5.0 OFF-SITE CONSEQUENCE ANALYSES ~~SUMMARY~~

MACCS2 [41] has been developed by Sandia National Laboratories for the NRC over the past decade. It is a consequence analysis code for evaluating the impacts of atmospheric releases of radioactive aerosols and vapors on human health and on the environment. It includes all of the relevant dose pathways: cloudshine, inhalation, groundshine, and ingestion. Because it is primarily a probabilistic risk assessment tool, it accounts for the uncertainty in weather that is inherent to an accident that could occur at any point in the future.

In 2001, the NRC initiated an effort to create a Windows-based interface and framework for performing consequence analyses. This effort was intended to address the following needs:

- To simplify and make more intuitive the effort required to create or modify input files,
- To reduce the likelihood of user errors in performing consequence analyses,
- To enable the user to simply and conveniently account for uncertainties in most of the real-valued input parameters, and
- To ~~dis~~ re place the original batch framework with a Windows-based framework.

The result of this development effort is the WinMACCS code. WinMACCS is currently integrated with an updated version of MACCS2, COMIDA2, and LHS (Latin Hypercube Sampling) to ~~perform~~ provide all of the required functionality.

Version 2.4.0.5 of the MACCS2 code was used for the SOARCA off-site consequence predicitions. This version includes a number of improvements to the original MACCS2 code, which can be categorized as follows:

- Atmospheric transport and dispersion modeling improvements; (e.g. morning or afternoon mixing heights, alternative Briggs plume rise model, alternative longer-range plume spreading model)
- Capability to describe wind directions in 64 compass directions (instead of 16);
- Increases in limits on several input parameters, e.g., a limit of 200 plume segments instead of the old limit of 4; and
- Up to 20 emergency-phase cohorts (instead of the original limit of 3) to describe variations in emergency response by segments of the population;
- Enhancements in treatment of evacuation speed and direction to better reflect the spatial and temporal response of individual cohorts;
- Capability to run on a cluster of computers instead of an individual processor;
- Addition of several options for latent cancer fatality dose response. (i.e. a user-input ~~truncation value for latent fatalities~~ a user-input yearly and lifetime dose truncation value, a user-input yearly truncation dose, the dose and dose rate effectiveness factor (DDREF) and LNT, and a 20-segment piecewise linear functional form)

Some of this development has been undertaken specifically to support the SOARCA work [60].

Specific aspects of the consequence modeling in SOARCA that depart from previous studies, such as NURG-1150 [5], are described in the subsequent subsections.

2/24

5.1 Weather Sampling

The weather-sampling strategy adopted for SOARCA uses the non-uniform weather ~~binning~~ sampling approach in WinMACCS. This approach has been available since MACCS2 was first released [41], but was not commonly used in the past. Weather binning is an approach used in MACCS2 to categorize similar sets of weather data based on wind speed, stability class, and the occurrence of precipitation. This sampling strategy was chosen as a means of improving the statistical representation of the weather. This point is discussed further in the subsequent paragraphs.

The weather bins are defined in a standard way that has origins in the NUREG-1150 [5] analyses. A set of 16 weather bins differentiate stability classes and wind speeds. An additional 20 weather bins include all weather trials in which rain occurs before the initial plume segment travels a distance of 32 km (20 mi). The bins differentiate rain intensity and the distance the plume travels before rain begins. The parameters used to define the rain bins are the same as those used in NUREG-1150 [5] and documented in the MACCS2 User's Manual [41].

For non-uniform weather sampling approach, the number of trials selected from each bin is the maximum of 12 trials and 10 percent of the number of trials in the bin. Some bins contain fewer than 12 trials. In those cases, all of the trials within the bin are used for sampling. This strategy results in roughly 1000 weather trials for both Peach Bottom and Surry. The strategy also results in each weather trial having a weight that is used in averaging the results. The weight reflects the number of weather samples in the bin and the number of bin samples chosen. The trials are sampled randomly from the bin.

Previous calculations, such as NUREG-1150, used about 125 weather trials but also used an additional strategy, rotation, to account for the probability that the wind might have been blowing in a different direction when the release began. This strategy uses wind-rose data constructed from the annual weather file to determine the probability that the wind might have been in any of the compass directions. The strategy used at the time of NUREG-1150 leveraged the weather data to get 125 x 16 = 1750 results for the computational price of 125, but at the price that the individual results are not truly independent.

MACCS2 does not allow the rotation option to be used in concert with the network evacuation option; therefore, rotation could not be used for SOARCA. The strategy adopted for SOARCA was chosen as a compromise between obtaining adequate statistical significance and of keeping central processing unit (CPU) time at a reasonable level.

5.2 Weather Data

Meteorological data used in the SOARCA project consisted of a year of hourly meteorological data using on-site meteorological tower observations for each site (8,760 data points per site for each meteorological parameter). This was primarily accomplished via a cooperative effort with the licensee. ~~As a comparative tool, site-specific latitudes and longitudes (or available locations closest to the site) were used to collect wind speed (in meters per second or m/s), wind direction (in degrees), precipitation (in 100th inches), and stability (defined as ΔT/ΔP) data from the National Climatic Data Center (NCDC) http://www.ncdc.noaa.gov)./database.~~ The meteorological data parameters were formatted for the MACCS2 (MELCOR Accident Consequence Code System, version 2) computer code.

