DETAILED DESIGN OF 700 MWE STEAM GENERATOR FEATURES

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1.0 INTRODUCTION

The next stage in the Indian nuclear power programme consists of building 700 MWe Indian Pressurized Heavy Water Reactor (IPHWR) units. This involves up-rating of all the plant equipment like reactor, steam generators (SGs), turbo-generator, major pumps, etc. The SG used in the current generation of IPHWRs (like the TAPS-3,4 twin units) which have an electrical power of 540 MWe, is a mushroom type, inverted U-tube, natural-circulation SG. The 700 MWe SG design has the same the tube diameter, tube pitch and outer diameter of the steam generator sections as the 434 MWth SG, with certain changes in geometry of the feed header, flow restrictor in the downcomer and flow distribution plate. These changes coupled with some process changes resulted in a 26% increase in steam flow rate while maintaining the same circulation ratio[1]. The paper describes detailing of these geometric changes using a CFD code for optimizing the flow field. After a brief description of SG each of these studies is comprehensively covered in the following sections.

2.0 SYSTEM DESCRIPTION

A schematic view of a U-tube steam generator is given in Fig.1. It consists of 2489 inverted U-tubes connected to a tube sheet at the bottom of the steam generator. The primary fluid's inlet and exit manifolds are connected to the bottom of the tube sheet, while a shell is welded to the other side of the tube sheet. The shell is expanded at the top to accommodate steam separators. Since the tubes are fairly long, supports are provided at various elevations to provide lateral rigidity and prevent them from excessive vibrations. A cylindrical shroud covers the U-tubes and provides a boundary between the riser and the downcomer.

The primary water enters through the inlet plenum of the Steam Generator, flows inside the U-tubes and transfers heat to the light water on the shell side. The feed water is provided at the top. This feed mixes with the water returned by the steam separator and flows down in the annular space between shell and shroud called down-comer. Subsequently, this water flows upwards over the U-tubes inside the shroud picks up heat, generates the steam and this two phase mixture rises to steam separators. The steam separators separate the steam and separated water mixes with feed water coming out of inverted J tubes from the feed header and flows down. The steam exiting from the separator goes through the driers to further decrease the moisture content to less than 0.25 %.

A comparative scaled drawings of 540MWe and 700 MWe SGs are presented in Fig.2. To increase the capacity of new unit by 26% the major changes in the geometry were the enhancement of height of both shroud and steam drum by 3 m. The diameters of the shroud, the shell and the drum were maintained same. The tube diameter and layout were also unchanged. Other than these issues and the process modifications the changes to optimize the flow fields were executed on the feed ring header, flow restrictor in the down comer and the flow distribution plate. These subassemblies were designed after three dimensional modeling and various parametric runs.

