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Study on the Optimal Irradiation Location for Radioisotope Production Using Heavy Water Reactors

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1. Introduction

Prostate cancer ranks as the third most common cancer among men aged 60 and above, according to statistics from the National Cancer Information Center for the year 2021 [1]. This underscores the significant health concern posed by prostate cancer among elderly men in South Korea, necessitating efficient diagnostic and therapeutic interventions. Medical radioisotopes play a crucial role in cancer treatment, addressing this pressing need. The recent FDA approval in 2022 of Lutathera, utilizing Lu-177 for prostate cancer therapy, has garnered considerable attention. However, the current production of Lu-177 relies on research reactors, which fall short of meeting the escalating demand. In response to this challenge, there is a burgeoning interest in utilizing existing nuclear power reactors, such as pressurized heavy-water reactors like Wolsong nuclear power plants (NPPs) operated by KHNP, for large-scale Lu-177 production.

The reason for aiming to produce Lu-177 from the Wolsong nuclear reactor is to leverage a technically proven technology, as large-scale commercial production utilizing the Canadian Bruce nuclear power plant's PHWR commenced in October 2022. This paper seeks to identify the optimal locations within the Wolsong nuclear reactor, a different Candu 6 reactor from Bruce, for irradiating the raw material Yb-176.

This paper focuses on leveraging the RFSP (Reactor Fueling Simulation Program) code to optimize the placement of guide tubes for inserting raw materials for neutron irradiation within PHWR reactor cores. The aim is to strategically position guide tubes at vertical flux detector locations to facilitate efficient neutron flux measurement and subsequent radioisotope production. The primary focus of this study is to compute neutron flux at various vertical positions for each port and determine the optimal insertion positions for maximizing neutron flux intensity.

2. Methods and Results

2.1 Reactor Structure and Measurement Port Locations

The structure of the Wolsong NPP is depicted in Fig. 1. In Figure 1, structure number 3 represents the Vertical Flux Detector units (VFDs), which are integral components for inserting detectors to control and monitor within the reactor core. The Wolsong NPPs are equipped with 26 VFDs strategically positioned along the upper portion of the reactor vessel. Due to the symmetry of the VFD locations, the analysis focuses on defining measurement port locations for one-quarter of the core's circumference, as shown in Fig. 2. Utilizing the RFSP code, computational simulations are conducted to analyze neutron flux distribution within the reactor core, with an emphasis on identifying optimal measurement port locations conducive to radioisotope production.

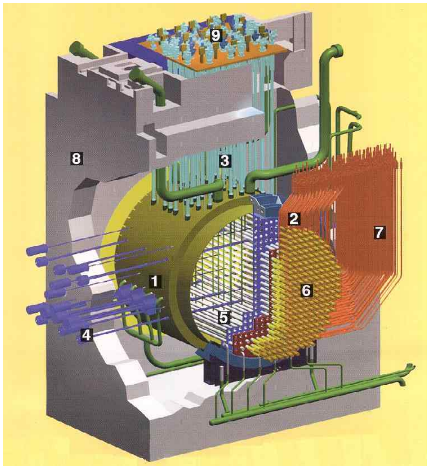

Fig. 1 Configuration of CANDU

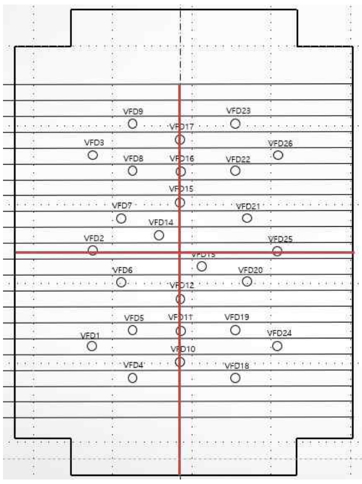

Fig. 2 Layout of VFD Placement: Reactor Top View

2.2 Characteristics of Raw Material Yb-176 for Neutron Irradiation

The raw material to be inserted into the reactor core is Yb-176, which undergoes neutron irradiation to transform into Yb-177 and subsequently decays into Lu-177. Yb-176 serves as a precursor for the production of Lu-177, a crucial radioisotope utilized in various medical applications, including prostate cancer therapy. Understanding the neutron activation process and decay chain dynamics is essential for optimizing radioisotope production efficiency within the reactor core.

2.3 Analysis of RFSP Results and Selection of Optimal Measurement Ports

Utilizing the RFSP code, computational simulations are conducted to model neutron flux distribution for nine out of the twenty-six ports illustrated in Figure 2 within the reactor core. The results obtained from these simulations provide insights into neutron flux intensity at various measurement port locations. Through the analysis of these results, the goal is to identify the port location and vertical position where the neutron flux is at its maximum, thereby ensuring efficient radioisotope production. Additionally, detailed analysis and comparison of neutron flux distributions at different measurement ports are conducted to determine the most suitable ports for facilitating the production of Lu-177.

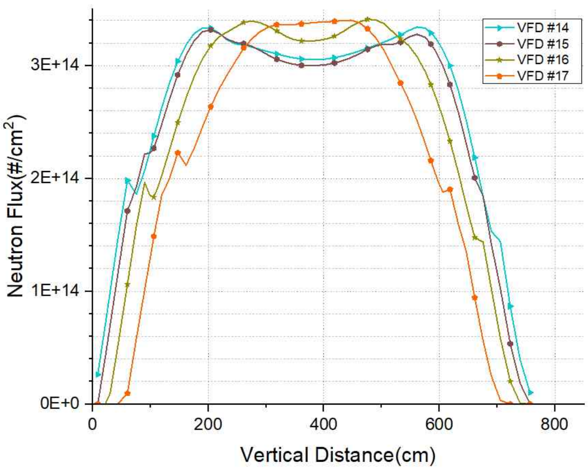

Fig. 3 Neutron Flux Profiles at VFD locations

Additionally, it is necessary to address potential false signals caused by beta radiation from the irradiated target to the platinum detector which provide signals for controlling LZC and SDS#1. While reactors are designed to operate for power generation purposes, the introduction of materials for isotope production and the subsequent radiation from these materials raise concerns about potential additional radiation affecting instrumentation and causing signal inaccuracies. The platinum detector, due to its immediate response, may provide false signals while extracting irradiated material. it could lead to a reactor power drop due to unnecessary signals.

3. Conclusions

In summary, this research aims to meet the increasing demand for medical radioisotopes, particularly in prostate cancer therapy, by optimizing measurement port locations and addressing associated challenges. The primary objective of this study was to identify ports for inserting raw materials efficiently within nuclear reactor cores. Additionally, future investigations will focus on assessing the impact of radiation-induced signal interference on instrumentation, ensuring accurate measurements and enhancing the overall efficiency of radioisotope production processes. Through these efforts, this study contributes to advancing the field of medical radioisotope production and meeting the growing needs of healthcare applications.

REFERENCES

[1] National Cancer Information Center. (2021). Cancer Statistics by Age Group: 2021. Retrieved from www.cancer.go.kr