# Probabilistic AI for Prediction of Material Properties (PROMAP)

**A feasibility study to combine Artificial Intelligence models with probabilistic methods to help predict the properties of materials used in the nuclear industry.**

## Introduction

Artificial Neural Network (ANN) aimed at predicting the environmental impact on material behaviours (fatigue and fracture) and key material properties from known chemical composition and processing history.

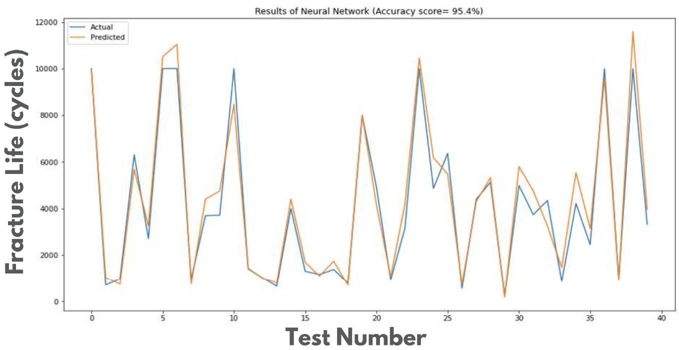
## Current capabilities

A deterministic ANN model trained from 246 experimental tests was used to predict fracture life results reached an accuracy of 95.4%, Another AI model was successfully trained using 58 steel types of various steel product forms (tubes, plates, bars etc) used in power plants to predict material properties (tensile properties, creep-rupture properties and hardness) from known chemical composition and processing history. The AI models accuracy ranges from 85% to 98%.


- Nawal Prinja, 'Artificial Intelligence for Engineering Projects', Research Seminar Series 2021-22, University of Bolton, School of Engineering, 14 October 2021


## The problem

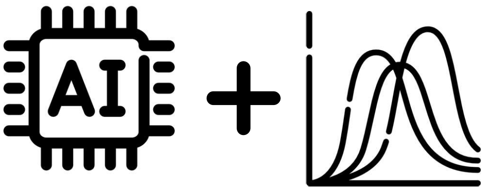
Currently, AI is not widely implemented within the Nuclear industry. Challenges in the industry include: 1) decommissioning ageing Nuclear plants; 2) cost reduction in building new plants; and 3) sparsity in data - costly to perform experiments.
Applications of AI within the industry include: 1) De-centralized decision-making (i.e. Autonomous systems); and 2) Technical assistance (e.g. System performance, and Material properties and behaviour).




The existing AI models are trained with deterministic data and models require a large number of physical tests to cover the natural variability in the material properties. However, the issue of sparse data has added a challenge to such data-centric AI approach.

## The solution

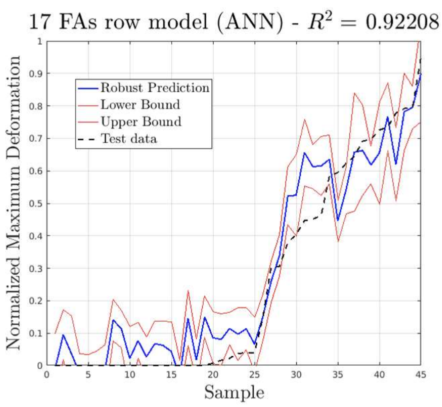
Combine ANN with Bayesian statistics and Interval Predictor Models to enhance the robustness of the response. This allows for the uncertainties from the sparse data and material variability to be accounted for and it allows to provide the necessary confidence associated with the prediction.




## Implementation

The probabilistic models are part of the Cossan software and tested to predict the response of nuclear fuel assembly subject to seismic events


- Altieri, D., Patelli, E., 2020. Machine learning approaches for performance assessment of nuclear fuel assemblies subject to seismic-induced impacts. ASCE-ASME Journal of Risk and Uncertainty: Part B. https://doi.org/10.1115/1.4046926


## Impact

It is well known that conscientiously accounting for uncertainty leads to better modelling and prediction. The proposed technology allows reducing the number of experimental campaigns required to characterise material properties. The proposed AI tool predicts material properties with high accuracy and provides the necessary confidence associated with such prediction. The outcome of this project will prove the applicability of AI technology in nuclear industry by providing tools that can be trusted.

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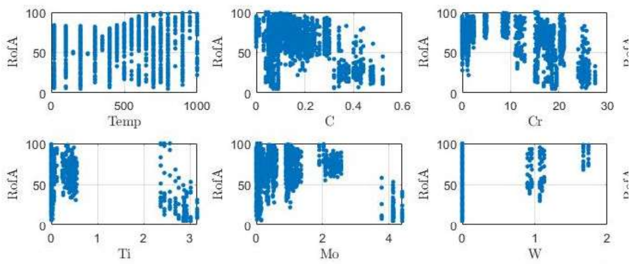
**Methodology and selected results obtained**

University of Strathclyde Engineering

## Data collection

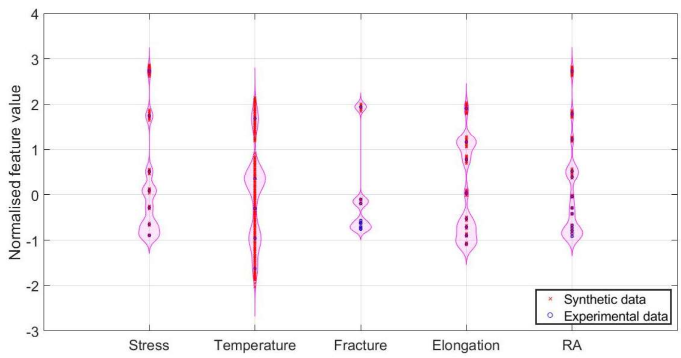
Experimental database from NIMS and INCEFA:

- Creep rupture data - 8005 observations;
- Tensile data - 2878 observations;
- Hardness data - 234 observations;
- Cycles to failure data - 198 observations.




