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SIMULATION OF A NORMAL TRIP OF PWR TYPE REACTOR USING PCTRAN SIMULATOR

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Abstract

This study focuses on monitoring the evolution of the hydrothermal parameters of a pressurized water reactor, with an estimated electrical output power of 600 MWe, using a simulator called PCTRAN, version 6.0.4, available from the IAEA, which is based on a generic two-loop pressurized water reactor (PWR) system

In the second scenario, a forced shutdown was attempted by the immediate insertion of the control rods, which resulted in confusion in the water levels inside the compressor, the steam generator, as well as the flow rate of the first cooling cycle. The effectiveness of the protection system inside the reactor to avoid any emergency situation or change Out of control for various hydrothermal parameters

The changes in the parameters of the installation did not result in any accident or unexpected danger, these parameters eventually returned to their acceptable values.

Keywords: PCTRAN, Thermal hydraulics, PWR, turbine leading mode, negative reactivity.

1. Introduction:

Nuclear power provides efficient and reliable electricity around the world [1]. Today, more than 400 commercial reactors are operating in more than 30 countries. The common definition of nuclear energy is the energy released by a chain reaction, such as fission or fusion. In practice, nuclear power uses fuel made from mined and processed uranium to produce steam and generate electricity. Nuclear power generation is the only source of electricity that can reliably produce a constant supply of electricity, known as baseload energy, without emitting greenhouse gases [2-3]. Nuclear energy has one of the lowest environmental impacts on land and natural resources of any electricity source. Nuclear power plants are a type of power plant that uses the process of nuclear fission to generate electricity. To do this, they use nuclear reactors in combination with the Rankine cycle, where the heat generated by the reactor converts water into steam, which turns a turbine and generator. Nuclear power provides the world with about 11% of its total electricity, with the largest producers being the United States and France [4].

Aside from the heat source, nuclear power plants are very similar to coal-fired power plants [5]. However, they require different safety measures because the use of nuclear fuel has very different properties than coal or other fossil fuels. They derive their thermal power from splitting the nuclei of atoms in their reactor core, with uranium being the dominant fuel of choice in the world today. Thorium also has potential use in nuclear power generation [6], but it is not currently used. Below is the basic operation of a boiling water power plant, which shows the many components of a power plant, as well as how the electricity is generated.

The field of study of nuclear thermal hydraulics is devoted to improving the current understanding of heat and mass transfer processes and fluid mechanics that transport energy and mass in nuclear systems and govern system performance and safety [7-8]. Key phenomena studied include conduction, convection and radiant heat transfer, phase change, and single- and multi-phase flows. In addition to the water used to transport heat in current reactors, the study in this area also covers gases, molten salts and coolants for advanced fission and fusion systems, as well as transport and mixing processes that occur inside reactor containment structures and in environmental systems.

This study focuses on monitoring the evolution of the hydrothermal parameters of a pressurized water reactor, with an estimated electrical output power of 600 MWe, using a simulator called PcTRAN [9-10].

2. PCTRAN

The simulator used in this work is called PCTRAN [11], version 6.0.4, available from the IAEA, which is based on a generic two-loop pressurized water reactor (PWR) system with inverted U-curvature (SG) and dry containment steam generators. The PWR, as noted above, is generic and could represent a Westinghouse, Framatome Design [12], or Kraftwerk Union with a thermal output of 1800 MW (th) (600 MW (e)).

