

## Chapter 46

# Application of Artificial Neural Networks to Reliable Nuclear Data for Nonproliferation Modeling and Simulation

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### ABSTRACT

*Detection and identification of special nuclear materials (SNMs) are an essential part of the US nonproliferation effort. Modern cutting-edge SNM detection methodologies rely more and more on modeling and simulation techniques. Experiments with radiological samples in realistic configurations, is the ultimate tool that establishes the minimum detection limits of SNMs in a host of different geometries. Modern modeling and simulation approaches have the potential to significantly reduce the number of experiments with radioactive sources needed to determine these detection limits and reduce the financial barrier to SNM detection. Unreliable nuclear data is one of the principal causes of uncertainty in modeling and simulating nuclear systems. In particular, nuclear cross sections introduce a significant uncertainty in the nuclear data. The goal of this research is to develop a methodology that will autonomously extract the correct nuclear resonance characteristics of experimental data in a reliable way, a task previously left to expert judgement. Accurate nuclear data will in turn allow contemporary modeling and simulation to become far more reliable, de-escalating the extent of experimental testing. Consequently, modeling and simulation techniques reduce the use and distribution of radiological sources, while at the same time increase the reliability of the currently used methods for the detection and identification of SNMs.*

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## 1. INTRODUCTION

Nuclear nonproliferation is of crucial significance to worldwide security, since it aims to limit the spreading of the extremely destructive nuclear weapons and to proceed toward nuclear disarmament as well. Among the top priorities is the detection of Special Nuclear Materials (SNM). The definition of a Special Nuclear Material (SNM), according to the Nuclear Regulatory Commission, is a material characterized (Atomic Energy Act of 1954) as Pu,  $^{233}\text{U}$ , or uranium enriched with isotopes  $^{233}\text{U}$  or  $^{235}\text{U}$ . These materials, for instance, can be used as the primary ingredients for nuclear explosives. It is, therefore, of paramount importance to detect SNM in fast and reliable ways to ensure the public health and safety.

The detection of SNM has to be accurate because it is necessary to be precise and careful when humans deal with such important and hazardous materials. On the other hand, the technique also needs to be fast. For example, it is not possible to keep a container with time-sensitive merchandise (i.e. fruit or vegetables) for a long time in a facility at the borders of the country trying to detect whether it contains SNMs or not.

The detection of SNM has become more and more dependent on modeling and simulation techniques to predict the behavior of the nuclear systems. Moreover, unreliable nuclear data is one of the main causes of uncertainty in modern modeling and simulation of nuclear systems. More specifically, nuclear cross sections introduce a large amount of uncertainty in the nuclear data. Cross section data is compiled by nuclear data experts based on the evaluation of experimental measurements of cross sections (Wigner, 1957). The process of determining nuclear cross section probabilities is a laborious process that is subject to expert judgment. Considering the importance of cross sections in accurate modeling and simulation of SNM detection instruments it is strongly believed that the aforementioned laborious evaluation of cross sections can be carried out faster and more reliably by utilizing Artificial Neural Networks (ANNs) (Tsoukalas & Uhrig, 1997; Demutl et al., 1998). To the best of our knowledge, nobody has tried this effort before.

Artificial Intelligence (AI) techniques have been vastly exploited in nuclear applications. The authors in (Alamaniotis & Tsoukalas, 2013) describe a neuro-SVM anticipatory system for online monitoring of radiation and abrupt change detection. Also a fuzzy logic radioisotopic pattern identifier on gamma-ray signals with application to security is another application based on AI by (Alamaniotis et al., 2014). The study in (McCoy et al., 2013) proposes a conceptual model for integrative monitoring of nuclear power plants operational activities based on historical nuclear incidents and accidents. Another approach, belonging in the wide area of Artificial Intelligence, is the one presented in (Liu et al., 2009) in which the authors, using a genetic algorithm, have applied a fuzzy-PID controller in the system of a nuclear reactor.

Artificial Neural Networks have been previously applied to the problems of nuclear engineering in fields other than nuclear data, such as nuclear criticality (Angelo, 2014), nuclear fuels (Susmikanti & Sulisty, 2014), diagnosing specific abnormal conditions (Uhrig, 1991). (Ghazali & Maslina, 2016) propose an ANN to model the fault detection of the area radiation monitor in nuclear power plants. Feed-Forward ANNs architecture has been utilized in various modelling, control and Fault Detection Applications (FDA) (Elnokity et al., 2012; Oliveira & Almeida, 2013). Moreover, the authors in (Akkurt & Çolak, (2002)) also used Feed-Forward ANN in order to model the operation of various components of a PWR reactor. The modelling and the design of a steam generator is developed by the authors in (Masini et al., 1999) using a Feed-Forward ANNs as well. Furthermore, ANNs are used (Nabeshimaa et al., 2002) for monitoring purposes. In particular, the authors in this paper propose a hybrid system using ANNs and a real time expert system based on rules for monitoring the operation of a nuclear reactor.

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