

Key Emerging Issues and Recent Progress Related to Plant Chemistry/Corrosion in PWR/VVER/CANDU Reactors

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1 Introduction

Operational issues with their link to other aspects are of large interest for Utilities as well as Regulators, Designers, Manufacturers and Laboratories.

This LCC11 report is covering 2 technical aspects dealing with secondary system and 1 with primary coolant:

- Secondary water chemistry options,
- Hide out and Hide out return of impurities from Steam Generators (SG),
- Primary Side recycling of waste.

The secondary side chemistry is one of the key factors that are influencing safety, reliability and particularly availability of Nuclear Power Plants of PWR and VVER type. With many steam generators (SG) of new design and tubing materials, the challenges are not the same as in the past where most of the SG tubing were made of Alloy 600 MA. This material was highly sensitive to corrosion, even in presence of very low level of impurities, more specifically in alkaline environment. Thus, the utilities had to focus on very low level of impurities such as chloride and sodium at SG blowdown. This is not any more the main and sole objective, although it is important to keep a high purity level in SG.

When selecting the chemistry specification at SG blowdown and the treatment with pH in the secondary system, a balance should now be made between low concentration of impurities and of corrosion products deposition in the SG, where the impurities may concentrate and create corrosion, even in presence of more resistant alloys.

Such a chemistry selection is governed by corrosion of the entire steam-water secondary system and particularly of the SG tubing, as a safety barrier. In addition to these safety and reliability aspects, the secondary water chemistry has an impact on operating and maintenance costs as well as on the environment, through:

- the type and concentration of reagents that are used;
- the need for SG cleaning for elimination of corrosion products;
- the purification systems, i.e. steam generator blowdown and for some plants the condensate polishers with the operating time before ion exchange resin regeneration and/or replacement.

Section 2 describes the various aspects of secondary water chemistry which include

- Description of the various secondary water chemistry treatments either with ammonia or amines;
- Advantages and disadvantages of the various options;
- Influence of the treatment on various materials of the secondary system: Copper alloys and Carbon Steel (Flow Accelerated Corrosion) with several impacts:
 - on corrosion product transport and deposition in the steam generator (tubesheet or tubing);
 - on the SG tubing heat transfer and plant power;
 - on the risk of impurities concentration within deposits and SG tubing corrosion;
 - on the need for SG cleaning, with the various available methods.

- The relation between the chemistry specification at SG blowdown and the various options of secondary treatment and purifications at SG blowdown and condensate polishing plant.
- How to optimise the chemistry specification for minimising the risk of corrosion, increase safety, plant availability, operating and maintenance costs, and releases into the environment.

The evaluation of chemistry in SG is continuously monitored during power operation at SG blowdown, but does not reflect what is concentrated or deposited within some areas with restricted flow, such as crevices, tubesheet sludge pile, via the so-called hide out process.

This should be additionally evaluated during shutdown, where a fraction of concentrated or deposited impurities are released and eliminated via SG blowdown.

Section 3 covers the description of:

- Hide out process and influencing parameters for different types of chemical elements or compounds (sodium, chloride, sulphate, calcium, magnesium, organic acids, etc.);
- The objectives of hideout return measurements, for follow up of corrosion risk, feedback of chemistry performances, for having an available tool in case of further anomaly of event;
- The interpretation of hide out return and its limitation.

Nuclear power plants designed, built and commissioned in the 1970s and 1980s contained facilities for the processing of liquid radioactive waste. These systems included recycle evaporators and miscellaneous evaporators. The recycle evaporators were to be used to process and recycle reactor grade water and the miscellaneous waste evaporators were to be used for processing the remaining waste generated by the plant to a quality suitable for discharge to the environment or an off-site burial site.

Section 4 discusses the recycling of primary water and the concurrent advantages and disadvantages. Recycling is important to minimize both the chemical and radiochemical releases into the environment. However, a specific focus is given to tritium impact from the recycling since this isotope is not removed by either evaporation or purification systems.

The buildup in plant tritium concentrations over the years can cause problems with worker exposure and increases in airborne releases. Techniques are described to model the buildup over the years using water and tritium mass balances. Methods are also described to estimate personnel dose from airborne tritium and to reduce airborne tritium releases.

This chapter will be useful for both plants that recycle the primary water and for those who do not.

2 Secondary side water chemistry (Francis Nordmann)

2.1 The challenges of secondary water chemistry

With design improvements and material replacements, the challenges of secondary water chemistry have changed over the last decades. Without giving a very old history, it may just be reminded that the first PWR SG tubing materials were made of stainless steel, close to 304, that was sensitive to chloride pollution, at a time when the condensers were not very tight, and leaks on plants cooled by sea water (or naval application) became an issue.

2.1.1 SG tubing material and corrosion

This was the reason for selecting a nickel base alloy, more resistant to chloride corrosion than typical 304 stainless steel. However, as shown below on Figure 2-1, the Alloy Inconel 600, selected by American industry and also used by several other vendors (mainly Japan and France) appeared to be sensitive to corrosion under phosphate treatment that was used to buffer any condenser leak. US vendors consequently decided to switch all the plants to All Volatile Treatment (AVT), i.e. with only volatile reagents such as ammonia or amines. Without the buffering effect of phosphate, denting (necking of SG tubes by corrosion of carbon steel tube support plates), induced several SG replacements in the USA. In addition, Alloy 600, sensitive to stress corrosion cracking (SCC) even with pure water and even more under alkaline conditions, with also intergranular attack (IGA) corrosion started in the 1980's to be the very first problem of nuclear industry in all the countries with this poor Mill Annealed Alloy 600 (600 MA).

