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Theoretical Analysis and Effect of Condenser In–leakage in the Secondary Systems of YGN–1, 2

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영광–1, 2호기 2차계통 복수기누설의 이론적 분석 및 영향평가

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Abstract

Corrosive environment may be generated within steam generators from condenser cooling water in–leakage. Theoretical analysis of the accumulation of chloride as a sea water impurity is being carried out for the condenser cooling water used at YGN–1,2 nuclear power stations. Calculations have shown that highly concentrated chloride solution would be produced within the steam generators in the case of sea water in–leakage. Maximum allowable design condenser leak rate(0.5 gpm) leads chloride concentration of 2.3 ppm at steam generator and 0.6 ppm at hotwell with the maximum blowdown rate and condensate purification. Concentration factor at steam generator is dependent only on both blowdown rate and condensate purification efficiency as follows,

$$\text{Concentration Factor} = \frac{(1-p+b)^2(1-f)^2\,F_M}{B},\quad (B \neq O)$$

Blowdown and condensate purification are evaluated as the only effective measures to remove impurities from the secondary systems.

요 약

복수기를 통한 해수유입은 증기발생기내에 부식환경을 조성시키게 한다. 이론적 분석을 통하여 복수기누설시에 해수중의 불순물인 염소가 2차계통내에 누적되는 경향을 영광원전을 모델로하여 평가하였다. 분석결과 해수누설시에 고농도의 염소가 증기발생기내에 누적되는 것으로 나타났으며, 이는 증기 발생기내의 수질을 산성분위기로 조성시킬 것으로 판단되었다. 복수기의 최대허용설계누설(0.5 gpm)시에는 증기발생기 취출수량을 최대로 늘리고, 복수기정화계통을 가동하더라도 증기발생기에 2.3 ppm 및 복수기집수정에 0.6 ppm의 염소가 누적되는 것으로 나타났다. 또한 증기발생기에서의 염소농축계수는 아래와 같이 전적으로 취출수량 및 정화계통효율에만 의존하는 것으로 나타났으며,

$$\text{농축계수} = \frac{(1-p+b)^2(1-f)^2\,F_M}{B},\quad (B \neq O)$$

취출수 및 정화계통은 2차계통내의 불순물을 제거하는데 효과적인 것으로 평가되었다.

Ⅰ. Introduction

The secondary system of PWR consists of steam generator, turbine, condenser and condensate demineralizer(CPP). It is designed to remove heat energy from the reactor coolant system in steam generators to produce steam and convert steam to electrical power via turbine generator. The exhausted steam is then condensed in the condenser and transfer the heat to the circulating sea water. The condensate is heated again in the feed water system and returned to the steam generators.

In case of the loss of condenser coolant tube integrity(condenser leak), it leads the ingress of sea water impurities like sodium chloride or Ca/Mg salts to the steam generators. These in turn result in acidic environments in the steam generators due to hydrolysis of salt, build-up of ionic impurities causing corrosion attack to steam generator materials and scaling on heat transfer surfaces.

Corrosion in steam generator is caused by the accumulation there of chemicals which are by themselves corrosive or which, on concentration, generate a corrosive environment. Such chemicals may be introduced into steam generator with the feed water via a leaking condenser which allows the raw condenser cooling water to mix with the condensate.

The major objective of this work is to gain a better understanding about the effect of condenser leak on corrosive impurity concentration in the systems. Blowdown and CPP demineralization are also considered together.

Ⅱ. System description

In this work, YGN-1 and 2 are chosen as modelling plants and the secondary system of YGN-1,2 PWR is schematically represented in

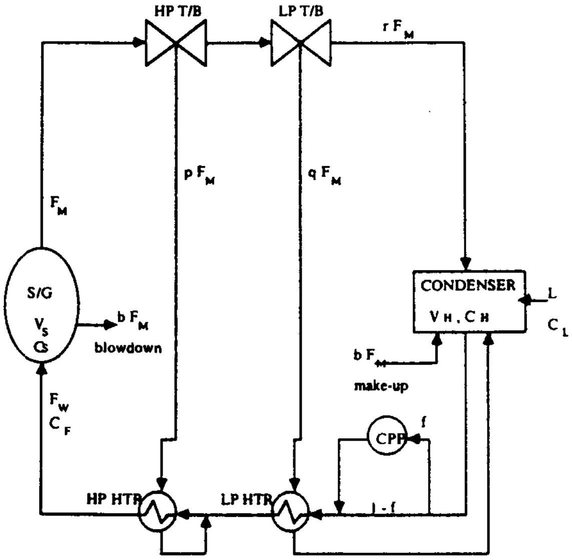

Fig.1 Simplified Secondary System of YGN-1,2 PWR.