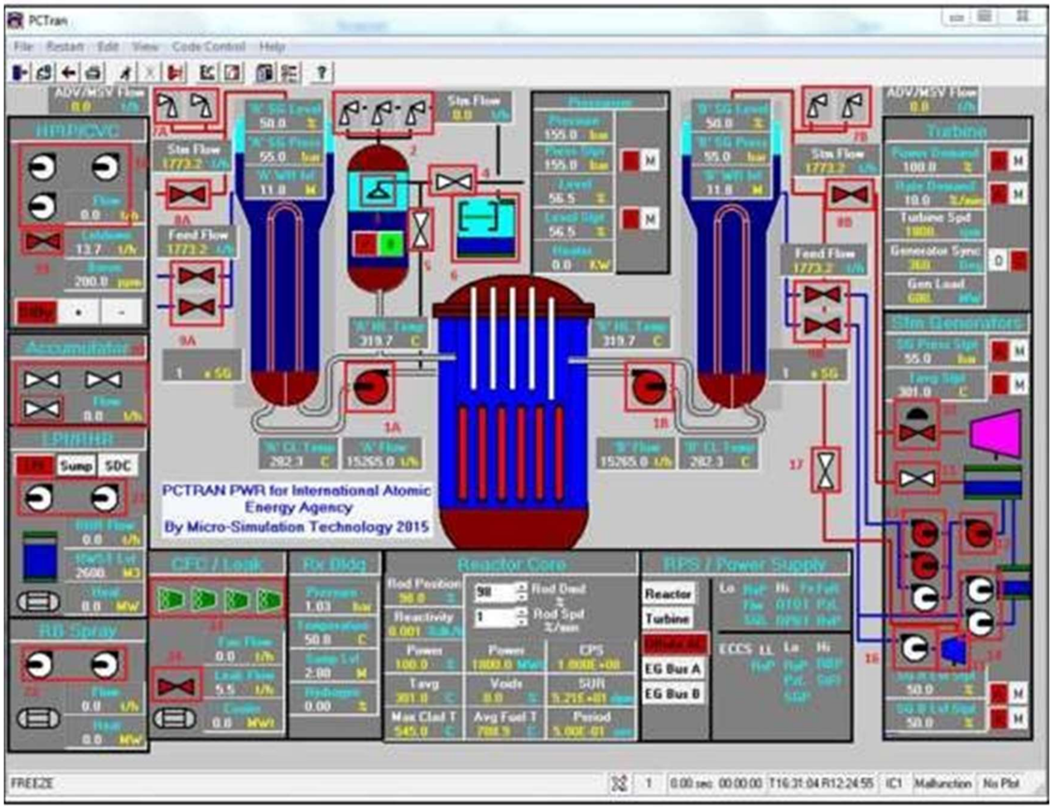
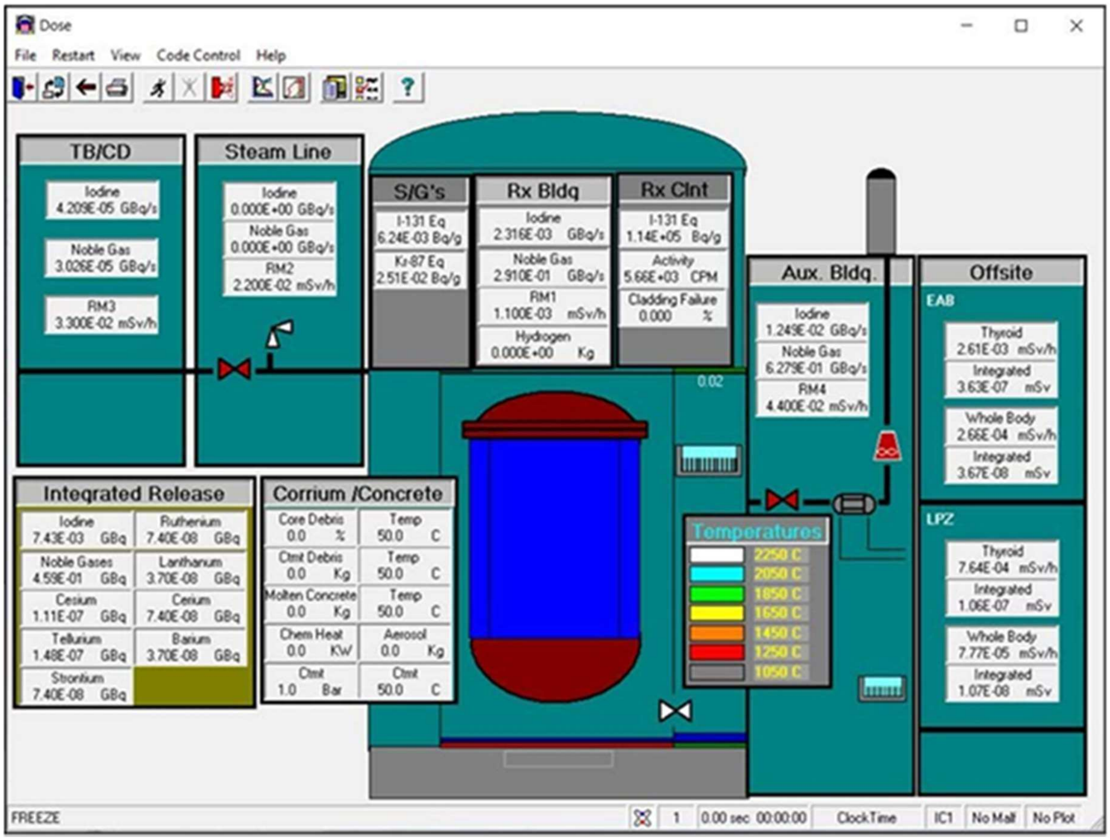


Figure. 1. Imitation screen of PCTRAN main system.