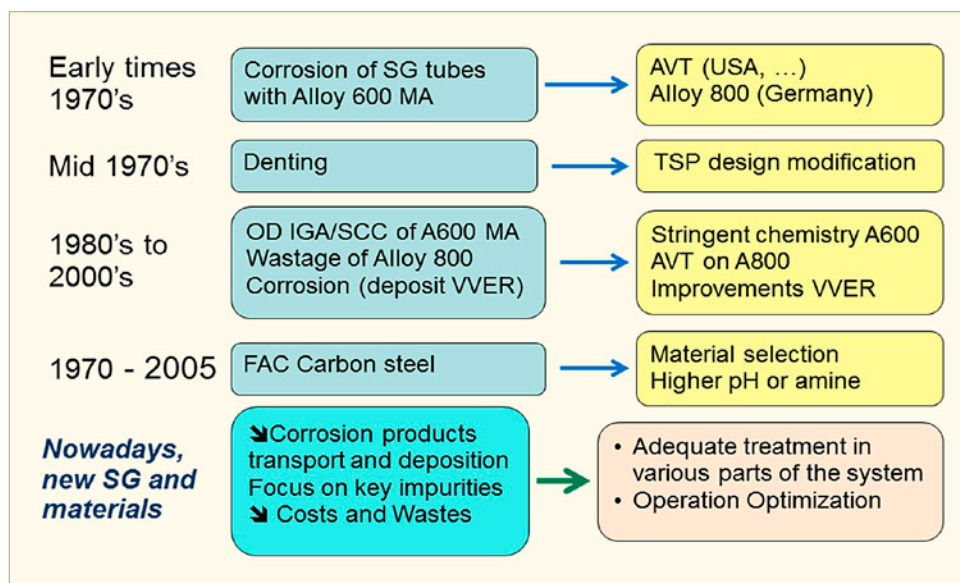


Figure 2-1: Evolution of secondary system issues from the 70's to now.

At the same time, German vendor Siemens/KWU had quickly decided to replace Alloy 600 by Alloy Incoloy 800, with a higher chromium content, thus not sensitive to SCC under pure water or limited amount of impurities, while the Russian designer kept the traditional alloy, similar to 304, but stabilized with titanium, as shown on Table 2-1.

Table 2-1: Main composition of nickel, iron based alloys and stainless steel used for SG tubing in PWR and VVER plants.

SG tubing material	Ni [%]	Cr [%]	Fe [%]
Alloy 600 MA/TT	>72	14-17	6-10
Alloy 690 TT	>58	27-31	7-11
Alloy 800 NG	30-35	19-23	42-51
Alloy 18-10Ti	10-11.5	17-19	69.5-73

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2.1.2 Flow Accelerated Corrosion (FAC)

At the same time, Flow Accelerated Corrosion (FAC) of Carbon Steel components of the secondary system, Low and High Pressure Heaters, Moisture Separator Reheaters (MSR), piping, etc., also became an issue. This was in many cases related to the presence either of copper alloys or of condensate polishing plants, both being not compatible with operating the secondary water chemistry at a sufficiently high pH. Some utilities, took remedial actions at an early time while other did not.

British and French Utilities were the precursors in applying amines after complete FAC evaluation with many laboratory tests. German utilities moved on design without copper alloy and high pH with ammonia (H-AVT). EPRI and US Utilities moved on amine treatment only later on after experiencing severe accident in Surry-2, as illustrated on Figure 2-2 and then Millstone-3 in 1990 (heater drain lines) and even later on at several other plants.

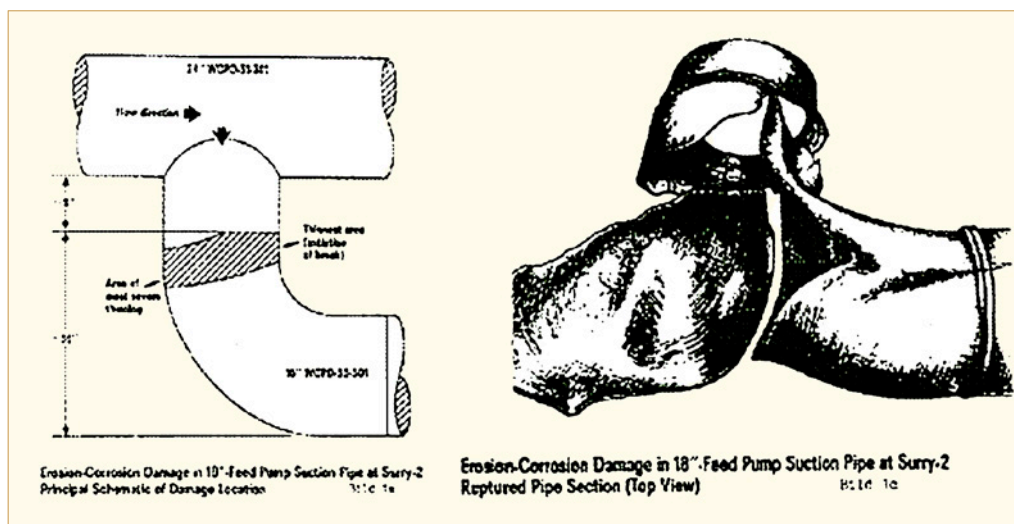


Figure 2-2: FAC on condensate line inlet to pump failure with 4 deaths at US plant Surry-2 in 1986.

VVER plants, with condensers suffering from significant leaks and the presence of condensate polishing plants and copper alloys, have been operated for a long time under ammonia at very low $\text{pH}_{25^\circ\text{C}}$ of ≈ 9 , which is absolutely insufficient for FAC protection of carbon steel components.

Thus, an accident occurred at VVER of Loviisa, in Finland, on 28 of May 1990, after 85 000 h, despite a high original nominal thickness of 18 mm of the main feedwater pipe of 325 mm diameter and a temperature of 165°C, Figure 2-3.



Figure 2-3: FAC with Rupture of Loviisa VVER in Finland in 1990.