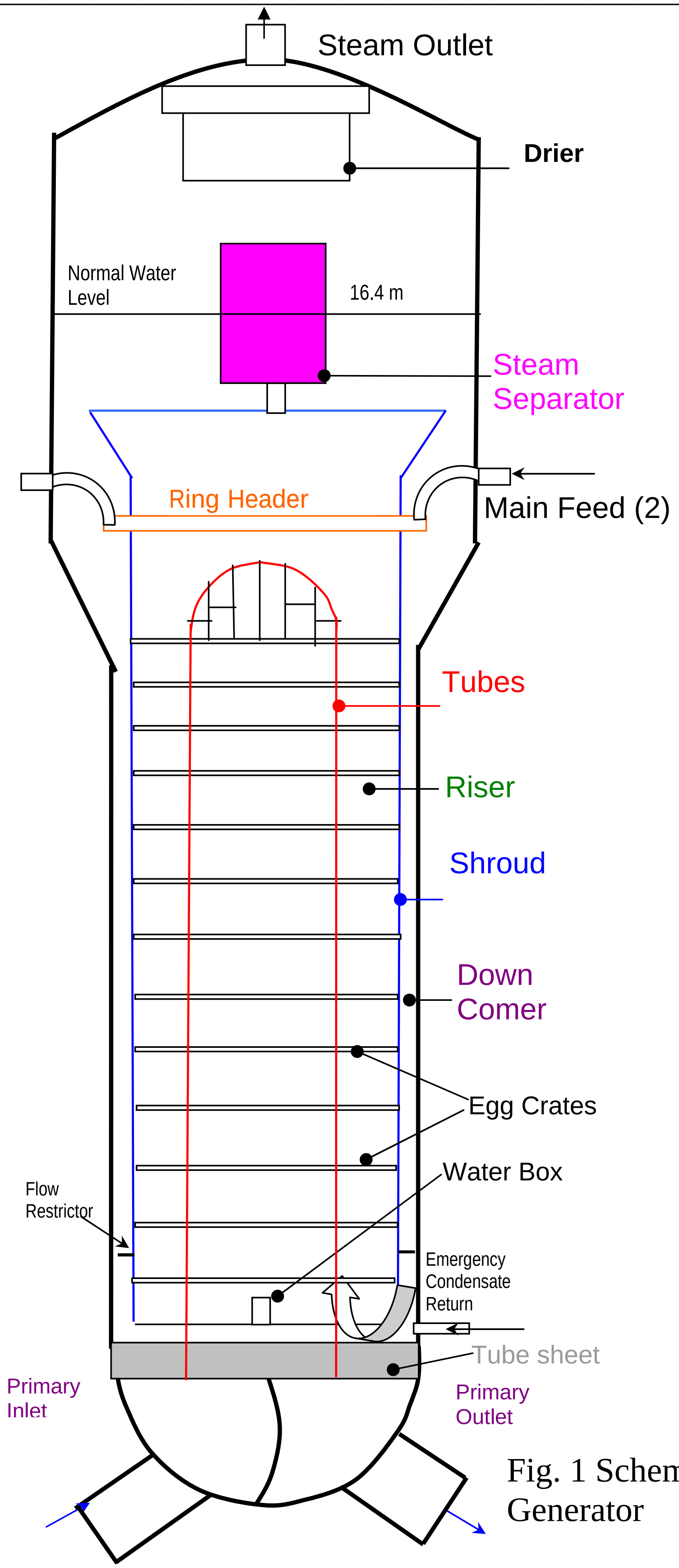

Fig. 1 Schematic View of Steam Generator

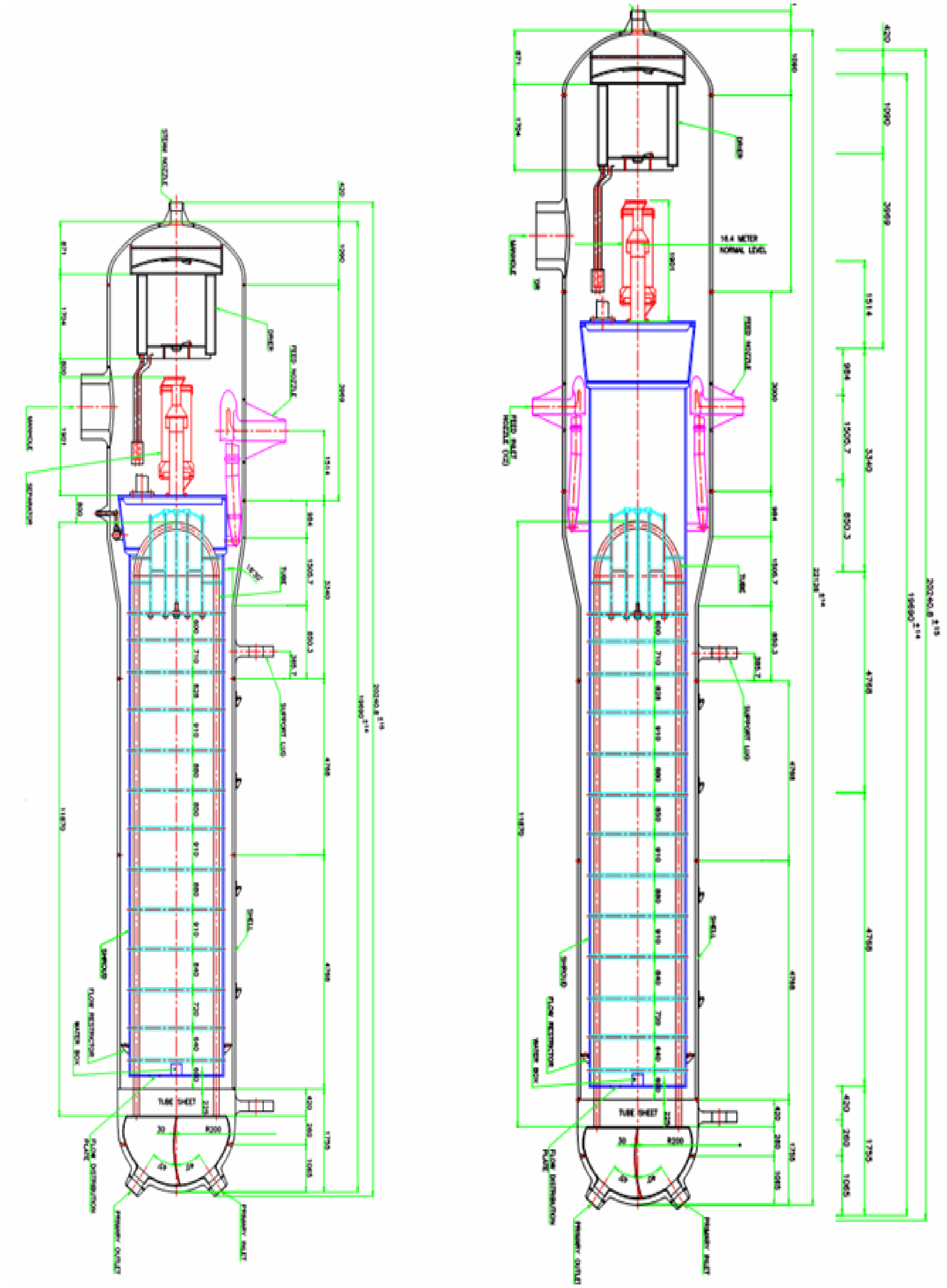

Fig.2 Comparison of 540MWe and 700MWe SGs

3.0 RING HEADER

A ring header is provided to distribute the feed flow circumferentially in the downcomer. The feed flow enters the ring header through the feed inlet nozzle, goose neck and a bellow. The basic design objective of the ring header is to have a uniform distribution of outflow through each J-tube. This will result in a uniform temperature distribution inside the downcomer. The same design principle was also used for the 700 MWe NPP SG. In 540 MWe Nuclear Power Plant (NPP) SG the ring header consists of a single header having 81 J-tubes with a block at 180^{o} to the feed entry. But in the 700 MWe SG the header is split into two symmetrical halves with a total of 86 J-tubes. Two separate cases considered different geometry for both plants. The geometry of ring feed header modeled for the 700 MWe SG is shown in Fig.3. A computational fluid dynamics (CFD) code has been used for the detailed analysis of the feed water ring header. Since the ring header has a complicated geometry, unstructured tetrahedral meshing scheme was used with a sizing function to restrict the maximum size of mesh. Flow was assumed incompressible and turbulent. A steady-state segregated solver with implicit formulation has been used. Inlet mass flow and outlet pressure were fixed as boundary conditions. Distribution of flow rate through each J-tube was analyzed and found satisfactory for a final design. The velocity contours and the path lines are given in Fig.4 and Fig.5 respectively.

