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Study on Severe Accidents of the New Generation WWER-1200 Reactor

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ABSTRACT

As the safety of new generation reactors regarding conditions of radioactive material leakage into the environment greatly attracted the attention of engineers and scientists in the nuclear industry, because if these nuclear radioactive materials enter the environment, they will leave irreversible influences on humans and the environment for years, hence, it is environmentally very essential to investigate the safety of nuclear reactors. The wwer-1200 reactor is a reactor under preparation, and many investigation has been performed on its safety, and all research has revealed that this reactor is safe during all accidents. In this research, numerous severe accidents were examined in this reactor. The results indicated that in only one case this reactor go beyond its design safety situations, which is the concurrent incidence of cooling-water loss and a fracture in the lower part of the reactor chamber without emergency cooling systems. And the results revealed the temperature of the fuel pellet and fuel sheath as the central safety layer.

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Introduction

Nowadays, because of the limitations of fossil resources, all developed countries utilize nuclear energy to produce electricity and supply energy. However, humans have not yet been able to provide a comprehensive analysis of nuclear accidents and lessening radioactive contamination. Because the influence of radioactive materials on the human body remains for generations and on the environment for centuries. One of the most significant sources of radioactivity in nuclear power plants is the cooling water of the reactor core as it deals directly with the reactor core and has a lot of radioactive constituents. In new generation reactors, the existence of some autoimmune issues inhibits the release of radioactive substances into the environment. In severe accidents, the risk of environmental contamination by radioactive elements as a result of the melting of the core is more significant than losses during the accident, as radioactive elements remain in the environment for a long time. Among the severe nuclear accidents, we can mention Three Mile Island, which was happened in 1979, as this accident caused the release of many radioactive materials into the environment.

Background

Zeidabadi et al. applied PCTRAN software in the WWER-1200 reactor to study the cooling water loss accident. The findings of their investigation indicated that the temperature and pressure during the cooling water loss accident do not go beyond the design criteria and this reactor is very safe for the environment [1]. Bagheri et al. used PCTRAN software to study the safety system of passive heat removal during the incident of cooling water loss in the WWER-1200 reactor. Their results indicated that by adding the passive heat removal system, safety parameters do not go beyond the acceptable value and improve safety conditions [1]. In severe accidents, the risk of environmental contamination by radioactive elements as a result of the melting of the core is more significant than losses during the accident as radioactive elements remain in the environment for a long time. Among the severe nuclear accidents, we can mention the Three Mile Island (1979) as this accident caused the release of many radioactive materials into the environment [2].Tanim et al. used PCTRAN software to study natural feedwater flow loss, steam generator pipe fracture, cooling loss incidents, and their likely consequences on different parameters such as a change in reactivity, steam flow, feedwater flow, pressure, etc. in WWER-1200 reactor by transient behavior analysis, and concluded that the results of this simulator for simulating nuclear accidents are in good line with the safety analysis report of the nuclear power plant [3]. Hossein Obeid Khan et al. studied the incidence of fracture in the steam line in a VVER-1200 nuclear power plant using PCTRAN software by transient analysis to produce response data of the plant's safety systems for an accident situation. In this research, a 1000 cm2 fracture in ring A of the steam line is considered. This fracture is considered the size of a "major fracture ", which is supposed to be responsible for numerous severe nuclear accidents in the past. It is also supposed that the AC power supply is not accessible off-site. The simulation was conducted for 300 seconds as most of the power plant safety characteristics must respond within 50 seconds of the start of the accident. The findings reveal that SCRAM starts within 22.5 seconds of the beginning of fracture, where the thermal power of the core rises about 105% of its nominal value. The maximum temperature of the fuel pellets and the fuel sheath are around 1850 and 620 0C, respectively, both of which are in the safety range. Lastly, readings from the radiation monitor display that no noteworthy radioactive elements are released into the environment during the accident. Consequently, it can be concluded that the release of radioactive elements in the environment surrounding the site of the steam line fracture is very improbable, provided that the safety systems of the power plant are completely operating [4]. This research aims to analyze the results of the simulation of a steam generator pipe fracture incident in a VVER-1200 nuclear reactor in PCTRAN. In the accident simulation, a 100% fracture of a complete pipe is considered. The simulation results indicate that the pressure and temperature change slightly but do not influence the reactor power and neutron flux because the VVER-1200 nuclear reactor has numerous safety characteristics that are responsible for the safety conditions. Also, the data obtained from the simulation is fully in line with PSAR (preliminary safety assessment report) data about the steam generator pipe fracture accident. These findings are estimated to provide valuable information in understanding and assessing the plant's ability to decrease the consequences of a steam generator fracture accident [2]. Thus far, many simulations have been implemented to analyze the safety of this sort of power plant. Most of the time, an accident was examined about 300 seconds after the accident. In this research, because an accident disrupts the performance of other immune systems and results in other accidents, the concurrent analysis of several different accidents without the functioning of immune systems was also performed. Likewise, because of a more detailed examination of nuclear accidents, we increased the investigation time of nuclear accidents for the long-term influences of these accidents.

