APPENDIX 15 G

DOSE MODELS USED TO EVALUATE THE CONSEQUENCES OF ACCIDENTS ANALYZED WITH THE ALTERNATIVE SOURCE TERM METHODOLOGY

15G.1 INTRODUCTION

San Onofre Units 2 and 3 are licensed for full scope implementation of the Alternative Source Term (AST) methodology for radiological consequence analyses. All future revisions to radiological analyses performed to show compliance with regulatory requirements shall address all characteristics of the AST and the Total Effective Dose Equivalent (TEDE) criteria of 10CFR50.67.

This Appendix 15G identifies the models used to calculate offsite radiological doses that would result from releases of radioactivity due to various postulated accidents that are credible following permanent cessation of power operations. The models are in accordance with the AST dose analysis methodology of Regulatory Guide (RG) 1.183.

Section 15G.2 summarizes the AST core and fuel rod fission product inventories calculated using the guidance in RG 1.183.

Section 15G.3 summarizes the model used in evaluating offsite dose consequences at the exclusion area boundary (EAB) and at the outer boundary of the low population zone (LPZ). This model is generic to the dose analyses evaluating offsite dose consequences.

15G.2 ACTIVITY INVENTORIES

The core and fuel rod fission product inventories were calculated using the guidance in RG 1.183.

15G.2.1 CORE AND AVERAGE FUEL ROD ACTIVITY INVENTORIES

Table 15G-1 summarizes the parameters modeled in the evaluation of the reactor core activity inventory. These parameters were examined parametrically to maximize the fission product inventory. The period of irradiation is of sufficient duration to allow the activity of dose significant radionuclides to reach equilibrium or to reach maximum values. The core inventory was developed using the SAS2H and ORIGEN-S modules of the SCALE code package. As discussed in RG 1.183, the NRC staff finds the use of isotope generation and depletion computer codes such as ORIGEN acceptable for developing the core inventory of fission products.

Table 15G-1
ACTIVITY INVENTORY MODEL PARAMETERS

PARAMETER	MODELED VALUE
Maximum Core Average Burnup	40.0 GWD/T
Maximum Core Average Enrichment	4.8 w/o U-235
Maximum Core Uranium Loading	95.5 MTU
Core Rated Thermal Power	3,438 MW-t
Core Thermal Power Uncertainty	0.58% actual, 2.0% modeled
Analyzed Core Thermal Power	3,507 MW-t
Minimum Number of Fuel Rods per Core	51,132 rods/core

The ORIGEN-S code was executed for various combinations of core average burnups and enrichments. Each ORIGEN-S code run evaluated the activity inventory in a single fuel assembly. In any code run, the maximum curie value of an isotope represents the sum of the ORIGEN-S code output identified as “Light Elements,” “Fission Products,” and “Actinides”. For each isotope, the maximum curie value from the ORIGEN-S code runs was chosen to represent the inventory of that isotope in the composite fuel assembly. Activity inventories were originated for various isotopes of the elements listed in RG 1.183 Table 5. The maximum full core accident source term was determined by multiplying the composite maximum fuel assembly activity inventory by 217 fuel assemblies per core.

Table 15G-2 summarizes the full core accident source term. The original list of isotopes was reduced to the Table 15G-2 listing of isotopes that are included in the Bechtel LocaDose code isotope library. Per the guidance of RG 1.183 Regulatory Position 4.1.1, the isotope libraries contain all radionuclides, including progeny from the decay of parent radionuclides that are significant with regard to dose consequences and the released radioactivity. The isotopes include all but one of the isotopes listed in the RADTRAD code isotope library as identified in NUREG/CR-6604 Table 1.4.3.3-2 (Reference 1). The missing isotope is Niobium-97m, which is a short-lived daughter of Zirconium-97, and which does not have a dose conversion factor in Federal Guidance Report 11 (Reference 2). Niobium-97m decays to Niobium-97. The code used for the AST analyses conservatively assumes that Zirconium-97 decays directly to Niobium-97.

