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Role of Artificial Intelligence Tools in U.S. Commercial Nuclear Power Operations [NRC-2021-0048]

The NRC requested comments on the current state of commercial nuclear power operations relative to the use of artificial intelligence (AI) and machine learning (ML) tools. Specifically, the NRC is exploring the potential for advanced computational and predictive capabilities involving AI and ML in the various phases of nuclear power generation operational experience and plant management. Comments were solicited on the state of practice, benefits, and future trends related to the advance computational tools and techniques in predictive reliability and predictive safety assessments in the commercial nuclear power industry.

The NRC requested comments on 11 questions to enhance the NRC's understanding of the short- and long-term applications of AI and ML in nuclear power industry operations and management, as well as pitfalls and challenges associated with their application. Framatome Inc.'s (Framatome's) response to the 11 questions are found in Attachment 1 to this letter.

If you have any questions related to this information, please feel free to contact me by telephone at (434) 832-3945 or by e-mail at Gary.Peters@framatome.com.

Sincerely,

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: Ngola Otto

1. What is status of the commercial nuclear power industry development or use of AI/ML tools to improve aspects of nuclear plant design, operations or maintenance or decommissioning? What tools are being used or developed? When are the tools currently under development expected to be put into use?

Metroscope is an AI/ML tool which originated in Electricite de France (EDF) R&D and is currently deployed on more than 40 units to determine root causes derived from symptoms. In this context, symptoms are defined as set of instrumentation deviations from a physics-based model. Metroscope is currently used to monitor faults and their root causes for the secondary-side (steam cycle) of power reactors and other fossil generation plants. Research is on-going in France to enhance the sensitivity and scope of equipment monitored by the tool. In the US, Framatome is engaged in DOE research to through the ARPA-E Gemina program to generalize the Metroscope methodology and tools for application to plant auxiliary systems.

AI/ML tools, software, processes, and concepts are actively being developed through internal (global) Framatome R&D as well as with external collaborators though non-destructive examination (NDE) agreements to provide support for the next generation of NDE methods and procedures. Ongoing R&D efforts include a focus on developing algorithms to enhance data analysis process including: data registration between historical examinations, feature extraction and data screening tools for visual and volumetric data streams, synergy processes to consider multiple (orthogonal) NDE data streams to provide a comprehensive assessment of structural integrity / leak tightness. At this point in time, some of these tools have been successfully developed and are being beta tested and evaluated with mockup and synthetic data streams. Additionally, Framatome (and others) are tracking the process(es) needed for future performance demonstration and qualification acceptance for integrating AI/ML into pre-service and in-service inspection procedures.

For reactor operation and control Framatome has begun to develop AI/ML I&C products such as the Operator Assistance Predictive System (OAPS) which will reduce operator burden and enhance plant safety while optimizing the operation of the reactor. The software employed is Artificial Narrow Intelligence, which is primarily goal seeking and operations optimizing. All of this is done with the anticipated need of greater plant flexibility due to changing demand on the grid.

2. What areas of commercial nuclear reactor operation and management will benefit the most, and the least, from the implementation of AI/ML? Possible examples include, but are not limited to, inspection support, incident response, power generation, cybersecurity, predictive maintenance, safety/risk assessment, system and component performance monitoring, operational/maintenance efficiency and shutdown management.

Predictive maintenance along with system and component monitoring benefit highly from AI/ML advances. The main reason is the opportunity to reduce conservative schedule-based maintenance in favor of accurate assessment of equipment health. Cost reduction in this area depends on the ability to reliably monitor and diagnose incipient stage faults for a range of credible root causes. Speed, accuracy, and reliability of detection are the critical attributes of

AI/ML tools to allow plants to leverage monitoring for cost savings. Metroscope addresses this challenge by providing detection reliability in a robust tool AI that makes use of root cause fault signatures from plant operating experience. False detection ratio is currently less than 10% in current use of Metroscope.

