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An Estimation of Human Error Probability of Filtered Containment Venting System Using Dynamic HRA Method

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1. Introduction

The human failure events (HFEs) are considered in the development of system fault trees as well as accident sequence event trees in part of Probabilistic Safety Assessment (PSA). As a method for analyzing the human error, several methods, such as Technique for Human Error Rate Prediction (THERP), Human Cognitive Reliability (HCR), and Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) [3, 4, 5] are used and new methods for human reliability analysis (HRA) are under developing at this time. This paper presents a dynamic HRA method for assessing the human failure events and estimation of human error probability for filtered containment venting system (FCVS) is performed. The action associated with implementation of the containment venting during a station blackout sequence is used as an example.

2. Methods and Results

2.1 Dynamic HRA method

The assessment of human reliability depends on the determination of both the required performance distribution and the achieved performance distribution. The quantified correlation between requirement and achievement represents a comparison between two competing variables. The success of the operators is governed by the time available for action (achievement) and the time required by the operators to diagnose the situation and act accordingly (requirement). Since both times are uncertain variables, the human error probability, HEP, is simply the fraction of times that the required time, T1 (operational time) exceeds the available time, T2 (phenomenological time).

$$\begin{aligned} HEP &= P\,(\mathrm{T1} > \mathrm{T2}) \\ &= \sum Prob\,[(\mathrm{T1} > t) \text{ and } (\mathrm{T2} = t)] \\ &= \sum P\,[(\mathrm{T1} > t) * (\mathrm{T2} = t)] \\ &= \int_0^\infty \left(1 - F_{T1}(t)\right) * f_{T2}(t)dt \end{aligned} \tag{1}$$

where $F_{T1}(t)$ is the cumulative distribution of the operational time, T1, and $f_{T2}(t)$ is probability density function (pdf) of the time, T2.

This method takes 3 steps:

1) Assessment of a stochastic distribution for T1.
2) Assessment of a stochastic distribution for T2.
3) Evaluation of these distributions as shown in Eq. (1) [6, 7].

2.2 The operator action for FCVS

The present method is applied to an operator action of venting the containment in a station blackout sequence before the containment fails. In the case of a severe accident, the FCVS is a system that can be used to protect the containment and the facility while mitigating radioactivity releases to the environment. The initiating of the venting may be fully passive or active if the operators open the isolation valves. The venting initiation is typically determined by the containment design pressure or the pressure that the operators are instructed to vent. The initiation pressure may vary significantly in the range of about 2 – 9 bar (abs) depending on the plant type, containment size, and other considerations. For this analysis, OPR 1000 were chosen for the reference plant and AREVA's FCVS model which is shown in Fig. 1 was considered. And it was assumed that the initiation pressure of the venting is 57 psi which is the containment design pressure [1, 2].

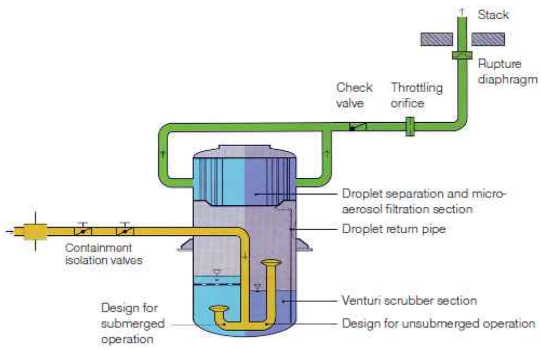

Fig. 1 AREVA's FCVS model

Based on the facts that the station would be blacked out, the failure of the operators to correctly initiate the strategy would be governed by two uncertain variables. The diagnosis and decision time (T_d) is the time available for the operators to recognize the accident situation and decide to initiate venting. It might take the execution time (T_e) to open two isolation valves. Since there is no operating procedure of the FCVS, it is assumed that the available time is the time between reactor vessel failure time (T_{vf}) and the time to reach a containment pressure of 68 psi, 1.2 times of the containment design pressure (T_{cf}).

Using these times, the human error probability associated with the probability that the required time, T_a

(T_e + T_d), exceed the available time, T_f (T_{cf} - T_{vf}), can be derived from Eq. (1).

2.3 Distribution of the phenomenological time, T_f

To obtain the distribution of the available time, MAAP code [8] was used to calculate the time of reactor vessel failure and the time to reach a containment pressure of 68 psi. Since the output of MAAP code was limited, distribution of the operational time was obtained by sensitivity analysis that investigates the effect of changes in input variables associated with the containment condition on out predictions.

Because there are a lot of input variables in MAAP parameters, FCHF, FAOX and EPSCU2 which affect containment condition were selected for the sensitivity analysis. FCHF is the flat plate critical heat flux and FAOX is the multiplier for the cladding outside surface and is used in oxidation calculation. EPSCU2 is the cutoff porosity below which the flow area and the hydraulic diameter of a collapsed core node are zero and has a negative correlation to hydrogen production.

A sample size of 50 was used to propagate the uncertainty for the key variables though the MAAP code and the applied method was Latin Hypercube sampling. The cumulative distribution of the available time is shown in Fig. 2.

