LWRS
LIGHT WATER REACTOR SUSTAINABILITY

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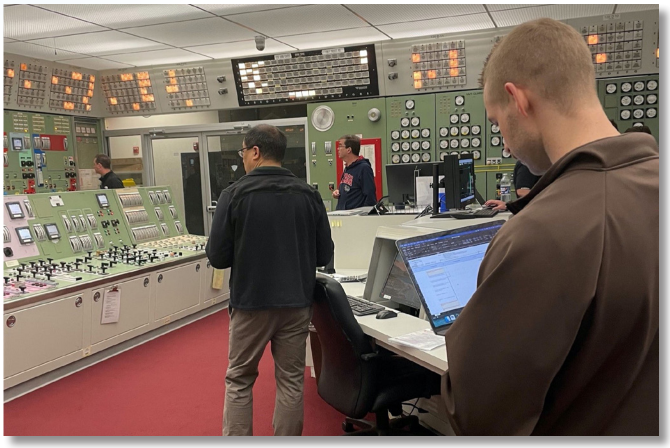
LWRS Program Research Supports License Amendment Request for Digital Upgrade

Light Water Reactor Sustainability (LWRS) Program researchers are working with Constellation Energy to adapt the application of NUREG-0711, "Human Factors Engineering (HFE) Program Review Model," to support the timely implementation of safety-related digital instrumentation and control upgrades at United States (U.S.) nuclear power plants. Four HFE reports were produced in collaboration with Constellation, Westinghouse, and Sargent & Lundy to support such an upgrade at Constellation's Limerick Generating Station. The reports address 1) HFE Program Planning and Management, 2) Operating Experience Review, 3) Function Analysis & Allocation and Task Analysis, and 4) Human-System Interface (HSI) Style Guide. These LWRS Program reports were provided to the U.S. Nuclear Regulatory Commission (NRC) by Constellation Energy in support of the Limerick digital upgrade License Amendment Request that was submitted to the NRC on September 26, 2022.

Follow-on HSI design and validation activities will be facilitated by the LWRS Program in late 2022 and 2023 to support a planned implementation at Limerick in 2024.

The Department of Energy is providing $50 million in a cost-sharing project with Constellation Energy to digitalize the control room at the company's Limerick nuclear power plant.



INL Human Factors Engineers Assessing Limerick Generating Station Main Control Room Operations to Support Design Changes

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U.S. DEPARTMENT OF ENERGY

Advanced Sensor Fusion Combined with Intruder Deliberate Motion Analytics

John L. Russell
Physical Security Pathway

Goals of LWRS Program's Physical Security R&D activities are to develop and deploy advanced technologies and provide the technical basis for optimizing physical security performance and reduce costs at nuclear power plants. One area of research includes sensor fusion linked with Deliberate Motion Analytics (DMA) which can take input from multiple sensors of different types, analyze the data, and determine if an adversary is approaching a facility. Sites using current commercial sensor technologies experience nuisance alarm rates (NAR) not caused by an intruder. Maintaining a low NAR while being able to detect intruders has the potential to decrease the cost of security at a nuclear power plant.

Figure 1 is a screenshot from radar during a 10-minute light rain shower, showing approximately 100 nuisance alarms. The high NAR makes it difficult for the security operator to identify a real intruder. One solution to reducing high NAR is to use DMA, the expected results are shown in Figure 2.

In collaboration with Management Sciences, Inc., LWRS Program researchers at Sandia National Laboratories have developed a sensor algorithm that uses deliberate motion to differentiate alarms caused by an intruder from those caused by other natural occurrences. DMA is capable of fusing multiple, complementary sensors, such as radar, Light Detection and Ranging (LiDAR) and video, to provide reliable detection. DMA allows elevated detection sensitivity to be set, enabling detection of stealthy intruders, but only declaring an alarm when deliberate motion toward a site is indicated. This technology will enable new security architectures and is estimated to reduce perimeter intrusion detection costs by 40%.

DMA is a multiple intelligence fusion algorithm for intrusion detection and tracking using a distributed, multi-layer tracking and classification algorithm. DMA's motion pattern recognition algorithms have demonstrated the ability to identify potential intruders inside and outside the perimeter intrusion detection system, successfully issuing alarms against positive tracks while filtering out background noise and non-threatening tracks from weather, foliage, and background traffic. When DMA determines a track to be a threat, an alarm is communicated using the standard dry contact switch, a typical alarm indication for commercial-off-the-shelf monitoring systems, making it easy to integrate with existing alarm monitoring systems. A bi-spectral pan-tilt-zoom camera slews to the DMA alarm location, thereby providing an image of the intruder to the alarm monitoring officer day or night negating the need for perimeter lighting.

Figure 1. Nuisance alarms generated during a light rain shower.

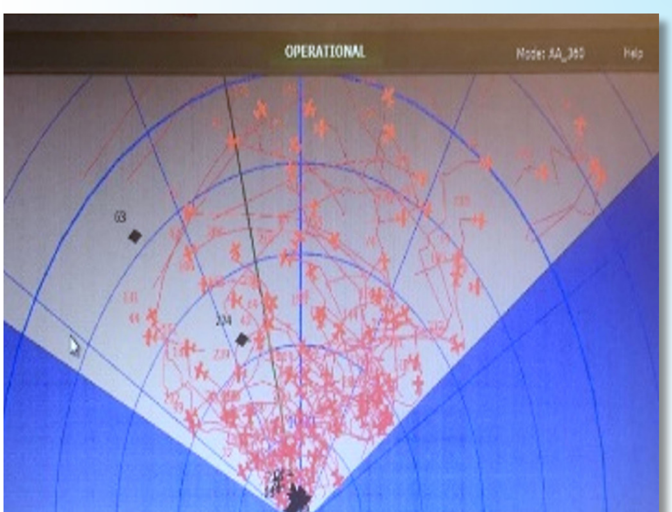
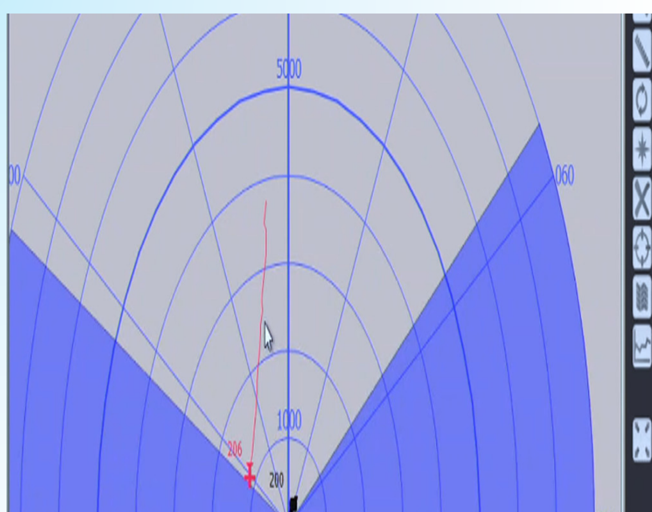


Figure 2. Expected results from DMA.



