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Coolant Flow Measurement at Different Core flow Conditions in PHWR Nuclear Power Plants

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Abstract— Flow distribution in the channels is the basic requirement for the removal of heat from the core effectively and evenly. The channel flow calculation at various gross core flow conditions is a challenging task for the nuclear core of Pressurized Heavy Water Reactor (PHWR).Individual channel flow is necessary for calculating the coasting down pattern of the flow during slow reduction of gross flow after loss of power to the circulating pumps. Individual Channel Flow is also important to predict the flow through different channels of the reactor at various conditions of the core. The various conditions may be the different combination of main pump operation or shutdown pump operation or different header pressure conditions or at various reactor power states. The flow through each channel is critical as it has to remove the heat from fuel. This flow is proportional to the thermal power produced by each channel. Since measurement of flow using instruments in all the channels is not feasible due to its complexity and economic considerations.

An algorithmic approach is modeled for simulating the flow at various header pressure conditions which will change at various operating as well as at different shut down (S/D) conditions. The design flow is matched with the calculated flow considering the various losses due to the flow barriers at normal operating conditions. The flow is simulated at different operating and at various core flow states by changing the inlet (I/L) header and outlet (O/L) header pressures. An algorithm is presented to compute the flow at various header I/L and O/L pressures.

Index Terms— "Flow algorithm, Core flow conditions, PHWR,Pessure difference,Channel flow,Flow Model,Design Flow". —

1 INTRODUCTION

Coolant in a nuclear power plant plays an important role to transport the primary heat from the core to secondary system to have the effective power generation. The pattern of flow distribution is decided based on the channel power which is a function of the fuel burn up ratio. In the matrix of coolant channels the central channels have more burn up ratio necessitating the maximum flow and the outer channels having less fuel burn up ratio demands less flow compared to inner channels.

The Primary Coolant Pumps which cater this flow through the North and South header systems to the entire channel matrix. The system of feeders through which the flow is distributed in the channels is undergoing various losses due to the bends restrictions and various constrained path due to fuel and other seal and shield plugs.

The flow through each channel is important as it has to remove the heat from fuel and this flow is proportional to the thermal power produced by each channel. Since measurement of flow using instruments in all the channels is not feasible due to its complexity and economic considerations. Therefore, an algorithmic approach is modeled for simulating the flow at various header pressure conditions which will change at various operating as well as at different Shut Down conditions.

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2.0 PHT SYSTEM

The Primary Heat Transport (PHT) System, main circuit, provides the means for transferring heat produced in the fuel to feed the water in steam generator (SG) in which steam is generated to run the turbine. The heat transport medium is pressurized by heavy water and is circulated through the main circuit by primary circulating pumps (PCPs). Bi-directional fuelling adopted for uniform neutron flux necessitates opposite bidirectional flow in adjacent channels. This has been accomplished by a series-parallel arrangement which has lower hold-up, lower piping cost and lower hydraulic losses as compared to parallel arrangement.The Nuclear Power Plants such as Kaiga plant which use valve-less system design for PHT main circuit, eliminate SG-PCP isolation valves. This system has the following advantages.

a) Availability of thermosyphoning as a passive mode.
b) Reduction of Radiation dose Intake for valve maintenance.
c) Reduction of potential heavy water leak points.

2.1 Main Circuit

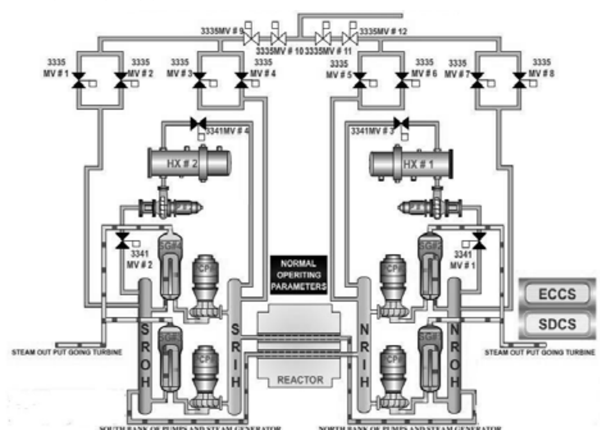

Fig-1 Primary Heat Transport System main circuit.

