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Evaluation of Severe Accident Risks: Surry Unit 1

Main Report

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4. CONSEQUENCE ANALYSIS

Offsite consequences were calculated with MACCS[1,2,3] for each of the source term groups defined in the partitioning process. This code has been in use for some time and will not be described in any detail. Although the variables thought to be the largest contributors to the uncertainty in risk were sampled from distributions in the accident frequency analysis, the accident progression analysis, and the source term analysis, there was no analogous treatment of uncertainties in the consequence analysis. Variability in the weather was fully accounted for, but the uncertainty in other parameters such as the dry deposition speed or the evacuation rate was not considered.

4.1 Description of the Consequence Analysis

Offsite consequences were calculated with MACCS for each of the source term groups defined in the partitioning process. MACCS tracks the dispersion of the radioactive material in the atmosphere from the plant and computes its its deposition on the ground. MACCS then calculates the effects of this radioactivity on the population and the environment. Doses and the ensuing health effects from 60 radionuclides are computed for the following pathways: immersion or cloudshine, inhalation from the plume, groundshine, deposition on the skin, inhalation of resuspended ground contamination, ingestion of contaminated water and ingestion of contaminated food.

MACCS treats atmospheric dispersion by the use of multiple, straight-line Gaussian plumes. Each plume can have a different direction, duration, and initial radionuclide concentration. Cross-wind dispersion is treated by a multi-step function. Dry and wet deposition are treated as independent processes. The weather variability is treated by means of a stratified sampling process.

For early exposure, the following pathways are considered: immersion or cloudshine, inhalation from the plume, groundshine, deposition on the skin, and inhalation of resuspended ground contamination. Skin deposition and inhalation of resuspended ground contamination have generally not been considered in previous consequence models. For the long-term exposure, MACCS considers following four pathways: groundshine, inhalation of resuspended ground contamination, ingestion of contaminated water and ingestion of contaminated food. The direct exposure pathways, groundshine, and inhalation of resuspended ground contamination, produce doses in the population living in the area surrounding the plant. The indirect exposure pathways, ingestion of contaminated water and food, produce doses in those who ingest food or water emanating from the area around the accident site. The contamination of water bodies is estimated for the washoff of land-deposited material as well as direct deposition. The food pathway model includes direct deposition onto crop and uptake from the soil.

Both short-term and long-term mitigative measures are modeled in MACCS. Short-term actions include evacuation, sheltering and emergency relocation out of the emergency planing zone. Long-term actions include later relocation and restrictions on land use and crop disposition. Relocation and land decontamination, interdiction, and condemnation are based on projected long-term doses from groundshine and inhalation of resuspended radioactivity. The disposal of agricultural products is based on the products' contamination levels and the removal of farmland from crop production is based on ground contamination criteria.

The health effects models link the dose received by an organ to predicted morbidity or mortality. The models used in MACCS calculate both short-term and long-term effects for a number of organs.

The MACCS consequence model calculates a large number of different consequence measures. Results for the following six consequence measures are given in this report: early fatalities, total latent cancer fatalities, population dose within 50 miles, population dose for the entire region, early fatality risk within 1 mile, and latent cancer fatality risk within 10 miles. These consequence measures are described in Table 4.1-1. For the analyses performed for NUREG-1150, 99.5% of the population evacuates and 0.5% of the population does not evacuate and continues normal activity. Details of the methods used to incorporate the consequence results for the source term groups into the integrated risk analysis are given in Volume 1 of this report.

4.2 MACCS Input for Surry

The values of most MACCS input parameters (e.g., aerosol dry deposition velocity, health effects model parameter values, food pathway transfer factors) do not depend on site characteristics. For those parameters that do depend on site characteristics (e.g., evacuation speed, shielding factors, farmland usage), the methods used to calculate the parameters are essentially the same for all sites. Because the methods used to develop input parameter values for the MACCS NUREG-1150 analyses and the parameter values developed using those methods are documented in Volume 2, Part 7 of this report, only a small portion of the MACCS input is presented here.

Table 4.2-1 lists the MACCS input parameters that have strong site dependencies and presents the values of these parameters used in the MACCS calculations for the Surry site. The evacuation delay period begins when general emergency conditions occur and ends when the general public starts to evacuate; non-farm wealth includes personal, business, and public property; and the farmland fractions do not add to one because not all farmland is under cultivation. In addition to the site specific data presented in Table 4.2-1, the Surry MACCS calculations used one year of meteorological data from the Surry site and regional population data developed from the 1980 census tapes. The following table gives the population within certain distances of the plant as summarized from the MACCS demographic input.

