ICMIEE20-105

Investigation on Thermal Hydraulic Parameters of a Nuclear Reactor (VVER-1200) due to Loss of Coolant Accident with Station Blackout and Failure of Emergency Core Cooling System

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ABSTRACT

This paper present computational analysis of severe accident in VVER-1200 where the plant is subjected to confront loss of coolant accident (LOCA) with station blackout (SBO) condition also with arbitrary failure of Emergency Core Cooling System (ECCS). The LOCA break appears in hot leg of the primary coolant circuit after 5 seconds of full cent percent power running condition. Thermal hydraulic parameters of generation 3+ VVER-1200 reactor core for different arbitrary break of LOCA has been investigated to find the impact of accidents in detail. Pressure, temperature, power fall down significantly after the accident happened due to SBO and LOCA for reactor trip occurrence. After 65 seconds, core level water rapidly decreases to 4m height when the Hydro-Accumulator automatically started to prevent core damage. Thermal power of reactor core, Turbine load, Nuclear flux power fall down after 18 seconds of the accident initiation. LOCA with SBO only is generally mitigated by ECCS in times but failure or unavailability of ECCS turns the core uncover, fuel melt, radioactive material release and finally core collapse by molten core concrete interaction. Initially after the accident, all system acts protective to mitigate the accident. But when all the core water vaporizes and ECCS water inconvenient to reach reactor core then fuel peak temperature along with clad temperature rise to design basis accident prescribed value after 750 to 900 seconds. For different size of LOCA, the results can show different behaviors in SBO situation.

Keywords: Thermal-Hydraulic (T-H) behavior, Loss of coolant accident (LOCA), VVER-1200 reactor, Emergency core cooling system (ECCS), Simulation.

1. Introduction

As a developing country, Bangladesh is going through intense electrical energy emergency period. Bangladesh have some noteworthy natural conventional energy sources but it is going to finished someday by using only those sources for generating electricity. Nuclear energy concept somehow represented as destructive source of energy but it's also a source of power generation and life savings purposes. In 2009, Bangladesh and Russia signed a memorandum on construction a nuclear power plant (NPP) named Rooppur Nuclear Power Plant (RNPP) near Pabna district where Russian State Atomic Corporation 'Rosatom' was instructed to be the head of the Project [1]. This biggest power plant project jointly directed by Bangladesh Atomic Energy Commission 'BAEC', Atomic Energy Commission of India 'AECI' and headed by Roastom [2]. VVER-1200 is the lattermost constructed and commissioned pressurizer water reactor (PWR). All the improvement developed by Russian state construction office, OKB Gidropress. This PWR use slow thermal neutron before interacting with fuel materials. It consists with many different features and accessories like primary circuit, secondary circuit, 4 cooling loops, main circulation pump, safety and relief valves and many more [3]. The reactor coolant system path from reactor coolant pump to reactor core known as hot leg and the path from reactor core to steam generator is known as hot leg. The primary coolant inside the core deposit at high pressure at 155 bar. This high pressure helps the vapor to avoid vaporize [4].

The nuclear facility built and design in that way so it can withstand every DBA (Design Basis Accident) and BDBA (Beyond Design Basis Accident). LOCA is common DBA for individual reactor design. LOCA defined as fracture, broken or partially broken inlet or outlet pipe at Reactor Cooling System (RCS). From this broken ends coolant discharge freely. LOCA happens due to many different condition and operational behavior of the core and others system. Every reactor core consists with many different measurements for emergency systems to mitigate every type of known accidents depend on previous knowledge and experiments.

VVER 1200 reactor plants have modern safety features designed and improved by Roastom, which

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give the plants ability to sustain starting different load varying events as well as others consequence under every accidental condition. When the reduction of leakage water temperature during ECCS injection drop in about 50℃-70℃ then it called SBLOCA and for LBLOCA the temperature has high reduction temperature about 120℃-150℃ [5]. Every alternative actions and decisions have much different outcome on every type of LOCA. The ECCS of VVER-1200 consist with different modern systems to mitigate every type of accident during operation or DBA and BDBA situation.

