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Scoping Analysis of MACCS Modeling Improvements for the Study of Protective Action Recommendations

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ABSTRACT

In late 2004, the U.S. Nuclear Regulatory Commission (NRC) initiated a project to analyze the relative efficacy of alternative protective action strategies in reducing consequences to the public from a spectrum of nuclear power plant core melt accidents. The study is documented in NUREG/CR-6953, "Review of NUREG-0654, Supplement 3, 'Criteria for Protective Action Recommendations for Severe Accidents,'" Volumes 1, 2, and 3. The Protective Action Recommendations (PAR) study provided a technical basis for enhancing the protective action guidance contained in Supplement 3, "Guidance for Protective Action Strategies," to NUREG-0654/FEMA-REP-1, Rev. 1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, " dated November 2011. In the time since, a number of important changes and additions have been made to the MACCS code suite, the nuclear accident consequence analysis code used to perform the study. The purpose of this analysis is to determine whether the MACCS results used in the PAR study would be different given recent changes to the MACCS code suite and input parameter guidance. Updated parameters that were analyzed include cohorts, keyhole evacuation, shielding and exposure parameters, compass sector resolution, and a range of source terms from rapidly progressing accidents. Results indicate that using updated modeling assumptions and capabilities may lead to a decrease in predicted health consequences for those within the emergency planning zone compared to the original PAR study.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
EPZ	emergency planning zone
ETE	evacuation time estimate
FGR	Federal Guidance Report
PAR	protective action recommendation
RDEIM	Regional Disruption Economic Impact Model
SIP	shelter-in-place
SOARCA	State-of-the-Art Reactor Consequence Analyses
STSBO	short-term station blackout
U.S. NRC	U.S. Nuclear Regulatory Commission

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1. INTRODUCTION

The protective action recommendation (PAR) study evaluated the effectiveness of protective action strategies following a severe radiological emergency at a nuclear power plant. This study, documented in NUREG/CR-6953, is divided into 3 volumes: Volume 1 contains technical analyses of the alternative protective action strategies, Volume 2 includes a detailed assessment of anticipated public responses based on focus group and telephone surveys and Volume 3 evaluated the effectiveness of two protective actions (evacuation and shelter-in-place (SIP)) to determine conditions for which one would be preferred to the other. Volume 3 makes the following recommendations based on radial distances around the nuclear power plant and predicted adverse health effects resulting from the accident [2]:

- For the 0 to 2-mile area around a nuclear power plant: evacuation is more protective when the evacuation time estimate (ETE) is less than 2 hours.

- For the 2 to 5-mile area: evacuation is more protective when the ETE is less than 3 hours.

- For the 5 to 10-mile area: SIP would likely be the initial protective action to allow a staged evacuation to proceed. If evacuation is the initial protective action for this area, it is more protective than SIP when the ETE is less than 3.2 hours.

The MACCS code is used for consequence analysis in both Volumes 1 and 3, but the scope of this report is with respect to Volume 3 specifically. Volume 3 of the original PAR study was completed over 10 years ago with MACCS version 2.4.0.1, and there is an interest in understanding the impact that newer MACCS capabilities and modeling assumptions would have on this study. Since that time, there have been numerous and significant updates to the MACCS model and input parameter guidance that could potentially influence the results if the same study were performed today.

1.1. Objective

The purpose of this scoping analysis is to determine if changes or updates in the MACCS code and input parameter guidance would impact the original PAR study consequence assessment that was used to make the recommendations above. This study is an initial effort to determine whether model and input parameter updates result in changes when compared to the methodology of the original PAR study.

1.2. Scope

The scope of this analysis includes an assessment of various updates and changes that could be incorporated into the consequence analysis methodology provided in Volume 3 of the original PAR study using the updated model and input parameter guidance in version 4.1.0.2 of the MACCS code. In addition to these updates—described in Section 1.3.1—this analysis highlights more recent modeling practices on population distribution, compass sector resolution, staged evacuation, representative ETEs, and accident timing when compared to the original PAR study.

1.3. Background

MACCS was developed by Sandia National Laboratories on behalf of the U.S. NRC with the main purpose of simulating and analyzing the impacts of severe nuclear accidents at nuclear power plants on the surrounding population and environment. MACCS achieves this by modeling the following [3]:

- atmospheric transport and dispersion and plume depletion,
- probabilistic treatment of meteorology,
- dosimetry,
- protective actions for the emergency phase, intermediate phase, and long-term phase,
- societal and economic costs, and
- radiogenic health effects (both early and latent).

1.3.1. MACCS model updates

The version of MACCS used for this scoping analysis is version 4.1.0.2. The updates to the MACCS code and input parameter guidance since the original study, which used MACCS version 2.4.0.1, serve as the main drivers for this scoping analysis. The sections below detail the updates to the model and the input parameter guidance developed since 2010.

1.3.1.1. Model Updates

Below is a list of some of the major model updates to the MACCS code over the past decade.

- Evacuation model update: Addition of the Keyhole evacuation model compared to the traditional circular evacuation model. Users can now define the evacuation region with the radius of the inner circular region, the number of sectors to evacuate beyond this region, and the outer radius of the evacuation region.

- Plume segment model update: Increased plume segment modeling capability up to 500 segments (compared to 200 segments originally), which provides more accurate plume modeling to account for weather changes and shifting wind directions.

- Economic model update: Addition of the Regional Disruption Economic Impact Model (RDEIM) versus the previous cost-based model. Both models account for evacuation, relocation, decontamination, depreciation, and condemnation but the RDEIM model accounts for losses of gross domestic product while the original model accounts for an expected rate of return.

- Atmospheric Transport and Dispersion Model update: Incorporation of the HYSPLIT, Lagrangian Particle Tracking model. Both HYSPLIT and the traditionally used Gaussian Plume Segment model determine the relative off-site radionuclide concentration downwind of a source by estimating the relative dispersion and deposition of the radionuclide particles. HYSPLIT, however, is a higher fidelity model that can be used for computing complex simulations.

- Enhanced nearfield modeling: Originally, MACCS treated building wake effects using what is known as the virtual source approach in which the dispersion parameters were characteristic of the building dimensions. To help enhance the nearfield capabilities of MACCS, the Ramsdell and Fosmire plume meander model from ARCON 96 was implemented and the U.S. NRC Regulatory Guide 1.145 plume meander model was updated [4].

1.3.1.2. Input parameter guidance updates

New sources of information relevant to the selection of input values for MACCS modeling have become available since the release of MACCS version 2.4.0.1. MACCS analysts can now consider the following sets of information that were previously not available.

- Recent information from the State-of-the-Art Reactor Consequence Analyses (SOARCA) Project and its application to MACCS analyses, which is described in NUREG/CR-7009 [5].

- Recent information taken from emergency preparedness plans and ETE studies that can be used to better simulate population movement especially with respect to:

    - Evacuation protocols/PARs,
    - Timing parameters for notification, evacuation, and sheltering, and
    - Characterizing average and bounding sites, rather than modeling as one uniform site.

- Recently updated dose coefficient files that use modified radiation weighting factors. These updated files are now the recommended files to use for MACCS analyses.

- The development of more source terms, including SOARCA source terms, non-light-water reactor source terms, and multi-unit source terms. The availability of additional source terms allows MACCS analysts to simulate a wide variety of accident scenarios to produce higher fidelity consequence analyses.

- Information from Fukushima insights and lessons learned. For example, reports were recently developed explaining that a considerable number of disaster-related deaths and injuries were related to physical and mental illness as well as trauma brought on by evacuation when the radiation levels in most evacuated areas were not greater than natural levels [6]. It could prove beneficial to consider this information when conducting evacuation models and estimating the effect a nuclear incident could have on the public.