TB/CD
Iodine 4.209E-05 GBq/s
Noble Gas 3.026E-05 GBq/s
RM3 3.300E-02 mSv/h

Steam Line
Iodine 0.000E+00 GBq/s
Noble Gas 0.000E+00 GBq/s
RM2 2.200E-02 mSv/h

S/G's
I-131 Eq 6.24E-03 Bq/g
Kr-87 Eq 2.51E-02 Bq/g

Rx Bldg
Iodine 2.316E-03 GBq/s
Noble Gas 2.910E-01 GBq/s
RM1 1.100E-03 mSv/h
Hydrogen 0.000E+00 Kg

Rx Clnt
I-131 Eq 1.14E+05 Bq/g
Activity 5.66E+03 CPM
Cladding Failure 0.000 %

Aux. Bldg.
Iodine 1.249E-02 GBq/s
Noble Gas 6.279E-01 GBq/s
RM4 4.400E-02 mSv/h

Offsite
EAB
Thyroid 2.61E-03 mSv/h
Integrated 3.63E-07 mSv
Whole Body 2.66E-04 mSv/h
Integrated 3.67E-08 mSv
LPZ
Thyroid 7.64E-04 mSv/h
Integrated 1.06E-07 mSv
Whole Body 7.77E-05 mSv/h
Integrated 1.07E-08 mSv

Integrated Release
Iodine 7.43E-03 GBq
Ruthenium 7.40E-08 GBq
Noble Gases 4.59E-01 GBq
Lanthanum 3.70E-08 GBq
Cesium 1.11E-07 GBq
Cerium 7.40E-08 GBq
Tellurium 1.48E-07 GBq
Barium 3.70E-08 GBq
Strontium 7.40E-08 GBq

Corrium /Concrete
Core Debris 0.0 %
Temp 50.0 C
Ctmt Debris 0.0 Kg
Temp 50.0 C
Molten Concrete 0.0 Kg
Temp 50.0 C
Chem Heat 0.0 KW
Aerosol 0.0 Kg
Ctmt 1.0 Bar
Ctmt 50.0 C

Figure. 2. Dose mimic PCTRAN screen.

PCTRAN models two reactor cooling system (RCS) loops, represented by loop A and loop B in the simulator. Figure 1 shows the main synoptic display of the PCTRAN installation that appears when the simulator is launched. It shows the main systems and their components such as the RCS, the Emergency Core Cooling System (ECCS), the turbine-generator system and the Reactor Protection System (RPS), in a single unified screen. Pumps and valves as shown in the figure. III.1. The components are numbered in order to describe them in the table and is intended to help the user better understand the components.

The components that exist in both loops are distinguished by A and B; e.g. pumps 1A and 1B and valves 8A and 8B. The red-colored components indicate the operation of open pumps and valves, while the white-colored components are vacuum pumps and closed valves. The mimic system is interactive and valves and pumps can be turned on/off by simply clicking on them. An alternative to the main synoptic display is the synoptic dose display shown in FIGURE.2.

3. Results et Discussions:

The reactor protection system (RPS) shuts down a PWR plant when certain safety system parameters, or instructions, are reached or controlled by the operator. Some of the crucial parameters, such as the pressure inside the pressurizer, the reactor coolant flow rate and the steam generator water level, etc., are continuously compared to the specified safe operating limits, and when a parameter exceeds its limit, the RPS automatically shuts down the reactor. This is called a "reactor trip" or "scram" [13]. With a reactor trigger signal, all control rods are inserted quickly to absorb neutrons in the reactor and thus stop the nuclear fission chain reaction. In this scenario, we will manually trip the reactor and observe how the NPP handles the decay heat of the reactor core after the trip.