In this investigation, Personal Computer Transient Analyzer (PCTRAN) used to analysis the problems. This software approved and used by International Atomic Energy Agency (IAEA) to different types of accident on real live simulation. In this paper mainly LOCA conditions for SBO and ECCS dual event is simulated.

A. S. Mollah publish a review about transient analysis of PWR with PCTRAN education tool simulator [6]. Sunday J. IBRAHIM et al. use PCTRAN to safety analysis for PWR to create positive awareness for general public [7]. Yi-Hsiang Cheng et al. introduce PCTRAN for nuclear power plant emergency response [8]. Yi-Hsiang Cheng et al. developed and publish dose consequence for nuclear response applications using PCTRAN [9]. Abid Hossain Khan with Md Shafiqul Islam published an article on VVER-1200 reactor inadvertent withdrawal of control rod effect based on PCTRAN [10]. VVER-1200 T-H parameters using PCTRAN analyzed by Nashiyat Fyza et al. with loss of offsite power and LOCA [11]. Arnob Saha et al. conduct rupture in steam generator tube analysis of VVER-1200 using PCTRAN [12]. Only some research work on RNPP VVER-1200 have been conducted. Whether RNPP is good or bad with different situation for Bangladesh is described by Siddiky et al [13]. Reza et al showed how RNPP can fulfill the annual load power demand by nuclear electricity production [14]. A review of power generation technologies, RNPP being environment friendly manners, nuclear waste disposal with eco- friendly manner is reviewed by Mollah et al [15]. A statistical research on safety issue of health and environment on RNPP project is conducted by M.S.Laskar [16]. In this paper T-H parameters for VVER-1200 due to LOCA with 507% area or 10-inch break at hot leg in station blackout (SBO) condition simulated with availability and unavailability of ECCS using PCTRAN VVER-1200 nuclear transient accident simulator. Different external condition like flood, tsunami, earthquake can have affected on the ECCS and emergency backup power generating diesel engine failure. This hypothetical accident situation probability is extremely low, but the geographic and socio-economical condition can bring disaster to the RNPP.

2. Methodology

Users can manually insert different initial condition and malfunction in PCTRAN control panel. In this simulation, initial condition of the plant taken from paper publish by Nashiyat Fyza et al. [11]. After defining malfunction and others initial and boundary conditions, the necessary parameters are measured to analysis the reactor performance. The operation of simulation in various condition is going to be initially given to the software and then the result outcome is represented in graphical plot. Malfunction set as LOCA with SBO for 10-inch failure fraction after 5 second of cent power running. The sequence of the simulation process can be showed as following table:

1.	Set and active the simulation for run. After 5s pause it.
2.	Use initial condition or set new initial condition of the reactor core as required.
3.	Describe malfunction with delay time and failure fraction.
4.	Run the simulation again in control panel.
5.	View transient plot and data for different variables respect to time.
6.	Save transient report for future analysis.

3. Computational result and discussion

This investigation is carried out with LOCA condition at Hot leg with arbitrary 10 inch or 507% of 100 cm^2 failure fraction break with loss of all AC power or station blackout conditions. Firstly, the analysis carried out for a design basis LOCA where the ECCS is running and secondly when all the ECCS, passive cooling system unavailable. Then all the relevant plots are discussed.

3.1 Analysis of LOCA at hot leg and SBO condition with all ECCS running

In this numerical study, a 507 cm^2 (10-inch diameter) stream line break in hot leg assumed to be acting. Using manually defined malfunction at hot leg with 507 cm^2 failure fraction and station blackout after 5 sec of the simulator to run in full power with steady state condition shown in fig.2. Fig.3. shows reactor trip and actuation of EWST system. After the accident, there is a rupture icon appeared in the hot leg with leak and loss of primary coolant. Due to rapid depressurization from reactor coolant system initially huge water flow through the leak. Fig.4(a) shows the flow through RCS leak which become gradually same after 230s. After 15.5s when the reactor trip and the control rod fall down to the core, water level gradually decreases and takes 21s to empty the pressurizer. At 66.5 seconds, the emergency water from EWST system EG Bus-A starts and provide direct water from river. The core water level decrease after 65s and increase at 122s after the accident with the help of EWST recovery refueling water storage tank. Upon actuation of hydro accumulators, ECCS provide water flow to reactor vessel so vessel water level slowly rise again and core level water restore fig.4(b). Pressurizer level water takes 25s to fully empty and after 310s gradually increase the level of it. But due to the leak loss of water, the pressurizer water again