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2. ORIGINAL PAR STUDY METHODOLOGY

The methodology used in Volume 3 of the original PAR study included the use of two rapidly progressing scenario source terms, a medium and high population density site, three evacuation speeds, and six protective action scenarios. Similarly, each scenario examined 11 different response delay variations that ranged from 0.5 to 5.5 hours in 30-minute increments [2]. This generated a total of 4,752 consequence results. All models used the ATMOS and EARLY modules of the MACCS code. The input parameters within these two modules were based on the parameters used in Sample Problem A, which is distributed to users with the MACCS code and is based on input data used for the NUREG-1150 calculations [7]. However, some parameters were from contemporaneous U.S. NRC projects.

The MACCS analysts at the time examined the risk of early and latent cancer fatalities, which were normalized by the maximum consequence value for both the early and latent cancer fatalities. These normalized risk values helped provide the analysts with the percent of maximum early or latent risk for each scenario and response delay. Considering uncertainties related to SIP, these normalized risk values were ultimately used to find the threshold travel speed and departure time [2] at which evacuation would be more protective than sheltering.

2.1. Source terms

Volume 3 of the PAR study uses two rapidly progressing source terms from U.S. NRC accident studies [2]. These source terms are labeled as source term "A" and "B" and both have releases that began in less than one hour from the initiating event, with total durations of less than three hours.

2.2. Site characteristics

The two sites chosen by the MACCS analysts for the original PAR study represented both a high population density site and a medium population density site. Site 1 had more than 200,000 residents within the 10-mile zone and site 2 had around 50,000 residents within the 10-mile zone. The population count and the relative locations of the population were determined using SecPop which is a code that uses census data and economic data along with a user defined spatial grid to determine the relative population distribution for a specific location. Volume 3 of the original PAR study used census data from 2000 to determine the site characteristics. Medium and high population density sites were chosen over a low population density site due to the longer ETEs and slower evacuation speeds these site characteristics would yield. The meteorological data used in the consequence analyses by the MACCS analysts was actual data taken from the two sites.

2.3. Evacuation speed

The evacuation speeds used in the original PAR study are 1 mph, 2 mph, and 3 mph. These speeds were taken from a cumulation of reviewed ETE studies. These speeds resulted in a corresponding travel time for each of the three zones studied in this analysis.

2.4. Protective action scenarios

Table 2-1 details the six protective action scenarios used in Volume 3 of the original PAR study. The use of these six scenarios allowed the analysts to vary SIP between the 0-2 mile, 2-5 mile, and 5-10 mile zones. For these scenarios the protective actions are defined as follows [2]:

- Immediate evacuation: residents within the affected area evacuate 30 minutes after the start of the accident.
- SIP then evacuation: residents within the affected area SIP at 30 minutes after the start of the accident. SIP durations are incrementally increased from 0.5 hours to 5 hours using 30-minute intervals.
- SIP then evacuate at 8 hours: residents in the 5-10-mile zone SIP at 30 minutes after the start of the accident for 8 hours and then evacuate.

Table 2-1 Volume 3 protective action scenarios

Scenario	0-2 miles	2-5 miles	5-10 miles
A	Immediate evacuation	SIP then evacuate	SIP then evacuate at 8 hours
B	SIP then evacuate	Immediate evacuation	SIP then evacuate at 8 hours
C	Immediate evacuation	Immediate evacuation	SIP then evacuate at 8 hours
D	SIP then evacuate	SIP then evacuate	Immediate evacuation
E	SIP then evacuate	SIP then evacuate	SIP then evacuate
F	Immediate evacuation	Immediate evacuation	Immediate evacuation

2.5. Response delays

All six scenarios varied the response delays for each of the three zones to correlate with the protective actions chosen for each scenario. All scenarios begin with a 30-minute delay to account for the time it takes the public to begin taking protective actions. This delay is included in the delay to shelter. As an example, the response delays used for scenario A are detailed in Table 2-2 below. The timings are defined as follows [2]:

- Delay to shelter: the delay from the start of the accident until the public enters a shelter.
- Delay to evacuation: the time from when the public enters the shelter to when they begin to evacuate.
- Depart: the time evacuees enter the roadway network (sum of delay to shelter and delay to evacuate).

There was a total of 11 response delay variations which are separated by cohorts in the MACCS model. Each cohort is evenly weighted with a weighted fraction of 0.091 (1/11) and each cohort is evenly distributed throughout the general population.

Table 2-2 Scenario A protective action timing (Hours) [2]

	0-2 Miles			2-5 Miles			5-10 Miles		
Scenario A	Delay to Shelter	Delay to Evac	Depart	Delay to Shelter	Delay to Evac	Depart	Delay to Shelter	Delay to Evac	Depart
Cohort 1	0.5	0	0.5	0.5	0	0.5	0.5	8.0	8.5
Cohort 2	0.5	0	0.5	0.5	0.5	1.0	0.5	8.0	8.5
Cohort 3	0.5	0	0.5	0.5	1.0	1.5	0.5	8.0	8.5
Cohort 4	0.5	0	0.5	0.5	1.5	2.0	0.5	8.0	8.5
Cohort 5	0.5	0	0.5	0.5	2.0	2.5	0.5	8.0	8.5
Cohort 6	0.5	0	0.5	0.5	2.5	3.0	0.5	8.0	8.5
Cohort 7	0.5	0	0.5	0.5	3.0	3.5	0.5	8.0	8.5
Cohort 8	0.5	0	0.5	0.5	3.5	4.0	0.5	8.0	8.5
Cohort 9	0.5	0	0.5	0.5	4.0	4.5	0.5	8.0	8.5
Cohort 10	0.5	0	0.5	0.5	4.5	5.0	0.5	8.0	8.5
Cohort 11	0.5	0	0.5	0.5	5.0	5.5	0.5	8.0	8.5

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3. UPDATED INPUTS AND METHODOLOGY APPLIED TO THE PAR STUDY

For this analysis, one representative MACCS model is used from the original PAR study in order to evaluate the potential outcomes of model changes. This specific case uses the following selections from the methodology detailed above.

- Source term "A"
- High population density site
- 1 mph evacuation speed
- Scenario A protective actions (Table 2-1)

For this scoping analysis, the representative case is altered to include specific code and input parameter guidance updates taken from the lists detailed in Section 1.3.1. The specific updates to inputs and methodology that were applied in this scoping analysis are described in the subsequent sections below. The updates are heavily influenced by the methodology and MACCS best practices used in the SOARCA Project [5].

3.1. Spatial grid and site characteristics

The high population density site file used for the original PAR study was built using SecPop with census data from 2000 and economic data from 2002. Therefore, a new site file was generated using SecPop to include census data from 2010 and economic data from 2007. This allows the site characteristics to be consistent with the most up-to-date information currently stored and used in SecPop. The spatial grid was also updated to be on a 64 compass sector basis with spatial intervals out to 100 miles. A comparison between the spatial grids used in the original PAR study and this analysis is detailed in Table 3-1 below.

Table 3-1 Spatial grid comparison

Original PAR Study (mi)	Current Analysis (mi)
0.10	0.10
0.32	0.32
0.75	0.75
1.00	1.00
1.32	1.32
2.00	2.00
2.50	2.50
3.00	3.00
3.50	3.50
5.00	5.00
7.00	7.00
10.00	10.00
13.00	12.50
16.00	15.00
20.00	20.00
	25.00
	30.00
	40.00
	50.00
	60.00
	70.00
	80.00
	90.00
	100.00

3.2. Meteorological file

The meteorological file used by the MACCS analyst in the original PAR study was consistent with the location of the site file and is defined on a 16-sector basis. In this analysis, the meteorological file was updated to be defined on a 64-sector basis. This allowed for the option to set NUMCOR in MACCS to be equal to 64 sectors. NUMCOR is the number of compass sectors in the spatial grid. Originally this value was set to 16 to be consistent with the meteorological file. Therefore, to allow for a higher resolution spatial grid, the meteorological file had to be converted to a 64-sector weather file. However, it is important to note that this update just expanded the 16 sector meteorological data to be 64 sectors meaning no additional/new weather data was used.