DMA's performance is based on its ability to recognize background noise and perform motion behavior analysis to focus and filter alarm indications from multiple sensors, such as filtering through the high NAR generated by video analytics scanning a grass field during windy conditions. DMA applies motion behavior analytics by aggregating the alarm position, track trajectory, and velocity of potential intruders as reported by multiple sensor hits. DMA exploits the concept of complementary sensor phenomenology, allowing the fusion of multiple complementary sensors whose strengths augment the weaknesses of another. Specifically, it combines sensor inputs in a way that allows sensors to augment physics-based limitations (e.g., an imager looking into the sun will not detect an intruder, but a radar will).

The two figures below show real-time DMA fusion of radar and thermal radar examples at a testbed at Sandia's Sensor Test and Evaluation Center. Figure 3 shows numerous raw radar hits (blue dots) and raw thermal radar hits (yellow dots) inside and outside a typical two-fence perimeter design. In this scenario, DMA does not declare an alarm, designated by the "No Alarm" indicator in the green circle. Figure 4 shows DMA declaring an alarm when quality tracks are formed by both radar and thermal radar and shows deliberate motion toward the secure side of the perimeter, designated by the dual-track and the "Alarm" indicator in the red circle. DMA algorithm decides when to fuse data from all sensors or only use alarm data from a specific sensor, enabling it to be much more adaptive and effective in noisy environments.

DMA is designed to be sensor agnostic, meaning it should be able to fuse sensor outputs from emerging and traditional intrusion detection sensors, including radar, LiDAR, thermal radar, video, microwaves, and buried line sensors. To date, the following sensors have been fused using DMA: radar and video analytics from cameras and thermal imagers; radar and thermal radar, and video analytics and a buried line sensor.

Test data collected to date include:

- Testing inside a traditional two-fence perimeter, fusing radar and video analytics over a period of six months yielded one nuisance alarm. DMA fused sensor system met U.S. DOE detection requirements.
- Testing beyond the fence in un-engineered terrain with 3 ft. changes in elevation and native foliage in a high desert environment yielded no nuisance alarms for 28 hours, where an estimated 160,000 raw sensor alarms were generated. DMA fused sensor system met DOE detection requirements. These are preliminary results due to the relatively short NAR collection period.

More nuisance alarm data should be collected in different environments before conclusively demonstrating DMA's capabilities. Current plans are to test DMA fused sensor systems during the winter at a northern state's nuclear power plant site and during the summer in a southern state's nuclear power plant site. The application of DMA and sensor fusion into LWR physical security strategies represents and enabling technology that will reduce nuisance and false alarms with high levels of detection performance, enabling optimized physical security designs and significant reduction of security costs.

Figure 3. DMA shows "No Alarm."

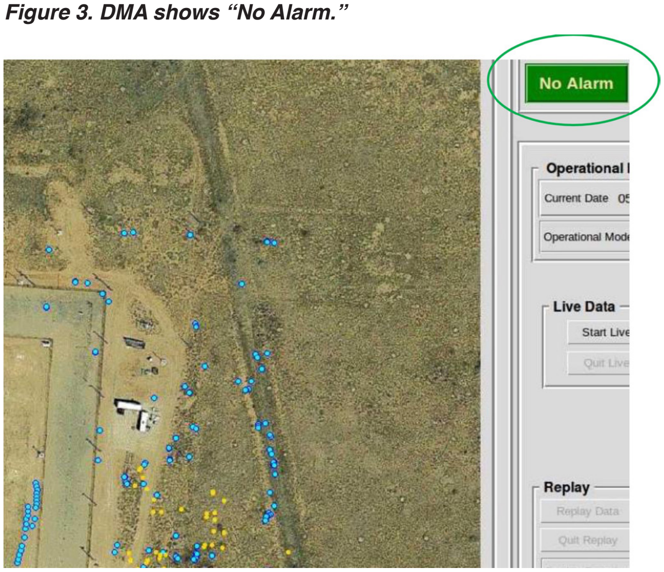


Figure 4. DMA shows "Alarm."

An Artificial Intelligence-driven MIRACLE for Condition Reports Screening and Processing

Ahmad Y. Al Rashdan, Brian M. Wilcken, Kellen M. Giraud
Plant Modernization and Risk-Informed Systems Analysis

In the nuclear power industry, issues are documented in a condition report. Experienced staff members routinely spend tens of hours every week reviewing condition reports. The initial review process of reports typically involves five to 10 people reading each condition report, assessing its impact and priority, and deciding what actions need to be taken and by whom. Once that is done, the reports are categorized to keep track of common issues in the plant. For significant issues, multiple detailed follow-up meetings and evaluations are performed.

This process costs the United States (U.S.) nuclear power industry hundreds of millions dollars every year. In addition to all the time it consumes, the manual and subjective nature of the process means that there is always a chance for an issue to be overlooked or underestimated, or for a decision to be made in error.

What is MIRACLE?

Machine Intelligence for Review and Analysis of Condition Logs and Entries (MIRACLE) is an artificial intelligence (AI) tool that automates condition report handling, as observed in Figure 5. MIRACLE reads through tens to hundreds of table fields, including free-form fields, sifting through text, and evaluating it against what it learned from the training sets, as also can be seen in Figure 5. It rapidly performs multiple functions in a split-second that are typically performed by plant staff.

MIRACLE is based on advanced natural language processors and a combination of multiple custom-designed AI neural networks that classify items and replicate human decisions. MIRACLE has two core capabilities. It can classify condition reports in order of importance, safety significance, etc. This is usually based on training MIRACLE with a dataset that includes those in the form of labels for it to learn and replicate the process. MIRACLE can also perform unsupervised machine learning (ML) (i.e., learn without 'labels'). It creates topic clusters (i.e., group of correlated words related to each topic) from training sets generated from nuclear power plants across the U.S. MIRACLE creates a nuclear dictionary of all the possible topics that can be assigned to a condition report. Those topics can be tagged by ML to each condition report. For example, if the free-form text in a condition report describes liquid material that looks like oil found near a pump, MIRACLE can assign one or more topics (e.g., 'leakage') to it. Even though leakage may not be explicitly mentioned in other reports, because of its ability to understand context, MIRACLE automatically assigns this 'leakage' topic, along with other topics, to all reports that contain similar related issues. From this, it can sort incidents into specific event classifications that are used holistically to track a plant's condition.

How is MIRACLE Different than Other Condition Reports Screening Tools?

Diverse Data Set: MIRACLE draws on data in condition reports collected from more than 25% of the nuclear reactors across the U.S., which potentially makes it a powerful tool in terms of accuracy and performance. This sheer mass of information gives MIRACLE unique functionalities, leveraging the data diversity to create scalable and easily transferable capabilities. A recent test of MIRACLE using data from two utilities proved significantly more accurate than using data from a single utility.

Topic Dictionary: MIRACLE has created a topic dictionary for nuclear power plants, that intelligently and automatically assign topics to condition reports. Data gathered from industry was used to create more than 100 categories of topics (e.g., badging, breakers, valves) that represent everything that can happen in a nuclear power plant. By this process, MIRACLE is consistent and systematic in assigning topics, which is a key requirement to making them useful in tracking performance.

Performance Tracking: The current industry approach is based on a simple search or filter rule and manual logging of specific occurrences of events to create a trend that is time-consuming and limited. This approach is susceptible to missing or extraneous, irrelevant events. Through MIRACLE, topics are automatically assigned to every condition report. Staff can track how many times an issue occurs in a defined amount of time and trend it. If issues are on the rise at different operators' plants—or across the industry—this will help to direct attention to issues.

