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AI/ML APPLICATIONS FOR NUCLEAR MATERIAL AND CONTROL AT SNL

An overview of recent work

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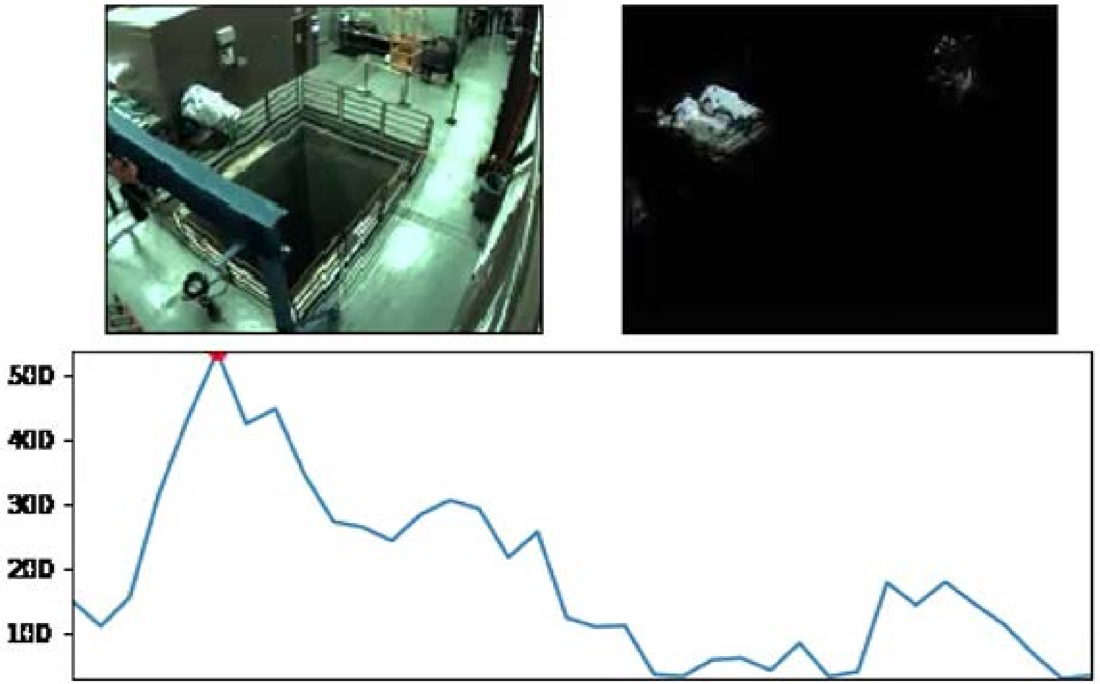
Presented by Alan Evans

Introduction to the Role of Artificial Intelligence in Strengthening the Security of Nuclear Facilities| February 6-8, 2024 | Vienna, Austria

SAND2023-13929PE

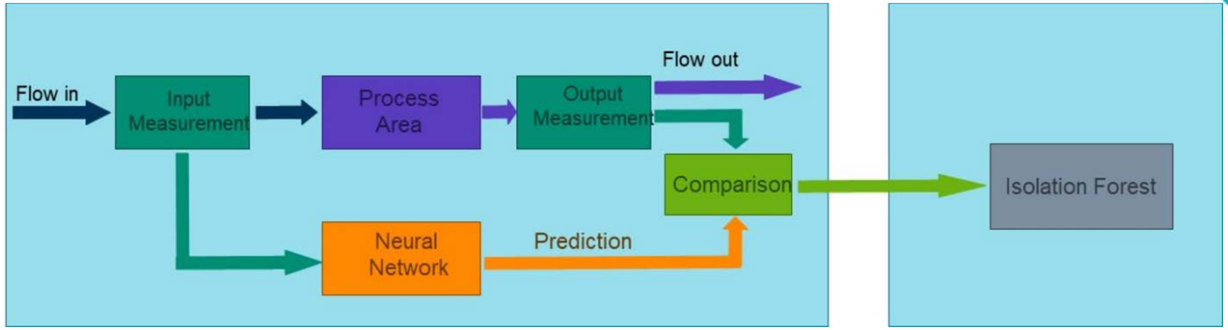
REDUCING THE BURDEN OF VIDEO SURVEILLANCE REVIEW