Fig-1 shows the main circuit of Primary Heat Transport System. The heavy water runs from inlet headers to inlet feeders into 306 coolant tubes, through the end fittings to outlet feeders and to the reactor outlet headers. The reactor utilizes restriction orifices in selected inlet feeders to achieve the required flow by the reactor channel ratings, to maintain equal outlet temperatures from all the channels. At full power, the temperature difference (ΔT) between I/L and O/L across each channel is 44.4oC. The reactor outlet headers distribute the flow to the respective steam generator. From the steam generator the heavy water arrives at the primary circulating pumps. There are four steam generators and four primary circulating pumps. Each pump is associated with its steam generator. The pumps discharge the flow into the reactor inlet headers. No common suction header has been provided and pumps are connected directly to the steam generators. From the reactor inlet headers the heavy water flows through the feeders and end fittings to the reactor coolant tubes.

In the PHWR having valve less system, flow path is always available to have continuous circulation through the core at all the times. Power extraction under possible modes of operation is as follows.

I. 2-2 Mode: All four PCPs operate extracting 100% reactor power. This is the normal mode of operation.

II. 1-1 Mode: One pump on each bank operates. Maximum 50% of reactor power can be extracted (assuming ΔT of 44.4oC).However setback is provided till 2 % of Full Power.

III. 2-0/0-2/1-0/0-1 Mode: Absolute trip

Thermo wells and Resistance Temperature Detector(RTD) inserts have been provided at inlet and outlet of each SG (heavy water side) to measure ΔT across SG. Provision also exists to measure ΔT of 8 selected channels (where flow is being measured) for the purpose of reactor power calculation.

2.2 Design parameters for main system:

Design pressure - 112.5 kg/cm^2
Design temperature - 300 ^{o}C
Material - Carbon Steel

Design pressure for coolant channels (Zr-2.5% Nb) at various temperatures is given below

250 ^{o}C = 111 kg/cm^2 (g)
262 ^{o}C = 109 kg/cm^2 (g)
300 ^{o}C = 104 kg/cm^2 (g).

2.3 Emergency Core Cooling System:

In the event of a leak from the primary system, cooling of the fuel can be maintained by the emergency core cooling system. The system injects heavy water from the heavy water accumulators when the PHT pressure at reactor inlet headers falls to 55 Kg/cm2. If the pressure continues to fall at 32 Kg/cm2 (along with conditioning signals) light water injection is initiated from light water accumulators. Further cooling is resorted by recirculation of water from and to the suppression pool by means of pumps. Decay heat in this condition is removed by plate type heat exchangers.

2.4 Shut Down Cooling System:

For cooling the system below 150^{o}C and for holding the system at low temperature during plant maintenance an auxiliary cooling system is provided which is called as shutdown cooling system. The system is connected between the reactor outlet and inlet header at west side on both the banks. The S/D system is also meant for providing header level control, for maintenance of S/D circuit valves, ECCS valves, Instrumented Relief Valves(IRV), feed check valves and ISI / maintenance on SGs and PCPs [1].

3.0 Description Of The System

3.1 Purpose Of The System

Low flow will result in temperature rise in the fuel channel which may lead to fuel failure if the channel is left unmonitored[2]. The detection of low flow can be achieved by one of the two methods. (1) Directly by measurement of channel flow. (2) Indirectly by measurement of channel outlet temperature or indirectly by varying pressure difference in the system.

While deciding the type of measurement, emphasis was given to have minimum number of welded joints, less number of tubes, instruments, mechanical joints, instruments to tube joints etc. so that chances of leakages are reduced as the system carries heavy water at high pressure and high temperature with the radioactivity present in the fluid.

3.2 Design Basis

The number of channels and their locations which employ channel flow measurement are decided on the following consideration [2].

(1) The channel thus selected should represent all zones i.e. at least one channel shall be selected from each zone. (2) Equal number of channels is selected from north and South zone.

4.0 Design consideration

General

The channel flow measurement is a safety related system. The design of channel flow instrumentation and control system calls for consideration of following criteria as stipulated in IAEA safety guides SG-D8 [3].

1) Single failure criteria
2) Fail safe design
3) Criteria of independence
4) Reliability
5) Diversity

The above criteria are adhered to our design in following ways:

a) Triplication instruments/instrument loops and using two out of three voting mode for actuation of final equipment.

b) Using fail safe philosophy for all alarm actuating device and relays used for actuation of logic [2].