The concentration of chloride in sea water that cools the condenser varies with times in ranges of 20000–22000 ppm. And it is assumed to be 20000 ppm in the present analysis.

Ⅲ. Modelling

The steaming rate(F_M) and the fraction of steam returning to steam generator (p) from high pressure turbine are dependent on reactor power as given by eq.(1) and (2).

$$F_M = 123768 + 5859P - 2.07\,P^2 + 1.7E\text{-}3\,P^3 \quad (1)$$

$$p = 2.38E\text{-}1 + 2.44E\text{-}4\,P - 1.85E\text{-}7\,P^2 + 4.32E\text{-}11\,P^3 \quad (2)$$

The remaining fraction of steam($q+r$) is ($1-p$) and the qualities of these steams are assumed to be pure, or not contaminated with sea water.

The CPP outlet is also assumed to be free of impurities(chloride, sodium etc.) for the computational purpose though it is not so in practice, but the concentrations of these impurities are negligible compared to the inlet concentration which is contaminated with sea water during condenser leakages.

The chloride build-up differential equations based on chloride mass balances for the two major reservoirs(steam generator and condenser hotwell) in the secondary system are as follows,

For condenser hotwell

$$\frac{dC_H}{dt}=\frac{LC_L}{V_H}-\frac{(1-p+b)F_M}{V_H}C_H \tag{3}$$

For steam generator

$$\frac{dC_S}{dt}=\frac{C_F(1-p+b)(1-f)F_W}{V_S}-\frac{b\ F_M}{V_S}C_S \tag{4}$$

The delay time involved in the transport of fluid between reservoirs is less than 30 seconds and has not been counted in the above equations.

The effect of this parameter was analysed to alter the concentrations marginally in the initial few minutes of the build-up and negligible in the long run. Hence this factor was not considered to be significant.

Solutions of eq.(3) and (4) with the initial conditions :at t=o

$C_H=C_H^o$ and $C_S=C_S^o$, are

$$C_H=\frac{L\ C_L}{(1-p+b)F_M}(1-e^{-(1-p+b)F_M t/V_H}) + C_H^o\ e^{-(1-p+b)F_M t/V_H} \tag{5}$$

$$C_S=\frac{C_F(1-P+b)(1-f)F_W}{b\ F_M}(1-e^{-bF_M t/V_S})+C_S^o\ e^{-bF_M t/V_S} \tag{6}$$

Substituting $C_F=C_H(1-p+b)(1-f)/(1+b)$, $F_W=F_M(1+b)$ and $bF_M=B$, equation (6) gives chloride ingress quation in the form of equation (7) as follows,

$$C_S=\frac{L\ C_L(1-p+b)(1-f)^2}{B}(1-e^{-Bt/V_S})(1-e^{-(1-p+b)F_M t/V_H})+C_S^o e^{-Bt/V_S} \tag{7}$$

The saturation concentrations of chloride subsequent to the onset of condenser leakage in two reservoirs(condenser hotwell and steam generator) are given below :

$$C_H^*=\frac{L\ C_L}{(1-p+b)F_M} \tag{8}$$

$$C_S^*=\frac{C_L\ (1-p+b)(1-f)^2\ L}{B} \tag{9}$$

where

C_H : Concentration in hotwell (ppb)

C_H^o : Initial concentration in hotwell (ppb)

C_H^* : Saturation concentration in hotwell (ppb)

C_S : Concentration in steam generator (ppb)

C_S^o : Initial concentration in steam generator (ppb)

C_S^* : Saturation concentration in steam generator (ppb)

F_M : Main steam flow rate (Ton/hr)

F_W : Feed water flow rate (Ton/hr)

B : Blowdown flow rate (Ton/hr)

L : Seawater leak rate (L/hr)

V_H : Mass of water in hotwell (Ton)

V_S : Mass of water in steam generator (Ton)

C_F : Concentration of impurity in feed water (ppb)

C_L : Concentration of impurity in sea water (ppm)

P : Reactor Power (MW_e)

b : Fraction of steam flow, blowdown

f : Fraction of condensate through condensate demineralizer

p : Fraction of main steam into high pressure heater from high pressure turbine

q : Fraction of main steam into condenser via low pressure heater

r : Fraction of main steam into condenser from low pressure turbine

t : Time (hr)

Ⅳ. Results and Discussion

Assuming maximum allowable design condenser leak rate of 0.5 gpm(113.5L/hr) and 3% of blowdown rate, Fig.2 and Fig.3 show chloride concentration build-up trends at condenser hotwell and steam generator respectively.

