Deep learning-based Radionuclide Identification for high temperature

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Introduction

- In severe accidents at nuclear power plants, **identifying radioactive isotopes** emitted from a nuclear reactor can play an important role in **understanding the progression of the accident**.
- However, the **high temperature environment** surrounding a nuclear reactor can greatly influence the performance of radiation measurement systems. [1]
- Additionally, the **degradation of a radiation detector's output** due to **high temperatures** can have a **devastating effect on nuclide identification algorithms**, which are based on the location of photopeaks in the spectrum.

Goal of This Study

- Proposal of a **deep learning-based radionuclide identification** which can identify nuclear isotopes **even with temperature fluctuations**.

Material and Methods

Gamma-ray spectrum measurements

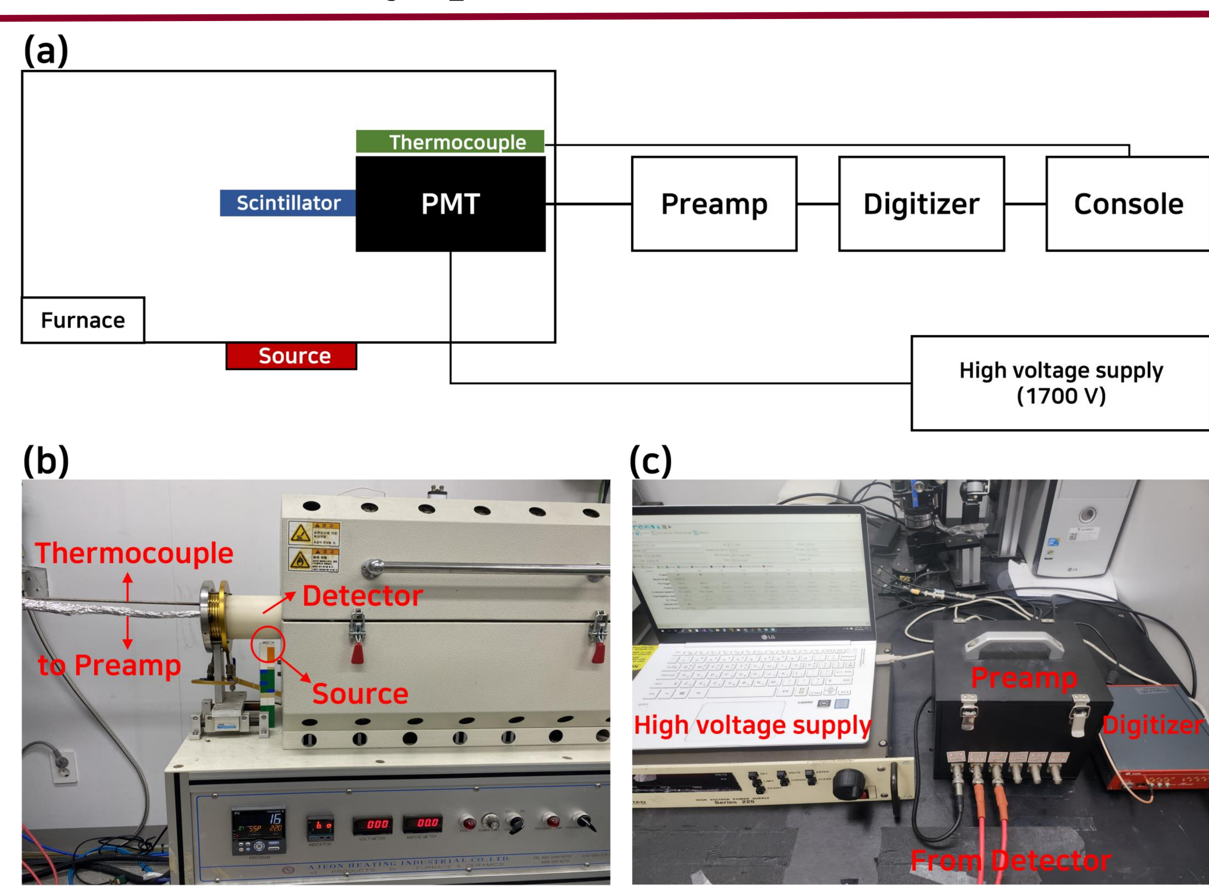

Fig. 1. (a) Schematic diagram and (b) experimental setup for collecting radiation measurement data at high temperature. (c) Front-end circuit and DAQ system for this experiment.

