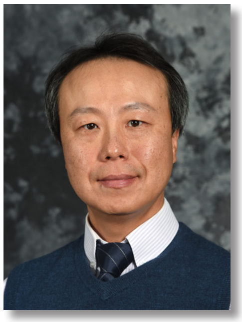
Status of Risk-Informed Multi-Physics Best Estimate Plus Uncertainty Method Development



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Risk-Informed Systems Analysis Pathway

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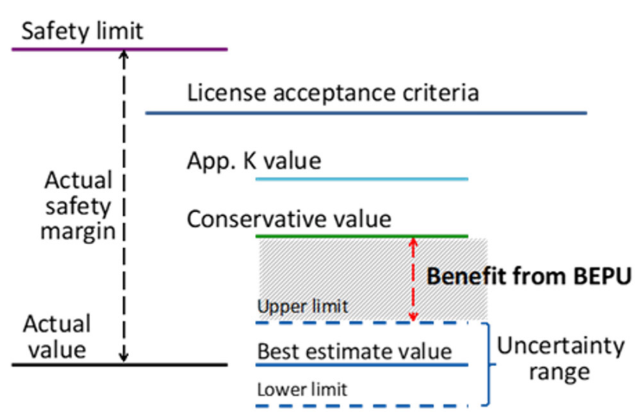
The Risk-Informed Systems Analysis (RISA) Pathway mainly uses the probabilistic safety assessment (PSA) approach to reduce conservatisms in LWR safety margins. A complementary approach that could further reduce unnecessary conservatisms is to combine the PSA approach and uncertainty analysis methodologies to cover multi-physics phenomena (e.g., neutronics, fuel performance, thermal-hydraulics) during safety analysis. This approach is called the risk-informed multi-physics best estimate plus uncertainties (BEPU) method. The RISA Pathway is exploring the BEPU method in its industry engaged demonstration projects by: (1) upgrading RELAP5-3D, the best estimate thermal-hydraulics code, to allow quantifying uncertainties from major physical phenomena during a loss-of-coolant (LOCA) scenario; and (2) by participating in an international benchmark program led by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD-NEA) for the validation and use of actual nuclear power plant operational data.

Sources of uncertainties include unavoidable errors introduced by assumptions and approximations used in thermal-hydraulics computational tools. By using a fully validated computer code with realistic data from experiments and operations, the BEPU method can quantify computational uncertainties. The BEPU method will, therefore, reduce conservatisms and increase safety margins during accident analysis. Figure 9 shows an example of a safety margin that can benefit from the use of the BEPU method. The BEPU method can provide additional safety margin (the shaded area in Figure 9) compared to a conservative approach, even measuring margin from upper limit of uncertainty range. For this reason, the U.S. Nuclear Regulatory Commission (NRC) allows licensing applications to use the BEPU method [1] which will also enhance the economics of U.S. nuclear power plants. This method is also applied to licensing for more than 20 nuclear power plants around the world.

Upgrade of RELAP5-3D for BEPU Analysis

RELAP5-3D, developed at Idaho National Laboratory (INL), is a best estimate nuclear power plant thermal-hydraulics analysis code that is used to evaluate safety margins. The general approach to quantify uncertainty is to apply a probability density function (PDF) to the field equation, which solves the physics. However, previous researchers could only apply PDF to the input file, which would generate additional uncertainties. The RISA-proposed approach allows the PDFs to be applied directly to the constant in the field equation source code. This approach produces a better-defined uncertainty band. The PDF can be set through a data-sampling tool such as the Risk Analysis Virtual EnviroNment (RAVEN). The RELAP5-3D source code was modified to receive the PDF from RAVEN. The reflood phase of a LOCA scenario was used for the demonstration, and clad temperature was compared. Shown in Figure 10 , the uncertainty band mostly covers data from experiments and non-BEPU simulations. It is noted that the temperature drop showed a large discrepancy between the experiments (near 100 seconds) and the non-BEPU simulation (near 80 seconds), which may lead to a misjudgment during a safety analysis. However, the BEPU method identified that

Figure 9. Comparison of safety margins between Appendix K, conservative and BEPU.



the discrepancy is due to the computational uncertainties. This is an example of the benefit from using the BEPU method that an analyst can correctly predict an acceptable range of physical phenomena changes.

OECD-NEA International Benchmark Program on the Multi-Physics BEPU Method

Since 2007, the OECD-NEA has been conducting research to understand multi-physics uncertainties using actual plant operation data from the following: Three Mile Island Unit 1 (PWR), Peach Bottom 2 (BWR), and Kozloduy Unit 6 and Kalinin Unit 3 (VVER, a Russian PWR). The research found that the uncertainties in neutronics are mainly from the covariance nuclear data libraries. The research is continuing for the coupled neutronics, kinetics, and thermal-hydraulics, including their feedback effects. The study also considers consistency between computational tools, and uncertainty from the scaling effect during modeling and simulation.

BEPU Application for Transition from Deterministic to Risk-Informed Approach

The BEPU method supports the transition from deterministic to a risk-informed approach. For example, safety analyses of nuclear fuel with higher enrichment and extended burnup cannot be completed using a purely deterministic approach because of the concern of fuel fragmentation, relocation, and dispersal (FFRD). With the current burnup limit of 62 GWd/MTU, the FFRD analysis is not required in the current deterministic LOCA analysis to meet the Code of Federal Regulation (CFR) Title 10 (10 CFR 50.46a) acceptance criteria. However, with the new limit of 75 GWd/MTU, the FFRD issue must be addressed. This phenomenon is very complex and not well understood, and more importantly there is a lack of data. As such, it has become an impediment to licensing for burnup extension. The risk-informed approach uses the process defined in NRC's guideline to determine the contribution of LOCA-induced FFRD to plant risk, by quantifying core damage frequency and large early release frequency, and burnup extension [2]. This could be the basis for seeking the NRC's approval to extend current practice of not including FFRD in the design-basis LOCA analysis performed following the 10 CFR 50.46 criteria. The goal of the risk-informed approach is to demonstrate that FFRD with peak rod average burnups in the range 62 to 75 GWd/MTU caused by LOCA events is of sufficiently low risk that it does not need to be included in the design-basis analyses of LOCA. The BEPU methodology supports risk-informed approaches to complex safety evaluations by providing a better understanding of the accident scenario conditions and associate uncertainties.

References

1. US Nuclear Regulatory Commission, Regulatory Guide 1.157: Best-Estimate Calculations of Emergency Core Cooling System Performance, May 1989.
2. US Nuclear Regulatory Commission, Regulatory Guide 1.174: An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes on the Licensing Basis, January 2018.

Figure 10. Cladding temperature behavior and uncertainty band at upper part of core.