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A New Emergency Response Model for MACCS

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1.0 Introduction

Under DOE sponsorship, as directed by the Los Alamos National Laboratory (LANL), the MACCS code (version 1.5.11.1) [Ch92] was modified to implement a series of improvements in its modeling of emergency response actions. The purpose of this effort has been to aid the Westinghouse Savannah River Company (WSRC) in its performance of the Level III analysis for the Savannah River Site (SRS) probabilistic risk analysis (PRA) of K Reactor [Wo90]. To ensure its usefulness to WSRC, and facilitate the new model's eventual merger with other MACCS enhancements, close cooperation with WSRC and the MACCS development team at Sandia National Laboratories (SNL) was maintained throughout the project.

These improvements are intended to allow a greater degree of flexibility in modeling the mitigative actions of evacuation and sheltering. The emergency response model in MACCS version 1.5.11.1 was developed to support NRC analyses of consequences from severe accidents at commercial nuclear power plants. The NRC code imposes unnecessary constraints on DOE safety analyses, particularly for consequences to onsite worker populations, and it has therefore been revamped.¹ The changes to the code have been implemented in a manner that preserves previous modeling capabilities and therefore prior analyses can be repeated with the new code.

A discussion of the rationale for making these code changes is given in Section 2. A complete description of all aspects of the new code's emergency response modeling capabilities is supplied as Section 3. A set of replacement pages for the MACCS User's Guide describing how to use the new models can be found in Section 4.

Appendix A provides guidance for its installation on a computer system. Appendix B discusses the Sample Problems provided with the new version of MACCS. Appendix C describes the verification efforts performed by the author. Finally, Appendix D describes the independent verification performed by Sandia National Laboratories.

2.0 Rationale for Code Modification

Under NRC sponsorship, MACCS was developed by SNL to assess the offsite consequences of severe accidents at commercial power plants. MACCS version 1.5.11 has been distributed to the general public by two government code centers since 1990 [Ch90, Jo90]. A maintenance release of the code (Version 1.5.11.1) which implements error corrections, a revised cancer model, and enhanced portability was submitted by SNL in July 1992 to the U.S. government's Energy Science and Technology Software Center (ESTSC) in Oak Ridge, TN for distribution to the public. MACCS version 1.5.11.1 is currently being distributed by the ESTSC.

¹ The NRC version of MACCS neglects radionuclides found in DOE facility accident source terms, offers limited flexibility in modeling worker evacuations, and limits shielding factors to one building type. The code modifications described in this report are limited to the treatment of emergency response actions. Other improvements to the code are being implemented by Sandia National Laboratories.

In the U.S., the vast majority of MACCS recipients are involved in DOE sponsored safety evaluations of government facilities. Few organizations are currently using MACCS to support NRC licensed private facilities such as nuclear power plants. When MACCS is used for assessments of DOE facilities, analyses are often hampered in two areas: (1) a lack of completeness in the set of radionuclides, and (2) a lack of flexibility in modeling emergency response actions.

An effort is now underway at SNL to greatly expand the set of radionuclides which can be considered by MACCS. Due to the modularity of the code's design it will be a straightforward effort to incorporate the improved emergency response model described in this report. In addition, SNL has reviewed this report to ensure that the final product of the current effort can be readily utilized in their code development activities. A test version of the new software was submitted to SNL for independent verification. The contents of a letter report describing that verification [Mi92] are listed in Appendix D. All of the errors discovered by SNL have been corrected in the current version of the software.

The code described in this report is to be considered as "in development" for use only by WSRC, SNL, and any other organizations designated by LANL. As a result of the code's development status, there are no plans to submit it to the government code centers. The software described in this report is intended for use by individuals familiar with the current version of MACCS and its documentation [Ch92]. It is requested of all recipients of this software that it not be disseminated to others without the authorization of LANL, the sponsor of this effort.

2.1 On-Site Worker Populations

MACCS is designated as a "offsite consequence" code in the Foreword to the code's documentation written by NRC staff [Ch90,Jo90]. For the most part, NRC safety analyses in the past have focused on accident consequences to offsite populations. Within the realm of severe accidents at nuclear power plants, in studies such as WASH-1400 [NR75] and NUREG-1150 [NR90], little attention has been given to the potential accident consequences faced by the onsite workers at a nuclear power plant.²

When MACCS is applied to safety evaluations of DOE facilities such as K Reactor, consideration must be given to workers at other locations on the SRS reservation. While most commercial nuclear power plants maintain an exclusion zone of less than a mile radius [Al83], the reservation boundary for the general public from K Reactor ranges from 5 to 15 miles depending on direction. Within that region, the daytime worker population of SRS may include over 20,000 people. Many of those individuals are located miles away at facilities wholly unrelated to K Reactor.

² The habitability of reactor control rooms during Design Basis Accidents is addressed in NRC standards. Also, current NRC studies on Low Power and Shutdown risks are addressing severe accident risks to onsite workers.

2.2 Radial Versus Network Evacuation

For most commercial power plants, the population of the ten mile radius Emergency Planning Zone (EPZ), could make use of a number of evacuation routes to leave the region immediately surrounding the power plant. If highways are blocked with traffic, city streets and smaller thoroughfares could be used as alternative routes. The major exceptions to this are (1) low population regions with few roads; (2) coastal regions; and (3) river or terrain-limited topographies.

It is assumed in MACCS that evacuation of the EPZ is accomplished by having individuals travel radially outward away from the accident location. There is no capability offered for having individuals travel on a pre-defined road network such as may be present at DOE reservations.

In most nuclear power plant analyses, this simplification does not introduce unacceptable errors. For the three exceptions listed above, the modeling of a network road model would be most important for coastal areas, especially when substantial transient recreational populations are present. For rural areas, the limited number of evacuation routes might not represent a significant impediment to the population since travel speeds out of the region could be very high.

At a DOE reservation such as the SRS there are a limited number of roads which may be used for evacuation of the onsite workers.³ At some SRS facilities, the only practical evacuation route might call for travel toward the accident location in order to leave the reservation. Furthermore, during severe weather conditions or seismic events there could be significant variations in travel speed during the course of an evacuation due to traffic jams. For these reasons, the MACCS evacuation model of radially outward travel at a constant speed represents an unreasonable restriction when applying MACCS to K Reactor for onsite evaluations.

2.3 Invariant Travel Speed

The NRC evacuation model requires the specification of a single travel speed for evacuating individuals. This does not allow the modeling of traffic delays developing during the course of the evacuation. A more realistic model would allow travel speeds to vary over the course of the evacuation. It is reasonable to suppose that at the beginning of an evacuation, travel speeds could be quite high. After roads become saturated, travel speeds would then decrease sharply. Finally, after the bulk of the vehicles have left the region, travel speeds for any remaining vehicles could then increase.

