06	2.25E-14	2.57E-10	2.42E-09
Ru-105	1.60E+04	3.81E-14	4.15E-12	1.23E-10
Ru-106	3.18E+07	1.04E-14	1.72E-09	1.29E-07
Rh-105	1.27E+05	3.72E-15	2.88E-12	2.58E-10
Sb-127	3.33E+05	3.33E-14	6.15E-11	1.63E-09
Sb-129	1.56E+04	7.14E-14	9.72E-12	1.74E-10
Te-127	3.37E+04	2.42E-16	1.84E-12	8.60E-11
Te-127m	9.42E+06	1.47E-16	9.66E-11	5.81E-09
Te-129	4.18E+03	2.75E-15	5.09E-13	2.09E-11
Te-129m	2.90E+06	3.34E-15	1.56E-10	6.48E-09
Te-131m	1.08E+05	7.46E-14	3.67E-08	1.76E-09
Te-132	2.82E+05	1.03E-14	6.28E-08	2.55E-09

TABLE 15B-2
PHYSICAL DATA FOR ISOTOPES (1)

DOSE CONVERSION FACTORS

Isotope	Half Life (sec)	Whole Body DCF ($Sv\text{-}m^3/Bq\text{-}sec$)	Inhaled Thyroid DCF (Sv/Bq)	Inhaled Effective DCF (Sv/Bq)
I-131	6.95E+05	1.82E-14	2.92E-07	8.89E-09
I-132	8.28E+03	1.12E-13	1.74E-09	1.03E-10
I-133	7.49E+04	2.94E-14	4.86E-08	1.58E-09
I-134	3.16E+03	1.30E-13	2.88E-10	3.55E-11
I-135	2.38E+04	8.29E-14	8.46E-09	3.32E-10
Xe-133	4.53E+05	1.56E-15	0.00E+00	0.00E+00
Xe-135	3.27E+04	1.19E-14	0.00E+00	0.00E+00
Cs-134	6.51E+07	7.57E-14	1.11E-08	1.25E-08
Cs-136	1.13E+06	1.06E-13	1.73E-09	1.98E-09
Cs-137	9.47E+08	2.73E-14	7.93E-09	8.63E-09
Ba-139	4.96E+03	2.17E-15	2.40E-12	4.64E-11
Ba-140	1.10E+06	8.58E-15	2.56E-10	1.01E-09
La-140	1.45E+05	1.17E-13	6.87E-11	1.31E-09
La-141	1.42E+04	2.39E-15	9.40E-12	1.57E-10
La-142	5.55E+03	1.44E-13	8.74E-12	6.84E-11
Ce-141	2.81E+06	3.43E-15	2.55E-11	2.42E-09
Ce-143	1.19E+05	1.29E-14	6.23E-12	9.16E-10
Ce-144	2.46E+07	2.77E-15	2.92E-10	1.01E-07
Pr-143	1.17E+06	2.10E-17	1.68E-18	2.19E-09
Nd-147	9.49E+05	6.19E-15	1.82E-11	1.85E-09
Np-239	2.04E+05	7.69E-15	7.62E-12	6.78E-10
Pu-238	2.77E+09	4.88E-18	3.86E-10	7.79E-05
Pu-239	7.59E+11	4.24E-18	3.75E-10	8.33E-05
Pu-240	2.06E+11	4.75E-18	3.76E-10	8.33E-05
Pu-241	4.54E+08	7.25E-20	9.15E-12	1.34E-06
Am-241	1.36E+10	8.18E-16	1.60E-09	1.20E-04
Cm-242	1.41E+07	5.69E-18	9.41E-10	4.67E-06
Cm-244	5.72E+08	4.91E-18	1.01E-09	6.70E-05

Notes:

(1) All isotopic data contained in this Table is obtained from Reference 15B-4.

TABLE 15B-3

BREATHING RATES

Time Period	Breathing Rate (m^3sec)
0 - 8	3.47-4[1]
8 - 24	1.75-4
24 - 720	2.32-4

(1) 3.47-4 = 3.47×10^{-4}