NRC staff performed quality assurance evaluations of all meteorological data presented using the methodology described in NUREG-0917, "Nuclear Regulatory Commission Staff Computer Programs for Use with Meteorological Data" [42]. Further review was performed using computer spreadsheets. NRC staff ensured there was joint data recovery rate in the 90th percentile, which is in accordance with Regulatory Guide 1.23 [43] for the wind speed, wind direction, and atmospheric stability parameters. Additionally, atmospheric stability was evaluated to determine if the time of occurrence and duration of reported stability conditions were generally consistent with expected meteorological conditions (e.g., neutral and slightly stable conditions predominated during the year with stable and neutral conditions occurring at night and unstable and neutral conditions occurring during the day). The mixing height data were retrieved from the EPA SCRAM database[4] (using years 1984-1992). Data needed for MACCS2 includes 10-meter wind speed, 10-meter wind direction in 64 compass directions, stability class (via Pasquill-Gifford scale and using representative values of 1-6 for stability classes A-F/G), hourly precipitation, and diurnal (morning and afternoon) seasonal mixing heights.

0.25 m/s

.0559 mph

5.2.1 Summary of Weather Data

A summary of the meteorological statistical data is presented in Table 2, which shows that the predominant ground-level wind directions were generally *blowing to* the same direction during each annual period for each nuclear site. It also shows that the annual average wind speeds were generally low, ranging from 2.02 to 2.63 m/s at ground-level. The atmospheric stability frequencies were found to be consistent with expected meteorological conditions. The neutral and slightly stable conditions predominated during the year with stable and neutral conditions occurring at night and unstable and neutral conditions occurring during the day. The wind direction and atmospheric stability (unstable, neutral, and stable) data are shown in Figure ~~8 and~~ Figure 9 for the years that were actually used in the consequence analyses, which were 2005 for Peach Bottom and 2004 for Surry.

6

Table 2 Statistical Summary of Raw Meteorological Data for SOARCA Nuclear Sites

Parameter		Peach Bottom Year 2005	Peach Bottom Year 2006	Surry Year 2001	Surry Year 2004†
Avg. Wind Speed (m/s)		2.25	2.63	2.02	2.28
Yearly Precipitation (hr)		588 (6.7%)	593 (6.8%)	388 (4.4%)	521 (5.9%)
Atmospheric Stability (%)	Unstable	21.43	20.56	7.09	3.94
	Neutral	63.97	62.34	69.67	77.59
	Stable	14.60	17.10	23.24	18.47
Joint Data Recovery (%)		97.53	99.25	99.58	99.24

† Year 2004, as used in the Surry meteorological analysis, is a leap year (8784 total hourly data points versus 8760 hourly data points for a regular annual period).

