MINIATURIZED NUCLEAR-POWERED BUS OPERATING SYSTEM

Program and System Specifications

Introduction

This article describes the process of designing and developing the miniaturized nuclear-powered control system for operating buses with specifications. The control system was designed and implemented using Ada-Spark. The system is inspired by The Big Bus (1976) American disaster comedy film which follows the maiden cross-country trip of an enormous nuclear-powered bus named Cyclops [1].
This nuclear control system of the bus includes:

- Activating and Deactivating the Nuclear Reactor.
- Starting the Bus.
- Managing the control rods of the reactor.
- Starting and Stopping the bus (managing the speed limit)
- Management of Nuclear radioactive waste.
- Management of water supply for cooling the reactor.

Preconditions and Assumptions

- There is always a minimum number of control rods in the reactor (at least 1)
- The water system is always full at the beginning.
- The reactor is activated by default at the beginning.
- The power increases or decreases by 20.
- The value of power used is the same as the speed limit of the bus.

System Structure

Reactor Activation System

By default, the reactor is activated. By using the toggle option we can *activate/deactivate* the reactor.

Control Rods Management System

By default, there are all control rods on the reactor. We can either *add* (if not full) or *remove* (if not empty) the control rods. The number of control rods determines the power needed to run the reactor and the temperature of the system. The power required and the temperature of the system are inversely proportional to the number of rods. For Example: If the reactor has a minimum control rod i.e., 1 then the power required is maximum (100) and the temperature is increased by 5 and if the reactor has maximum control rods i.e., 5 then the power required is minimum (20) and temperature is increased by 1 only.

Reactor Operating System

Conditions

- To run the reactor, it must be activated first.
- The temperature of the system should be less than Max Temperature – 5.
- The speed of the bus should be less than the maximum speed and speed limit of the bus.
- There should be at least a minimum of control rods in the reactor.
- The radioactivity of the reactor should be less than the maximum radioactivity.

Results: The reactor is started and temperature and radioactivity increase.

Bus Start/Stop System

- To start the bus the initial speed should be 0.
- The reactor must be activated.
- Once started the bus will gain speed.
- Conditions where the bus will stop automatically.
    - The system overheats and there is no water supply to cool the system.
    - The radioactive waste has reached the maximum amount.
- Once the bus stops.
    - Speed and power become 0.
    - Temperature falls to a minimum.
    - The water supply can be refilled.
    - Radioactive waste can be removed.

Heating and Water Supply System

- The system will overheat when the temperature reaches a maximum level.
- A water supply is needed to cool the system.
- Water will be supplied automatically when the system overheats.
- The system cools with a rate of 10%. At one time about 5 litres of water is supplied which will drop the temperature by 50. If the water supply runs out and the system overheats the bus will stop for refill.

Radioactive Waste Management

- The radioactive waste is generated as long as the reactor is operating.
- When the waste reaches its threshold, the bus will stop automatically to remove and manage the waste.

The system is implemented in 3 files with additional required SPARK Ada packages.

- bus_control_system.ads
- bus_control_system.adb
- main.adb

Global variables, record type and range are used to store the required information of the system. To execute the system the main.adb file is used, and the system is displayed in the console.

Hazard Analysis Using Event Tree Analysis (ETA)

A sequence of events in this control system will be traced until they may or may not lead to an accident and to identify the sequence of events a decision tree is drawn.

Analysing Case: The Water System Stopped Working *- In this case, if the water supply system or refill process is not working then the temperature keeps on rising and when the maximum temperature is reached the bus will stop and no longer operate*.

