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Title: Machine Learning Methods for Antineutrino-Based Safeguards

Abstract

While there have been recent improvements in antineutrino detectors, more research is required to support the data processing side of near-field antineutrino-based nuclear reactor monitoring systems. With such a small antineutrino flux detected, these systems need to include optimized statistical inference techniques to properly verify the operational state of nuclear reactors. In this work, we evaluate various machine learning approaches that can be applied to strengthen antineutrino-based reactor safeguards systems. More specifically, variations of support vector machine (SVM) algorithms have been used to determine the safeguards power of a simulated, diverted Advanced Fast Reactor (AFR) as well as to isolate radiation-induced background detector events.

Previously, a chi-squared goodness-of-fit statistical approach was used to analyze the safeguards power of 12 different diversion scenarios for a simulated AFR. The results utilizing this data processing method were far below the current IAEA low-probability event threshold limit, especially if a reactor operator attempted to mask the diversion. By switching to a machine learning approach, however, we observed more nuance patterns in the dataset that led to safeguards power improvements. Although there is a large uncertainty associated with the model sampling technique, there were mean safeguards power improvements up to factors of 10^9.

In most cases, background radiation inhibits perfect detection, and therefore interpretation of the data. Background removal is usually done by subtracting the energy spectrum of the background radiation from the total spectrum. Alternatively, novelty detection algorithms have been applied to attempt to classify individual non-background counts as anomalies, based on a background-only dataset. A one-class SVM was used to classify the data based on time interval spacing features. This results in a program that allows the user to adjust the number of non-background, or anomalies, that are to be preserved through the adjusting of the SVM's hyperparameters.