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IMPORTANCE OF EMERGENCY RESPONSE ACTIONS TO REACTOR ACCIDENTS WITHIN A PROBABILISTIC CONSEQUENCE ASSESSMENT MODEL*

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SUMMARY

An uncertainty and sensitivity analysis of early health consequences of severe accidents at nuclear power plants as a function of the emergency response parameters has been performed using a probabilistic consequence assessment code. The importance of various emergency response parameters in predicting the consequences for a range of accident source terms was determined through training a neural network algorithm which relates the sensitivity of the output to various choices of the input. Extensions of this approach should be helpful to planners in prioritizing the emergency responses at nuclear power plants.

I. INTRODUCTION

Planning of emergency response measures for low probability, high consequence, severe accidents at nuclear power plants is required of licensees under Title 10 Part 50 Appendix E of the Code of Federal Regulations.[1] The objectives of emergency response are to achieve a substantial reduction in early severe health effects (early injuries and fatalities) in the event of a worst case release and to provide dose savings for people whose projected doses would exceed the EPA's protective action guides over a spectrum of accidents.[2] The measures considered in emergency response planning (EP) include warning of the affected population in the Low Population Zone (LPZ), (generally within a 10-mile radius of the plant) after the declaration of a general emergency, followed by sheltering and/or evacuation of the people within the LPZ. The relative effectiveness of these measures in meeting EP objectives depends on a number of factors:

A. characteristics of the release, generally known as the source term resulting from the accident (magnitude of the core inventory of fission products released to the environment, the timing and duration of the release, and the height and energy of the release),

B. weather at the time of and following the release (windspeed, atmospheric stability, rainfall, etc.),

C. specific values assigned to the parameters which define the emergency response strategy such as a) percent of the population within the LPZ which participates in the response, b) the delay between the time at which the warning is given and the time at which the response action begins, c) the duration of the response, e.g., sheltering, d) the effective evacuation speed at the site, e) the extent of shielding to different exposure pathways afforded by sheltering, f) and the particular mode of evacuation employed.

Within a probabilistic risk assessment framework, the characteristics of the source term and the weather may be considered as uncertainty parameters and the factors defining the emergency response strategy as sensitivity parameters, whose assigned values for any particular accident scenario will impact the outcome of the consequences, e.g., early health effects, resulting from the accident. The impact of the uncertainty due to weather variability can be evaluated through a probabilistic consequence code which performs statistical sampling over a large number of input weather data points. This paper is devoted to examining the relative importance of the parameters affecting the effectiveness of the emergency response countermeasures on the early health effects. Sensitivity calculations which relate the change in early health effects to changes in the values of delay time, evacuation speed, duration of sheltering, etc. have been carried out across a range of selected, hypothetical source terms representative of severe accidents at pressurized water reactors. The consequence calculations have been carried out

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using the MACCS2 probabilistic consequence assessment code[3] with a site data weather file and an offsite population distribution from the Surry nuclear power plant site located in southeastern Virginia. A similar study for one particular source term, based on an earlier version of the MACCS code,[4] using the method of partial (rank) correlation coefficients and coefficients of determination to evaluate the sensitivity of the model output to changes in uncertain model inputs, was reported by Gallego and Jiminez.[5] In this paper, we use a neural network procedure to determine the sensitivity of the output to changes in selected input parameters.

II. METHODOLOGY AND TOOLS

The methods employed in this study consisted of consequence calculations using the MACCS2 code and NeuroSolutions^{TM} [6], a PC-based neural network simulation code for the sensitivity analysis.

MACCS2 is an extension of the MACCS code, originally developed under the sponsorship of the U.S. NRC, used for Level 3 Probabilistic Safety Analyses of nuclear power plants. MACCS2, which was developed under USDOE sponsorship, includes an extended radionuclide library (which allows it to calculate consequences from accidents at nuclear facilities other than commercial light water reactors), a more realistic site evacuation model, and an extended food chain model for predicting long-term doses due to ingestion. MACCS2 has recently undergone beta testing both in the U.S. and abroad. Like its predecessor code, MACCS2 takes weather variability into account by sampling from an annual file of hourly weather data at the accident site, reads user-defined site data files on population distribution, emergency and mitigating actions, and calculates numerous health and economic consequences, both for the emergency phase and for long periods of time for user selected accident source terms. In the present study, only the early health consequences (fatalities and injuries) during the emergency phase have been used in the sensitivity analyses.