3.1. Description of the simulation

To perform this operation in the simulator, Table .1 provides a step-by-step procedure for the simulation with the corresponding values of the relevant variables.

Table.1: Steps in a Normal Reactor Trip Scenario [9]

STEP	PROCEDURE STEPS
Setup	Load initial condition #1 100% POWER EOC, or #2 100% POWER MOC, or #3 100% POWER BOC.
1	Run the simulator for about 5 seconds to achieve a steady-state condition.
2	Freeze the simulation.
3	Manually trip the reactor by clicking the ‘Reactor’ button in the Reactor ProtectionSystem (RPS) section.
4	Resume the simulation (speed up the simulator if needed).
5	Observe the reactor trip and the subsequent turbine trip.
6	Observe the closure of the Main Feedwater Isolation Valves (FWIVs) on low T_{avg} (281°C) at about45 seconds.
7	Observe the automatic actuation of the auxiliary feedwater system on low steam generator waterlevel (17%) at about 1750 seconds.
8	Observe the following variables changing: (1) Rod position (%) (2) Reactor power (MWt) (3) T_{avg} (°C) (4) Pressurizer pressure (bar) (5) Pressurizer level (%) (6) Steam generator pressure (bar) (7) Steam generator level (%)

In step 3, a reactor trip signal is generated manually. FIGURE.3, which corresponds to step 5, shows the tripping of the reactor and turbine due to the automatic triggering of the turbine trip signal when the reactor trip. In step 6, the main feed water is isolated due to the low temperature of the primary system coolant (FIGURE 4).

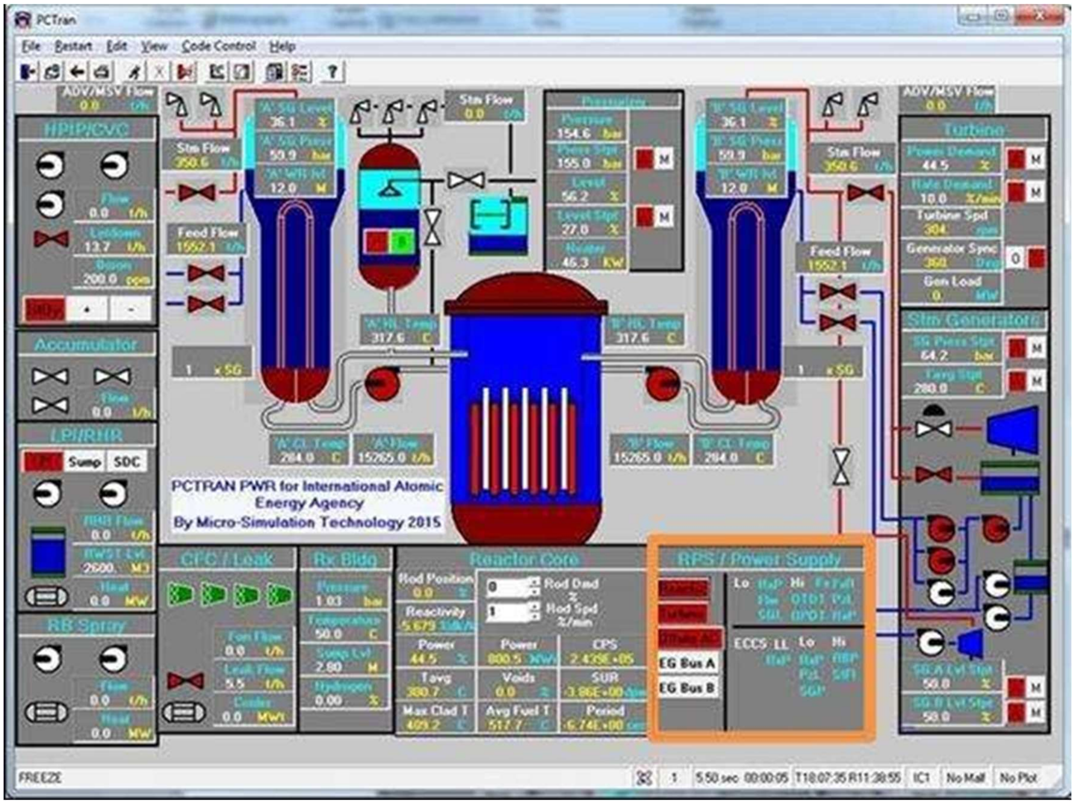


Figure. 3. Manual shutdown of the reactor followed by a turbine shutdown.