Fig.4 and Fig.5 also represent the effects of leak rates on steam generator chloride concentrations with leak rate of 10–120 liters/hr.

Although 100% of condensate put into condensate demineralizer(CPP) when there is appreciable leak, all of impurities are not purified because of the degradation of ion exchange resin with time. So the efficiency of condensate demineralizer is assumed to be 50% average.

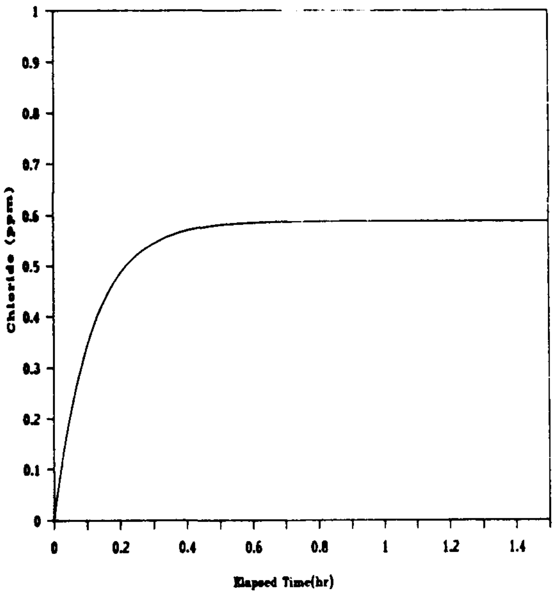

Fig.2 Chloride Concentration Build-up at Hotwell with Leak Rate of 0.5 gpm. (Blowdown=3%, CPP=50%, Reactor Power =100%)

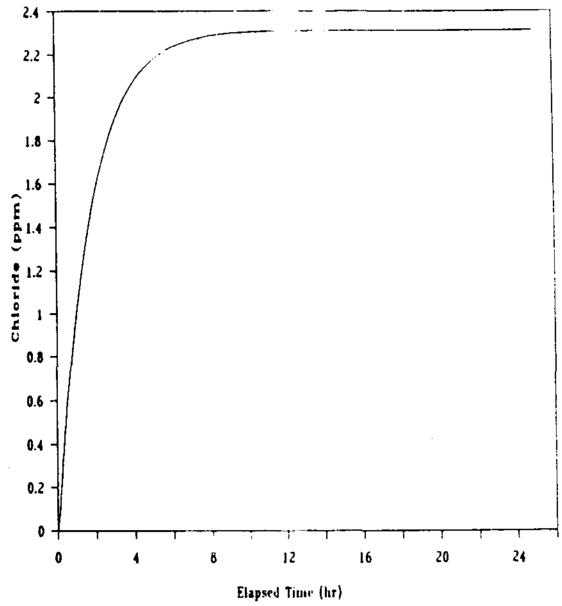

Fig.3 Chloride Concentration Build-up at Steam Generator with Leak Rate of 0.5 gpm. (Blowdown=3%, CPP=50%, Reactor Power =100%)

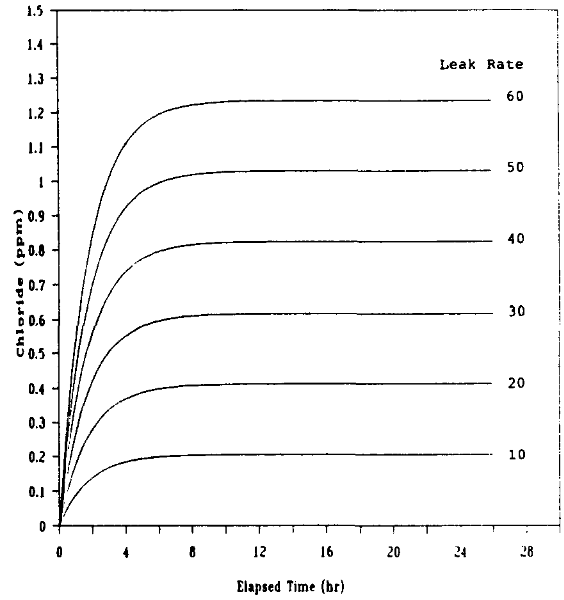

Fig.4 Chloride Concentration Build-up at Steam Generator with Leak Rate 10–60 L/hr. (Blowdown=3%, CPP=50%, Reactor Power =100%)