Table 4.1-1
Definition of Consequence Analysis Results

Variable	Definition
Early fatalities	Number of fatalities occurring within 1 year of the accident.
Total latent cancer fatalities	Number of latent cancer fatalities due to both early and chronic exposure.
Population dose within 50 miles	Population dose, expressed in effective dose equivalents for whole body exposure (person-rem), due to early and chronic exposure pathways within 50 miles of the reactor. Due to the nature of the chronic pathways models, the actual exposure due to food and water consumption may take place beyond 50 miles.
Population dose within entire region	Population dose, expressed in effective dose equivalents for whole body exposure (person-rem), due to early and chronic exposure pathways within the entire region.
Individual early fatality risk within one mile	The probability of dying within one year for an individual within one mile of the exclusion boundary (i.e., Σ (ef/pop)p, where ef is the number of early fatalities, pop is the population size, p is the weather condition probability, and the summation is over all weather conditions).
Individual latent cancer risk within 10 miles	The probability of dying from cancer due to the accident for an individual within 10 miles of the plant (i.e., Σ (cf/pop)p, where cf is the number of cancer fatalities due to direct exposure in the resident population, pop is the population size, p is the weather condition probability, and the summation is over all weather conditions; chronic exposure does not include ingestion but does include integrated groundshine and inhalation exposure from $t = 0$ to $t = \infty$).

Distance From Plant		Population
(km)	(miles)	
1.6	1.0	9
4.8	3.0	354
16.1	10.0	73,411
48.3	30.0	~~593,504~~
160.9	100.0	2,825,702
563.3	350.0	53,947,736
1609.3	1000.0	155,943,904

354 / 28.3 = 12 persons sq mile

73411 / 314 = 233 persons sq mile

2825702 / 31400 =

97

There is considerable variation in the sector populations (out to 1000 miles) as well. The NNE and WNW sectors have populations of about 25 million, while the ENE sector has a population of only about 30,000.

The evacuation parameters for the seismic risk analyses differed from those for the analysis for internal initiators. (1) It was estimated that for earthquakes with PGAs greater than 0.6 g there would be no effective evacuation and many structures would be uninhabitable. Thus, the population in the emergency response zone is modeled as being outdoors for the first 24 h and then relocating at 24 h. (2) For earthquakes with PGAs less than 0.6 g, it was judged that evacuation would be possible, but that it would start later and proceed at a slower pace than an evacuation for an internal initiator. Thus, for seisms with PGAs less than 0.6 g, the delay time is 3.0 hours (1.5 times the normal delay time) and the evacuation speed is 0.9 m/s (half the normal evacuation speed). This is referred to as degraded evacuation for low acceleration earthquakes.

earthquakes

Table 4.2-2 lists the shielding factors for the Surry consequence analysis. One set of shielding factors was used for internal and fire initiators, and two sets were used for the seismic initiators. The MACCS code considers three different portions of the population or cohorts during the emergency phase of an accident. The appropriate shielding factors are applied according to the response of the people to the declared emergency. (1) The evacuate and take shelter shielding factors apply only during the emergency phase of the consequence calculation. (2) The normal activity shielding factors apply to all those who are not actively evacuating or taking shelter. (3) Thus, the normal activity shielding factors apply to individuals before they begin evacuating or taking shelter, to individuals who choose not to evacuate or take shelter, and to everyone outside the emergency response zone. (4) Furthermore, the normal activity shielding factors are used for all exposure calculations after the emergency phase of the accident, that is, for the chronic exposure computations.

For seismic initiators, the shielding parameters are modified in addition to the evacuation parameters. For the inhalation and skin pathways, it was estimated that buildings would offer no effective protection following an earthquake because of broken windows. The effectiveness of being indoors is reduced for groundshine as well because the broken windows allow deposition within buildings.

earthquakes

Table 4.2-1
Site Specific Input Data for Surry MACCS Calculations

Parameter	
Reactor Power Level (MWt)	2441
Containment Height (m)	50
Containment Width (m)	40
Exclusion Zone Distance (km)	0.52
Evacuation Delay (h)	2.0
Evacuation Speed (m/s)	1.8
Farmland Fractions by Crop Categories	
Pasture	0.41
Stored Forage	0.13
Grains	0.21
Green Leafy Vegetables	0.002
Legumes and Seeds	0.15
Roots and Tubers	0.003
Other Food Crops	0.004
Non-Farm Wealth ($/person)	84,000
Farm Wealth	
Value ($/hectare)	2613
Fraction in Improvements	0.25

For internal and fire initiators, and for low acceleration (PGA < 0.6 g) seismic initiators, the three cohorts treated by MACCS are: (1) those who evacuate; (2) those who continue normal activities; and (3) those who take shelter. Exposure to each cohort is calculated using the shielding factors shown in Table 4.2-2. The risk results reported for these initiators are based on the judgment that 99.5% of the population in the emergency response zone would evacuate and the other 0.5% would continue normal activities. The sheltering cohort is not utilized for these initiators.