3.3. CHRONC module addition

Since the original PAR study did not include the CHRONC module, it was decided by the MACCS analysts to incorporate this module into this analysis. The CHRONC module simulates events that occur after the emergency phase and includes calculations for individual health effects from both external and internal dose pathways and calculates economic costs for emergency response actions and long-term protective actions [8]. Nonetheless, this update had no effect on the results of this study given both the original study and this analysis focused on early phase protective actions.

3.4. Cohorts

For this analysis, the cohorts were designated using the SUMPOP function in MACCS to better model the intended population distributions. Using this option, three population distributions are used. Population distribution 1 refers to the entire population, population distribution 2 is the shadow population (i.e., people who evacuate without any instruction from response officials to do so), and population distribution 3 is non-evacuation. Table 3-2 lists the eight cohorts in the three different distributions that were generated for this study. These cohort designations and corresponding distributions align closely with the cohort definitions for the SOARCA Surry Integrated Analysis [9]. The one difference is the general public in this analysis is split up into three cohorts (early, middle, and late) to account for the assumption that the general public evacuate at varying times.

Table 3-2 Updated population distribution over cohorts

Cohort #	Population	Population Distribution 1	Population Distribution 2	Population Distribution 3
1	Early Public	0.055	0	0
2	Middle Public	0.22	0	0
3	Late Public	0.22	0	0
4	Tail Public	0.1	0	0
5	Schools	0.25	0	0
6	Special Facilities	0.15	0	0
7	Shadow Public (10-20 mi)	0	0.2	0
8	Non-Evac Public	0.005	0.8	1

3.5. Keyhole evacuation

The original PAR study uses the circular evacuation model which assumes the evacuation region is a circular area. This analysis altered the evacuation model so that the cohorts follow the models detailed in Table 3-3. Most of the cohorts are modeled to follow a keyhole evacuation assuming that emergency officials declare this and the public responds accordingly. However, the early public cohort is modeled using the circular evacuation model because this cohort is considered members of the public that leave early regardless of what they are told. This cohort is assumed to make their own protective action decisions based on their own information and motivation, meaning that they won't follow a traditional keyhole evacuation. Similarly, the shadow public is the public that is living in the 10-20 mile area that would not be called to evacuate because they are outside the prescribed 10-mile evacuation zone, but 20% of this cohort is expected to evacuate because they are assumed to feel threatened by a potential release. The shadow cohort in this update was expanded out to 20 miles from the original 15-miles due to the expanded voluntary evacuation region seen in some large-scale evacuations. This is a conservative change and should not be applied to future analyses without further evaluation and evidence that such behavior is representative of evacuations in the U.S. Schools are also modeled using the circular evacuation model because all schools within the emergency planning zone (EPZ) are expected to evacuate at the same time before the evacuation is broadcast to the public.

Table 3-3 Updated Evacuation Models for Each Cohort

Cohort	Evacuation Model
Early Public	Circular
Middle Public	Keyhole
Late Public	Keyhole
Tail Public	Keyhole
Schools	Circular
Special Facilities	Keyhole
Shadow Public (10-20 mi)	Circular
Non-Evacuating Public	No Evacuation

The keyhole evacuation model represents a keyhole-shaped evacuation area. This includes a circular evacuation area surrounding the accident site, and an additional evacuation area downwind of the site [8]. A visual representation of a keyhole evacuation model can be seen in Figure 3-1 below and for this specific analysis, for the cohorts using the keyhole evacuation model, there was a 2-hour keyhole forecast with a 5-mile center to a 10-mile keyhole.

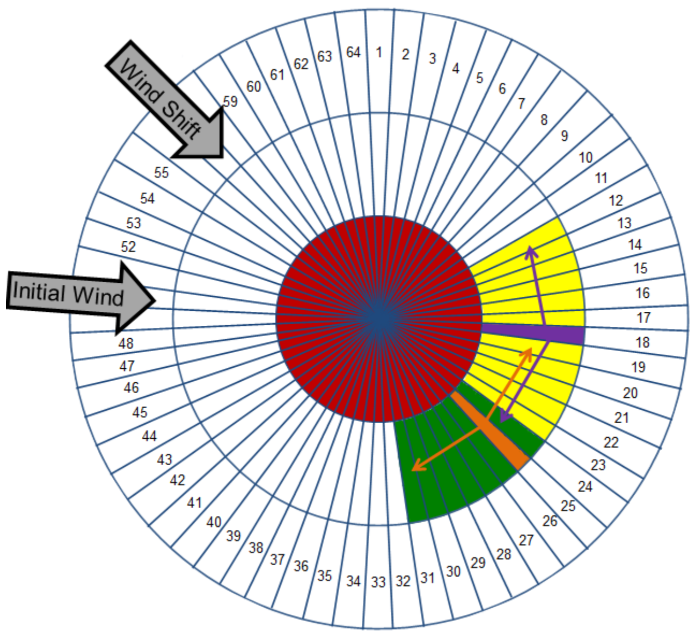

Figure 3-1 MACCS keyhole evacuation model demonstration [7]

3.6. Shielding and exposure parameters

The shielding and exposure parameters include the cloudshine protection factor, the inhalation protection factor, breathing rate, the skin protection factor, and the groundshine protection factor. These parameters can be varied based on the population activity (i.e., evacuation, normal, or sheltering) and can also be varied for each defined cohort as well. In the original PAR study, the shielding and exposure parameters are consistent for all 11 cohorts and were taken directly from NUREG-1150 for Peach Bottom [7]. For this scoping analysis, values consistent with the MACCS best practices, sample problems, and parameter guidance at the time of this analysis are used, and these values are expected to change as new MACCS parameter guidance is developed. The cloudshine and skin protection factors were taken from the SOARCA Surry Integrated Analysis Study [9] while the groundshine protection factors were taken from the Task 5 Letter Report: MACCS Uncertainty Analysis of EARLY Exposure Results [9], and the inhalation protection factors were taken from EPA's Evacuation Risks: An Evaluation (EPA-520/6-74-002) study [11]. A comparison between the shielding and exposure parameters for the original and this scoping analysis is detailed below in Table 3-4.

Table 3-4 Shielding and exposure parameter comparison

	Activities	Cloudshine protection factor	Inhalation protection factor	Breathing rate (m^3/s)	Skin protection factor	Groundshine protection factor
Original PAR Study	Evacuation	1.00	0.98	2.66E-04	0.98	0.50
	Normal	0.75	0.41	2.66E-04	0.41	0.33
	Sheltering	0.60	0.33	2.66E-04	0.33	0.20
Current Scoping Analysis	Evacuation	1.00	0.98	2.66E-04	0.98	0.40
	Normal	0.68	0.46	2.66E-04	0.46	0.20
	Sheltering	0.60	0.25	2.66E-04	0.33	0.10

3.7. Updated emergency response

The evacuation speeds of 1 mph, 2 mph, and 3 mph in the original PAR study were driven by ETE studies conducted at the time Volume 3 was written [2]. However, for this analysis, the initial evacuation phase speed and middle evacuation phase speed are adjusted to be more realistic with expected evacuation conditions. Additionally, due to the different population assignments for each cohort, the evacuation parameters such as notification alarm, delay to shelter, and delay to evacuation are adjusted accordingly. Table 3-5 below details the changes made to the evacuation parameters and evacuation speeds. Emergency response input parameters were established using information from ETEs, and subject matter expert knowledge regarding regulatory guidance pertaining to offsite notification and public response. Based on knowledge of current ETEs, speeds in the range of 20-40 mph are consistently used to provide realism.