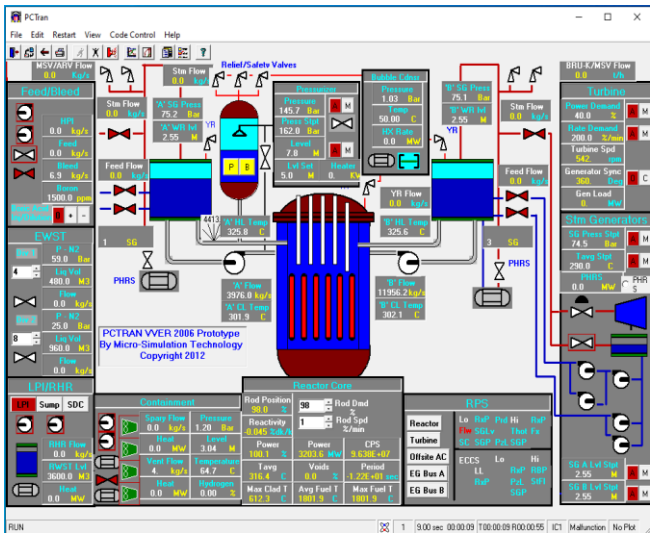


Fig.2 Initiation of 507 cm^2 hot leg LOCA with SBO

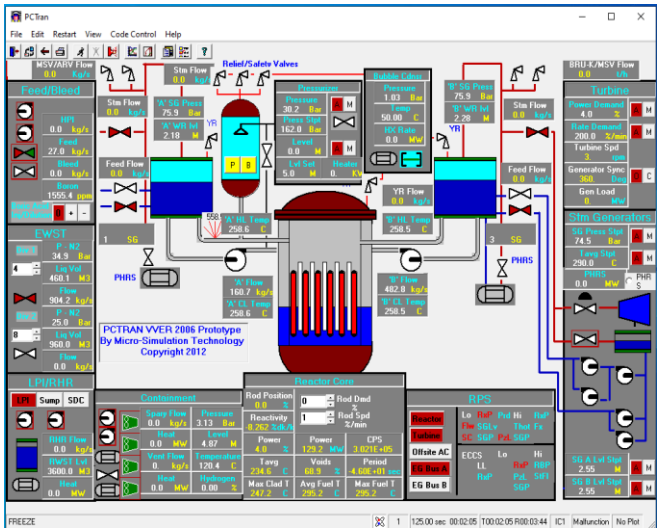
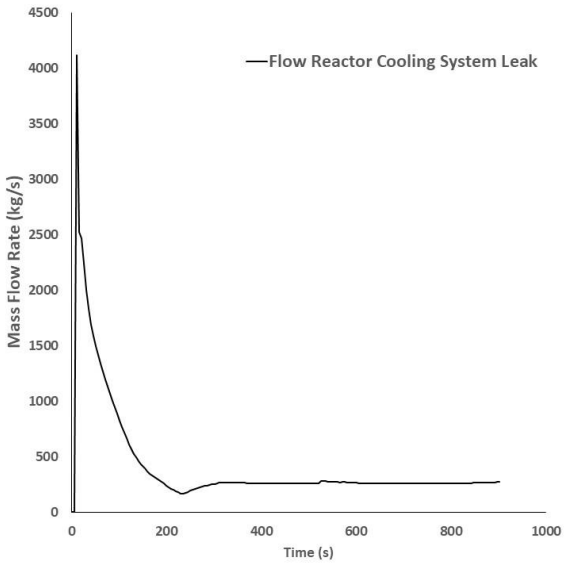
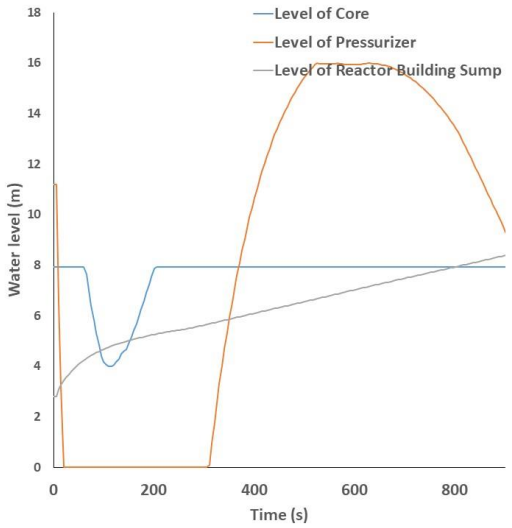