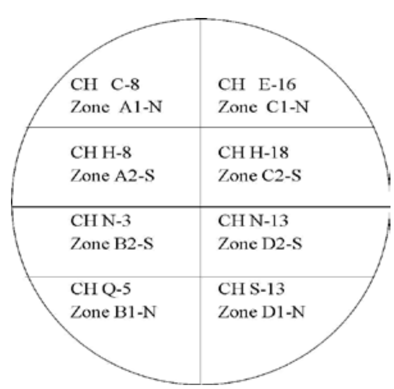

Fig-2 Zonal Representation for representative Channel flow measurement

5.0 CHANNEL FLOW FOR DIFFERENT HEADER PRESSURES

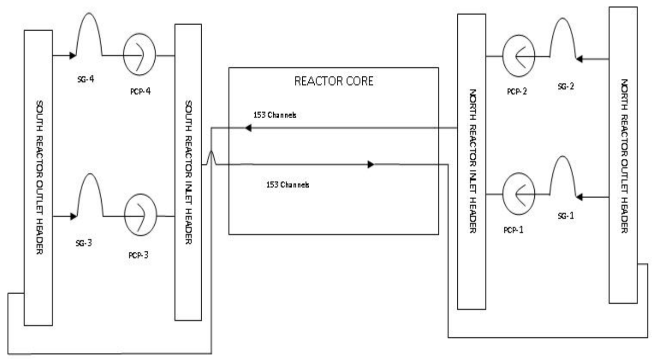

Fig-4 Ray diagram of Primary Heat Transport System

Fig-4 shows the coolant flow path in Primary Heat Transport System.The thermal rating of the 306 fuel channels varies according to the flux pattern with a maximum to minimum ratio of approximately 2.4.It is necessary to match the coolant flow to the heat generated in each channel to minimize the variation in outlet coolant temperature. Uniformity in coolant conditions is essential as these are basic parameters in the channel structural design and in the plant thermal cycle. The flow resistance of feeders is designed to provide an appropriate flow of coolant to each channel at rated difference in circulating head between the reactor headers. The hydraulic analysis takes account of the channel flow losses which include an orifice element mounted on the end fitting shield plug and also a inconel restrictions orifice in some of the inlet feeders [4].These channels are classified into 153 North Upstream channels fed from NRIH to SROH and 153 South Upstream channels fed from SRIH to NROH. The overall flow control is done as per the design flow pattern through the feeder and the total PCP flow is matched with total out coming flow through the reactor. This balances the actual flow with channel flow [4].

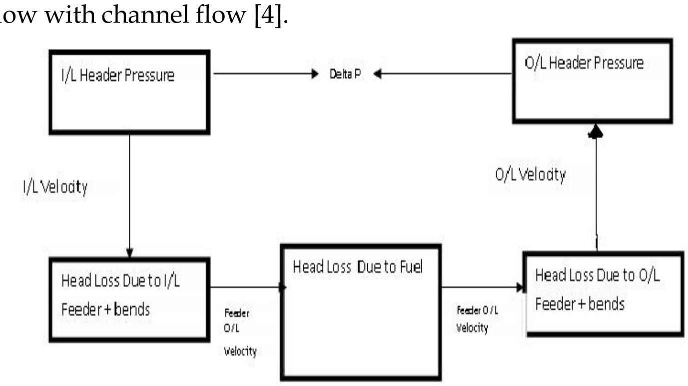

Fig-3 Flow calculation Algorithm

The Pattern of Feeder arrangement at the reactor core can be broadly classified in to 4 cases.

Case-1 Feeders with single diameter at the I/L and O/L without orifice.

Case-2 Feeders with single diameter at the I/L and O/L with orifice.

Case-3 Feeders with Two diameters at the I/L and O/L without orifice.

Case-4 Feeders with Two diameters at the I/L and O/L with orifice.

The Coolant through the reactor core passes through the system of feeders arranged at Inlet and Outlet. The Head loss of the coolant is measured in the following manner [5].