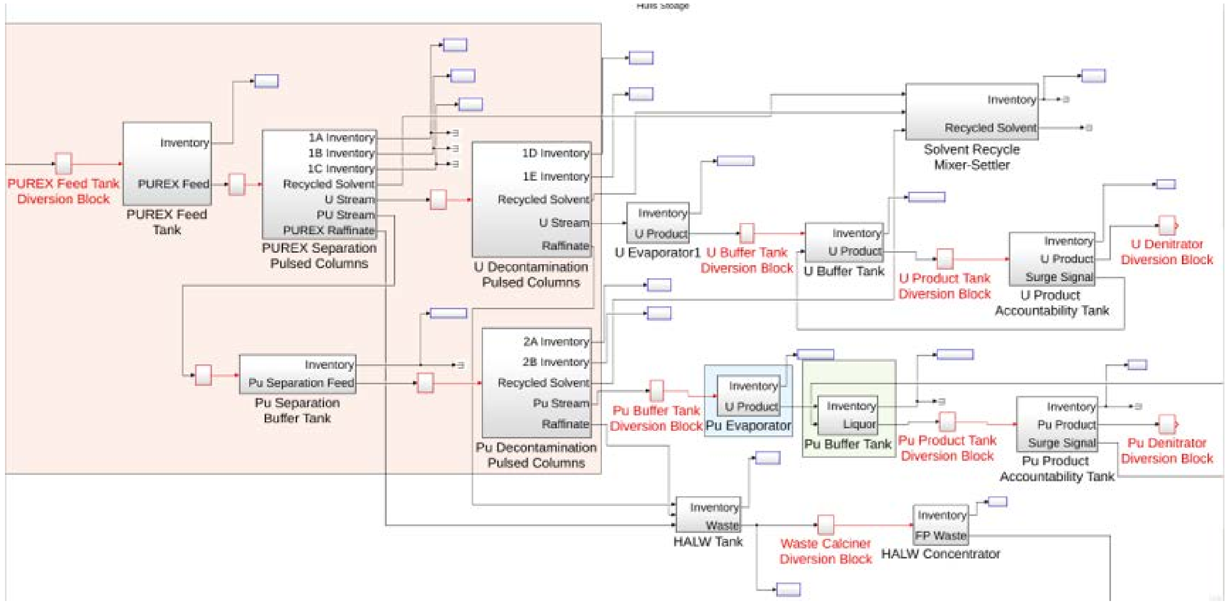
- Video surveillance review is a tedious task that involves manual review of massive quantities of data.
- Only a few segments of the video sequences are relevant.
- A machine learning-based algorithm was developed to flag anomalous segments of video surveillance data.
- Trained only on normal behaviors, so extensive knowledge of anomalies not required.
- Algorithm transitioned from SNL to IAEA.
- Spatio-temporal Anomaly Detection in Video (Smith, Rutkowski, and Hamel) - *SAND2019-13677PE*



ANOMALY DETECTION IN HETEROGENEOUS DATA STREAMS

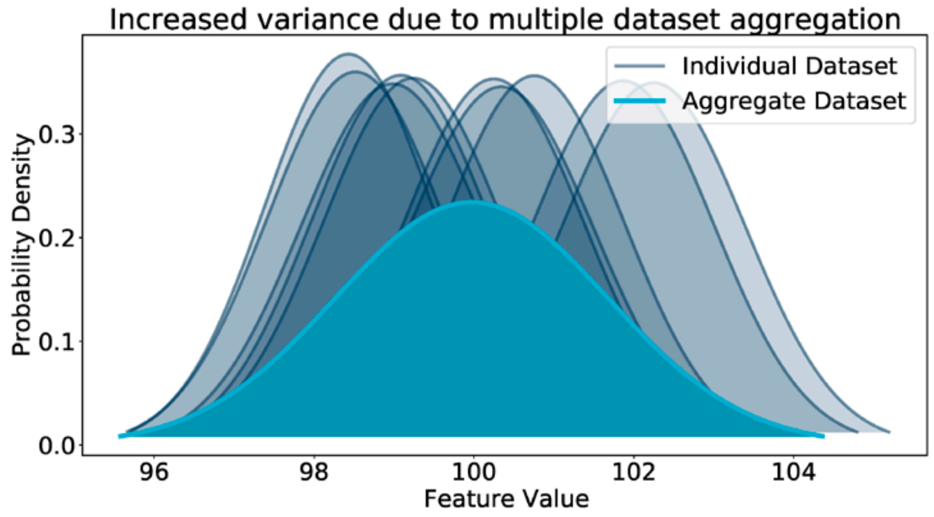
- Accountancy of large scale bulk nuclear facilities is expensive as many destructive assay (DA) measurements are often required.
- Could machine learning more fully utilize existing data streams and rely less on DA?
- Yes, but: particular sensor calibration and experimental setup are required for good results.
- Insights from Applied Machine Learning for Safeguarding a PUREX Reprocessing Facility (Shoman, et al.) *https://www.osti.gov/biblio/1888430*