Table 3-5 Updated evacuation parameters and information

Cohort #	Notification Alarm (hr)	Delay to Shelter (hr)	Delay to Evacua-tion (hr)	Evacua-tion Start (hr)	Initial Evacua-tion Phase Duration (hr)	Initial Evacua-tion Phase Speed (mph)	Middle Evacua-tion Phase Duration (hr)	Middle Evacua-tion Phase Speed (mph)	Distance Traveled Through End of Middle Phase of Evacuation (mi)
1	1.50	0.25	0.25	2.00	0.50	20.0	0.50	10.0	15.0
2	1.50	1.50	1.00	4.00	0.50	15.0	0.50	10.0	12.5
3	1.50	3.00	1.50	6.00	0.50	15.0	0.50	10.0	12.5
4	1.50	6.50	1.50	9.50	0.50	20.0	0.50	20.0	20.0
5	1.00	0.25	3.25	4.50	1.00	10.0	1.00	10.0	20.0
6	1.00	0.25	8.25	9.50	1.00	15.0	1.00	15.0	15.0
7	1.50	1.50	1.00	4.00	1.00	15.0	1.00	10.0	25.0
8	1.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

3.8. Updated dose coefficient files

The dose coefficient files in MACCS convert the air and ground radionuclide concentrations to both doses for specific organs and to the whole body [12]. The original PAR study used a federal guidance report (FGR) 13 dose coefficient file that was created in 2007. An updated version of the FGR 13 dose coefficient file was released in 2018 and this file was used in this scoping analysis. Differences between the two FGR 13 data sets includes the modified radiation weighting factors for the alpha radiation of the breasts and red marrow organs [12]. Similar to the CHRONC module update described in Section 3.3, this update had no effect on the original PAR study conclusions since only whole-body health effects were considered.

3.9. Additional source terms

Although the source term "A" in the original PAR study is still used in this analysis, it was decided to bring in two additional source terms to enhance comparisons. The first additional source term, realization 37 (Rlz 37), is derived from the SOARCA Surry analyses and is a variant of a short-term station blackout (STSBO) scenario that includes a containment bypass and steam generator tube rupture [9]. This accident scenario was categorized as one of SOARCA's severe accident scenario groups and more details on this event can be found in the NUREG/CR-7110, Vol. 2, Rev. 1 report. The second source term, realization 554, is from the SOARCA Sequoyah Integrated Deterministic and Uncertainty Analyses [13] and is consistent with a STSBO early release. A more in-depth discussion of this release is found in NUREG/CR-7245. As explained in the original PAR study methodology, the two source terms used by the MACCS analysts were rapidly progressing. The SOARCA source terms, on the other hand, have a less severe and more prolonged release and represents an end of cycle source term. Table 3-6 includes a more detailed explanation of the specific release timing differences between the three source terms. The source term derived from the Surry analyses is referred to as "SOARCA Surry STSBO Rlz 37" and the source term taken from the Sequoyah analyses is referred to as "SOARCA Sequoyah STSBO Rlz 554" throughout this scoping analysis.

Table 3-6 Source term selection comparison

Original PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
Release starts <1 hour after initiation Modeled release period of ~21 hours ~60% of Iodine released from inventory	Release starts ~2 hours and 45 minutes after initiation Modeled release period of ~48 hours ~0.11% of Iodine released from inventory	Release starts ~ 3 hours after initiation Modeled release period of ~72 hours ~5.1% of Iodine released from inventory

3.10. Summary of potential consequential updates

Despite the numerous model and input parameter guidance updates discussed above, only a few are expected to have a significant change to the performance of the original PAR study. The consequential updates include:

- Compass sector resolution updates

- Cohort selection
- Population density
- Source term selection

3.10.1. Compass sector resolution updates

As described in Section 3.2, an initial modification to the analysis was to increase the grid resolution from 16 to 64 compass sectors. MACCS reports results averaged over the area in each spatial element. Increasing the number of sectors may provide more representative results when these areas are too wide to provide enough precision for a narrow plume.

The use of 64 compass sectors requires a 64-sector site file and a 64-sector meteorological file. A site file with 64 sectors can more accurately represent the spatial distribution of the population and can thereby affect the results. The 64-sector meteorological file in this analysis was converted from the 16-sector meteorological file. As such, the file is based on the original weather data containing 16 wind directions. It contains no additional information, and in this case, it is unlikely to have any effect on the results.

When a meteorological file does consider additional wind directions as a 64-sector meteorological file is capable of, it can affect results. When plumes are relatively narrow, more wind directions may better capture plume spread from small variations in wind direction by allowing plume segments to travel in more directions than the model would otherwise consider. As such, this can result in smaller peak doses in those directions than MACCS would otherwise compute.

3.10.2. Cohort selection

Volume 1 of the PAR study has three cohorts that represent the public living within the EPZ, the population within the shadow evacuation region, and the population within the EPZ who would choose not to evacuate. In Volume 3 of the PAR study, the MACCS analysis had eleven cohorts that define a uniform site population within the plume exposure EPZ. This was done using an equivalent population weight fraction of 0.091 as discussed in Section 2.5.

Since Volume 3 of the original PAR study was published, the development of cohort definitions has expanded to allow for a greater number of cohorts and for those cohorts to be spread non-uniformly within grid subdivisions. In more recent MACCS analyses, cohort definitions and timings are divided and developed based on the anticipated behaviors of specific population groups within the EPZ. For this analysis, eight cohorts are defined across three population groups (public, shadow, and non-evacuating). The details of the cohorts and population used in this analysis are shown in Table 3-7, Table 3-8, and Figure 3-2.

Table 3-7 Cohort definitions

Cohort	Definition
Early Public	The portion of the public living in the plume exposure EPZ who begin their evacuation with minimal delay notification. This group of people is assumed to work at, or near home, would already have an evacuation bag prepared, and would not need to wait for other family members before beginning their evacuation. They may also decide to evacuate the area prior to being instructed to do so by response officials.
Middle Public	The portion of the public living in the plume exposure EPZ who would receive notification of the event and be able to leave their place of work and travel home with minimal delay. This group of people is assumed to work close to their home. It was also assumed this group of people would need to prepare themselves and their home for an evacuation but would be well enough informed that they could do so efficiently and effectively. This group would either not have to wait for family members or could connect with their family shortly following the initial notification. This cohort follows sheltering and evacuation instructions as directed by response officials.
Late Public	The portion of the public living in the plume exposure EPZ who may have a delayed notification of the event. This group may also need more time to prepare to leave work and/or may have a greater distance to travel home. It was assumed that this group of people need more time to prepare themselves and their home for an evacuation. This group would likely wait to connect family members prior to beginning their evacuation. This cohort follows sheltering and evacuation instructions as directed by response officials.
Tail Public	The portion of the public living in the plume exposure EPZ who will be greatly delayed. They could have a delayed notification of the event or may need more time to prepare to leave their work and/or may have a greater distance to travel home. It was assumed this group of people need more time to prepare themselves and their home for an evacuation. This group would likely wait to connect family members prior to beginning their evacuation. This cohort follows sheltering and evacuation instructions as directed by response officials.
Schools	If an event would occur while school is in session, schools would typically be notified prior to the public if the event resulted in a Site Area Emergency (SAE). Schools would be dismissed as a precaution, prior to the public being instructed to evacuate, and children would be routed to a pickup location outside of the EPZ. Parents are assumed to be instructed to pick up their children at this alternate location.
Special Facilities	Special facilities for these analyses were defined as the population residing within hospitals, nursing homes, prisons, or transit-dependent populations. For this study, it is assumed that this population would enter a sheltering response mode immediately following a notification to do so. However, due to increased risks of moving these populations, it was assumed special facilities would shelter for longer periods before deciding to evacuate. Mobilization of evacuating these populations would typically occur over a longer period of time.
Shadow Public	The portion of the public living outside the plume exposure EPZ who evacuate without any instruction from response officials to do so. For this study, there was an assumed 20% shadow population in the 10- to 20-mile region.
Non-Evac Public	The portion of the public who decide not to evacuate. Within the plume exposure EPZ, it was assumed 0.5% of the public will decide not to evacuate even if instructed by response officials.

