Study of Accident in VVER-1000 with Total Blackout, Primary LOCA and Options for Safety System Pumps Recovery

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Abstract. After the Fukushima accident an extreme event with combination of several design basis accidents is shown to be possible. The detailed analyses of such events, including an extended station blackout, where all the onsite and offsite power is failed, became very important. In this work is presented an analysis of small break LOCA combined with total blackout. Two different scenarios are considered – with availability of all three high pressure safety system pumps TQ4 and the other scenario is with availability of one middle pressure TQ3 pump. Maximal diameter which could be compensated by one TQ3 pump is defined.

Keywords: LOCA, safety systems, blackout, severe accident

List of abbreviations

AC/DC	– Alternating current/ direct current
BDBA	– Beyond Design Basis Accident
DBA	– Design Basis Accident
DG	– Diesel Generator
IAEA	– International Atomic Energy Agency
LOCA	– Loss of Coolant Accident
MCP	– Main Coolant Pump
MSIV	– Main Steam Isolation Valve
PRZ	– Pressurizer
SBO	– Station Blackout
SCRAM	– Emergency shutdown of the reactor (safety control rod axe man)
SG	– Steam Generator
VVER	– Type of water-water cooled reactor

1 Introduction

After the Fukushima accident new rigorous requirements were issued by the IAEA concerning selection of the right actions in case of severe accidents. According these requirements new calculations should be done which include combination of several design basis accidents.

This report presents calculations performed with RELAP5 computer code [1-3] and input model for VVER 1000 reactor design. In the calculation it was simulated total loss of offsite power, reactor SCRAM, small leakage from primary circuit and not availability of safety system diesel generators. The available options for power supply recovery from outside sources are also considered. Three different sizes of the leakage are compared.

Subject of analysis: RELAP model for reactor VVER-1000/ V230 type is used for the calculation. It is a pressurized water reactor. The model consists (includes) of a reactor vessel, four loops, with four steam generators and four main circulation pumps. It has a Pressurizer? attached with a surge line to the fourth hot loop. All primary equipment is situated in air-tight containment vessel. Safety systems are 3 channels. Each channel consists of high pressure, middle pressure and low pressure train, supplying water to the reactor, as well as trains, feeding water to the Steam generators on the secondary side. According to the scenario in the analyzed accident all active safety systems are unavailable since they rely on electrical pumps. In addition there are 4 accumulators, which are passive safety systems. They supply borated water directly to the reactor in case of accidents with dropping the pressure on primary side. The make-up and blow-down systems are also modeled, but due to the scenario they are not functioning.

The steam generators are horizontal type. All steam lines are connected in the common main steam header. Each steam generator could be isolated from the main steam line by main steam isolation valve MSIV. In case of stopping the turbine, the excessive steam could be sent to the condenser by steam dumps to the condenser. If there is no vacuum in the condenser, the steam could be released into the atmosphere by steam dumps to the atmosphere. The secondary steam dump devices releasing steam to the atmosphere are fully functioning [4,5].

2 Description of the Used Software and the Model

This analysis has been performed with the code RELAP 5/mod 3.3. RELAP5 is developed for best-estimate simulations of transients in cooling circuits of light water reactors during postulated accidents or operational transients. This code models connected behavior of the primary coolant system in the core during Loss of coolant accidents [10-12] and operational transients, such as ATWS, loss of offsite power, loss of feed water and loss of circulation.Using the common modeling approach allows the simulation of large amount of thermal-hydraulic systems. Also in the code are included control and managing systems primary and secondary circuit to allow modeling

