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Nuclear Evacuation Analysis Code (NUEVAC):

A Tool for Evaluation of Sheltering and Evacuation

Responses Following Urban Nuclear Detonations

Larry D. Brandt, Ann S. Yoshimura

Prepared by
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Abstract

The NUClear EVacuation Analysis Code (NUEVAC) has been developed by Sandia National Laboratories to support the analysis of shelter-evacuate (S-E) strategies following an urban nuclear detonation. This tool can model a range of behaviors, including complex evacuation timing and path selection, as well as various sheltering or mixed evacuation and sheltering strategies. The calculations are based on externally generated, high resolution fallout deposition and plume data. Scenario setup and calculation outputs make extensive use of graphics and interactive features. This software is designed primarily to produce quantitative evaluations of nuclear detonation response options. However, the outputs have also proven useful in the communication of technical insights concerning shelter-evacuate tradeoffs to urban planning or response personnel.

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Contents

1. Introduction.....	7
2. NUEVAC Design Goals	8
3. NUEVAC Program Structure	8
4. NUEVAC Program Element Descriptions.....	9
4.1 Fallout Data.....	9
4.2 Population Data.....	10
4.3 Shelter-Evacuate Strategies	10
4.4 Evacuation Zone and Movement Specification	11
4.5 Integrated Dose Calculation.....	14
4.6 Population Impact Evaluation Measures	16
4.7 Regional Sensitivity and Graphical Output Options.....	17
5. NUEVAC Exemplary Point Analysis Capabilities.....	18
5.1 Interactive Database Queries	18
5.2 Exemplary Point Analysis and Sensitivity Calculations.....	18
5.3 Links to Google Earth.....	19
6. Summary	20
Appendix: NUEVAC – Operational Features.....	21

Figures

Figure 1. Principal functional elements of NUEVAC	9
Figure 2. Exemplary evacuation regions for a typical Gaussian plume. (Alternative movement options are illustrated.)	12
Figure 3. Plume and evacuation plan for illustrative Los Angeles 10kt scenario.....	13
Figure 4. Illustrative polygonal evacuation zones for northwest lobe of LA scenario	14
Figure 5. Fitting protocol for IMAAC dose rate data	15
Figure 6. Integration of evacuation dose along prescribed evacuation route	15
Figure 7. Probit model used in NUEVAC injury and fatality calculations	16
Figure 8. Illustration of spatial effectiveness graphical outputs (improvement due to informed evacuation over shelter-in-place).....	17
Figure 9. Illustration of exemplary route depiction in Google Earth.....	19
Figure A-1. Use of the NUEVAC evacuation plan generator	22
Figure A-2. Analysis setup in NUEVAC.....	23
Figure A-3. Illustration of NUEVAC integrated dose outputs	24
Figure A-4. Illustration of NUEVAC health effects outputs	24

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NUclear EVacuation Analysis Code (NUEVAC):

A Tool for Evaluation of Sheltering and Evacuation

Responses Following Urban Nuclear Detonations

1. Introduction

The growing likelihood of the detonation of an improvised nuclear device (IND) in a U.S. city is motivating government planners at all levels to develop capabilities that would improve response and save lives if such an event were to occur. The fallout of radioactive particles following a nuclear detonation can create large contaminated areas in which the radiation intensity to exposed personnel is extremely hazardous. The decision to seek shelter or to evacuate the hazardous area is one of the most critical and time-urgent problems facing individuals in a fallout zone. In order to support the development of sound guidance, analyses that consider the wide diversity of attack parameters, situational assessment conditions, and local environments must be performed. Sheltering and evacuation decisions are complicated by uncertainties in the fallout intensity and distribution, as well as many other unknown factors in the response environment that will affect radiation dose levels.

The NUclear EVacuation Analysis Code (NUEVAC) has been developed by Sandia National Laboratories to support the analysis of shelter-evacuate (S-E) strategies following an urban nuclear detonation. This tool can model a range of behaviors, including complex evacuation timing and path selection, as well as various sheltering or mixed evacuation and sheltering strategies. It allows the zoning of an urban area with occupants of each zone assigned a specific shelter-evacuate action. It enables a diverse set of sensitivity studies of the effects of attack and response variables on regional radiation dose distributions, injuries, and fatalities. The software can also perform more detailed analyses of the decisions facing individuals within or near the fallout region. This exemplary point analysis capability is essential in developing and communicating a deep understanding of the response tradeoffs for both analysts and responders.

The focus of the NUEVAC tool is on decisions that must be made by local responders within the first 72 hours after an urban nuclear detonation. The primary applications of the model to date have involved low yield terrorist scenarios. These analyses have focused on the avoidance of acute radiation sickness associated with relatively high integrated dose levels. The less severe hazards (e.g., cancer risk) associated with lower dose levels are expected to emerge as significant response concerns after the initial crisis response interval.

This report summarizes the modeling assumptions and functional characteristics of NUEVAC Version 1.0. The code was developed and exercised for the analysis of scenarios in support of the Department of Homeland Security (DHS).¹ The results from NUEVAC have informed a number of analyses in support of federal IND response guidance development.² The software has been exercised and verified through the analyses completed as a part of these studies. NUEVAC (Version 1.0) remains a research tool, and continues to evolve in response to ongoing analysis of new shelter-evacuate issues.

2. NUEVAC Design Goals

Several design goals determined the structure and operational characteristics of NUEVAC. These are outlined below.

- Ability to Interface to Major Fallout Phenomenology Models – NUEVAC does not model the fallout deposition processes resulting from a nuclear detonation. Instead, these data are imported from one of several existing models that have been developed for that purpose. A design goal was to provide options for use of data from the principal available fallout codes.
- Interactive Capability to Define Shelter-Evacuate Strategies – The model needed to enable straightforward, interactive, graphics-based definition of the wide variety of S-E strategies of interest. Since many strategies involve different actions as a function of location within the fallout region, flexible approaches to zoning the region, followed by prescription of S-E actions for each zone, were also required.
- Capability for Regional and Exemplary Point Analyses – Evaluation of the number of injuries and fatalities on a regional basis is essential for comparing overall effectiveness of S-E strategies. However, the detailed analysis of single points within the overall S-E plan is also required for the understanding and communication of decision tradeoffs for individuals within the hazardous area.
- Graphical Tools for Output Presentation and Analysis – Geographical depictions of the effectiveness and tradeoffs for both the population and exemplary results were considered essential features of the tool.

3. NUEVAC Program Structure

The structure of NUEVAC is illustrated by the flow diagram shown in Figure 1. The code takes as inputs the high resolution spatial fallout data produced by the selected fallout generation model. NUEVAC then implements the desired S-E strategy and calculates the total integrated dose and health effects on individuals at each cell within

¹ The development of NUEVAC was sponsored by DHS Science and Technology Directorate in support of the IND Response Studies of the DHS Office of Health Affairs.