Table 3-8 Population and cohort distributions

Population			Population Distribution							
			Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Cohort 6	Cohort 7	Cohort 8
#	Symbol	Label	Early Public	Middle Public	Late Public	Tail Public	Schools	Special Facilities	Shadow Public	Non-Evac Public
1	P	Public	0.055	0.22	0.22	0.10	0.25	0.15	0	0.0050
2	S	Shadow	0	0	0	0	0	0	0.20	0.80
3	N	Non-Evac	0	0	0	0	0	0	0	1.0

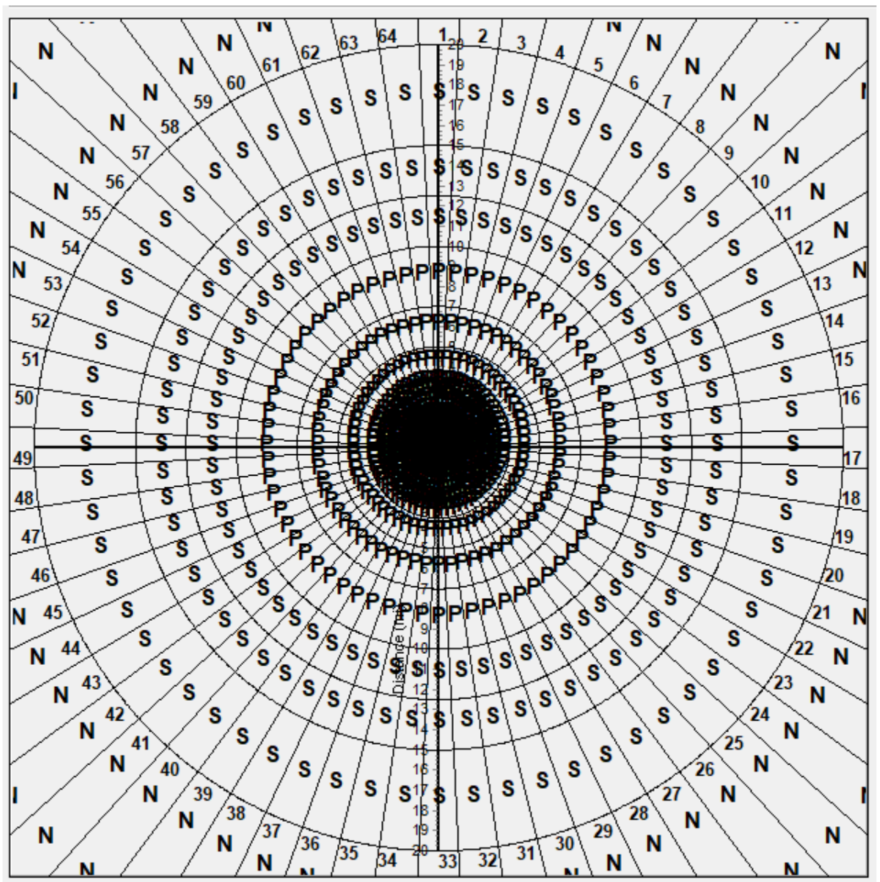

Figure 3-2 Array of population type designation

3.10.3. Site File Updates

The site file used in the original PAR study encompassed 20 miles around the reactor incident. However, a common practice is to use a much larger modeling domain. For instance, the SOARCA analyses used site files that extend to 1,000 miles [5]. For the benefit of the analyst running MACCS, the site file for this analysis was expanded to include data within 100 miles. The spatial distances used in this updated analysis are shown in Table 3-9. The site file was also updated to include census data from 2010 and economic data from 2007 instead of census data from 2000 and economic data from 2002. This update changes the overall population count and distribution over the spatial grid given the 10-year difference between census data sets. This naturally effects the number of health effect cases and the number of displaced individuals.

Table 3-9 Updated spatial array

#	Radial Distance from Plant (miles)
1	0.10
2	0.32
3	0.75
4	1.00
5	1.32
6	2.00
7	2.50
8	3.00
9	3.50
10	5.00
11	7.00
12	10.00
13	12.50
14	15.00
15	20.00
16	25.00
17	30.00
18	40.00
19	50.00
20	60.00
21	70.00
22	80.00
23	90.00
24	100.00

3.10.4. Source term selection impact

Volume 3 of the original PAR study considers accident sequences that resemble a large, early release from a beyond design basis accident. While large early releases cannot be ruled out, they certainly do not represent a typical accident scenario. In the decade since the PAR study, understanding of nuclear reactor accident sequences has improved. This is due to both studies completed since the Fukushima Daiichi accident and to advancements in accident progression modeling capabilities with tools such as MELCOR. One of the major findings in the SOARCA project is that source terms tend to be more prolonged and delayed than previously expected, as shown during the Fukushima accident. While this allows for more time to take protective actions, a prolonged release also lowers the potential for early health effects. Prolonged releases have less decay energy and more time to deposit within the reactor buildings, which decreases the overall release size. Also, prolonged source terms that are spread over the course of hours have less concentrated releases. Assuming even a minor amount of wind shift, this decreases the maximum potential dose that any single location can experience.

Studies such as SOARCA provide hundreds of source terms to consider. Due to the limited scope of this analysis, only two SOARCA source terms were chosen as alternates to the PAR study source term. Analysts chose SOARCA Uncertainty Analysis Reference Cases for both Surry (Realization 37) and Sequoyah (Realization 554) because they are well documented and have a relatively early release. A comparison of the cumulative releases of the Cesium and Iodine chemical groups for all three source terms used in this analysis can be seen in Figure 3-3. Both the Sequoyah and Surry source terms have a smaller total release of both iodine and cesium than the original PAR source term by a factor of ~10 and ~1,000. The much longer durations are also apparent in Figure 3-3.