in file as budged near and .3 for calm = 2.1 mph

4 EPA SCRAM website: http://www.epa.gov/scram001/mixingheightdata.htm

change to 2006

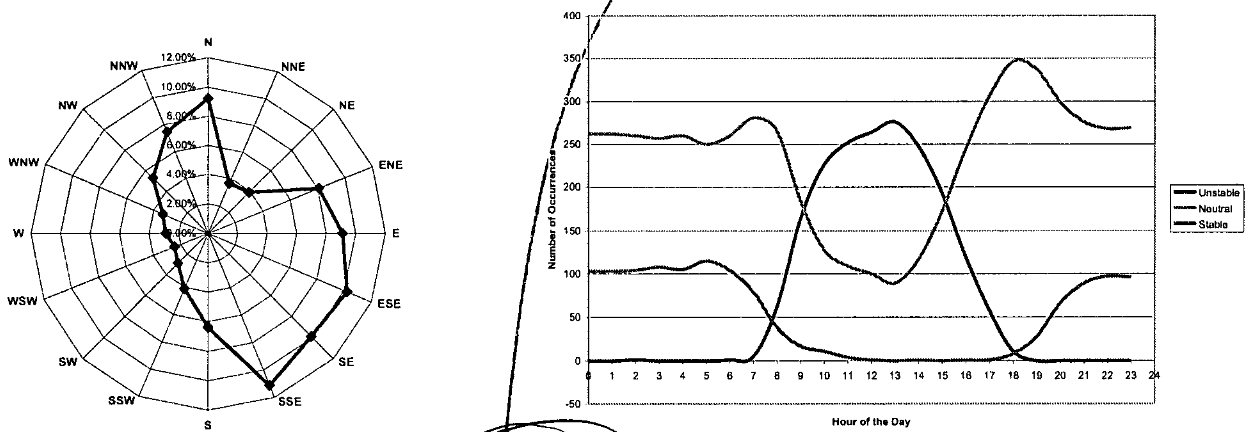

Figure 8 Peach Bottom – Year 2005 – Wind Rose and Atmospheric Stability Chart

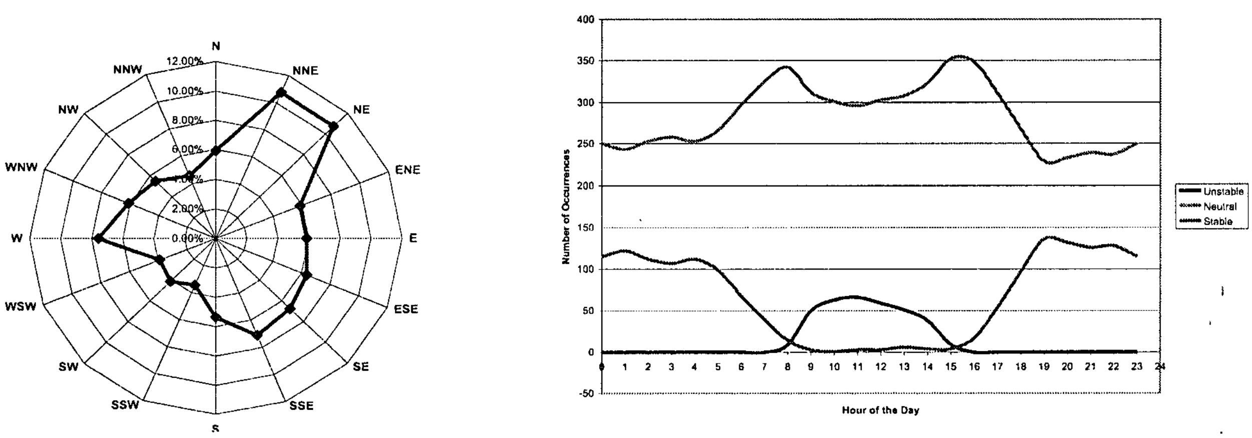

Figure 9 Surry – Year 2004 – Wind Rose and Atmospheric Stability Chart

5.3 Emergency Response Modeling

An objective of the SOARCA project was to model the emergency response in a realistic and practical manner using site-specific emergency planning information. The analysis included modeling of ~~response activities at the cohort level,~~ timing of onsite and offsite decisions, and implementation of protective actions applied to multiple population segments (cohorts). Advancements in consequence modeling, specifically the development of WinMACCS, facilitated detailed integration of protective actions into consequence analysis providing an evolutionary advancement over previous studies. WinMACCS allows temporal and spatial elements of sheltering and evacuation to be modeled.

Emergency response programs for nuclear power plants (NPPs) are designed to protect public health and safety in the unlikely event of a radiological accident. These emergency response programs are developed, tested, and evaluated and are in place as an element of defense in depth.

off-site response organizations

Detailed emergency response planning is in place within the 10-mile EPZ with consideration that such planning provides a substantial base for expansion of response efforts in the event that this proves necessary [44]. Site specific information was obtained from OROs to support development of timelines by which protective actions would most likely be implemented, including early actions such as evacuation of schools following declaration of a site area emergency. Integrating the response plan elements and a best estimate of the protective actions that would be implemented by each cohort was undertaken for the SOARCA project to improve the overall fidelity of the consequence analyses.

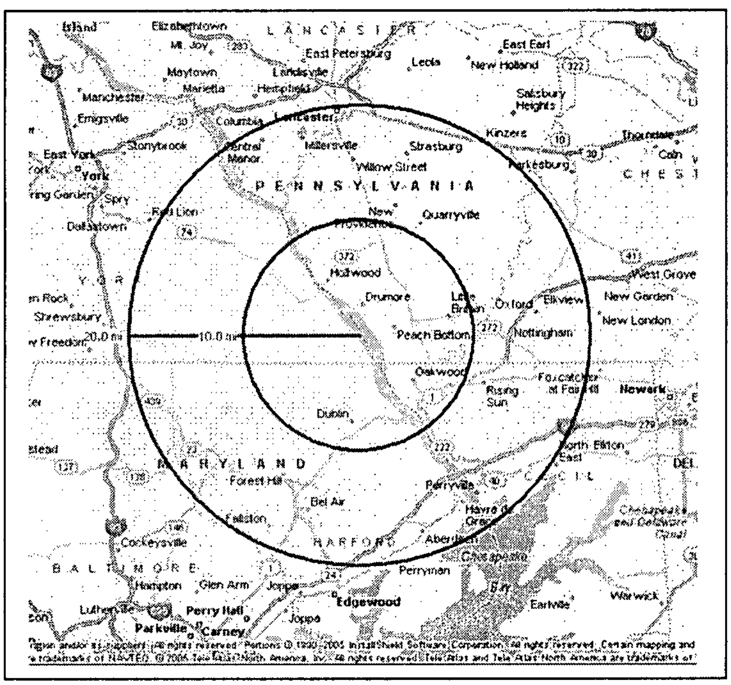

Figure 10 10 and 20 Mile Radial Distances around the Peach Bottom Site

The SOARCA project provided an opportunity to assess response by populations within the 10-mile EPZs and to assess possible variations of emergency response for the two sites studied. These variations include evacuation and sheltering of population groups outside the 10-mile EPZ to a distance of 20 miles from an NPP. It is not expected that areas beyond the EPZ would need to take protective actions, but if they did, the protective actions would be limited to areas based on plume projections. It was assumed that OROs would be aware of source terms and resultant

these kinds of? clarify -

therefore, only

doses that could require protective actions beyond 10 miles and would identify the need for such protective actions and direct that they be implemented in an ad hoc manner. For dose calculation purposes, it was assumed that evacuees traveled to a point 30 miles from the site.

The initiating event for many of the accident scenarios considered by SOARCA is a large earthquake close to the plant site. For this event, it was assumed that severe damage would be generally localized (e.g., 30-40 km from the site). Because characterization of emergency response is based on the timing of actions by onsite and offsite response organizations to protect public health and safety, generally by instructing the public to evacuate or shelter, potential effects of an earthquake need to be considered. However, there is considerable uncertainty in characterizing the impacts of an earthquake; therefore, the SOARCA project addressed the earthquake affects in a separate calculation. A consequence analysis was performed for the accident sequences for each site, and a single seismic analysis was performed at each site for the more ~~most~~ severe seismic accident postulated for the site. (i.e., for Surry the most severe was ISLOCA, which is solely an internal event)