1. Head Loss due to I/L feeder
2. Head loss due to I/L feeder with 900 bends.
3. Head loss due to Fuel path.
   (This Loss is the combination of End Fittings, Fuel path Loss and the Shield plugs loss)
4. Head Loss due to O/L feeder.
5. Head Loss due to O/L feeder with 900 bends.
6. Head loss due to orifice at peripheral channels as a flow balancing restriction.

The Design flow is converted into velocity at the Inlet and the velocity at the outlet is calculated by considering the losses [5].

Case-1 Procedure for calculation of losses in feeders of single diameter without orifice [5, 6].

Channel No: North/South Design flow Q in Kg/hr

INLET FEEDER

Inlet feeder diameter D in mm = D in m

Inlet feeder Length L in mm = L in m

No. of bends in inlet feeder N

OUT LET FEEDER

Outlet feeder diameter d in mm = d in m

Outlet feeder length l in mm = l in m

No. of bends in outlet feeder n1

Since D=d because of single diameter feeders

Total feeder length L=L+l in m

Area of inlet feeder A1=πD2/4

Q=A1V1 Q′= (Q/3600*885.4) m3/s where Q = flow

Velocity at the inlet V1=Q′*4/πD2 m/s

γ = viscosity = 0.01*10-4 = 10-6 Pa-s

Re= (V D1/ γ) = V D/10-6 where Re is Raynolds number

Co-efficient of friction $f=0.0008+(0.05525/(Re)^{0.237}$

FRICTION LOSS IN FEEDER OF DIAMETER D

$h_f(D) = 4 f^* L^*V_1^2/ 2^*g^* D$ **(i)**

INLET LOSSES

$I_1=h_i+h_o+h_B$ Feeder inlet loss (ii)

h_i= (0.5 V12)/2g Head loss when water enters the feeder from header

Feeder exit or outlet loss

h_o= (V12)/2g Head loss when water exit the feeder D

Feeder bend loss

h_B= [(0.1 V12)/2g]*N1

OUTLET LOSSES

$O_1=h_i+h_o+h_b$ (iii)

Feeder inlet loss

hi= $(0.5\,V_1^2)/2g$ Head loss when water enters the feeder from channel

Feeder exit or outlet loss

$h_o= (V_1^2)/2g$ Head loss when water exit the feeder d

Feeder bend loss

$h_b = [(0.1\ V12)/2g]*n1$

HEAD LOSS IN FUEL PATH[7]

Diameter of fuel bundles pencils d=15.21mm = 0.01521m
$Ad = \pi d2/4$
Diameter of fuel bundles D=82.50mm = 0.0825 m
$AD = \pi D2/4$
Length of the fuel column L=6000mm = 6 m
Area for water flow (AD-Ad) Af =0.00192M2
$hf\ (fuel) = [[f/2(\pi d*19)+ \pi D]*2L*V32]/ Af*g$ (iv)
A1V1=AfV3
V3= A1V1/Af

HEAD LOSS IN SHIELD PLUGS [8]

Hsp=[Inlet Bend Loss (a)+ hf (b)+ Loss in holes (c) + Outlet Bend Loss (d)]*2 (v)
Inlet Bend Loss = (0.1 V12)/2g (a)
Outer diameter of liner tube d=90.6mm=0.0906 m
$a_{sp} = \pi d2/4$ m2
Inner diameter of end fitting D=107.57mm=0.10757 m
$A_{sp} = \pi D2/4$ m2
Length of liner tube Ls=1850mm=1.85m
Area for water flow A sd=Asp-asp m2
A1V1=AspV4
$hf1= [[f/2(\pi d+ \pi D]*2Ls*V42] / As*g$ (b)
Note: V4= A1V1
Diameter of holes in the shield plug dh- ø of hole-12.7mm = 0.0127m
$Ah = \pi dh2/4$ A1V1=Ah Vh Vh =A1V1/Ah
Vh-Velocity of water passing through hole
Velocity at vena Contracta Vc =Vh/0.62
Loss in holes = [(VC- Vh)2/2g]*52 (c)
Outlet Bend Loss = (0.1 V32)/2g (d)
Note: A1V1=AfV3 V3= A1V1/Af

Case-2 Procedure for calculation of losses in feeders of single diameter with orifice [5, 6].