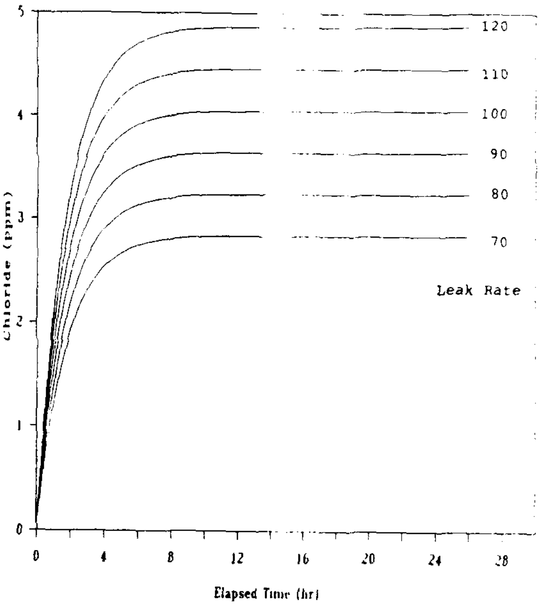

Fig.5 Chloride Concentration Build-up at Steam Generator with Leak Rate 70–120 L/hr. (Blowdown=3%, CPP=50%, Reactor Power =100%)

At 977 MWe normal power operation(blowdown 1%, CPP=50%), the leak rates that would result in a steam generator bulk water chloride concentration of 20–1000 ppb are given below:

chloride (ppb) at S/G	leak rate (L/hr)
20	0.334
100	1.67
500	8.35
1000	16.7

Since 100 ppb chloride concentration at steam generator is subject to action level Ⅱ which requires reactor power reduction to 30% or less to decrease heat flux, 100 ppb chloride concentration limit is thought to be much enough to prevent steam generator damages from sea water leaks.

The effect of reactor power on the saturation chloride concentration(C^*) in steam generator and condenser hotwell at a leak rate of 0.5 gpm with 3% of steaming rate as blowdown and 50% of condensate purification is shown in Fig.6.

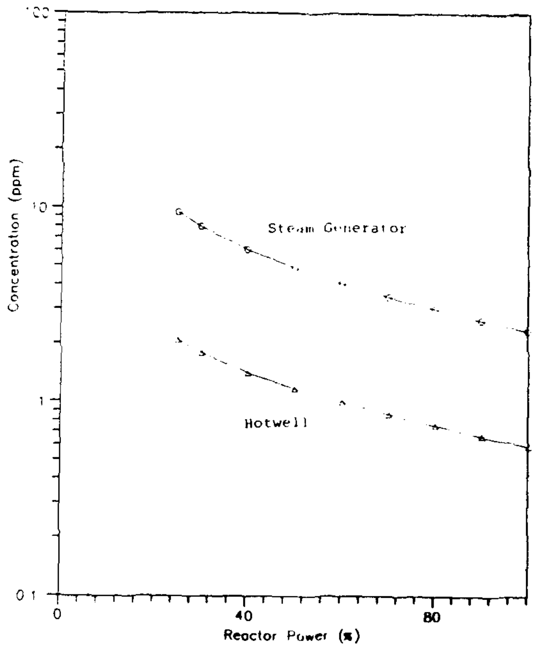

Fig.6 The Effects of Reactor Power on Saturation Concentration with Leak Rate 0.5 gpm. (Blowdown=3%, CPP=50%)