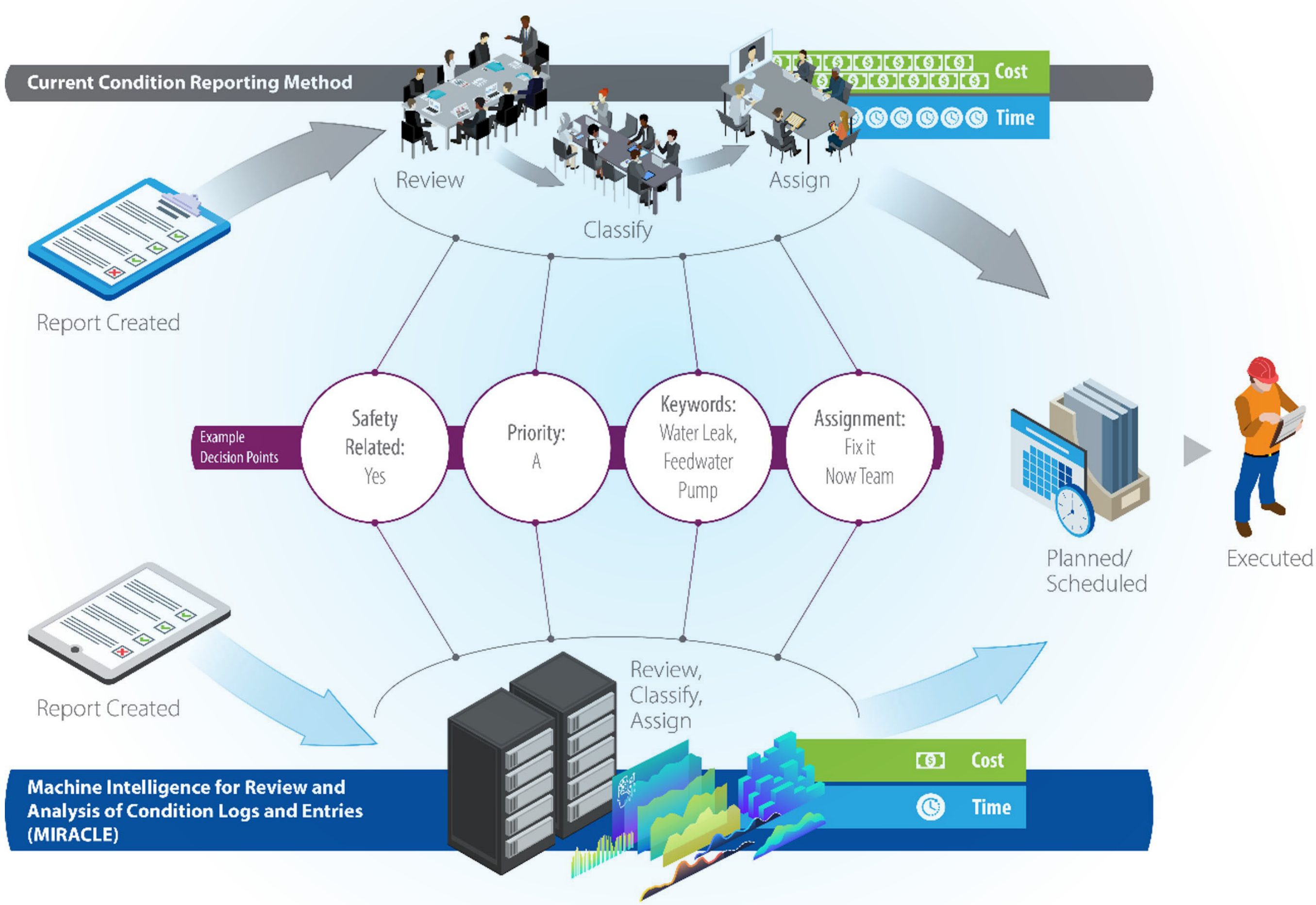
Flexibility: MIRACLE offers a flexible model that can work with any type of plant data with minimal effort required for data preparation. Without such data flexibility, each time a user applies AI or ML they would need to prepare data to supply it to the specific model. This makes MIRACLE easy to deploy, a key objective of its design.

Sparse Events: MIRACLE's use of industry-wide data overcomes specific plant data limitations or coding errors. This is important for events. For example, a 'safety condition adverse to quality' is a very important event, but rarely occurs at most plants. Because it is such a rare event, it is nearly impossible to train an ML tool to reliably detect one. When data are combined across multiple utilities, however, MIRACLE may gain enough occurrences to train to classify such events accurately.

Conclusion

MIRACLE improves nuclear safety and reduces operating and maintenance costs by making systematic decisions. It can help plants reduce errors and eliminate significant time, paperwork, and meetings. By drastically reducing the hours each worker must spend reviewing and processing condition reports at nuclear plants, and by speeding up the time problems are identified and addressed, providing a broader perspective on plant and industry performance, MIRACLE offers a way for plant owners to improve efficiency and safety.

Figure 5. MIRACLE replaces significant review time, paperwork, and meetings performed by the humans within the overall work management process of a nuclear power plant.



Human-Centered Design of Systems to Enable Integrated Operations for Nuclear

Larry J. Hettinger, PhD
Lawrence J. Hettinger PhD, LLC,

Jeffrey C. Joe
Plant Modernization Pathway

One objective of the LWRS Program is to develop innovative technical and organizational approaches to promote the sustainability of nuclear energy as an economically viable source of clean energy. In support of this objective, the concept of Integrated Operations for Nuclear (ION) is an initiative being pursued in conjunction with the nuclear industry to develop effective, integrated technical and organizational solutions to emerging socio-economic challenges in the industry.

The nuclear power industry is looking for ways to take advantage of current and emerging technologies to reduce operations and maintenance (O&M) costs while maintaining or improving safety and performance. These technologies (e.g., AI, robotics, augmented reality) will significantly reduce the O&M costs associated with many tasks at nuclear power plants. The introduction of new and emerging technologies must be done systematically within the context of organizational systems. Changes in technology and related changes in organizational structure and performance are inextricably intertwined. The goal of ION is to help manage this process in an efficient, scientifically valid manner.

Partnering with the industry is an important means of grounding scientific research in the realities of existing and planned systems. During 2021, LWRS Program researchers, at Idaho National Laboratory, collaborated with Xcel Energy on the design and selection of advanced technologies to support two separate sociotechnical areas of concern. These included: (1) the design of a set of prototype human-computer interface displays to support the reduction of human workload associated with the preparation, conduct, and follow-up of management review meetings; and (2) the identification of potential commercial-off-the-shelf (COTS) systems to support the safe and effective performance of maintenance activities, particularly those taking place within irradiated spaces.

As seen in Figure 6, each of these efforts, or use-cases, involved the application of analysis and design approaches focused on the joint optimization of safety, efficiency, and effectiveness across people, technology, processes, and governance through knowledge representation, knowledge elicitation, and cross-functional integration. Generally referred to as 'sociotechnical' methods, these techniques incorporate the design principles summarized above through an emphasis on user-centered design and the application of a set of analytic tools derived from systems engineering, human factors engineering, cognitive engineering, and other related domains. Each use case provided the opportunity to assess the effectiveness of sociotechnical methods in helping to establish and achieve nuclear power plant design objectives, while also assisting Xcel Energy in achieving its own design and cost-savings objectives.