² For discussion of these analyses, see: Brandt, L.D. and A.Y. Yoshimura, "Analysis of Sheltering and Evacuation Strategies following an Urban Nuclear Detonation", Sandia Laboratories Report, SAND2009-3299, June 2009.

the region. The graphical tools for exemplary point analysis can access data points throughout the region, including input fallout data, integrated dose from the S-E plan, and sensitivities to variations in that plan. Many of these functional areas will be described in the sections that follow.

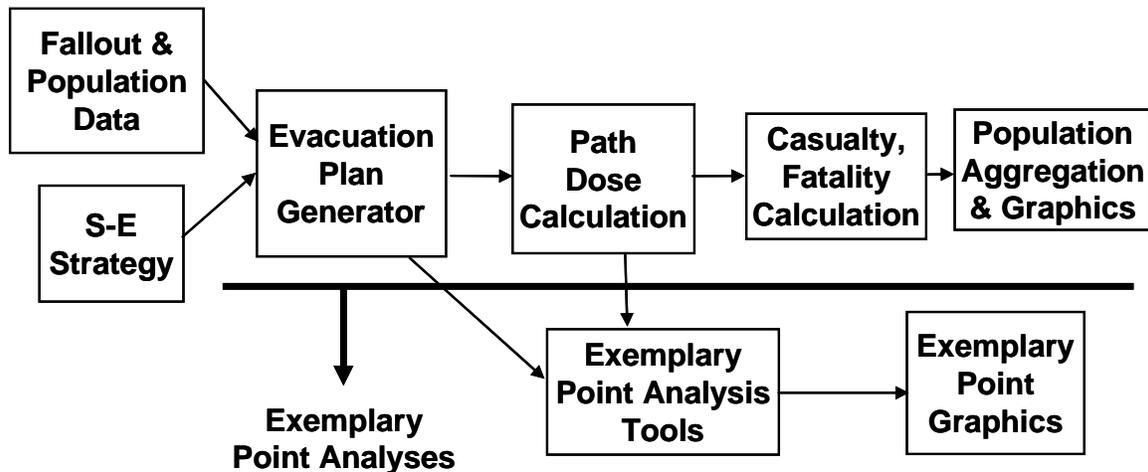


Figure 1. Principal functional elements of NUEVAC

4. NUEVAC Program Element Descriptions

4.1 *Fallout Data*

The simulation of the effects of nuclear detonations, including calculations of fallout deposition, has been a major area of scientific activity for over the last fifty years. Several modern fallout codes offer the capability to calculate time-dependent, spatial dose rates for a wide range of nuclear detonation characteristics and meteorological conditions. The underlying data that characterizes the radiation (dose rates) field resulting from a postulated urban nuclear detonation must be imported to NUEVAC from one of these fallout models. For studies performed to date, S-E evaluations have employed high resolution scenarios developed for DHS by the Interagency Modeling and Atmospheric Assessment Center (IMAAC) at Lawrence Livermore National Laboratory (LLNL). The baseline scenario employed in initial studies of shelter-evacuate options was a 10kT detonation in downtown Los Angeles. That scenario will be used to illustrate the features of NUEVAC in this report.³

³ The principal shelter-evacuate sensitivity studies performed for the DHS-OHA project utilized a Los Angeles 10kT detonation assumed to occur in the downtown area using meteorological conditions for July 15, 2006. For this scenario, winds were light and there was significant wind shear at low altitudes. This resulted in a very wide fallout deposition pattern, with two significant lobes.

Data on fallout intensity over a rectangular grid of points covering the fallout area is required as input to NUEVAC. Currently, the model supports analyses of rectangular grids with data point spacing of 100 or 250 meters. While data from IMAAC is used in the homeland security analyses, similar data from the DoD Hazard Prediction Analysis Code (HPAC), or from other fallout models, could be employed. Dose rate and integrated dose rate for at least one time following the passage of the fallout cloud must be supplied by the fallout model for each point in the regional grid. This is a minimum requirement. Generally dose rate and integrated dose data is available at several times during the first 72 hours following the detonation. Dose rate levels at early times, particularly the period during which the fallout particles are deposited, will improve the accuracy of integrated dose estimates from NUEVAC for early response actions. The internal fitting routines and spatial interpolation algorithms employed in NUEVAC to extend the data from the fallout models are described in a subsequent section. These allow NUEVAC to compute an integrated dose that accurately reflects both the time variation (deposition and decay) and the spatial changes along the evacuation path.

4.2 Population Data

The IMAAC fallout data used for initial applications by NUEVAC incorporates the Oakridge National Laboratory LandScan population database as an integral part of the high resolution output. A second analysis option is also available for prescribing population density in NUEVAC. It specifies the population density as a function of the radial distance from the point of detonation. The user must input the functional dependence of population density on the distance from the burst point. While this mode does not capture the detailed population distribution in specific scenarios, it can be useful for sensitivity studies where it is desirable to separate effectiveness variations due to meteorology and other uncertainties from the variations associated with population density within the fallout region.

4.3 Shelter-Evacuate Strategies

For Cold War scenarios involving multiple, high yield, detonations on metropolitan areas, fallout radiation over large areas was predicted to be so intense that immediate shelter in high quality, designated fallout shelters was the recommended strategy. However, for the single, lower yield, terrorist scenarios of primary concern today, a much wider range of sheltering and evacuation options might prove to be life saving. For small detonations that do not destroy regional communication and response infrastructure, execution of a situation-specific sheltering and evacuation policy may be possible.

In the initial analysis space, the following strategies were of principal concern:

- **Early, Informed Evacuation:** Individuals immediately shelter-in-place to minimize exposure to falling radioactive particulate, then evacuate when better situational assessment indicates the hazard zones and safest evacuation directions. Determinants of the optimal initial shelter interval and regrets associated with poorly-timed or misdirected evacuations are key issues associated with this strategy.

- Shelter-in-Place: One frequently recommended strategy is to shelter-in-place for an extended period (1 to 3 days) following the detonation to allow deposited radioactive material to decay to a safer level, hence reducing the dangers of leaving the region.
- Early Move to Better Shelter: Individuals would immediately shelter-in-place to avoid direct contamination during fallout deposition, but soon after the detonation transit to more effective, nearby shelters (e.g., subway stations, building basements).
- Radial Evacuation from Detonation Location: Radial evacuation has been used as a surrogate for uninformed evacuation away from the detonation area.