Reactor WWER-1200

The WWER-1200 reactor is made in Russia and is a type of pressurized water reactor (PWR). In this reactor, water enters the reactor from the cold base at a temperature of about 290 0C, and in addition to cooling the reactor core, it also slows down neutrons. It then cools the core of the reactor by passing through the core and exits the reactor core at a temperature of 330 0C. It is then transferred to the steam generators through the hot base and after cooling through the cold base returns to the reactor core, and this closed cycle is repeated uninterruptedly during normal operation of the reactor. Table 1 shows the features of the reactor.

Table 1: Characteristics of Reactor

Plant Parameters	Operating Value
Core Thermal Power	3200 MW
Pressure inside Reactor Core Structure	162.0 bar
Pressure inside Reactor Containment Building	1.03 bar
Maximum Cladding Temperature	610.8°C
Maximum Fuel Temperature	1800°C

PCTRAN Simulator

PCTRAN is the most effective simulator for all types of light-water nuclear reactors and is specially designed for different types of power plants including ABWR, AP1000, PWR, and ESBWR. The range of PCTRAN simulation extends to severe BWR accidents and Rad Puff for dose dispersion of all of the above-mentioned items. PCTRAN has been nominated by the International Atomic Energy Agency as the annual training base for International Atomic Energy Agency simulators. Specific simulator models have been installed in nuclear power plants and institutes around the world to be applied in training, analysis, potential safety assessment, and emergency training [4].

Figures 1 and 2 shows the simulation inside and outside the reactor building in this software.

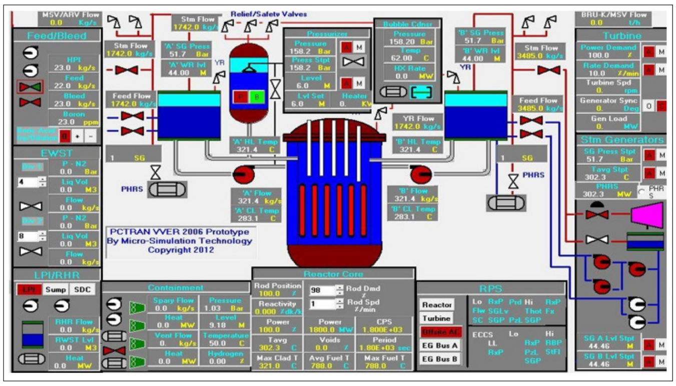

Figure 1: Simulator Environment inside the Reactor Building

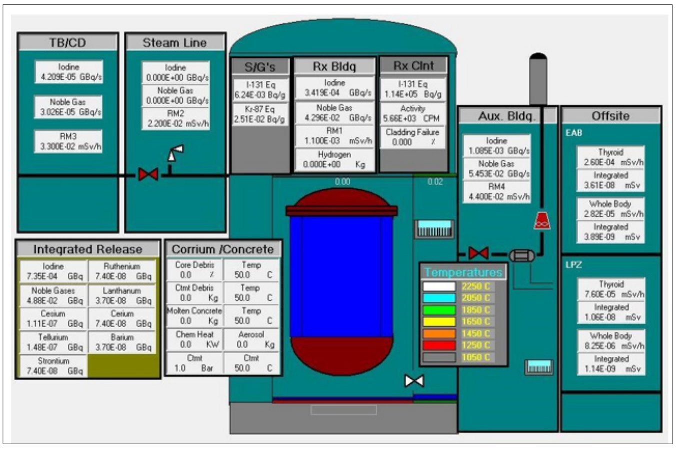

Figure 2: Simulator Environment outside the Reactor Building

Safety Criteria

In theory, contamination should not occur if the radioactive material does not go beyond the five safety barriers. These safety criteria for WWER-1200 reactors include:

- **Fuel Pellets:** to enclose fission products in case of fuel element failure
- **Fuel Sheath:** to enclose fission products and avoid contamination of the primary coolant when fuel pellet failure happens
- **Pressure Chamber:** to limit fission products in case of fuel sheath failure
- **Primary Containment Building:** To enclose radioactive elements inside the reactor building in case of radioactive material escaping from the cooling circuits
- **Secondary Containment Building:** To inhibit radioactive elements when failure occurs in the primary containment building. Environmental pollution occurs when radioactive materials pass through this layer. Table 2 specifies the parameters of the above safety layers.

Table 2: Safety Parameters of Reactor Safety Layers

Safety Barrier	Safe Operating Limit
Fuel Pellet	Temperature ≤ 2200°C to prevent meltdown [31]
Fuel Cladding	Temperature ≤ 1480°C to prevent embrittlement [31]
Pressure Vessel	Pressure ≤ 110% of Nominal Value [31]
Primary Containment Building	Pressure ≤ 414 kPa [32]

Method

First, to validate the software with real power plant data, an incident from the simulator was validated with power plant data. The validation results were very close to the real data conditions.

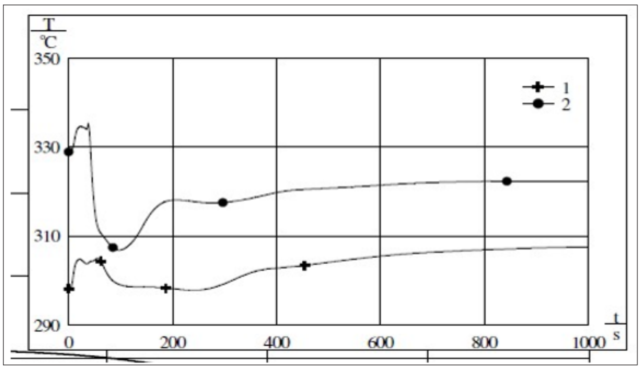

Diagram 1: Results of Power Plant Safety Analysis Report During a Cooling Water Loss Accident

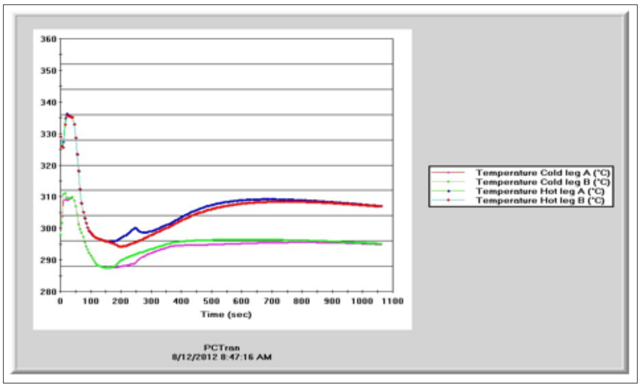

Diagram 2: Simulation Results of Cooling Water Loss Accidents

In Diagram 1 actual data of the power plant and parameters of temperature of water entering and leaving the reactor core in the cooling water loss accident and in Diagram 2 results of temperature of water entering and leaving the reactor core during the cooling water loss accident were validated. The validation results are very acceptable. Then the simulation was continued with confidence in the accuracy of the results.

Thus far, most simulations have been conducted to assess the safety of power plants in 911 seconds after the start of operation of the power plant. Likewise, the temperature of the fuel pellets and fuel sheaths were analyzed as the most significant leak layers against radioactive materials

.Scenario 1

Concurrent failures of 100% fractures in the water pipe entering the reactor core and the water pipe leaving the reactor core.

Figure 3 reports the fracture site and Diagram 3 represents the temperature of the fuel pellet and fuel sheath during the accident.