Channel No: North/South Design flow Q in Kg/hr

INLET FEEDER

Inlet Feeder Diameter and length are noted as in case-1
Diameter of orifice Dor = mm = m

OUT LET FEEDER

Inlet Feeder Diameter and length are noted as in case-1
Diameter of orifice dor =in mm =in m

FRICTION LOSS IN FEEDER

hf (D) = 4 f* L*V12/ 2*g* D where f=0.0008+ (0.05525/ (Re) 0.237
Re is Raynolds number (i)

INLET LOSSES

I1=hi +ho +hB + hor (ii)
hi, ho, hB are calculated as in Case-1
Head loss in inlet orifice =hor
Diameter of orifice Dor = mm= m
Area of orifice $Ao = \pi\ Dor2/4$ =m2
A1V1=Ao Vor Vo= Velocity of water passing through orifice
Vor =A1V1/Aor
Velocity at vena Contracta Vc =Vor/0.62
Loss in orifices hor = [(VC- Vor)2/2g]

OUTLET LOSSES

O1=hi+ho+hb+hor (iii)
hi,ho,hb are calculated as in Case-1
Head loss in outlet orifice = hor
Diameter of orifice dor =mm= m
Area of orifice $aor = \pi\ dor2/4$ = m2
A1V1=aorvor Vor= Velocity of water passing through orifice
vor =A1V1/ao
Velocity at vena Contracta vc =vor/0.62
Loss in orifices = [(vC- vor)2/2g]

HEAD LOSS IN FUEL PATH

is calculated as in case-1 (iv)

HEAD LOSS IN SHIELD PLUGS

Hsp is calculated as in case-1 (v)

Case-3 Procedure for calculation of losses in feeders of two different diameters without orifice. [5,6]

Channel: North/South Design flow Q=Kg/hr

INLET FEEDER

First feeder diameter D1=mm= m First feeder length L1= mm= m
Second feeder diameter D2=mm= m Second feeder length L2= mm = m
No. of D1 Bends N1 =
No. of D2 Bends N2 =

OUT LET FEEDER

First feeder diameter
d1=mm= m First feeder length l1= mm = m
Second feeder diameter
d2=mm= m Second feeder length l2= mm = m
No. of d1 Bends n1=nos
No. of d2 Bends n1=nos
Ld1D1=L1+l1= m
Ld2D2=L2+l2= m
Since D1=d1 $A1=\pi D12/4$
Since D2=d2 $A2=\pi D22/4$
Q=A1V1=A2V2 V2=A1V1/A2
Q′= (Q/3600*885.4) m3/s $V=Q'*4/\pi D12$ m/s
γ = viscosity = 0.01*10-4 = 10-6 Pa s
Co-efficient of friction f=0.0008+ (0.05525/ (Re) 0.237) where Re= $(V\ D1/\gamma)$ = V D1/10-6
Friction loss in Feeder of diameter D1
hf (D1d1) = (4 f* Ld1D1*V12) / 2*g* D1
Friction loss in Feeder of diameter D2
hf (D2d2) = (4 f* Ld2D2*V22) / 2*g* D2 (i)

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Note: V2=A1V1/A2

INLET LOSSES

I1=hi +he+ho+hb1+hb2 (ii)
Feeder inlet loss hi= (0.5 V12)/2g Head loss when water enters the feeder from header
Feeder expansion loss he= (V1-V2)2/2g Head loss when feeder expands V2=A1V1/A2
Feeder exit or outlet loss ho= (V22)/2g Head loss when water exit the feeder V2=A1V1/A2
D1 Feeder bend loss h(D1d1)= [(0.1 V12)/2g]N1
D2 Feeder bend loss h(D2d2)= [(0.1 V22)/2g]N2
Note: V2=A1V1/A2

OUTLET LOSSES

O1=hi+he+ho+hb1+hb2 (iii)
Feeder inlet loss hi= (0.5 V22)/2g Head loss when water enters the feeder from channel
Feeder contraction loss hc= (0.5 V12)/2g Head loss when feeder contract
Feeder exit or outlet loss ho= (V12)/2g Head loss when water exit the feeder)
d1 Feeder bend loss h(D1d1)= [(0.1 V12)/2g]n1
d2 Feeder bend loss h(D2d2)= [(0.1 V22)/2g]n2