4.4 Evacuation Zone and Movement Specification

The overall fallout region must be divided into a group of evacuation zones in order to evaluate the effectiveness of strategies that respond to the characteristics of specific scenarios. A sequence of sheltering and evacuation actions can then be specified for each zone, with all individuals in that zone at the time of detonation assumed to execute the prescribed protocol for their zone. Two approaches to regional zoning have been implemented. These are differentiated by the shapes used to subdivide the region. The first employs annular segments and the second, polygons. The evacuation plan generator is an interactive, graphical software tool that permits rapid and accurate specification of zone boundaries and the sheltering and/or movement actions for individuals who are initially in the zones.

Circular Arc Zones

The first option for zoning the fallout region utilizes circular arcs and radial line segments from the detonation location to form the boundaries of each region. This zoning protocol enables specification of evacuation strategies that are well adapted to “normal” Gaussian plume shapes, since those shapes are often approximately symmetric around their radial centerlines. However, this form of zoning does not capture neighborhood boundaries, or physical and road features that might be important in the execution of an evacuation plan. An illustrative example for a Gaussian plume of six arc-bounded evacuation zones and the movement options available in each is shown in Figure 2. The selection of six zones is for illustration only. Any number of zones may be specified in actual analyses. The options for movement from any cell within a zone (indicated by the green squares in Figure 2) include:

- Shelter (No movement; protection factor specified) for a specified time
- Radial movement away from detonation point at a specified velocity for a specified time
- Movement to specified point at a specified velocity
- Movement in specified direction at a specified velocity for a specified time
- Movement to a specified line segment at a specified velocity

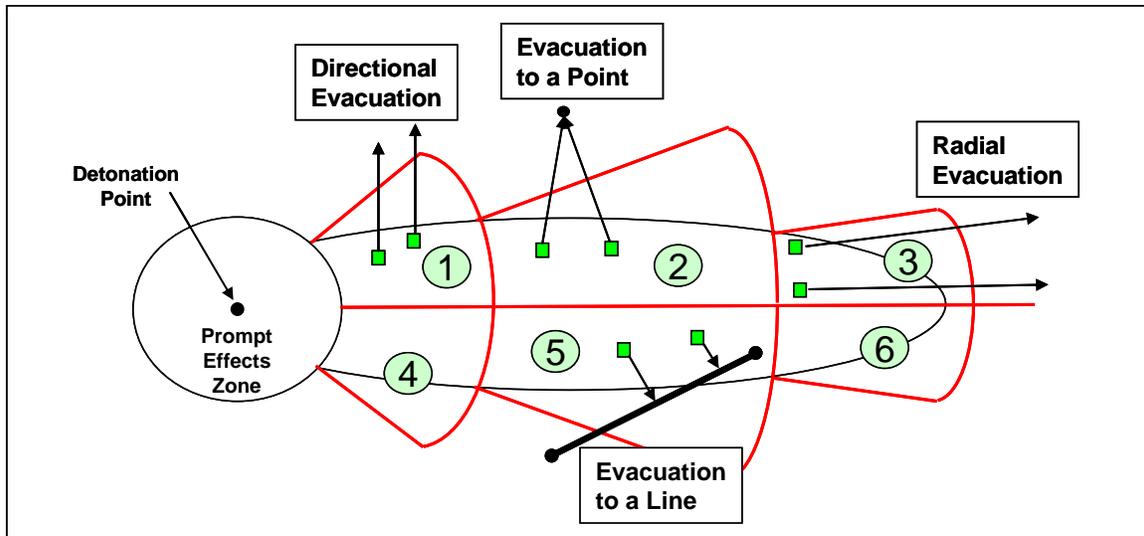


Figure 2. Exemplary evacuation regions for a typical Gaussian plume. (Alternative movement options are illustrated.)

The shelter-evacuation protocol for any zone consists of a series of these commands. Piecewise linkage of these elements together can create a very complex sheltering and evacuation profile. Using this approach, the effects of obstructions, irregular evacuation routes, and choke points can be included in the evacuation plan. However, the model does not treat congestion, so there is no change in evacuation velocity with the number of individuals proceeding along a specified evacuation route. Individuals outside of all designated evacuation zones are assumed to shelter-in-place at a prescribed, default shelter protection factor.

The implementation of arc-bounded evacuation zones for the illustrative Los Angeles 10kt scenario is shown in Figure 3. The plan is based on the subdivision of the hazardous fallout area into thirteen zones bounded by circular arcs and radial lines from the detonation point. The evacuation plan is defined for the region outside of the moderate blast damage area (~1.5 km from the detonation point for the 10 kt case). The single exit line from each zone shows the evacuation direction for all occupants within the zone. The movement protocol for most zones (except for the three interior zones near the center of the bi-modal plume) is constant velocity movement in the direction indicated. The three interior zones evacuate to the point circled on the figure, then north out of the area. The zone boundaries and the evacuation paths for each zone were generated within the NUEVAC evacuation zone generator. This internal tool permits the zones and paths to be specified against a background showing geographical features and the plume shapes at a selected time. The generator converts the graphical decisions into software that is then employed by NUEVAC in the computation of the population and exemplary point results. The paths for the illustrative case are for “informed” behavior, since the movement protocols are based on knowledge of the plume shape. Generally the evacuation routes are determined visually by the analyst using the evacuation plan generator. Hence, they are not mathematically optimized, but do represent good hazard avoidance decisions.