Fig.3 Reactor trip and actuation of EWST



(a)



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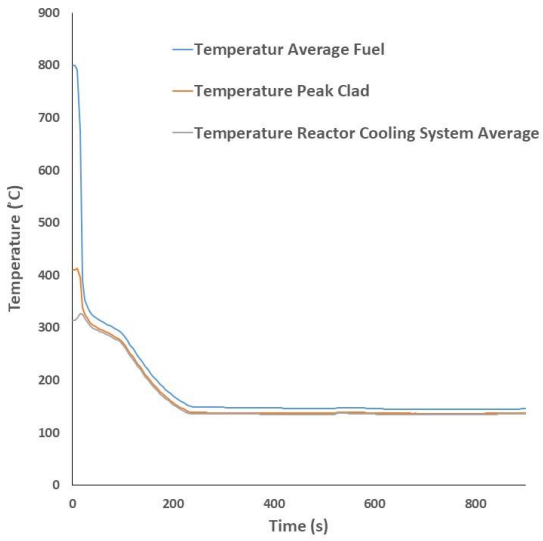
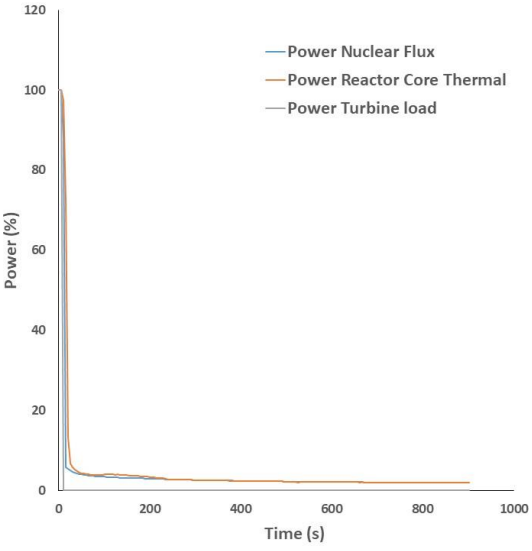


(c)



(d)

Fig.4 (a) RCS leak mass flow rate (kg/s) **(b)** Different Level of water NPP (m) **(c)** Average fuel, peak clad, RCS average temperature (°C) **(d)** Different power (Core thermal, Nuclear

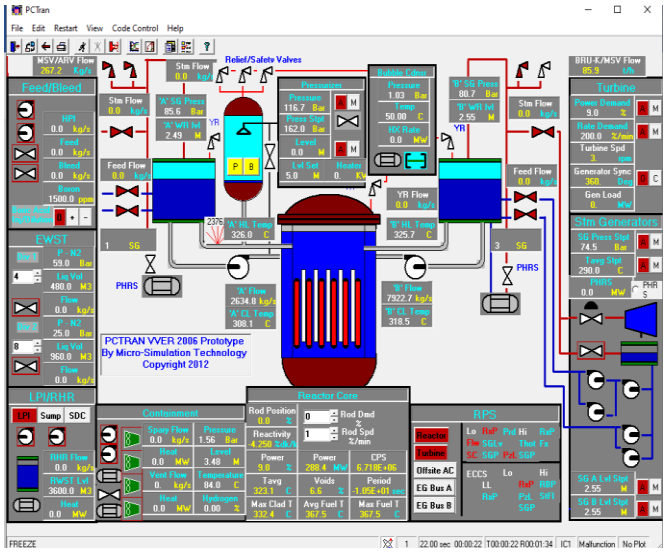
flux, Turbine Load)(%) for hot leg break at LOCA with SBO situation.