Then, it appeared surprising that Japanese utilities, which were focusing on IGA/SCC of their units with Alloy 600, had decided to have condensate polishers on all their units, operated at a low pH under ammonia, which was known to be inadequate for FAC. Moreover, they did not perform in service inspection to monitor the thinning of carbon steel components with areas sensitive to FAC. As a consequence, a very severe accident occurred at Mihama 3, on 9 August 2004, as shown on Figure 2-4. The failure was a burst of a feedwater piping of 560 mm diameter at 150°C, located between last LP heater and deaerating tank. It happened during the 21st cycle of operation with a residual thickness of 1.4 mm for an original nominal thickness of 10 mm. The unit had operated 18 cycles with ammonia at low pH and only the last 2 cycles with an amine (ETA) and without any control of Piping thickness. The consequence, 5 workers killed, was even worse since the burst took place 5 days before shutdown and with many workers in the turbine hall, ready for the 1st scheduled inspection.



Figure 2-4: Main Feedwater Piping Rupture at Mihama 3, in August 2004 [Kepco, 2005].

This FAC phenomenon, an accelerated generalized corrosion of carbon steel, is depending on 3 conditions:

- a material with very low content of chromium (< 0.1%),
- a high velocity of the flow, quickly eliminating the dissolved iron,
- an insufficient alkaline environment, in absence of oxygen.

Consequently, FAC may be solved by:

- the selection of stainless or low alloyed steel (in replacement of carbon steel),
- the protection against high flow velocities,
- the selection of proper chemistry allowing a sufficient pH at local temperature, which is fully described in Section 2.3, a sufficient pH having other advantages, since decreasing FAC rate will, in the same way, decrease the quantity of iron oxides transported to the SG where they may deposit.

The two options are using ammonia at a $pH_{25^{\circ}C}$ close to 10 or an amine treatment, particularly in presence of copper alloys or condensate polishing plants, both being incompatible with ammonia at high pH.

As early as 1983, EDF, the French Utility, decided to switch to amine treatment (morpholine) all its plants having copper alloys, which were unable to operate at a sufficiently high pH with ammonia to mitigate FAC. Figure 2-5 shows that the pH at 25°C cannot exceed 9.3 in presence of copper alloys:

- In presence of copper alloys, limitation of $pH_{25^{\circ}C} \sim 9.2$;
- without copper, more open choice, with increased pH (optimum close to 10) and the upper limit comes from economic and environmental constraints;
- orange areas represent acceptable areas in presence of other constraints, mainly from purification systems, costs and wastes releases.

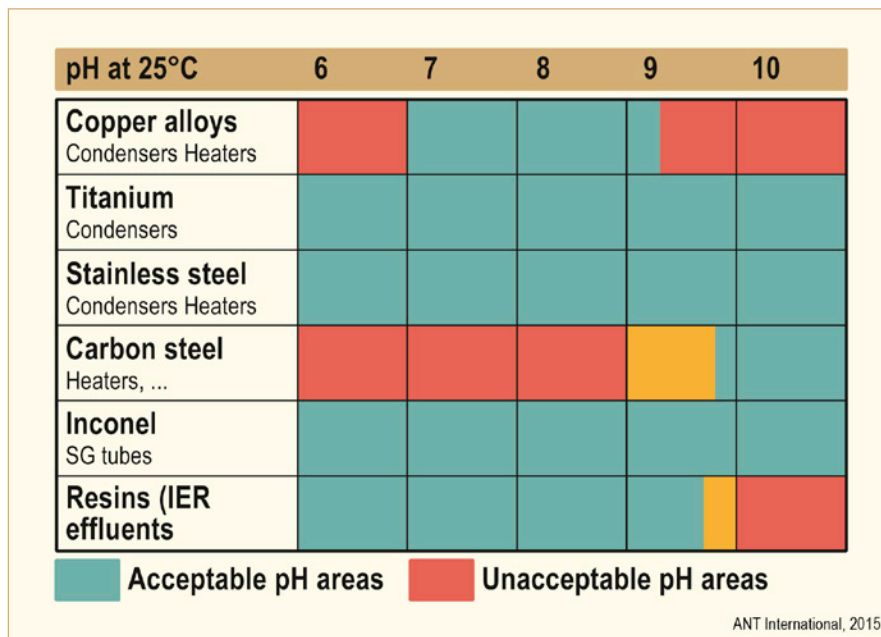


Figure 2-5: Strategy for various materials compatibility, after [Odar & Nordmann, 2010].

2.1.3 Corrosion products deposits in SG

After having replaced most of SG with Alloy 600MA by SG with highly resistant Alloy 690, according to its higher Cr content with sufficient Ni proportion, IGA/SCC should not any more the first priority of most of the utilities in the 2010's.

Several SG problems, not only the corrosion but also the thermal efficiency and the thermo-hydraulic issues, can be counteracted by keeping the SGs clean from corrosion products. As it is confirmed by field experience: All plants, where adequate secondary side corrosion product control was performed, were free of these SG degradation problems, or at least less affected in the case of highly sensitive Alloy 600 MA tubing. In the past when large amount of acidic or alkaline impurities entered the SGs, corrosion easily occurred. Then with more satisfactory water chemistry in the plants, where insufficient attention was paid for the corrosion product control, the SG problems still continued. This confirms the importance of adequate selection of the secondary side water chemistry in addition to avoid the presence of large impurities.

In the 2000's, the key issue is becoming the quantity of corrosion products deposits within SG. This may happen on tube surface, as illustrated on Figure 2-6 in Russian VVER units, or on tubesheet or, in broached holes of Tube Support Plates (TSP) as shown on Figure 2-7 in the French case of Cruas. This has been the cause for Flow Induced Vibration (FIV) and significant SG tubing leaks, heavy maintenance activities for cleaning the SGs.