For high acceleration (PGA > 0.6 g) seismic initiators, the cohorts are different. It is desired that the exposure be calculated as if everyone in the emergency response zone remains outdoors for 24 h after the earthquake which initiates the accident, and then relocates. This was accomplished within the structure of MACCS by placing everyone in the emergency response zone in the "shelter" cohort, and setting the shelter shielding factors to values appropriate for people outdoors. (The normal activities cohort could not be used to represent the population outdoors within the emergency response zone because a hot spot relocation criterion is applied to this

Table 4.2-2
Shielding Factors Used for Surry MACCS Calculations

Radiation Pathway	Population Response: Evacuate	Population Response: Normal Activity	Population Response: Take Shelter
Internal and Fire Initiators			
Cloudshine	1.0	0.75	0.60
Groundshine	0.5	0.33	0.20
Inhalation	1.0	0.41	0.33
Skin	1.0	0.41	0.33
Seismic Initiators (PGA < 0.6 g)			
Cloudshine	1.0	0.75	0.60
Groundshine	0.5	0.50	0.40
Inhalation	1.0	1.0	1.0
Skin	1.0	1.0	1.0
Seismic Initiators (PGA > 0.6 g)		outside 10 miles	
Cloudshine	N.A.	0.75	1.0
Groundshine	N.A.	0.33	0.7
Inhalation	N.A.	0.41	1.0
Skin	N.A.	0.41	1.0

N.A. - Not Applicable

cohort at 12 h, and because the normal activity shielding factors are also utilized outside the emergency response zone and for the chronic exposure calculations.) MACCS calculations were performed for emergency response zones with radii of 5, 10, and 20 miles. The results reported in this volume use the results for an emergency response zone of 10 miles radius. That is, the consequence calculation for high acceleration seismic initiators uses the shielding factors shown in the shelter column of Table 4.2-2 for the population within 10 miles of the plant for the first 24 h, and uses the shielding factors shown in the normal activity column for the people farther than 10 miles from the plant and for all chronic exposures.

The normal activity shielding factors are used in the chronic exposure calculations for all initiators. The entries in Table 4.2-2 show that this results in less chronic exposure shielding for the low acceleration seismic initiators than for the other initiators. As groundshine dominates the chronic exposure pathways, the use of 0.5 for the groundshine shielding factor yields a chronic exposure estimate about 50% higher than that which would have been obtained using a shielding factor of 0.33 for the low acceleration seismic initiators. As the earthquake damage will be limited to a few tens of miles and will be limited in time as well, the use of chronic exposure shielding factors for seismic initiators that are different from the normal chronic exposure shielding factors is difficult to justify. If the study were to be repeated in the future, the approach used for low acceleration seismic initiators would be discarded and the method used for high acceleration earthquakes would be modified to treat low acceleration events by the adoption of an earlier relocation time.

4.3 Results of MACCS Consequence Calculations

The results given in this section are conditional on the occurrence of a release. That is, given that a release takes place, with release fractions and other characteristics as defined by one of the source term groups, then the consequences reported in this section are calculated. The tables and figures in this section contain no information about the frequency with which these consequences may be expected. Information about the frequencies of consequences of various magnitudes is contained in the risk results (Chapter 5).

4.3.1 Results for Internal Initiators

The integration of the NUREG-1150 probabilistic risk assessments uses the results of the MACCS consequence calculations in two forms. In the first form, a single mean (over weather variation) result is reported for each consequence measure. This produces a nSTG x nC matrix of mean consequence measures, where nSTG is the number of source term groups and nC is the number of consequence measures under consideration. For internal initiators at Surry, nSTG = 52 and nC = 6. The resultant 52 x 6 matrix of mean consequence measures is shown in Table 4.3-1. The source terms that give rise to these mean consequence measures are given in Table 3.4-4. Some of the cases indicated in Table 3.4-4 have a zero frequency and no consequence results are reported for these cases in Table 4.3-1. The mean consequence measures in Table 4.3-1 are used by PRAMIS[3] and RISQUE in the calculation of the mean risk results for internal initiators at Surry. An early