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A SYSTEMATIC APPROACH TO CONTAINMENT PERFORMANCE CRITERIA*

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The objective of this study is to demonstrate how to specify containment performance criteria in a systematic way given top level safety goals.[1] The multiobjective optimization approach proposed by Cho, et al.[2] was adopted as a method for deriving a finite manageable set of self-consistent relations between the top level safety goals and specific sets of measures of containment performance.

The current trial safety goals proposed by the NRC goes from a design objective figure of 10^{-4} for annual frequency of core melt to guideline numbers for early fatalities and for delayed fatalities.[3] In Ref. 3, no numerical guideline for containment performance was included. Instead, it was assumed that qualitative guidance and the operation of the other numerical guidelines could be relied on to guide regulation of containment effectiveness.

An alternative is to specify containment system performance in some quantitative fashion. If this can be done, and if the specified performance can be demonstrated with some reasonable level of confidence, it will help to provide greater consistency between top level safety goals (health risk indices) and lower level design objectives (plant performance indices, i.e., core melt frequency and containment performance criteria). The question then arises as

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to how best to specify containment performance. Such specification may take several possible forms, either probabilistic or deterministic. For example, the Advisory Committee on Reactor Safeguards (ACRS) defines containment performance in terms of the likelihood of a large scale uncontrolled release of radioactive materials, assuming that a fuel melt has occurred.[4] (For more comprehensive discussions on the quantification of containment performance criteria, see Ref. 5.)

For the formulation of multiobjective optimization problem, three objective functions were chosen as a global set of measures of plant performance: expected acute fatalities (A), expected latent fatalities (L), and the cost (G) of achieving a particular set of values for the first two members of the global set. Eight decision variables were identified for a pressurized light water reactor with a large dry containment as a specific set of measures of containment performance.[1] The selection of these eight decision variables was based on the observation that the main containment functions are to: 1) mitigate thermal-hydraulic loads produced by accidents; 2) sustain such loads without loss of integrity; and 3) prevent bypass of containment. These three categories of functions, which the containment is intended to perform, covers various safety systems involved in a specific containment design.

Once the objective functions and decision variables were identified, the mathematical relationships between them were provided by the results of Probabilistic Risk Assessment (PRA) studies. Since a PRA is known as the best method for systematically evaluating the risk of nuclear power plants, it seemed reasonable to use PRA models as mathematical relationships between the objective functions (acute and latent fatalities) and the decision variables (system reliabilities). Since the reliability cost is not provided by PRA models, two basic functional forms of the system reliability cost were assumed. It is difficult to determine the detailed forms of the cost functions; therefore, parametric sensitivity studies were done and the results are given in Ref. 1.

By introducing reliability cost, a multiobjective optimization problem for determining lower level containment performance criteria was formulated in the following manner:

- To minimize acute and latent fatalities, and the reliability-cost, subject to the safety goals and feasible ranges of decision variables.

The above multiobjective optimization problem was solved by the direct search method.[1] The direct method generated 74 noninferior solutions. Table 1 shows five of them (S12, S57, S61, S21, and S1). For each noninferior solution, a set of global values (risk indices and cost) and a corresponding set of containment performance criteria (system reliabilities, etc.) are displayed. In the last column, corresponding PRA values of a reference plant (O-PRA) are given. Such a table can be used either by a decision maker for further preference assessment among the viable design options (i.e, among the noninferior solutions) or by a designer for possible design improvements by comparing current design values to those of the solutions from the multiobjective optimization.

Table 1 The Values of Decision Variables

	Noninferior Solutions					
	S12	S57	S61	S21	S1	O-PRA
A_s*	8.79	9.81	8.44	9.68	30.62	27.5
R	55.21	59.94	85.55	87.90	84.95	61.0
CSSI	4.44-2	4.07-2	1.08-2	5.21-2	2.13-2	1.0-3
CSSR	9.82-1	5.28-1	3.45-1	4.80-1	4.99-2	1.0-1
RHR	1.02-2	7.39-3	6.04-2	1.43-2	9.80-2	1.0-3
F	2.97-2	2.82-2	1.19-1	1.54-2	1.48-6	1.0-3
C1	3.58-2	5.58-1	2.12-2	1.08-2	1.14-5	3.0-3
V	8.30-2	4.81-4	3.46-8	8.90-6	1.08-10	1.4-7
A/CM	8.04+3	7.21+1	1.93	1.05	2.51-5	0.05
L/CM	2.08+6	1.35+4	1.18+2	2.41+2	2.83	21.0
G	1.50+8	1.95+8	3.24+8	3.31+8	2.19+10	9.28+9

*NOTE: A_s = amount of reinforcing steel, ft^2/ft
R = containment radius, ft
CSSI = unavailability of spray system in injection mode
CSSR = unavailability of spray system in recirculation mode
RHR = unavailability of residual heat removal system
F = unavailability of fan cooler system
CI = probability of containment isolation system failure
V = probability of containment bypass
CM = core melt frequency

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