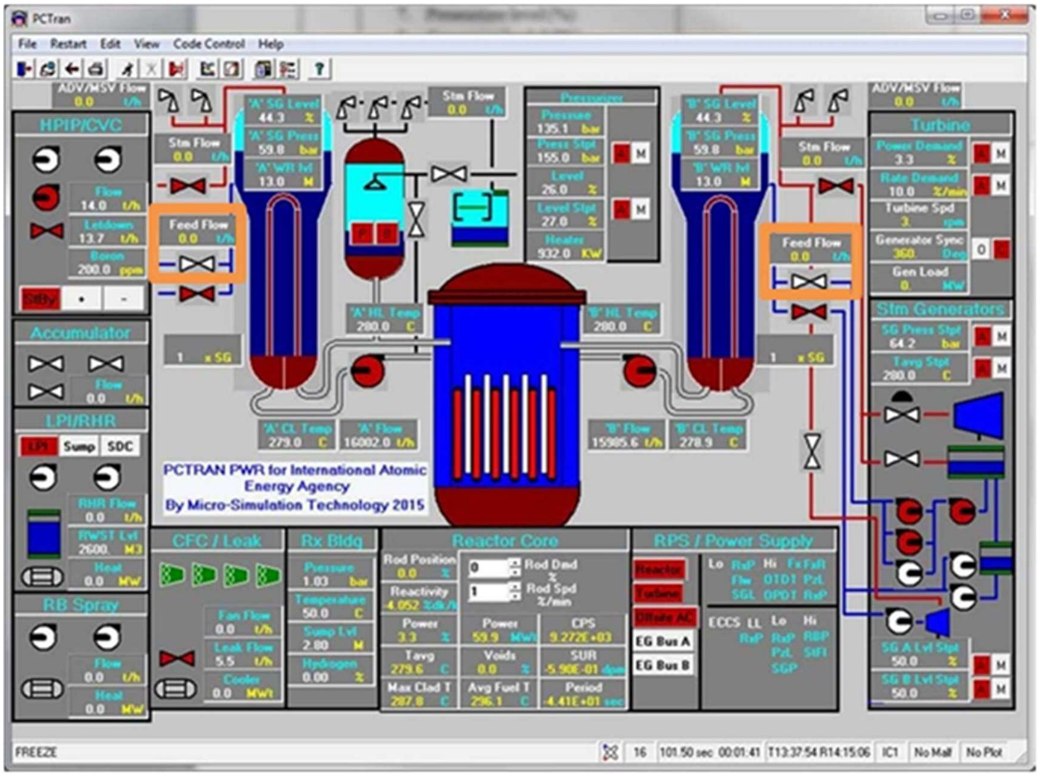


Figure. 4. Closing the feed water isolation valves.