A high-level seismic analysis specific to each site was performed by NRC. The seismic analysis indicated that long-span bridges close to each site are unlikely to survive the earthquake and are assumed to be impassible during emergency response. Some smaller bridges and road crossings were also assumed to fail and some roadways were identified as failing where underlying soils could slide off into adjacent waterways. Residential and commercial structures would be damaged, but generally survive the earthquake. The local electrical grid is assumed to be out of service due to the failure of overhead power lines, switchyard equipment, or other failures. There is no backup power system for the sirens at Peach Bottom, so they would be unavailable; however, backup power is available for the sirens at Surry. Offsite response organizations would have to perform route alerting to notify the population of the need to take protective actions in areas where sirens are not functional. This consists of emergency responders driving through neighborhoods using loudspeakers or going door to door to notify residents of the emergency. Route alerting is a routine and effective method of informing the public [45]. Response parameters that may be affected by an earthquake, including mobilization of the public, evacuation speed, and shielding, ~~etc.~~ were developed to reflect the potential impact.

SOARCA used

The ~~SOARCA~~ approach to consider the effects of a seismic event as a separate calculation was due to the uncertainties related to such an event. The scope of SOARCA did not include a detailed analysis of the effects of a large magnitude earthquake on local infrastructure. ~~However, as a state-of-the-art analyses, it was necessary to identify the seismic event as important and to consider the potential effects. Performing a seismic calculation and analysis using the most severe accident at each site provides insights into the potential consequences from such an~~ event.

5.3.1 Baseline Analyses of Emergency Response

For each accident sequence that resulted in a radioactive release to the environment that would invoke protective actions, a baseline case was developed and modeled using WinMACCS. The baseline case represents the protective action planning in place for EPZs [44]. Initial protective actions at Surry, for which guidance is provided in Supplement 3 to NUREG – 0654/FEMA-REP-1, Rev.1 [44], would likely include evacuation of the 2-mile zone around the

NPP and evacuation of a 5-mile downwind keyhole, as shown in Figure 11. Pennsylvania implements a 360 degree 10 mile evacuation. For consistency in approach, the analyses include evacuation of the public residing within the 10-mile EPZ, a 20-percent shadow evacuation of the public residing in the 10 to 20 mile zone outside the EPZ, and sheltering of the remaining public within the 10 to 20 mile zone outside the EPZ for both sites. The population beyond 20 miles was not assumed to evacuate, although this segment of the population is relocated if projected doses exceed EPA guidelines. than was possible for previous studies

Population subgroups, called cohorts, were defined to provide greater fidelity in the treatment of emergency response. For each site, six cohort groups were established. The makeup of the cohort groups varied by site depending on the population distributions and emergency management actions. As a general assumption, the accident scenario was assumed to occur during school hours, and one cohort was established for schoolchildren within the EPZ. Other cohorts included the general public within the EPZ, general public in the 10 to 20 mile zone, special facilities within the EPZ, shadow evacuees, and a non-evacuating cohort.

provided by the Licensees

evacuation time estimate

The SOARCA project used the ETE to derive speeds for evacuating cohorts. ~~For~~ nuclear power plants, Appendix E of 10 CFR 50 Section IV requires that an analysis of the time required to evacuate be provided for various sectors and distances within the EPZ for transient and permanent residents. An ETE is developed by licensees to support this requirement and is a tool that provides emergency managers information on how long it may take to evacuate a portion or all of the EPZ. Using this information, emergency managers can decide if evacuation is the most appropriate protective action for a specific accident. The site specific ETEs were used to establish the evacuation related input parameters for WinMACCS. For assessment of movement of the public residing between 10 to 20 miles, outside the EPZ, additional ETEs were developed for each site using the Oak Ridge Evacuation Modeling System (OREMS). OREMS was used to develop ETEs for the general public within the 10 to 20 mile zone for all sites. The level of detail in developing these ETEs was significant and included the general public and special facility population groups, e.g., hospitals, nursing homes, and prisons.

The non-evacuating cohort represents the overall fraction (0.5% in this case) of the population who did not evacuate when asked to do so.

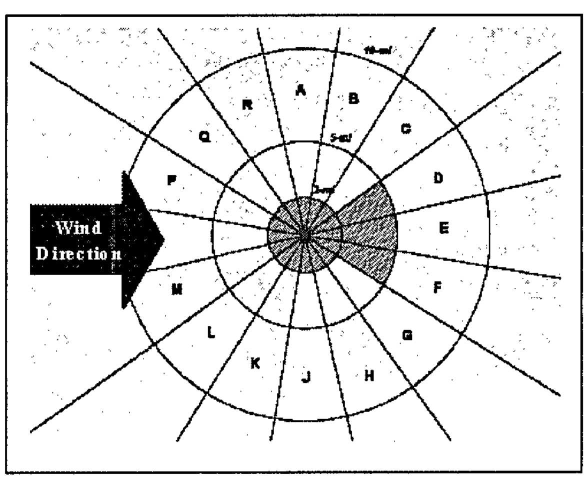

Figure 11 Standard Keyhole Evacuation

a newly-developed option in MACCS2 allowed modification of the speeds for grid elements when road conditions would suggest speed up or slowdown including the speeds were multiplied by e.g. 0.— for each cohort for every hour when precipitation was occurring.

Using WinMACCS, the emergency-planning protective action related parameters were integrated into the consequence modeling. WinMACCS allows for the movement of multiple cohorts and accommodates speed and direction variations for each evacuating cohort. To develop input for WinMACCS, the evacuation routes were reviewed to determine the likely directions that evacuees would travel. The evacuation area was mapped onto a grid with 64 compass sectors and 15 radii, which was used as the basis for the network evacuation model in WinMACCS. The same WinMACCS evacuation network was used for all accident sequences at each site. Response timing and evacuation speed parameters were developed specifically for each accident sequence. For dose modeling purposes, all evacuees were assumed to travel to a point 30 miles from the plant.