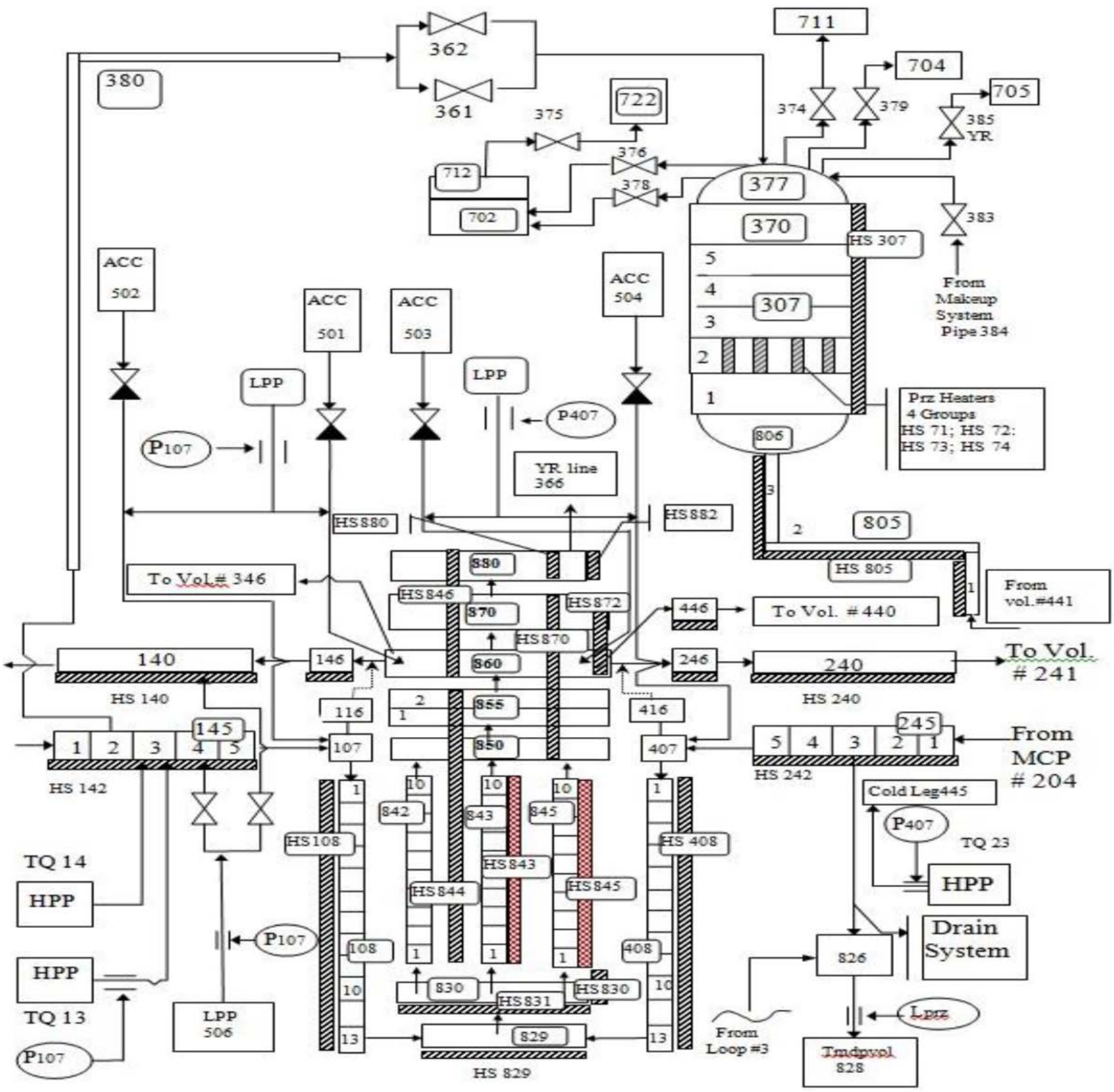

Figure 1. Reactor and Pressurizer RELAP5/Mod 3.3 Four Loops Model.

of the plant control, turbine control, condensers and feed waters systems control.

The RELAP model of the VVER-1000 plant is developed based on design plant data [4,12]. It consists of different modules to simulate reactor systems. The nodalization schemes of used model for VVER-1000 are shown in Figure 1 and 2.

3 Overview

Two different scenarios are calculated with different available safety systems. The main accident is common and it is total loss of off-site and in-site power supply. Those scenarios include loss of all external power supply and not starting any of the three safety system diesel generators due to common reason. Such common reason could be losing all 6 spray pools due to severe winds.

The initiating event is the combination of 2 events:

— total loss of onsite and offsite power supply;

— loss of coolant accident.

The most limiting LOCA is on the cold leg between MCP and the reactor [6,7].

First scenario includes starting of all three TQ4 pumps. Each TQ4 pump can supply 6 m^3/h borated water in primary circuit, total 18 m^3/h.