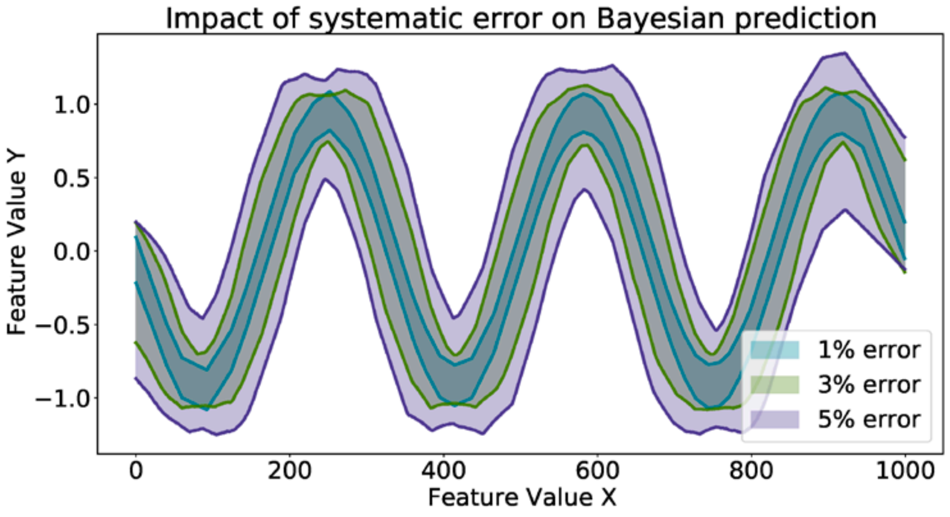




DISCOVERING LIMITS OF MACHINE LEARNING FOR NMAC DATA STREAMS

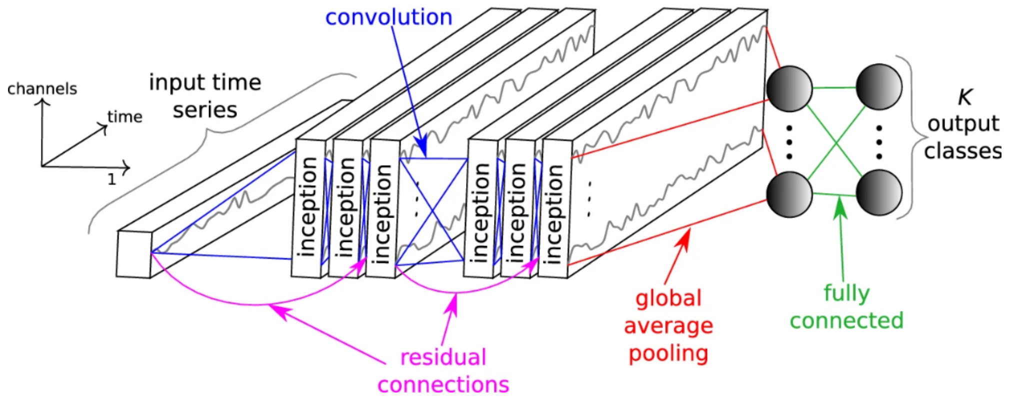
- Measurement uncertainty is an important driver for bulk material accountancy performance.
- Machine learning is hypothesized to improve material accountancy, but how does measurement uncertainty impact machine learning?
- For unsupervised learning, there are limits for detecting material loss that are based on underlying measurement uncertainty
- No free lunch; examples of anomalous behavior essential for improving performance
- Impact of measurement error on deep neural networks for nuclear material accountancy (Shoman, Burr) *https://doi.org/10.1016/j.nucengdes.2022.112113*

