1.4 Facility Targeting, Protection and Mission Decision Making Using the VISAC Code

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The Visual Interactive Site Analysis Code (VISAC) has been used by DTRA and several other agencies to aid in targeting facilities and to predict the associated collateral effects for the go, no go mission decision making process. VISAC integrates the three concepts of target geometric modeling, damage assessment capabilities, and an event/fault tree methodology for evaluating accident/incident consequences. It can analyze a variety of accidents/incidents at nuclear or industrial facilities, ranging from simple component sabotage to an attack with military or terrorist weapons. For nuclear facilities, VISAC predicts the facility damage, estimated downtime, amount and timing of any radionuclides released. Used in conjunction with DTRA's HPAC code, VISAC also can analyze transport and dispersion of the radionuclides, levels of contamination of the surrounding area, and the population at risk. VISAC has also been used by the NRC to aid in the development of protective measures for nuclear facilities that may be subjected to attacks by car/truck bombs.

1.0 INTRODUCTION

The Visual Interactive Site Analysis Code (VISAC) is a Java-based graphical expert system developed by ORNL for the Defense Threat Reduction Agency (DTRA), Nuclear Regulatory Commission (NRC) and other sponsors. VISAC provides security specialists and mission planners with a coordinated capability to predict and analyze the outcomes of different accidents/incidents at nuclear and industrial facilities. Damage to the facility structures and critical components is calculated by using blast correlations to scale from experimental test data for effects such as concrete wall breach [1]. The incidents modeled in VISAC can range from simple individual equipment sabotage to complex scenarios that utilize a range of military weapons, simulated truck or car bombs, or satchel charges. The target facility is generated by either customizing existing 3-D CAD models for near real-time analysis or creating a new model from scratch. Using event/fault tree methodology, VISAC provides the probability of facility kill, the probability of undesirable collateral effects (chemical or radiological releases), and an estimate of facility downtime. VISAC is supplied with a library of models that can be customized by the user in both geometry and logic using the code's graphical editing features to approximate a number of facilities of interest. Most VISAC scenarios can be run in a few seconds on a modern laptop PC.

2.0 VISAC

To be an effective tool for targeting, facility protection, and mission decision making, VISAC must efficiently integrate the three concepts of target modeling, blast damage assessment and event/fault tree consequence analysis into a user-friendly, operational code. Facility geometric information for both critical component locations and structural details of nuclear facility buildings is stored by VISAC in text files compatible with the BRL-CAD format used in the weaponeering community [2]. VISAC uses algorithms similar to those from the EVA-3D/MEVA [3, 4] weapons effects codes for damage assessment. Kill probabilities calculated from the damage algorithms for each individual critical component are then fed back to event/fault tree models to determine the overall effect of the component damage on the facility and the expected downtime.

2.1 Blast Modeling in VISAC

VISAC must be able to quickly calculate blast damage to building structures and also plant critical components to determine the resulting operational condition of the facility and to calculate any possible collateral effects. There are two common approaches for numerical modeling of blast effects: One method involves hydrocodes such as CTH and DYNA-3D, which are based on first-principle solutions for the conservation equations of mass, momentum, and energy in the shock wave interactions, combined with sophisticated equations of state for the materials involved. While hydrocode calculations are excellent for looking at the details of specific shock wave behavior, the computer run times required are too long to use them for calculations involving large numbers of components or structures. The alternative approach makes use of empirical correlations derived from experimental test data to represent blast effects on components and structures. This second approach is the blast modeling methodology selected for incorporation into VISAC. Using correlations allows VISAC to analyze overall facility vulnerability in a fast-running code without trying to reduce the calculations to first principles. Correlations can generate remarkably accurate results for blast effects as long as they are not extrapolated outside the range of applicable data.

The blast assessment algorithms programmed into VISAC were adapted from correlations that actually date back to empirical test data on weapons effects that was generated by the National Defense Research Committee (NDRC) during World War II [1]. Curve fits to the NDRC test data are available for concrete wall breach probability, blast overpressure as a function of scaled distance from an explosion, and expected overpressure enhancement due to reflective surfaces surrounding the charge.

Once VISAC has applied the NDRC correlations to determine which concrete walls are breached by a blast and how the shock overpressure is propagated through air spaces exposed to the explosion, it is necessary to calculate kill probabilities for the critical components. These component failure probabilities then serve as input for the event/fault tree models that assess overall facility kill probability and the potential for a radiological release from the facility. Thus each critical component in the VISAC facility model must have an associated fragility function expressed in terms of blast overpressure.