5.3.2 Sensitivity Analyses of Emergency Response

After completion of the baseline analysis, three variations were conducted as sensitivity analyses including:

- Evacuation to a distance of 16-miles from the plant. For this analysis, complete evacuation of 16-miles around the plant was assessed. The members of the public in the 16 to 20 mile zone were assumed to shelter.
- Evacuation to a distance of 20-miles from the plant. For this analysis, an ETE was developed for the 20-mile area to provide realistic modeling parameters for the movement of the public.
- Delay in implementation of protective actions. This analysis included an assumption that there could be a 30 minute delay in the implementation of protective actions by the public. This sensitivity study assumes that upon receipt of notifications from offsite authorities, cohorts take 30 minutes longer to start the implementation of protective actions than they do in the baseline analysis.

5.3.3 ~~Integration with Consequence Modeling~~

basically all of this was said at the top of this page!

WinMACCS was used to integrate the emergency-planning protective actions into the overall consequence modeling. WinMACCS allows for the movement of ~~different~~ population groups, ~~referred to as~~ cohorts, and accommodates speed and direction variations of the evacuating cohorts. To fully utilize the functions of WinMACCS, the evacuation routes were assessed to determine the directions that evacuees would take. ~~The evacuation area was mapped onto a grid with 64 compass sectors and 15 radii.~~ This grid was used as the basis for the network evacuation model in WinMACCS. ~~The same WinMACCS evacuation network was used for all accident sequences at each site.~~ Only timing ~~and evacuation speed~~ parameters were ~~adjusted to account for the specifics of each accident sequence~~.

5.4 Source Term Evaluation from MELCOR to MACCS2

Source term evaluation for each of the accident sequences was performed using MELMACCS [47]. MELMACCS reads a MELCOR plot file and extracts information useful for source term definition for MACCS2. A number of user options have to be selected when using MELMACCS. The following paragraphs describe the specific choices made for SOARCA.

The first set of choices is related to the chemical groups or classes to be included in the analysis. Here, the standard set of fission product groups, i.e., the Xe, Cs, Ba, I, Te, Ru, Mo, Ce, and La groups, are all included in the analyses. A related quantity defining the burnup to be assumed when calculating the fission product inventory depends on the plant type. In an effort to provide a best-estimate fission product inventory for Peach Bottom, an ORIGEN calculation was performed for SOARCA to estimate the inventory at mid-cycle, for which peak-rod burnup is estimated to be 49 MWd/kg. These data were used in MELMACCS to specify the inventory for MACCS2 and the MACCS2 input is, therefore, consistent with the MELCOR calculation. An analogous calculation was not performed for Surry; instead, a previously available fission product inventory based on the regulatory limit of burnup, 65 MWd/kg for the peak fuel rod, was used. This inventory should be conservative in the sense of being overestimated, at least for most of the fission products that do not reach secular equilibrium by mid-cycle.

A set of parameters define the ground elevation (grade) in the MELCOR reference frame, the height of the building from which release occurs, and the initial plume dimensions. The MELCOR analyses used in SOARCA use reactor shutdown as the reference time, so the time of accident initiation is always set to zero in the MELMACCS input.

Aerosol deposition velocities are calculated by MELMACCS based on the geometric mean diameter of each aerosol bin, as defined in the MELCOR analysis. The deposition velocities are based on expert elicitation data using the median value of the combined distribution from the experts [48]. Typical values for surface roughness and mean wind speed, 0.1 m and 2.2 m/s, respectively, are additional parameters used to determine the deposition velocities in MELMACCS. Mean wind speeds were determined from the specific weather files used in the consequence analyses. The deposition velocities used in SOARCA are displayed in the following table:

The MELCOR analysis provides the aerosol geo. chem. elements group in each aerosol bin for each plume segment.

Table 3 Deposition Velocities Used in the SOARCA Analyses

Bin #	Median Diameter (μm)	Deposition Velocity (m/s)
1	0.15	5.35×10^{-4}
2	0.29	4.91×10^{-4}
3	0.53	6.43×10^{-4}
4	0.99	1.08×10^{-3}
5	1.8	2.12×10^{-3}
6	3.4	4.34×10^{-3}
7	6.4	8.37×10^{-3}
8	12.	1.37×10^{-2}
9	22.	1.70×10^{-2}
10	41.	$1.70 \cdot 10^{-2}$

Finally, significant releases were broken up into one-hour plume segments. Longer plume segments were sometimes used for trivial releases, such as those where the segment content is a very small fraction of the total release, since finer resolution of these releases was not necessary to maintain the fidelity of the calculation.

5.5 Types of Site-Specific Parameters Used

Weather data for each site are taken from meteorological archives provided by each plant (see Section 5.2). The raw data were processed into 64 compass sectors in order to use the angular resolution capabilities in WinMACCS 3.4 and MACCS2 2.4.

Site files were initially created by SECPOP2000 [49] for 16 compass sectors, which is the only angular resolution supported by that code. WinMACCS was then used to interpolate these site files onto the 64 compass-sector grid that was used for the consequence analyses. The granularity of the population data for 16 compass directions is maintained for the 64 compass direction data. The SECPOP2000 population data were also scaled by a factor of 1.0533 to account for US average population growth between the years 2000 and 2005.