HEAD LOSS IN FUEL PATH

Diameter of fuel bundles pencils d=15.21mm=0.01521m
Ad=πd2/4= m2
Diameter of fuel bundles D=82.5mm=0.0825m
AD=πD2/4= m2
Length of the fuel column L=6000mm=6m
Area for water flow (AD-Ad) Af=0.00192m2
hf (fuel) = [[f/2(πd*19)+ πD]*2L*V32] / Af *g (iv)
Note:A1V1=AfV3 V3= A1V1/Af

HEAD LOSS IN SHIELD PLUGS

Hsp=[Inlet Bend Loss(a)+ hf (b)+ Loss in holes(c) +Outlet Bend Loss(d)]*2 (v)
Inlet Bend Loss = (0.1 V22)/2g (a)
Outer diameter of liner tube d=90.6mm=0.0906 m
asp= πd2/4= m2
Inner diameter of end fitting D=107.57mm=0.10757m
Asp= πD2/4= m2
Length of liner tube Ls=1850mm=1.85m
Area for water flow A sd=Asp-asp = m2
A1V1=AspV4
hf1= [[f/2(πd+ πD]*2Ls*V42]/ As*g (b)
Note: V4= A1V1/Asp
Diameter of holes in the shield plug
d_h- ø of hole-12.7mm = 0.0127m
$A_h= \pi d_h^2/4 \quad A_1V_1=A_h V_h \quad V_h =A_1V_1/A_h$
Vh-Velocity of water passing through hole
Velocity at vena Contracta Vc =Vh/0.62
Loss in holes = [(VC- Vh)2/2g]*52 (c)
Outlet Bend Loss = (0.1 V32)/2g (d)
Note: A1V1=AfV3 V3= A1V1/Af

Case-4 Procedure for calculating feeders of two different diameters with orifice. [5,6]

Channel: North/South Design flow Q=Kg/hr

INLET FEEDER

Inlet Feeder Diameter and length are noted as in case-3
Diameter of orifice Do = mm = m

OUT LET FEEDER

Inlet Feeder Diameter and length are noted as in case-3
Diameter of orifice Do = mm = m
Ld1D1=L1+l1= m
Ld2D2=L2+l2= m
Since D1=d1 A1=πD12/4
Since D2=d2 A2=πD22/4
Q=A1V1=A2V2 V2=A1V1/A2
Q'= (Q/3600*885.4) m3/s V=Q'*4/πD12 m/s
Co-efficient of friction f, Friction loss in Feeder of diameter D1 and diameter D2 are calculated as in case-3
Friction loss in Feeder of diameter D1hf (D1d1) = (4 f* Ld1D1*V12) / 2*g*D1
Friction loss in Feeder of diameter D2hf (D2d2) = (4 f* Ld2D2*V22) / 2*g* D2 (i)

INLET LOSSES

I1=hi +he+ho+hb1+hb2+hor (ii)
hi ,he,ho,hb1,hb2are calculated as in case-3
Head loss in inlet orifice =hor is calculated as in case-2

OUTLET LOSSES

O1=hi+he+ho+hb1+hb2+hor (iii)
hi,he,ho,hb1,hb2 are calculated as in Case-3
Head loss in outlet orifice =hor is calculated as in case-3

HEAD LOSS IN FUEL PATH

hf (fuel) = [[f/2(πd*19)+ πD]*2L*V32] / Af *g (iv)
is calculated as in Case-3

HEAD LOSS IN SHIELD PLUGS

is calculated as in case-3
Hsp=[Inlet Bend Loss(a)+ hf (b)+ Loss in holes(c) +Outlet Bend Loss(d)]*2 (v)
Inlet Bend Loss = (0.1 V22)/2g (a)
Outer diameter of liner tube d=90.6mm=0.0906m
asp= πd2/4= m2
Inner diameter of end fitting D=107.57mm=0.10757m
Asp= πD2/4=m2
Length of liner tube Ls=1850mm=1.85m

