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Title: QUANTIFICATION OF BRANCH PROBABILITIES FOR LEVEL 2 PSA OF I-SMR USING MELCOR-BASED UNCERTAINTY ANALYSIS

Author's: Hong, Sein (Korea, Republic of)[1]; Kang, Hyunkook (Korea, Republic of)[1]; Cho, Jaehyun (Korea, Republic of)[1]
Affiliaton's: 1 - Chung-Ang University
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Innovative SMR (i-SMR) is being developed with enhanced inherent and passive safety features; however, their severe accident risk characteristics have not yet been sufficiently quantified within Level 2 probabilistic safety assessment (PSA) framework. In conventional Level 2 PSA, branch probabilities associated with accident progression are often assigned based on engineering judgement or assumptions derived from large light-water reactor designs, limiting their applicability to advanced SMR concepts. In the current i-SMR design, explicit mitigation systems for accidents following core damage are not incorporated. Consequently, containment vessel (CV) integrity cannot be assured once RV failure occurs. Accordingly, this study defines RV failure as upper boundary of accident progression, and develops a Level 2 PSA framework tailored to the design characteristic. This study proposes an uncertainty-informed methodology for quantifying branch probabilities used in Level 2 PSA based on objective and quantitative evidence. Deterministic severe accident analysis using the MELCOR code is integrated with the PSA framework. Core Damage scenarios obtained from Level 1 PSA are grouped into plant damage states (PDS), and representative accident scenarios are selected for analysis. For each scenario, MELCOR-based Monte Carlo uncertainty analysis is performed by systematically varying key parameters related to thermal-hydraulic behavior and core degradation phenomena. The resulting statistical outcomes are used to quantify branch probabilities associated with RV failure. The quantified branch probabilities are incorporated into Level 2 PSA model constructed using containment vessel event tree (CET) and decomposition event tree (DET). Based on this framework, RV failure probability and large early release frequency (LERF) are evaluated as key severe accident risk metrics. The results demonstrate that the proposed methodology improves the objectivity and reliability of branch probability assignment compared to conventional approaches. The proposed framework provides a practical basis for severe accident risk assessment for i-SMR.

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