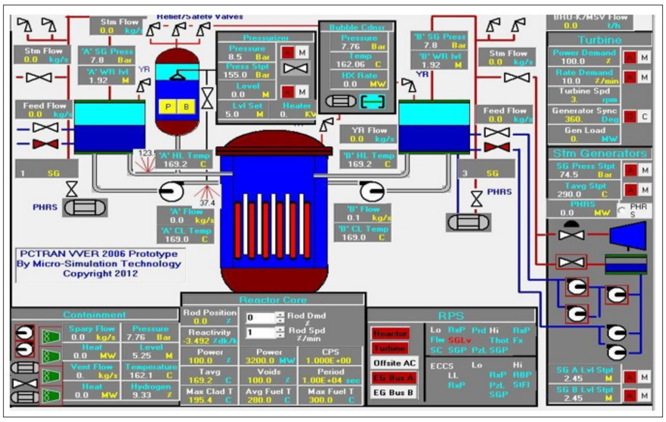

Figure 3: Reactor Chamber in Scenario 1

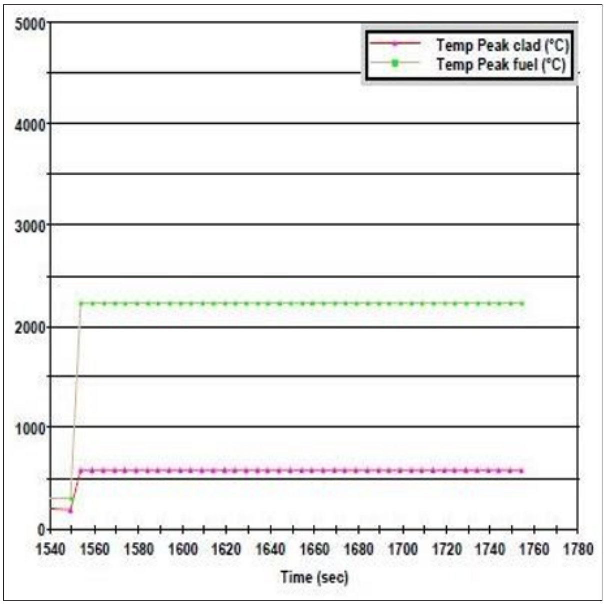

Diagram 3: Temperature of Fuel Pellets and Fuel Sheaths

The results of these two accidents were reported concurrently in 1760 seconds, which reveals that the temperature of the fuel pellet and the fuel sheath did not go beyond their safety criteria in Table 2.

Scenario 2

Figure 4 shows a fracture incident in the reactor building and Diagram 4 shows pressure assessment in the fourth layer of the safety criteria.