- We used a **Ce:GPS** scintillator (3×3×10mm^3) coupled with a 19-mm diameter Hamamatsu **R3991A-07 photomultiplier tube** (PMT) to detect gamma rays.
- The PMT was supplied with a voltage of 1700V, and its anode signal was sent to a charge sensitive preamplifier, which was then shaped/amplified and digitized using a high speed DT5730 digitizer (500 MS/s, 14-bit resolution, CAEN).
- We measured **^{137}Cs, ^{57}Co, ^{133}Ba** radiation sources and collected pulses while changing the temperature at **25 °C, 50 °C, 75 °C, 100 °C, 125 °C, and 150 °C**.

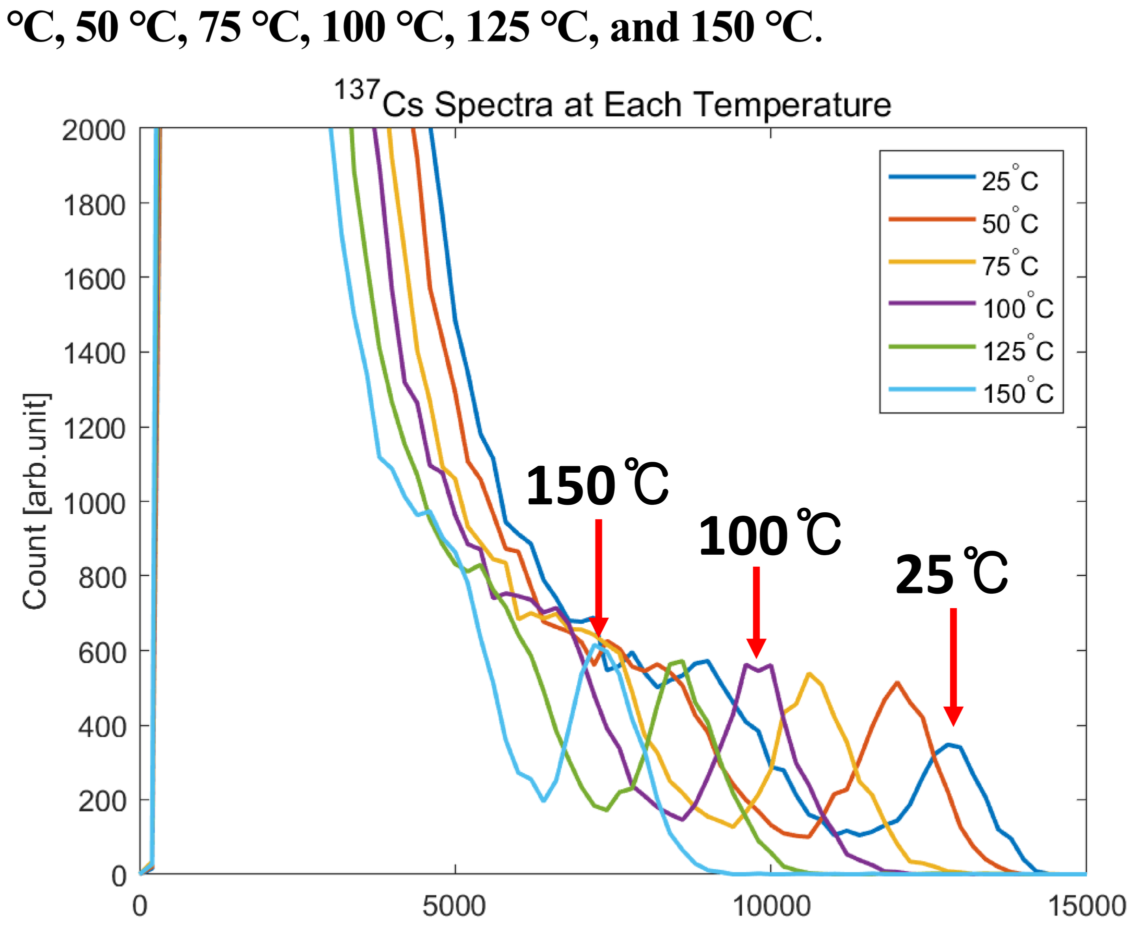

Fig. 2. Measured ^{137}Cs spectra at temperatures of 25 ℃, 50 ℃, 75 ℃, 100 ℃, 125 ℃, and 150 ℃.

Architecture of deep neural network (DNN)

- The architecture used in this study can be summarized as follows.
  1) Configuration : Five layers and one Softmax layer (fully connected)
  2) Activation function for hidden layers : ReLU
  3) Optimizer : Adam optimizer (Adaptive Moment Estimation)
  4) Learning rate : 0.001
  5) Loss function : Categorical cross-entropy loss function
- The hyperparameters listed above are commonly used in machine learning and optimized to improve performance.[2]

Material and Methods

Training and testing dataset

- The dataset used for the deep learning model was divided into **seven classes** to identify the three types of radiation sources, as indicated in Table I.
- **Classes 0-2** each consisted of 1,200 gamma-ray spectra generated using 100,000 pulses measured for **one source** at the same temperature.
- Of these, 1,000 spectra were designated as the training dataset , while the remaining 200 spectra were designated at the test dataset.
- For **classes 3-6**, the spectra were created by **mixing** 10,000 pulses randomly selected from the measured pulses for each source at the same temperature, ensuring that the proportion of pulses from **any one source was at least 20%.**