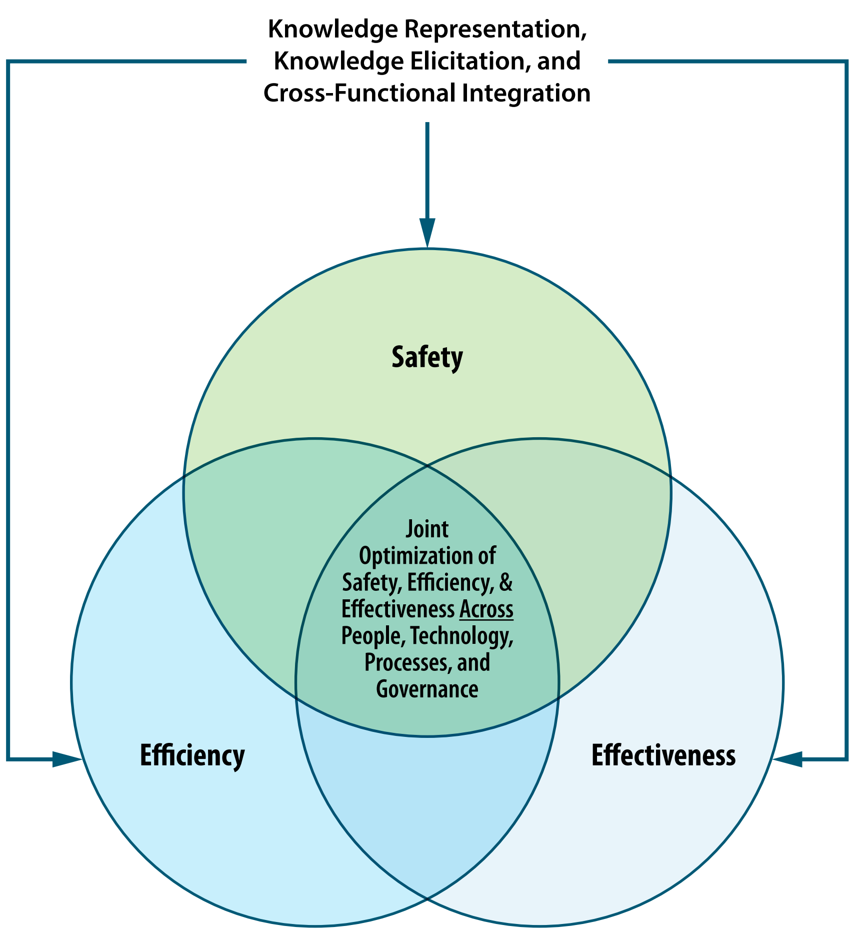
There were two common themes underlying each use case. This first concerned the team's focus on the sociotechnical implications of introducing novel technologies into current and future organizational systems, while the second emphasized the importance of user-centered design. Sociotechnical concerns primarily involve accounting for the impact of new technologies on the structure and function of existing and future organizational structures, with the goal of developing both in a coordinated, synchronous manner. User-centered design is an approach to the design of these novel technologies that emphasizes the importance of including representative end-users in all stages of system development and integration. Now commonly used in industry and government, user-centered design helps to reduce risks associated with problems such as attempting to introduce technical systems that do not address user needs, do not support performance objectives, and/or are poorly usable.

In the first use case, the LWRS Program, Xcel team collaborated on the design of a set of prototype human-computer interfaces intended to facilitate management-level communications, decision-making, and other activities. The specific problem area the team selected involved reducing the amount of human workload associated with management review meetings, while improving related efficiencies and performance. The amount of human workload that goes into preparing for, conducting, and following up on actions from management review meetings can be enormous, typically regarding data collection, reduction, analysis, preparation and presentation of the findings, and assignment and tracking of the actions. Given that no acceptable COTS systems currently exist supporting these goals, the team focused on developing a novel system of its own. These efforts resulted in a set of prototype human-computer interfaces whose development will continue throughout 2022, culminating in a proof-of-concept assessment and requirements documentation.

The second use case focused on the identification of current and emerging COTS technologies whose integration with maintenance activities, particularly those in irradiated spaces, could help reduce O&M costs while enhancing overall safety and performance. COTS solutions were examined in this use case because of their increasing, successful use in other current industrial settings. Following a detailed analysis of current technical, personnel, and procedural requirements, the team identified specific sets of tasks that might benefit most from the integration of technologies such as robots, drones, virtual and augmented reality, wear sensors, and computers. This was followed up by discussions with vendors of systems of these types to gain further specificity on their performance characteristics and suitability for supporting the desired tasks. These efforts culminated in the team's presentation in 2022 to Xcel leadership of existing and emerging systems that could potentially support their economic and performance goals.

The overall process and its outcomes were well received by Xcel Energy, which demonstrated the utility of sociotechnical methods in nuclear power plant systems design efforts. Further details can be found in the report, titled, Nuclear Work Function Innovation Tool Set Development for Performance Improvement and Human Systems Integration, INL/EXT-21-64428. The LWRS Program looks forward to continuing this partnership and generating useful findings and approaches for the industry.

Figure 6. Joint optimization of safety, efficiency, and effectiveness through knowledge representation, knowledge elicitation, and cross-functional integration.



Initial Experience with the ARENA Cable/Motor Test Bed



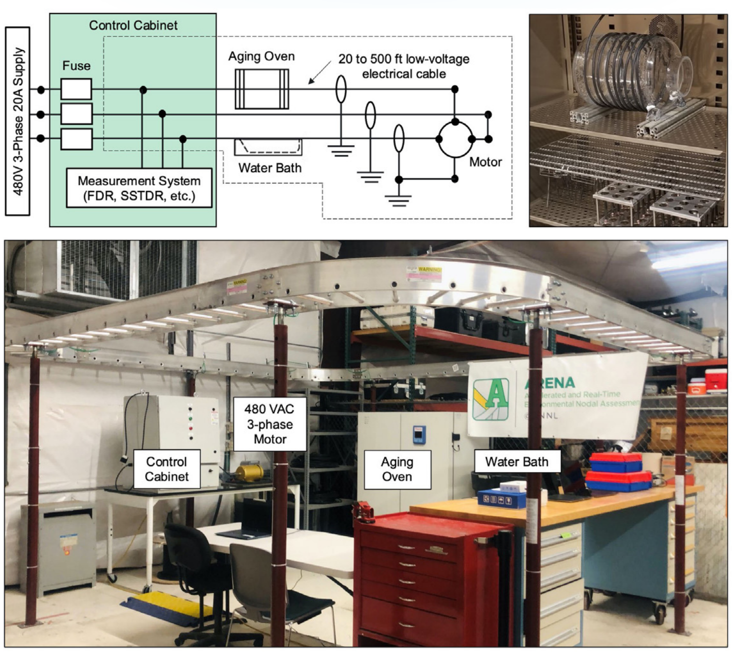

S.W. (Bill) Glass, Leo S. Fifield, Mychal P. Spencer, Aishwarya Sriraman
Materials Research Pathway

Degradation of installed electrical cables within nuclear power plants is known to occur as a function of age and operating environment. With more than 1,000 km of power, control, and instrumentation cables typically found in nuclear power plants, complete cable replacement is a severe cost burden. To reduce this cost, methods are needed to nondestructively assess degradation of cable materials. Pacific Northwest National Laboratory (PNNL) is advancing the science of nondestructive cable inspection in our Accelerated Real-Time Environmental Nodal Assessment (ARENA) cable /motor test bed [1]. The ARENA test bed consists of a 480 VAC 3-phase cable and motor system powered through a control cabinet, as shown in Figure 7, which allows damaged and degraded components to operate without challenging the utility supply. It readily supports various online, live-wire, and offline nondestructive examination (NDE) tests to detect and evaluate component damage as well. The ARENA test bed includes a large oven for accelerated thermal aging, a water trough for water exposure, elevated cable trays for supporting lengths of cable that can be undisturbed for extended test durations, and the possibility to introduce phase to phase or ground-faults at various locations between the supply and the motor load. The ARENA test bed is supplemented by an extensive array of standard cable test techniques, plus it has the capability to model and simulate the test arrangement with a finite-element digital twin to improve understanding of the physical measurements.