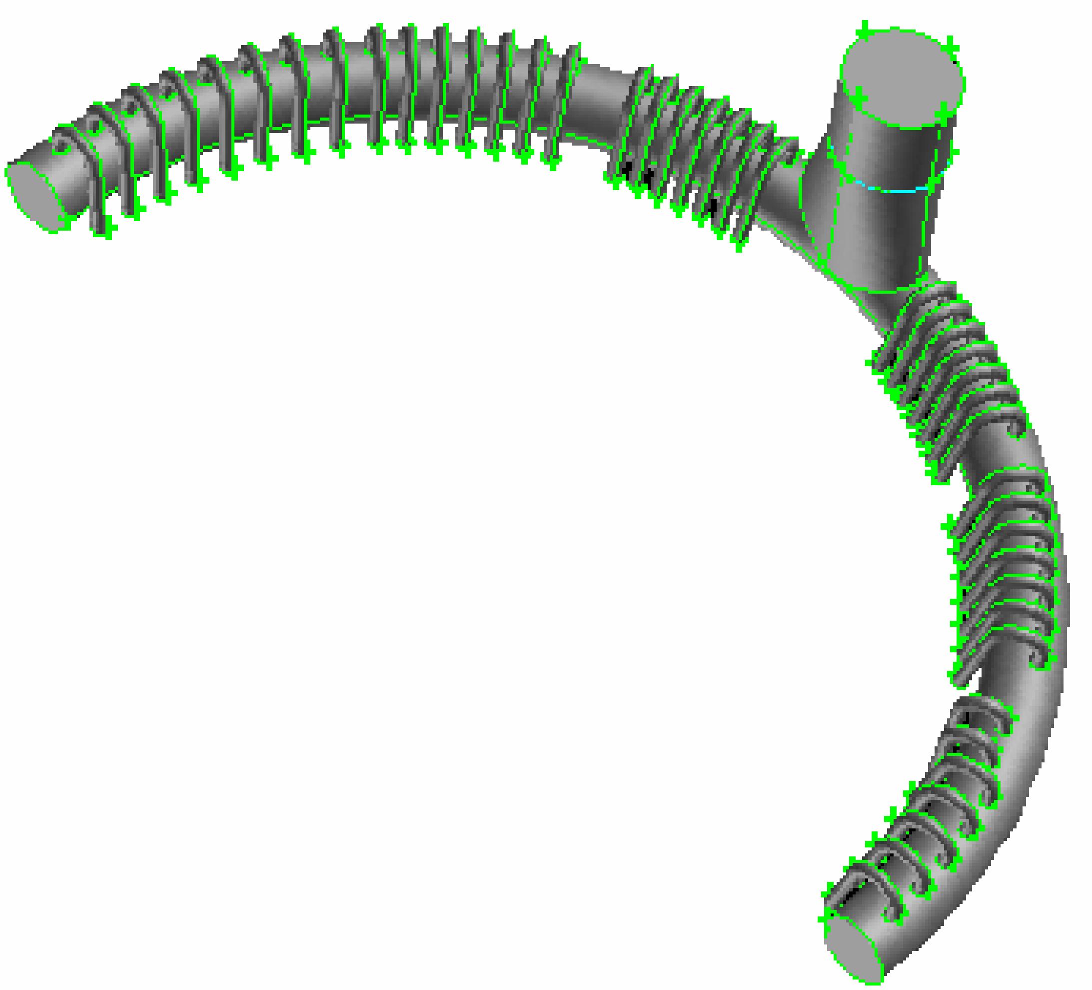

Fig.3 The Geometry Modeled for the Feed Ring Header Analysis of 700 MWe SG

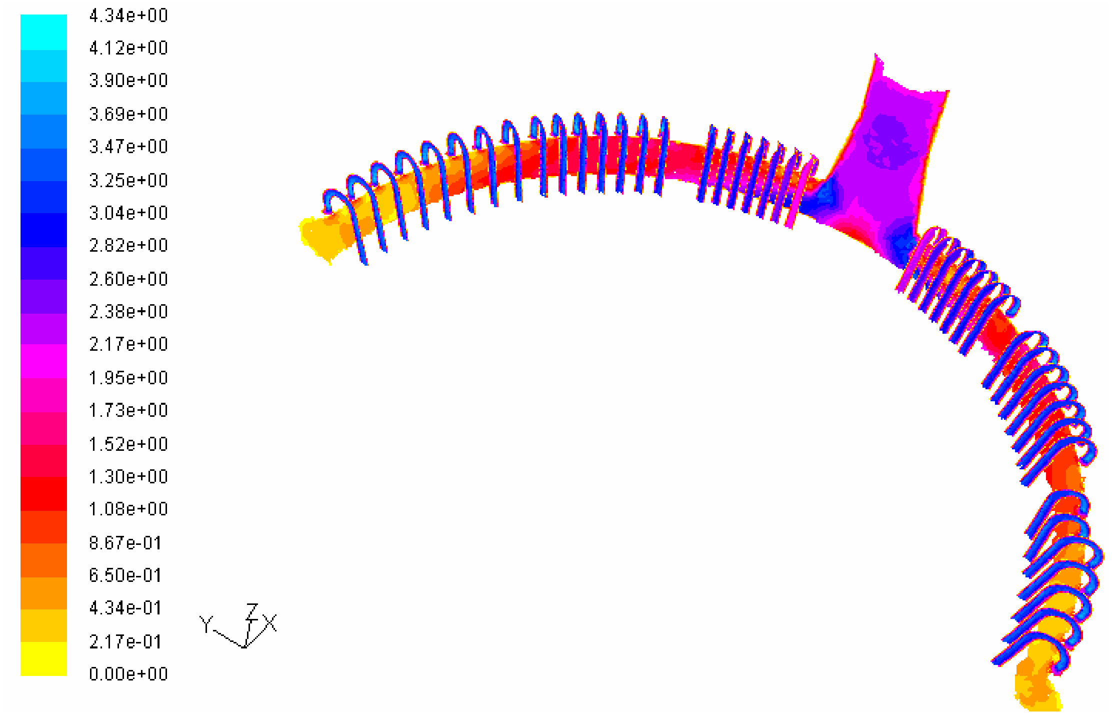

Fig. 4 Velocity Contours (in m/s) of Feed Header and J Tubes

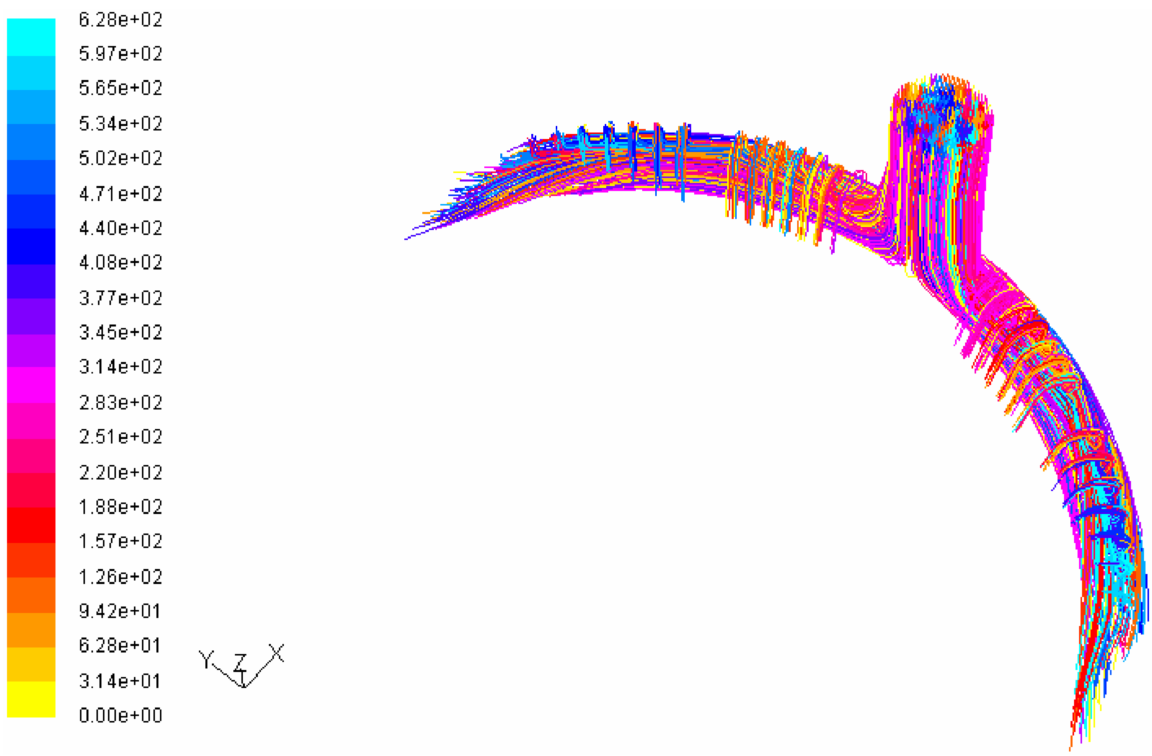

Fig. 5 Path lines coloured by particle ID for Fluid in the Feed Header and J Tubes

4.0 FLOW RESTRICTOR

Flow stability of the SG natural-circulation loop depends upon the ratio of pressure drop in the single-phase region to the pressure drop in the two-phase region. A flow restrictor is placed in steam generator downcomer to maintain the ratio in the stable region. The flow restrictor used in the 540 MWe SG was an annular plate with four quadrants. Each quadrant has 12 circular holes and a clearance of 12.5 mm near the shell inner diameter for the flow. A typical quadrant of the flow restrictor and associated attachments are shown in Fig.6. A different flow restrictor having enhanced opening was designed for the 700 MWe SG to maintain the required circulation ratio in the SG. The entire geometry was modeled in this analysis. For this task, a 3-dimensional steady-state segregated solver with implicit formulation was applied. Pressure contours across the 540MWe and 700 MWe flow restrictors where a hole is present are given in Fig.7 and Fig. 8 respectively. In case of 540MWe SG the pressure drop across the flow restrictor was 0.11 bar for the downcomer flow corresponding to 100 % full power condition. The same restrictor geometry was applied to 700 MWe SG and got 0.18 bar drop. New geometry with increased hole diameter resulted in a pressure drop of 0.13 bar and accepted for the SG.