In the first step, a series of MACCS2 calculations were performed for three source terms, distinguished, for simplicity, only by the timing of the release, and for various values of input emergency response parameters described below. The series of results for the consequence measures, early injuries and fatalities, were analyzed using a commercially available PC-based neural network simulation environment, NeuroSolutions^{TM}. This program was used to create a neural network, trained to predict these two consequence measures for four emergency response variables: delay time of sheltering, duration of sheltering, fraction of LPZ population participating in the emergency action, and evacuation speed. A Multilayer Perseptron neural network architecture was selected for this analysis. With no hidden layers, the convergence in training was achieved with the mean square error of 10^{-3}. The significance of each input variable for the two output variables, early fatalities and injuries, was predicted by the network and expressed as percentage of the significance of all input variables. Note that normalized values of input and output variables were used in the analysis by the neural network.

III. SENSITIVITY CALCULATIONS

The three source terms selected were taken from an assessment of severe accident progression for a loss of offsite power plant damage state at the Surry nuclear power plant, a 3-loop Westinghouse PWR, performed by Nourbakhsh[7], based on the results of the NUREG-1150 study[8]. The containment failure mode is early failure, at or shortly after vessel breach. For the sake of simplicity, to reduce the number of calculations, the magnitudes of the release fractions of various fission product groups and the energy and height of release were fixed and only the release time relative to the time of accident initiation was varied. Three release times, 2 hours, 5.5 hours, and 10.5 hours, after reactor scram were assumed in setting up the input source terms. The Surry weather and site data files developed for the NUREG-1150 study were used to set up the calculations. The range of values selected for the emergency response input parameters are shown in Table 1. The first row of values shown in Table 1 are broadly representative of the parameter values assumed for the plants evaluated in the NUREG-1150 study. The other rows provide a range of values used in the sensitivity analysis. Figure 1 shows the time lines of the assumed emergency response actions in relation to the release time.

Three sets of calculations of the early health consequences were performed. In the first set (release at 2 hours) 81 outputs were obtained by varying the four input variables over each of their three sets of assumed values shown in Table 1. In two other sets, releases at 5.5 and 10.5 hours, respectively, the evacuation speed had two values to give a total of 54 outputs. The outputs and inputs were then fed into and used to train the neural network in order to obtain a measure of the sensitivity of the output to the input for each calculation set. This measure provides a determination of the relative importance of each input in predicting the output for a particular scenario.

The results of calculations are presented in Figure 2, which shows the relative importance of various assumed input variables for two particular values of the early health consequences, mean values of the early fatalities and early injuries, for the three release times.

Table 1. Emergency Scenario Input Parameters

Delay to Shelter, hr	Duration of Sheltering, hr	Participation in Sheltering, (percent)	Evacuation Speed, m/s
2	8	99	2.6
4	12	90	1.1
6	16	80	0.5

IV. DISCUSSION

Figure 2 shows that for the release time of 2 hours, the most important emergency response variable affecting both early fatalities and injuries is the duration of sheltering, followed closely by the delay in taking shelter and the evacuation speed. The fraction of people in the LPZ who participate in the emergency response (over the range of 99 percent to 80 percent) has a much lower importance. This is intuitively reasonable, considering the relative timeliness of the various actions displayed in Figure 1. The release begins at or before the assumed values of the delay time in taking shelter, so the entire population in the LPZ is potentially exposed; the duration of sheltering is a more important parameter in this case. Conversely, for the later release time of 10.5 hours, the fraction of persons who participate in the action is the most important and duration of sheltering has a lesser importance; in this case, it is only the people who do not participate who will be exposed to the passage of the plume without any benefit of the protection afforded by sheltering.

This calculation should be regarded as preliminary. It was carried out mainly to test whether neural network training could be usefully employed to explore uncertainty issues in emergency response planning of severe accidents. The results obtained appear to suggest that this is indeed the case. Depending on the timing of the release that occurs, the analysis suggests which actions should be given more attention. These preliminary results now need to be extended over a larger range of possible source terms and weighted by the probability of the release to obtain a more detailed representation of the importance of various emergency response measures.