In the **second scenario** one TQ3 pump is available. Three different cases are presented:

- Dy32;
- Dy100;
- Dy150.

The purpose of the study is to estimate maximal diameter of the break, which could be compensated with one TQ3

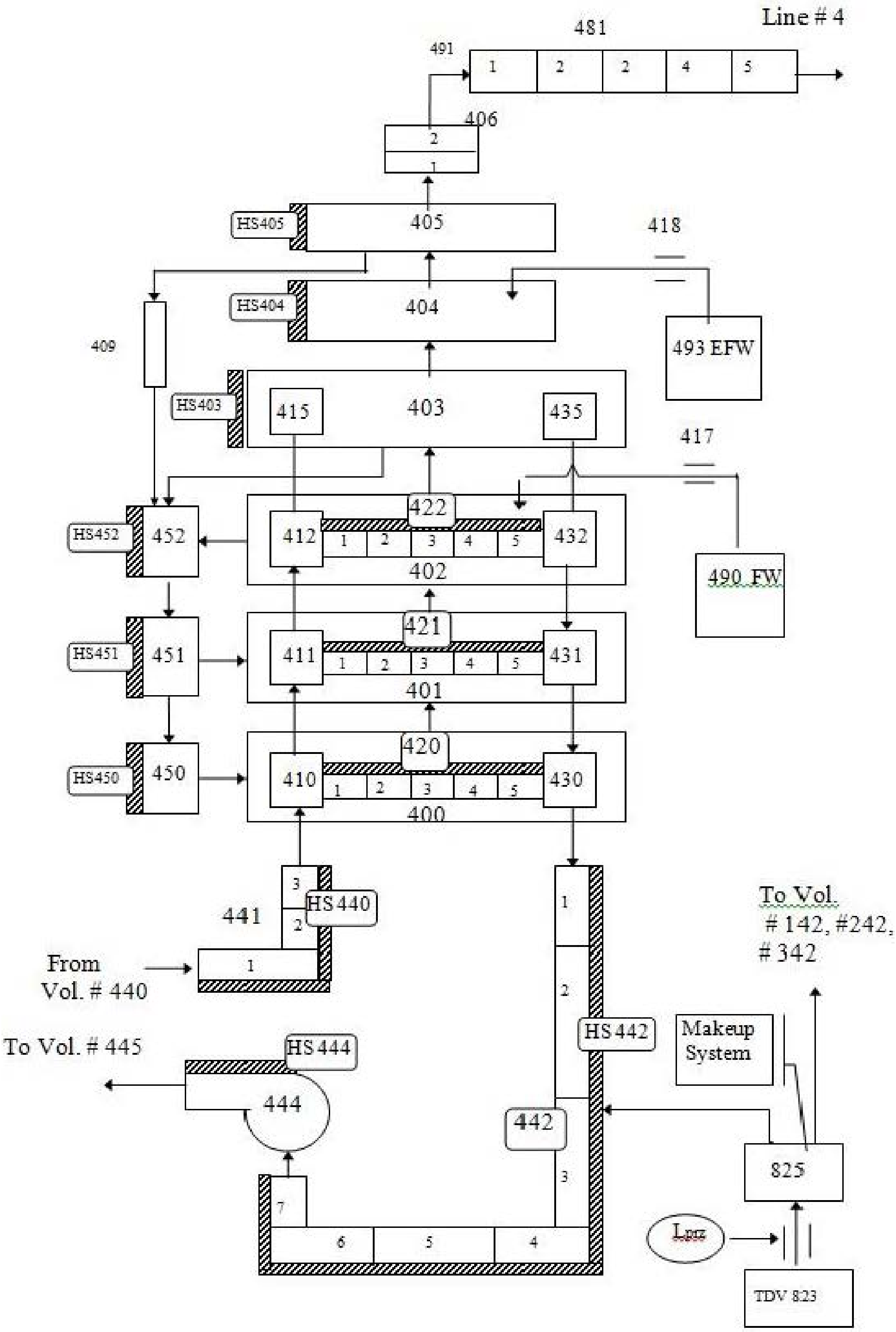

Figure 2. Steam Generator RELAP5/Mod 3.3 Four Loops Model.

pump and no damage to the core would occur.

The chronology of the main events is shown below.

Both scenarios are started by simultaneous loss of offsite and onsite power and small break LOCA.