- To verify the temperature dependency of the deep learning model in identifying nuclides at untrained temperatures, **the spectra obtained at 75 °C and 100 °C were used as only test datasets.**
- Additionally, to account for temperature variations, **linear interpolation** was employed, and the interpolation ratio was determined based on the **positions of the photopeaks**.

Table I. Dataset used for deep learning

Class Number	*Gamma-ray Sources*
0	^{137}Cs
1	^{57}Co
2	^{133}Ba
3	^{137}Cs, ^{57}Co
4	^{137}Cs, ^{133}Ba
5	^{57}Co, ^{133}Ba
6	^{137}Cs, ^{57}Co, and ^{133}Ba

Results

- The **shifts and changes in photopeaks** can be observed in the spectra as the temperature varies, as shown in Fig. 2.
- **The trained deep learning model was able to identify nuclides with high accuracy regardless of temperature, from spectra obtained at 25 °C, 50 °C, 100 °C, and 150 °C.**
- Furthermore, the trained deep learning model could identify radionuclides from spectra obtained **at 75 °C, and 125 °C**, which were not used for training the deep learning model, with an accuracy of **96% and 85.2%,** respectively.
- Upon implementing linear interpolation, the accuracy improved to 100% and 91.7% **at 75 °C, and 125 °C, respectively,** as indicated in Table II.

Table II. Classification accuracy by temperature

Temperature	*Accuracy*	*Accuracy after interpolation*
25 °C	100%	100%
50 °C	100%	100%
75 °C	96%	100%
100 °C	100%	100%
125 °C	85.2%	91.7%
150 °C	100%	100%
ALL	96.9%	98.6%

Discussion & Conclusion

- **We proposed a deep learning model capable of identifying radionuclides irrespective of temperature variations**.
- The proposed deep learning model demonstrates a high level of accuracy in identifying radionuclides, even when temperature fluctuations are present.
- In future research, we will employ techniques such as **CNN, MCNP4** to enhance the nuclide identification algorithm [3].
- Moreover, we aim to assess the nuclide identification capabilities of the trained model on a more **extensive range of nuclides.**

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