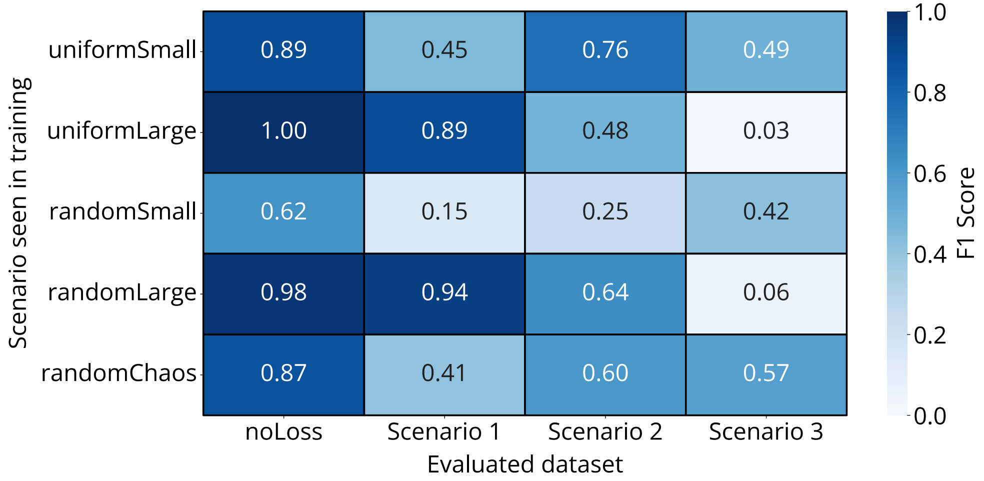




OVERCOMING LIMITATIONS OF SUPERVISED LEARNING FOR ANOMALY DETECTION IN NMAC

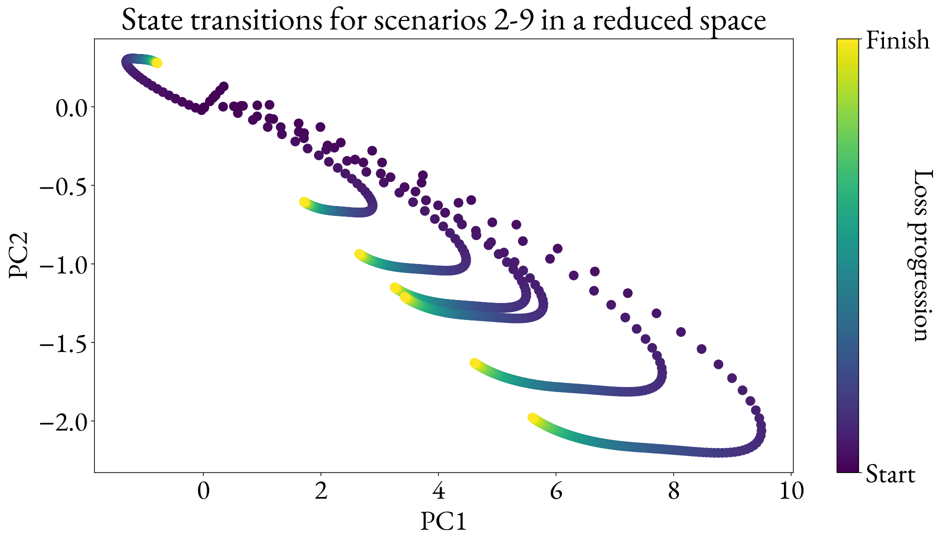
- Supervised learning often outperforms unsupervised approaches, which rely on a proxy metric for a learning task.
- Supervised approaches can often be challenging to implement in NMAC as not all anomalous conditions are known.
  - Performs poorly on unseen scenarios in many cases.
- Could synthetic data and randomized, but constrained, anomalies be used to boost performance on unseen scenarios?
- Preliminary work suggests yes, but further work is required for validation.
- The Power of Priors: Improved Enrichment Safeguards (Shoman, Honnold) *https://www.osti.gov/biblio/2003777*