This corrosion products deposition represents one of the new key challenge that is largely covered by selecting an optimum secondary water chemistry and its impacts, detailed in next sections.

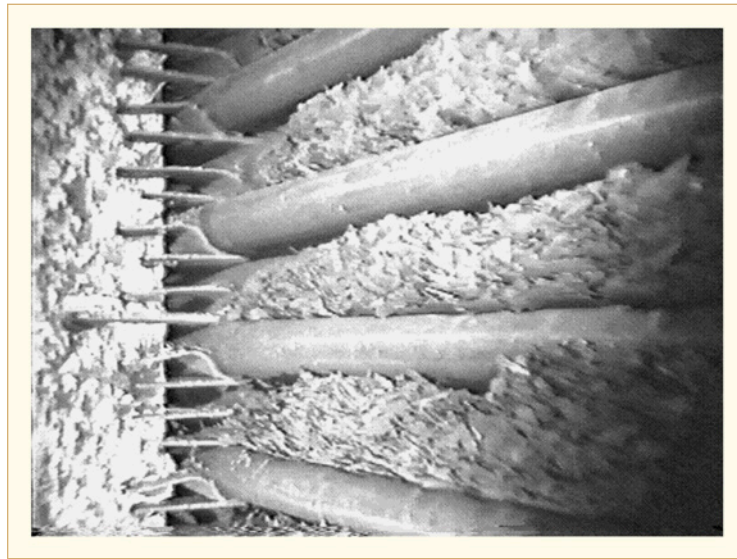


Figure 2-6: SG deposits as flat scales in the lower rows of a VVER plant operating at low FW pH values [Mamet et al, 2002].

3 Hide out and hide out return (Francis Nordmann)

3.1 Hide out process

Soluble species, like ionic impurities, which are transported by Feedwater into the SG will concentrate in the bulk water due to steaming if they are virtually non-volatile, i.e. if their distribution coefficient steam/water is <1 . The concentration factor of these species depends on their exact volatility. In order to compensate the concentration mechanism in the bulk water, SG blowdown (SGBD) is designed with a typical flow rate of 0.5 to 1% of the FW flow rate. Many of the impurities, like NaCl, NaOH, have a steam to water distribution coefficient in the range of 10^6 to 10^5 at the SG operating temperatures, Figure 3-1. For these non-volatile species, the expected concentration factor is ~ 200 and 100 in the bulk water directly depending on respective SGBD rate of 0.5% and 1%.

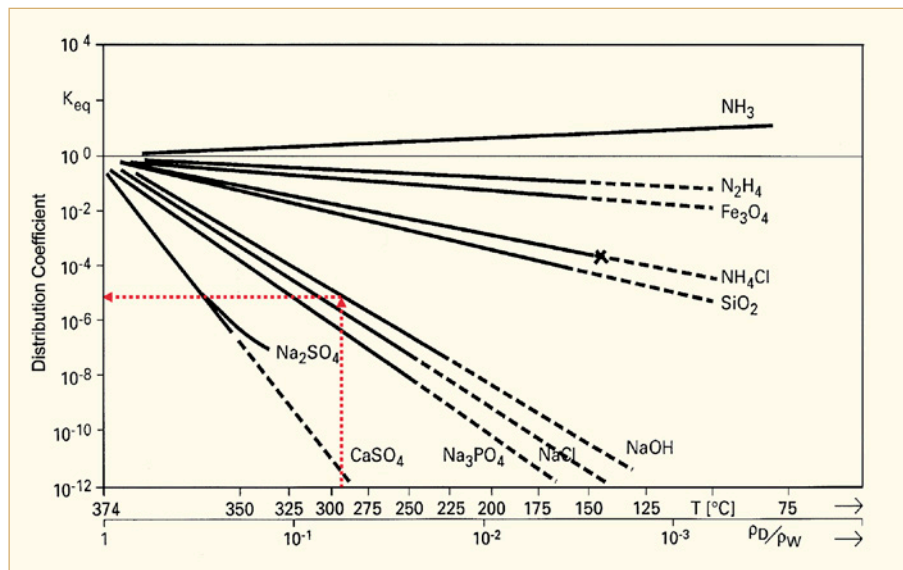


Figure 3-1: Steam to water distribution coefficient of salts as a function of temperature and pressure [Jonas, 1977].

Soluble species in the RSG bulk water can hide out by competing mechanisms. Based on the experience, the measured SG bulk water impurity concentration is usually lower than the expected one according to additional concentration factors. Impurities partially disappear from the bulk water by adsorption and/or by concentration mechanism beneath the deposits or in areas of restricted flow. This phenomenon, called “Hide Out” (HO), is thus occurring by one or several of the following mechanisms:

- Adsorption on tube surfaces or surface oxide deposits,
- Precipitation of compounds with low solubility,
- Concentration in tube surface deposit crevices,
- Concentration in areas with restricted flow, TSP crevices or top of Tubesheet deposits.

The driving force for the impurity concentration in such flow restricted geometries is the heat transfer with super heating and the boiling. Local super heat in crevices is defined as temperature difference between the crevice and the bulk water, illustrated on Figure 3-2 :

$$\Delta T = T_2 - T_1$$

Where

T_2 = Local temperature in the crevice
 T_1 = Secondary side SG bulk water temperature

