COMPBRN IIIe - A Computer Code for Fire Risk Analysis

Vincent HO, George APOSTOLAKIS
University of California, Los Angeles, CA USA

ABSTRACT

This paper presents an updated version of COMPBRN, a computer code that has been used extensively in Probabilistic Risk Assessments (PRAs) to quantify fire hazards in nuclear power plants. This updated version of the code, COMPBRN IIIe, can significantly reduce the time required to perform a fire risk assessment.

1 INTRODUCTION

In most of the nuclear power plant fire risk analyses performed to date, the computer code COMPBRN (Siu 1983; Chung et al. 1985; Ho et al. 1988) has been used to quantify the time interval between fire initiation and damage to critical components, called the fire growth time (Siu and Apostolakis 1986; Kazarians et al. 1985). The code characterizes the environment surrounding selected combustibles, e.g., cables, and determines each object's thermal response to its environment. Consequently, the time to damage of various safety related components can be determined.

The earlier versions of the COMPBRN code was originally designed to be used by experienced fire risk analysts. User-interface is limited and users have to develop their own uncertainty analysis tools in a fire risk assessment. In the past years, the number of COMPBRN users has increased significantly. Most of the users find it difficult to prepare the input files due to the limited interface and to locate the hard-to-find parameter value inputs. Furthermore, most novice users do not fully understand the application of the COMPBRN code and ignore the required uncertainty analysis associated with their assessments.

The updated version of the code, known as COMPBRN IIIe (Ho et al. 1990), incorporates an intelligent interface with a material property database to assist the users in the preparation of the input file. An uncertainty analysis module is also incorporated to assist the users to perform a probabilistic fire risk analysis directly, without using another computer code or having to design an uncertainty propagation driver. Since the

SMiRT 11 Transactions Vol. M (August 1991) Tokyo, Japan, © 1991

running time of the code is minimal, these improvements can significantly reduce the time required to perform a fire risk assessment.

2 OVERVIEW OF THE COMPBRN IIIE CODE

Treatment of the state-of-knowledge uncertainties (Apostolakis 1987) is perhaps one of the most important aspects in a PRA. Since there is a significant amount of uncertainty inherent in the models and the input parameters used in a room fire simulation, the users must incorporate an uncertainty analysis tool, such as a Monte Carlo driver or response surface, to assess the uncertainties. Thus, the estimated damage time of the specified objects should be represented by probability distributions rather than point values. This requires the repeated execution of the computer code for all fire risk scenarios in selected locations.

The COMPBRN code is specifically designed to be used in a probabilistic analysis. The typical running time of COMPBRN uncertainty analysis on an IBM PC is in the order of minutes (single run is within seconds). This makes an uncertainty analysis for fire risk scenarios feasible and manageable.

2.1 General description

The basic approximation of the code is the division of the compartment into three regions: (1) a layer of hot gases that accumulate under the ceiling; (2) the fire plume; and (3) the rest of the room (which is assumed ambient). Fig. 1 depicts the essential elements of this approximation in a compartment fire simulation and the heat transfer mechanisms that influence the target in the upper right-hand corner. In general, a fire