³ However, at SRS the workforce is better trained for emergency conditions than is the general populace surrounding commercial nuclear power plants. Annual emergency exercises are held which involve the reactor area personnel and the emergency operations staff. All regular workers at SRS are required to undergo extensive training on emergency preparedness.

2.4 Population Groups

The definition of a population distribution in the NRC emergency response model allows two options: (1) a uniform population density outside of a specified exclusion boundary, or (2) a data file with population counts for each element of the polar coordinate grid system. The NRC model allows the definition of up to three emergency response scenarios with results combined either by "fraction of the people" or "fraction of the time" [Ch90].

Of the two combination options, the fraction-of-the-people option is the more commonly used. For instance, in the MACCS Sample Problems distributed with the code it is assumed that 95% of the populace will evacuate the EPZ after notification is given. The remaining 5% will stay in place, but, if their doses exceed certain criteria, after a delay period has elapsed they are assumed to be instantly removed from the contaminated area.

A possible application of the fraction-of-the-time option could be to represent external events such as loss of offsite power due to severe weather, earthquakes, etc. The analysis could thereby consider the impact of external events on the ability to carry out evacuation in a timely manner. The interpretation might be that some fraction of core melts are expected to be caused by external events that could impede emergency response actions.

The NRC emergency response model allows the use of only a single population distribution around the release point. This population is then considered homogeneous with respect to the selected emergency action scenarios (e.g., 95% of the people). If a scenario is specified for 95% of the people, then the calculations are based on the assumption that 95% of the people in each spatial element are subject to the designated actions. There is no capability in the NRC model for considering simultaneously, in a single MACCS run, the general population, as well as discrete subgroups such as hospital and prison populations whose evacuation could be very difficult.

It is desirable to remedy this limitation by allowing MACCS to utilize a different population data block for each of the up to three emergency response scenarios the code can consider in a single run. This would allow, for instance, an analysis where some workers are assumed to remain in the area with respiratory protection (rescue and fire teams wearing Scott air packs) while the remainder are evacuated.

Another possible application is to represent differences in shielding factors according to building type. Workers in trailers will in general receive less shielding than workers in large modern offices where ventilation rates can be controlled. Population files could thus be constructed to represent each category of building construction with a suitable set of shielding factors being used for each cohort.

In regard to its treatment of shielding factors, the NRC code is restricted to using the same set of shielding factors for each of the up to three emergency response scenarios. The user defines shielding factors to be used for three different types of activities: (1) "normal" activity, (2) evacuation, and (3) sheltering. That single set of shielding factors is then utilized for the scenarios. There is no provision in the NRC model for defining one set of shielding factors to

be associated with the first emergency response scenario and an alternative set for the other scenarios.

2.5 Inability to Model a Graded Response

The NRC emergency response model allows the user to specify various circular regions subject to the emergency actions of evacuation and sheltering. However, that code does not allow the specification of both actions to take place in a given region. The user must choose one or the other. Thus, there is no means of modeling a scenario where individuals are notified to take shelter and then carry out a phased evacuation from the areas which are at risk.

2.6 Reference Time for Actions

In the NRC emergency response model there are two reference times used to determine when a given type of action will begin. For evacuation and sheltering actions, the time at which they are initiated is based on the "alarm time" (variable OALARM) [Ch90] normally associated with the declaration of a General Emergency [NR87] at a commercial nuclear power plant.⁴ The assumed sequence of events after declaration of the General Emergency is that some delay period would elapse and then the civil authorities would be notified and given recommendations on protective actions for the public. If such actions are then ordered, some time could elapse before their actual implementation by the populace.

For dose-dependent early relocation (the "hot-spot" and "normal" relocation actions), the reference time for those actions remains, as in the prior model, the arrival time of the first plume. This model assumption is not considered to be a limitation in applying MACCS at DOE sites. Thus, the new model treats those actions in the same manner as its predecessor.

3.0 Capabilities of the New Model

The new model is structured in such a manner as to allow the analyst a great deal of flexibility in defining emergency response strategies. This is achieved within a framework that is conceptually simpler than the NRC model. For most sites, it will probably be unnecessary to utilize all the features of the new model. However, availability of the new modeling features will facilitate performance of sensitivity studies, etc., to evaluate alternative assumptions for emergency response.

⁴ The terminology used at DOE facilities to define the various levels of emergency conditions is different from that used by the NRC. At DOE facilities the evacuation and/or sheltering of the workforce could be initiated before a declaration of General Emergency.

3.1 Definition of Emergency Response Scenarios

The new model, as well as its predecessor, allows the user to specify up to three emergency response scenarios. The population data associated with each of these scenarios may be defined either (1) with a single population data block (as with the previous version of MACCS), or (2) a separate population data block may be defined for each of the emergency response scenarios. If multiple population distributions are defined, the user is then unable to define fraction-of-the-people or fraction-of-the-time weighting factors for summation of the overall results. In that case, the various results are simply added together in reporting the CCDF summary tables generated by the code.

As in the previous code, evacuation and sheltering actions may be modeled in the region surrounding the release point. Exterior to the evacuation and sheltering region, dose-dependent relocation actions may take place in exactly the same manner as with the previous code using the so called hot-spot and normal relocation dose criteria.

The user may no longer define a sheltering region per se since evacuation and sheltering actions have been merged together. However, this merging of the two actions has been accomplished in a manner that allows emulation of the NRC model's features. In the new code's modeling of the evacuation and sheltering region, the user explicitly defines the reference time to be used for initiation of the action as being either: (1) the alarm time (input variable OALARM) associated with the source term; or (2) the arrival time of the first plume reaching the downwind location. In the region beyond the evacuation and sheltering region, i.e., the so called relocation zone, the reference time point for actions remains the plume arrival time, and no change to the NRC model has been made.

The evacuation/sheltering region is user-specified to extend to a given radial distance (i.e., radial spatial interval). For each radial distance in this region, the user specifies a sheltering period (which may have a zero duration) that occurs prior to the initiation of the evacuation. During the sheltering phase, shielding factors appropriate for sheltered activity are used to calculate doses for the individuals in contaminated areas.

By allowing the delay times to vary for each individual ring of the polar grid, a staged evacuation may be modeled where the evacuation delay time increases as a function of distance. If desired, each emergency response scenario, of the three allowed, may utilize its own set of shielding factors.

At the termination of the sheltering phase, the resident individuals initiate their travel out of the region. In each of the up to three scenarios the user defines whether evacuation is to: (1) follow radial paths (as in the NRC code); or (2) follow complex paths defined as a network.

The actions defined for each of the up to three scenarios are wholly independent of the other scenarios. That is, a radial evacuation may be used for the first scenario, a network evacuation could be defined for the second scenario, and the third could have neither evacuation or sheltering taking place with the entire region subject only to dose-dependent relocation actions.

The summation of results from these scenarios for the overall CCDF is performed either (1) using a single population distribution with weighting fractions, or (2) using different population distributions and simply adding the results together without applying any weighting factors.

