7.2 Severe Accidents

As stated in NUREG-1555, "Severe accidents are those involving multiple failures of equipment or function and, therefore, the likelihood of occurrence is lower for severe accidents than for Design Bases Accidents, but the consequences of such accidents may be higher." Because the probability of a severe accident is very low for the ABWR, severe accidents are not part of the design basis for the plant. However, NRC requires, in its Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants (50 FR 32138), the completion of a probabilistic risk assessment (PRA) for severe accidents for new reactor designs. This requirement is codified under 10 CFR 52.47.

GE completed a PRA as part of the Standard Safety Analysis Report (SSAR), Amendment 35 for the ABWR design (Reference 7.2-1). The ABWR design was prepared as part of GE's application for design certification. NRC reviewed the ABWR design and the review was documented in NUREG-1503 (Reference 7.2-2). NRC has certified the ABWR design, concluding that the ABWR is of a robust design, and that the design meets NRC's safety goals.

The GE PRA for the ABWR established a containment event tree that defined the possible end states of the containment following a severe accident. These end states can logically be grouped to produce 10 source term categories that represent the entire suite of potential severe accidents. An accident frequency was assigned to each of the 10 source term categories.

GE then used the CRAC-2 (Calculations of Reactor Accident Consequences, Reference 7.2-3) code to model the environmental consequences of the severe accidents using the generic meteorology, population, and evacuation characteristics as described in Section 19E.3 of the Standard Safety Analysis Report (Reference 7.2-1). CRAC-2 is a revision of the CRAC program developed in support of NRC's Reactor Safety Study (often referred to as WASH-1400) to assess the risk from potential accidents at nuclear power plants.

7.2.1 STP-Specific Analysis

STPNOC has updated the generic analysis by including site-specific characteristics of the STP site. The purpose of this STP-specific analysis is two fold: 1) to disclose the impacts of severe accidents, and 2) to support the severe accident mitigation alternatives (SAMA) analyses presented in Section 7.3.

To evaluate site-specific consequences of severe accidents, STPNOC used the MACCS2 (MELCOR Accident Consequence Code System, Version 2) computer code, which was developed by NRC for this purpose (Reference 7.2-4). The pathways modeled include external exposure to the passing plume, external exposure to material deposited on the ground, inhalation of material in the passing plume or resuspended from the ground, and ingestion of contaminated food and surface water. The MACCS2 code primarily addresses the dose from the air pathway, but also calculates the dose from surface runoff and deposition on surface water. The MACCS2 code also evaluates the extent of contamination.

To assess human health impacts from severe accidents, STPNOC determined the collective dose to the 50-mile population, the number of late cancer fatalities, and the number of early fatalities associated with a severe accident. A 50-mile circular area is the standard range used in modeling consequences to the offsite population from an airborne release. Economic costs were also determined, including the cost of emergency response actions and long-term protective actions. Emergency response costs include compensation for evacuees and relocated people who are removed from their homes as a result of radiation exposure during the course of the accident (food, housing, transportation, and lost income). Longer-term protective action costs within a 50-mile radius include:

- Costs of interdiction of farms, residences, and food
- Decontamination of farm and residential land
- Permanent condemnation of residential and farm land, milk, and crops

Five files provide input to a MACCS2 analysis. The first three are as follows:

- ATMOS provides data to track the material released to the atmosphere as it is dispersed and deposited. The calculation uses a Gaussian plume model. Important inputs in this file include the core inventory, release fractions, and geometry of the reactor and associated buildings. To the extent possible, the input data are the same as those in the GE CRAC-2 input files in the generic probabilistic risk assessment.
- EARLY provides inputs to calculations regarding exposure in the time period immediately following the release. Important site-specific information includes emergency response information such as evacuation time.
- CHRONC provides data for calculating long-term impacts and economic costs and includes region-specific data on agriculture and economic factors.

These MACCS2 files access:

- A meteorological file, which uses actual STP meteorological monitoring data.
- A site characteristics file that is built using SECPOP2000 (Reference 7.2-5). SECPOP2000 incorporates 2000 census data for the 50-mile region around the STP site. For this analysis, the census data were modified to include transient populations and were projected to the year 2060. All releases are modeled as occurring at ground level.

The results of the MACCS2 analysis and accident frequency information from GE (Reference 7.2-6) were used to determine risk, which is the product of the frequency of an accident and the consequences of the accident. The sum of the accident frequencies is known as the core damage frequency and includes only internally initiated events. The consequence can be either collective radiation dose or economic cost. Dose-risk is the product of the radiation dose and the accident frequency. Because the ABWR's severe accident analysis addressed a suite of accidents, the individual risks are added to provide a total risk. The same process was applied to estimating cost-risk. Therefore, risk can be reported as person-rem per reactor year or dollars per reactor year.