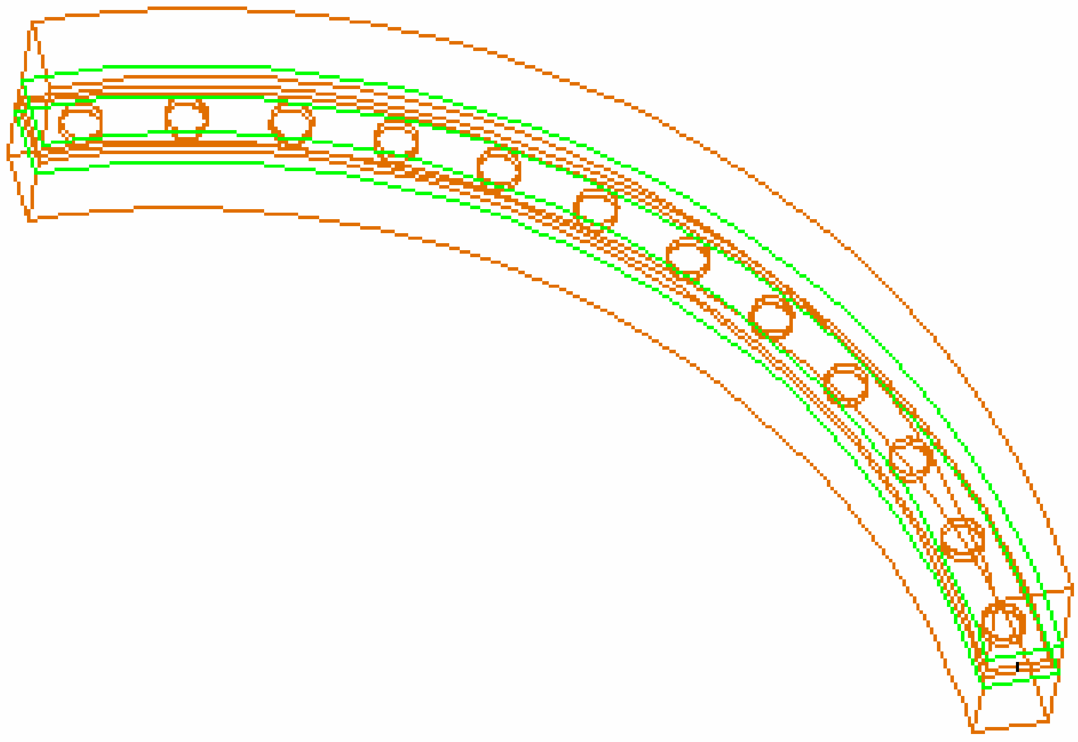

Fig.6 One Quadrant of the Flow Restrictor

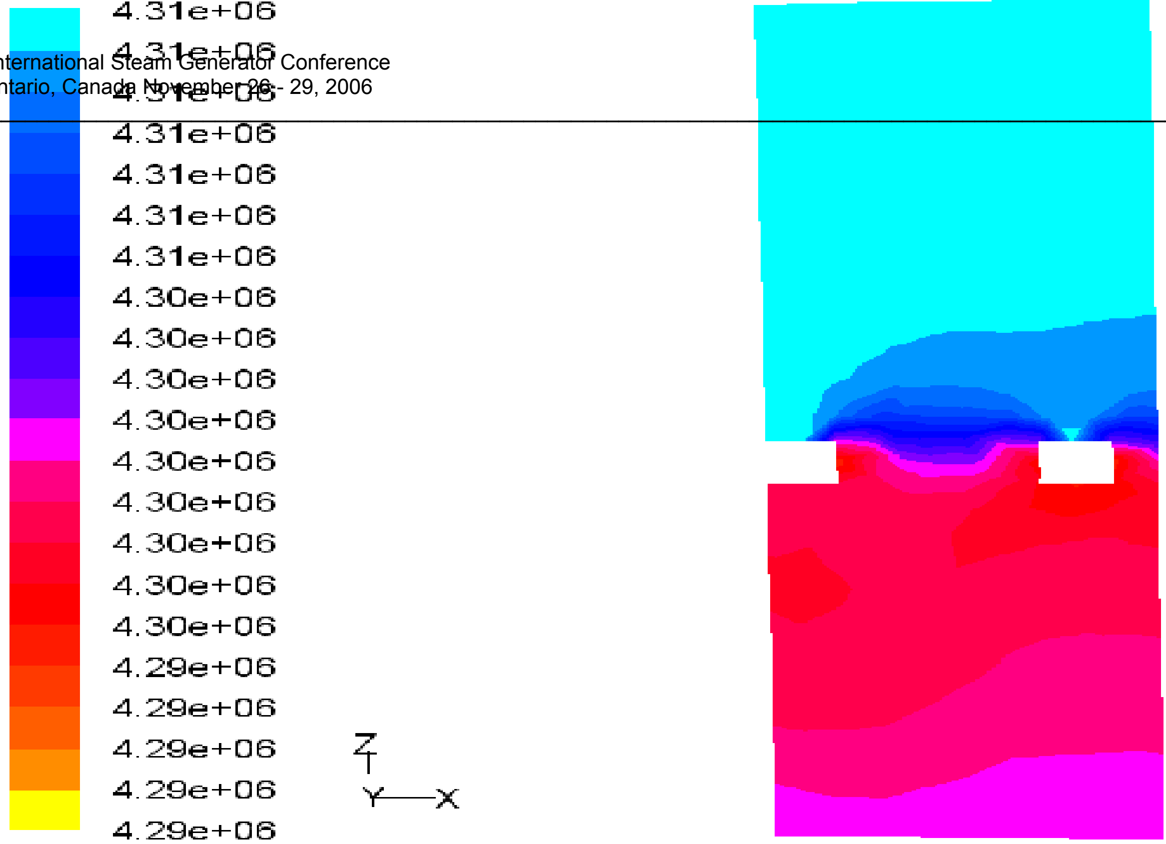

Fig. 7 Pressure Contours (in Pascal) for the540MWe Flow Restrictor Where a Hole is Present