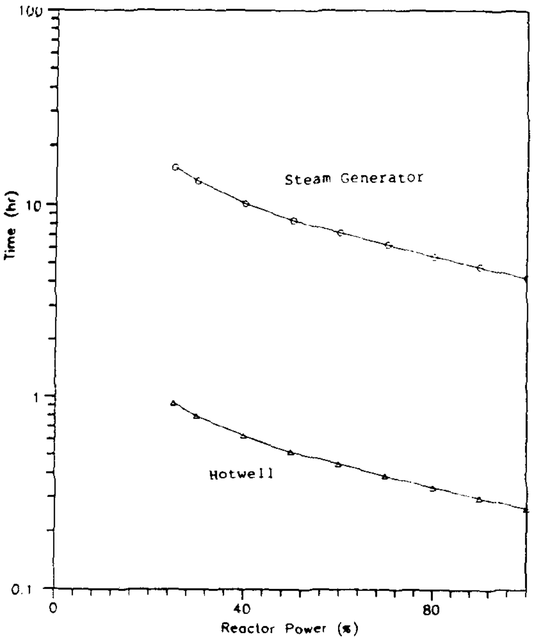

Fig.7 The Effects of Reactor Power on Rise Time with Leak Rate 0.5 gpm.(Blowdown=3%, CPP=50%)

Since steaming rate decreases with reactor power, the saturation concentration is expected to be increased. The time taken to reach 90% of saturation concentration(0.9 C*) is defined as rise time and it is directly related to reactor power as shown in Fig.7.

Therefore in relation to action level II which requires power reduction, power reduction will resulted in higher accumulation of chloride concentration by a factor of 3.5 at steam generators.

During normal operation(blowdown=1%, CPP=50%), time required to reach action level I and II after the onset of condenser leak is dependent on leak rate as shown in Fig.8.

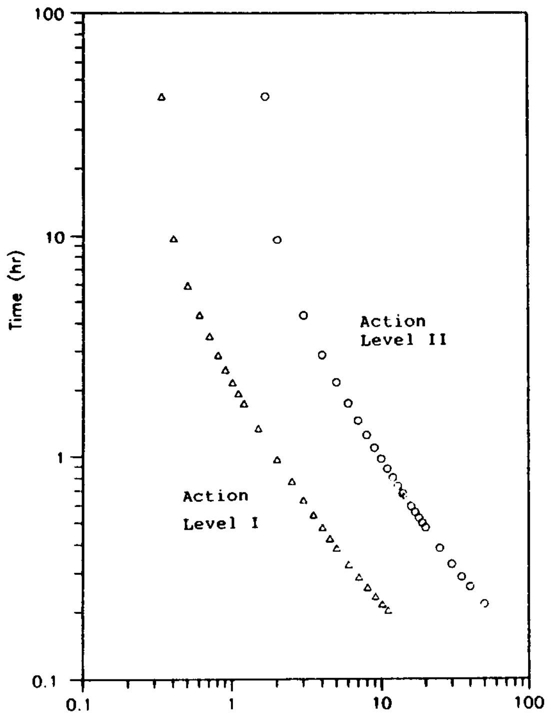

Fig.8 Time Required to Reach Action Level I & II with Leak Rates. (Blowdown=1%, CPP=50%, Reactor Power =100%)

It takes only 12 minutes to reach action level I (20 ppb chloride) with 11 liters of sea water leak, But leak rate of 0.3 or less will not exceed the action level I concentration forever.

Fig.9 and Fig.10 show blowdown and condensate demineralizer(CPP) effects on steam generator chloride build-up with maximum allowable design leak rate of 0.5 gpm. And concentration factor defined as C_S^*/C_H^* is shown in Fig.11.

The concentration factor at steam generator is dependant only on both blowdown rate(%) and the fraction of condensate through CPP(f) as follows,

Concentration Factor=

$$\frac{(1-p+b)^2(1-f)^2 F_M}{B}, (B \neq 0)$$

So it is desirable to increase blowdown rate to the maximum as soon as possible when condenser leak is monitored at hotwells.

