# open-sourcing safety, risk, and reliability tools

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The United States nuclear industry is facing a strong challenge to ensure maximum safety while enhancing economic benefit. In this respect, the Light Water Reactor Sustainability (LWRS) Program at the Idaho National Laboratory (INL) has been promoting a wide range of research and development in this field to maximize the safety, economics, and performance of these nuclear power plants (NPPs) through improved scientific understanding. One of the best practices to achieve this goal is to identify and optimize safety margin, which can in turn lead to cost reduction. To do this, under the LWRS framework, the Risk-Informed Systems Analysis (RISA) Pathway focuses on the optimization of safety margin and minimization of uncertainties to ensure both safety and economics at the highest level.

The main purpose of the RISA Pathway is to support the U.S. nuclear industry with the aim to improve economics, reliability, and sustain safety of current NPPs over periods of extended plant operations. The goals of the RISA Pathway are twofold: (1) deploy the risk-informed tools and methods that enable better representation of safety margins and factors that contribute to cost and safety; and (2) conduct advanced risk-assessment applications with industry to support margin management strategies that enable more cost-effective plant operation.

The goal of this document is to present the development of several software tools designed to perform safety, risk and reliability analysis of power plants that are currently under development and being used for RISA applications. These tools are summarized in Table 1.

TABLE 1. Summary of LWRS-RISA developed tools.

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| **Name** | **Use cases** | **Repository** | **License** |
| RAVEN | * Model optimization * Uncertainty propagation * Data Analysis | <https://github.com/idaholab/raven> | Open-source (Apache-2) |
| SR2ML | * Component reliability models * Margin based solver * Equipment reliability data analysis methods | <https://github.com/idaholab/sr2ml> | Open-source (Apache-2) |
| LOGOS | * Project prioritization * Project scheduling | <https://github.com/idaholab/logos> | Open-source (Apache-2) |
| EMRALD | * Graphical user interface for model creation * Event-driven risk and reliability simulation | <https://github.com/inl-labtrack/EMRALD> | MIT License |
| VERT | * LWR generation and probabilistic risk assessment models * LWR PRA models | <https://hpcgitlab.inl.gov/mandd/vert> | Release through NDA (to be released open source soon) |

RAVEN is a software framework that is designed to perform parametric and stochastic analyses based on the response of complex systems codes. It can communicate directly with the system codes described above, which are currently used to perform plant safety analyses. The provided Application Programming Interfaces allow RAVEN to interact with any code if all the parameters that need to be perturbed are accessible by input files or via python interfaces. RAVEN is capable of investigating system response and exploring input spaces using various sampling schemes, such as Monte Carlo, grid, or Latin hypercube. However, RAVEN’s strength lies in its system feature discovery capabilities such as constructing limit surfaces, separating regions of the input space leading to system failure, and using dynamic supervised learning techniques.

The Safety, Risk, Reliability Model Library (SR2ML) is a software package that contains a set of reliability models designed to be interfaced with the INL developed RAVEN code. These models can be employed to perform both static and dynamic system risk analysis and determine risk importance of specific elements of the considered system. Two classes of reliability models have been developed; the first class includes all classical reliability models (fault trees, event trees, Markov models and reliability block diagrams) which have been extended to deal not only with Boolean logic values but also time dependent values. The second class includes several component ageing models. Models included in these two classes are designed to be included in a RAVEN ensemble model to perform time dependent system reliability analysis (e.g., dynamic analysis). Similarly, these models can be interfaced with system analysis codes within RAVEN to determine failure time of systems and evaluate accident progression (static analysis).

LOGOS contains a set of discrete optimization models that can be employed for capital budgeting optimization problems. LOGOS integrates economic and reliability risk in a single analysis framework. More specifically, provided SSC health information (e.g., failure rate or failure probability), operational and maintenance costs, replacement costs, cost associated with component failure, and plant budget constraints, LOGOS provides the optimal set of projects (e.g., SSC replacement or refurbishment) that maximizes profit and satisfies the provided requirements. The input data listed above can be either deterministic or stochastic in nature, i.e., they can be point values or probability distribution functions. In the latter case, several scenarios are generated by sampling of the provided distributions. The developed models are based on different versions of the knapsack optimization problem. Two main classes of optimization models have been initially developed: deterministic and stochastic. Stochastic optimization models evolve deterministic models by explicitly considering data uncertainties (associated to constraints or item cost and reward). These models can be employed as standalone models or interfaced with the INL developed RAVEN code to propagate data uncertainties and analyse the generated data (i.e., sensitivity analysis).

EMRALD is a state-based discrete event simulation tool that can calculate system failure probabilities, couple multiple simulations, and perform dynamic PRA. A key part of the EMRALD tool is to develop an object-oriented model that is flexible enough to support the varied dynamic simulation models (e.g., fails to operate, fails on demand). By having a state-based approach, it can integrate different hazards into a single comprehensive model. For example, a single model can include fire-, flooding-, transient-, and seismic-initiating events. Each of these events becomes a trigger into the state-based approach that tells the model to make a transition based upon the specific initiator. A graphical user interface is available to create complex, nested-types models.

Generation Risk Assessment (GRA) is a systematic method for prioritizing SSCs based on the estimated impact on the loss of future electricity generation. GRA is a useful tool in supporting equipment reliability (ER) programs, but construction of the models is time consuming and costly. The Versatile Economic Risk Tool (VERT) eliminates the time and costs associated with developing the GRA model. VERT quickly and effectively evaluates the economic risk that systems and sub-systems impose on NPPs. ER programs coupled with VERT can improve operational performance. Knowing what systems and sub-systems contribute the most to derates at NPPs can give valuable insight to maintenance and inspection activities. Improvement of NPP operational performance also can directly result in safety improvements and reduced risks. Understanding the degradation of systems, structures, and components has become vital for establishing long active periods of NPP operation. Several programs, including the proactive management of materials degradation program developed by the NRC, have been undertaken to address the SSC degradation. VERT introduces time-dependent capabilities into GRA modelling. VERT can directly use the knowledge gained from degradation programs to provide time-dependent analysis of component economic risks.

References

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