After the loss of onsite and offsite power:

— Actuates SCRAM of the reactor;

— MCP are turned off, they continue to run about three more minutes because of the inertia in the flywheel;

— The PRZ heaters switch off;

— The make-up pumps turn off, there are no primary make-up and blow-down.

On secondary circuit:

— The generator switches off, main circuit breaker switches off;

— Main steam isolation valves of the turbine close;

— Turbine-driven feed water pumps stop, additional feed water pump does not start, emergency feed water pumps do not start;

— There is no feed water to the steam generators;

— Steam dump to the condenser is not available;

— Steam dump to the atmosphere is available;

On safety systems:

- Diesel generators do not start;
- Hydro accumulators are available.

3.1 Available power supply options

According to the scenario there is no offsite power supply available, in addition due to common reason all 3 safety system diesel generators are lost. The available options for ensuring power supply are starting of additional stationary unit diesel generator GZ, which could supply nominal power 5.4 MW. The other options are mobile diesel generators GZ 105 (106) which are 400 kW power or other common GZ 100, which is 1 MW power.

It could supply 800 kW QF pump and one high pressure safety system TQ3 pump 800 kW. The QF pump is necessary to cool-down the bearings and the seals heat-exchangers. The power needs for other safety system pumps are 3 TQ4 pumps $\times$ 40 kW maximal.

According to Table 1 safety diesel generators will be unavailable, due to the scenario.

Table 1. Available power supply options

	Safety diesel generators GV, GW, GX	Additional stationary diesel generator	Mobile diesel generator GZ 105 or GZ 106	Common diesel generator one for both units
Maximal power output per unit	3×6 MW	5.4 MW	400 kW	1 MW

TQ4 pumps could be supplied by all available mobile and stationary diesel generators, because they have low power demand.

The only option for supplying TQ3 and QF pump is additional stationary diesel generator GZ. TQ3 pump without QF pump will not be operable.

Other mobile diesel generators are not sufficient to supply TQ3 and QF.

4 Main Results

The **first calculation** is performed with total blackout and small LOCA Dy 32. Restoration of all 3 TQ4 pumps is assumed in the beginning of accident. These pumps supply 6 m^3/h each. These 18 m^3/h are not enough to compensate the leak even through small LOCA with Dy 32 and after uncovering the core the natural circulation and cooling through steam generators become ineffective and the core is starting to heat up. If no additional measures are taken the steam-zirconium reaction will start and the core melt could occur.

The **next three calculations** are performed assuming that 1 TQ3 pump is restored after one hour after the accident. The three cases are with different diameters of the break – Dy 32, Dy 100 and Dy 150.

Table 2. Three cases with different LOCA diameters

	Case 1 Dy32	Case 2 Dy100	Case 3 Dy150
Total SBO	0	0	0
SCRAM	1–4 s	1–4 s	1–4 s
Stop of MCP	3 min	3 min	3 min
Starting one TQ3 pump	3600 s	3600 s	3600 s
Reaching 1200°C cladding temperature	never	never	3400 s

In Table 2 is presented comparison between these 3 cases with different LOCA diameters. In all cases 1 TQ3 pump is switched on in 3600 sec. The ECCS are operable (they are passive system), as well as BRU-A system (they are powered by 1st category power supply from batteries)

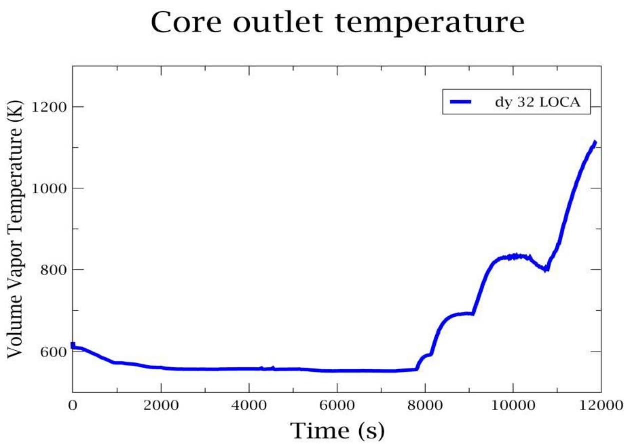

Figure 3. Total blackout and LOCA Dy 32, all 3 TQ4 pumps in operation.