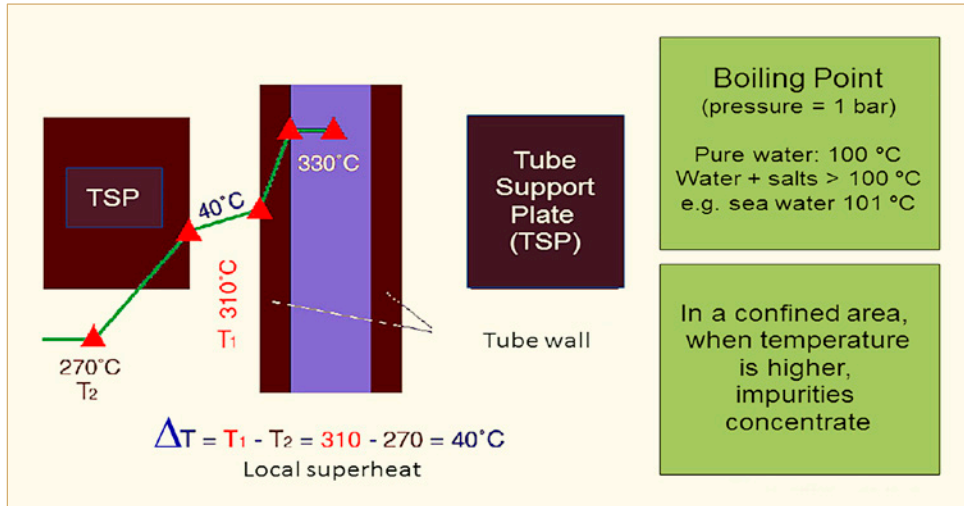


Figure 3-2: Superheat in tube to Tube Support Plate (TSP) crevices of old PWR design.

Figure 3-3 shows how the impurities may concentrate in deposits above the top of the tubesheet, in sludge pile, which is another location of restricted flow, avoiding renewal of the water and where the impurities will concentrate due to the boiling. In the upper blue part of the sludge pile, the water flow is sufficient to avoid this hide out by concentration process. No water may reach the lower blue part, which is below a thick deposit of sludge. Finally, the concentration is the highest in the intermediate red part, located at a certain distance from the top of the sludge pile, allowing water with impurities to reach it without allowing this water to be easily renewed.

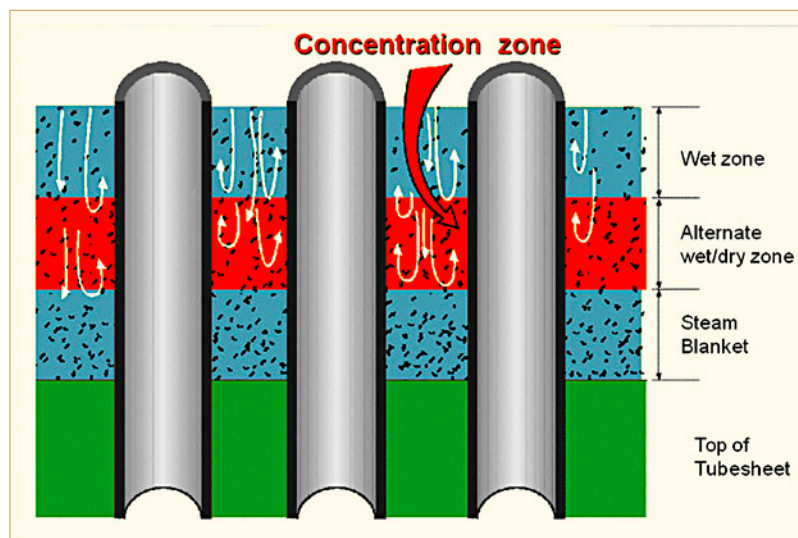


Figure 3-3: Zone of corrosion risk due to concentration process in Sludge pile above tubesheet.

In the crevices, the temperature being higher than in the bulk water, the relation between boiling temperature and pressure for pure water is affected. To better explain it, the relation between boiling temperature and pressure is drawn on the upper curve of the left part of Figure 3-4. However, when some salts are present in the water, for the same pressure, the boiling temperature is increased. This phenomenon is governed by the Ebullioscopy law. It is similar to the well-known cryoscopy law, applied to avoid the presence of ice on the roads in winter, where the freezing temperature of water is also affected by the presence of salts. Increasing salt concentration in the crevices results in an increase of boiling temperature in the flow restricted crevices, left part of Figure 3-4.

Together with restricted cooling of the tubes and Ebullioscopy effect, the crevice temperature can be increased at maximum up to the primary side temperature, resulting in a super heating of approximately $\Delta T = 40^\circ\text{C}$ (difference between the primary water in the SG tube at the corresponding location and the bulk water on the secondary side). It is clear that this super heating is higher in hot leg than in cold leg and in the bottom part of the hot cold leg than in its upper part. This is why the concentration process will be higher in the lower hot leg part and this is also where the corrosion is the generally the worse, which may also be due to the simple effect of temperature on the corrosion kinetics. Finally, the higher the ΔT , the higher is the concentration of the salt impurities in the crevices. Sodium hydroxide, highly soluble, may reach extremely high values if enough amount of impurity is brought to the location where concentration process takes place, as it can be seen on right part b of Figure 3-4.