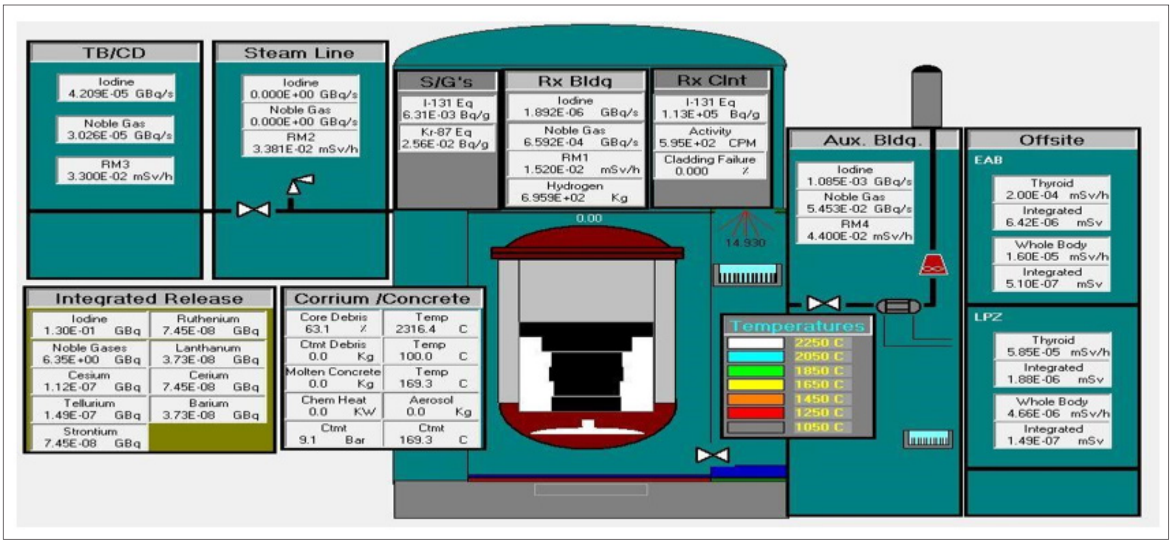

Figure 4: The fracture in the Reactor Building

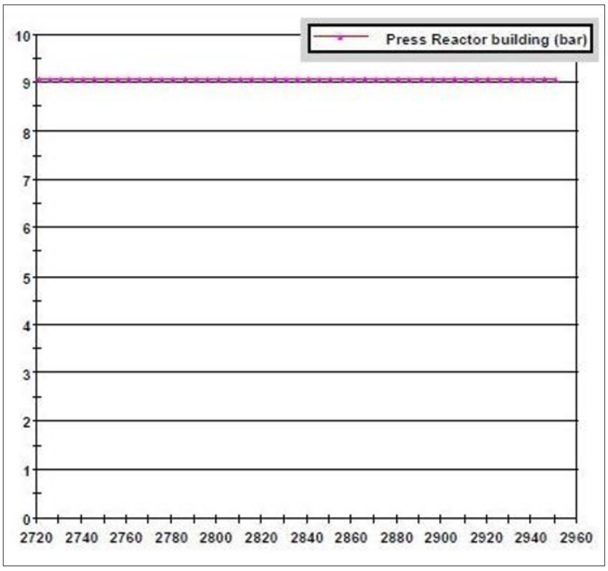

Diagram 4: Pressure in the Outer Chamber of the Reactor Building

The results of the analysis indicated that during this severe accident, the reactor chamber pressure did not go beyond the safety criteria of Table 2. These findings were reported in up to 2950 seconds from the onset of the accident.

Scenario 3

The assessment of the temperature of the fuel pellet and the fuel sheath in the concurrent accidents of loss of cooling water and fracture of the lower part of the reactor chamber without the presence of emergency cooling systems of the reactor core. Figure 5 displays the fracture site in the simulator environment and Diagram 5 represents the temperature of the fuel pellet and the fuel sheath during the concurrent accident of the loss of cooling water and the fracture of the lower part of the reactor.