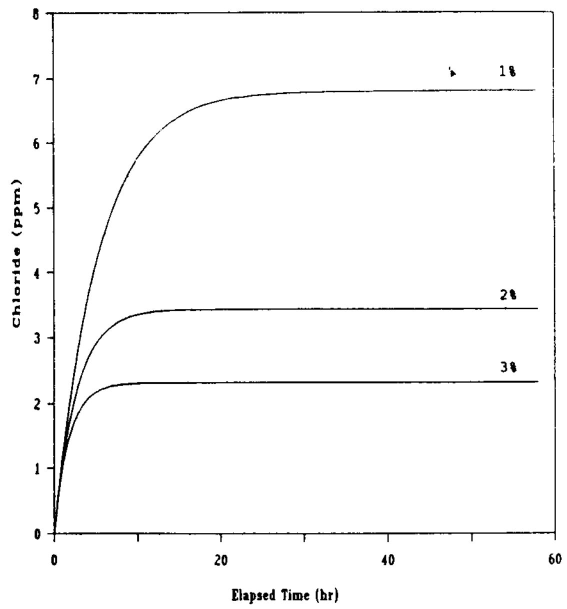

Fig.9 The Effects of Blowdown Rate on Steam Generator Chloride Concentration Build-up with Leak Rate 0.5gpm. (CPP=50%, Reactor Power=100%)

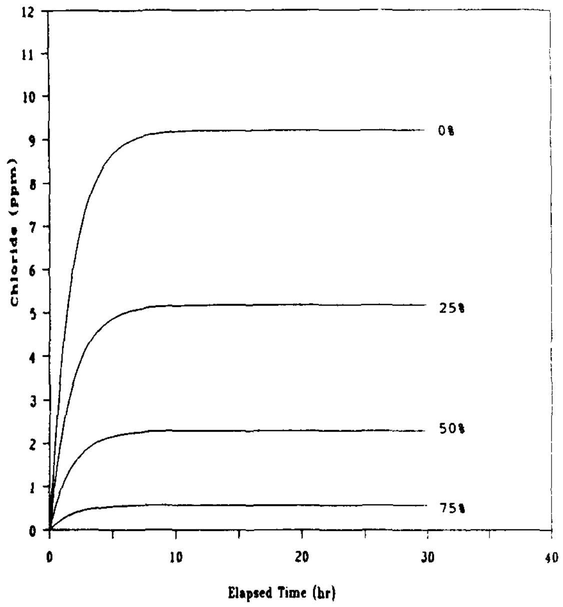

Fig.10 **The Effects of Condensate Demineralizer on Steam Generator Chloride Concentration Build-up. (Blowdown=3%, Reactor Power=100%, Leak Rate=gpm)**

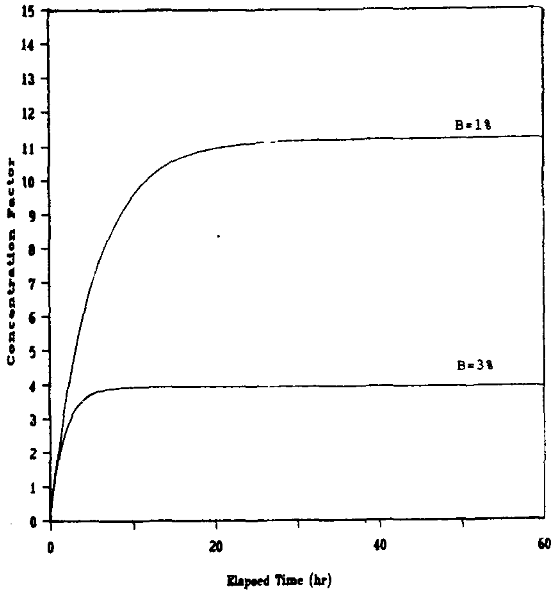

Fig.11 **The Effects of Blowdown Rate on Concentration Factor. (CPP=50%, Reactor Power =100%)**

Ⅴ. Conclusion

Theoretical analysis of the build-up of chloride has carried out for the condenser cooling water used at YGN-1,2 nuclear power stations.

It was revealed that highly concentrated chloride solutions would be produced within the steam generator when there was appreciable condenser in-leakage. But leak rate of 0.3 L/hr or less would not affect the existing standard.

Reactor power reduction when action level Ⅱ is reached will be resulted in higher accumulation of chloride by a factor of 3.5 at steam generator.

Maximum allowable design condenser leak rate(0.5 gpm) leads chloride concentration of 2.3 ppm at steam generator and 0.6 ppm at hotwell in spite of maximum blowdown rate(3%) and 100% condensate purification flow with 50% efficiency.

Concentration factor at steam generator is dependent only on both blowdown rate(%) and the fraction of condensate through condensate demineralizer as follows,

Concentration Factor=

$$\frac{(1-p+b)^2(1-f)^2\,F_M}{B},(B\neq0)$$

Further study on condensate demineralizer efficiency analysis and the accumulation within steam generator crevices is needed.