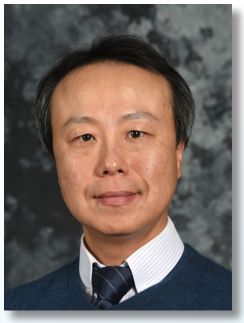
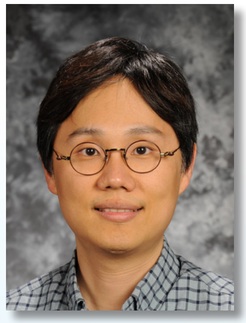
Validation of Risk-Informed Tools and Methods: NEUTRINO Flooding Analysis Tool

An assessment of technical maturity and a credible validation of the risk-informed tools and methods being developed through Light Water Reactor Sustainability (LWRS) Program research will facilitate interest, confidence, and transfer of risk-informed technologies to the nuclear industry. These "tools" are comprised of computer software platforms to perform risk-informed analyses to a variety of nuclear power plant applications. The Risk-Informed Systems Analysis (RISA) Pathway is validating risk-informed tools to develop an appropriate approach to be applied to risk-informed activities. The goals of a validation include the assessment of the validation status and to quantify the technical maturity, identify technical gaps, propose improvements for verification and validation, and develop dedicated validation methods for risk-informed systems analysis. This article summarizes the validation status assessment activity of the flooding analysis computational software NEUTRINO, which is being used in the RISA Pathway (see Figure 1).

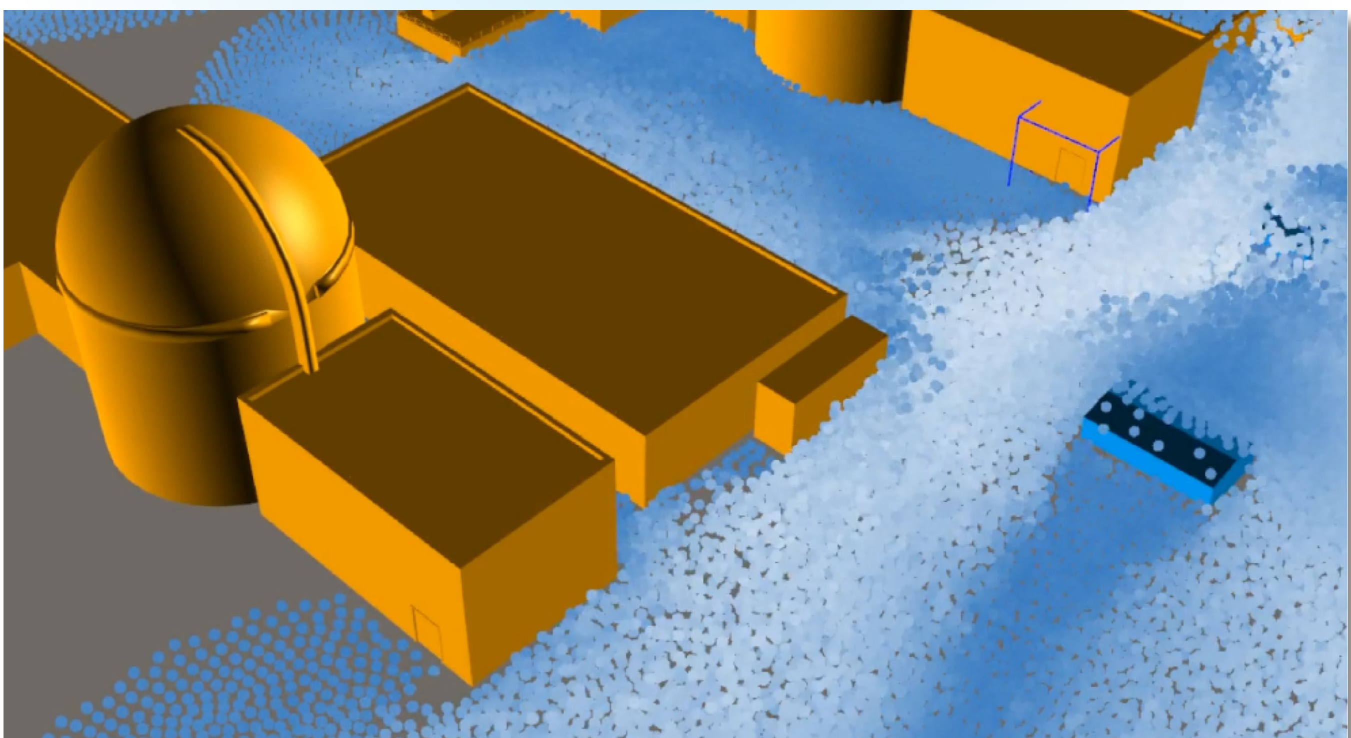
Yong-Joon Choi and Jun Soo Yoo
Risk-Informed Systems Analysis Pathway