Table 15G-2 (sheet 1 of 2)
REACTOR CORE ISOTOPE INVENTORY AT SHUTDOWN

ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]
XE-131M	1.22E+06	BR-82	3.43E+05	TE-131M	1.92E+07	SR-94	1.63E+08
XE-133M	6.05E+06	BR-83	1.42E+07	TE-131	7.90E+07	SR-95	1.46E+08
XE-133	1.93E+08	BR-84	2.73E+07	TE-132	1.34E+08	RU-103	1.55E+08
XE-135M	4.06E+07	BR-85	3.12E+07	TE-133M	9.20E+07	RU-105	1.12E+08
XE-135	7.05E+07	BR-87	5.10E+07	TE-133	1.11E+08	RU-106	6.08E+07
XE-137	1.80E+08	BR-88	5.10E+07	TE-134	1.92E+08	RH-103M	1.55E+08
XE-138	1.79E+08	CS-134M	4.56E+06	SB-124	8.79E+04	RH-105	1.02E+08
KR-83M	1.43E+07	CS-134	1.87E+07	SB-125	1.03E+06	RH-106	6.73E+07
KR-85M	3.12E+07	CS-135	5.97E+01	SB-126M	5.13E+04	PD-107	1.32E+01
KR-85	1.09E+06	CS-136	5.58E+06	SB-126	4.37E+04	PD-109	4.06E+07
KR-87	6.38E+07	CS-137	1.25E+07	SB-127	8.57E+06	MO-99	1.80E+08
KR-88	8.98E+07	CS-138	1.90E+08	SB-129	3.06E+07	TC-99M	1.59E+08
KR-89	1.15E+08	CS-139	1.79E+08	SE-79	7.86E+00	TC-99	1.55E+03
I-129	3.62E+00	RB-86	1.90E+05	BA-136M	6.36E+05	TC-101	1.59E+08
I-130	2.50E+06	RB-87	2.54E-03	BA-137M	1.19E+07	CO-57	0.00E+00
I-131	9.37E+07	RB-88	9.20E+07	BA-139	1.82E+08	CO-58	2.21E+05
I-132	1.36E+08	RB-89	1.22E+08	BA-140	1.81E+08	CO-60	4.60E+05
I-133	1.98E+08	RB-90	1.14E+08	BA-141	1.66E+08	LA-140	1.90E+08
I-134	2.26E+08	TE-125M	2.23E+05	SR-89	1.24E+08	LA-141	1.67E+08
I-135	1.87E+08	TE-127M	1.44E+06	SR-90	9.48E+06	LA-142	1.66E+08
I-136	9.20E+07	TE-127	8.48E+06	SR-91	1.53E+08	LA-143	1.63E+08
I-137	9.46E+07	TE-129M	5.95E+06	SR-92	1.55E+08	ZR-93	1.56E+02
I-138	4.73E+07	TE-129	2.91E+07	SR-93	1.68E+08	ZR-95	1.78E+08