V. REFERENCES

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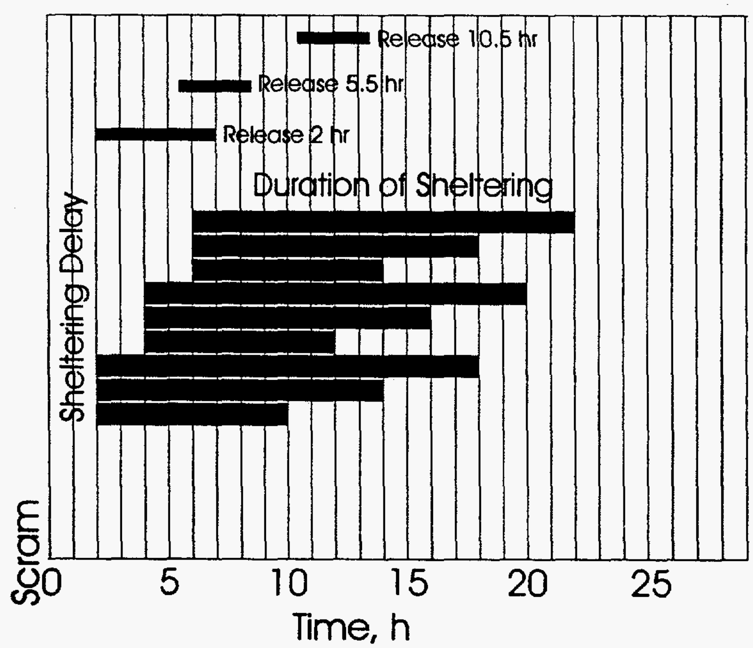

Figure 1: Timelines of Emergency Response Actions vis-a-vis Release Times

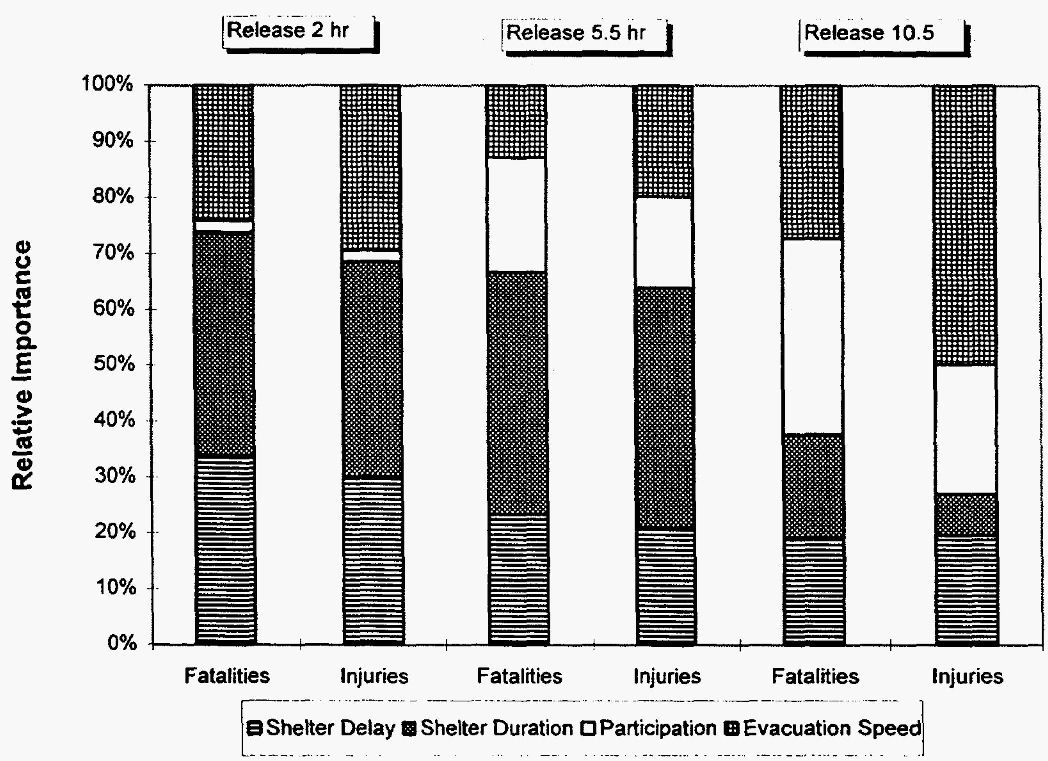

Figure 2: Relative Importance of Emergency Response Actions with Respect to Early Health Consequences

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