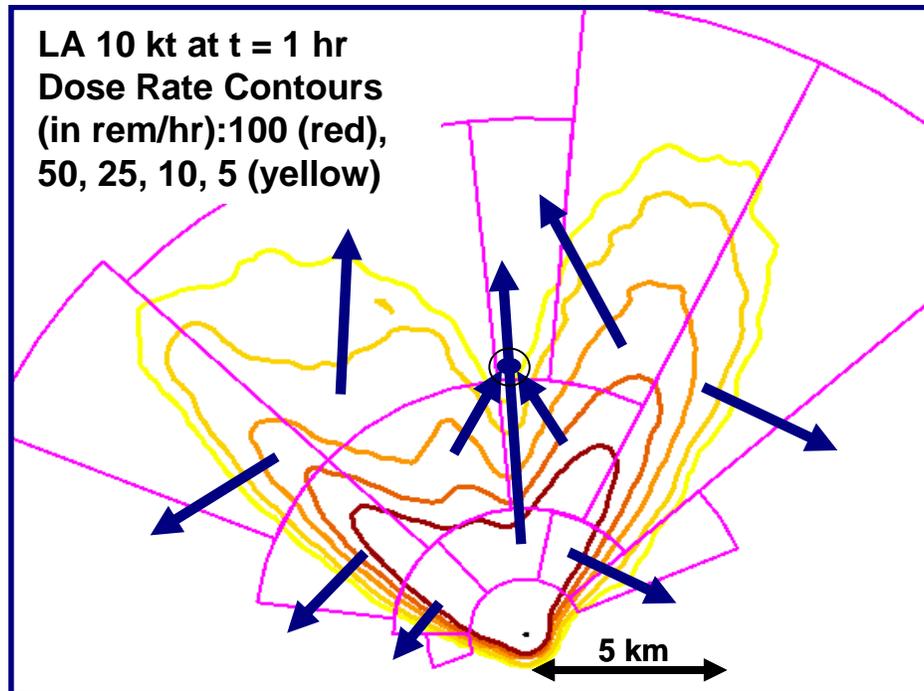


Figure 3. Plume and evacuation plan for illustrative Los Angeles 10kt scenario

Polygonal Zones

The second option for zoning fallout areas utilizes polygons with the number of vertices and location of those vertices chosen to best represent executable evacuation plans. This approach for zoning is well suited to a priori specification by urban planners, and for ease of communication of instructions following a detonation. The same movement alternatives can be applied to polygonal zones as were described above for arc-bounded zones. An example of a polygonal zoning plan for the western lobe of the Los Angeles baseline scenario is shown in Figure 4. For this example, the zones are generally aligned with the street grid for more straightforward description and execution of the strategy. When such alignment is used, the protocol of movement to a line at the edge of the zone could guide individuals to the best arterial or freeway for evacuation. Similarly, some of the zones surround one of the major freeway evacuation routes, in this case zones 3 and 6 surround the Hollywood Freeway (US 101). In this illustrative plan, the zone 3 occupants evacuate to the nearest point along the yellow line (which approximates the path of the freeway), and then northwest out of the fallout area. Using these tools, many significant features of the street grid can be incorporated into the evacuation plan, but without the necessity of detailed modeling of the grid. The nature of the fallout plume must still be considered in the designation of a polygonal evacuation plan in order to achieve good effectiveness. For example, the dividing line between zones 6 and 7 in the figure lies approximately along the peak dose rate line of the northwest lobe of the plume. This placement is essential in preventing occupants from evacuating through the peak dose rate regions of the fallout area when safe regions can be reached by less threatening, alternate routes.

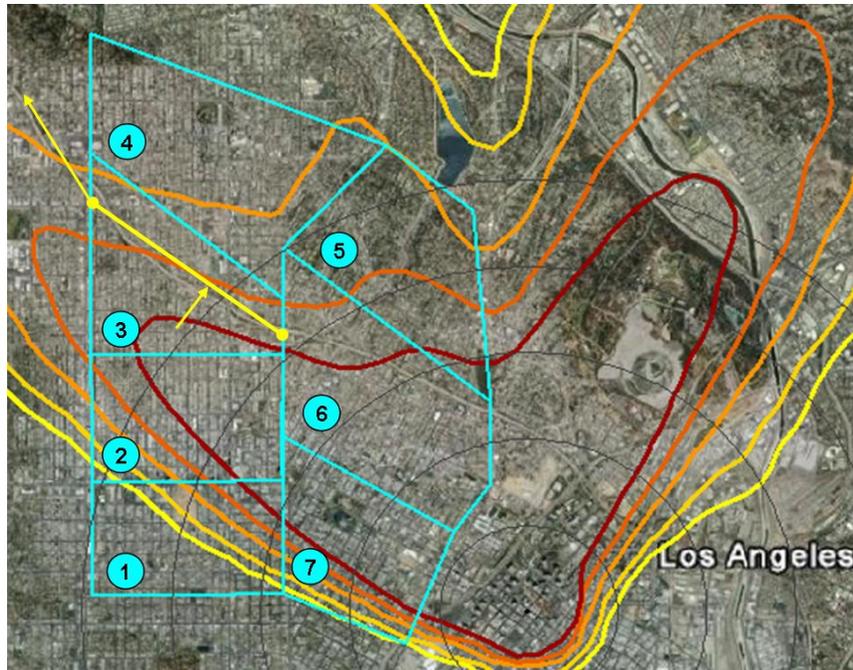


Figure 4. Illustrative polygonal evacuation zones for northwest lobe of LA scenario

4.5 Integrated Dose Calculation

Initial studies using NUEVAC have drawn on high resolution scenarios developed for DHS by IMAAC. The data files from IMAAC specify the fallout dose rate at selected times following the detonation (15, 30, and 45 minutes; 1, 2, 4, 12, and 24 hours) and integrated dose for other times (2, 4, 6, 12, and 24 hours). NUEVAC calculates the dose rate at any time for any point within the fallout area using a software routine that fits the high resolution IMAAC data with the power law fallout decay model. This is illustrated in Figure 5. The fitting curve employs the standard $t^{-1.2}$ decay assumption for fallout radiation. The fitted curve matches all IMAAC dose rate points by a transition from the forward calculation of the earlier point and the reverse calculation of the upcoming point within any time interval. The initial ramp of the dose rate from zero up to its maximum value is also fit with power law curve in such a way that the integrated dose under the fitted curve matches the two hour value provided for each grid point by the IMAAC data. The shape of the early dose rate curves (including the discontinuities at the input data points) is only an approximate representation of the deposition phase of the fallout. However, the integrated dose calculations for all evacuation departure times past the peak dose rate (i.e., less than a half hour in high dose rate regions) are accurately modeled, relative to the IMAAC model data, by this protocol.

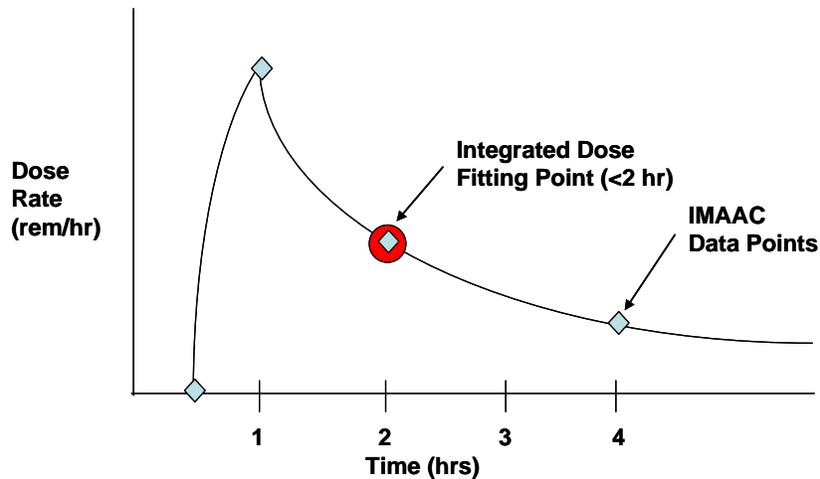


Figure 5. Fitting protocol for IMAAC dose rate data

NUEVAC includes both temporal decay and spatial variations in radiation levels in its calculation of dose accumulated within a shelter or along an evacuation path. The way this is accomplished is illustrated in Figure 6. The figure illustrates the evacuation path through a small section of the 250 meter by 250 meter high resolution data field. The dose rate at any time for any of the data grid points is provided by the temporal interpolation calculation described above. For a walking evacuee proceeding through the grid at 3 km/hr, dose integration occurs at one minute (50 meter) intervals, shown as the circular waypoints on the evacuation path. At each integration point, a bi-linear interpolation of the dose rate from the four closest points in the data field is used to update the integrated dose. In this fashion, both the temporal and spatial changes are updated for each 50 meter waypoint along the path.