Consequence analyses were performed using the standard approach of evaluating accidents in the following two phases:

1. Emergency phase is the period of time beginning with the initiating event and continues for about 1 week. The release from the plant and plume transport through the MACCS2 grid occur during this phase. Emergency response, i.e., evacuation and relocation of the population in order to reduce exposures and doses, also occurs during this phase.
2. Long-term phase is the period following the emergency phase and continues for 50 years. Three actions take place during the long term phase. Land that is contaminated above the level that is allowable for habitation is decontaminated and potentially interdicted for an additional period. During this time, the land is not available for human habitation. Land that cannot be restored to habitability is condemned, in which case the residents do not return during the long-term phase.

Shielding factors applied to evacuation, normal activity, and sheltering for each relevant dose pathway (i.e., inhalation, deposition onto skin, cloudshine, and groundshine) were evaluated for each site based on values used in NUREG-1150. One departure from the NUREG-1150 values is for normal activity. Each of the normal activity values was reevaluated assuming that the average person spends 19 percent of the day outdoors and 81 percent of the day indoors [44]. The value for each of the pathways was evaluated as a linear combination of 19 percent of the value for evacuation and 81 percent of the value for sheltering.

Site-specific values are used to determine long-term habitability. Most states adhere to EPA guidelines that allow a dose of 2 rem in the first year and 500 mrem per year thereafter. The EPA recommendation has traditionally been implemented in MACCS2 as 4 rem during the first 5 years (2 rem + 4 x 0.5 rem) of exposure and that convention is adopted here. Some states, like Pennsylvania, have a stricter habitability criterion, 0.5 rem/yr beginning in the first year. Thus, the habitability or return criterion is site specific and is discussed further in Appendix A and Appendix B. ~~The DHS has also established a process for determining habitability which will allow a larger role for state and local governments to determine what is accep~~table.

EPA which will been changed in case of a real accident, has not yet

adopted this

the consumer price index

Other site-specific parameters include farmland and nonfarm-land values. These are also scaled from NUREG-1150 values using CPI as the basis for price escalation. A scaling factor of 1.09 was used to account for inflation between the years 2002 and 2005. Although the SOARCA project did not report economic consequences directly, land values did influence the modeling decision to either decontaminate or condemn land. If the cost of decontamination was assessed to be higher than the land value the land was assumed to be condemned. Since the public would not be allowed to return to condemned land, the land values did have an effect on the predicted long term health consequences.

5.6 Reference to the Other, Non-Site Specific Parameters

There are a number of parameters used in the SOARCA analyses that are not site specific. They are described in the following paragraphs.

Ingestion of contaminated food and water is not treated in the SOARCA analyses. The reasoning is that adequate supplies of food and water are available in the US and can be distributed to areas affected by a reactor accident. Some farm areas would be taken out of production, at least for a period of time, while other areas would be put into production to compensate and maintain a level food supply without needing to resort to consumption of contaminated food. Likewise, bottled or filtered water from uncontaminated areas would be distributed to affected areas so that no one would need to consume contaminated water.

Some states have distributed potassium iodide (KI) tablets to people who live near commercial nuclear power plants. KI has been distributed within the EPZ at the Peach Bottom and Surry sites. The purpose of the KI is to saturate the thyroid gland with iodine so that further uptake of iodine by the thyroid is diminished. If taken at the right time, the KI can nearly eliminate doses to the thyroid gland from inhaled radioiodine. Ingestion of KI is modeled for half of the residents near plants where KI has been distributed by the state or local government. A further assumption is that most residents do not take KI at the optimal time (shortly before to immediately after plume arrival) so the efficacy is only 70%, i.e., the thyroid dose from inhaled radioiodine is reduced by 70%.

Much of the non-site-specific data used for consequence analysis in SOARCA are taken from a set of reports that document a joint NRC/Commission of the European Communities (CEC) expert elicitation study [48]. The data taken from this study include atmospheric dispersion parameters, dry deposition velocities, wet deposition parameters, and acute health-effect parameters. In all cases, the median values extracted from the elicitation study [48] are used for point-value consequence analyses in SOARCA.

add a statement about why the 50th percentile is the one to use vs mean

In general evacuation was modeled within a 10-mile emergency planning zone (EPZ) at both sites but the sensitivity of the off-site consequences to important variations on the 10 mile EPZ were also considered (see Section 5.3.2). For dose calculations all evacuees are assumed to travel to a distance of 30 miles from the site. Outside of the EPZ, the population was assumed to relocate if the projected dose during the emergency phase exceeded a set of two upper bounds.

and for the non-evacuating cohort within the EPZ

These bounds were based on a range of dose levels published by the EPA, which is 1 to 5 rem. In SOARCA, the upper limit of this range, 5 rem, was used to trigger hot spot relocation for both Surry and Peach Bottom and the lower limit of this range, 1 rem, was used to trigger normal relocation for Surry while 0.5 rem was used for Peach Bottom to be consistent with the Pennsylvania habitability criterion. In MACCS2, hot-spot relocation is performed first and normal relocation second. The choices of times associated with normal and hot-spot relocation depended on the specific accident scenario because the first priority of emergency responders is generally to evacuate those within the EPZ. So it was assumed that hot-spot relocation would ~~commence sometime~~ begin after evacuation was complete. The scenario-specific time for completion of the relocation actions includes time to identify the involved area.