## Stochastic enhancement of dataset

Using a Gaussian Mixture Distribution approach while retaining physical relation between variables.




## Probabilistic AI

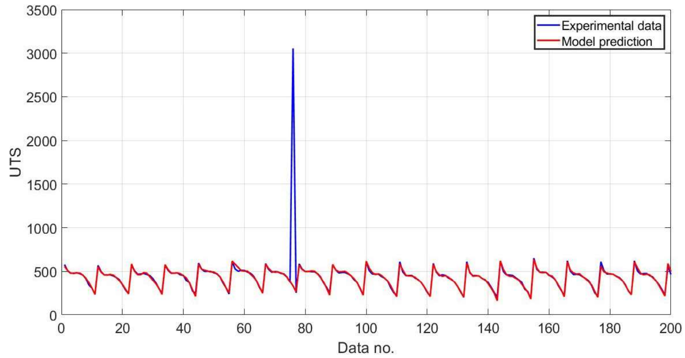
- Trained using enhanced stochastic dataset;
- Validated using experimental data;
- Trained sets of ANNs (Considered model uncertainty);
- Merging results using Bayesian statistics: Adaptive Bayesian Model Selection;
- Provide a confidence bound on the prediction output.

## Selected results

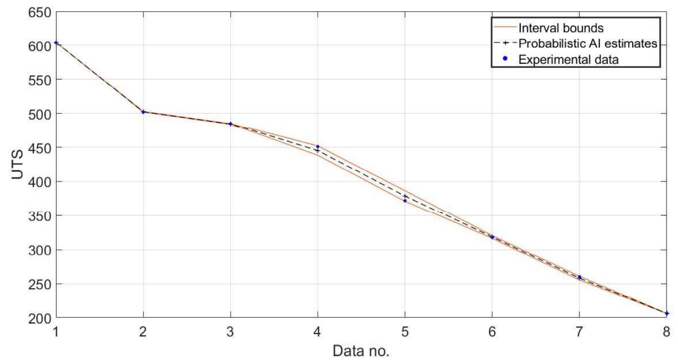
Excellent accuracy for predicting material properties - e.g. Ultimate Tensile Strain (UTS).

| Configuration | R-squared score relative to Trained output from Synthetic data | | | | | | |
|---|---|---|---|---|---|---|---|
| | Creep Rupture Prediction | | | Tensile Properties Prediction | | | |
| | Fracture | Elongation | RA | PS_02 | UTS | Elongation | RofA |
| 23 – 18 – 1 | 99.49 | 99.63 | 99.57 | 94.65 | 99.71 | 95.64 | 92.84 |
| 23 – 18 – 9 – 1 | 99.98 | 99.88 | 99.83 | 99.62 | 99.71 | 92.16 | 92.83 |
| 23 – 27 - 18 – 9 – 1 | 99.98 | 99.91 | 99.96 | 99.81 | 99.87 | 92.24 | 93.56 |
| 23 – 64 – 32 – 16 – 1 | 99.97 | 99.94 | 99.91 | 99.91 | 99.97 | 99.02 | 98.38 |
| 23 – 64– 1 | - | - | - | 99.85 | 99.86 | - | 92.84 |
| 23 – 32– 1 | - | 99.12 | 98.56 | - | - | 95.65 | - |
| 23 – 64 – 32 –8– 1 | 98.14 | - | - | - | - | - | - |

Robustness against "bad data".




Prediction with confidence.




## Conclusions

This study has achieved 4 objectives:

- Demonstrated the feasibility of merging AI with probabilistic tools;
- Increased robustness and accuracy of AI tools;
- Provided confidence on predictions;
- Data-bases and codes are published on: https ://github.com/cossan working group

## Next steps

This feasibility study has paved the way to future use of AI technology in the nuclear industry where probabilistic approaches guarantee the robustness and confidence for the prediction of properties of new materials. Including incertitude in training data is a common defence against adversarial attacks. This is an essential requirement for the use of AI technology in any safety-critical task.

## References


- S. Tolo, X. Tian, N. Bausch, V. Becerra, T. V. Santhosh, G. Vinod, and E. Patelli (2019). Robust on-line diagnosis tool for the early accident detection in nuclear power plants. Reliability Engineering & System Safety, 186, 110–119. doi: 10.1016/j.ress.2019.02.015
- Sadeghi, J., Angelis, M. de, Patelli, E., 2019. Efficient training of interval Neural Networks for imprecise training data. Neural Networks 118, 338–351. doi: 10.1016/j.neunet.2019.07.005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COSSAN Software

www.cossan.co.uk