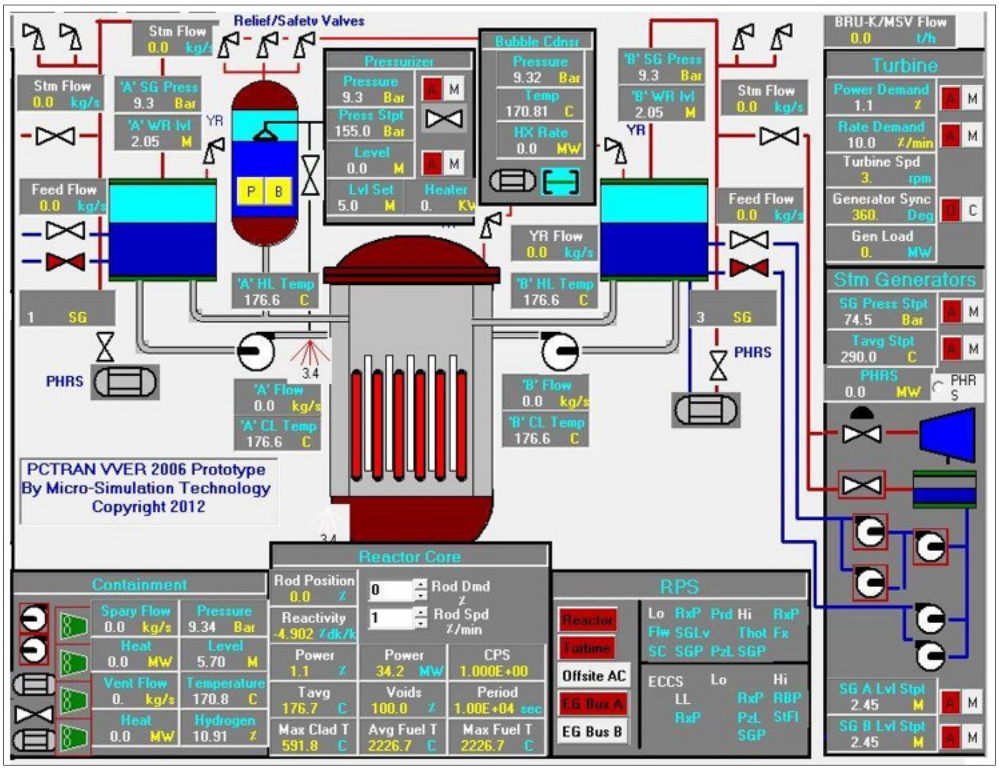

Figure 5: Concurrent Accident of the Entering Pipeline to the Reactor and Melting of the End of the Reactor

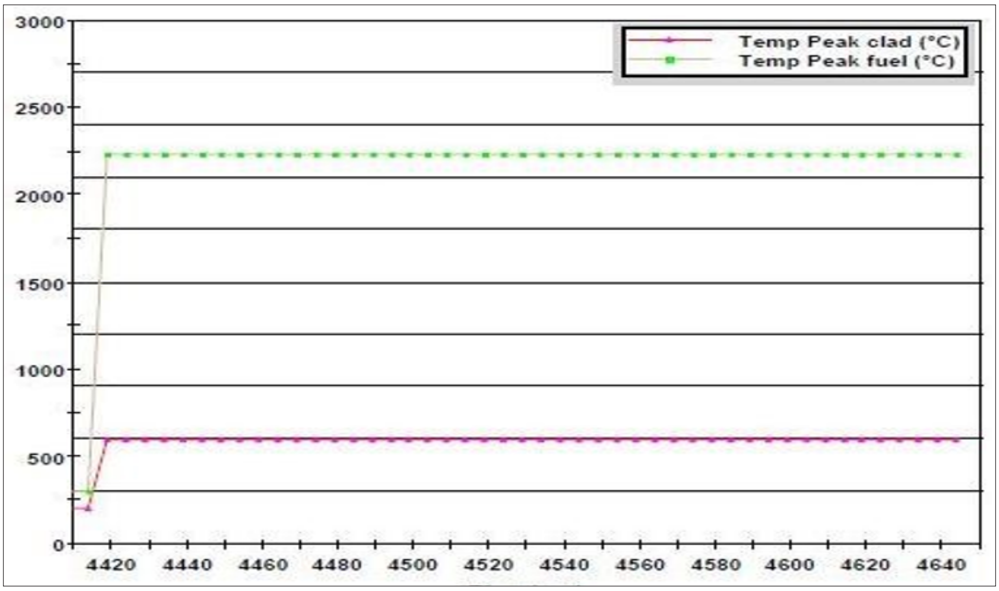

Diagram 5: The Temperature of the Fuel Pellet and the Fuel Sheath in Scenario 3

The results of Scenario 3 display that the temperature of the fuel pellet, as the most significant layer of deep defense against severe accidents, goes beyond the safety criteria according to Table 2. Unlike other conventional simulations, this accident was reported up to 4640 seconds. New safety systems are required in this type of accident, as this reactor is safe in the analysis of different nuclear accidents, but it is not safe in this type of accident, and because of the construction of this type of nuclear reactor, it requires new measures to be considered for this type of incident [5-6].

Scenario 4

Major fracture incident in the reactor building without considering the emergency cooling systems of the reactor core. Figure 6 shows the accident in the software environment.