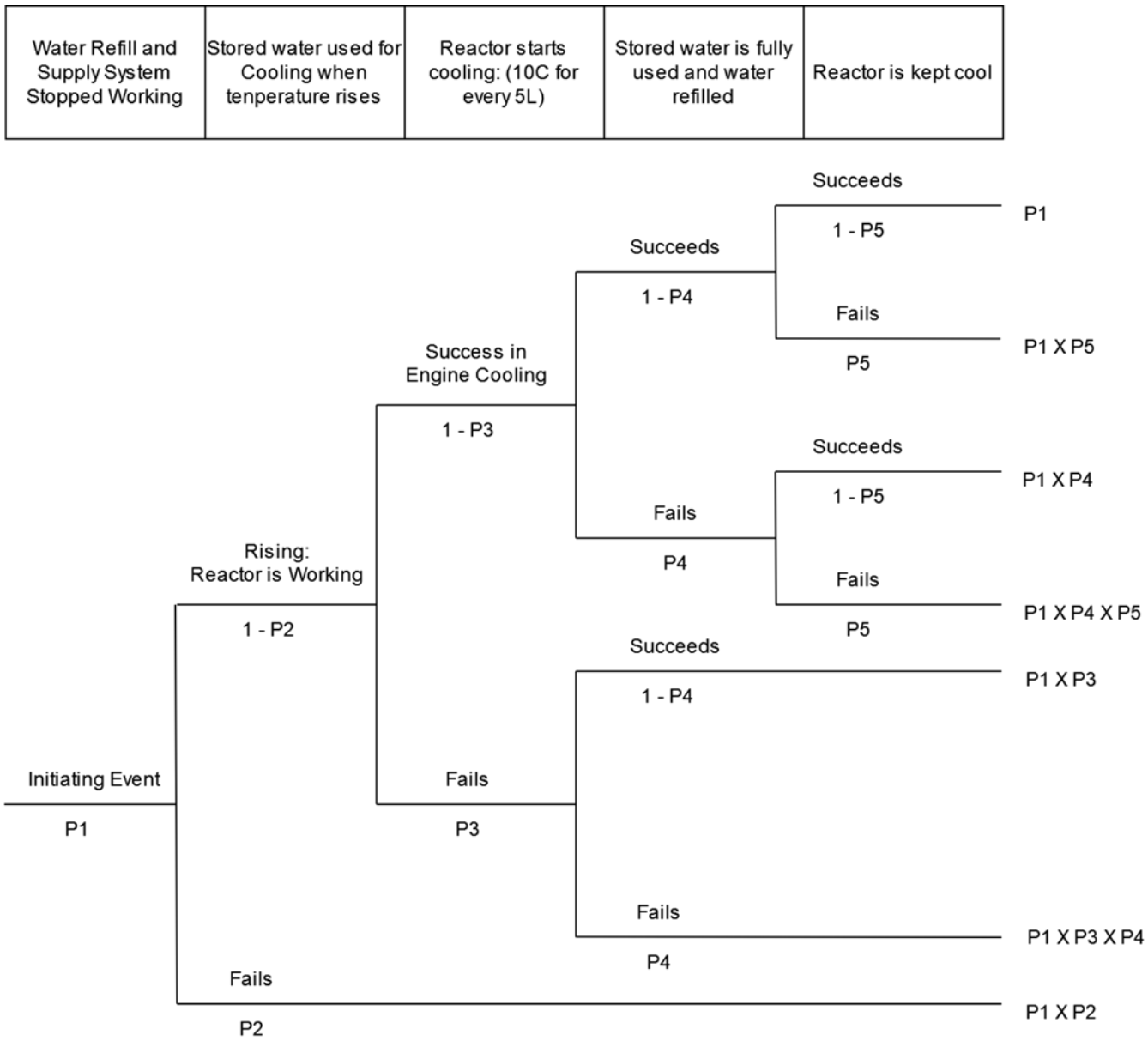

Figure 1: Hazard Analysis

System Demonstration

Control System Console

- The main console of the bus control system
- Have multiple options in the menu to control the system such as:
    - To see the current status of the bus and reactor.
    - To activate/deactivate the reactor.
    - To manage the control rods
    - To start/stop the bus.
    - To manage water supply.
    - To manage radioactive waste.
    - To go back to the main menu and to exit the console.