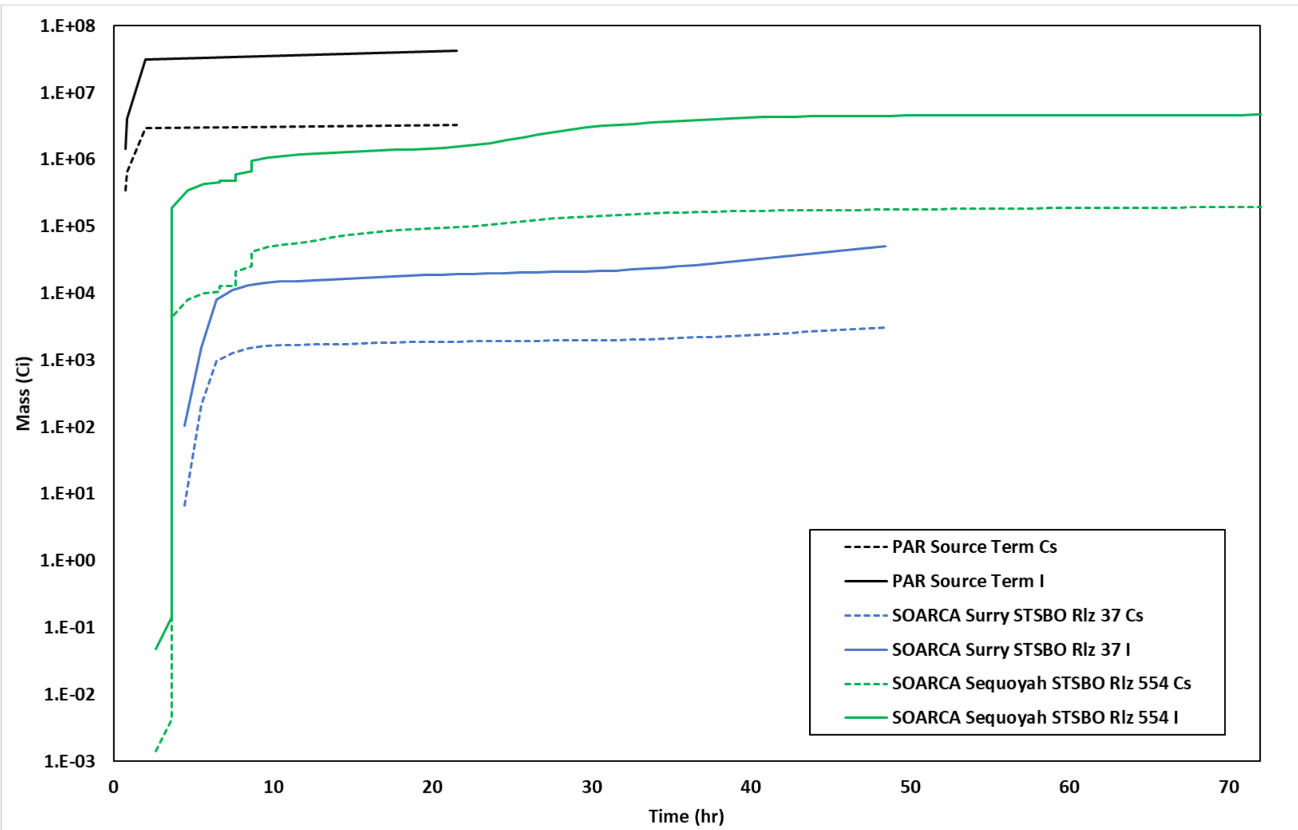

Figure 3-3 Cumulative release for the original PAR study source term and the two SOARCA source terms

4. RESULTS

The original PAR study normalized the data output to present a common platform for review of the six scenarios with respect to the early fatalities and the latent cancer fatalities [2]. Due to differences in the methodology used between the original PAR study and this scoping analysis, when assessing the updated input/methodology results specifically, it was decided to compare the mean values for the sum of the overall cohort results for both the early fatalities and latent cancer fatalities. The impact of population evacuation over time and source term selection were assessed as well. The intention is to show the overall difference in the results when applying the changes discussed in Section 3 of this report. To identify the specific contributions for some updates, multiple sensitivity analyses were also performed as described in Section 4.3.

4.1. MACCS version comparison

The purpose for this comparison is to observe whether there were any significant changes in results from the updates to the MACCS code itself. For this comparison, none of the updates discussed in Section 3 were made. The original PAR study case was simply re-modeled in MACCS version 4.1.0.2 and the results for cohort 1 were compared. As seen in Table 4-1, when comparing version 2.4.0.1 and version 4.1.0.2 and using the non-uniform bin sampling weather model, the reported number of mean latent fatality health effect cases for cohort 1 remains consistent. Although the mean early fatality health effect cases slightly increase, the change is small, due mostly to a difference in weather trials.

Because most weather trials do not result in peak values, the average is based on a small set of extreme weather trials that do result in early fatalities and is heavily influenced by the tail of the distribution. The difference may be simply due to the different weather trials that are sampled in the two analyses, which is anticipated to occur since the two MACCS versions use different compilers.

Table 4-1 Comparison of mean health effect cases for cohort 1 across MACCS versions

Health Effect Cases		Version 2.4.0.1 Non-Uniform Bin Sampling	Version 4.1.0.2 Weather Model	
			Non-Uniform Bin Sampling	Stratified Random Sampling
Early Fatality	0-2 mi	2.25E-01	7.96E-01	3.60E-01
	2-5 mi	7.68E-02	4.95E-01	1.61E-01
	5-10 mi	4.25E-05	5.58E-05	1.90E-04
Latent Cancer Fatality	0-2 mi	3.05E+01	3.17E+01	3.34E+01
	2-5 mi	2.10E+02	2.07E+02	2.24E+02
	5-10 mi	1.46E+02	1.57E+02	1.53E+02

As seen in Table 4-1, an additional calculation was performed sampling all weather trials using the stratified random sampling option. In this model, the number of early fatalities again changes by approximately the same amount as before. This indicates that the results are within the range anticipated given the variability of the sample mean. The precision of the results could be further investigated by evaluating differences in results of individual weather trials, but this was not pursued. Nonetheless, these results show that there is no significant difference between the results using the different MACCS versions and that any bug fixes within the past 10 years had no considerable effect on this study.

4.2. Updated input/methodology results

This section displays a comparison between the original PAR study and the updated input/methodology results. A summary of all the updates described in Section 3 that were included in the "Version 4.1.0.2 With Updates" results is listed below.

- Updated site file with more recent census data
- A 64 compass sector grid instead of a 16-sector grid
- The addition of the CHRONC module to display impacted population results
- Revised cohort definitions that align more with the SOARCA study
- The use of the keyhole evacuation model in addition to circular
- Updated shielding and exposure parameters
- Updated emergency response based on current ETEs and current knowledge of offsite notification and public response
- More recent dose conversion factor files
- The utilization of additional source terms (Surry Rlz 37 and Sequoyah Rlz 554)

4.2.1. Comparison to original PAR study

When comparing the early and latent cancer fatalities between the original PAR study using MACCS version 2.4.0.1 to this analysis, results indicate that the health consequences decreased when the updated modeling tools and methodologies described in Section 3 were applied. As expected, the choice of source term has a significant impact, as shown by the decrease in anticipated latent cancer fatalities when using a smaller source term released over a longer time span. It is assumed that the main drivers for the difference in health effect cases (besides source term selection) between this analysis and the original PAR study are updates such as the keyhole evacuation model, compass sector resolution/site file updates (as discussed in Section 3.10), the updated shielding and exposure parameters and the difference in cohort assignments coupled with their updated evacuation speeds. As reported in Section 3.7, the updated evacuation speeds used in this analysis were much faster than what was used in the original PAR study (refer to Section 2.3). Several sensitivity cases were completed to evaluate these assumptions further and are detailed in Section 4.3.

Table 4-2 Mean early fatalities comparison

Radial Distance (mi)	Original PAR Version 2.4.0.1	Version 4.1.0.2 with Updates		
		PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-2	2.48E+00	7.19E-02	0.00E+00	0.00E+00
2-5	1.70E+00	5.40E-03	0.00E+00	0.00E+00
5-10	4.67E-04	1.18E-06	0.00E+00	0.00E+00
0-10	N/A	7.72E-02	0.00E+00	0.00E+00
0-50	N/A	7.72E-02	0.00E+00	0.00E+00

Table 4-3 Mean latent cancer fatalities comparison

Radial Distance (mi)	Original PAR Version 2.4.0.1	Version 4.1.0.2 with Updates		
		PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-2	3.35E+02	1.92E+02	2.06E+00	4.94E+01
2-5	1.67E+03	5.99E+02	3.10E+00	5.49E+01
5-10	1.61E+03	9.76E+02	2.65E+00	5.77E+01
0-10	N/A	1.77E+03	7.82E+00	1.62E+02
0-50	N/A	2.81E+04	5.17E+02	9.48E+03

4.2.2. Population movement

The CHRONC module within MACCS facilitates assessment of the impacted population from a given release into the environment. The impacted population includes evacuees and relocated individuals for each phase [8]. MACCS reports the early phase impacted population for the following categories [8]:

- Evacuees not affected by plume—evacuees who can return during or immediately after the emergency phase
- Evacuees affected by plume—evacuees who may not be able to return to their homes immediately after the emergency phase
- Normal emergency phase relocation—relocatees affected by normal relocation during the emergency phase
- Hotspot emergency phase relocation—relocatees affected by hotspot relocation during the emergency phase

For this analysis, the total number of displaced individuals from the 0-10 mile area during the early phase was determined by taking the sum of people from the four categories listed above. The number of displaced individuals is reported for the updated model using the PAR study source term and the two SOARCA source terms in Table 4-4. Section 4.2.3 goes into more detail regarding the differences between the source terms.