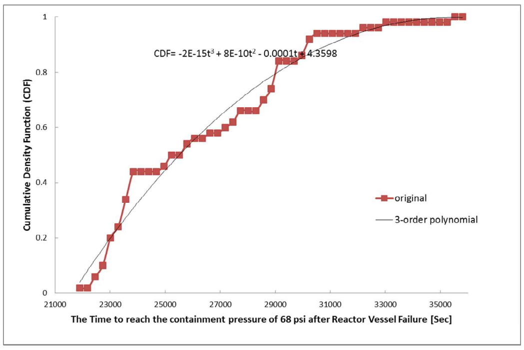

Fig. 2 The cumulative distribution of phenomenological time Produced from MAAP code with 50 LHS Samples

2.4 Distribution of the operational time, T_a

It is required to find the distribution of the required time by the operators. Since FCVS is not yet installed in the reference plant and the current procedures of the reference plant are not developed for initiating the venting, the timing for the operator action cannot be obtained from the historical record. Instead, the time to reach the initiation pressure of the venting by MAAP code was used to be the operational time

A sample size of 50 was also used to propagate the uncertainty for the key variables though the MAAP code and Latin Hypercube sampling. The cumulative distribution of the operational time is shown in Fig. 3.

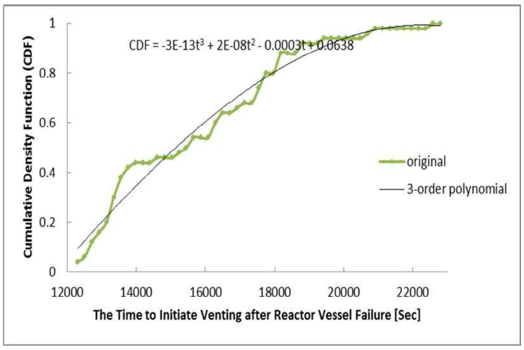

Fig. 3 The cumulative distribution of the operational time Produced from MAAP code with 50 LHS Samples

2.4 Results

To solve the Eq. (1), the distribution of the random variables, the phenomenological time (T_f) and the operational time (T_a) should be obtained. A two-parameter Weibull distribution, represented as Weibull (λ, β), is considered here and its functional form is as follow:

$$f(t) = \frac{\beta}{\lambda}\left(\frac{t}{\lambda}\right)^{\beta-1} exp[-\left(\frac{t}{\lambda}\right)^{\beta}],\ \lambda > 0\ and\ \beta > 0\ for\ t > 0 \quad (2)$$

$$F(t) = 1 - \ exp[-\left(\frac{t}{\lambda}\right)^{\beta}] \quad (3)$$

$$\mu = \lambda\,\Gamma(1+\frac{1}{\beta}) \quad (4)$$

$$\sigma^2 = \lambda^2\,\{\Gamma(1+\frac{2}{\beta}) - [\Gamma(1+\frac{1}{\beta})]^2\} \quad (5)$$

where Γ, λ and β are a gamma function, the scale factor and the shape factor, respectively.

Eq. (4) and (5) are used to estimate λ and β. In case of the phenomenological time, T_f, the mean, μ, is set to be the sample mean of 7.2 hours and the variance, σ^2, is the sample variance of 0.8 hours based on the Figure. 2. By solving Eq. (4) and (5) numerically, λ_f and β_f is estimated to be 7.5 and 9.6, respectively.

In case of the operational time, T_a, the mean, μ, is set to be the sample mean of 4.3 hours and the variance, σ^2, is the sample variance of 0.5 hours based on the Figure. 3. By solving Eq. (4) and (5) numerically, λ_a and β_a is estimated to be 4.5 and 7.1, respectively.

Using the obtained distributions, the Eq. (1) becomes as follows:

$$HEP = \int_0^{\infty}[1 - F_{T_a}(t)]f_{T_f}(t)dt$$

$$= \int_0^{\infty} \exp\{-(\frac{t}{\lambda_a})^{\beta_a}\}[\frac{\beta_f}{\lambda_f}(\frac{t}{\lambda_f})^{\beta_f - 1}\exp\{-(\frac{t}{\lambda_f})^{\beta_f}\}]dt \quad (6)$$

By the Eq. (6), the HEP is calculated to be about 8.82×10^{-3}. In case that the distribution of the available time is same with that of the required time by the operators, the calculated HEP is increased to be a value of 0.49. Therefore, if the distribution of the available time is so close to that of the required time by the operators, the calculated HEP can be significantly increase.

3. Conclusions

In this report, dynamic HRA method was used to analyze FCVS-related operator action. The distributions of the required time and the available time were developed by MAAP code and LHS sampling.

Though the numerical calculations given here are only for illustrative purpose, the dynamic HRA method can be useful tools to estimate the human error estimation and it can be applied to any kind of the operator actions, including the severe accident management strategy.

Acknowledgements

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REFERENCES

[1] KINS, "Review on the requirements of containment filtered venting system performance", KINS/RR-1108, 2014.

[2] Nuclear Energy Agency, "Status report on filtered containment venting, nuclear safety" NEA/CSNI/R(2014)7, 2014.

[3] Swain, A.D, and Guttmann H.E., Handbook of human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, NUREG/CR-1278, U.S.NRC, 1990

[4] Hannaman, A.J, et. al, Human Cognitive Reliability Model for PRA Analysis, NUS-4531, EPRI, 1994

[5] Gertman, D., Blackman, H., Byers, J., Haney, L., Smith, C., & Marble, J., The SPAR-H Method, NUREG/CR-6883, U.S.NRC, 2005.

[6] Jae, M and Apostolakis, G.E, The Use of Influence Diagrams for Evaluating Severe Accident Management Strategies, Nuclear Technology, Vol.99, p.142-157, 1992.

[7] Jae, M, A New Dynamic HRA method and Its Application, International Journal of Reliability and Applications, Vol.2(1), p.37-48, 2001.

[8] FAI, User's Manual for MAAP4: Modular Accident Analysis Program for LWR Power Plants, Fauske & Associates, 1994.