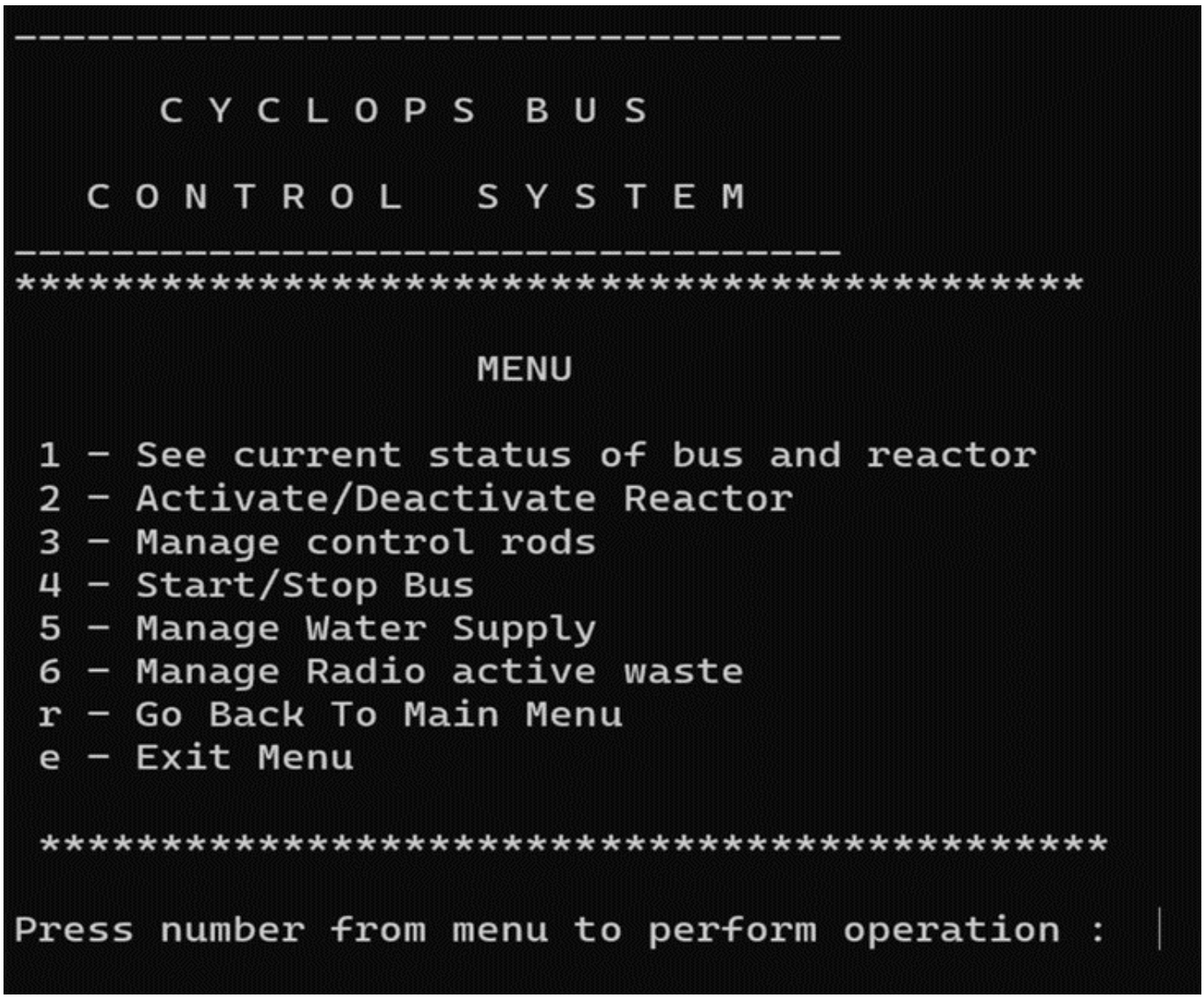

Figure 2: Control System Console and Menu

Pressing 1

System Status

- When menu 1 is pressed, the current status of the bus and reactor are shown.
- Here the status shows that the reactor is activated (by default in the beginning), there are 5 control statuses and the level of water is 50 (always full at the start).

```
Press number from menu to perform operation :  1

 SYSTEM STATUS

 Power :  0
 Speed :  0
 Reactor Status : ACTIVATED
 Control Rods Status :  5
 Water System Status :  50
 Temperature of Reacture :  0
 System Heat Status : NORMAL
 Radio active Waste Status:  0
```

Figure 3: System Status

Pressing 2

Activating/Deactivating Reactor

- By using menu option 2 from the console, we can activate or deactivate the reactor. By default, the reactor is activated.
- **Condition:** If the Reactor is activated and the speed of a bus is 0 then deactivate the reactor.

```
Press number from menu to perform operation :  2
Status of Reactor:DEACTIVATED

Press number from menu to perform operation :  2
Status of Reactor:ACTIVATED
```