decreases after 700s. The reactor building sump water also gradually increase due to the loos from cooling system. The EWST system huge makeup water started when the reactor core water level down to 4m to maintain the core submerged in water at transient event. Fig.4(c) showed different temperature of fuel, clad, average RCS temperature. Fig.4(d) showed different power of the core section which gradually turns to zero after some cycles.

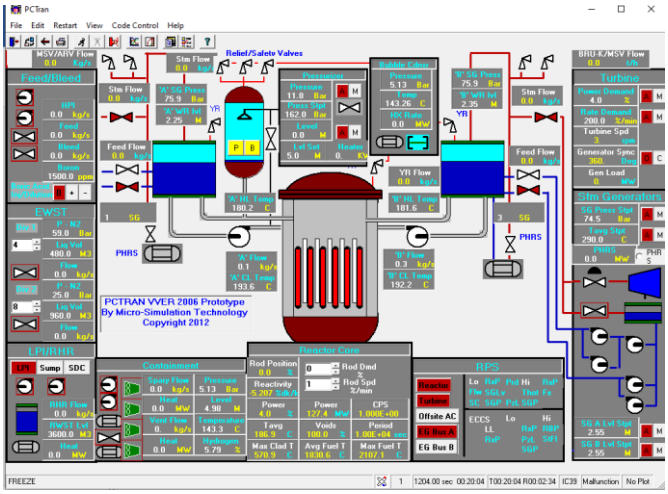
3.2Analysis of LOCA at hot leg and SBO condition without all ECCS running

Due to station blackout, the feed water system, HPIS, LPIS, containment building water provider can't start at the time of LOCA initiation. EWST actuation automatically when the core water level below down to a specific level. Hypothetically, for different malfunction or natural crisis reasons, if the EWST can't able to provide the necessary coolant water flow. As a result, LOCA can turn to a severe accident.

In this following simulation, a 507 cm^2 LOCA in hot leg and station blackout with loss of all ECCS equipment are simulated. It is a hypothetical accident cause unavailability of all those ECCS equipment at a same time is very less probabilistic. But following different sever accident like TMI and others all necessary emergency system shut down and level 7 class disaster happened. So, it's necessary to investigate this type of accident. Fig.5(a) show instantaneously reactor trip down after the SBO accident with unavailability of ECCS. Fig.5(b) show uncover at reactor and increasing H_2 gas concentration inside reactor. Fig.5(c) followed by observe core melting process in dose mimic interface. Fig.5(d) represent the final core metal concrete interaction with debris and slump.



(a)



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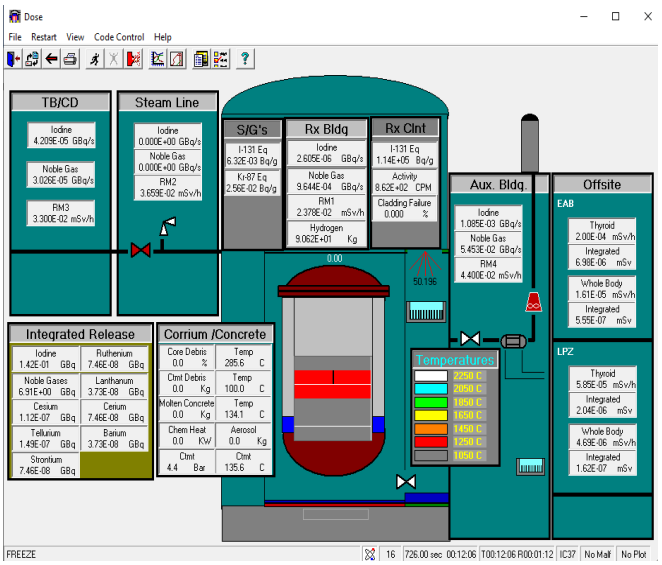