As mentioned previously, NDE (pre-service and in-service) inspections of components and piping systems (including primary systems) can significantly benefit from AI/ML methods. Not only from a cost perspective (efficient data analysis) but also support / improve defense-in-depth strategies to ensure structural integrity of systems and components. As AI/ML tools are not subject to human factors, these advanced processes provide a complimentary tool for the NDE analyst for rapid screening and focused attention on suspect regions of interest. AI/ML implementation can further provide benefit to industry by providing efficient and accurate means to detect and monitor service induced degradation by providing a conservative risk assessment of the component when predictive analytics are incorporated to govern planned repair / replacement activities; minimizing emergent repair needs. The result could be a more robust and efficient protocol for maximizing the NDE data streams and providing actionable data in a planned fashion.

The implementation of AI/ML for reactor operations offers an opportunity to safely and efficiently operate both the existing fleet and plants which will be developed and built. These tools will enhance operators' abilities to plan and prepare for plant transients. AI/ML allow for the integration of large data streams which go beyond human abilities to process, but which help inform decisions about operations.

AI/ML may also allow for semi-autonomous or autonomous operation, which when coupled with advanced designs allows for safer and more efficient operation.

3. What are the potential benefits to commercial nuclear power operations of incorporating AI/ML in terms of (a) design or operational automation, (b) preventive maintenance trending, and (c) improved reactor operations staff productivity?

Accurate monitoring for known root causes may be able to functionally replace some scheduled maintenance (b) and operations tasks (c). Additional opportunity for reduction may also be available when monitoring and diagnostics is used as alternate treatment to replace programmatic requirements altered by risk-informed component categorization. Enabling AI/ML tools would need to be reliable and conservative in their detection capability, technically transparent and verifiable, and able to link instrumentation anomalies to root causes. Metroscope is one technology containing these characteristics, providing the rationale for the current ARPA-E research by Framatome. In addition to extending maintenance, early detections also provide ability to extend component life and maintain performance.

An important part of nuclear power operations centers on the results of the NDE performed during planned outages by not only providing reasonable assurance of structural integrity of systems, but also for regulatory compliance and licensing commitments. Incorporation of AI/ML into NDE strengthens the preventative maintenance (including repairs / replacement activities) and improves overall staff productivity by targeting and planning these intrusive activities

outside of an emergent basis. Early detection of potential degradation of components and systems with the assistance of AI/ML is an example of how AI/ML can support efficient nuclear power operations.

4. What AI/ML methods are either currently being used or will be in the near future in commercial nuclear plant management and operations? Example of possible AI/ML methods include, but are not limited to, artificial neural networks, decision trees, random forests, support vector machines, clustering algorithms, dimensionality reduction algorithms, data mining and content analytics tools, gaussian processes, Bayesian methods, natural language processing, and image digitization.

Relating to the benefits of predictive maintenance and condition monitoring, several methods are currently in use. These include clustering algorithms for anomaly detection, and gaussian approaches for correcting instrument error based on adjacent or physically redundant data. In this same scope, Metroscope employs a Bayesian method to find root causes leveraging physics models, expert knowledge and operating experience. In addition to the variety of AI/ML methods listed in the question, autocorrelation methods are also being explored for NDE applications.

5. What are the advantages or disadvantages of a high-level, top-down strategic goal for developing and implementing AI/ML across a wide spectrum of general applications versus an ad-hoc, case-by-case targeted approach?

The advantage of high-level strategic goals is that many methods may be generalized to other areas with proper research and incremental development. The disadvantage is that real benefits in operation and maintenance relies heavily on expert knowledge to build the tools. For this reason, knowledge-based AI tools may show more promise for strategic advancement because they can be used to contain precise embedded engineering knowledge. Knowledge-based AI relies on a physics model or digital twin rather than pure data-driven methods.

Having a top-down approach for the incorporation and implementation of AI/ML has strengths in providing a roadmap to synergize various data streams to provide accurate actionable maintenance and operation activities. As simple as harmonizing various NDE data (ultrasonic, visual, etc.) with operational information can provide a good benefit for determining the expected remaining life of a component or weld. If implemented from a top-down approach holistic risk is managed differently and efficiencies can be gained accordingly. However, there are advantages also with an ad-hoc approach for phased integration of AI/ML that supports the development of trust in the system.