Validation status assessment of flooding analysis tool NEUTRINO

The NEUTRINO [1] tool is a general-purpose simulation and visualization computational fluid dynamics code that uses a smoothed particle hydrodynamics (SPH) mesh-free, particle-based solver. SPH has the advantage of accurate visualization and, along with component fragility experiments, has been used in various RISA Pathway flooding hazard analysis programs [2], as observed in Figure 1.

The validation status assessment of NEUTRINO focused on examining the simulation capability for flooding hazards analysis and identifying the need for improvements. In order to assess simulation capability, the applicable nuclear power plant flooding hazard scenarios were investigated based on the: hazard source; hazard mode; associated physics; regulatory/industry concerns; and potentially impacted system, structure, and components (SSCs) of the nuclear power

Figure 1. Example of high-fidelity flood representation at a site-level resolution.



plant. The investigated flooding hazard phenomena were re-categorized into three hazard types: (1) water rising; (2) pressure and wave; and (3) debris migration and related physical phenomena.

The degree of importance for each flooding-related phenomena was then ranked by the Phenomena Identification and Ranking Technique (PIRT) [3]. Developed by the U.S. Nuclear Regulatory Commission (NRC), the PIRT method has been used in the nuclear industry to help in determining the priority of relevant physical phenomena for nuclear reactor regulations and safety analysis. Extension of the PIRT method allows identifying and prioritizing research needs, and supports cost-effective experiments and simulations. A three-level scale was used for phenomena importance ranking:

- High: Dominant impactful phenomena. Requires high accuracy experiments and modeling.
- Medium: Moderate impactful phenomena. Requires medium accuracy experiments and modeling.
- Low: Small or no impactful phenomena. Exhibits a basic level of experiment or modeling.

Table 1 shows the assessment results for the importance ranking exercise, as well as the NEUTRINO code

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Table 1. Ranking of importance and NEUTRINO code development status for flooding hazard analysis.

Hazard Type	Major Phenomena	Importance	NEUTRINO Code	
			Capability	Validation
Water rising	Water level / wetting area – most common in flooding scenarios and gives significant consequences, such as SSC failure, during a flooding event.	High	High	High
Pressure and wave	Velocity profile (wave propagation and dissipation) – Improvement is needed for artificial compressibility test and viscosity formulation. The code uses an advanced numerical model to avoid the particle size influence during simulations.	High	High	High
	Vortex (turbulence) – Since the flooding hazard is dominated by large-scale flow, the importance of vortex is relatively low.	Low	Medium	Medium
	Fluid-solid impact (impact forces, spray) – Despite a continuous effort to improve numerical models for accurate simulations, experiment and validation activities are limited.	High	Medium	Low
Debris migration	Buoyancy – The code has a good ability to simulate the effect and is highly validated through floating scenarios and the falling of solids in water.	Medium	High	High
	Fluid-solid interaction (debris travelling) – The code has a medium level of simulation capability and the validation status is insufficient.	High	Medium	Low
	Solid-solid interaction (collision, force impact) – The code shows low capability in this area and no direct validation has been performed.	High	Low	Low

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development status for flooding hazard analysis. The major phenomena considered are identified as critical areas that a flooding analysis tool should have for a demonstrated simulation capability.

As evaluated, the NEUTRINO code has good capabilities for the visualization of fluid movement and water buoyancy. However, in order to use it in risk-informed analysis in nuclear power plant accident scenarios, additional validation activity may be needed for fluid-solid impact and fluid-fluid/-solid interaction phenomena, which can contribute to safety impacts to nuclear power plants during flooding hazard events. Potential future applications of NEUTRINO that would include these specific phenomena may need to perform validation to understand the limits of the software. However, other phenomena representation appears to be at a medium- to high-level of modeling maturity.

References

1. http://www.neutrinodynamics.com.
2. C. Smith, et al., Risk-Informed External Hazards Analysis for Seismic and Flooding Phenomena for a Generic PWR, INL/EXT-17-42666, 2017.
3. D.J. Diamond, Experience using Phenomena Identification and Ranking Technique (PIRT) for Nuclear Analysis, Brookhaven National Laboratory, 2006.