Initial studies with the ARENA test bed have included assessments of frequency domain reflectometry (FDR) to detect cable exposure to water [2], and more recently, spread-spectrum time domain reflectometry (SSTDR) to assess ground-faults. FDR measurements require the cable to be disconnected from the live source or de-energized, as observed in Figure 8. A broad-band chirp is injected onto one conductor of the cable with a second conductor serving as a reference or ground. Any impedance changes cause a reflection of the chirp that is processed in the frequency domain, and then transformed to the time domain. Since the propagation velocity of the signal is known, the reflection time can be related to the distance along the cable. SSTDR measurements do not require the cable to be disconnected from the live source allowing measurements on energized cables. As with FDR, SSTDR correlates an injected signal with impedance mismatch reflections in the time domain so any detected reflections can be correlated to the distance along the cable based on wave propagation velocity.

One concern for cables in service is whether being dry or immersed in water can damage

Figure 7. ARENA cable and motor test bed for 480 VAC 3-phase systems, including thermal and water aging.



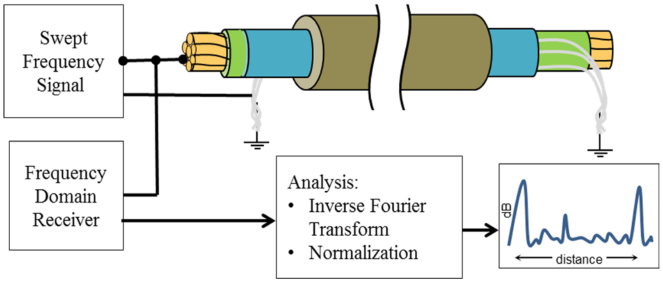


Figure 8. FDR test arrangement. Peaks in the distance response correspond to the time response based on the wave propagation speed in the cable.

the insulation over time. If FDR tests could be extended to determine if and where cables were exposed to moisture, damage could be minimized by selectively drying or lifting the cable above potentially damaging moisture. To assess feasibility of immersion detection, both shielded and unshielded cables were tested for their FDR response with a portion of the cable submerged, as shown in Figure 9, where the presence of water coming into contact with an undamaged and unshielded cable was clearly detected as an FDR peak. This peak was equally detectable with or without a connected motor. The response of the shielded cable to the presence or absence of water was substantially undetectable either with or without the motor connected.

Another concern is the requirement that NDE measurements be taken when the source is offline. Online SSTDR has been shown to detect conductor and insulation damage in rail and aircraft cable systems [3], but has not been extensively explored for nuclear power plants applications. We are exploring the applicability of SSTDR in the ARENA test bed toward nuclear power plants by measuring ground-faults ranging from a complete short circuit to 1k Ω at various lengths along a 100-ft cable. While ground-faults were difficult to detect, they were visible when the baseline signal was subtracted, as shown in Figure 10, thus supporting the usage of this online technique in nuclear power plants. The ARENA cable/motor test bed offers numerous cable test possibilities. Continuing tests with low-voltage FDR and SSTDR for cable faults are planned to expand and address the effect of motors, higher voltage cables, and simulations of test signals in the ARENA cable test configuration.

References

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[2] Glass, S. W., M. P. Spencer, A. Sriraman, L. S. Fifield, and M. S. Prowant. 2021. Nondestructive Evaluation (NDE) of Cable Moisture Exposure using Frequency Domain Reflectometry (FDR). PNNL-31934. PNNL, Richland, WA, USA.

[3] Furse, C., P. Smith, M. Safavi, and C. Lo. 2005. "Feasibility of spread spectrum sensors for location f arcs on live wires." IEEE Sensors Journal 5(6): 1445–1450. doi: 10.1109/JSEN.2005.858900.

Figure 9. (left) With the shielded cable, there is no clear indication of the presence or absence of water. (right) With the unshielded cable, there is a clear indication where the cable goes through the water trough.

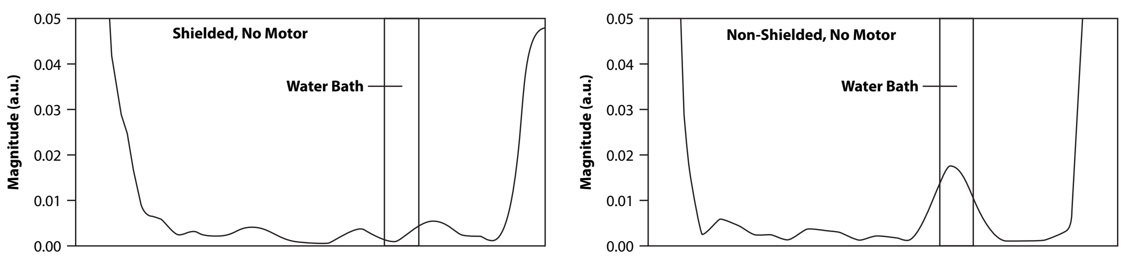
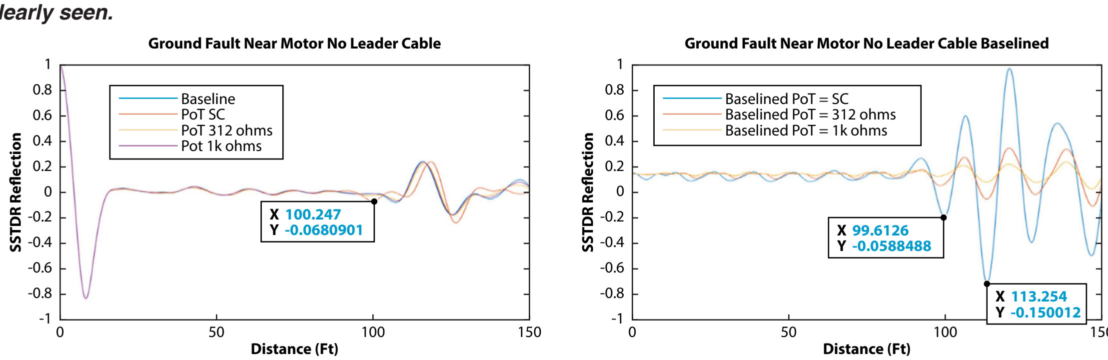


Figure 10. (left) SSTDR raw ground-fault signal where difficult to detect. (right) Baseline-subtracted where clearly seen.