3.2 Variable Evacuation Speeds

In the new model, the user divides the evacuation period into three phases. These phases are denoted as early, middle, and late. For each of the three phases of the evacuation, the user defines the travel speed to be utilized by the evacuees during that period of time. For situations where only one or two evacuation speeds are defined, the duration of the first and/or second evacuation phase may be set to zero.

For both types of evacuation, i.e., radial and network, the implementation of the travel speed model is identical. Three travel speeds are defined in the EARLY User Input File. As individuals traverse the path defined for them, their speed of travel can vary due to transitions from one phase to the next. If these transitions occur while an individual is traversing a spatial element, the code uses linear interpolation to determine the traversal time for that element.

In order to allow all individuals to leave the evacuation region, the late phase is considered to extend in time as long as is necessary for all evacuating individuals to leave the region. Thus, the user specifies the duration of the early and middle evacuation periods but no duration is specified for the late phase.

The initial evacuation period begins when the first individuals begin their travel out of the region and extends in time for the user-specified duration, DURBEG. After that period has elapsed, the middle phase evacuation period takes place for the user-specified duration DURMID. Finally, the remainder of time necessary for all individuals to complete their travel is considered the late phase evacuation period.

3.3 Radial Versus Network Evacuation

If the radial evacuation model is chosen, the new code operates in the same manner as its NRC predecessor with the exception that the evacuation speed may be defined as variable over time (as described in the previous section).

The network evacuation model requires the user to specify a destination direction for each spatial element (nodes) in the evacuation network. With respect to a coordinate system where all individuals are facing away from the release point, the four possible destinations are: forward, rightward, backward, and leftward. Forward travel is away from the release point. Rightward travel is a clockwise rotation. Backward travel is towards the release point. Leftward travel is a counterclockwise rotation. For elements adjoining the release point (i.e., radial index number 1), only three possible directions are allowed. Thus, an input error will result if backward travel across the grid centerpoint is specified.

Elements at the outer boundary of the region are not required to have a destination direction away from the release point (i.e., in the forward direction) though at least one boundary element must offer an outbound path. The network must not contain any closed loops or cycles (i.e., paths that repeat on themselves). An illustration of a generalized network path is given as Figure 1.

As in the NRC model, when individuals complete their travel on the evacuation path by reaching a user-specified distance from the release point, they are then assumed to avoid further exposure during the emergency phase considered by the EARLY module of MACCS.

4.0 User's Guide Supplement for the New Model

The general framework of data specification is very similar to that used for versions 1.5.11 and 1.5.11.1 of MACCS. The following sections describe the specification of input data for the new code. Readers familiar with MACCS Sample Problems A, B, and C [Ch90] are advised to refer to Section A.1 of this report for a brief description of how to implement prior modeling assumptions with the new code.

4.1 Input Variables Which Are No Longer Processed

With the implementation of the new model, several input variables for the EARLY module are no longer utilized by MACCS. If these variables are included on an EARLY User Input File, their values will be ignored. The variables no longer processed by the code, and the reasons for their deletion, are as follows:

- INIEVA - shelter and evacuation zones have been combined;
- LASEVA- replaced with the new variable NUMEVA;
- EDELAY- replaced with the new variable DLTEVA;
- TTOSH1 - replaced with the new variable DLTSHL;
- SHELT1 - replaced with the new variable DLTEVA;
- LASHE2 - shelter and evacuation zones have been combined;
- TTOSH2 - replaced with the new variable DLTSHL;
- SHELT2 - replaced with the new variable DLTEVA.

4.2 Modifications to Prior Input Variables

The input variable ESPEED is utilized by the new code but three values are now required to be supplied. The NRC code uses only a single value. The three evacuation speeds thus defined are used for the initial, middle, and late phase of the evacuation.

The input variable WTNAME, which, in the NRC code, determines whether fraction-of-the-people or fraction-of-the-time weighting is to be used in combining results, is now allowed to take on three possible values: PEOPLE, TIME, or SUMPOP. The new SUMPOP option indicates that results are to be combined by simple unweighted summation.

Figure 1
Example Evacuation

If SUMPOP is specified, the weighting fraction input variable, WTFRAC, will not be processed. Furthermore, if SUMPOP is specified, the user must define in the Site Data File a separate population distribution for each of the up to three emergency response scenarios. The option of a uniform population density (POPFLG='UNIFORM') is not allowed in these cases. The population distribution used for CHRONC is obtained by summing the population distributions defined for EARLY. For example, if a given spatial element on the grid was defined to have 12, 20, and 30 individuals, respectively, for the three different emergency response scenarios, the long-term calculations performed by the CHRONC module would be based on 62 individuals being resident at that location.

The shielding and exposure factors for cloudshine, groundshine and inhalation (CSFACT, SKPFAC, GSHFAC, PROTIN, and BRRATE) may now be redefined for each emergency response scenario. The NRC code utilized a single set of these factors for both EARLY and CHRONC. The CHRONC module, if exercised, will use numeric values from the last emergency response scenario that was defined in the EARLY User Input File.⁵

4.3 New and Modified Input Variables in the Emergency Response Model

Variable Name: POPFLG

Variable Type: Character, Scalar

Allowed Value: 'FILE' or 'UNIFORM'

Purpose: Specifies whether the population is to be defined by the Site Data File or if it is to be uniformly distributed. If a value of UNIFORM is specified, the program will not process the Site Data File, instead, the input variables IBEGIN and POPDEN are used to define the population distribution. The specification of UNIFORM is not allowed if the SUMPOP option (defined below) is to be specified.

Variable Name: WTNAME

Variable Type: Character, Scalar

Allowed Value: 'PEOPLE' or 'TIME' or 'SUMPOP'

Purpose: Defines the type of weighting to be used in generating the overall weighted sum of results. If PEOPLE or TIME are selected, the code's behavior is unchanged from the NRC version of MACCS. If the SUMPOP option is selected, the value of WTFRAC is not processed and the overall weighted sum is generated by simple summation. Also, the selection of SUMPOP indicates that the Site Data File will include a separate population distribution for each emergency response cohort (see Section 4.5).

⁵ The CHRONC module, which calculates exposures after the 1-7 day emergency phase, is typically not applicable to DOE workforce evaluations.

Selection of SUMPOP requires that the population be defined via a Site Data File. An input error will thus result if the user specifies both WTNAME='SUMPOP' and POPFLG='UNIFORM' in a single run of the code.

Example Usage:

*

* Define the type of weighting to be used

*

EZWTNAME001 'PEOPLE'

Variable Name: EVATYP

Variable Type: Character, Scalar

Allowed Value: 'RADIAL' or 'NETWORK'

Purpose: Defines whether a radial or network evacuation is to be modeled. If the radial option is chosen, the code automatically generates a network path where all individuals travel radially outward.