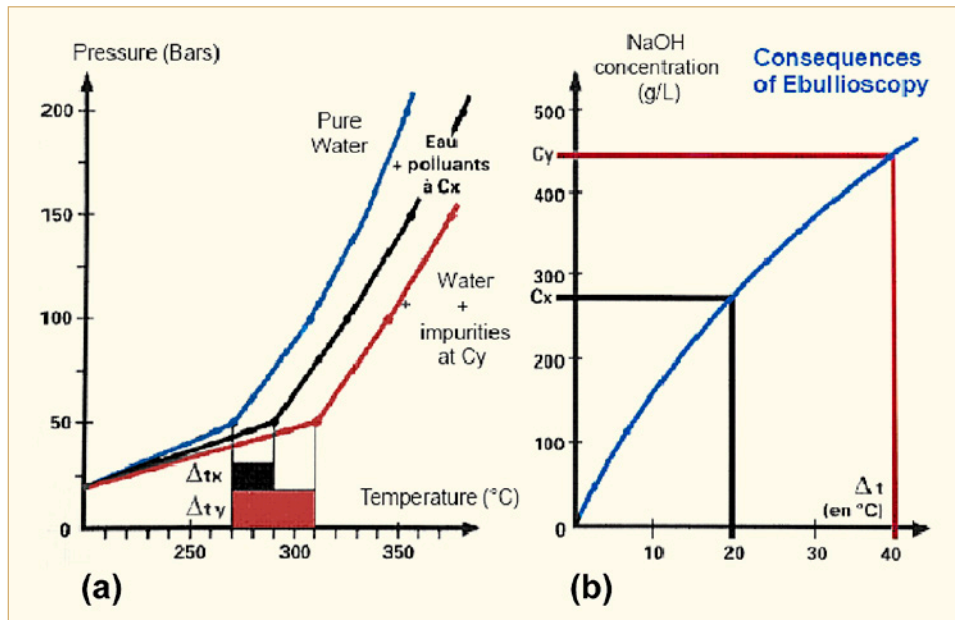


Figure 3-4: Ebullioscopy effect: (a): Saturation curve of water at different impurity concentrations (b): Impurity concentration as a function of super heating [Odar & Nordmann, 2010].

The concentration mechanism is more precisely schematically illustrated for TS deposits and TSP crevices in Figure 3-5. The outer surface and upper part of these deposits are wetted by SG bulk water containing trace amounts of impurities. Accordingly, impurities penetrate with water in those areas. The lower part of the deposits is usually dry due to overheating by heat transfer from the primary side and insufficient cooling, since no sufficient water can reach the area beneath the deposits. As already explained, between wet and dry zones, exists an alternate wetting and drying zone, where the water penetrating into the deposit, starts to evaporate because of higher temperature by locally super heating and moves away from this area as steam. In those alternate wetting and drying areas, salt concentrations can become very high, leading to the formation of local aggressive environments.

4 Primary Side recycling of waste (Dewey Rochester)

4.1 Background

Nuclear power plants designed, built and commissioned in the 1970s and 1980s contained facilities for the processing liquid radioactive waste. These systems included recycle evaporators and evaporators, often termed miscellaneous waste evaporators, for processing liquid waste that wasn't suitable for recycling.

Figure 4-1 is a simple diagram of a basic nuclear steam supply system (NSSS) including the boron recycle evaporator. Not included in this particular diagram, but usually present, is a similar miscellaneous waste processing evaporator system.

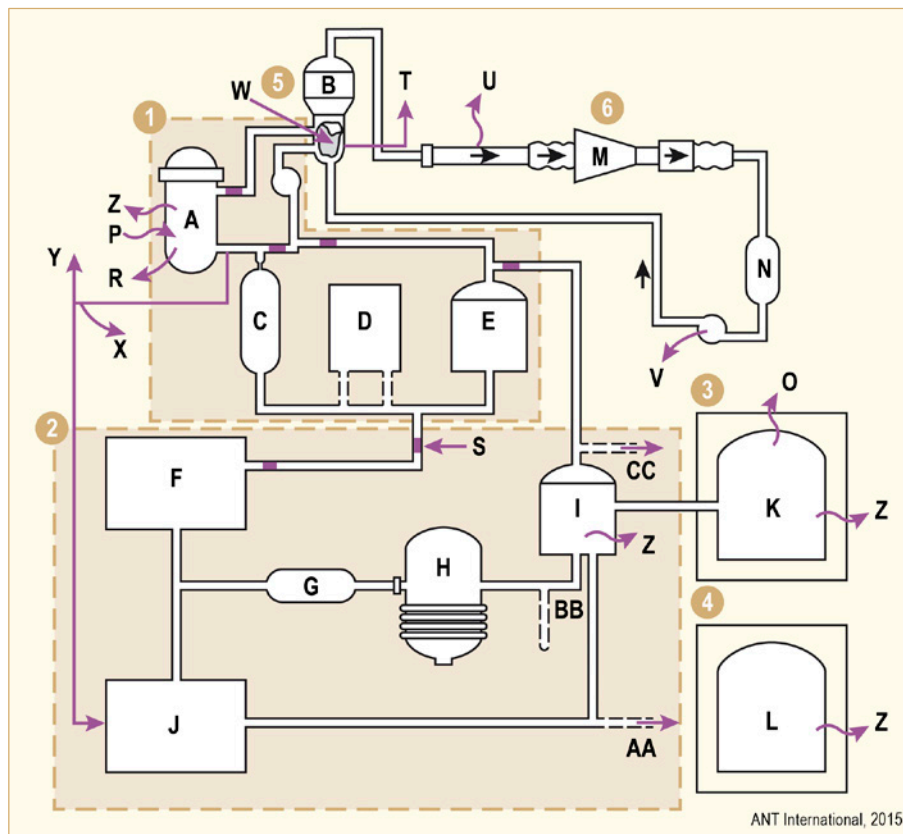


Figure 4-1: Basic nuclear power plant diagram with Boric Acid recycle Evaporator.