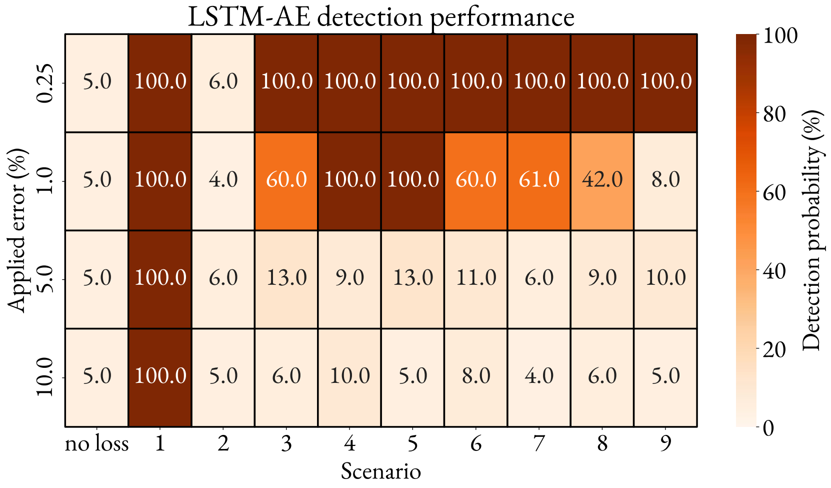




DATA-DRIVEN TECHNIQUES FOR ANOMALY DETECTION IN MOLTEN SALT REACTORS

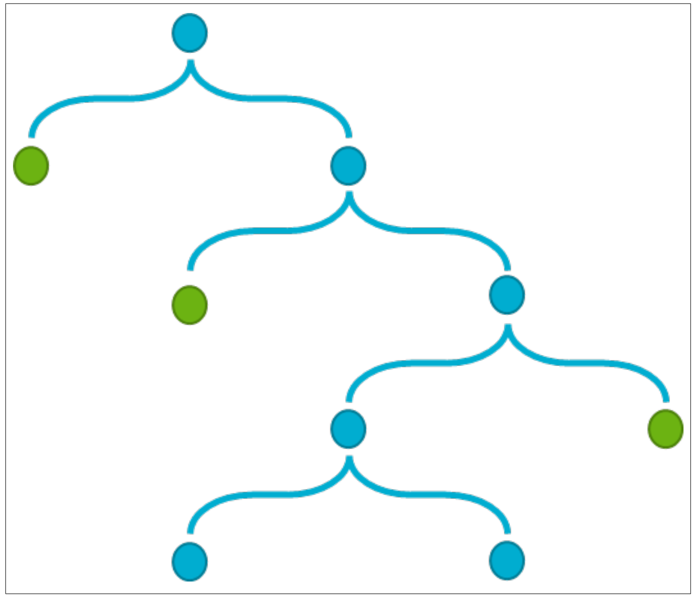
- Liquid-fueled molten salt reactors could have large fissile inventories that create challenges for traditional accountancy techniques.
- Existing signals collected for operations could be used to detect material loss and improve NMAC.
- Machine learning combined with large set of observable sensor data could detect anomalies, but design-specific features could limit applicability
- Improved Safeguards of Molten Salt Reactors using Process Monitoring (Shoman) *SAND2023-11902PE*