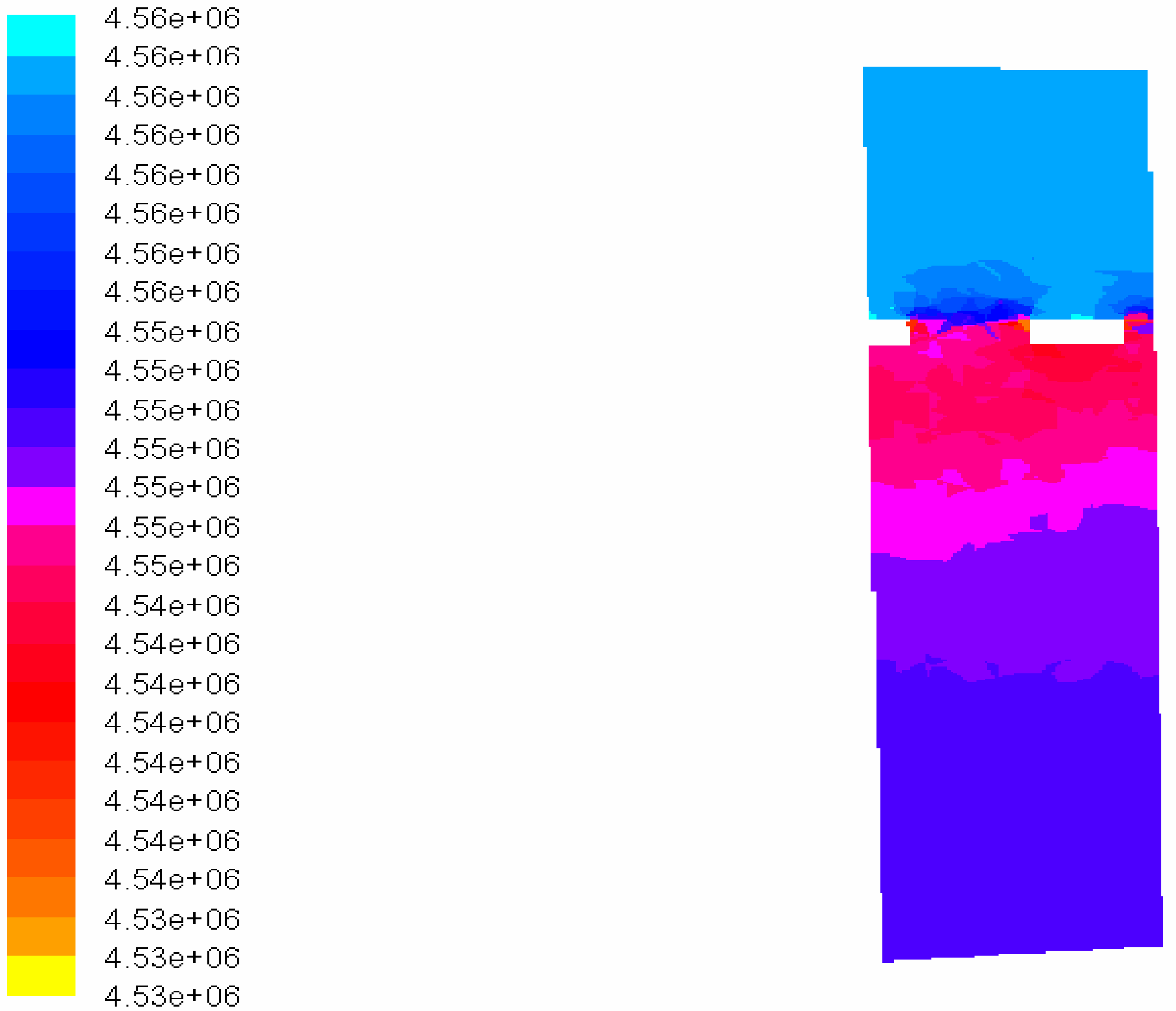

Fig.8 Pressure Contours (in Pascal) for the700MWe Flow Restrictor Where a Hole is Present

5.0 FLOW DISTRIBUTION PLATE

The flow distribution plate (FDP) is placed above the tube sheet at an optimal distance. It is attached to the bottom of the shroud and kept in position using tie rods fixed to the tube sheet. The objective of the flow distribution plate (FDP) analysis was to obtain the pressure loss of the FDP and check for any low flow zone above the tube sheet. An area with low flow would result in crud deposits on the tube sheet. Pressure drops below and through the FDP also affect the circulation ratio in the SG. Since there are 2489 U-tubes inside the SG, the porous media approach was used for the modeling of the tube bundle and the diametrical clearance between the FDP and the tubes. A water box is placed between two FDPs in the tube free zone to reduce the tube bundle bypass of riser flow. A scaled down model of actual tube bundle with 400 tubes have been modeled to arrive at the loss coefficients in three directions. An unstructured tetrahedral meshing scheme was used. The problem was solved as a steady-state, incompressible, 3-dimensional, turbulent flow problem. Results were validated against the KWU results for 540 MWe NPP SG. Runs were performed for various distances of the FDP from the tube sheet and the cut-out size inside the FDP. These variables were optimized for a minimum pressure drop and a minimum low flow area above the tube sheet.