If the network option is chosen, the user is required to supply data for variable IDIREC. Furthermore, the selection of network evacuation is inconsistent with the straight-line plume (i.e., IPLUME=1) dispersion option. When a network evacuation is specified, the user must specify a value of 2 or 3 for IPLUME. Thus, the centerline dose and risk results (Type 6 and Type 7) are unavailable when the network evacuation option is selected.

Example Usage:

*

* Define the evacuation to follow a network path

*

EZEVATYP001 'NETWORK'

Variable Name: ESPEED

Variable Type: Real, Array

Allowed Range: 1.0E-6 <= value <= 1.0E+6 (meters/second)

Purpose: Defines the travel speed of evacuees during the three phases of the evacuation: initial, middle, and late. The initial evacuation phase begins when the first individual begins to travel on their path out of the region. The durations of the initial and middle phases of the evacuation are defined by input variables DURBEG and DURMID.

The late phase of the evacuation extends as long as necessary for all individuals to complete their travel. The user must supply three values for this parameter.

Example Usage:

*

* Evacuation travel speeds for three evacuation phases (m/s)

	(initial)	(middle)	(late)
EZESPEED00	1.8	1.8	1.8

Variable Name: REFPNT

Variable Type: Character, Scalar

Allowed Value: 'ALARM' or 'ARRIVAL'

Purpose: Defines the reference time point for actions in the evacuation and sheltering zone. If ALARM is chosen, the reference time point for these actions is the offsite alarm time (OALARM) as defined in the ATMOS source term definition. If ARRIVAL is chosen, the reference time for evacuation and sheltering actions is the arrival of the first plume at the spatial element.

Example Usage:

*

* Reference Time Point For Evacuation and Sheltering

*

EZREFPNT001 'ARRIVAL'

Variable Name: DURBEG

Variable Type: Real, Scalar

Allowed Value: $0.0 \leq \text{value} \leq 86400.0$ (seconds)

Purpose: Defines the duration of the initial phase of evacuation. This phase starts when the first individual in the shelter and evacuation region begins their evacuation from the region. The evacuation speed used during this phase of the evacuation is the first value of array ESPEED.

Example Usage:

*

* Duration of the Initial Phase of the Evacuation

*

EZDURBEG001 86400.0

Variable Name: DURMID

Variable Type: Real, Scalar

Allowed Value: $0.0 \leq \text{value} \leq 86400.0$ (seconds)

Purpose: Defines the duration of the middle phase of evacuation. This phase begins at the termination of the initial phase of the evacuation from the region. The evacuation speed used during this phase is the

second value of ESPEED. After the middle phase has elapsed, evacuees travel at the speed defined by the third value of ESPEED.

Example Usage:

*
* Duration of the Middle Phase of the Evacuation
*
EZDURMID001 86400.0

Variable Name: NUMEVA

Variable Type: Integer, Scalar

Allowed Range: $1 \leq \text{value} \leq \text{LASMOV}$

Purpose: Defines the number of radial spatial elements (i.e., contiguous rings) comprising the sheltering and evacuation region. For each ring of the region, values of DLTSHL and DLTEVA must be supplied.

Note: A clarification of the difference between LASMOV and NUMEVA is necessary. LASMOV defines the outer boundary of the region which shelterees and evacuees traverse. In contrast, NUMEVA defines the region where individuals are subject to sheltering and/or evacuation. It is possible to assign the same value to both parameters, however there is no requirement that this be the case. An example of LASMOV being larger than NUMEVA is the NUREG-1150 evacuation assumption, where the residents of a 10 mile EPZ travel to a distance of 20 miles.

Example Usage:

*
* Number of Rings in the Shelter and Evacuation Region
*
EZNUMEVA001 12 (region extends to a 10 mile radius)

Variable Name: DLTSHL

Variable Type: Real, Array

Allowed Range: $0.0 \leq \text{value} \leq 86400.0$ (seconds)

Purpose: Defines the delay that elapses from the reference time point REFPNT to when individuals take shelter. The user must supply NUMEVA values for this parameter, one for each ring in the shelter/evacuate region.

Example Usage:

*
* Delay Time to Take Shelter
*
EZDLTSHL001 7200. 7200. 7200. 7200. 7200. 7200.
EZDLTSHL002 7200. 7200. 7200. 7200. 7200. 7200.

Variable Name: DLTEVA

Variable Type: Real, Array

Allowed Range: $0.0 \leq \text{value} \leq 86400.0$ (seconds)

Purpose: Defines the delay that elapses from the beginning of the shelter period to when individuals begin their evacuation. The user must supply NUMEVA values for this parameter, one for each ring in the shelter/evacuate region.

Example Usage:

*
* Delay Time to Begin Evacuation
*

EZDLTEVA001	0.	0.	0.	0.	0.	0.
EZDLTEVA002	0.	0.	0.	0.	0.	0.

Variable Name: IDIREC

Variable Type: Integer, Array

Allowed Value: $1 \leq \text{value} \leq 4$

Purpose: Defines the destination direction of every spatial element in the evacuation and sheltering region. The destination direction is defined in terms of a coordinate system where all individuals are facing away from the centerpoint of the polar grid. A value of 1 indicates forward travel (i.e., radially outward); 2 indicates travel to the right (i.e., clockwise travel); 3 indicates travel backward toward the centerpoint; and 4 indicates leftward (or counter-clockwise) travel.

For every ring in the evacuation and sheltering region, i.e., at intervals extending out to LASMOV, an input data card must be supplied. Each of those LASMOV cards contain 16 values, corresponding to the compass points N through NNW. The network path defined below is illustrated in Figure 1.

Example Usage:

*
* Define the evacuation network
*

	N				E				S				W				
EZIDIREC001	2	2	2	1	4	4	2	1	4	1	1	1	1	4	4	4	(first ring)
EZIDIREC002	2	2	2	1	4	4	2	1	4	1	2	2	1	4	4	4	(second ring)
EZIDIREC003	2	2	2	1	4	4	3	1	3	2	2	2	1	4	4	4	(third ring)

4.4 New Output Measure: Peak Dose on the Spatial Grid

MACCS allows the reporting of centerline doses (i.e., the Type 6 results) only when the straight-line plume option without rotation (IPLUME=1) is selected. However, the network evacuation model may not be utilized when IPLUME is set to 1. For a number of reasons, it is desirable to allow the reporting of individual doses for network evacuation scenarios. To address this need, a new output measure is implemented, denoted as the "Type A" result. This result is based on the total dose at each distance over a selected range of distances in a manner analogous to the Type 6 results. The implementation of this result differs from the other in that there is no capability for reporting a breakdown of individual doses by pathway.

This result is requested in the EARLY User Input File and produced for each emergency response scenario. There is no dependence on population data. The dose is reported for phantom individuals assumed to be present at all locations. If the CHRONC module is exercised, this result is then automatically produced by CHRONC as well.