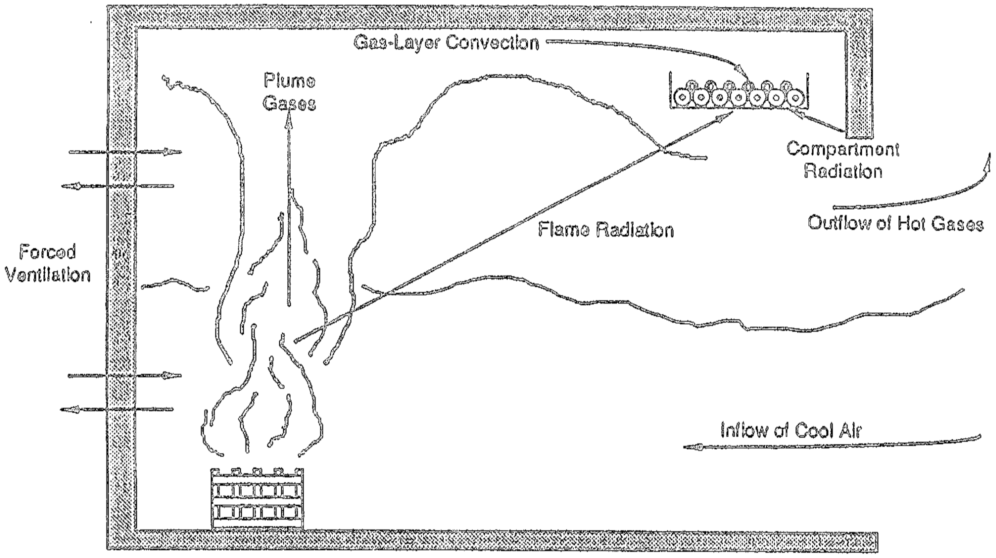


Fig. 1 - Typical Features of a Zone Model Room Fire Simulation

is modeled using a quasi-static approach which incorporates a large number of steady-state models available in the literature for different aspects of a fire's behavior. Upon determining the average temperature and thickness of the ceiling gas layer, the heat fluxes to any objects in the room are calculated. The size, intensity and overall characteristics of the fire are thereby updated and serve as input for the next time step. Damage of an object is predicted to occur when the surface temperature exceeds its prescribed damage temperature.

2.2 Intelligent interface

COMPBRN IIIe, unlike its predecessors, is a menu-driven interactive computer program designed to be used on IBM AT and PS/2, and their true compatibles. Users can perform an uncertainty analysis to propagate the parameter uncertainties without leaving the COMPBRN IIIe environment or using additional software. This makes COMPBRN IIIe a truly probabilistic fire risk analysis computer code.

The major modules included in COMPBRN IIIe are: (1) the Fire Damage Time Assessment Module, (2) the Tutorial Module, and (3) the Database Management Module. Users can interact with any of the modules via a menu-driven system. At any point of execution, the users can activate the on-line text-sensitive help windows via a designated key. The error checking feature will detect and respond to input errors with help windows to assist the users to enter acceptable data.

The initial step in using COMPBRN IIIe is to become familiar with the scenario, to assume a pilot fire location, and to identify the physical parameters, room parameters input/output requirements. This step sets forth the scope of the analysis such as the number of target components, doorway and ventilation parameters, the time step size and simulation period, etc. Once the overall parameters and the size of the problem are specified, a computer model of the scenario can be developed. At the same time, the fuel property data are gathered. When all necessary information is available, the input file can be prepared utilizing the interactive Input File Development option in the Fire Damage Time Assessment Module in COMPBRN IIIe.

3 SIMULATION OF EXPERIMENTS

A set of room fire experiments (Cline et al. 1983) has been performed to test the validity of the claim that a 6.10m (20 ft) separation distance without intervening combustibles or fire hazards would be sufficient to ensure that at least one train of cables would remain functional. Simulation results of the preliminary experiments are presented in (Ho et al. 1990). We present the results of the second preliminary experiment in this paper.

3.1 Description of the experiments

The room configuration of Experiment 2 is depicted in Fig. 2. The compartment is 4.27 m (14 ft) wide, 7.62 m (25 ft) long, and 3.05 m (10 ft) high. A tank contains a fuel load of 10 gallons of heptane is placed against the left wall. A doorway of 2.44 m (8 ft) by 2.44 m (8 ft) is located on the right wall. Horizontal cable trays are separated from the heptane by a horizontal distance of at least 6.1 m (20 ft). The cable trays, one of