An overpressure fragility function consists of a plot showing the component kill probability versus the peak overpressure experienced by the component, as seen in the example function given by Fig. 1. Typically, fragility functions are defined by specifying a minimum overpressure, P_{low}, below which the component kill probability is zero and a maximum overpressure, P_{high}, above which it is unity. The fragility function is then interpolated between P_{low} and P_{high} using either a linear approximation or a logarithmic fit so that any component exposed to an overpressure P between P_{low} and P_{high} is assigned a fractional kill probability between 0 and 1. Estimates of overpressure fragilities for various categories of equipment can be found in Young, et al. [3], Glasstone [5], and Stephens [6]. These sources were used to develop the fragility functions for blast modeling in VISAC.

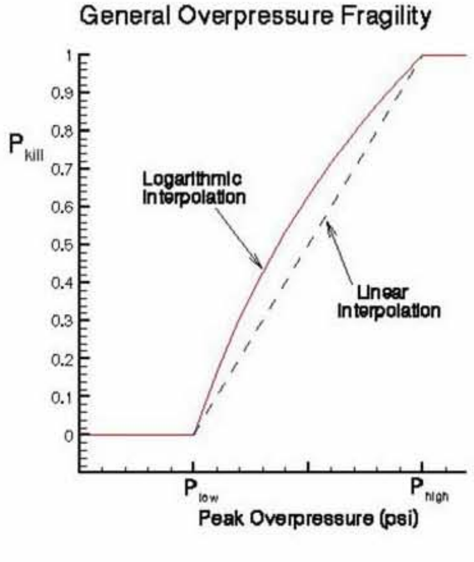

Fig. 1. Example showing the general form for a component fragility function in terms of peak blast overpressure

2.2 Event/Fault Tree Analysis in VISAC

Event tree/fault tree methodology has been applied for decades in the nuclear industry for consequence assessment and determining the probability of reactor core damage during accident sequences [7]. Basically, event trees track the progress of an accident sequence and define the safety systems that can be applied to avoid undesirable consequences. At each branch of an event tree, an underlying fault tree shows the critical components (connected by AND or OR logic gates) necessary for that safety system to function. VISAC adopts this modeling approach to calculate the probability of collateral damage and potential radiological releases associated with attack scenarios at nuclear facilities, and adds another "facility kill" fault tree to determine the probability that the plant would be forced to shut down by the incident.

Ordinary event/fault tree calculations typically involve very small component failure probabilities for the cut sets (groups of components whose simultaneous failure would lead to failure for an overall system fault tree), so that certain mathematical shortcuts such as the rare events approximation [8] or the Esary-Proschan approximation [9] are useful for evaluating sequence probabilities. On the other hand, in vulnerability analysis critical component failure probabilities tend to be high, so these approximations are no longer valid. Therefore VISAC had to introduce some unusual evaluation techniques based on Bayesian analysis and Monte Carlo methods to solve for the sequence probabilities efficiently [10]. VISAC allows a user to set up the system logic model on a detailed basis using an arbitrarily large number of event trees and fault trees referenced to basic events that are critical components in the facility model. A coarser "building level" analysis is also possible, in which only the facility buildings are basic events in the logic model and failure of a building implies loss of function for all critical components and systems located in that building.

2.3 VISAC Facility Downtime Calculation

The cut sets of VISAC's fault tree for facility kill are also vital for estimating facility downtime. Each cut set of the facility kill fault tree consists of a group of equipment without which the plant cannot operate. The overall expected downtime from an attack scenario is thus given by assigning a kill probability and a downtime to each cut set kill path and summing over the cut sets where the overall expected downtime has been normalized by the overall facility kill probability to make it conditional on facility kill. VISAC calculates a strictly serial repair process where damaged components are expected to be fixed sequentially one after the other and also a parallel downtime that assumes workers at the plant can repair the equipment associated with multiple cut sets of the facility kill tree simultaneously. VISAC provides the user both of these downtimes for each scenario.

3.0 VISAC ANALYSIS

VISAC provides a very fast "what if" analysis for various accident/incident scenarios and also facility damage/consequence contour maps. Specifically VISAC returns the facility kill probability, core melt probability for a nuclear reactor, chemical release and fire effects probability for a reprocessing facility and estimates of the downtime for each facility. When used in conjunction with DTRA's HPAC code, VISAC will also provide the transport and deposition of the released material as well as the population at risk.