The overall weighted sum of results represents the combination of doses calculated by EARLY and CHRONC. Great caution should be taken with the use of the summed results since the peak doses from the various cohorts may occur at different angular locations. Summation of these values is most likely meaningless if multiple plume segments are allowed to travel in different directions (i.e., when NUMREL is greater than 1 and IPLUME is equal to 2 or 3).

Variable Name: NUMA

Variable Type: Integer, Scalar

Allowed Range: $1 \leq \text{value} \leq 10$

Purpose: Defines the number of results of this type being requested.

Variable Name: NAME

Variable Type: Character, Array

Allowed Range: $1 \leq \text{length} \leq 10$

Purpose: Defines the name of the organ for this dose measure.

Variable Name: I1DISA

Variable Type: Integer, Array

Allowed Range: $1 \leq \text{value} \leq \text{NUMRAD}$

Purpose: Defines the inner boundary of the region for which this result is to be calculated.

Variable Name: I2DISA

Variable Type: Integer, Array

Allowed Range: $1 \leq \text{value} \leq \text{NUMRAD}$

Purpose: Defines the outer boundary of the region for which this result is to be calculated.

Example Usage:

*
* Peak Dose Found on the Spatial Grid
*

TYPEANUMBER 2

	NAME	I1DISA	I2DISA	
TYPEAOUT001	'EDEWBODY'	1	26	(0-1609 km)
TYPEAOUT002	'RED MARR'	1	26	(0-1609 km)

4.5 Changes to Site Data File Processing

If the user specifies that fraction-of-the-people or fraction-of-the-time weighting is to be performed (see variable WTNAME in Section 4.3) the new code functions exactly the same as MACCS 1.5.11.1. In cases where the SUMPOP option is selected, the processing and interpretation of population data is treated in a different manner, as described below.

For each emergency response scenario (of the up to three allowed) defined in the EARLY User Input File, a distinct population distribution must be supplied in the Site Data File. In MACCS 1.5.11.1, the population data block is delimited with the header card POPULATION beginning at column two, followed by the population data. When the SUMPOP option is selected with the new code, the header cards for each population data block are POPULATION1, POPULATION2, and POPULATION3 corresponding to the respective emergency response scenarios, all beginning at column two. An error will result if the number of population data blocks does not equal the number of emergency response scenarios defined in the EARLY User Input File.

APPENDIX A

Installation Instructions

- (1) Install MACCS Version 1.5.11.1 on the host computer and verify its proper installation by running the sample problems supplied with the code.
- (2) Create a separate file directory for the new code and use PKUNZIP to decompress the installation files stored on the distribution diskette in the file MAXER.ZIP.
- (3) Compile and link the appropriate version of the FORTRAN source code. Two versions are supplied. PCMAXER.FOR is intended for use on IBM-compatible PCs (a 486 is highly recommended), while VXMAXER.FOR is the FORTRAN source code for VAX/VMS systems.

Execution of the new code is accomplished in a manner identical to that used with its predecessor. If the Job Control Language (JCL) files RUNMAXPC.BAT and RUNMAXVX.COM were modified when installing MACCS 1.5.11.1 on the host computer, e.g., to change file directory names, the locally modified JCL files should work with the new code.

There are no changes in the manner in which the code obtains its specification of input filenames. There are no changes to the dose conversion factor file (DOSDATA.INP). Prior Site Data Files can be utilized with the new software in conjunction with the fraction-of-the-people and fraction-of-the-time weighting options for summation of results.

APPENDIX B

Sample Problems

B.1 Sample Problems A, B, and C

The MACCS Sample Problems A, B, and C described in the MACCS User's Guide can be exercised, using files supplied on the distribution diskette, in a manner identical to that of the NRC version of MACCS:

```
RUNMAXER IN1C IN2C IN3C "" "" LISTC
RUNMAXER IN1B IN2B IN3B METSUR SURSIT LISTB
RUNMAXER IN1A IN2A IN3A METSUR SURSIT LISTA
```

B.2 Preliminary K Reactor Test Case

Using preliminary data supplied by Jackie East of WSRC [Ea92], a test case illustrating some of the new code's capabilities was prepared. This test case focused exclusively on the potential consequences to workers present at the Savannah River Site (SRS) during a severe accident at K Reactor. WSRC defined two sets of assumptions: one for internal events and the other for external events. For simplicity of presentation, only the internal events scenario was used in preparing the present K Reactor test case. Substitution of the parameters for external events (i.e., longer delay times and lower travel speeds) is a straightforward matter.

Apart from the emergency response scenarios and population counts supplied by WSRC, a large amount of other information was required to exercise MACCS. Such information includes the reactor inventory, source term, etc., as well as numerous other model parameters. For the current test case, this other information was taken from Sample Problem A. Thus, the predicted consequences should be viewed solely as an illustration of the new code's usage. Also, the emergency response assumptions described here should not be regarded as definitive.

The definition of scenarios was divided between (1) K Area personnel, and (2) personnel at other SRS locations. K Area personnel were assumed to begin their evacuation at half an hour after accident initiation (i.e., scram). At that time, they traveled a slightly jagged northward path to C Area, approximately three miles away. The personnel at other SRS locations were assumed to take shelter an hour after scram and remain sheltered for twelve hours. Radiation exposure for the evacuees was terminated when they reached a distance of three miles from K Area. Radiation exposure for the sheltered personnel in other areas was terminated after twelve hours.

The onsite population grid was prepared using population counts for each of 22 different areas at SRS, all of them within 11 miles of K Reactor. Using a topographic map of SRS, these populations were assigned to the MACCS polar grid. The first ring of the grid was placed at a distance of 0.1 km and subsequent rings were spaced at one mile intervals beginning at one mile from K Area.

In order to implement the two scenarios, i.e., evacuation for K Area personnel, and sheltering for the other areas; it was necessary to define two population distributions. With a single run of the MACCS EARLY module, the resultant consequence measures were combined using the SUMPOP option. That is, the results from the two simulations were combined by simple summation. The SUMPOP option is not available in the NRC versions of MACCS.

The first population distribution consists of all zeroes except for the single spatial element adjoining the centerpoint containing the 1111 workers of K area. The first ring of the polar grid was set at a radius of 0.1 km so that those workers began their travel very close to the release point. The second population distribution represents the population of the other areas at SRS. K Area personnel were not double-counted.

The evacuation of K Area personnel was modeled by defining a network comprising all spatial elements within the 0-3 mile region. Even though evacuees do not traverse all elements in the region, the code requires that a travel direction be specified for each element in the network. In order to ensure an absence of closed loops (i.e., cycles) a radially outward travel direction (i.e., IDIREC=1) was used for all the elements which were not traversed by the evacuees.

