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# Nuclear Power Plant Simulation Game

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**Abstract**

This project focuses on creating a nuclear power plant game simulator that introduces players to the key fundamentals of a nuclear power plant and its systems in an entertaining way. The game features a simulation of the fission chain reaction within the nuclear reactor and a simulation of the power plant's cooling system. The player takes on the role of an operator in the control room, and their goal is to put the power plant into operation and keep it running safely without any accidents. Failure events randomly occur during the power plant's operation, making it more challenging for players to keep the nuclear power plant running safely.

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## 1. Introduction

It is well known that nuclear power is one of the most efficient and powerful sources of electricity worldwide today. However, only a small fraction of people truly understand what it takes to operate these nuclear power plants and how to operate them safely. Some nuclear power plants offer guided tours to the public, providing a brief overview of how the facility works and how it is operated. While these tours can be informative on a theoretical level, they typically do not focus on the practical aspects of the power plant operation.

The goal of this work was to develop a game simulator that places the player in the role of the power plant operator, allowing them to learn the fundamentals of plant operation through hands-on experience. The player gets to experiment with all the systems and learn through this direct engagement. This project includes the creation of simulation models of real systems used in the power plant, specifically the simulation of the fission chain reaction within the reactor and the nuclear power plant's cooling system.

To enhance immersion, the game's visuals are highly inspired by the Chernobyl Nuclear Power Plant, specifically Unit 4. The simulator also features random real-world failure events to make the game more entertaining and engaging. Players must respond appropriately to these events to avoid possible accidents and maintain safe operation.

## 2. Fission Chain Reaction Simulation

The fission chain reaction is a process that occurs within the nuclear reactor core and is used to generate thermal power. In this process, the nucleus of a heavy atom is split into two smaller nuclei while releasing a large amount of energy and more neutrons. These newly released neutrons can trigger more fissions, creating a fission chain reaction. Nuclear power plants most commonly use *uranium-235* as the fissile material. Its nucleus can split more than 40 different ways, producing over 80 different fission fragments [1]. For simplification, this game simulator considers only one specific way of nuclear fission, which is graphically illustrated in **Figure 1**.

Simulating this reaction is necessary to determine the thermal power that is being generated. The neutron flux in the reactor core is continuously simulated and computed using the Runge-Kutta numerical method. The differential equation used for this simulation is presented as equation **(1)** in the poster.

The reactor's reactivity is affected by control rods, which can be moved by the player. There are specific control elements that allow the player to interact with these control rods. They are shown in **Figure 2**. To move a rod, the player must first select it by pressing the colored buttons on the control panel (the light above the button indicates that the rod is selected). Once the desired control rods are selected, the player can use a small lever to insert or withdraw the selected control rods.

## 3. Cooling System Simulation

The cooling system is an essential part of nuclear power plants. All components of the reactor are designed to operate at a specific temperature limit. The cooling system ensures that enough heat is removed from the reactor and prevents failure of components or a reactor core meltdown. Importantly, the additional heat is used to create steam, which drives the steam turbine, leading to electricity power generation.

The cooling system of a pressurized water reactor used in this game simulator is divided into three circuits. The primary circuit cycles the coolant between the reactor core vessel and the heat exchanger. The secondary circuit is used to transfer heat from the primary circuit coolant to the secondary circuit coolant by using the heat exchanger. The tertiary circuit cools the secondary circuit and cools the coolant itself using a specific physical process inside the cooling tower. The flow of the coolant and the interaction between specific parts within the cooling system is visualized in **Figure 3**.

The basic specific heat capacity formula is used to derive the differential equation used to describe the temperature change over time based on the incoming heat [2]. This equation is presented as equation **(2)** in the poster. Each part of the cooling system computes its coolant's outlet temperature based on its inlet coolant's temperature and coolant flow rate. This simulation is continuous as well.

The player can turn on and off specific water pumps, which are used to circulate the coolant. The state of these pumps directly affects the coolant flow rate and the amount of heat transferred. Switches are used to control both the water pumps and the turbine, which can be seen in **Figure 4**. The temperatures within each part of the cooling system are displayed to the player on rectangular indicators located at the upper part of the control panel.

By default, this game simulator uses specific coolant properties for water, but the player can set custom values for these properties before starting the game.

## 4. Failure Events System

The simulator includes random real-world failures that affect other power plant systems. These events include power outages, turbine failures, or water pump failures. The consequences of the event depend on the specific type and cause of each failure.

The simulation of this system is discrete and is described by the Petri net, which can be seen in **Figure 5**.

The core logic of this system involves the generation of random events after the time intervals determined by an exponential distribution. Once an event occurs, its type is chosen based on defined probabilities. The event then becomes active, begins to affect other relevant systems, and the player is notified that this failure has occurred. The player can initiate the repair of this failure using the telephone game object placed on the left of the control panel. Interacting with the telephone opens an in-game window (**Figure 6**), where the player can choose the specific part of the power plant he wants to be repaired. Once the repair is requested, a loading bar is shown to indicate how much longer this repair will take. While the repair is still in progress, the player must ensure that the power plant remains in a safe state.

Each type of failure also maintains the cause of this failure, which affects how critical the failure is and how long it takes to repair it. The maximum amount of active events at the same time is limited, as well as the minimal time duration between the occurrence of events with the same failure type. The frequency, probabilities and other mentioned aspects of possible failures are influenced by the difficulty of the game chosen by the player in the main menu when starting a game.

## 5. Conclusions

This project has developed a nuclear power plant simulator using the Unity game engine that provides players entertaining and interactive learning experience about the fundamentals of a nuclear power plant. By simulating the fission chain reaction and the cooling system, the game allows the player to experiment with the model of a nuclear power plant and help them understand processes involved in energy production and maintenance not only theoretically.


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## References


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