Researchers Model the Economics of Energy Storage



Paul W. Talbot, Dylan J. McDowell, Jason K. Hansen
Flexible Plant Operation and Generation

Energy storage is an important new technology for use in energy systems. Should owners of every electrical utility invest in this technology? It depends on several factors. LWRS Program researchers at Idaho National Laboratory (INL) have developed a simulation model to help decision-makers consider the relevant factors and evaluate energy investment decisions. The model is called HERON which stands for Holistic Energy Resource Optimization Network. In December 2021, researchers released HERON 2.0 which includes an 'energy storage' component.

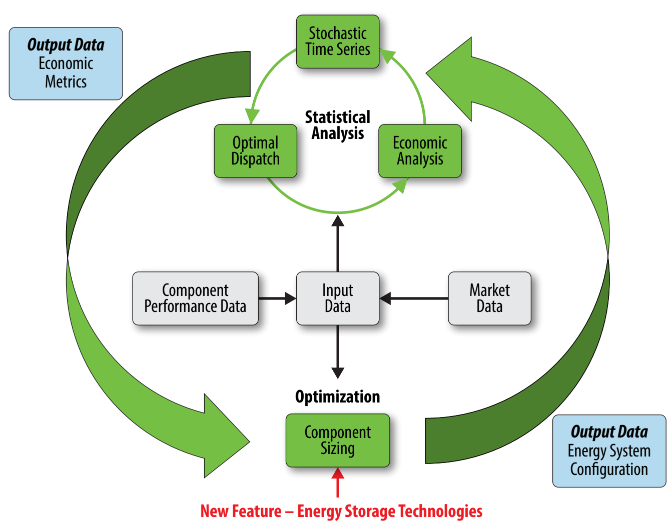
HERON 2.0 is a computational framework that takes input data, optimizes a decision, and then outputs the economic results. The input data includes cost and performance characteristics of system components and pricing data for markets where system products might be sold. An important feature of HERON 2.0 is that it represents uncertainty in pricing data based on known statistical features of the observed pricing data. Then it simulates millions of possible system configurations, looking at alternative sizes for each of the components in the system. The optimization is economic because for each iteration (i.e., possible configuration) in the simulation, the framework records the Net Present Value (NPV) revenues less costs.

Researchers set the model up to run in a comparative fashion. They define a 'with' system that contains the new technology under consideration and a 'without' system that simulates outcomes in the absence of the new technology. HERON 2.0 records the NPV from both cases to obtain what the researchers refer to as the 'Delta NPV,' or the computed profitability difference of the two cases. Figure 11 shows the data flow and analytical workflow that HERON 2.0 follows.

With the energy storage component added, researchers can identify which configuration of energy storage technologies optimizes the economic performance of the system. This feature can be used to answer questions such as, what size should the energy storage system be, how many units should be installed, and others. But most importantly, because HERON 2.0 represents uncertainty in the pricing data, the answers to these questions reflect market risks where the energy system, with storage included, will engage.

The researchers tested out HERON 2.0's new addition on a case study based on the electricity market in New York state (i.e., New York Independent System Operator [NYISO]). This market relies on a portfolio of energy-generating technologies, the mix of which contribute to a level of price volatility the researchers were after. They created a set of cases for analysis based on policy and projected costs of nuclear energy. The policy case reflected a representative clean energy standard and the nuclear costs were modeled under a baseline scenario and a scenario of low-cost nuclear. The modeled energy storage technologies were representative of concepts under development, and for which estimated preliminary cost and performance data were available. Figure 12 shows the stylized energy system the researchers evaluated. Excess heat from the nuclear generator is stored in one of the modeled energy storage technologies. Then later, when electricity prices rise to a level where additional sales improve profitability, the stored heat is converted to electricity for market sale. The energy system also represented battery storage for wind and solar.

Figure 11. HERON Analysis Workflow.



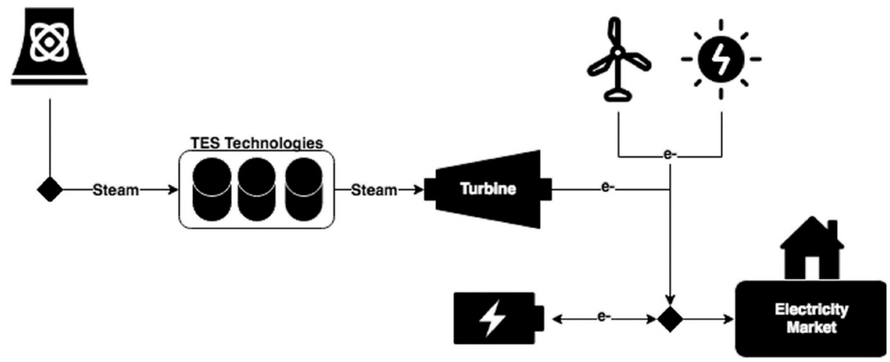


Figure 12. Modeled Energy System in NYISO.

Figure 13 shows an example of the output data from the scenarios evaluated in the report, "A Technical and Economic Assessment of Light Water Reactor Flexible Operation for Generation/Demand Balancing to Optimize Plant Revenue," INL/EXT-21-65443 issued in December 2021. The plots show how the model simulates the build out of a nuclear capacity under an optimized scenario. This occurs because in the example, and under economic optimization, energy storage improves the economic performance of the nuclear reactors. The plot of the economic metric, NPV, shows how the performance changes in the modeling iterations.

Notably, in the scenarios analyzed in this case study, HERON found that building out a larger nuclear and storage capacity was more profitable in scenarios that contained higher energy prices. These high-priced conditions offset the large capital expenditure costs required to construct nuclear and storage facilities. The optimal solution found under this condition indicates the importance of minimizing upfront capital expenditures while maximizing cash flow and revenues. Particularly as the United States heads into an era of rising rates and cost of capital, these metrics will hold more weight in future analyses.

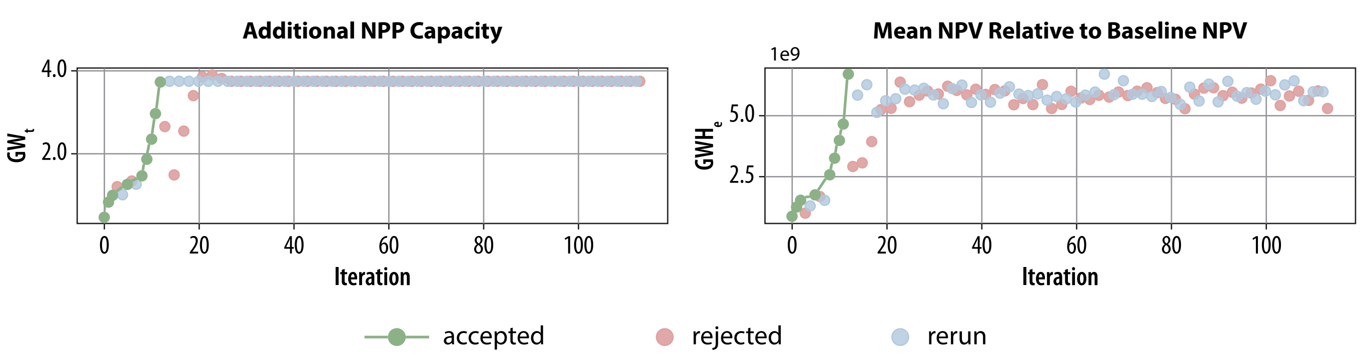
HERON 2.0 simulates the size possibilities of the nuclear facility and the thermal energy storage options. It also can be set up to evaluate additional market opportunities and generation technologies of interest.