Incidents include:

- Weapons – satchel charge, truck bomb, military weapon, etc. placed anywhere in or around the facility
- Defined Accident - failure of a specific system
- Region Damage – all components in a specific area fail
- Component damage – individual components fail with specific probabilities.

In addition, multiple incidents can be specified in any combination and as functions of time.

Figure 2 shows a view of a typical VISAC model of a generic nuclear reactor. The critical components are shown in red both inside and outside the facility.

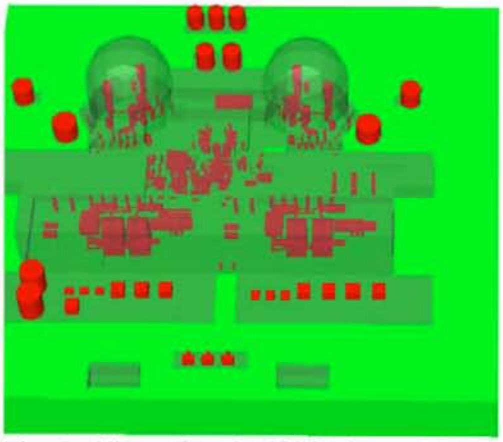

Fig. 2. View of typical VISAC model.

Output from a VISAC scenario can be obtained in tabular or graphical form. For the tabular form, VISAC provides

- Failure probabilities for each fault tree system
- Consequence probabilities for each event tree
- Facility downtime
- Release estimates
- Transport and deposition of released material
- Population at risk
- List of walls broken and hole size estimates

For the graphical form, VISAC can provide views of the facility highlighting the holes in walls and damaged equipment, views of the fault trees showing the broken components and a graphical representation showing the most probable path through the event tree.

Figure 3 shows a typical fault tree with the damaged components crossed out.

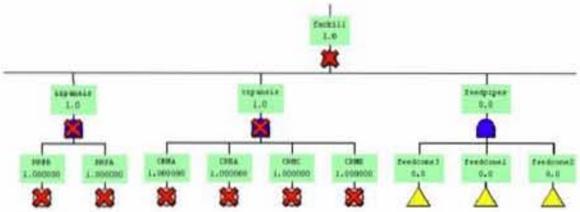

Fig. 3. Typical fault tree showing damaged components from a VISAC scenario.

While running an individual VISAC scenario is very quick, many different locations must be checked to determine the optimum target point for achieving the desired results. Usually when targeting a facility like a nuclear reactor it is desired to maximize the kill probability and the facility down time while minimizing the adverse collateral effects. A secondary consideration to this would be to minimize the population at risk. To achieve this VISAC can be run in a batch mode with a grid of points for where weapons are to be detonated. This code option produces a contour map showing the results at thousands of locations for each particular weapon. Separate contour maps for facility kill probability, probability of collateral damage, and facility downtime can be produced. Grids locations can be inside or outside of the facility. Figures 4 through 6 show the graphical results for facility kill, probability of collateral damage, and downtime from running VISAC on an internal grid for a generic nuclear reactor facility. In the figures red is the highest probability at 80 to 100% and blue is the lowest at less than 20%.

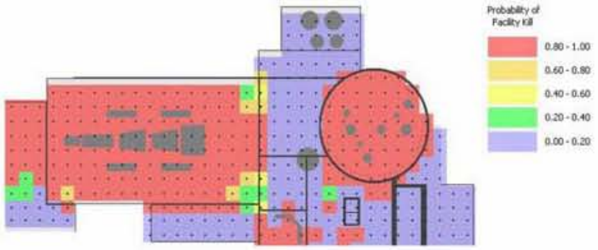

Fig. 4. Facility kill probability for a facility.

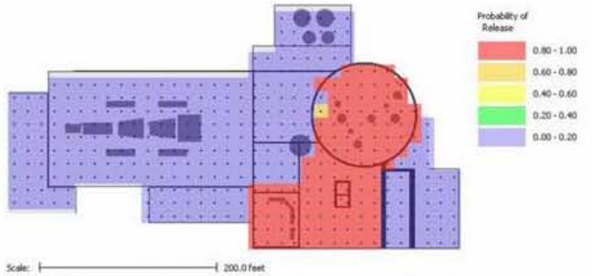

Fig. 5. Probability of adverse collateral damage.