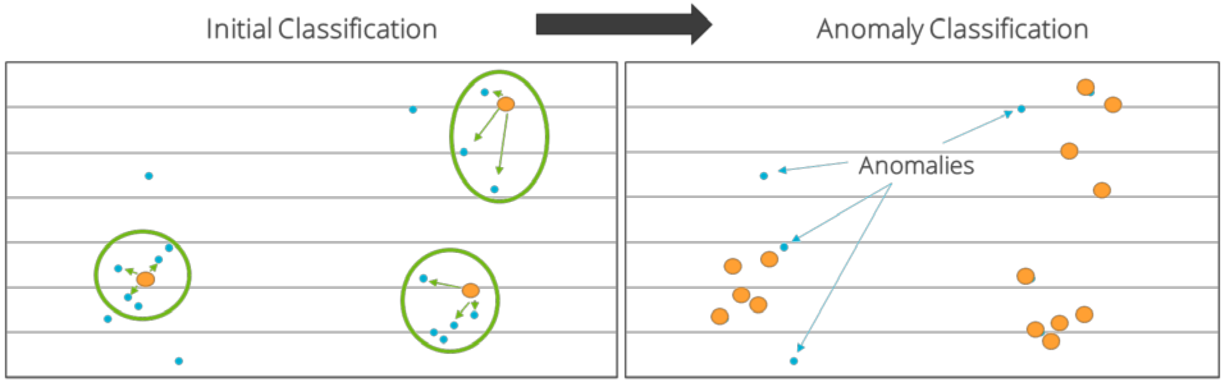




ENHANCED NMAC OF PEBBLE BED REACTORS USING MACHINE LEARNING

- Monitoring pebbles in a pebble bed reactor as they circulate through the core is an important NMAC objective.
- Machine learning combined with gamma spectroscopy could enable NMAC by design by highlighting important features for anomaly detection.
- Expected anomalies resulted in large gamma spectroscopy changes that are easy to detect.
- Machine learning performed well, but might not be necessary.
- Development of Machine Learning Algorithms for Pebble Bed Modular Reactor Misuse Detection (Faucett, Elliot) *In press*

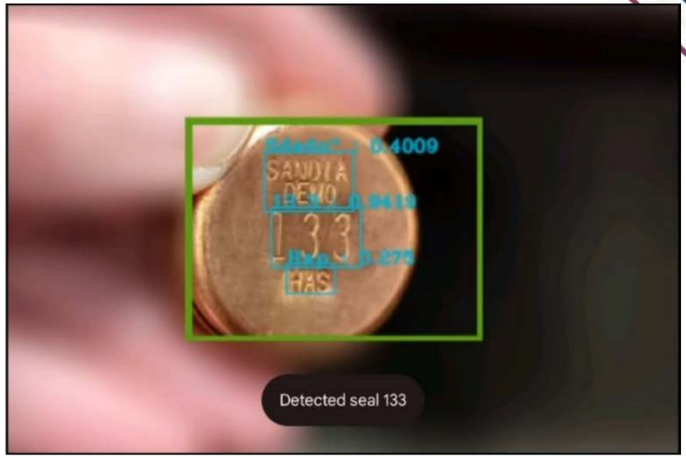




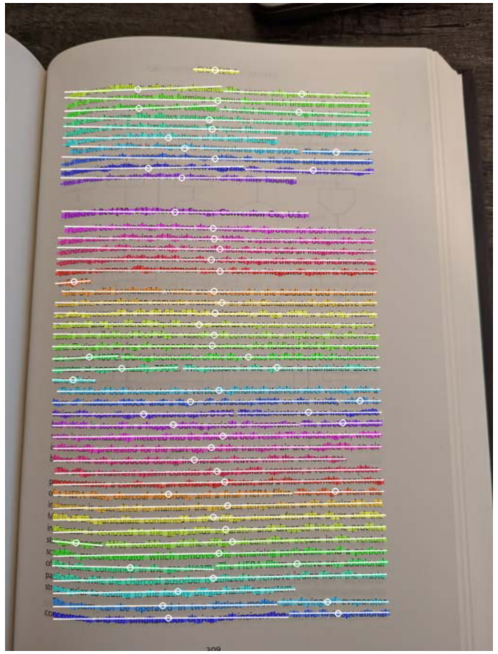
AN INTEGRATED SMART DIGITAL ASSISTANT TO IMPROVE IN-FIELD SAFEGUARDS INSPECTION ACTIVITIES

- Safeguards inspections involve several tasks, some of which can be tedious and error-prone.
- A smart digital assistant could help reduce the amount of time spent on these tedious tasks.
- A prototype, INSPECTA, has been developed and demonstrated for a variety of these tasks, namely seal verification.
- Incorporates on-device machine learning for optical character recognition, speech recognition, speech synthesis, information retrieval, and more.
- Inspecta Annual Technical Report (Smartt, et al.)
- Machine learning at the edge to improve in-field safeguards inspections (Shoman, et al.) *In press*

Predicted bounding boxes from Text Detection algorithm



Feedback to user upon successful match



QUESTIONS