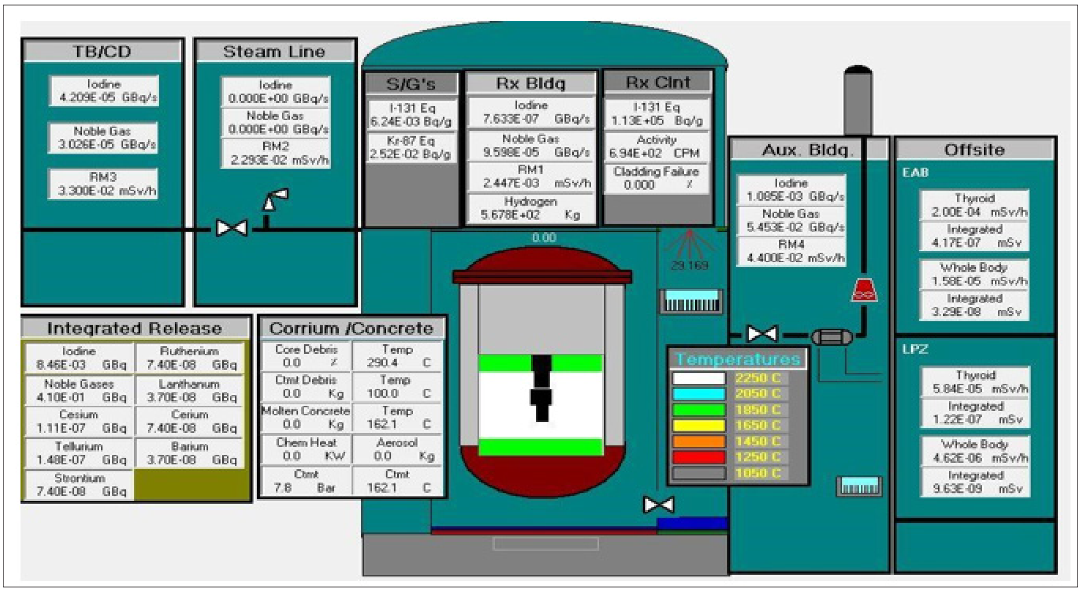

Figure 6: Fracture in the Reactor Building without Considering the Reactor Emergency Cooling Systems.

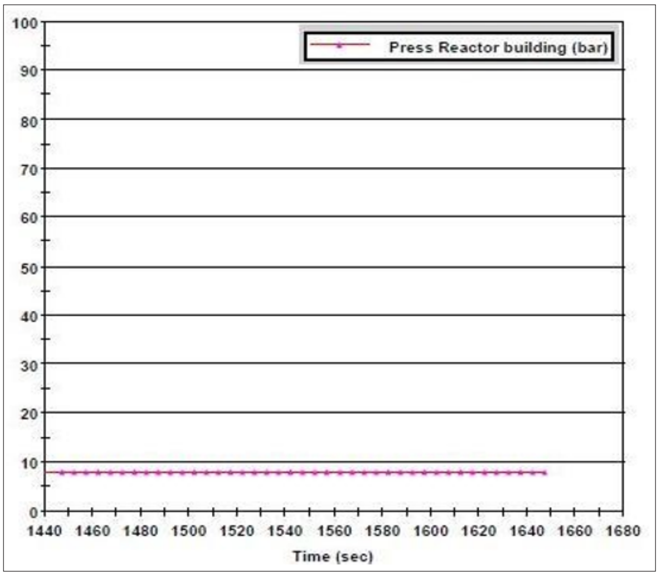

Diagram 6: Pressure in the Reactor Building in Scenario 4

Diagram 6 indicates the major fracture event in the reactor building without emergency cooling systems of the reactor core. The findings of this simulation reveal that the reactor chamber pressure did not go beyond its safety value during the safety criteria in Table 2, and is also safe in this accident.

Discussion and Conclusion

As in the analysis of WWER-1200 reactors, single accidents were analyzed for a short time, in this research, severe accidents in long periods were studied to assess the safety of the reactor. The results of this simulation indicated the temperature of the reactor fuel pellet in WWER-1200 during the concurrent accident in the cooling water pipe entering the reactor core and the fracture of the lower part of the reactor chamber, without considering the emergency cooling systems of the reactor core, goes beyond the safety standards and has the risk of melting the reactor core. These type of nuclear power plants are under construction, so it requires a solution to this type of severe accidents in the safety analysis of the plant. This analysis also provides valuable information to the designers of these types of nuclear reactors to improve safety, avoid environmental contamination during nuclear accidents, and benefit from sustainable energy.

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