6. With respect to AI/ML, what phase of technology adoption is the commercial nuclear power industry currently experiencing and why? The current technology adoption model characterizes phases into categories such as: the innovator phase, the early adopter phase, the early majority phase, the late majority phase, and the laggard phase.

Given the highly regulated and specialized nature of the commercial nuclear power industry, and the economics of the energy market, the adoption phases ranges from early majority to late

majority. While the excellent culture of industry sharing lends to the spread of trusted technologies well, an investment is required to "fail fast" in an innovator and early adopter phase. Nuclear plant profitability generally inhibits these phases.

As AI/ML adoption continues to increase, and success is demonstrated in alternative markets and industries, the adoption for the commercial nuclear power industry becomes easier where acceptance standards and qualification guidance can be generated, vetted, and accepted. Without experience from the early adopters it is difficult to define the essential variables and assign quality assurance metrics that are essential for the nuclear power industry.

Work ongoing in the EU to demonstrate the state of the art of machine learning in nuclear inspections is evidenced in a Position Paper published by the European Network for Inspection and Qualifications. It can be found at https://snetp.eu/wp-content/uploads/2020/07/ENIQ_Position_Paper_qualification_AI_ML_NDT_system_v13.pdf.

Currently there exist laws which prohibit the use of technologies which would adjust reactor power automatically or autonomously without a licensed operator making the power manipulations. These laws would need to be updated to allow for uptake of many of these technologies and why currently the US plants lag other nations in their adoption of AI/ML tools.

7. What challenges are involved in balancing the costs associated with the development and application of AI/ML tools, against plant operational and engineering benefits when integrating AI/ML into operational decision-making and workflow management?

One main challenge is capturing accurate and credible operations and maintenance cost data that supports the benefit in a return-on-investment study. Referring to knowledge-based AI, there is an investment required to embed engineering knowledge in models. Additionally, AI/ML can require specialized skills to maintain which trade-off against the benefits of their use.

Acceptance, qualification(s), and integration into existing NDE procedures are also challenges that need to be overcome. For example, modifications to inspection procedures often require re-qualifications that are costly. These costs need to be offset with a defined benefit and or supplemental support to provide motivation for development and resulting integration of the AI/ML tools and processes.

8. What is the general level of AI/ML expertise in the commercial nuclear power industry (e.g. expert, well-versed/skilled, or beginner)?

In the areas of predictive maintenance, some areas like cluster analysis for monitored anomalies are well-versed. In the same domain the industry may be characterized as beginner when considering other tools.

From the NDE perspective, Framatome is well-versed/skilled and in addition leverages and partners with technology vendors that are expert level in various AI/ML technologies. These vendor experts understand the AI/ML platforms as well as have experience with NDE data streams.

9. How will AI/ML effect the commercial nuclear power industry in terms of efficiency, costs, and competitive positioning in comparison to other power generation sources?

The opportunity is significant in comparison with fossil generation due to typical operating and maintenance costs that may be reduceable with robust monitoring and diagnostics.

10. Does AI/ML have the potential to improve the efficiency and/or effectiveness of nuclear regulatory oversight or otherwise affect regulatory costs associated with safety oversight? If so, in what ways?

Yes, if diagnostics can reasonably expand in coordinated with risk-informed categorization, oversight might be improved by simplification of inspections and standardized rationale for maintenance deferral. This is especially true when regulator AI/Ml competencies increase with operating sites.

11. AI/ML typically necessitates the creation, transfer and evaluation of very large amounts of data. What concerns, if any, exist regarding data security in relation to proprietary nuclear plant operating experience and design information that may be stored in remote, offsite networks?

Concerns are cyber intrusion, loss of export control, and enterprise risk from public and shareholder perception. However, cloud systems now exist with cyber controls that make data as secure as private intranet networks. The industry will benefit from standardization of data classification and network security requirements.

Novel NDE AI/ML techniques are exploring edge AI platforms that consist of hardware that is co-located with inspection systems and are prepared to process data locally without the need to transfer. This significantly reduces transfer time and minimizes security risks / exposure.