Figure 4: Activate/Deactivate Reactor

Pressing 3

Managing Control Rods

- Pressing 3 in the console menu will manage the control rods.
- This includes adding (if not full) and removing (if not empty) the control rods.
- By default, there are all control rods on the reactor which is 5.
- The number of control rods determines the power needed to run the reactor and the temperature of the system. The power required and the temperature of the system are inversely proportional to the number of rods.
- There is always the minimum number of control rods in the reactor (at least 1)

```
Press number from menu to perform operation :  3
type a to add control rod
type b to remove control rod
a
Already have maximum Control Rods

Press number from menu to perform operation :  3
type a to add control rod
type b to remove control rod
b
Control Rod has been removed from the reactor : 4
Control Rod is removed

Press number from menu to perform operation :  1

 SYSTEM STATUS

 Power :  0
 Speed :  0
 Reactor Status : ACTIVATED
 Control Rods Status :  4
 Water System Status :  50
 Temperature of Reacture :  0
 System Heat Status : NORMAL
 Radio active Waste Status:  0
```

Figure 5: Control Rods Management

Pressing 4

Starting the bus

- Press 4 to start/stop the bus
    - Conditions to start the bus:
        - The reactor must be activated
        - The initial speed should be 0

```
Press number from menu to perform operation :  4

Press number from menu to perform operation :  Max Bus Speed : 80 Speed :  2  Temperature of Reactor :  4  Radioactive W
aste :  1   System Heating : NORMAL
Max Bus Speed : 80 Speed :  3  Temperature of Reactor :  8  Radioactive Waste :  2   System Heating : NORMAL
Max Bus Speed : 80 Speed :  4  Temperature of Reactor :  12  Radioactive Waste :  3   System Heating : NORMAL
Max Bus Speed : 80 Speed :  5  Temperature of Reactor :  16  Radioactive Waste :  4   System Heating : NORMAL
Max Bus Speed : 80 Speed :  6  Temperature of Reactor :  20  Radioactive Waste :  5   System Heating : NORMAL
Max Bus Speed : 80 Speed :  7  Temperature of Reactor :  24  Radioactive Waste :  6   System Heating : NORMAL
Max Bus Speed : 80 Speed :  8  Temperature of Reactor :  28  Radioactive Waste :  7   System Heating : NORMAL
Max Bus Speed : 80 Speed :  9  Temperature of Reactor :  32  Radioactive Waste :  8   System Heating : NORMAL
Max Bus Speed : 80 Speed :  10  Temperature of Reactor :  36  Radioactive Waste :  9   System Heating : NORMAL
Max Bus Speed : 80 Speed :  11  Temperature of Reactor :  40  Radioactive Waste :  10   System Heating : NORMAL
Max Bus Speed : 80 Speed :  12  Temperature of Reactor :  44  Radioactive Waste :  11   System Heating : NORMAL
Max Bus Speed : 80 Speed :  13  Temperature of Reactor :  48  Radioactive Waste :  12   System Heating : NORMAL
```

Figure 6: Starting the bus

As we can see the bus has started to gain speed, the temperature of the reactor starts rising, radioactive waste is increasing and the system heat is also rising.

Once the temperature of the reactor reaches greater than 200, a notification of reactor system overheating is displayed and water supply to the reactor has started. The system heating is now changed to high from normal. The value of water 5 (50-5=45 remaining) is used to reduce the temperature by 50. The new reactor temperature is down to 158 from 204. The temperature will again start to rise until it again reaches greater than 200, which then requires another water supply.

```
Max Bus Speed : 80 Speed :  50  Temperature of Reactor :  196  Radioactive Waste :  49   System Heating : NORMAL
Max Bus Speed : 80 Speed :  51  Temperature of Reactor :  200  Radioactive Waste :  50   System Heating : NORMAL
Max Bus Speed : 80 Speed :  52  Temperature of Reactor :  204  Radioactive Waste :  51   System Heating : NORMAL
Reactor system is overheating, supply water. Heat Status: HIGH
Supplying water to the reactor.
Remaining Water Amount:  45
Max Bus Speed : 80 Speed :  53  Temperature of Reactor :  158  Radioactive Waste :  52   System Heating : HIGH
Max Bus Speed : 80 Speed :  54  Temperature of Reactor :  162  Radioactive Waste :  53   System Heating : HIGH
Max Bus Speed : 80 Speed :  55  Temperature of Reactor :  166  Radioactive Waste :  54   System Heating : HIGH
Max Bus Speed : 80 Speed :  56  Temperature of Reactor :  170  Radioactive Waste :  55   System Heating : HIGH
```