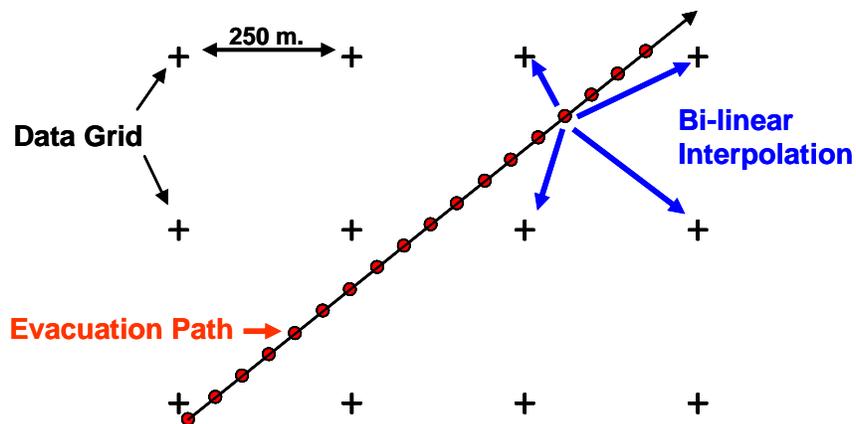


Figure 6. Integration of evacuation dose along prescribed evacuation route

4.6 Population Impact Evaluation Measures

The estimation of population effects for S-E strategies is based on calculation of the integrated dose for a single representative individual located at each of the data points in the fallout data array. The impact on each person within this cell is assumed to be the same as this representative individual. Two types of output metrics are computed by NUEVAC for each cell and then aggregated to create the overall population metric.

Integrated Dose Distributions

The integrated dose (in rem) for the representative individual in each cell is accessible through an interactive query feature in NUEVAC. In addition, NUEVAC provides cumulative histograms of the number of individuals who receive greater than specified threshold doses. Histograms of the number of cells with integrated dose levels within specified ranges can also be generated.

Injury and Fatality Estimates

Reduction in the incidence of acute radiation sickness has been a primary metric for initial analyses of S-E options. NEUVAC employs a probit model to estimate incidence of acute radiation injuries and fatalities as a function of integrated dose.⁴ The incidence probabilities for injuries and fatalities as a function of dose are shown in Figure 7.

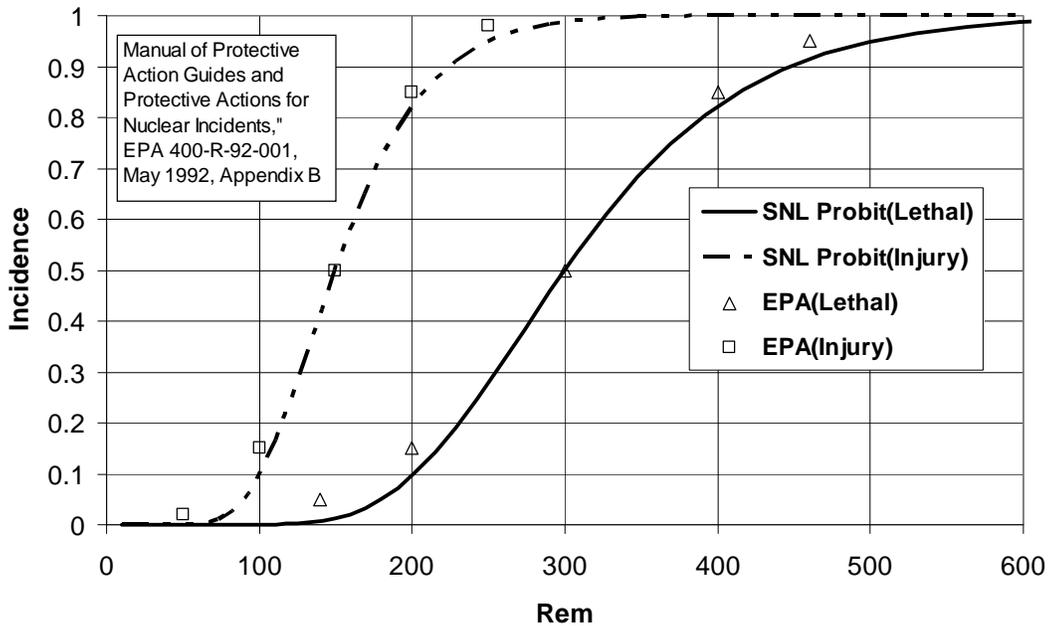


Figure 7. Probit model used in NUEVAC injury and fatality calculations

⁴ Probit injury/lethality data from Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 400-R-92-001, May 1992, Appendix B.

4.7 Regional Sensitivity and Graphical Output Options

Meteorological Sensitivities

Uncertain meteorological conditions at the time of the detonation can have significant impacts on the effectiveness of any S-E strategy. A complete analysis of these uncertainties would involve generation of a range of scenarios representing met conditions of interest, followed by the analysis of each scenario. However, one way to assess the sensitivity of S-E strategy effectiveness to meteorological variations is to alter the angular position of the plume without changing its shape. While this represents a very constrained shift in the wind shear parameters, the results offer insights regarding the robustness of alternative plans. This angular shifting of the wind fields can be done internally by NUEVAC, without the generation of a new scenario database.

Spatial Depiction of Population Results

One of the most intuitive and powerful ways of depicting the outcome of sheltering and evacuation actions is through spatial diagrams that portray the threshold integrated doses, or injury/fatality incidence. Perhaps even more useful are differential plots that show the relative performance of two S-E strategies for each cell within the regional fallout area. The nature of these spatial outputs is illustrated by the differential plot shown in Figure 8. This figure compares the reduction in fatality probability for an informed evacuation strategy (with a departure time 3 hours after the detonation) versus a shelter-in-place strategy (with a shelter protection factor of 4). The different levels of green shading indicate the decrease in fatality probability when occupants of each cell pursue evacuation over shelter-in-place. Differential plots similar to this can be generated for any two strategies computed within NUEVAC.

