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Analysis of Radionuclide Releases from Long Term Station Blackout Accident from the Potential Nuclear Reactor Technologies in Uganda

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1. Introduction

As stated in its 2002 energy policy and Uganda's Vision 2040, Uganda is looking into the potential of incorporating nuclear energy into its energy mix. This action seeks to address the anticipated increase in energy demand for sustainable and industrial growth while also adhering to measures to mitigate climate change by lowering carbon emissions in the nation [1]. Uganda intends to construct two nuclear power plant units, each with a capacity of 1000 MW, with the first unit scheduled to commence operations in 2031. A comprehensive feasibility study carried out by the country recommends the deployment of Pressurized Water Reactor (PWR) from the AP1000, APR1000, or VVER1000, for the project [2]. This study's objective is to analyze and recommend the best technology that, in the case of a serious nuclear accident, the amount of radionuclides released into the environment is minimal. Previous studies have indicated that the loss of coolant accident and the long-term station blackout (LTSBO) are rated as severe accidents, but the LTSBO is much more serious since it usually takes a longer period of time, which is the reason for which it was chosen in this study to compare the quantities of radionuclides released by the various proposed technologies [3]. The LTSBO is classified as a Beyond Design Basis Accident that occurs when both the on-site and off-site power sources fail to supply electricity, typically as a result of natural disasters such as earthquakes, tsunamis, tornadoes, violent winds, and flooding [4]. The LTSBO accident gets more serious when the Emergency Core Cooling System (ECCS) of the NPP fails to work and the core uncovers resulting in the release of radionuclides into the atmosphere [5]. This study focused on mainly four radionuclides of ^{133}Xe, ^{131}I, ^{134}Cs, and ^{137}Cs which pose serious risks to human health and the environment [6].

In this research, four different reactor technologies: AP1000, APR1000, and VVER1000 were examined. All four reactor types were subjected to a simulation of the LTSBO accident, which exposed the reactor core for three hours, with each reactor type having a gross electrical capacity of 1000 MWe.

2. Methods and Results

This section describes the LTSBO accident sequence, scenarios, and the graphical representation of the simulation results and their analysis. The accident sequences were divided into three parts namely with no ECCS and with the presence of the ECCS designed to mitigate the LTSBO for a period of 24 hours and 48 hours. The sequence of the accident is indicated in table 1 for the descriptions. Nuclear power plants are designed with appropriate active and passive ECCS to mitigate the progression of accident to a more serious and dangerous state.

Table I: Accident sequence during the LTSBO

Scenario	Time taken before radionuclides are released	Event description
A	8 hours	Reactor shut down occurred at 04:00 and due to no passive ECCS, the core uncovered after 8 hours [this is the RASCAL default LTSBO PWR delay time between loos of coolant and the start of release). The core was recovered after a period of 3 hours.
B	32 hours	Reactor shut down was at 04:00 and due to the presence of the passive ECCS for 24 hours, the release of the radionuclides started after 32 hours [8h+24h] on the second day.
C	56 hours	Reactor shut down was at 04:00 and due to the presence of the passive ECCS for 48 hours, the release of the radionuclides started after 56 hours [8h+48h] on the third day.

A leak rate of 0.5 % vol/day was assumed and the radionuclide release was for 3 hours with the sprays off in all scenarios A, B and C during the LTSBO. The software code of RASCAL 4.3.4 was used to obtain the source terms in line with these assumptions and the accident sequence and scenarios indicated in Table I.

Fig. 1 presents the individual radionuclide releases for each reactor technology, both with and without the passive Emergency Core Cooling System (ECCS). Across all three scenarios, the amount of each radionuclide released decreased, with ^{133}Xe, ^{131}I, ^{134}Cs, and ^{137}Cs showing the lowest levels of atmospheric release. Furthermore, while ^{133}Xe, ^{131}I exhibited a gradual decrease from scenario A to C due to their short half-lives of 8.02 days and 5.27 days respectively, ^{134}Cs, and ^{137}Cs remained constant across all scenarios for each reactor technology. This is because ^{134}Cs, and ^{137}Cs have much longer half-lives of 2 years and 30 years respectively, hence their release amounts cannot be affected within the short simulation time of this LTSBO accident case scenarios.

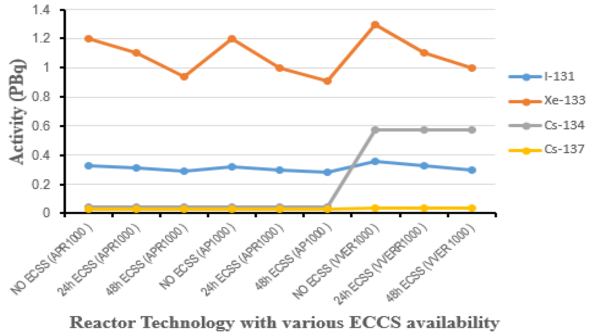

Fig. 1. Individual Radionuclide releases for each technology without and with passive ECCS

The data presented in Fig. 2 demonstrates that the implementation of the Emergency Core Cooling System (ECCS) resulted in a gradual reduction of total activity released by each reactor technology. Notably, the individual reactor technology total activity released followed a clear pattern: AP1000, APR1000, and VVER1000, with VVER1000 recording the highest amount of activity released in all three scenarios. This variation in the total activity released can be attributed to the distinct design features of each reactor technology, particularly with regard to their ability to mitigate beyond-design-basis accident cases. Overall, these findings provide valuable insights into the potential impacts of different reactor technologies in case of a severe accident.

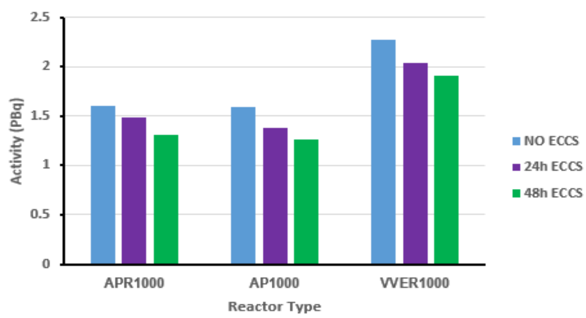

Fig. 2. Total activity releases per technology without and with the passive ECCS.

3. Conclusion

The availability of the ECCS had an effect on the overall activity released per technology in the simulation of the LTSBO using four reactor technologies. The findings demonstrated an increase in the overall activity release from AP1000, APR1000, and VVER1000 Although choosing a technology relies on a variety of factors, including cost, performance, refueling time, vendor preference, operational and accident safety, as well as the ability to reduce accidents, Considering the issue of radiation safety, which is closely related to the amounts of radionuclides that would be released into the atmosphere in the event of a nuclear accident, this study proposes the country to make the selection with preference given to the technology producing the least total activity to the atmosphere and this would be in the order of AP1000, APR1000, and VVER1000.

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