Area for water flow A sd=Asp-asp=m2
A1V1=AspV4
hf1= [[f/2(πd+ πD]*2Ls*V42]/ As*g (b)
Note: $V_4 = A_1V_1/A_{sp}$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
A								27600	28800	31000	30900	28800	27600								A
B						27200	29000	31900	35700	36000	35900	35700	31900	29000	27200						B
C				28500	29000	30400	33200	37100	40700	43000	43000	40700	37100	33200	30400	29000	28500				C
D			28800	30800	33300	35500	38200	43100	44500	46800	45700	44500	43200	38200	35500	33300	30800	28800			D
E			33500	37200	39600	40200	43000	45500	47300	46900	47900	47300	45400	43000	40200	39600	37200	33500			E
F		35900	37300	42400	44100	45300	44400	48200	48300	49100	48900	46200	46200	44400	45300	44100	42400	37300	35900		F
G		37900	42300	45800	47700	47700	45900	48200	48200	50400	50300	48200	48200	45900	47700	47700	45700	42300	37900		G
H	34300	38800	45200	48500	51400	51400	48300	49400	49800	51200	51300	49800	50500	48300	50100	51300	48500	45200	38800	34300	H
J	35800	41400	46400	51000	51500	49600	49000	50900	51000	51500	51400	51000	50700	49100	49800	51500	51000	46500	41400	35800	J
K	35800	41600	47100	51000	50900	50600	50200	51100	51500	51600	51100	51500	51200	50200	50500	50900	51000	47100	41600	35800	K
L	35900	41500	46900	49500	51500	50500	50400	51200	51100	51300	51500	51100	51200	50400	50500	51500	49500	56900	41400	35900	L
M	36000	41100	45500	49100	50700	50300	50200	51000	50400	51400	51600	50400	51100	50200	50300	50800	49200	45500	41100	36000	M
N		40600	45000	49600	50400	49900	49900	51100	50900	50600	50800	50900	51100	49900	49900	50500	49400	45000	40600		N
O		36900	42100	44900	48700	48600	48600	50200	49900	50700	50700	49900	50200	48600	48600	48700	44900	42100	36900		O
P		34300	37600	42800	44800	44900	46500	50000	50400	50500	50500	50400	50000	48500	44900	44900	42800	37700	34300		P
Q			33100	36700	42100	41100	45200	48400	49500	50400	50400	49400	48400	45200	41100	42100	36700	33100			Q
R			28000	29500	33900	36300	39700	44600	48100	48000	48000	48100	44600	39700	36300	33900	29500	28000			R
S					30000	29700	32700	39100	41300	41800	41800	41300	39100	32700	29700	30000					S
T						26100	29900	33200	36100	38300	38300	36100	33200	29900	26100						T
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	

flow monitoring channels RAM EXTENSIONS ARE TO BE USED IN CHANNELS IN BLUE / RED COLOR
Same colour-North upstream, different colour south upstream

Fig-5 Design flow through the core expected

Diameter of holes in the shield plug dh- ø of hole-12.7mm = 0.0127m
$A_h = \pi d_h^2/4$ $A_1V_1 = A_h V_h$ $V_h = A_1V_1/A_h$
Vh-Velocity of water passing through hole
Velocity at vena Contracta Vc =Vh/0.62
Loss in holes = [(VC- Vh)2/2g]*52 (c)

Outlet Bend Loss = (0.1 V32)/2g (d)

Note: $A_1V_1 = A_fV_3$ $V_3 = A_1V_1/A_f$

Flow Calculation

Total Loss (T_L)=(i)+(ii)+(iii)+(iv)+(v)

as calculated in all the 4 cases.I/L Header Pressure Ip=Kg/Cm^2
O/L Header Pressure Op= Kg/Cm^2
$\Delta P = I_p - O_p$ Kg/Cm^2
$(\Delta P/\sigma) = T_L = V_1^2 * 0.89$
$V_1^2 = T_L/0.89$
V1= √ (TL/0.89) = (Δ P/σ)
Actual Flow is calculated using the formula:
QActual=V1*A1*3600*885.4
The actual flow calculated is compared with design flow as shown in Fig-5 and the result found is within 5% tolerance.

7.2 ACKNOWLEDGMENTS

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5.0 CONCLUSION

It has been found from analysis that flow calculated matches with the design flow through the individual channel within the tolerance of ±5%.The flow calculated for different header pressures and the result is compared with the flow calculated in the instrumented channels and the flow calculated in the commissioning procedures at various header pressures. The calculated flow matches with the commissioning procedure flow within the tolerance of ±5%.

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