7.2.2 Consequences to Population Groups

The pathway consequences to population groups including air pathways, surface water, and groundwater pathways are discussed in the following sections. The presence of threatened and endangered species and federally designated critical habitat are discussed in Subsections 2.4.1 and 2.4.2. The impacts on threatened and endangered species due to the previously calculated radiation exposure levels are discussed in Subsection 5.4.4.

7.2.2.1 Air Pathways

Each of the accident categories was analyzed with MACCS2 to estimate population dose, number of early and latent fatalities, cost, and farm land requiring decontamination. The analysis assumed that 95% of the 50-mile population was evacuated following declaration of a general emergency. For each accident category, the risk for each analytical endpoint was calculated by multiplying the analytical endpoint by the accident category frequency and adding across all accident categories. The results are provided in Table 7.2-1.

7.2.2.2 Surface Water Pathways

People can be exposed to radiation when airborne radioactivity is deposited onto the ground and runs off into surface water or is deposited directly onto surface water. The exposure pathway can be from drinking the water, submersion in the water (swimming), undertaking activities near the shoreline (fishing and boating), or ingestion of fish or shellfish. For the surface water pathway, MACCS2 only calculates the dose from drinking the water. The maximum MACCS2 severe accident dose-risk to the 50-mile population from drinking the water is 3.4×10^{-4} person-rem per year of ABWR operation. This value is included in the air pathways dose (Table 7.2-1) and is the sum of all accident category risks.

Surface water bodies within the 50-mile region of the STP site that are accessible to the public include the Colorado River, the Gulf of Mexico, and other smaller water bodies. In NUREG-1437, the NRC evaluated doses from the aquatic food pathway (fishing) for the current nuclear fleet of reactors (Reference 7.2-7). For sites discharging to small rivers, the NRC evaluation estimated the uninterdicted aquatic food pathway dose risk as 0.4 person-rem per reactor year. For sites near large water bodies, values ranged from 270 person-rem per reactor year (Hope Creek on Delaware Bay) to 5500 person-rem per reactor year (Calvert Cliffs on Chesapeake Bay). Although the STP site is not specifically identified in this NUREG-1437 analysis, it would more likely fall between the small river analysis and the least impactive large water body analysis (Hope Creek), given the STP site's distance from nearby major water bodies (6 to 10 miles). Actual dose-risk values would be expected to be much less (by a factor of 2 to 10) due to interdiction of contaminated foods (Reference 7.2-7). Furthermore, because the ABWR atmospheric pathway doses are significantly lower than those of the current nuclear fleet, it is reasonable to conclude that the doses from surface water sources would be consistently lower than those reported above for the surface water pathway.

Surface water pathways involving submersion in the water and undertaking activities near the shoreline are not modeled by MACCS2. Neither does NUREG-1437 provide specific data on submersion and shoreline activities. However, it does indicate that these contributors to dose are much less than for drinking water and consuming aquatic foods, especially at estuary sites.

7.2.2.3 Groundwater Pathways

People can also receive a dose from groundwater pathways. Radioactivity released during a severe accident can enter groundwater or can move through an aquifer that eventually discharges to surface water. The consequences of a radioactive spill are evaluated in COLA Part 2, FSAR Subsection 2.4S.13 and the results show that if radioactive liquids were released directly to groundwater, the isotopic concentrations would be below 10 CFR 20 effluent limits before they reached a drinking water receptor.

NUREG-1437 also evaluated the groundwater pathway dose, based on the analysis in NUREG-0440, the Liquid Pathway Generic Study (LPGS) (Reference 7.2-8). NUREG-0440 analyzed a core meltdown that contaminated groundwater that subsequently contaminated surface water. However, NUREG-0440 did not analyze direct drinking of groundwater because of the limited number of potable groundwater wells and limited accessibility.

The LPGS results provide conservative, uninterdicted population dose estimates for six generic categories of plants. These dose estimates were one or more orders of magnitude less than those attributed to the atmospheric pathway. NUREG-1437 compares STP 1 & 2 groundwater pathway severe accident doses to the results of NUREG-0440 with results very much less than the LPGS value. (STP is analyzed as a small river plant in Table 5.18 of NUREG-1437.) Since the LPGS values were very much less than the atmospheric pathway, it is reasonable to conclude that the atmospheric pathway dominates the groundwater pathways at the STP site. The proposed location for STP 3 & 4 has the same groundwater characteristics as the location for STP 1 & 2. The severe accident frequency for the ABWR (1.5×10^{-7} per reactor year) is lower than that of STP 1 & 2 (1×10^{-5} per reactor year). Therefore, the doses from the STP 3 & 4 groundwater pathway would be smaller than from the existing units.