The K Reactor test case can be exercised as follows:

```
RUNMAXER IN1_K IN2_K "" MK8610 SITE_K LIST_K
```

B.3 Evacuation Test Case Prepared by Sandia National Laboratories

In carrying out the verification of the code at SNL, a test case was prepared which exercised the network evacuation model. The test was designed so that individuals at discrete locations would travel on paths that would, depending on their initial location, either: (1) travel directly under the plume; (2) travel on a path perpendicular to the plume; or (3) completely avoid exposure. This is the 5 m/s windspeed test case described in Section D.2.7. It can be exercised as follows:

```
RUNMAXER IN1_S IN2_S "" "" SITE_S LIST_S
```

APPENDIX C

Software Testing Performed by the Author

C.1 Rerun Sample Problems A, B, and C With The New Code

When the new code is given equivalent input, results should be identical.

The evacuation scenario (cohort 1) was modeled by setting the three evacuation speeds to 1.8 m/s. The reference time point for action was defined as the offsite alarm time. The delay to take shelter was defined to be 7200 seconds and the subsequent delay to begin evacuation was defined to be zero. The input cards implementing these choices are as follows:

EZLASMOV001	15					
EZESPEED001	1.8	1.8	1.8			
EZEVATYP001	'RADIAL'					
EZDURBEG001	86400.0					
EZDURMID001	0.0					
EZREFPNT001	'ALARM'					
EZNUMEVA001	12					
EZDLTSHL001	7200.	7200.	7200.	7200.	7200.	7200.
EZDLTSHL002	7200.	7200.	7200.	7200.	7200.	7200.
EZDLTEVA001	0.0	0.0	0.0	0.0	0.0	0.0
EZDLTEVA002	0.0	0.0	0.0	0.0	0.0	0.0

The relocation-everywhere scenario (cohort 2) was modeled in exactly the same manner as was done in MACCS 1.5.11.1 with the following card:

EZLASMOV001	0
-------------	---

The sheltering scenario (cohort 3) was modeled by defining the evacuation speed to be 1.E6 m/s. Individuals in the 0-16 km region take shelter 2700 seconds after the offsite alarm time. The duration of their sheltering was set to 43200 seconds. After the conclusion of the shelter period, evacuation at a very high speed allows the termination of their exposure.

EZLASMOV001	15					
EZESPEED001	1.E6	1.E6	1.E6			
EZEVATYP001	'RADIAL'					
EZDURBEG001	86400.0					
EZDURMID001	0.0					
EZREFPNT001	'ALARM'					
EZNUMEVA001	12					
EZDLTSHL001	2700.	2700.	2700.	2700.	2700.	2700.
EZDLTSHL002	2700.	2700.	2700.	2700.	2700.	2700.
EZDLTEVA001	4.32E4	4.32E4	4.32E4	4.32E4	4.32E4	4.32E4
EZDLTEVA002	4.32E4	4.32E4	4.32E4	4.32E4	4.32E4	4.32E4

Test Results: Results from Sample Problems A, B, and C were identical.

C.2 Proper Validation of Input Data and Graceful Error Recovery

Input files were prepared where invalid input values were supplied for each modified input data element. The code should diagnose the user input errors and exit gracefully. In addition to the specification of input parameters of the wrong type or outside the range of validity, a number of more complex errors were tried. These included the following: (1) a network path that included a cycle, (2) a path that traversed the centerpoint, and (3) a mismatch between number of population distributions and number of emergency response scenarios.

Test completed. Error recovery was successful in all cases.

C.3 Comparison of "Peak" Dose Results to "Centerline" Doses

The new Type A results were compared to the Type 6 results generated in the same run. Peak doses should be slightly less than centerline doses in all cases. Two constant weather cases were run using stability classes A and F. Examination of the ATMOS and EARLY debug results was performed to check the correctness of the peak dose results.

Test completed. Peak doses compared as expected to centerline doses.

For narrow plumes at small distances, the difference was up to 10% while for wide plumes and large downwind distances, the difference was less than 5%.

C.4 Test for Generation of Identical Results When IPLUME is Varied

For the case of a single plume release and a uniform population distribution, the results calculated with IPLUME = 1, 2, and 3 should be identical. The weather sampling option was used (METCOD=2) for this test. EARLY was exercised with three emergency response scenarios: evacuation, relocation, and sheltering. A radially outward evacuation was modeled for three test cases by setting EVATYP='RADIAL' and for another three test cases (everything else being equal) where the network evacuation option was selected and all paths set to the outward direction.

Case #	EVATYP	IPLUME
-----	-----	-----
1	RADIAL	1
2	RADIAL	2
3	RADIAL	3
4	NETWORK	1
5	NETWORK	2
6	NETWORK	3

Test results showed exactly identical results for Cases 2, 3, 5, and 6. Results of Cases 1 and 4 were identical. The two sets of results were only slightly different. There were less than ten (out of 300) consequence measures (all of them cancer results) where results differed by at most a few percent.

Note: While the reason for these small discrepancies was not determined, the same small discrepancy was observed when these test cases were rerun with the NRC code (MACCS version 1.5.11.1). Thus, the cause of discrepancy is unrelated to the code modifications being tested.

C.4 Test for Lack of Sensitivity to Evacuation Phase Durations

When three identical values of evacuation speed are used, but the duration of the initial and middle evacuation phases are varied, consequence measures should be invariant.

Case #	DURBEG	DURMID
-----	-----	-----
1	0.0	1000.0
2	3600.0	0.0
3	3600.0	1000.0

Test results showed all consequence measures to be exactly identical.

C.5 Test the Use of Different Shielding Factors for Each Cohort

Set up a single run where three emergency response scenarios are identical except for the shielding factors utilized. Each scenario is defined in such a manner that only one of three pathways (cloudshine, inhalation, and groundshine) is in effect--the other pathways are zeroed out. Examine the centerline dose results (Type 6) from each cohort to determine if in fact only a single pathway is active.

Test completed without error. Shielding factors can vary between emergency response scenarios.

C.6 Processing Multiple Population Distributions

When the WTNAME='SUMPOP' option is selected, test for proper summation of results from the various cohorts. A set of Site Data Files were prepared, all based on the Sample Problem A Surry file. These new files utilize the Surry population distribution, but the same distribution is repeated for each of the three cohorts using POPULATION1, POPULATION2, and POPULATION3 as the header cards for each section. Hand calculations will be used to check if results are being properly added into the "overall weighted sum" cohort presented on the output listing.

Test completed without error. Hand calculations confirmed proper summation of results.

C.7 Proper Interaction Between Plume Arrival Time and Exposure

Using the constant-weather option (METCOD=4), hand calculations were used to determine the plume arrival time at various spatial elements within the evacuation/sheltering region. By introducing small variations into the evacuation delay times, it was possible to determine the accuracy of the timing calculations. These cases used a very high evacuation speed to simulate the immediate removal of evacuees at various times. The variation of parameters included three different values for DURBEG and DURMID.

Test completed without error. For evacuation delay times of up to 10000 seconds, the accuracy of the timing was within 1 second.