In the race to decarbonize the U.S. economy, clean, new energy technologies will be needed in energy systems. Because of the LWRS Program's research on HERON 2.0, decision-makers in the energy systems arena now can evaluate the economic performance of emerging technologies. HERON 2.0 allows for better understanding of how energy storage technologies drive economic outcomes. Those interested in adding energy storage technologies to their systems may want to consider applying HERON 2.0 in their analysis.

Reference

1. Li, B., Talbot, P. W., McDowell, D. J., and Hansen, J. K. (2021). Release a public version of HERON (HERON 2.0) with improved algorithms for the treatment of energy storage (Vol. INL/EXT-21-65473). United States: Idaho National Laboratory.
2. McDowell, D., Wrobel, A., Talbot, P., Frick, K., Bryan, H., Hansen, J.,. Boyer, C. (2021). A Technical and Economic Assessment of LWR Flexible Operation for Generation/ Demand Balancing to Optimize Plant Revenue (INL/EXT-21-65443). United States: Idaho National Laboratory.

Figure 13. Example of Optimization Results.



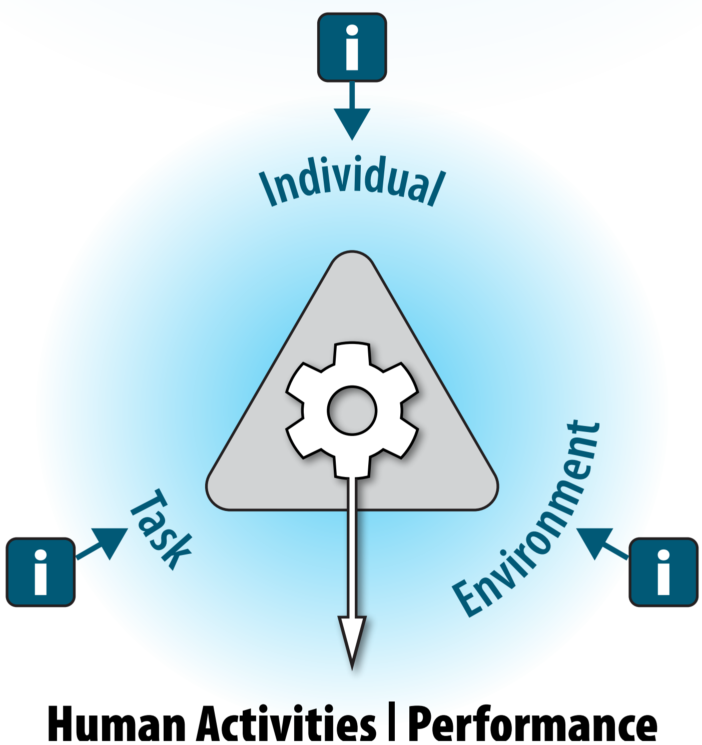
HUNTER: A Digital Operator for Risk Analysis

Ronald L. Boring, Thomas A. Ulrich, Jooyoung Park
Risk-Informed Systems Analysis Pathway

Human reliability analysis (HRA) is the study of human error. HRA is integrated into probabilistic risk assessment (PRA) models at nuclear power plants to consider potential challenges to plant operations. Because plants have multiple levels of defense in depth—from human second checkers to engineered safety systems—the opportunity for an unintended human action to have a significant negative consequence on plant safety is minimal. PRA and HRA together ensure that all hardware and human risks are mitigated during operations.

Since the first HRA method—the Technique for Human Error Rate Prediction (THERP) [1]—HRA methods have been worksheet based. Scenarios of human activities are analyzed, and human error probabilities are calculated using lookup tables and simple quantification approaches. Dozens of HRA methods exist, each tailored to different applications. Many of these techniques have been incorporated into software tools like the widely used Electric Power Research Institute (EPRI) HRA Calculator [2].

Figure 14. Conceptual framework for HUNTER.



The Risk-Informed Systems Analysis (RISA) Pathway within the Light Water Reactor Sustainability (LWRS) program is developing new tools to support industry needs for advanced risk analysis. A new generation of computation-based risk analysis tools draws on advances in simulation to enable more comprehensive risk modeling than has been possible in the past. There are emerging areas of risk analysis not yet fully covered in HRA. For example, plant upgrades like control room modernization introduce new digital instrumentation and control technology. New technologies lack operating experience needed to inform traditional HRA methods.

Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER) was developed under the LWRS Program as an easy-to-use computation based HRA modeling framework to allow enhanced HRA capabilities for plants. It provides the ability to create a digital human model to be used in simulations of plant scenarios. These scenarios can be executed in a repeated Monte Carlo fashion, allowing what-if modeling for novel contexts. For example, the range of human activities involved in deploying FLEX equipment under a variety of situations could be simulated automatically using HUNTER. A similar effort using conventional HRA methods would typically require extensive manual analyses, proving labor and time intensive.

In March 2022, researchers in RISA published the first software release of HUNTER [3]. The HUNTER software features a first-of-a-kind graphical user interface to simplify model development. HUNTER integrates three core modules—task, environment, and individual (see Figure 14) into a simple-to-use interface (see Figure 15).

- The *task* module is based on plant operating procedures. The procedures specify the interface between the plant and operator, coordinating