Table 15G-2 (sheet 2 of 2)
REACTOR CORE ISOTOPE INVENTORY AT SHUTDOWN

ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]	ISOTOPE	CORE INVENTORY [curies]
ZR-97	1.69E+08	SM-153	5.01E+07	CE-143	1.64E+08	TH-230	0.00E+00
ND-144	0.00E+00	Y-89M	1.33E+05	CE-144	1.29E+08	TH-232	0.00E+00
ND-147	6.55E+07	Y-90M	5.82E+02	PU-236	5.34E+01	TH-234	0.00E+00
EU-152	9.37E+02	Y-90	9.94E+06	PU-237	7.05E+02	U-233	0.00E+00
EU-154	7.68E+05	Y-91M	8.85E+07	PU-238	3.56E+05	TH-229	0.00E+00
EU-155	3.12E+05	Y--91	1.51E+08	PU-239	3.60E+04		
EU-156	2.65E+07	Y-92	1.56E+08	PU-240	5.16E+04		
NB-93M	2.16E+02	Y-93	1.13E+08	PU-241	1.53E+07		
NB-95M	2.05E+06	Y-94	1.75E+08	PU-242	2.50E+02		
NB-95	1.79E+08	Y-95	1.77E+08	PU-243	4.95E+07		
NB-97	1.70E+08	CM-242	5.08E+06	PU-244	0.00E+00		
PM-147	1.87E+07	CM-243	2.26E+03	NP-236	1.24E-03		
PM-148M	3.30E+06	CM-244	3.91E+05	NP-237	4.04E+01		
PM-148	1.84E+07	CM-245	3.06E+01	NP-238	4.67E+07		
PM-149	5.97E+07	CM-246	8.05E+00	NP-239	2.03E+09		
PM-151	1.95E+07	CM-247	4.34E-05	GD-152	0.00E+00		
PR-143	1.58E+08	CM-248	1.97E-04	U-232	0.00E+00		
PR-144M	1.81E+06	AM-241	1.57E+04	U-234	0.00E+00		
PR-144	1.30E+08	AM-242M	1.06E+03	U-236	0.00E+00		
SM-147	1.97E-04	AM-242	9.20E+06	U-237	0.00E+00		
SM-148	0.00E+00	AM-243	2.93E+03	U-238	0.00E+00		
SM-149	0.00E+00	CE-141	1.67E+08	PA-233	0.00E+00		
SM-151	5.14E+04	CE-142	3.19E-03	TH-228	0.00E+00		

Consistent with the guidance of RG 1.183 Regulatory Position 3.1, for events that do not involve the entire core, Table 15G-3 summarizes the average fission product inventory of each damaged fuel rod as determined by dividing the Table 15G-2 total core inventory by the minimum number of fuel rods in the core.

Per RG 1.183 Regulatory Positions 3.2 and 3.4, the only elements to be considered in design basis analyses for non-LOCA events, including fuel handling accidents, are xenon, krypton, iodine, bromine, cesium, and rubidium.

Table 15G-3 (sheet 1 of 2)
AVERAGE FUEL ROD ISOTOPE INVENTORY AT SHUTDOWN

ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]
XE-131M	2.38E+01	BR-82	6.71E+00	TE-131M	3.76E+02	SR-94	3.19E+03
XE-133M	1.18E+02	BR-83	2.78E+02	TE-131	1.54E+03	SR-95	2.86E+03
XE-133	3.78E+03	BR-84	5.35E+02	TE-132	2.62E+03	RU-103	3.04E+03
XE-135M	7.94E+02	BR-85	6.11E+02	TE-133M	1.80E+03	RU-105	2.19E+03
XE-135	1.38E+03	BR-87	9.97E+02	TE-133	2.17E+03	RU-106	1.19E+03
XE-137	3.52E+03	BR-88	9.97E+02	TE-134	3.76E+03	RH-103M	3.03E+03
XE-138	3.50E+03	CS-134M	8.91E+01	SB-124	1.72E+00	RH-105	2.00E+03
KR-83M	2.79E+02	CS-134	3.67E+02	SB-125	2.01E+01	RH-106	1.32E+03
KR-85M	6.11E+02	CS-135	1.17E-03	SB-126M	1.00E+00	PD-107	2.58E-04
KR-85	2.13E+01	CS-136	1.09E+02	SB-126	8.55E-01	PD-109	7.94E+02
KR-87	1.25E+03	CS-137	2.44E+02	SB-127	1.68E+02	MO-99	3.52E+03
KR-88	1.76E+03	CS-138	3.71E+03	SB-129	5.98E+02	TC-99M	3.10E+03
KR-89	2.25E+03	CS-139	3.50E+03	SE-79	1.54E-04	TC-99	3.03E-02
I-129	7.09E-05	RB-86	3.72E+00	BA-136M	1.24E+01	TC-101	3.11E+03
I-130	4.88E+01	RB-87	4.97E-08	BA-137M	2.32E+02	CO-57	0.00E+00
I-131	1.83E+03	RB-88	1.80E+03	BA-139	3.56E+03	CO-58	4.33E+00
I-132	2.67E+03	RB-89	2.38E+03	BA-140	3.54E+03	CO-60	9.00E+00
I-133	3.87E+03	RB-90	2.24E+03	BA-141	3.24E+03	LA-140	3.72E+03
I-134	4.41E+03	TE-125M	4.37E+00	SR-89	2.42E+03	LA-141	3.26E+03
I-135	3.65E+03	TE-127M	2.81E+01	SR-90	1.85E+02	LA-142	3.24E+03
I-136	1.80E+03	TE-127	1.66E+02	SR-91	2.98E+03	LA-143	3.19E+03
I-137	1.85E+03	TE-129M	1.16E+02	SR-92	3.03E+03	ZR-93	3.04E-03
I-138	9.25E+02	TE-129	5.69E+02	SR-93	3.28E+03	ZR-95	3.48E+03

