RELAP5 MODEL OF THE ITER VACUUM VESSEL COOLING SYSTEM

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A RELAP5-3D (Ref. 1) model of the Vacuum Vessel (VV) Primary Heat Transfer System (PHTS), Ref. 2, of the International Thermonuclear Experimental Reactor (ITER) has been developed to study system performance during normal and abnormal operating conditions and to evaluate alternative designs. This paper describes the RELAP5 model and presents some results.

The VV is configured in the doughnut shape of the ITER Tokamak where the plasma is contained. It consists of two concentric steel structures with cooling water circulating in between them. The volume between the structures is divided into 18 parallel, independent, vertical segments (each segment is a 20º sector) attached alternatively to two separate cooling loops, so that, each loop cools 9 alternating segments. Each cooling loop is able to remove half of the total heat load of the VV during normal operation, which is 10 MW (peak pulsed power). The cooling water enters the VV at the bottom at 373.1 K and 1.1 MPa, circulates at a flow rate of 475 kg/s per cooling loop (950 kg/s both loops), and exits at the VV top. The VV cooling loops are also safety systems designed to remove heat under abnormal conditions. During abnormal conditions (like loss of off-site electric power), the pumps will not be available, and one VV cooling loop should remove the nuclear decay heat of the complete VV and its internal components (first wall, blanket and divertor) under natural convection conditions. The decay heat of the VV itself is small (26.5 kW at time zero), but the decay heat of the internal components is significantly larger. The internal components transfer heat to the VV by conduction and radiation.

In the 2004 ITER design, each VV cooling loop has air-to-water heat exchangers (HXs) located outside, on the roof of the building. This location is undesirable because the HXs are subjected to external hazards, like wind, tornado, aircraft crash, etc. In the alternative design investigated here, the HXs will be moved inside the building, to be located inside the Vacuum Vessel Pressure Suppression System (VVPSS) tank. This is a large tank (1200 m^3 volume) with a large amount of water (650 m^3) which is under low pressure (4.2 kPa) in order to quench steam generated by potential pipe breaks inside the VV. Under this alternative design, the VVPSS tank will serve two different functions at different times: quench tank for potential VV pipe breaks and cooling sink for the VV PHTS under accident conditions.

The HXs to be placed inside the VVPSS tank will consist of double-jacket tubes with the VV cooling water circulating inside the tubes and component cooling water (CCW) at a temperature of 301K circulating inside the jackets. The VV cooling loop transfers heat to the CCW and this jacket configuration thermally isolates the VV cooling loop from the VVPSS tank water during normal operation. During abnormal conditions, CCW will not circulate and the VV cooling water will transfer heat to the VVPSS water through the water-filled jackets. Water in the VV cooling loops will circulate by natural convection. The VV is the heat source, and the heat sink is the VVPSS tank, located at a high elevation. There are two HXs, one for each VV cooling loop. Each HX is designed to remove 1.5 MW of continuous power when the CCW circulates inside the jackets. When working in a passive mode (no CCW circulation, transferring the heat to the water in the PSS tank), each HX is capable of removing ~0.2 MW.

Fig. 1 shows an isometric view of the RELAP5-3D model of one cooling loop of the VV PHTS. The complete VV has two cooling loops like this. Each loop includes three separate systems (VV and HX primary, secondary of HX, and PSS tank) which were modeled with 100 volumes, 95 junctions and 218 heat structures. The VV is shown on the left, the HX and the pressurizer on the right (top), and the pump at the bottom. Fig. 2 shows calculated coolant temperatures during plasma pulsed operation. Temperatures of the coolant leaving and entering

the VV and leaving the HX are shown. During the first 1000 s, each VV loop was heated at 1.5 MW continuous power, followed by 5 MW pulses of 400 s duration with 1400 s dwell time. The HX can remove 1.5 MW of power, therefore, during the 5 MW plasma pulse power, the coolant temperatures increase. During the dwell time (at no power), the coolant temperatures decrease. Temperatures oscillate by about 1 K. The maximum temperature of the VV cooling water is always below 375 K (shown in red as VV-OUT in Fig 2). After the third pulse, the temperature oscillations are stable.

During abnormal operation, the pumps in the VV cooling loops and in the CCW system are shutdown and natural convection will be established in the VV cooling loops. The VV coolant flow goes from 475 kg/s/loop with the pump on to only 12 kg/s/loop under natural convection conditions. Only one VV cooling loop is assumed to operate and to remove the decay heat load of the complete VV and associated structures. Fig. 3 shows the VV coolant temperature (in and out) during 115,200 s (32 h) of decay heat operation under natural convection conditions. The VV coolant temperature reaches a maximum value of only 375.4 K at 115,200 s. The decay heat is transferred to the water in the VVPSS tank; its temperature increases by 6 K during all this time. This calculation demonstrates that one single VV PHTS cooling loop is capable of removing the decay heat of the complete VV and associated structures during 32 h of operation at no power. After 32 h the power is assumed to be restored.