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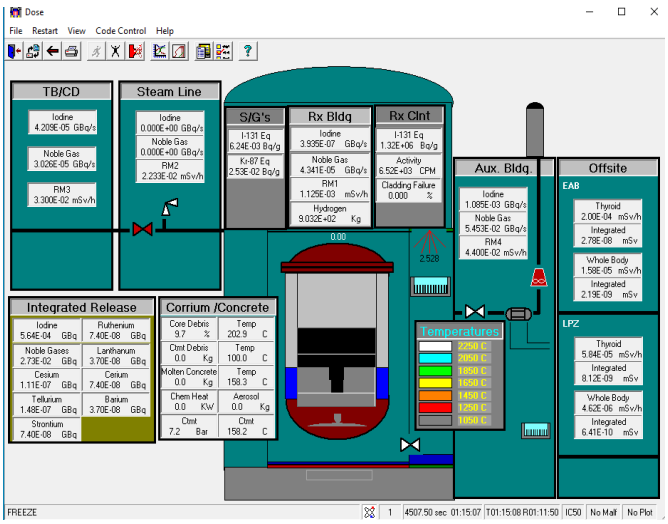
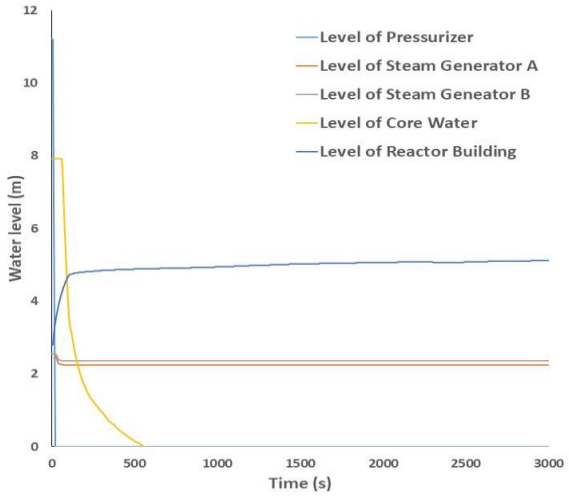


(d)

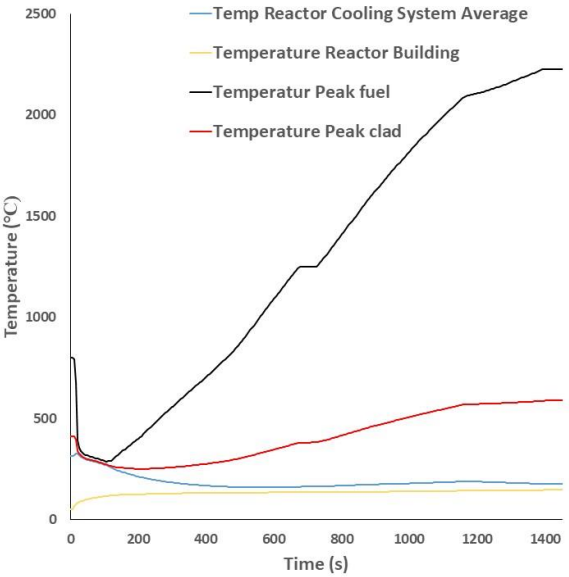
Fig.5 (a) Reactor state after accident trip with empty pressurizer **(b) Uncovery** of core after 1200 seconds **(c) Core melting** process in dose mimic **(d) Vessel penetration** by