7.2.3 Comparison to NRC Safety Goals

The ABWR SSAR (Reference 7.2-1) evaluates performance of the ABWR under generic conditions to three safety goals: (1) individual risk goal, (2) societal risk goal, and (3) radiation risk goal. These goals are defined in the following subsections.

7.2.3.1 Individual Risk Goal

The risk to an average individual in the vicinity of a nuclear power plant of experiencing a prompt fatality resulting from a severe reactor accident should not exceed one-tenth of one percent (0.1%) of the sum of "prompt fatality risks" resulting from other accidents to which members of the U.S. population are generally exposed. As noted in the Safety Goals Policy statement (51 FR 30028), "vicinity" is defined as the area within one mile of the plant site boundary. "Prompt Fatality Risks" are defined as the sum of risks which the average individual residing in the vicinity of the plant is exposed to as a result of normal daily activities (driving, household, chores, occupational activities, etc.). For this evaluation, the sum of prompt fatality risks was taken as the U.S. accidental death risk value of 36.9 deaths per 100,000 people per year (Reference 7.2-9).

7.2.3.2 Societal Risk Goal

The risk to the population in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1%) of the sum of the cancer fatality risks resulting from all other causes. As noted in the Safety Goal Policy Statement (51 FR 30028), “near” is defined as within 10 miles of the plant. The cancer fatality risk was taken as 187.5 deaths per 100,000 people per year based upon National Center for Health Statistics and U.S. Census Bureau data for 2002-2004 (Reference 7.2-9, Reference 7.2-10, Reference 7.2-11, and Reference 7.2-12).

7.2.3.3 Radiation Dose Goal

The probability of an individual exceeding a whole body dose of 0.25 sievert at a distance of one-half mile from the reactor shall be less than one in a million per reactor year.

Table 7.2-2 provides the quantitative evaluation of these three safety goals, the generic ABWR calculation of these risk values, and the STP-specific calculation of these risk values.

7.2.4 Conclusions

The total calculated dose-risk to the 50-mile population from airborne releases from an ABWR reactor at the STP site would be 0.0043 person-rem per reactor year (Table 7.2-1). This value is less than the value calculated by GE in the Technical Support Document for the ABWR (Reference 7.2-6); 0.269 person-rem for 60 years plant life, which is equal to 4.48×10^{-3} person-rem per reactor year), less than the population risk for all current reactors that have undergone license renewal, and less than that for the five reactors analyzed in NUREG-1150 (Reference 7.2-13), which range from 50 to 5,000 person-rem per reactor year for dose-risk. As reported in NUREG-1811 (Reference 7.2-14), the lowest dose-risk for reactors currently undergoing license renewal is 0.55 person-rem per reactor year.

Comparisons with the existing nuclear reactor fleet (Subsection 7.2.3.2) indicate that risk from the surface water pathway is small. Under the severe accident scenarios, surface water is primarily contaminated by atmospheric deposition. The ABWR atmospheric pathway doses are significantly lower than those of the current nuclear fleet. Therefore, it is reasonable to conclude that the doses from the surface water pathway at STP 3 & 4 would be consistently lower than those reported in Subsection 7.2.3.2 for the current fleet.

The risks of groundwater contamination from a severe ABWR accident (see Subsection 7.2.2.3) would be much less than the risk from currently licensed reactors. Additionally, interdiction could substantially reduce the groundwater pathway risks.

For comparison, as reported in Section 5.4, the total collective dose from STP 3 & 4 normal airborne releases is expected to be 0.5 person-rem annually. As previously described, dose-risk is dose times frequency. Normal operations have a frequency of one. Therefore, the dose-risk for normal operations is 0.5 person-rem per reactor year. Comparing this value to the severe accident dose-risk of 0.0043 person-rem per reactor year indicates that the dose risk from severe accidents is approximately 0.9 percent of the dose risk from normal operations.

The probability-weighted risk of cancer fatalities (early and late) from a severe accident for STP 3 or 4 is reported in Table 7.2-1 as 2.6×10^{-6} fatalities per reactor year. The probability of an individual dying from any cancer from any cause is approximately 0.23 over a lifetime. Comparing this value to the 2.6×10^{-6} fatalities per reactor year indicates that individual risk is 0.0011% of the background risk, which is less than 0.1% of the background risk.