The dose conversion factors (DCFs) used in the SOARCA analyses are based on Federal Guidance Report (FGR)-13 [50]. This guidance report also recommended changes to the biological effectiveness factors (BEFs) for alpha radiation for two of the organs used to estimate latent cancer health effects to be consistent with the way the risk factors for cancers associated with those organs were evaluated. The two organs are bone marrow and breast; for these organs the BEFs for alpha radiation were changed from the standard value of 20 to 1 and 10, respectively. Doses to these organs are used to evaluate occurrences of leukemia and breast cancer, respectively. Keith Eckerman also recommended using dose to the pancreas as a surrogate for dose to soft tissue to estimate residual cancers. Because MACCS2 does not currently read the data for the pancreas from the dose conversion factor file, a workaround was created. Values of the dose coefficients for the pancreas were copied into the organ called bladder wall. Thus, residual cancers are associated with the organ called bladder wall, which actually contains data for the pancreas.

add how particle size distribution was handled

add a paragraph on DDREF include that it is in the denominator

Keith Eckerman [51] also recommended risk factors for latent health effects that come from the National Research Council's Committee on the Biological Effects of Ionizing Radiations (BEIR) V report [52] and are consistent with the modified DCF file described in the preceding paragraph. These risk factors include 7 organ-specific cancers plus residual cancers that are not accounted for directly. All else being constant, the effect of the change to BEIR V from BEIR III used in previous studies would be to increase the estimated LCFs by a factor of 3.

Decontamination parameters are based on values from NUREG-1150. Two levels of decontamination are considered, just as in NUREG-1150. The cost parameters associated with decontamination are adjusted to account for inflation using the CPI. Costs associated with a reactor accident are not considered in this report; however, these parameters do affect decisions on whether contaminated areas can be restored to habitability and therefore affect predicted doses and risk of health effects.

insert (A) as a new ¶.

5.7 Reporting Latent cancer Health Effects

Experts generally agree that it is difficult to characterize cancer risk for some organs because of the low statistical precision associated with relatively small numbers of excess cases. This limits the ability to estimate trends in risk. From an epidemiological standpoint, in most if not all cases, the number of latent cancer fatalities (LCFs) attributable to radiation exposure from accidental releases from a severe accident would not be detectable above the normal rate of cancer fatalities in the exposed population (i.e., the excess cancer fatalities predicted are too few to allow the detection of a statistically significant difference in the cancer fatalities expected from other causes among the same population). For example, in 2006, the World Health Organization (WHO) estimated that 16,000 European cancer deaths will be attributable to radiation released from the 1986 Chernobyl nuclear power plant accident, but these predicted numbers are small relative to the several hundred million cancer cases that are expected in Europe through 2065 from other causes. Furthermore, WHO concluded that, "it is unlikely that the cancer burden from the largest radiological accident to date could be detected by monitoring national cancer statistics."

New findings have been published from analyses of fractionated or chronic low-dose exposure to low, linear energy transfer (LET) radiation; in particular, a study of nuclear workers in 15 countries, studies of persons living in the vicinity of the Techa River in the Russian Federation who were exposed to radioactive waste discharges from the Mayak Production Association, a study of persons exposed to fallout from the Semipalatinsk nuclear test site in Kazakhstan, and studies in regions with high natural background levels of radiation have recently been performed. Cancer risk estimates in these studies are generally compatible with those derived from the Japanese atomic bomb data. Most recent results from analyzing these data are consistent with a linear or linear-quadratic dose-response relationship of all solid cancers together and with a linear-quadratic dose-response relationship for leukemia.

ies

In the absence of additional information, ~~the~~ International Commission on Radiological Protection (ICRP), the National Academ~~y~~ of Science, and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have each indicated that the current scientific evidence is consistent with the hypothesis that there is a linear, no threshold (LNT) dose response relationship between exposure to ionizing radiation and the development of cancer in humans.

Conversely, the French National Academy of Medicine, in "Dose-effect relationships and estimation of the carcinogenic effects of low doses of ionizing radiation," March 30, 2005 [53], p. 1, advocates the following:

> A linear no-threshold relationship (LNT) describes well the relation between the dose and the carcinogenic effect in this dose range (0.2 to 3 Sv) where it could be tested. However, the use of this relationship to assess by extrapolation the risk of low and very low doses deserves great caution. Recent radiobiological data undermine the validity of estimations based on LNT in the range of doses lower than a few dozen mSv which leads to the questioning of the hypotheses on which LNT is implicitly based.

While the French National Academy of Medicine raises doubts regarding the validity of using LNT to evaluate the carcinogenic risk of low doses (less than 100 millisieverts (mSv) (10 rem)) and even more so for very low doses (less than 10 mSv (1 rem)), it did not articulate what exact value should be ascribed to a dose threshold.

Ultimately, external and internal exposures to individual members of the public are converted from collective organ dose to LCFs using MACCS2. The LNT model raises the concern that the summation of trivial exposures may inappropriately attribute LCFs to individuals far from the site of the accident. While the possibility of LCFs from very low doses cannot be ruled out, organizations such as ICRP and the Health Physics Society (HPS) consider it to be an inappropriate use of these exposures. While the National Council on Radiation Protection and Measurements (NCRP) supports the LNT model, it recommends binning exposures into ranges and considering those ranges separately. Furthermore, in situations involving trivial exposures to large populations, ICRP and NCRP have noted that the most likely number of excess health effects is most likely zero, when the collective dose to such populations is equivalent to the reciprocal of the risk coefficient (about 20 person-Sv (2000 person-rem)). Nevertheless, issues remain related to assessing public exposure, estimating offsite consequences, and communicating these assessments to the public. Several organizations, such as ICRP, have addressed this issue. In its most recent recommendations (ICRP Report 103, "The 2007 Recommendations of the International Commission on Radiological Protection," approved March 2007), ICRP stated the following [54]:

> Collective effective dose is an instrument for optimization, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because the assumptions implicit in the calculation of collective effective dose (e.g., when applying the LNT model) conceal large biological and statistical uncertainties. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided. Such computations based on collective effective dose were never intended, are biologically and statistically very uncertain, presuppose a number of caveats that tend not to be repeated when estimates are quoted out of context, and are an incorrect use of this protection quantity.