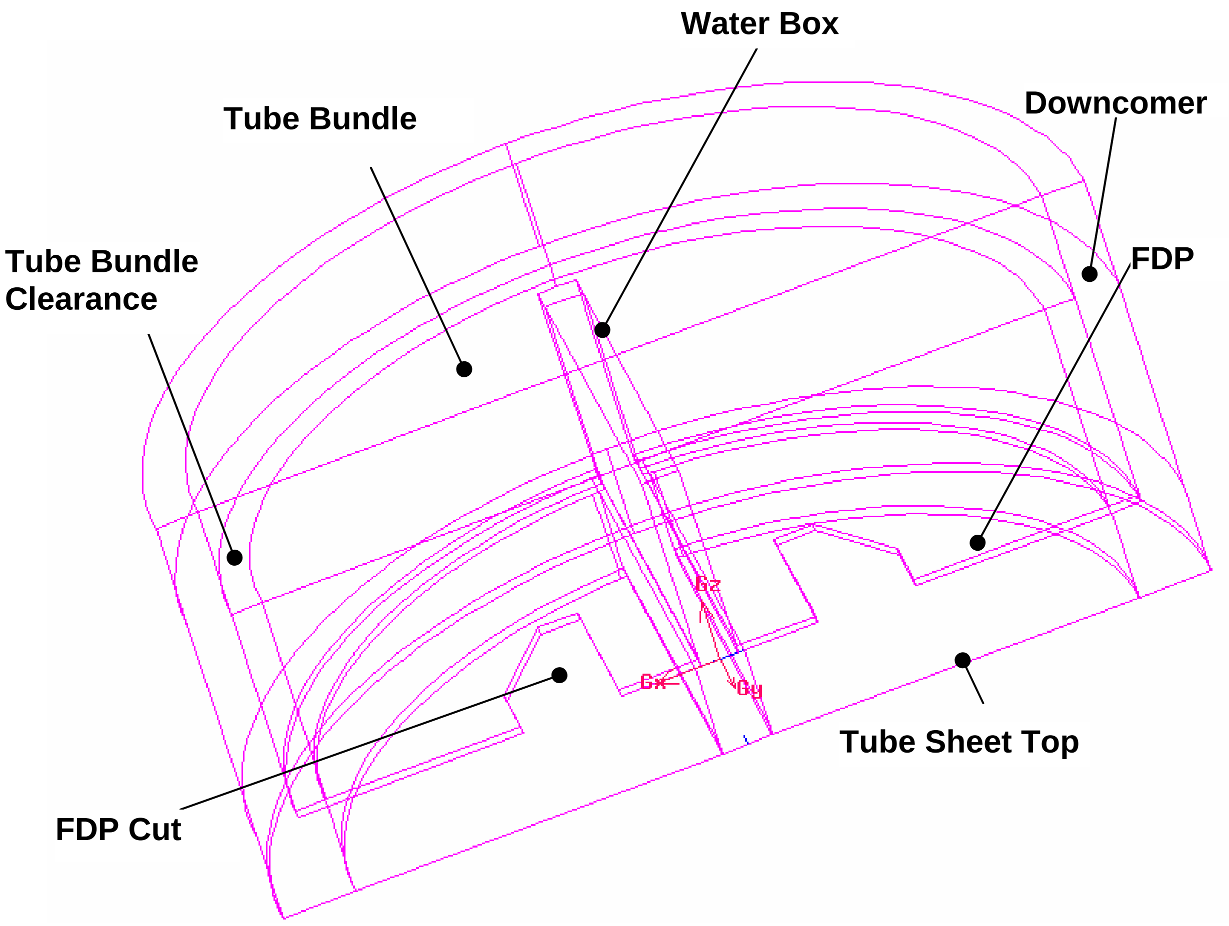

Fig. 9 Symmetric Half of the FDP and Associated Features

6.0 CONCLUSION

Detailed designs of SG components were executed for the next generation IPHWR. A CFD code was used for the detailed design of the components which gave insight into the process design of SG. The results were compared with the existing operating units and found acceptable. As far as possible existing design features were maintained.

7.0 REFERENCES

1. Benny John and S.G. Ghadge, “Design of Steam Generator for 700 MWe IPHWR”, Paper No. 6460, Proc. Of ICAPP ’06, Reno, NV, USA, June 4-8, 2006.