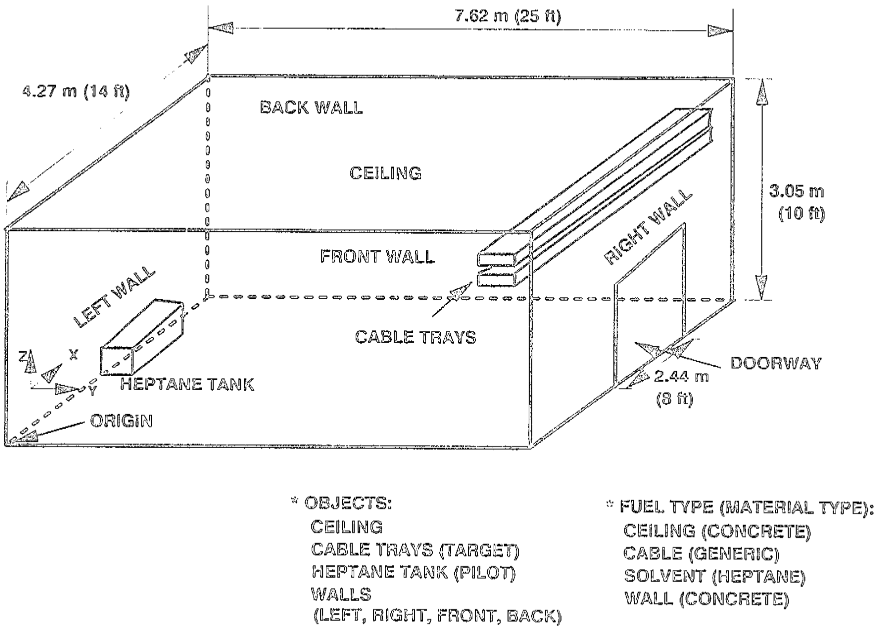


Fig. 2 - Illustration of the Computer Model for Experiment 2

which is directly above the other, are located in the far corner, close to the ceiling.

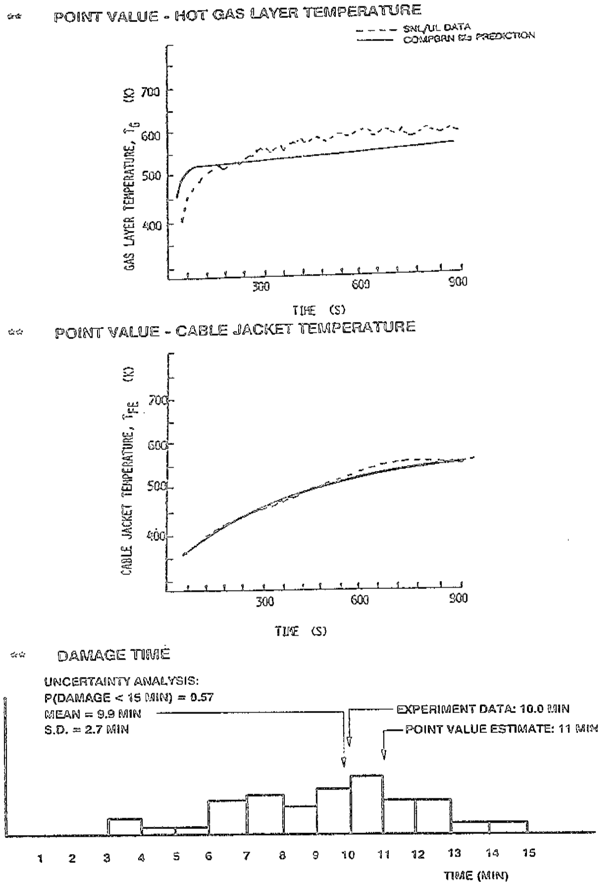
3.2 Simulation results

Fig. 3 presents the results of the point estimate prediction for the damage time, the hot gas layer temperature and cable jacket temperature, and a distribution for the damage time. These predictions are plotted against the experimental observations. The point estimate results can be used as reference points to investigate the effect of parameters to the damage time; however, the users should not rely upon only these point values for fire growth time assessment.