Table 4-4 Comparison of mean displaced individuals

Radial Distance (mi)	Version 4.1.0.2 with Updates		
	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-10	254,237	264,303	266,866

4.2.3. Comparison between source terms

When comparing the original PAR study source term to the two SOARCA source terms selected for this analysis, all three consider early environmental releases with releases starting under 10 hours from accident initiation. The original PAR study source term has a considerably larger fraction of radionuclides released, which correlates to the high peak dose as a function of distance shown in Figure 4-1. When reviewing the population dose, the relative dose when compared to the original PAR study source term decreases significantly for the SOARCA source terms. Similarly, the population weighted risk for early and latent cancer fatalities also decreases for the two SOARCA source terms. This is due to the differences between the PAR study source term and the two SOARCA source terms explained in Section 3.10.4.

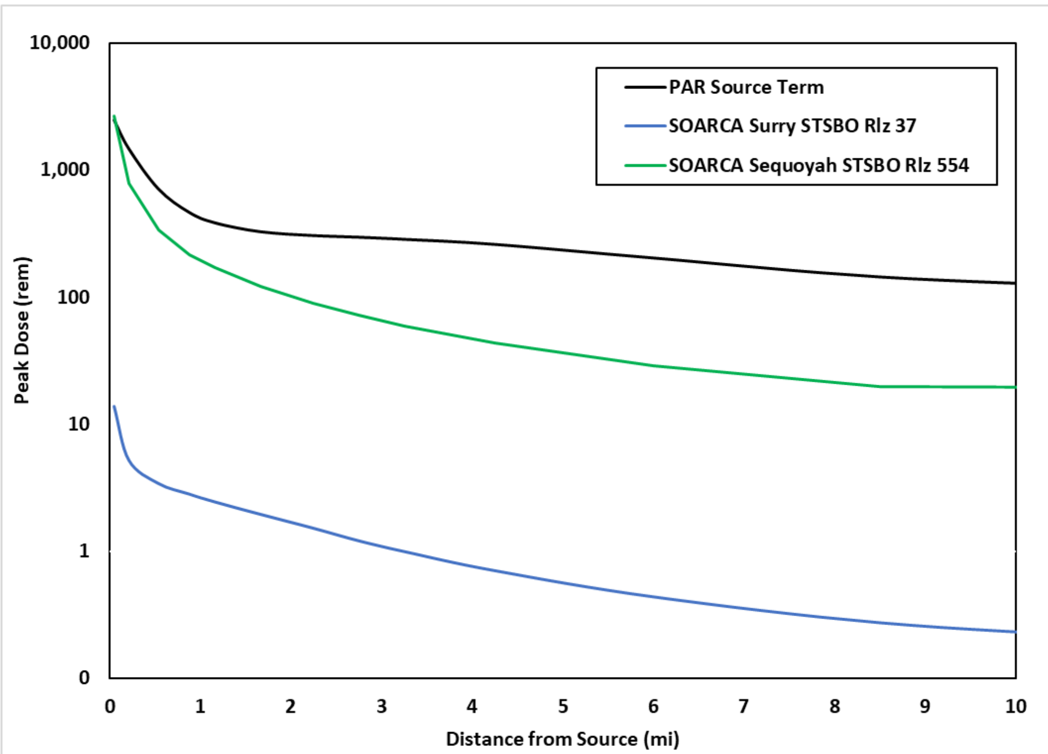

Figure 4-1 Peak dose comparison for the three source terms

Table 4-5 Mean population dose (rem) comparison

Radial Distance (mi)	Version 4.1.0.2 with Updates		
	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-2	2.41E+05	3.83E+03	6.09E+04
2-5	7.77E+05	5.75E+03	8.93E+04
5-10	1.33E+06	4.90E+03	1.07E+05
0-10	2.34E+06	1.45E+04	2.57E+05
0-50	4.76E+07	9.55E+05	1.71E+07

Table 4-6 99th percentile population-weighted individual risk of an early fatality comparison

Radial Distance (mi)	Version 4.1.0.2 with Updates		
	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-10	2.89E-07	0.00E+00	0.00E+00

Table 4-7 Mean population-weighted individual cancer fatality risk comparison

Radial Distance (mi)	Version 4.1.0.2 with Updates		
	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-2	1.42E-02	1.56E-04	3.19E-03
2-5	9.01E-03	4.79E-05	6.71E-04
5-10	5.00E-03	1.40E-05	2.51E-04
0-10	6.43E-03	2.92E-05	4.98E-04

4.3. Sensitivity cases

Several sensitivity cases were chosen to determine the impact that individual model and input parameter updates (see Section 3) had on the results when compared to the original PAR study. All sensitivity cases use the source term "A" case with a high population density site, 1 mph evacuation speed, and the scenario A protective actions detailed in Section 2 of this study. Additionally, all MACCS models for the cases below were completed using MACCS version 4.1.0.2 to avoid any additional impacts such as the ones discussed in Section 4.1. All one-way sensitivity analyses compare the early fatalities and latent fatalities within the EPZ (0-10 miles) for cohorts 1, 4, 7, and 10 as seen in Table 2-2. These results are likely representative of all of the estimated early fatalities for these cohorts within the entire spatial grid but could potentially only cover a small portion of the total latent cancer fatalities within the modeling domain. Additionally, the total number of displaced individuals within the EPZ are compared using the same methodology as Section 4.2.2.

4.3.1. Implementation of the keyhole evacuation model

As discussed in Section 3.5, a sensitivity analysis on the keyhole evacuation model was performed. This analysis focused on the original PAR study case with and without the use of the keyhole evacuation model. As can be seen in Table 4-8 and Table 4-9 below, the addition of the keyhole evacuation model with a 2-hour keyhole forecast and a 5-mile center to a 10-mile keyhole, ultimately had no effect on the health effect cases but it did affect the number of displaced individuals. The number of displaced individuals decreased by approximately 9%. A majority of the individuals within the EPZ still evacuate with the keyhole model due to the assumption within the MACCS code that once more than half of the sectors have been evacuated due to the changes in wind direction, all remaining sectors are evacuated as well. Therefore, depending on the release duration and weather conditions, a large portion of the population can still be evacuated when implementing a keyhole evacuation model. Additionally, another phenomenon that isn't reflected in these total values is the change in timing of evacuation. When using the keyhole evacuation model, approximately half of the total number of displaced individuals is evacuated within the first hour of release and the rest perform a staged evacuation as time progresses which can help with congestion during evacuation. Nonetheless, this sensitivity analysis demonstrated that with roughly the same number of estimated health effects, overall social disruption can potentially be minimized when using a keyhole evacuation scenario.

Table 4-8 Comparison of the mean health effect cases within the EPZ when using different evacuation models

Cohort	Circular Evacuation Model		Keyhole Evacuation Model	
	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality
Cohort 1	1.29E+00	3.96E+02	1.29E+00	3.96E+02
Cohort 4	2.88E+00	3.85E+02	2.88E+00	3.85E+02
Cohort 7	1.15E+00	3.07E+02	1.15E+00	3.07E+02
Cohort 10	7.99E-01	2.90E+02	7.99E-01	2.90E+02

Table 4-9 Comparison of the mean displaced individuals within the EPZ when using different evacuation models

Radial Distance (mi)	Circular Evacuation Model	Keyhole Evacuation Model
0-10	254,100	232,100

4.3.2. Updated shielding and exposure parameters

This sensitivity case focused on determining the effect the updated shielding and exposure parameters listed in Table 3-4 had on the mean health effect cases and the total number of displaced individuals. As seen in Table 4-10 and Table 4-11, for the early fatality health effect cases and the displaced individuals, there was essentially no change in the results and the latent cancer fatality health effect cases decreased by approximately 4-9% depending the specific cohort. The updated shielding and exposure parameters likely did not change the dose enough to have a significant effect. Nevertheless, protective actions can significantly change shielding and exposure parameters to a greater degree than the sensitivity explored here.