APPENDIX D

Verification Performed by Sandia National Laboratories

The following text was taken, without modification, from the SNL letter report [Mi92] describing the testing performed by Jeffery Foster (Technadyne Engineering Consultants, Inc.) under contract to SNL.

D.1.0 Introduction

The MACCS code (version 1.5.11.1) has been modified by Technadyne Engineering Consultants for Los Alamos National Laboratory (LANL) under the sponsorship of the Department of Energy (DOE). These modifications were implemented to include several additional capabilities in the code's modeling of emergency response actions. The purpose of this effort was to assist the Westinghouse Savannah River Company (WSRC) in performing a Level III analysis for the Savannah River Site (SRS) probabilistic risk analysis (PRA) of the K reactor. In order to facilitate the merger of these new capabilities with the existing MACCS code under development at Sandia National Laboratories (SNL), close cooperation has been maintained between the development team at SNL and the author of the new emergency response model at Technadyne Engineering Consultants. As part of this cooperative effort, SNL agreed to perform independent testing of the new model. The test plan developed for this purpose and the results of the testing are documented in Section D.2. These tests comprise Phase I of the testing which uncovered some initial errors. Phase II of the testing is described in Section D.3 and includes rerunning some of the tests affected by these errors with the corrected code. Section D.4 contains several suggestions for making the code and documentation more user friendly.

D.2.0 Test Plan

The test plan was designed to test the new version of the code in three major areas, 1)backward compatibility to ensure that older modeling capabilities remain intact, 2)input checking and error messages associated with new variables added for the new modeling capabilities and old variables with new or amplified meanings, and 3)reasonable results for new scenarios not possible with the previous version of the code.

D.2.1 Backward Compatibility

The new MACCS code includes additional capabilities and requires some additional input. However, this input should be capable of precisely describing the problems previously addressed with MACCS. Sample Problems A, B, and C from the MACCS documentation set [Ch90] were rerun with the new code on SNL's VAX/VMS system. While the new code may perform its calculations slightly differently, or perhaps in a different order for spatial elements, the results should be equivalent. Input files for Sample Problems A, B, and C were copied from prior runs of MACCS and modified to account for the change in variables of the new code. These

modifications should be adequately described in documentation for the new version of MACCS [Ch92].

Results:

Output results were compared to earlier results using the VAX/VMS DIFF file comparison routine. Some differences produced were expected and not attributable to calculational changes. Problems B and C included only 5 occurrences of unexpected differences and these were limited to differences of 1 in the third digit printed. Problem A produced some 50 such differences and 14 of slightly more significance. Of these, two represented relative differences of only 8%, two of 19%, and the others were all less than 3%. These differences are similar to some seen in comparing MACCS results from UNIX systems with those from VAX systems and represent minor differences due to calculational changes.

D.2.2 Definition of Emergency Response Scenarios

- a. Define 4 scenarios in the input file.

Results:

Program aborted with error message:
"ONLY THREE EVACUATION STRATEGIES ARE ALLOWED"

- b. Define 3 scenarios but include only 2 population data blocks in the site data file.

Results:

Program aborted with error message:
"Looking for the data separator: POPULATION2
But instead found the string: LAND FRACTION"

- c. Define multiple populations in the site data file but set WTNAME=PEOPLE.

Results:

Program aborted with error message:
"Looking for the data separator: POPULATION
But instead found the string: POPULATION1"

Also defined POPFLG='SUMPOP'.

Results:

Program aborted with error message:
"POPFLG MUST BE EITHER UNIFORM OR FILE"

- d. Specify POPFLG = UNIFORM and WTNAME = SUMPOP.

Results:

Program aborted with error message:
"ERROR: You have specified that POPFLG=UNIFORM and
WTNAME=UNIFORM, this combination not allowed"

The above message should state WTNAME=SUMPOP not UNIFORM. This was related to the developer and should be rectified.

- e. Repeat a calculation with REFPNT=ALARM and ARRIVAL and check that results show higher doses when evacuation is tied to the plume arrival time.

Results:

Running the new code with these cases as two cohorts showed identical results. After trying several scenarios to assure that one cohort would be exposed to the plume while the other would escape it still showed no differences, a brief examination of the code was done. **This examination and discussions with the developer uncovered two coding errors.**

Variable FRSTEV was initialized to 0.0 and then reset using the FORTRAN function MIN. Thus its value was always 0.0, which had the same effect as setting OALARM to 0.0. In addition, the start times of the evacuation phases were incorrectly calculated unless OALARM was intended to be zero.

The other error involved storage of the new character variable, REFPNT, from one scenario (cohort) to another. This error could be circumvented by running MACCS for only a single scenario at a time. MACCS was run for one scenario at a time for these two scenarios involving REFPNT and the results then showed the higher doses and effects that would be expected. Several hand calculations were done to determine cohort and plume arrival times to verify the differences shown for the radial elements.

These errors were corrected by the developer during this code testing process in order to expedite further testing.

- f. Run MACCS with a typographical error for REFPNT (entered ARRARM in the record for REFPNT001).

Results:

Program aborted with error message:
"REFPNT must be either ALARM or ARRIVAL"

- g. Define different sets of shielding factors for otherwise identical scenarios. Used the same input file as for Test 2.2e. but changed the shielding factors for Cohort 2. The values for normal activity were increased to 1.0 which should produce increased doses and effects.

Results:

A successful run showed Cohort 2 with higher doses and health effects cases than Cohort 1. Since the shielding factors are old variables and are numeric they were properly stored between cohorts unlike the values of REFPNT in Test 2.2 e.

- h. Use 'RADIAL' for Cohort 1 and 'NETWORK' for Cohort 2.

Results:

Program aborted with error messages for change cards:

```
***** RECORD NUMBER xxx IS BEING IGNORED
BECAUSE CHANGE CARDS CAN ONLY REPLACE
PREVIOUSLY DEFINED RECORDS"
```

When intending to use EVATYP=NETWORK for the second or third Cohort the user must "introduce" the EZIDIREC cards along with the base case. This was done, and the MACCS run was successful using EVATYP='RADIAL' for Cohort 1 and EVATYP='NETWORK' for Cohort 2. This demonstrates that the new code will allow changes in EVATYP for different cohorts.

However, since EVATYP is a character variable it was probably not correctly stored for this run (each cohort was run with EVATYP='NETWORK' but Cohort 1's network simulated a radial evacuation). Therefore, it is recommended that the test be repeated using a NETWORK that is not identical to RADIAL and should produce a predictable change in the results.

D.2.3 Variable Evacuation Speeds

- a. Define ESPEED with values above or below the limits.

Results:

Program aborted with error message:

```
"...LOOKING FOR ESPEED...
...REAL VALUE OUT OF RANGE:..."
```

- b. Define ESPEED with only 1 or 2 values rather than 3.