Figure 4-1 Legend

Equipment

- A Reactor and Primary Coolant System (RCS)
- B Steam Generator (SG)
- C Letdown Demineralizer
- D Boron Thermal Regeneration System (Westinghouse)(BTRS)
- E Volume Control Tank (VCT)
- F Bleed Holdup Tank (boric acid)
- G Demineralizers
- H Boric Acid Recycle Evaporator
- I Reactor Makeup Water Storage Tank (RMWST)

J	Reactor Coolant Drain Tank
K	Spent Fuel Pool (SFP)
L	Refuelling Water Storage Tank (RWST)
M	Turbine
N	Condenser

Processes

O	evaporation
P	production of tritium
Q	removal for tritium control
R	shim (boric acid) bleed
S	SG blowdown
T	steam leak
U	condensate leak
V	primary to secondary leak
W	primary coolant leak
F	fraction of primary coolant leaving as a gas
Y	radioactive decay
Z	discharge from reactor coolant decay tank
AA	discharge from Reactor Coolant Drain Tank (RCDT)
BB	discharge of shim bleed (boric acid)
CC	discharge from reactor makeup water storage tank (RMWST)

The numbers in Figure 4-1 are:

1. Primary system
2. Liquid radioactive waste system and reactor water makeup system
3. Spent fuel pool
4. Refuelling water storage tank (RWST)
5. Steam generators
6. Balance of secondary system

Originally NSSSs were designed and built to recycle both evaporator distillate and the evaporator concentrate (boric acid) to minimize radioactive releases and boric acid. These measures were thought to reduce costs for the purchase of boric acid and labour costs for the mixing of boric acid. For many plants these assumptions were found to be false. However, for some plants recycling lived up to its potential.

Several problems were encountered that prohibited the recycle goals from being achieved. Some of the major problems were:

- The inability of the plant to keep and maintain proper liquid segregation between the relative pure reactor coolant bleed and the other miscellaneous waste from RCS leaks and auxiliary system leaks. The latter introduces chemical containments that must be dealt with before the liquid can be reintroduced into the reactor coolant system. Most plants elected to discharge this waste rather than treat and recycle it.
- The recycle (and miscellaneous waste) evaporators were undersized. Many were in the range of 4 to 144 l/min. The evaporators were often incapable of achieving their rated capacity.
- The volume of waste produced was greatly underestimated, at least in the early days, which required larger capacity evaporators than those originally installed which lead to alternate means of treatment and disposal.
- The evaporators required considerably more resources, such as maintenance, than originally projected. This made other waste processing options, such as treatment by ion exchange resin, more attractive and less expensive.

Some of the more attractive and less expensive options (in some cases) were:

- Reverse osmosis (RO) – this has been found to be very effective in the treatment of laundry (detergent) waste. Decontamination factors (DF) ($\frac{\text{Activity In}}{\text{Activity Out}}$) of 2 can be achieved.
- Filtration:
 - Cartridge type filters – these are usually coupled with other processing options. Filters can be made of pressed paper, matted fibers, or porcelain materials. These filters are generally used in low pressure, low temperature systems.
 - Precoat type filters – these are useful in some situations although limited by temperature, pressure and flow extremes. Additionally, the large quantities of precoat material must be disposed of and can pose significant problems.

Filters remove radioactive particulates but will not remove dissolved (ionic) species. The DF for filters is usually about 1 which indicates that most of the radioactive species are ionic.

- Ion Exchange – an ion exchange demineralizer contains an active polymer that exchanges mobile ions from the surrounding solution. The active polymer is essentially a plastic bead, which has some weakly attached ions. Hydrogen- hydroxide (HOH) type is typically used. As the liquid passes over the bead it readily exchanges ions on the bead with ions in the liquid. The cation resin has a positive ion attached (H^+) while the anion resin has a negatively charged hydroxide ion (OH^-). A demineralizer containing both cation and anion types of resin is a mixed bed ion exchanger.

Mixed bed ion exchangers are capable of processing liquids to excellent purity. Sometimes the resin effectiveness can be impaired by insoluble species such as oil or particulates by being absorbed on the resin surface. This condition is termed fouling. Filters employed prior to the demineralizers are often used to mitigate fouling problems.

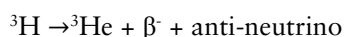
A precursor to recycling any reactor grade water is the separation from other waste streams/inputs. Waste streams such as equipment drains, sumps, steam generator blowdown, primary to secondary leakage, and laundry waste should not be allowed to come in contact with reactor coolant grade water. Generally, non-reactor grade liquids that have a tritium content of less than 10% of the primary coolant, because of their composition, should not be processed for reuse. The reason for not recycling these liquids is that the low tritium concentration may be an indicator of other contaminants that may be in the water. Additional chemical analyses may be needed to determine the suitability of the water for processing and recycling. The recycle system is designed to process reactor grade water which enters the liquid waste system. The liquid comes primarily from feed and bleed operations during the cycle. Other sources may be from the refuelling cavity, core flood tanks, refuelling water storage tank, reactor water storage tank and bleed holdup tanks.

4.2 Recycle of Evaporator Distillate

4.2.1 Tritium

The plants that elected to recycle the evaporator distillate were presented with a problem that did not exist for those plants that chose to discharge the treated radioactive waste to the environment. Early on, plants that chose to recycle the evaporator distillate were predicted to have increased tritium concentrations later in plant life. Depending upon the tritium source term this could present a serious problem in the future [Smith, 1977].

Tritium is a pure β -emitter with a maximum energy of 18.6 KeV and an average energy of 5.7 KeV. These are low energies compared to most other beta emitters and can be easily shielded. The outer layer of dead skin is enough to stop all of the beta external to the body. Only if tritium enters the body can it produce a significant dose.



Tritium decays to the more stable helium atom. Since the anti-neutrino does not interact with matter it is of no biological significance.

The physical half-life is 12.3 years compared to a biological half-life of approximately 10 days. Tritium does not penetrate the skin so it poses only an internal dose concern. Tritium is usually present as “tritiated water” or HTO which can be ingested into the body as a liquid or inhaled as a vapour. Once ingested in the form of water, it is evenly distributed throughout the body in about one to two hours. In cases of severe tritium intake, the biological half-life can be reduced to four to eight days using dialysis machines.

As shown in Table 4-1 most of the tritium in PWRs comes from the boric acid in the water which is added as a neutron moderator. Lesser amounts of tritium in the RCS comes from the diffusion of tritium through the controls rods and nuclear fuel but less than the B-10 reaction. Were enriched Li-7 (99.99%) *not used* most of the tritium would be produced by the Li-6 reaction. VVERs do not use lithium for pH control so this is not an issue for those types of PWRs.