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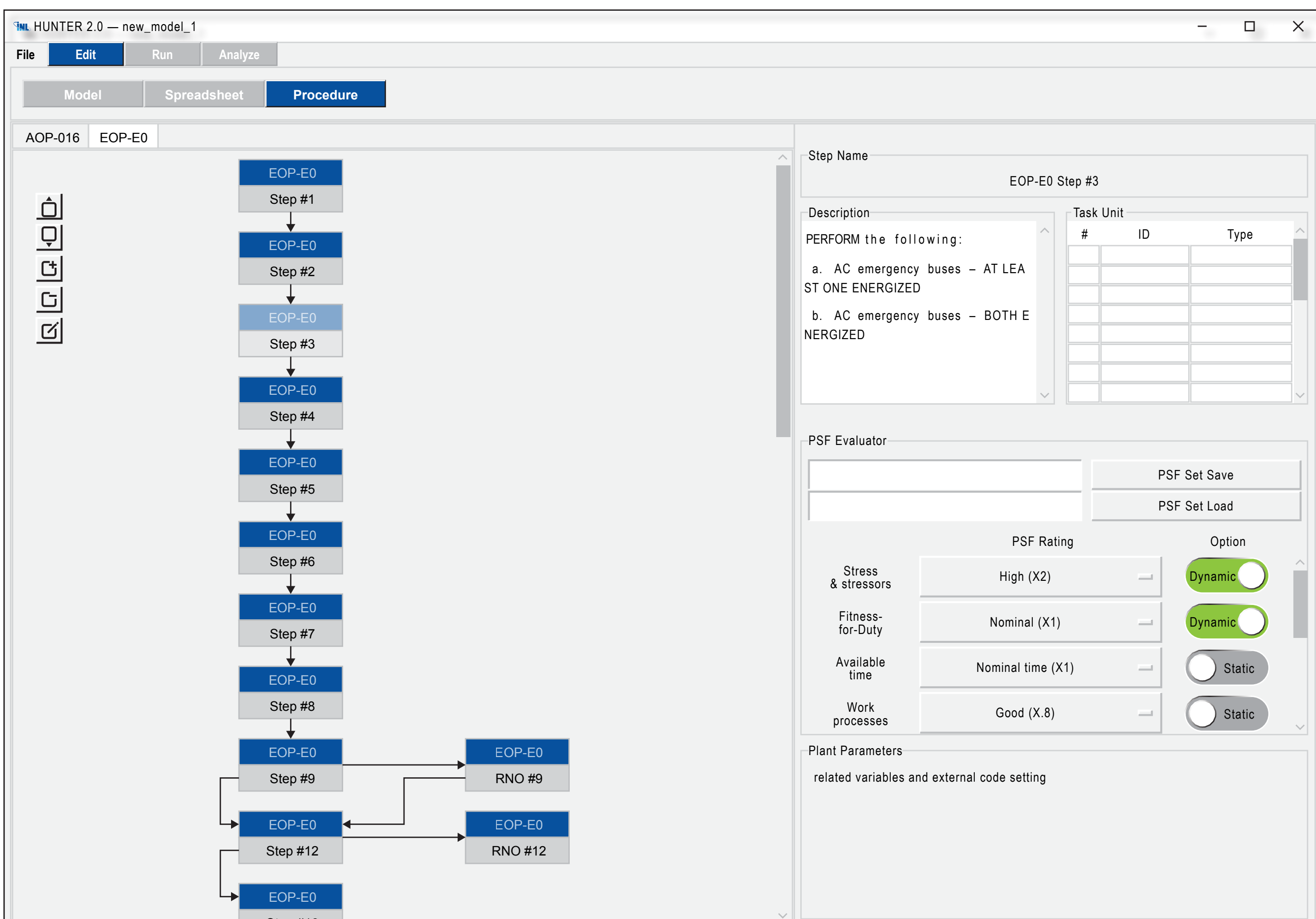

Figure 15. HUNTER procedure editor.

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operator actions and decisions and monitoring inputs from the plant.

- The *environment* module represents the plant simulation. In the initial release, HUNTER coupled with a RELAP5-3D thermal hydraulics model of a three-loop pressurized water reactor. The interface between HUNTER and RELAP5-3D meant that the HUNTER digital operator could virtually take actions on the plant while monitoring plant states.
- The *individual* model accounts for those factors that influence the performance of the digital operator. In HUNTER, performance influences are auto calculated based on distributions from psychological research and from plant parameters. These factors increase or decrease the error rate or time to execute.

Already with the release of the software, HUNTER provides a uniquely accessible entry point into the power of computation-based risk modeling. Next, the HUNTER team will model scenarios that are relevant to emerging risk analyses needs at plants. These demonstrations will be made publicly available to help demonstrate the value of computation based HRA for industry applications.

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1. NUREG/CR-1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," U.S. Nuclear Regulatory Commission, 1983.
2. EPRI 3002022904, "HRA Calculator Version 6.0a," Electric Power Research Institute, 2021.
3. INL/RPT-22-66564, "Software Implementation and Demonstration of the Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER)," Idaho National Laboratory, March 2022.

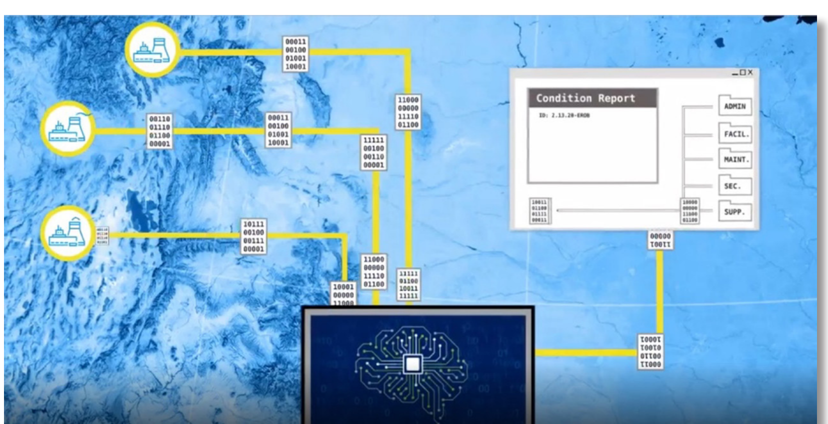
Machine Intelligence for Review and Analysis of Condition Logs and Entries (MIRACLE) awarded a 2022 research and development (R&D) 100 Awards

Celebrating its 60th year, the R&D 100 Awards program is widely considered one of the most prestigious among the R&D community, honoring innovation pioneers and their contributions to science and technology. The R&D 100 Awards recognize some of the most game-changing breakthroughs that have the potential to change how science is done and that make a lasting impact on our everyday lives. The full list of winners may be viewed on R&D World.

In the nuclear power industry, every issue, no matter how small, is documented in a condition report. In each plant, hundreds of these are reviewed and characterized every week by dozens of people. MIRACLE employs machine learning and natural language processing to automate this process, saving millions of dollars while improving safety.

The talented and dedicated LWRS Program researchers that developed this innovative artificial intelligence tool are Ahmad Al Rashdan (principal investigator), Brian Wilcken, Cameron Krome, and Kellen Giraud.

Visit the LWRS Program website (LIGHT WATER REACTOR SUSTAINABILITY PROGRAM - Videos (inl.gov) to view the video on MIRACLE.



LWRS Program Leader Receives American Nuclear Society Special Award

Bruce Hallbert was awarded the American Nuclear Society (ANS) 2022 Special Award for Outstanding Contributions to Retaining the Operations and Lifetime of Zero-Carbon Nuclear Reactors. The ANS Special Award was established in 1962 and topics for the awards have come from the many varied areas of nuclear science and engineering fostered by the Society. This year's award is for 'Outstanding Contributions to Retaining the Operations and Lifetime of Zero Carbon Nuclear Generators.' Bruce received this award for his dedication to the creation and deployment of the DOE's LWRS Program, benefiting the continued operation of U.S. nuclear power plants.

Bruce's focus over the past 12 years has been on initiating and ultimately leading the DOE's LWRS Program.

Bruce's current role is as the Director of the Technical Integration Office for LWRS Program, this position has the responsibility for leading the DOE investment in sustaining the current nuclear power fleet through multiple programmatic areas including risk-informed initiatives, alternative revenue approaches such as hydrogen production, physical security technical approaches, materials research for long-term operation, and plant modernization via digitization and enhancement to work processes. The budget for these types of applications and deployment opportunities has grown to $50 million per year under Bruce's leadership.

Dr. H. M. "Hash" Hashemian presenting the award to Bruce Hallbert at the 2022 ANS Meeting.

Recent LWRS Program Reports

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Flexible Plant Operations & Generation

- *Plan for Scaling Up Hydrogen Production with Nuclear Power Plants, INL/RPT-22-68155.*

Risk-Informed Systems Analysis

- *An Integrated Framework for Risk Assessment of High Safety-significant Safety-related Digital Instrumentation and Control Systems in Nuclear Power Plants: Methodology and Demonstration*
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- *Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER) Demonstration: Part 1, Empirical Data Collection of Operational Scenarios*

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To submit information or suggestions, contact
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