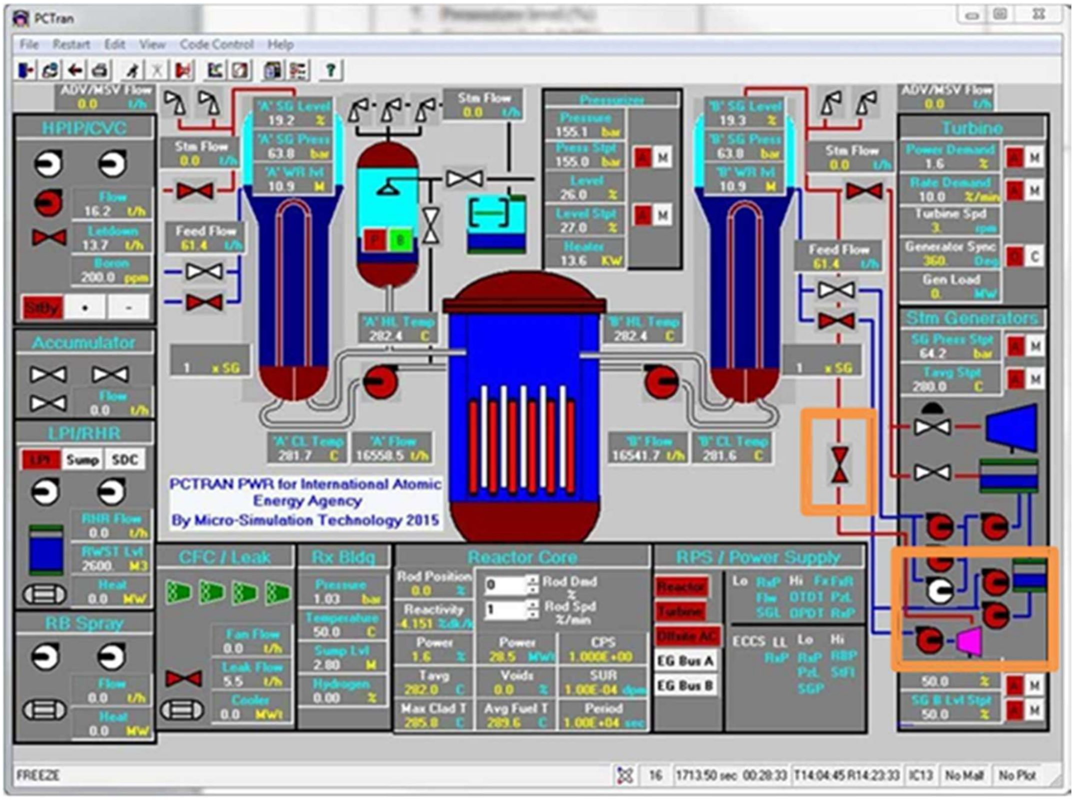


Figure. 5. Powered auxiliary power system.

3.2. Description of transient behavior

A reactor shutdown (or jamming) [14-15] is the result of operator action in the control room or automatic activation of the reactor protection system (RPS). When the RPS is actuated, control rods are quickly inserted into the core within seconds to absorb neutrons, stopping the fission chain reaction. Due to the rapid insertion of the control rod, the power of the reactor core quickly drops to less than 5% (see Figure .6). However, the core still generates waste heat due to the radioactive decay of fission products that have accumulated during reactor operation.

Therefore, to remove waste heat in the core after the turbine is tripped, the turbine bypass valve opens to let the steam flow directly to the condenser. When the SG water level is below a preset value (narrow range of 17%), the auxiliary feedwater (AFW) system, consisting of a turbine-driven auxiliary pump and two motor-driven auxiliary pumps, is automatically actuated to supply feed water to the SGs and maintain a heat sink.

3.3. Description of the transient curve

FIGURE.6 shows the thermal power of the reactor and the turbine load during the simulation. When the reactor trips due to the insertion of control rods, the power of the reactor decreases rapidly; however, it does not immediately reach 0% due to the heat of decay of the fission fragments. On the other hand, the turbine load drops to 0% due to turbine tripping, which occurs quickly after the reactor trip.

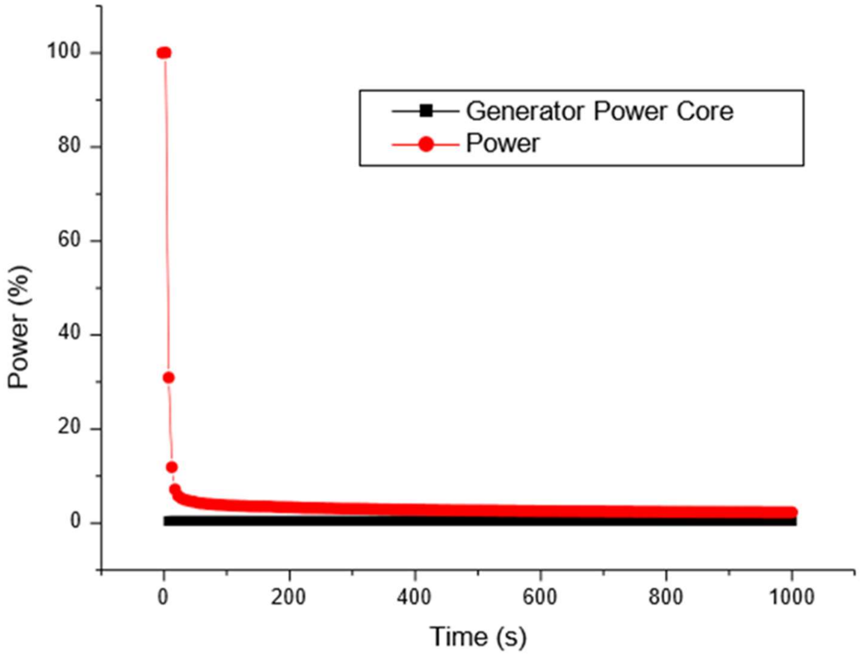


Figure. 6. Reactor Power Output and Turbine Load (%).