In conclusion, this RELAP5-3D model of the ITER VV PHTS has been used to check normal and abnormal operation of the cooling system and has demonstrated the feasibility of this alternative design of locating the VV PHTS HXs inside the VV PSS tank, being cooled by CCW during normal operation and by the water in the VV PSS tank during abnormal conditions.

References

1.- *RELAP5-3D Code Manual*, INEEL-EXT-98-00834, Rev. 2.4, Idaho National Laboratory (2006).

2.- Jan Berry et al., "Bringing a Star to Earth," *Chemical Engineering Progress*, Vol. 105, No. 4, 26, April 2009.

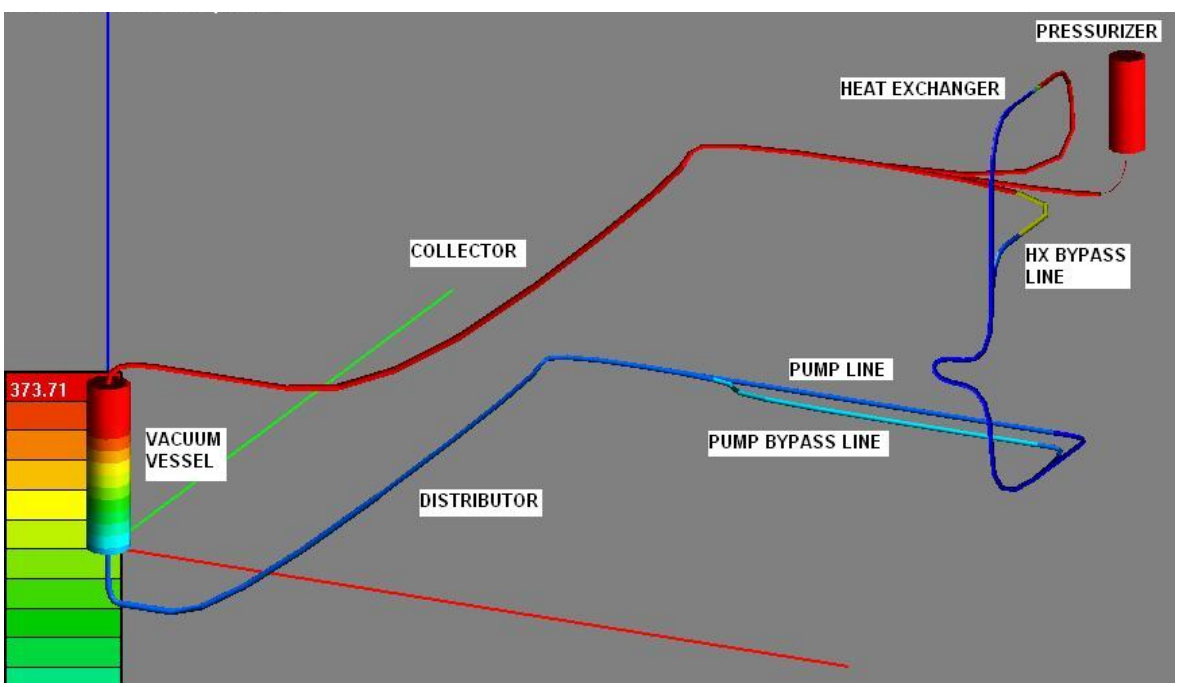

Fig. 1. RELAP5-3D model of one cooling loop of the VV PHTS

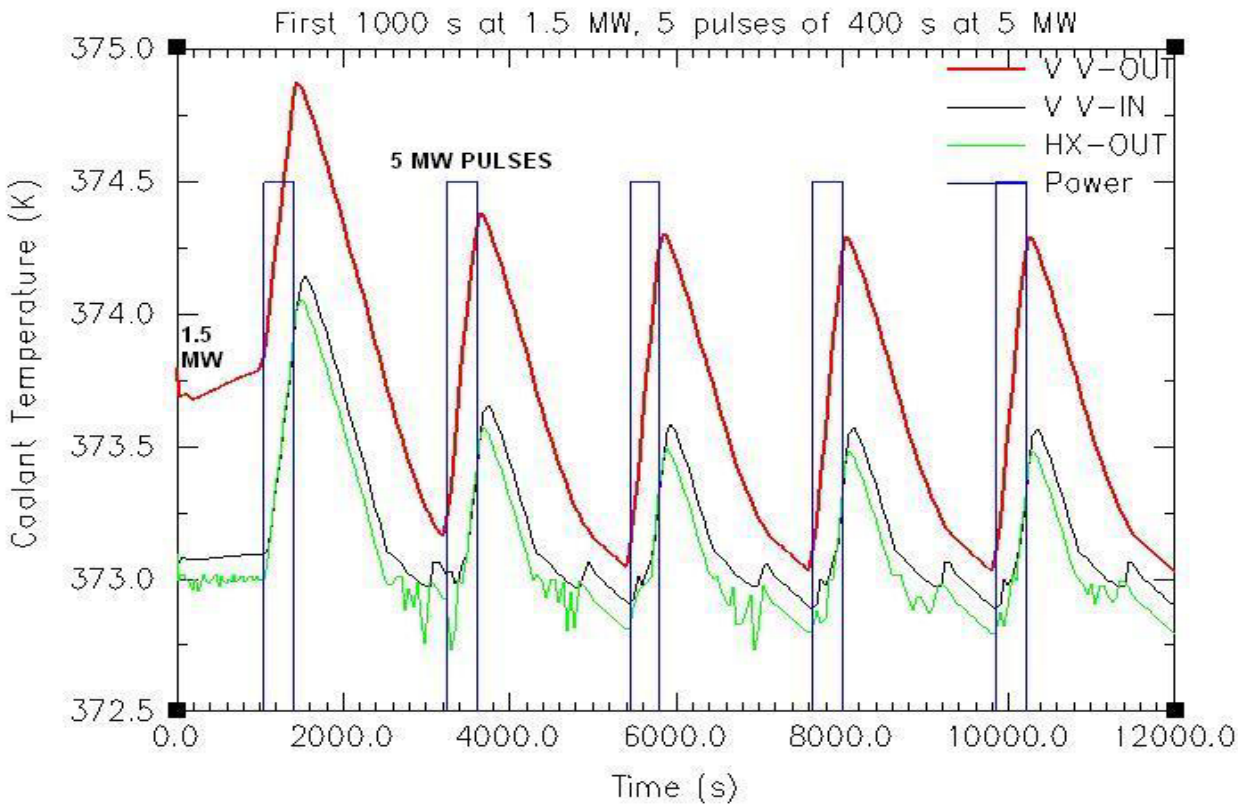

Fig. 2. VV calculated coolant temperatures during normal pulsed operation (5 MW pulses)

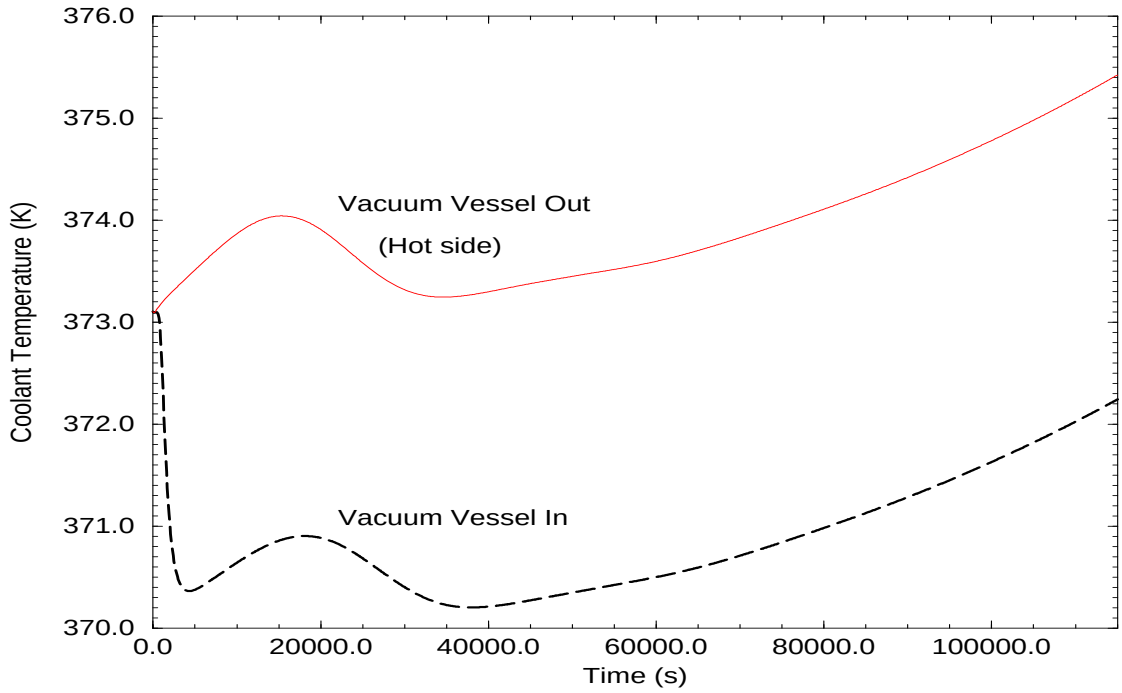

Fig. 3. VV calculated coolant temperatures during 115,000 s (32 h) of decay heat operation and natural convection flow (no pump)