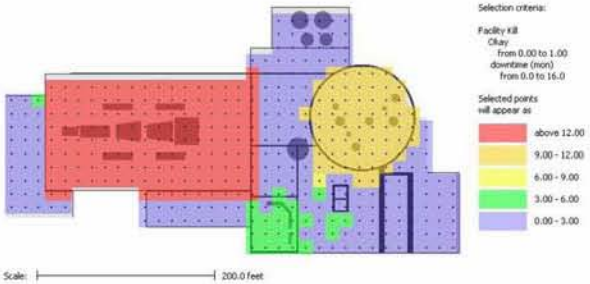

Fig. 6. Expected facility downtime.

By examining these three figures together, a set of locations for the most desirable strike points may be determined to achieve the desired results. The optimum locations determined from the figures can then be used to assess whether the results from the strike are worth the possible unintended collateral damage. This information can then be used as one of the inputs to the mission go, no go decision.

The grid feature can also be used to address protective measures that need to be taken to safeguard a facility. For example, to determine the measures that need to be taken to safeguard a facility from a truck bomb, grids can be outside the facility and a truck bomb detonated at the grid locations. Figure 7 shows the results from this type of calculation. As can be seen from the figure the risk to the facility from vehicle bombs can be greatly reduced by improving the security at only a few locations.

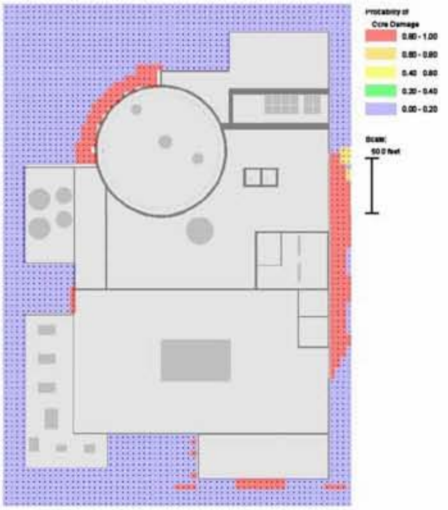

Fig. 7. Facility protective measure for defense against a truck bomb.

As mentioned earlier, if the analyst has a copy of DTRA's HPAC 5 software installed on their PC, then VISAC can provide transport and deposition of any releases as well as the population at risk. These plots are available in the traditional HPAC format or can be overlaid on Google maps. Figures 8 and 9 are examples of these types of plots.

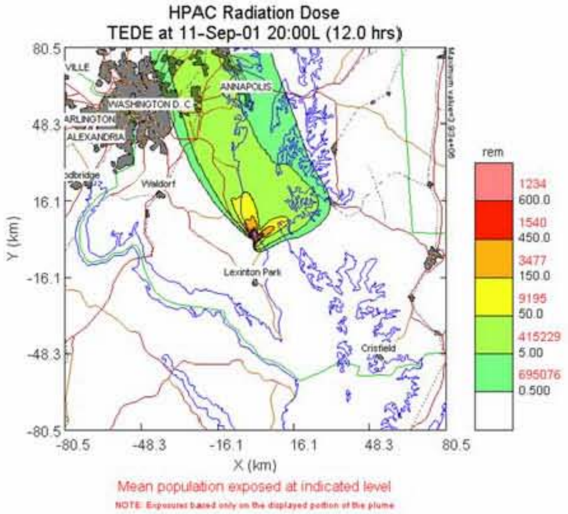

Fig. 8. Typical HPAC plot for radionuclide

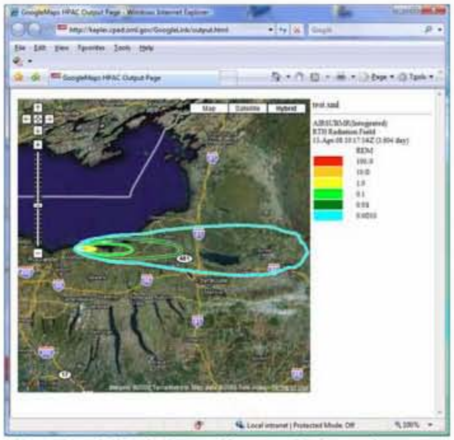

Fig. 9. VISAC radionuclide release overlaid on GoogleMaps.

4.0 CONCLUSIONS

- VISAC integrates target geometric modeling, blast damage assessment, and event/fault tree consequence analysis.
- The VISAC code successfully uses correlation blast modeling to generate quick facility vulnerability results.
- Results from the VISAC analysis can be used to
  - Optimize target locations to achieve the desired results
  - Provide the locations requiring increased protective measure
  - Aid in the mission go no-go decision making

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6.0 ACKNOWLEDGMENT

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