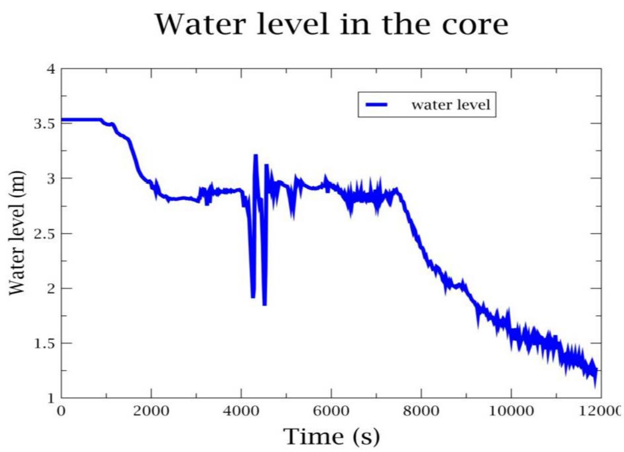

Figure 4. Total blackout and LOCA Dy 32, all 3 TQ4 pumps in operation.

Powering the TQ4 pumps is not enough to compensate even small LOCA like Dy 32. But still it is useful supply them, because they deliver solution with high boron concentration. The additional stationary diesel-generator GZ could supply not only TQ4 pumps but also one set QF and TQ3 pump from one safety system. One TQ3 pump could manage small LOCA up to 100 mm. For larger breaks it is recommendable to try to supply TQ3 and QF pumps from at least 2 safety systems.

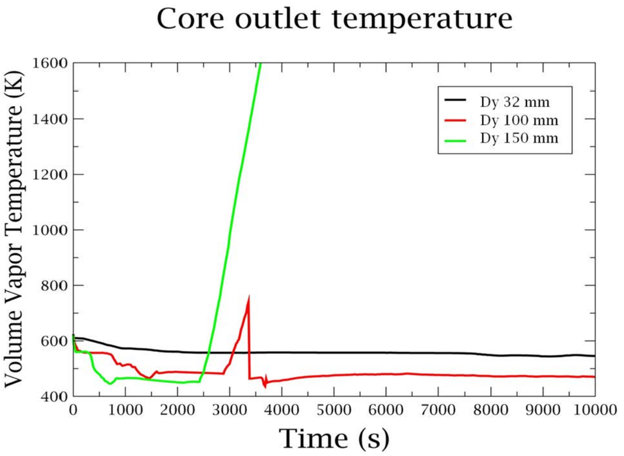

Figure 5. Total blackout and LOCA Dy 32, Dy 100 and Dy 150, one TQ3 pump in operation.

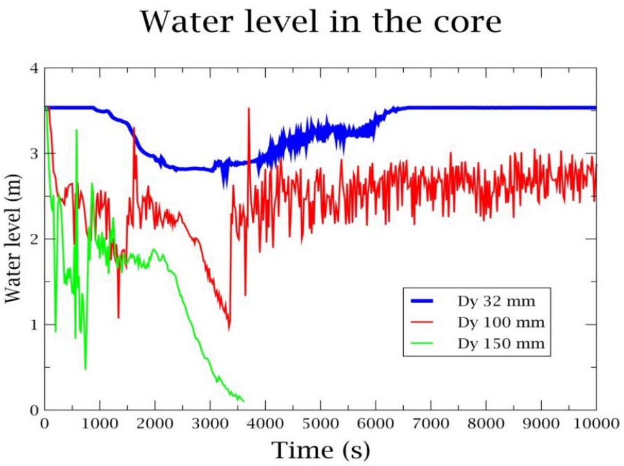

Figure 6. Total blackout and LOCA Dy 32, Dy 100 and Dy 150, one TQ3 pump in operation.

5 Conclusions

Powering the TQ4 pumps is not enough to compensate even small LOCA like Dy 32. But still it is useful supply them, because they deliver solution with high boron concentration. The additional stationary diesel-generator GZ could supply not only TQ4 pumps but also one set QF and TQ3 pump from one safety system. One TQ3 pump could manage small LOCA up to 100 mm. For larger breaks it is recommendable to try to supply TQ3 and QF pumps from at least 2 safety systems.

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