Although ICRP provided qualitative guidance regarding situations where collective dose should not be used, it did not provide guidance regarding when these concepts actually are, and are not, appropriate, nor did it clearly articulate the boundaries within which the calculations are valid, as well as the dose ranges for which epidemiological and cellular or molecular data provide information on the health effects associated with radiation exposure. ICRP did note, however, that when ranges of exposures are large, collective dose may aggregate information inappropriately and could be misleading for selecting protective actions.

The National Academy of Sciences reported the following [52]:

> The magnitude of estimated risk for total cancer mortality or leukemia has not changed greatly from estimates in past reports such as Biological Effects of Ionizing Radiation (BEIR) and recent reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and ICRP. New data and analyses have reduced sampling uncertainty, but uncertainties related to estimating risk for exposure to low

doses and dose rates and to transporting risks from Japanese A-bomb survivors to the U.S. population remain large.

The National Academy of Sciences go on to conclude that, "current scientific evidence is consistent with the hypothesis that there is a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancer in humans."

Many groups acknowledge the uncertainties associated with estimating risk for exposure to low radiation doses. One important question that remains is what offsite health consequences are attributable to very low radiation exposure. In its most recent recommendations (ICRP Report 103), described above, ICRP warned that the computation of cancer deaths based on collective effective doses involving trivial exposures is not reasonable and should be avoided, but it did not explicitly provide a quantitative range for which exposures should not be considered. However, in ICRP Report 104, "Scope of Radiological Protection Control Measures" [55], ICRP concludes that the radiation dose that is of no significance to individuals should be in the range of 20–100 microsieverts (μSv) (2–10 millirem (mrem)) per year whole body dose. The International Atomic Energy Agency (IAEA) has stated that an individual dose is likely to be regarded as trivial if it is of the order of some several millirems per year. Although there is no scientific basis for defining a trivial dose, the ICRP and IAEA definitions of trivial dose may provide a basis to address truncation of offsite radiation exposure and the attribution of health consequences.

NCCa delete this

Alternatively, HPS developed a position paper, "Radiation Risk in Perspective," revised August 2004 [56], to specifically address quantitative estimation of health risks. This position paper concludes that quantitative estimates of risk should be limited to individuals receiving a whole body dose greater than 0.05 Sv (5 rem) in 1 year or a lifetime dose greater than 0.1 Sv (10 rem), in addition to natural background radiation. HPS also concluded that risk estimates should not be conducted below these doses. The position paper further states that low dose expressions of risk should only be qualitative, discuss~~ed~~ a range of possible outcomes, and emphasize~~d~~ the inability to detect any increased health detriment. The difference between the HPS view and those expressed by ICRP and IAEA is the detectability of a health consequence versus the difficulty of assessing the effects of exposure to trivial doses.

The SOARCA

~~As discussed above,~~ the LNT model provides a viewpoint that is consistent with the regulatory approach of the NRC ~~which is based on LNT~~ and past analyses using the MACCS2 code have assumed an LNT dose response model. Additionally, these past analyses (e.g., NUREG-1150) calculated LCFs to 1,000 miles with forced deposition to account for all non-inert radionuclides in the dose calculation. Continued use of the LNT model provides consistency and comparability with previous work. The NRC is neither changing nor contemplating changing radiation protection standards and policy as a result of an approach taken in ~~this~~ study to characterize offsite health consequences for low probability events. On the other hand, the NRC can use different approaches for different applications. Therefore, the SOARCA analyses consider a range of dose truncation values, ranging from LNT on one hand to the Health Physics Society recommendation (5 rem/yr and 10 rem lifetime) on the other hand. Two intermediate dose-truncation levels are also considered. One is the 10 mrem/yr dose truncation value suggested ICRP Report 104; the other is US-average background radiation of 620 mrem/yr. Results for these four dose-truncation levels are reported without bias for each of the accident scenarios considered in the SOARCA study.

The statistic that is chosen to convey the likelihood of LCFs resulting from an accident at a NPP is the mean, population-weighted, individual risk. This value is more meaningful than the predicted number of LCFs in the sense that it is representative of similar NPPs operating in areas with different population densities. The term "population-weighted" carries the meaning of the effect of population distribution, along with wind rose probabilities, on the predicted risk. This statistic is simply the number of predicted fatalities divided by the population within a specified region. The use of the word "mean" is intended to convey that the results are ~~arithmetic~~ averages over the annual weather data used in the analysis. The initial phase of the SOARCA analyses only considers uncertainty in the weather; subsequent uncertainty analyses will consider the effect of source term and other input uncertainties on the predicted consequences. ~~In the subsequent uncertainty analyses, "mean" will represent the arithmetic average in a broader sense.~~

Each weather sequence carries an individual weight

Mean, population-weighted, individual risks are presented from 0 to 50 miles. The 0-10 mile range represents the population within the EPZ. The range from 0 to 50 mi is generally used in severe accident mitigation alternative (SAMA) and severe accident mitigation design alternative (SAMDA) analyses.