Advanced Physics-Based Fluid System Performance Monitoring to Support Nuclear Power Plant Operations

Final CRADA Report

Nuclear Science and Engineering Division

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prepared by
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Participants: LPI Inc.

August 31, 2021

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Non Proprietary Final CRADA Report

For the Office of Scientific and Technical Information (OSTI)

CRADA Number: 2017-17202.00

CRADA Title: Advanced Physics-Based Fluid System Performance Monitoring to Support Nuclear Power Plant Operations

CRADA Start Date 2017 – **End Date** 2020

DOE Program or Other Government Support

Program office: Office of Technology Transitions

Program manager name: Derick Ogg

Program manager phone or email: Click or tap here to enter text.

Participant(s)

Participant 1 name: Thomas Esselman

Complete address: LPI Inc, 36 Main St, Amsebury MA 01913

Participant 2 name: Click or tap here to enter text.

Complete address: Click or tap here to enter text.

Participant 3 name: Click or tap here to enter text.

Complete address: Click or tap here to enter text.

Argonne National Laboratory

Argonne PI(s): Richard Vilim

Funding Table

To add rows, right-click in bottom row and select "Insert" "rows above".

	Planned Funding	Actual Funding	In-Kind
Government	500,000\$	500,000\$	
LPI Inc	500,000\$	500,000\$	450,000\$
Enter Participant 2 here	\$	\$	\$
Enter Participant 3 here	\$	\$	\$
Total	1,000,000\$	1,000,000\$	450,000\$

Nature of Work

Describe the research (summary of Scope of Work and principal objectives of the CRADA):

This project targeted performance monitoring requirements for nuclear power plants with the goal of improving plant economics. We introduced a new and innovative technology to the industry that can reduce operations staffing levels by automating surveillance and can reduce maintenance staffing levels by providing early detection of degrading equipment.

A beta-stage release of the PRO-AID power plant equipment fault diagnostic software ready for deployment in nuclear power plants will be delivered and demonstrated in a utility pilot project. To provide for efficient use of DOE funds the aim is to generate a minimum viable product for which we can prove the value of the product. The end state product will be serviceable for use in either a simulator environment or plant environment. The former provides a means for demonstration of the diagnostic capability for faults unlikely to be encountered in day-to-day operations.

DOE mission area(s):

Energy and Environmental Science and Technology

Choose an item.

Choose an item.

Conclusions drawn from this CRADA; include any major accomplishments:

Algorithms were developed for performing quantitative diagnosis at the system level. Physics-based information of the system is utilized as a supplement to sensor data and serves to constrain the possible diagnostic predictions to those that are physically consistent. At the component level, the underlying physics laws are employed to formulate the parametric performance models for each component. At the system level, available conservation laws and related constitutive equations are utilized to solve for unmeasured process variables. Such analytically solved variables, generalized by the concept of virtual sensors, allow one to construct additional diagnostic models which are otherwise not possible due to the sensor set limitations.

The commercialization plan for PRO-AID is underway. Our commercial partner LPI Inc. has made it an objective to integrate the PRO-AID code with their maintenance optimization and asset planning software. LPI has engaged Curtiss Wright to add this new ANL-LPI capability to their PEPSE software. PEPSE provides real-time plant thermal performance data and has been installed in nuclear plants across the country. Curtiss Wright has joined with LPI and Argonne to submit a proposal for funding under the DOE NE Industry Opportunities Advanced Nuclear Technology Development program. Under this proposal LPI and Argonne will combine their software as described above and Curtis Wright will act as software developer to incorporate this under their PEPSE plant performance software.

Technology Transfer-Intellectual Property**Argonne National Laboratory background IP:**

Click or tap here to enter text.

Participant(s) background IP:

R.B. Vilim and A.M. Heifetz, "Transient Multivariable Sensor Estimation," Patent No. 9,574,903, U.S. Patent and Trademark Office, issued February 21, 2017.

Identify any new Subject Inventions as a result of this CRADA:

T. Nguyen, R. Vilim, and R. Ponciroli, "Fault Diagnosis Framework for Standalone Component," filed U.S. Patent Office, December 2020.

T. Nguyen, R. Vilim, and R. Ponciroli, "Fault Diagnosis Framework for Multi-Component System," filed U.S. Patent Office, December 2020.

R. Vilim, T. Nguyen and H. Wang, "Sensor Assignment Optimization," filed U.S. Patent Office, December 2020.

Summary of technology transfer benefits to industry and, if applicable, path forward/anticipated next steps towards commercialization:

The commercialization plan for PRO-AID is underway. Our commercial partner LPI Inc. has made it an objective to integrate the PRO-AID code with their maintenance optimization and asset planning software. LPI has engaged Curtiss Wright to add this new ANL-LPI capability to their PEPSE software. PEPSE provides real-time plant thermal performance data and has been installed in nuclear plants across the country. Curtiss Wright has joined with LPI and Argonne to submit a proposal for funding under the DOE NE Industry Opportunities Advanced Nuclear

ANL-1060 (07/17/2019)

Technology Development program. Under this proposal LPI and Argonne will combine their software as described above and Curtis Wright will act as software developer to incorporate this under their PEPSE plant performance software.

Other information/results (papers, inventions, software, etc.):

1. T. Nguyen and R.B. Vilim, "A Probabilistic Model-Based Diagnosis Framework for Fault Detection and System Monitoring in Nuclear Power Plants," *Annals of Nuclear Energy*, Vol. 149, August 25, 2020.
2. T. Nguyen, R. Ponciroli, T. Kibler, M. Andersen, M. Strasser, R. Vilim, "A Physics-Based Parametric Regression Approach for Feedwater Pump System Diagnosis," submitted to *Annals of Nuclear Energy*, May 9, 2021.
3. T. Nguyen, R. Ponciroli, P. Bruck, T. Esselman, J. Rigatti, R.B. Vilim, "A Digital-Twin Approach to System-Level Health Monitoring for Increased Diagnosis Specificity," undergoing internal review, to be submitted to *Annals of Nuclear Energy*, June 2021.
4. R. Vilim, T. Nguyen and R. Ponciroli, "Explainable and Trustworthy Diagnostics Achievable through Process-Based Automated Reasoning," 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, virtual meeting, June 14-17, 2021.
5. R. Vilim and T. Nguyen, "Physics-based Automated Reasoning for Health Monitoring: Sensor Set Selection," 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, virtual meeting, June 14-17, 2021.
6. Y. Liu, B. Kochunas, T. Nguyen, H. Ley, R. Vilim, "A Parallel Capability Using Genetic Algorithm for Sensor Assignment Optimization with Process-Constrained Data-Analytic Diagnosis," 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, virtual meeting, June 14-17, 2021.
7. T. Nguyen, R. Vilim, and R. Ponciroli, "Fault Diagnosis Framework for Standalone Component," patent application, filed U.S. Patent Office, December 2020.
8. T. Nguyen, R. Vilim, and R. Ponciroli, "Fault Diagnosis Framework for Multi-Component System," patent application, filed U.S. Patent Office, December 2020.
9. R. Vilim, T. Nguyen and H. Wang, "Sensor Assignment Optimization," patent application, filed U.S. Patent Office, December 2020.
10. T. Nguyen, "Model-Based Diagnostic Frameworks for Fault Detection and System Monitoring in Nuclear Engineering Systems," Ph. D. thesis, University of Michigan, December 2020.

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