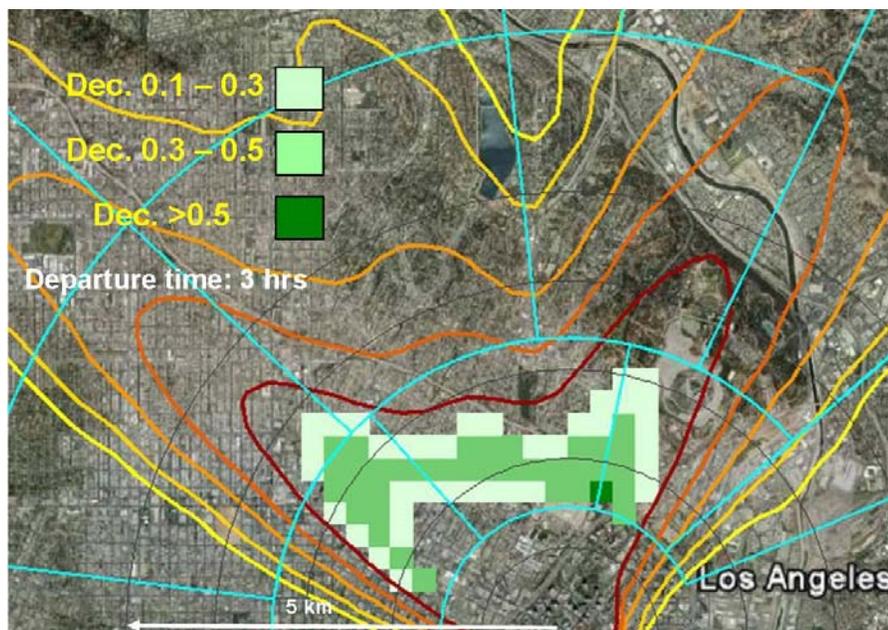


Figure 8. Illustration of spatial effectiveness graphical outputs (improvement due to informed evacuation over shelter-in-place)

5. NUEVAC Exemplary Point Analysis Capabilities

As discussed earlier, the analysis of exemplary points within the S-E plan can be extremely important in assisting both the analyst and regional planner in understanding the fundamental tradeoffs associated with sheltering and evacuation responses. NUEVAC has implemented interactive features that allow rapid understanding of the fallout data, dose histories, and performance sensitivities for points in the region. Calculations of the dose profiles during transit for exemplary point analyses utilize the same path integration protocol described above for the regional analyses. Many of these outputs are generated and made available graphically by NUEVAC in the exemplary point analysis mode. These include the features described below.

5.1 Interactive Database Queries

Dose Rate Data

The dose rate at any point and time within the fallout region can be accessed graphically through NUEVAC in the exemplary point mode. The same data interpolation algorithm used in the calculation of integrated S-E dose levels is employed in this mode.

Linear Path Dose Rate Variation

NUEVAC shows a graphical depiction of dose rate variation along a linear path that is input via an interactive tool. This utility offers analysts a rapid mechanism for understanding the relative exposure levels along an evacuation route at any time following the detonation.

5.2 Exemplary Point Analysis and Sensitivity Calculations

Dose-Time Histories

One of the most useful analysis routines built into NUEVAC exemplary point calculations automatically generates both graphical and tabular data describing the time variation of integrated dose for an individual executing a prescribed evacuation plan. This tool, used in conjunction with the evacuation plan generator, allows visualization of the dose experienced by an individual starting from any point in the region.

Exemplary Point Time-of-Departure Sensitivity

The timing of sheltering and evacuation actions is a critical parameter in determining S-E strategy effectiveness. NUEVAC has incorporated an internal tool that allows sensitivity results to be produced showing the variation of integrated dose with the start time for evacuation. These calculations employ the movement protocols for the evacuation zone where the exemplary point is located.

5.3 Links to Google Earth

Presentation of the routes and dose rates associated with evacuation within the Google Earth application has proven to provide a flexible and compelling way to illustrate the impacts of S-E decisions. NUEVAC can generate files in the .kml format that illustrate with a vertical line the dose rate an evacuee would experience at each time step in the exit from the hazardous fallout region. Figure 9 illustrates three evacuation profiles from one high intensity fallout point within the Los Angeles illustrative scenario. The profiles represent alternative evacuation routes, each with a very different dose rate profile, that might be chosen by an evacuee. The spacing of the vertical lines in the figure represents the evacuation progress at one minute intervals (i.e., 50 meters for the 3 km/hr evacuation velocity assumed for this calculation). Once the routes and dose rate histories are depicted in Google Earth, all of the three-dimensional, graphical tools in that application can be employed to review the results.



Figure 9. Illustration of exemplary route depiction in Google Earth

6. Summary

NUEVAC has been an essential tool enabling the analysis of sheltering and evacuation strategies by Sandia National Laboratories in support of Department of Homeland Security objectives for development of response guidelines for urban nuclear detonation scenarios. The tool has evolved in response to analysis questions as they arose, and is expected to continue this evolution through current projects in this area. The interactive and graphical features of the code have been integral to its design, providing avenues for clearer understanding of the phenomenology, for validation of code function, and for communication of principal analysis results. Version 1.0 of the code remains a research tool for use by Sandia analysts. However, the functional capabilities of the code could become more broadly applicable if local efforts to plan for nuclear detonation response become more widespread.

Appendix

NUEVAC – Operational Features

Some of the operational characteristics of NUEVAC can be described using pictorials of the computer screen that an analyst encounters at various points in assessment of a S-E strategy. Several such “screen shots” are reviewed in this appendix to provide an enhanced understanding of the features included in the software. However, since this document is a high level functional description rather than a user manual, the specific definition and options associated with many of the illustrated program features will not be described in detail.

Evacuation Zone Generation

Several key features of the evacuation plan generator within NUEVAC are illustrated in Figure A-1. The figure illustrates an intermediate point in the generation of the polygonal evacuation plan shown earlier in Figure 4. At this point in the process, the zones have been generated by a graphical (“click-and-drag”) definition of the vertices of the polygon. Zone 3 is currently selected, and the definition of the movement strategy for that zone is in process. The window at the left of the figure shows the parameters that have been interactively defined. The first phase of the prescribed plan is a shelter-in-place for three hours following the detonation. The second is movement to a line that approximates the location of the Hollywood Freeway through the zone. This line is defined by selecting and dragging the endpoints of the line to their desired location. The next movement instruction is for individuals along the line to begin movement to the northwest along the Hollywood Freeway. This is done by defining movement toward the point illustrated by the yellow circle just outside of the zone. Again, designation of the location of this point can be done interactively by the analyst. The Evacuation Region Editor (shown on the left side of Figure A-1) then displays a small pulldown menu (near the bottom of the Editor window) where the next evacuation action can be selected. In this case, it would likely be movement to another waypoint in the evacuation on the freeway to the northwest. When all movement steps are described for all evacuation zones, the evacuation plan generator automatically produces an xml file that guides the calculation of integrated dose levels for each cell in the region. The close integration of extensive interactive graphics into the planning process makes even complex, multi-zone plans a straightforward task for the analyst.