MCCI (Molten core-concrete interaction) due to LOCA without ECCS at SBO condition

the cladding and steam are accelerated and when all the water vaporizes fuels residual heat increase and fule collapse. Fig.6(a). shows different water level of reactor System like pressurizer, steam generator, core water and reactor building. The pressurizer initially triggers after the accident and level of SGs water slightly decrease. Core water gradually emptied due to high heat produce inside the reactor core. Reactor building sump recirculation process terminated at certain point when there no water left to carry the poison. Different temperatures like reactor building, peak fuel, peak clad, RCS average temperature are plotted in fig.6(b) for initial 1500 seconds. Rising of temperature rapidly increased after core fuel emersion unavailability of coolant water flow. Peak fuel temperature exceeds the prescribe value of 1480℃ after 800-900 seconds [17]. Fuel temperature resulting reaction between Zirconium



(a)



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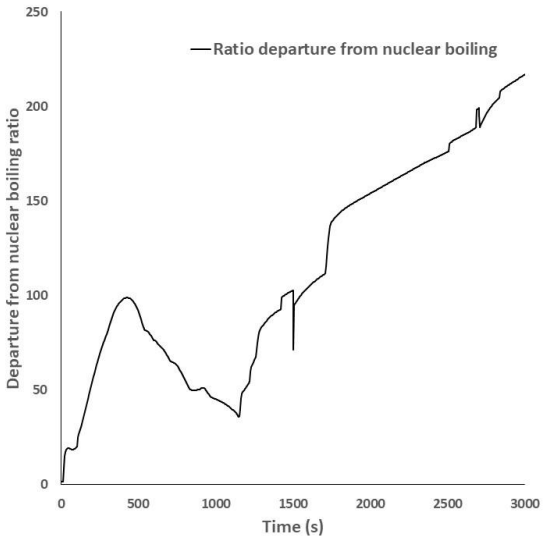

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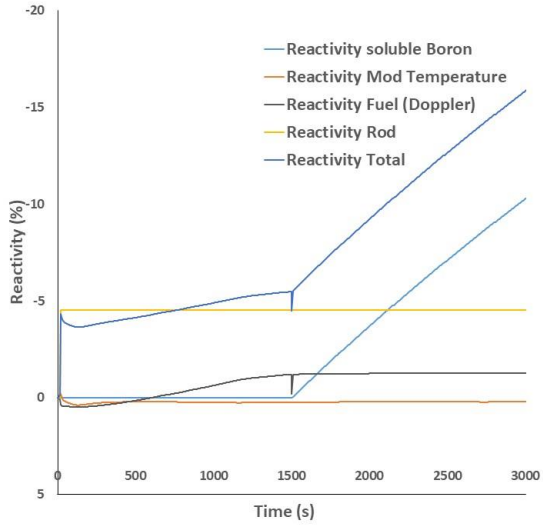

(d)

Fig.6 (a) Pressurizer, SG-A, SG-B, reactor core, reactor building **water level** (m) (**(b)** Peak fuel, RCS average, peak clad, RB **temperature** (℃) **(c)** Departure from nuclear boiling ratio **(d) Reacticvity** of soluble boron, modifier temperature, fuel doppler, rod and total (%) due to LOCA without ECCS at SBO condition

and water accelerated increase clad temperature. Fig.6(c) shows departure from nuclear boiling ratio (DNBR) which definition can be found from reference [18]. After rapid increasing of fuel burnup inside reactor, the core become unstable and then core materials are melt down for heat flux increasing process. Different reactivities are shown in fig.6(d). Due to increase fuel temperature inside core, the fractional reactivity change called fuel doppler reactivity. When their explosion happens, reactivity of different section progresses very much and spread radioactive materials. H_2 inside RB and Zr-oxidation also increase after 500s. Void of RCS, H_2 gathering inside core and fuel Zircaloy cladding oxidation have significant interference on the situation of core meltdown.

4. Summary

This numerical investigation showed different T-H parameters characteristics of VVER-1200 NPP at LOCA with SBO condition availability of ECCS and unavailability situation. LOCA can happened into any type of reactor plant. In this investigation, it's shows that the EWST can able to mitigate LOCA at time of station blackout providing direct water to the core. But if the emergency bus of EWST somehow malfunction or disable at the time of SBO with LOCA, then the accident can turn into a disaster like TMI or other NPP accidents. So it's very important for every NPP along with RNPP to insure and provide all the safety check to active and passive systems machineries to ready to confront any situation.

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