Figure 7: Notification of reactor speed overheating, water supply has started

The reactor temperature has again reached greater than 200 and a similar case to the above is repeated. In the figure below we can also see that the bus has reached its maximum speed as well.

```
Max Bus Speed : 80 Speed :  75  Temperature of Reactor :  196  Radioactive Waste :  74   System Heating : HIGH
Max Bus Speed : 80 Speed :  76  Temperature of Reactor :  200  Radioactive Waste :  75   System Heating : HIGH
Max Bus Speed : 80 Speed :  77  Temperature of Reactor :  204  Radioactive Waste :  76   System Heating : HIGH
Reactor system is overheating, supply water. Heat Status: HIGH
Supplying water to the reactor.
Remaining Water Amount:  35
Max Bus Speed : 80 Speed :  78  Temperature of Reactor :  158  Radioactive Waste :  77   System Heating : HIGH
Max Bus Speed : 80 Speed :  79  Temperature of Reactor :  162  Radioactive Waste :  78   System Heating : HIGH
Max Bus Speed : 80 Speed :  80  Temperature of Reactor :  166  Radioactive Waste :  79   System Heating : HIGH
Bus has reached its maximum speed limit
Max Bus Speed : 80 Speed :  80  Temperature of Reactor :  170  Radioactive Waste :  80   System Heating : HIGH
Bus has reached its maximum speed limit
Max Bus Speed : 80 Speed :  80  Temperature of Reactor :  174  Radioactive Waste :  81   System Heating : HIGH
Bus has reached its maximum speed limit
```

Figure 8: The Reactor is overheating, the water supply has started and the bus has reached its maximum speed

The process continues.

Case 1: The bus has now stopped automatically as there is no more water supply to cool the system as shown in the figure below. Water needs to be refilled with the option 5.

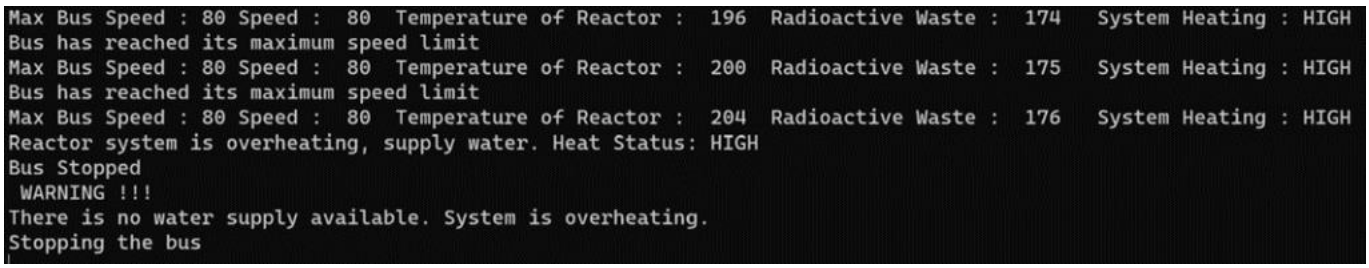

Figure 9: Bus stopped automatically due to high heat and no water supply

Case 2: In this case, the system temperature is under control, but the radioactive waste has reached its maximum level, triggering the bus-stopping function. The bus stops automatically, and the waste needs to be removed to continue the journey.

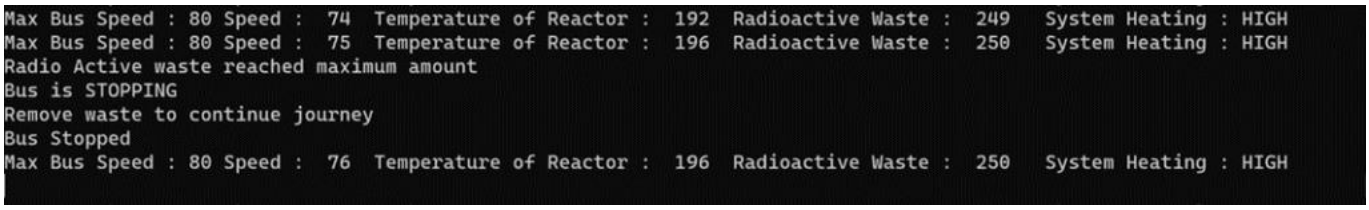

Figure 10: Bus stopped automatically - radioactive waste reached the maximum

The code for the system and pdf version of this article can be found here: ***GitHub***

References

[1]L. J. C. Fred Freeman, “The Big Bus,” 22 10 1976. [Online]. Available: https://www.imdb.com/title/tt0074205/. [Accessed 25 November 2022].