7.2.5 References

7.2-1 "Deterministic Evaluations," Chapter 19E, ABWR Standard Safety Analysis Report, Amendment 35, General Electric.

7.2-2 "Final Safety Evaluation Report Related to Certification of the Advanced Boiling Water Reactor Design," NUREG-1503, July 1994.

7.2-3 "Calculations of Reactor Accident Consequences Version 2, CRAC2: Computer Code User's Guide," NUREG/CR-2326, February 1983.

7.2-4 "Code Manual for MACCS2: User's Guide," NUREG/CR-6613, SAND97-0594, Volume 1, Chanin, D. I. and M. L. Young, Sandia National Laboratories, Albuquerque, New Mexico, May 1998.

7.2-5 "SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program," NUREG/CR-6525, Rev. 1, August 2003.

7.2-6 "Technical Support Document for the ABWR," Revision 1, MPL No. A90-3230, General Electric, San Jose, California, November 18, 1994.

7.2-7 "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," NUREG-1437, May 1996.

7.2-8 "Liquid Pathway Generic Study: Impacts of Accidental Radioactive Releases to the Hydrosphere from Floating and Land-Based Nuclear Power Plants," NUREG-0440, February 1978.

7.2-9 "Table A. Deaths percentage of total deaths, death rates, and age-adjusted death rates for the 15 leading causes of death in 2002," National Vital Statistics Report, CDC, United States, Volume 54, Number 10, January 31, 2006. Available at http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_10.pdf, accessed May 7, 2007.

7.2-10 GCT-T1-R. Population Estimates, 2006 Population Estimates, USCB (U.S. Census Bureau). Available at http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=01000US&-_box_head_nbr=GCT-T1-R&-ds_name=PEP_2006_EST&-_lang=en&-format=US-9S&-_sse=on, accessed May 7, 2007.

7.2-11 "Table 10. Number of Deaths from 113 Selected Causes, by Age: United States 2003," National Vital Statistics Report, Volume 54, Number 13, April 19, 2006, CDC. Available at http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_13.pdf, accessed May 7, 2007.

7.2-12 "Table 1. Deaths, Age-Adjusted Death Rate, and Life Expectancy at Birth, by Race and Sex, and Infant Death Mortality Rates, by Race: United States 2003 and 2004," National Center for Health Statistics, CDC. Available at http://www.cdc.gov/nchs/products/pubs/pubd/hestats/finaldeaths04/finaldeaths04_tables.pdf#2, accessed May 7, 2007.

7.2-13 "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, June 1989.

7.2-14 "Environmental Impact Statement for an Early Site Permit (ESP) at the North Anna ESP Site," NUREG 1811, December 2006.

Table 7.2-1 Impacts to the Population and Land from Severe Accidents Analysis

Environmental Risk from Airborne Releases					
		Number of Fatalities (per reactor year)			
Year of Meteorological Data	Population Dose-Risk (person-rem per reactor year)	Early	Late	Cost in Dollars (per reactor year)	Land Requiring Decontamination (acres per reactor year)
1997	4.2×10^{-3}	**4.8×10^{-13}**	2.5×10^{-6}	2.5	1.6×10^{-4}
1999	4.2×10^{-3}	4.4×10^{-13}	2.5×10^{-6}	2.2	1.6×10^{-4}
2000	**4.3×10^{-3}**	3.7×10^{-13}	**2.6×10^{-6}**	**2.6**	**1.8×10^{-4}**

NOTE: Bold print represents the highest value among the three years considered

Table 7.2-2 Comparison to NRC Safety Goals

Safety Risk			
Year of Meteorological Data	Prompt Fatality Risk (individual 0-1 mile) (deaths per reactor year)	Cancer Fatality Risk (0-10 mile cancers) (deaths per year per reactor year)	Probability of Exceeding 0.025 Sv (25 Rem) at 0.5 mile (per reactor-year)
1997	**2.1×10^{-14}**	7.7×10^{-13}	6.6×10^{-10}
1999	1.9×10^{-14}	**8.5×10^{-13}**	**6.9×10^{-10}**
2000	1.6×10^{-14}	7.2×10^{-13}	6.5×10^{-10}
Safety Goal [1]	$<3.7 \times 10^{-7}$	$<1.9 \times 10^{-6}$	$<1.0 \times 10^{-6}$
Generic ABWR Analysis [1]	2.2×10^{-13}	1.3×10^{-12}	$<1.0 \times 10^{-9}$

[1] Reference 7.2-1
NOTE: Bold print represents the highest value among the three years considered