The sudden insertion of the rod introduces a large negative reactivity that is sufficient to shut down the reactor in a matter of seconds. The initial negative reactivity spike shown on the FIGURE.7 is due to the rapid insertion of the rod. The abrupt reduction in fuel and coolant temperatures then introduces positive reactivity due to the negative temperature coefficients of the fuel and moderator (MTC). However, the negative reactivity of the control rods then keeps the core subcritical with a significant margin of the order of -4% dk/k.

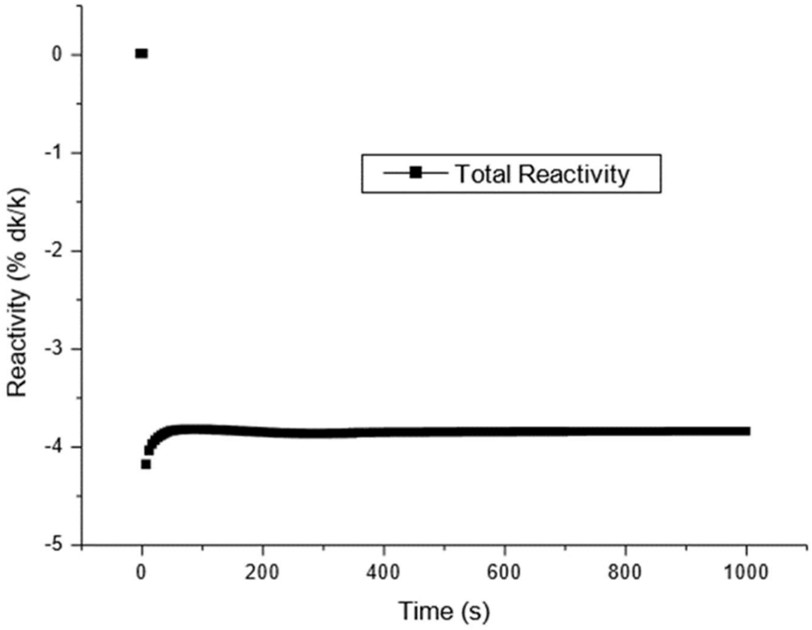


FIGURE. 7. Total reactivity (% dk/k).

FIGURE.8 shows the temperatures of the hot and cold branches of Loop A, as well as the average temperature of the SCR. The temperature of the hot leg decreases rapidly after the reactor is shut down for about the first 100 seconds, then increases for about 150 seconds due to waste heat and reduced heat transfer to the secondary side. Finally, there follows the slow reduction of the decay heat.

The cold leg temperature initially increases due to the closing of the main turbine control valve, which does not involve any heat transfer to the secondary side. It then decreases after the turbine is triggered due to the rapid reduction in core power during the first 100 seconds. Similar to the behavior of hot leg temperature after the first 100 seconds, the cold leg temperature increases for about 150 seconds due to the decay heat and the reduction of heat transfer to the secondary side, and then the slow decay heat reduction follows.