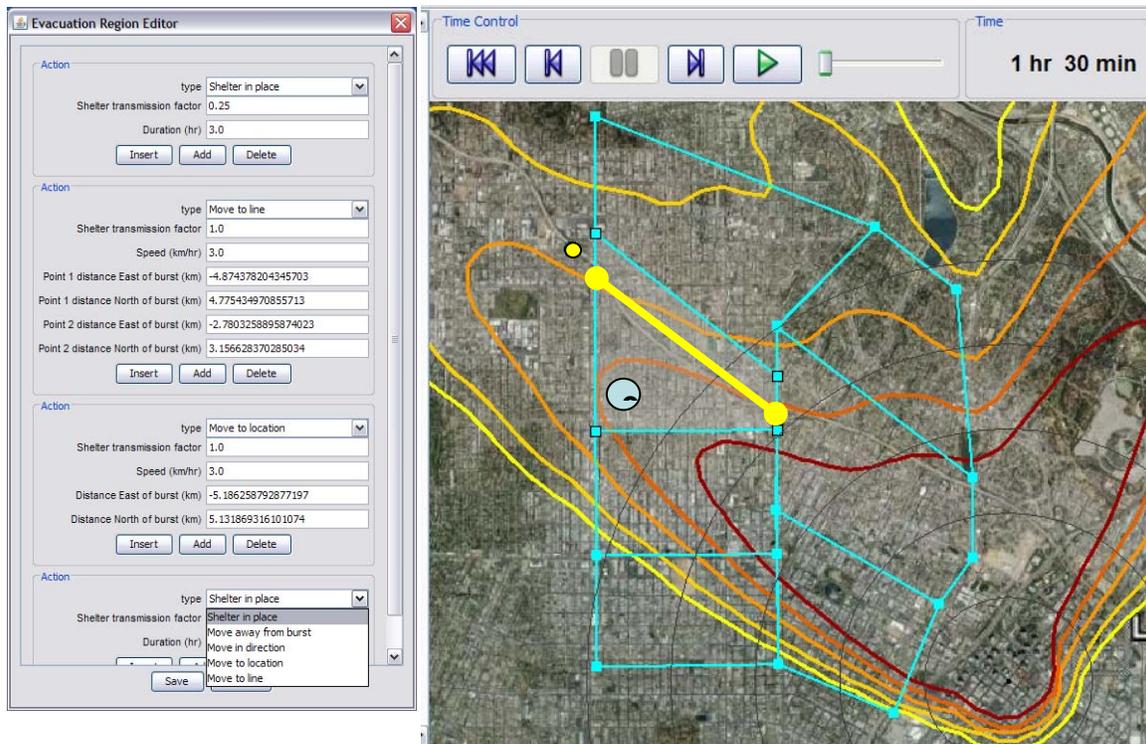


Figure A-1. Use of the NUEVAC evacuation plan generator

NUEVAC Analysis Setup

Figure A-2 illustrates several steps in preparation for the calculation of the effectiveness of a regional S-E strategy. In this case, a plan using circular arcs and radial segments is shown. The text box on the screen points toward an exemplary evacuation path originating in one of the zones. The solid pink dot along the path shows the progress of an individual executing that evacuation plan from the origination point at the time indicated at the top of the screen. The time slider allows the analyst to animate the individual's progress and the dose rate contours. This is an important step in confirming that intended evacuation actions are implemented in the calculations. Also shown in the upper left is a pulldown menu used to load underlying databases used in the calculation. The fallout field data, population data, and evacuation plan are the three principal input files required for the calculation. During the setup period, a range of other exemplary point analysis tools (as noted earlier in the report) are also available to assist the analyst in understanding the integrated dose-time history and its sensitivity to the timing of evacuation and other key variables.

NUEVAC Population Outputs

Figures A-3 and A-4 show the two primary modes of spatial effectiveness output generated within NUEVAC. In Figure A-3, the cells are color-coded by the dose level (24 hour dose in rem) received during the execution of the defined evacuation plan. The health effects, as defined by the probit dose response model, are shown in Figure A-4.

Differential figures, showing the difference in either dose or incidence of threshold health effects between the defined strategy and a pure shelter-in-place response, can also be selected as an output option. In addition to these graphical outputs, the number of people who are exposed at greater than a set of threshold dose levels, or the number of people who are injuries or fatalities (as calculated by the probit dose response model) are shown in the window at the left of the screen.