Table 15G-3 (sheet 2 of 2)
AVERAGE FUEL ROD ISOTOPE INVENTORY AT SHUTDOWN

ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]	ISOTOPE	AVG. ROD INVENTORY [curies]
ZR-97	3.31E+03	SM-153	9.80E+02	CE-143	3.21E+03	TH-230	0.00E+00
ND-144	0.00E+00	Y-89M	2.61E+00	CE-144	2.52E+03	TH-232	0.00E+00
ND-147	1.28E+03	Y-90M	1.14E-02	PU-236	1.04E-03	TH-234	0.00E+00
EU-152	1.83E-02	Y-90	1.94E+02	PU-237	1.38E-02	U-233	0.00E+00
EU-154	1.50E+01	Y-91M	1.73E+03	PU-238	6.96E+00	TH-229	0.00E+00
EU-155	6.11E+00	Y-91	2.95E+03	PU-239	7.04E-01		
EU-156	5.18E+02	Y-92	3.06E+03	PU-240	1.01E+00		
NB-93M	4.23E-03	Y-93	2.22E+03	PU-241	2.98E+02		
NB-95M	4.02E+01	Y-94	3.42E+03	PU-242	4.88E-03		
NB-95	3.50E+03	Y-95	3.47E+03	PU-243	9.68E+02		
NB-97	3.32E+03	CM-242	9.93E+01	PU-244	0.00E+00		
PM-147	3.65E+02	CM-243	4.41E-02	NP-236	2.42E-08		
PM-148M	6.45E+01	CM-244	7.64E+00	NP-237	7.89E-04		
PM-148	3.60E+02	CM-245	5.98E-04	NP-238	9.12E+02		
PM-149	1.17E+03	CM-246	1.57E-04	NP-239	3.97E+04		
PM-151	3.81E+02	CM-247	8.49E-10	GD-152	0.00E+00		
PR-143	3.10E+03	CM-248	3.85E-09	U-232	0.00E+00		
PR-144M	3.54E+01	AM-241	3.06E-01	U-234	0.00E+00		
PR-144	2.53E+03	AM-242M	2.07E-02	U-236	0.00E+00		
SM-147	3.85E-09	AM-242	1.80E+02	U-237	0.00E+00		
SM-148	0.00E+00	AM-243	5.73E-02	U-238	0.00E+00		
SM-149	0.00E+00	CE-141	3.26E+03	PA-233	0.00E+00		
SM-151	1.01E+00	CE-142	6.24E-08	TH-228	0.00E+00		

Consistent with RG 1.183 Section 3.1, the fuel handling accident, spent fuel cask drop accident, and spent fuel pool boiling dose analyses model 17 months of radioactive decay prior to an event. Table 15G-4 summarizes the average fuel rod isotope inventory for use in these AST dose analyses. Table 15G-4 determines the fission product inventory of an average fuel rod following cessation of power operations by decaying the Table 15G-3 average rod inventory for 17 months.