An increase in shielding causes a proportional decrease in the dose. Changes in dose, however, will have different impacts on early fatality risk compared to cancer fatality risk because these risks have different dose-response relationships. For early fatalities, as the amount of shielding increases, at some point, doses no longer cross the dose threshold necessary to cause early fatalities. Cancer fatality risk on the other hand, is not known to have a dose threshold as the early fatality risk model has. While uncertain, the cancer risk model used in this study is the linear no threshold model with a low dose adjustment using a dose and dose rate effectiveness factor. This model assumes low doses are proportional to cancer risk. Therefore, changes in shielding and exposure are proportional to the cancer risk so long as doses remain in the low dose region, but may result in a step change in the cancer fatality risk equal to the dose and dose rate effectiveness factor if they do not. Depending on the size of the source term and other factors that affect dose, many exposures may never exceed the threshold used to define the bounds of the low-dose region.

Table 4-10 Comparison of the mean health effect cases within the EPZ when using the updated shielding and exposure parameters

Cohort	Original Parameters		Updated Parameters	
	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality
Cohort 1	1.29E+00	3.96E+02	1.25E+00	3.78E+02
Cohort 4	2.88E+00	3.85E+02	2.81E+00	3.65E+02
Cohort 7	1.15E+00	3.07E+02	1.11E+00	2.82E+02
Cohort 10	7.99E-01	2.90E+02	7.74E-01	2.63E+02

Table 4-11 Comparison of the mean displaced individuals within the EPZ when using the updated shielding and exposure parameters

Radial Distance (mi)	Original Parameters	Updated Parameters
0-10	254,100	254,100

4.3.3. Compass sector resolution sensitivity

To support the discussion in Section 3.10.1, a sensitivity analysis was also completed for the adjustment of the compass sector resolution from 16 sectors to 64 sectors. In order to perform a sensitivity that only considers the compass sector resolution, the original 16-sector site file from the PAR study was not used. Instead, a new 16-sector site file was created using the more recent census data. This matches the data used in the upgraded 64-sector site file as discussed in Section 3.10.3 and ensures the only variable for this sensitivity analysis is the number of compass sectors.

As seen in Table 4-12, when the spatial grid is increased to 64 compass sectors, the mean health effect cases for the four cohorts assessed decreased. However, as seen in Table 4-13, the number of displaced individuals remains the same.

Table 4-12 Comparison of the mean health effect cases within the EPZ when adjusting the compass sector resolution from 16-sectors to 64-sectors

Cohort	16 Compass Sectors		64 Compass Sectors	
	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality
Cohort 1	1.48E+00	4.05E+02	1.00E+00	2.98E+02
Cohort 4	3.14E+00	3.94E+02	2.30E+00	2.92E+02
Cohort 7	1.25E+00	3.21E+02	8.47E-01	2.41E+02

Cohort 10	9.37E-01	3.05E+02	6.12E-01	2.31E+02

Table 4-13 Comparison of the mean displaced individuals within the EPZ when adjusting the compass sector resolution from 16-sectors to 64-sectors

Radial Distance (mi)	16 Compass Sectors	64 Compass Sectors
0-10	267,300	267,300

4.3.4. Source term sensitivity

To further assess the impact of different source terms with different release characteristics, a sensitivity analysis on the results was also completed for the PAR source term and the two SOARCA source terms with the use of both the circular evacuation model and the keyhole evacuation model.

4.3.4.1. Using the circular evacuation model

As can be seen in Table 4-14 below, the comparison of the mean health effect cases between the original PAR study source term and the two SOARCA source terms is significant. The difference shown in the results below is consistent with the results shown in Section 4.2.3. Additionally, the number of displaced individuals decreased for the SOARCA Surry STSBO Rlz 37source term and increased for the SOARCA Sequoyah STSBO Rlz 554 source term. It is assumed that the number of displaced individuals for the Sequoyah source term is higher than the number of displaced individuals for the PAR source term because Sequoyah Rlz 554 has a more prolonged release (See Section 3.10.4).

Table 4-14 Comparison of the mean health effect cases within the EPZ when using the circular evacuation model and different source terms

Cohort	PAR Source Term		SOARCA Surry STSBO Rlz 37		SOARCA Sequoyah STSBO Rlz 554	
	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality
Cohort 1	1.29E+00	3.96E+02	0.00E+00	1.18E-01	0.00E+00	1.38E+02
Cohort 4	2.88E+00	3.85E+02	0.00E+00	1.29E-01	0.00E+00	1.47E+02
Cohort 7	1.15E+00	3.07E+02	0.00E+00	1.45E-01	0.00E+00	1.59E+02
Cohort 10	7.99E-01	2.90E+02	0.00E+00	1.70E-01	0.00E+00	1.74E+02

Table 4-15 Comparison of the mean displaced individuals within the EPZ when using the circular evacuation model and different source terms

Radial Distance (mi)	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 554
0-10	254,100	253,900	254,300

4.3.4.2. Using the keyhole evacuation model

Comparing Table 4-16 and Table 4-17 to Tables 4-14 and 4-15 shows essentially no difference in health effect cases between the two evacuation models but there is a difference when comparing the number of displaced individuals. For the original PAR source term and the two SOARCA source terms, social disruption is minimized with the keyhole evacuation model even though the number of health effect cases remains the same. This difference in displaced individuals between the two evacuation models is in line with the results seen in Section 4.3.1.

Table 4-16 Comparison of the mean health effect cases within the EPZ when using the keyhole evacuation model and different source terms

Cohort	PAR Source Term		SOARCA Surry STSBO Rlz 37		SOARCA Sequoyah STSBO Rlz 554	
	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality	Early Fatality	Latent Cancer Fatality
Cohort 1	1.29E+00	3.96E+02	0.00E+00	1.21E-01	0.00E+00	1.39E+02
Cohort 4	2.88E+00	3.85E+02	0.00E+00	1.31E-01	0.00E+00	1.47E+02
Cohort 7	1.15E+00	3.07E+02	0.00E+00	1.48E-01	0.00E+00	1.59E+02
Cohort 10	7.99E-01	2.90E+02	0.00E+00	1.73E-01	0.00E+00	1.75E+02

Table 4-17 Comparison of the mean displaced individuals within the EPZ when using the keyhole evacuation model and different source terms

Radial Distance (mi)	PAR Source Term	SOARCA Surry STSBO Rlz 37	SOARCA Sequoyah STSBO Rlz 544
0-10	232,100	249,600	253,800

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5. CONCLUSIONS

This analysis sought to determine if more recent updates to the MACCS code, input parameters, and modeling methodologies would result in changes to the MACCS results (that ultimately influenced the conclusions) of the original PAR study. Absent a more detailed study, results from this initial effort should not be used to enact any changes to current PAR guidance. The results indicate that updated best practice modeling assumptions and capabilities do lead to changes in health consequences.

Overall, this current scoping study results in fewer health consequences than the original PAR study. The choice of source term had the largest impact on the health consequences, but the compass sector resolution update showed a difference as well. Additionally, the choice of source term coupled with the use of the keyhole evacuation model also impacted the number of displaced individuals. The use of updated shielding and exposure parameters also affects health consequences; however, the updated values considered in this analysis are not significantly different, so their impact is minimal compared to the choice of source term and the use of a 64-compass sector grid. A broader range of shielding and exposure parameters would likely yield different results.

The original PAR study recommended protective actions strategies that minimize radiogenic health consequences. However, it may also be worth recognizing that excessive evacuation and relocation cause other societal impacts. This analysis considered the number of displaced individuals as a measure of social disruption and significant variations in the EPZ was observed when using different modeling practices. Minimizing social disruption may also be important in determining which protective action strategies are best. This may be particularly true for source terms that produce relatively few radiogenic health effects. As such, consideration of more source terms that result in fewer health consequences and recognition of the potential harm that excessive protective actions can have (such as those discussed in NUREG/CR-7285 "Nonradiological Health Consequences from Evacuation and Relocation" [14]), could affect our understanding of the best protective actions to take.

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