Because of the large number of Monte Carlo trials, some of the trial runs may result in cable damage at different time periods, and some of the runs may result in no-damage within the simulation time. It is interesting to note that if these two groups of data are allowed to combine to determine the damage time distribution, the no-damage data will severely distort the results by pulling the tail of the distribution of damage time towards infinity. Therefore, the two groups of data must not be mixed together in assessing the distribution of damage time. A simple way to avoid this problem is to first separate the runs that involve damage from the no-damage runs. The probability p(damage) is, then, assessed as:

$$p(damage) = \frac{(total\ trials\ -\ no\text{-}damage\text{-}trials)}{total\ trials}$$

This probability is the conditional probability of the damage times obtained from the trials that resulted in damage. For example, during the simulation of Experiment 2, 100 sample points were used. Eighty-five out of the 100 trials resulted in no damage. The other fifteen trials resulted in cable damage at different periods of time. Therefore, we can conclude that the damage time distribution (as illustrated in Fig. 3) is "distributions of time-to-damage given damage," and the probability of damage in this simulation is 0.15. The unconditional probability distribution of the damage time can then be assessed. If the users do not follow this procedure, the distribution they obtain may have little or no bearing on the real damage time.


POINT VALUE - HOT GAS LAYER TEMPERATURE

POINT VALUE - CABLE JACKET TEMPERATURE

DAMAGE TIME

UNCERTAINTY ANALYSIS:
P(DAMAGE < 15 MIN) = 0.57
MEAN = 9.9 MIN
S.D. = 2.7 MIN

EXPERIMENT DATA: 10.0 MIN

POINT VALUE ESTIMATE: 11 MIN

Fig. 3 - Simulation Results of Experiment 2

4 CONCLUDING REMARKS

The coherence of data selected from distributions in a Monte Carlo type analysis must be carefully accounted for. For example, a user does not know the exact material of Cable X he is analyzing; but he knows that there are only two types of cables present in the room, namely, PVC-A and PVC-B, and he needs to assess the density and thermal conductivity of Cable X. It is known that PVC-A is less dense but with a higher thermal conductivity than PVC-B. The user decides to use pool data that combine the properties of both types of cables. He fits a distribution for the density of Cable X with PVC-A's data at the lower end and PVC-B's data at the higher end, and vice versa for the thermal conductivity. These distributions are then called cable-to-cable variability distributions.

Now, if the user wishes to perform a Monte Carlo type analysis and randomly select values from the two distributions in his analysis, he, unknowingly, has violated the rules of data coherence. Since the values selected from the distributions are random in nature, it is very likely that values may be selected from the low end of both of the distributions. Thus, values that describe the density of PVC-A and the thermal conductivity of PVC-B are selected in the same trial to describe Cable X. This nonphysical usage of values will lead to unmeaningful results in the analysis, since there is no cable in the room that displays both a low value of density and thermal conductivity. Ho et al. (1990) provides examples and methodology to eliminate the common mistakes that can be injected into a fire risk analysis.

REFERENCES

Apostolakis, G. (1987). Uncertainty in Probabilistic Safety Assessment, presented at the 9th Conference on Structural Mechanics in Reactor Technology, Lausanne, Switzerland, August 17-21.

Chung, G., Siu, N. and Apostolakis, G. (1985). Improvement in Compartment Fire Modeling and Simulation of Experiments. Nuclear Technology, Vol. 69, pp. 14-26.

Cline, D., von Riesemann, W.A. and Chavez, J.M. (1983). Investigation of Twenty Foot Separation Distance as a Fire Protection Method as Specified in 10CFR50, Appendix R. NUREG/CR-3192, SAND83-0306.

Ho, V., Siu N. and Apostolakis, G. (1988). COMPBRN III - A Fire Hazard Model for Risk Analysis. Fire Safety Journal, Vol. 13, pp. 137-154.

Ho, V. Chien, S. and Apostolakis, G. (1990). COMPBRN IIIe - An Interactive Computer Code for Fire Risk Analysis. UCLA-ENG-9016, University of California, Los Angeles.

Kazarians, M., Siu, N. and Apostolakis, G. (1985). Fire Risk Analysis for Nuclear Power Plants-Methodological Developments and Applications. Risk Analysis, Vol. 5, pp. 33-51.

Siu, N. (1983). COMPBRN - A Computer Code for Modeling Compartment Fire. NUREG/CR-3239, U.S. Nuclear Regulatory Commission.

Siu, N. and Apostolakis, G. (1986). A Methodology for Analyzing the Detection and Suppression of Fires in Nuclear Power Plants. Nuclear Science and Engineering, Vol. 94, pp. 213-226.