Per RG 1.183 Regulatory Positions 3.2 and 3.4, the only elements to be considered in design basis analyses for fuel handling accidents are xenon, krypton, iodine, bromine, cesium, and rubidium. The limited number of elements listed in Table 15G-4 is consistent with RG 1.183 Appendix B Section 3, which indicates that particulate radionuclides (i.e., cesium and rubidium) are retained by the water in the fuel handling building fuel storage pool.

TABLE 15G-4: AVERAGE FUEL ROD ISOTOPE INVENTORY
AT 17 MONTHS POST-SHUTDOWN

ISOTOPE	AVERAGE FUEL ROD INVENTORY 17 MONTHS AFTER SHUTDOWN [curies]
BR-82	0.0
BR-83	0.0
I-129	7.09E-05
I-130	0.0
I-131	1.49E-16
I-132	0.0
I-133	0.0
I-134	0.0
I-135	0.0
KR-83m	0.0
KR-85m	0.0
KR-85	1.95E+01
KR-87	0.0
KR-88	0.0
XE-131m	2.16E-12
XE-133m	0.0
XE-133	2.17E-26
XE-135	0.0

In addition to the average fuel rod isotope inventory listed in Table 15G-4, the spent fuel pool boiling dose analysis considers a release of tritium from damaged fuel rods. The tritium content in a single fuel rod at 17 months post-shutdown is 1.49 curies.

15G.2.2 RADIAL PEAKING FACTOR

Consistent with the guidance of RG 1.183 Regulatory Position 3.1, to account for differences in power level across the core, radial peaking factors (RPFs) are applied to the Tables 15G-3 and 15G-4 average fuel rod isotope inventories in determining the activity inventory of the damaged fuel rods.

15G.3 OFFSITE DOSE MODEL

Regulatory Guide 1.183 Regulatory Position 4.1 provides guidance to be used in determining the total effective dose equivalent for persons located at or beyond the exclusion area boundary, including the outer boundary of the low population zone. This section addresses the applicability of this guidance to the dose analyses as it relates to the offsite dose exposure parameters.

The characteristics of the offsite dose exposure parameters as modeled in the AST dose analyses are summarized in Tables 15G-7 and 15G-8 for the EAB and LPZ dose receptors, respectively. The dose conversion factors are consistent with those documented in Federal Guidance Reports (FGR) 11 and 12.

TABLE 15G-7
EAB DOSE EXPOSURE PARAMETERS

EXCLUSION AREA BOUNDARY PARAMETER	MODELED VALUE
EAB dose acceptance criterion, Rem TEDE	Varies by event
EAB dose exposure duration, hours	2-hour window
Committed effective dose equivalent (CEDE) dose conversion factors	Per FGR-11
Effective dose equivalent (EDE) dose conversion factors	Per FGR-12
EAB breathing rate, event duration, m^3/second	3.5E-04
EAB atmospheric dispersion factor, event duration, seconds/m^3	2.72E-04

TABLE 15G-8
LPZ DOSE EXPOSURE PARAMETERS

LOW POPULATION ZONE PARAMETER	MODELED VALUE
LPZ dose acceptance criterion, Rem TEDE	Varies by event
LPZ dose exposure duration, hours	Event Duration
Committed effective dose equivalent (CEDE) dose conversion factors	Per FGR-11
Effective dose equivalent (EDE) dose conversion factors	Per FGR-12
LPZ breathing rates, m^3/second 0 to 8 hours 8 to 24 hours 1 day to end of event	 3.5E-04 1.8E-04 2.3E-04
LPZ atmospheric dispersion factors, seconds/m^3 0 to 8 hours 8 to 24 hours 1 to 4 days 4 days to end of event	 7.72E-06 4.74E-06 3.67E-06 2.67E-06

Consistent with RG 1.183 Regulatory Position 4.1.1, the offsite dose calculations determine the total effective dose equivalent (TEDE), which is the sum of the committed effective dose equivalent (CEDE) from inhalation and the deep dose equivalent (DDE) from external exposure. Consistent with RG 1.183 Regulatory Position 4.1.4, the effective dose equivalent (EDE) from external exposure is used in lieu of DDE in determining the contribution of external dose to the TEDE. The calculation of the CEDE and EDE components of the TEDE consider all radionuclides identified in section 15G.2, including progeny from the decay of parent radionuclides, that are significant with regard to dose consequences and the released radioactivity.