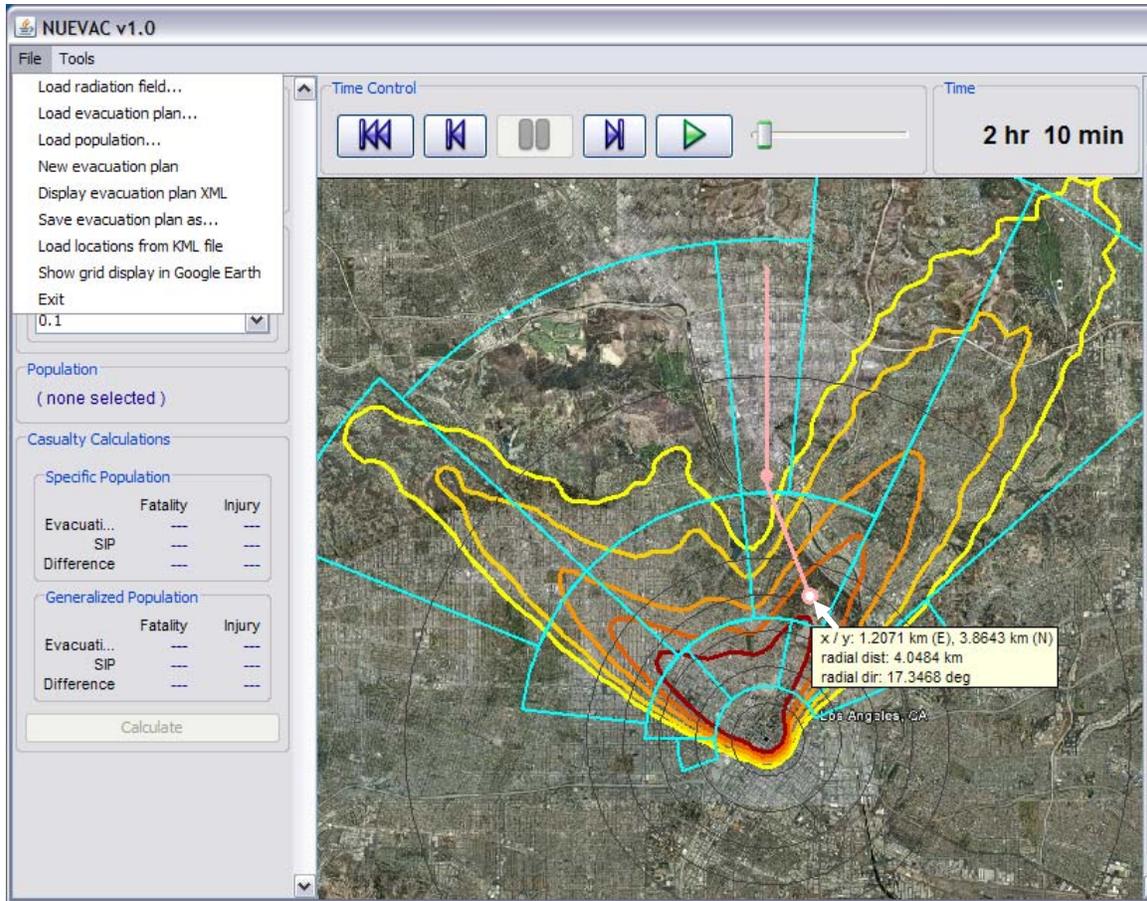


Figure A-2. Analysis setup in NUEVAC

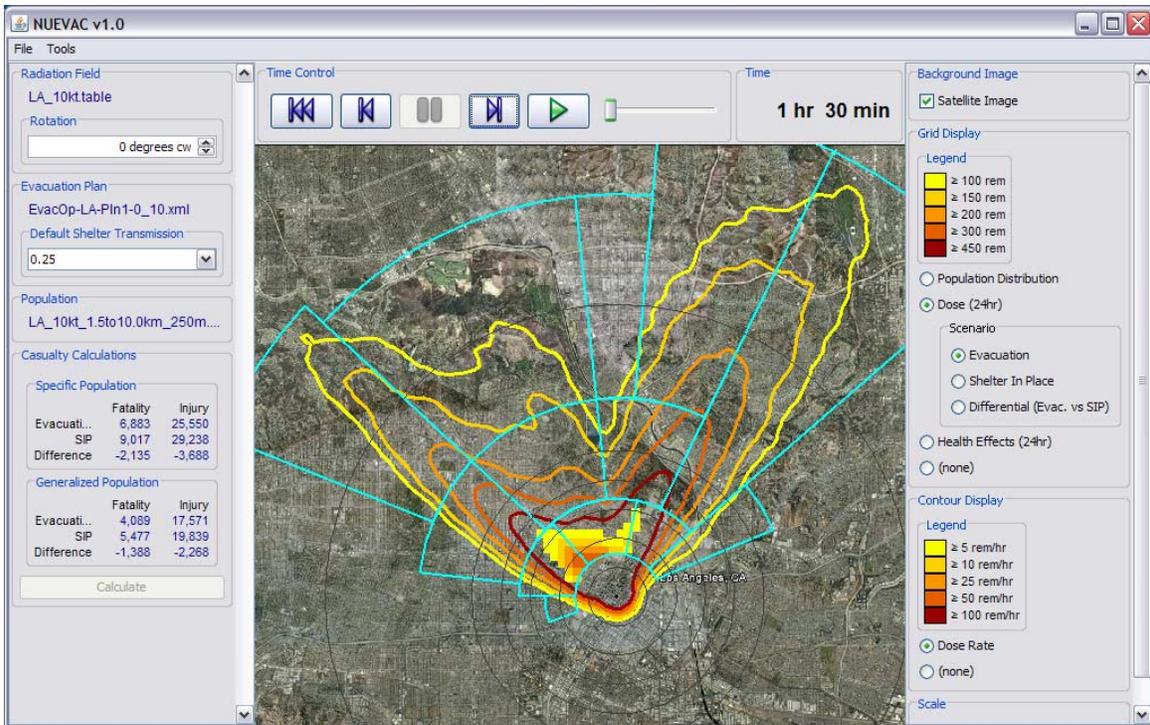


Figure A-3. Illustration of NUEVAC integrated dose outputs

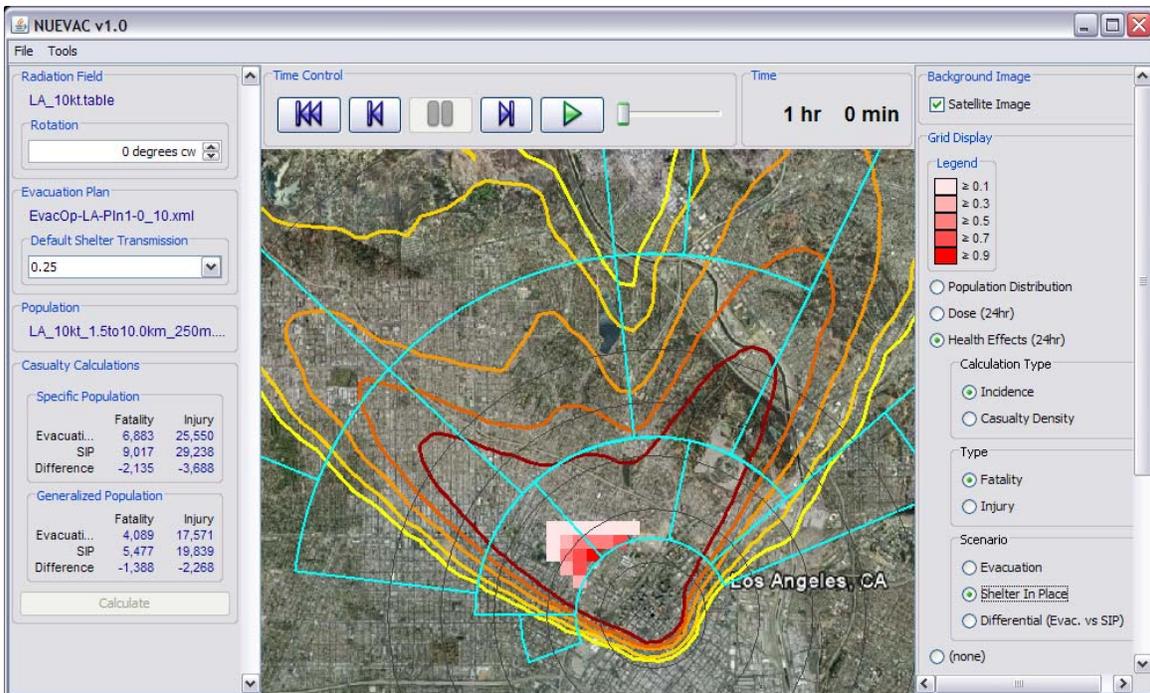


Figure A-4. Illustration of NUEVAC health effects outputs

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