There are several modes of production for tritium (T) in light water PWRs as shown in Table 4-1 [Reiss et al, 2010].

Table 4-1: Sources of Tritium in Pressurized Water Reactors [Reiss et al, 2010].

Formation Reaction	Source	Bq/annum
U-235(n,f)T	Ternary fission	6.7E+14
Pu-239(n,f)T	Ternary fission	
B-10(n,2α)T	Boric acid	4.8E+13
Li-7(n,nα)T	LiOH	5.6E+11
Li-6(n,α)T	Impurities in LiOH	5.6E+11
H-2(n,γ)T	Hydrogen content in water	9.3E+11
ANT International, 2015		

Figure 4-2 shows the decay of tritium using the physical half-life of 12.3 years. The relatively long life of tritium is one of the reasons for concern. Fortunately, the biological half-life of tritium is much lower, approximately 10 days (actually about 9.4 days but usually rounded to 10 days). The biological half-life of tritium varies considerably and is dependent upon bodily secretion rates, temperature and fluid intake. Increasing the intake of water (or other liquids) in the body will reduce the biological half-life considerably although to achieve a 3 day half-life would require extreme efforts (increase of 2 to 20 liters of fluid). Figure 4-3 shows the decay for biological half-lives for both 10 and 3 days for comparison.

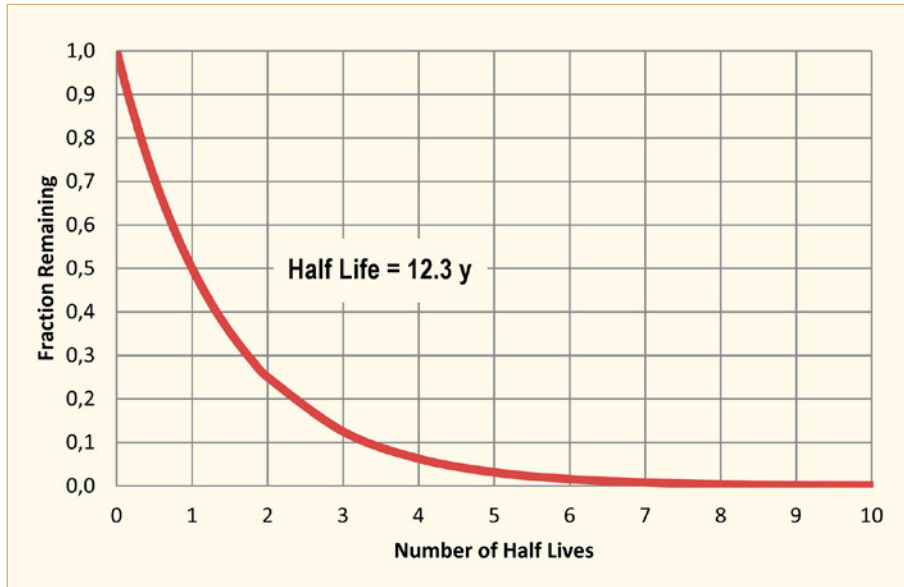


Figure 4-2: Tritium decay chart – physical half life.

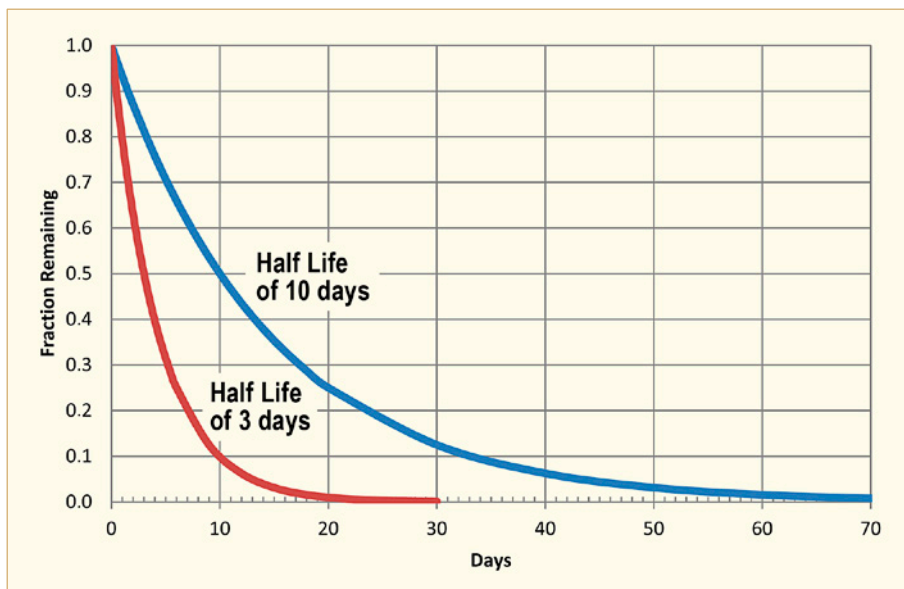


Figure 4-3: Tritium decay chart - biological half lives.

Tritium doses depend upon the amount initially ingested and how long it remains in the body. In the U.S. National Council on Radiation Protection Report 30, the Annual Limit of Intake (ALI) is 3 GBq (81 mCi) [Idaho State University, 2015]. The Committed Effective Dose Equivalent (CEDE) in soft tissue is 17.3 μ Sv per MBq (64 mrem/mCi) ingested. An ALI is the amount of radioactivity required to receive a dose of 50 mSv (5 rem) of equivalent whole body dose for the year. To calculate the dose from tritium, estimate the amount of tritium initially ingested in the body and use the CEDE factor 37 MBq/640 μ Sv (1 mCi/64 mrem). For example, if a worker has an intake of 148 MBq (4 mCi), the worker would receive a dose of 2.56 mSv.

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