Consistent with RG 1.183 Regulatory Position 4.1.2, the AST analyses model CEDE inhalation dose conversion factors taken from the column headed “effective” in Table 2.1 of Federal Guidance Report 11 (Reference 2).

Consistent with RG 1.183 Regulatory Position 4.1.3, for the first 8 hours, the breathing rate of persons at the outer boundary of the LPZ is assumed to be 3.5E-4 cubic meters per second. From 8 to 24 hours following the accident, the breathing rate is assumed to be 1.8E-4 cubic meters per second. After that and until the end of the accident, the rate is assumed to be 2.3E-4 cubic meters per second. The breathing rate for persons at the EAB is assumed to be 3.5E-4 cubic meters per second for the event duration.

Consistent with RG 1.183 Regulatory Position 4.1.4, the AST analyses model EDE external exposure dose conversion factors taken from the column headed "effective" in Table III.1 of Federal Guidance Report 12 (Reference 3).

Consistent with RG 1.183 Regulatory Positions 4.1.5, 4.1.6 and 4.4, the radiological criteria for the EAB and for the outer boundary of the LPZ are in 10CFR50.67. These criteria are stated for evaluating reactor accidents of exceedingly low probability of occurrence and low risk of public exposure to radiation (e.g., a large-break LOCA). For events with a higher probability of occurrence, postulated EAB and LPZ doses should not exceed the criteria tabulated in RG 1.183 Table 6.

Consistent with RG 1.183 Regulatory Position 4.1.5, the maximum EAB TEDE for any two-hour period following the start of the radioactivity release is determined and used in determining compliance with the dose criteria. The dose code used in the AST dose analyses determines the maximum two-hour TEDE at the EAB by calculating the postulated dose for a series of small time increments and performing a "sliding" sum over the increments for successive two-hour periods. The time increments appropriately reflect the progression of the accident to capture the peak dose interval between the start of the event and the end of radioactivity release.

The AST dose analyses for exposure to individuals at the EAB and LPZ consider immersion of the individual in the radioactive plume released from the facility. Consistent with RG 1.183 Regulatory Position 5.3, the atmospheric dispersion values for the EAB and the LPZ that were approved by the NRC staff during initial facility licensing are used in performing the AST radiological analyses. These atmospheric dispersion factors for the EAB and LPZ are presented in Tables 15G-7 and 15G-8 for the EAB and LPZ, respectively. Consistent with RG 1.183 Regulatory Position 4.1.7, no correction is made for depletion of the effluent plume by deposition on the ground.

Radioactive material contained in a plant structure is assumed to be a negligible radiation shine source to the offsite dose receptors relative to the dose associated with immersion in the radioactive plume (i.e., environmental cloud) released from the facility.

REFERENCES

1. NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation," prepared by S.L. Humphreys, T.J. Heames, L.A. Miller, and D.K. Monroe, Sandia National Laboratories, April 1998.

2. Federal Guidance Report No. 11, EPA 520/1-88-020, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," prepared by K.F. Eckerman, A.B. Wolbarst, and A.C.B Richardson, U.S. Environmental Protection Agency, 1988.

3. Federal Guidance Report No. 12, EPA 402-R-93-081, "External Exposure to Radionuclides in Air, Water, and Soil, Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance," prepared by K.F. Eckerman and J.C. Ryman, U.S. Environmental Protection Agency, 1993.