Results:

Program aborted with error message:

```
"...LOOKING FOR ESPEED...
...REAL VALUE NOT FOUND..."
```

- c. Define ESPEED with 4 values, fourth value entered was very low.

Results:

Successful run. VAX/VMS DIFF comparison with an earlier correct run showed no differences. The fourth value is ignored as a comment, as mentioned in the earlier MACCS documentation describing the MACCS input routines.

D.2.4 Network Evacuation

- a. Define network travel across the release point. Entered a 3 in the first IDIREC record.
Results:

Program aborted with error message:
"ERROR: Backward travel not allowed across centerpoint
IDIREC=3 was specified for direction number 5"

- b. Define a network with no exits from the boundary elements. Set all 16 values for IDIREC015 to 2 thus defining a large circular closed loop.

Results:

Program aborted with error message:
"ERROR IN "EARLY" USER INPUT, CANNOT PROCEED"

The above message is not very detailed. The same message is output when a simple closed loop is defined other than in the boundary elements. This was mentioned to the code developer. A more informative message is included elsewhere and will be repositioned to the end of the output file.

- c. Define a travel direction of 0.

Results:

Program aborted with error message:
"...LOOKING FOR IDIREC...
...INTEGER VALUE OUT OF RANGE:..."

- d. Define a RADIAL network by entering all 1's in IDIREC records.

Results:

Successful run. Comparison with a prior run showed no differences.

- e. Enter too few IDIREC records. For LASMOV=15 and NUMEVA=12 there should be 15 IDIREC records supplied.

Results:

Program aborted with error message:
"...LOOKING FOR IDIREC AT RECORD:...
...RECORD ID NOT LOCATED"

When too many IDIREC records are entered the extras are ignored and a warning is printed as for other records that were never accessed.

D.2.5 Obsolete Input Variables

- a. Define values for old variables. When the Sample Problems A, B, and C were run, the values for the old variables INIEVA, LASEVA, EDELAY, TTOSH1, SHEL1, LASHE2, TTOSH2, and SHEL2 remained in the input deck.

Results:

Successful run. The records for these variables were reflected in the MACCS output file preceded by the warning message:
"***** WARNING -- THE FOLLOWING RECORDS WERE NEVER
ACCESSED *****"

D.2.6 Different Evacuation Speeds

- a. Define different travel speeds for the three evacuation periods. Defined three cohorts with ESPEED as follows:

ESPEED	1.2	1.2	1.2	Cohort 1
ESPEED	2.4	1.2	1.2	Cohort 2
ESPEED	1.2	1.2	2.4	Cohort 3

Results:

Results for both health effects and doses showed the three cohorts ranked 1, 3, 2 as expected since Cohort 2 evacuates faster in Phase 1 and Cohort 3 gains this advantage only in Phase 3 of the evacuation. Note: The coding error discovered in Test 2.2 e. (setting FRSTEV = 0.0) has the same effect as reducing OALARM to 0.0 because of the steps in calculating the start times for the evacuation phases. This was desirable for Test 2.6 since it was intended to start the evacuation soon enough for Cohort 3 to see some advantage from its higher speed in Phase 3, (i.e. some of the population can escape ahead of the plume.)

D.2.7 Distinct Populations and Network Evacuation Routes

A more complex scenario was designed to test the code's new capability at modeling distinct evacuation routes. A site data file was built that included three population blocks located on the Northeast radial at indices 4, 7, and 12. The plume was restricted to the northerly direction by defining IPLUME = 3, using METCOD = 3, and supplying 120 METDAT records. Three different evacuation routes were designed for the three cohorts allowable. Cohort 1 simulated a RADIAL network providing for evacuation directly outward along the Northeast radial. Cohort 2 was a network that defined evacuation in a counter-clockwise direction, under the plume on the Northerly radial, and continuing to the Northwest radial and then evacuated radially. The last, Cohort 3, was evacuated counter-clockwise to the Northerly radial and then evacuated radially travelling under the Northerly plume until evacuation is complete. The expected results should show Cohort 1 with zero doses and health effects, Cohort 2 with some consequences due to their brief passage under the plume, and Cohort 3 with substantially higher consequences due to their exposure while travelling parallel with the plume.

Results:

Initial runs were unsuccessful at achieving results as predicted. Several runs were made with wind speeds of both 2 m/s and 5 m/s but Cohort 1 included values not anticipated, i.e. doses were non-zero. Type 6 output was being produced until it was determined that this type of output, "Centerline Dose to Organs vs. Distance," was incompatible with network paths with circumferential components.

Discussions with the developer confirmed this and further, revealed an oversight in Subroutine EPCALC. A variable, IHITIT, was being used in EPCALC to limit duplicate calculations, taking advantage of the symmetry of the model. However, in the case of networks with non-radial elements the model no longer displays such symmetry. The subroutine was modified by the developer to initialize variable IHITIT as .FALSE. when EVATYP is 'RADIAL' (as before) but to make it .TRUE. when EVATYP is 'NETWORK.'

Further Results:

The problem was rerun with this fix implemented and the output showed values for health effects only for indices 4, 7, and 12 as expected. Cohort 1 showed zeroes since

evacuation was immediate and away from the plume. Health effects for Cohort 2 were low for both wind speeds while Cohort 3 values were substantial. These results verified that the new code was calculating values dependent on the evacuation routes input with IDIREC records in the EARLY input file.

D.3.0 Phase II Testing

Since several errors were discovered in Phase I testing, some of the tests could not be completed as planned. Code corrections were implemented immediately so that testing could proceed and these tests were rerun as described in Section D.2. Therefore, the Phase II retesting was completed along with Phase I. Since testing time was limited and software testing can never be 100% complete some further tests are recommended.

Test 2.2 h. should be rerun with different networks and Test 2.7 should be repeated with several different scenarios to provide further testing of the network evacuation model. Some further testing with different combinations of sheltering and evacuation should be considered. In addition, tests carried out on the VAX should be replicated with the PC version since some minor differences were noted in previous comparisons for MACCS 1.5.11.1.

D.4.0 Other Suggestions

The errors discovered in this testing were all discussed with the code developer and corrections were carried out directly. Several further suggestions include:

- 1) Redisplay of the IDIREC records in a formatted output may be desirable for users making substantial changes to evacuation routes since the input routine reflects these values with an error message for each line so that a neat table is not shown.
- 2) Documentation describing IDIREC records should use clockwise and counter-clockwise descriptions since "left" and "right" can be confusing in the tabular form required for IDIREC input.
- 3) TYPE 6 Output should be disallowed when EVATYP is NETWORK. Some further documentation on selecting output allowable and/or desirable for network evacuations may be useful particularly regarding output for doses received by different population blocks.
- 4) Documentation of the weather model for the original MACCS code is not as clear as may be possible. This was particularly noticeable when setting up Test 2.7 for a wind of constant speed and direction in order to make results somewhat predictable.

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