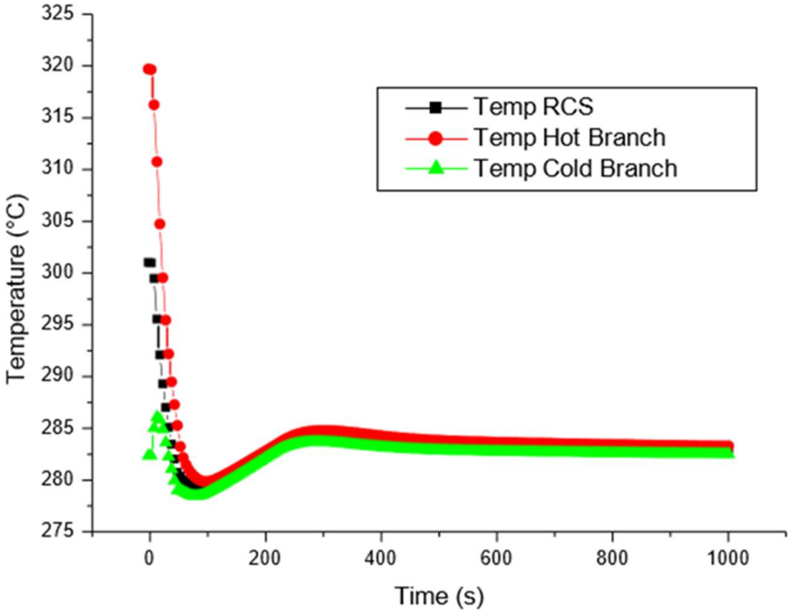


Figure. 8. Reactor water temperature (°C).

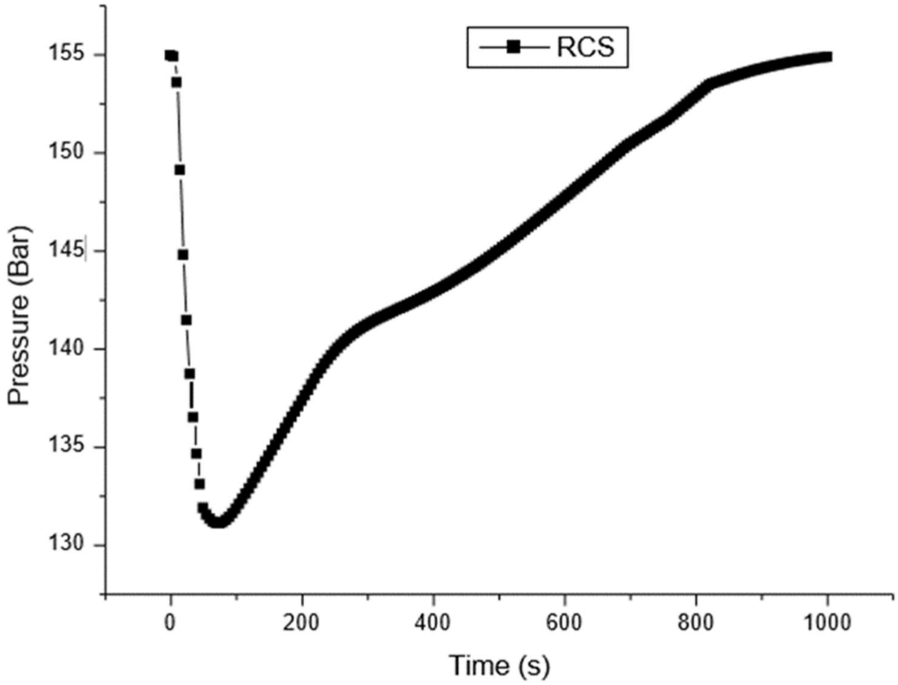


Figure. 9. Reactor cooling system pressure (bar).

Since the pressure of the reactor coolant system is directly dependent on the coolant temperature, the rapid decrease in the average reactor coolant temperature after the reactor shutdown results in a reduction in SCR pressure during the first 100 seconds shown in FIGURE.9. After this reduction, the SCR pressure is increased to the order of 155.0 bar by the automatic actuation of the pressurizer's electrical resistance.

4. Conclusion

In this work, we have tried to provide the reader with elements of understanding of the operation of a pressurized water reactor, by giving him, as far as necessary, some significant characteristics and technical justifications of certain components of a PWR. After a general presentation of the operation of a PWR reactor and its main circuits, the present study is divided into two parts. The first part concerns the theoretical study of the speciation of the primary fluid at 25°C, during the operation and during the cold shutdown of a reactor.

This allowed us to track the evolution of the different components of a nuclear facility, starting with the reactor core where heat is produced by the fission reaction, this is a method that differs from the traditional method in which fossil fuels are burned to produce heat. Monitoring of changes in hydrothermal parameters on the core, compressor, steam generator and turbines. Shows the utmost importance of such a process. An increase in temperature can lead to an increase in pressure and thus an explosion of one of the components of the system.

In the imagined scenario, a forced shutdown was attempted by the immediate insertion of the control rods, which resulted in confusion in the water levels inside the compressor, the steam generator, as well as the flow rate of the first cooling cycle. Effectiveness of the protection system inside the reactor to avoid any emergency situation or out-of-control change for various hydrothermal parameters.

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