STEAM GENERATORS LIFE EXTENSION EXPERIENCE AT KANUPP

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ABSTRACT

Karachi Nuclear Power Plant (KANUPP) commissioned in 1972 has been operating under PLEX since Jan 2004, after completion of 30 years of its design life. It is planned to extend its life at least by another 15 years after necessary upgrades and re-licensing outages (RLO) by local regulators. KANUPP has six steam generators (SGs), with half-inch diameter Monel-400 tubes. In-service inspection is being carried out regularly in compliance with plant and regulatory requirements (CSA N285.4 for tubes and ASME codes for shell and internals). Degradation is prominent in tubes under sludge from pitting/wastage and denting at first tube support plate (Corten steel) in all the six SG units. Uptil now there has been only one instance of a tube leakage and so far 99 tubes (i.e. 1.2% of the total tubes) have been plugged based on wall thinning and severely dented at first tube support plate.

A regular monitoring program that is in place includes inspection of tubes, primary and secondary internals, shell, supports and connection welds. Plugging criteria for tubes is $\geq$ 40% for wall thinning and $\leq$ 0.250 inch opening for denting using stabilizer bars. An extensive monitoring program for condition assessment is in hand to keep a watch on the rate and morphology of degradation mechanisms and surveillance on susceptible areas unless remedial and control measures are effectively in place.

KANUPP steam generators have so far undergone partial water lancing in 2000, hydraulic analysis study, mechanical integrity and comprehensive inspection of tube, overall condition assessment, internals, shell welds and supports inspection.

1.0 INTRODUCTION:

Karachi nuclear Power Plant (KANUPP) is a 137 MW (e) CANDU and went into commercial operation in October 1972. The initial plant design life was 30 years until 2002 and is now operating under PLEX for another 15 years.

KANUPP Steam Generators (six units) are manufactured by M/s Babcock & Wilcox (B&W), Canada, with half-inch diameter Monel-400 'U' tubes (1355 in each SG unit) and lattice bar support plates of Corten steel. In-service inspections in 1993, 1996,1998, 1999, 2000, 2003 & 2006 have revealed SG tubes by denting at first tube support plate and pitting under sludge. Control measures such as water lancing, chemistry control, continuous blow down, condenser tube plugging/re-tubing, regular surveillance and inspection have already in place. The present life management strategies for KANUPP SGs [1] is reviewed for improvement where needed.

2.0 GENERAL RESULTS OF INSPECTIONS:

Based on eddy current, gauging of denting extent at first Tube support Plate (TSP), visual examination of primary, secondary side internals and NDE of vessel welds and supports examination, following are the general results.

2.1 During 33 years of plant operation, one tube that leaked in 1990 was subsequently located and plugged.

2.2 So far a total of 99 tubes (i.e. 1.2 % of total tubes) in all SGs are plugged based on wall thinning and denting criteria.

2.3 From regression curve (Fig-1) until latest inspection, about 5% tubes (~407 tubes) in all six SG units shall be plugged up to 2018 considering linear extrapolation approach on ET and denting monitoring result data up to 2006.

2.4 The tubes are designated as dented (i.e. $\leq$ 0.350″ opening) at 1st TSP of hot leg region. Now the rate of denting is slowed down.

2.5 Maximum sludge height above tube sheet is ~11″ after 33 years of plant operation using AVT since 1976.

2.6 No fretting damage reported so far either from loose parts or from pre heater baffle plates or structural damage of any sort from the various VT examinations.

2.7 Upper internal inspection of one SG out of six units was performed in this (2006) outage, which did not show reportable evidence of degradation, nor from FAC etc.

2.8 Mechanical integrity evaluation for dented tubes [2] concluded that plugging criteria for severely dented tubes of KANUPP SGs is a conservative approach and hence may be continued.

2.9 No reportable abnormality is reported in primary side and secondary side vessel welds till inspection result 2006.

2.10 From inspection and condition assessment, it is concluded that there is no indication of an associated safety risk in the short term, however, recommend to carry out increased inspection and water lancing.

3.0 AREAS OF CONCERN:

3.1 Sludge pile above tube sheet.

3.2 Corrosion products at 1st tube support plate crevices in hot leg region, resulting in tubes denting.

4.0 CONDITION ASSESSMENT OF KANUPP STEAM GENERATORS:

4.1 Steam Generator Thermal Hydraulic Evaluation [3]:

The thermal hydraulic study conducted in year 2000, indicates that the tube and structure condition is not hampering the usual performance and reliability of the SG units. Also that no untoward risk is associated while the unit is in service considering the design intent and operational parameters.

4.2 Mechanical Integrity Evaluation For Dented Tubes [2]:

The stress and strain distribution at tube denting area is safe and plugging criteria (0.25") of severely dented tube is conservative and adequate. Based on flow-induced vibration, under condition even if the sludge is removed on 1st TSP region, it is improbable for the tubes to fail under flow-induced vibration.

4.3 Secondary / independent evaluation in 2006 [4]:

The condition assessment concluded that if denting can be slowed significantly (water lancing, chemistry & inspection etc.) and the effects of the present degradation mitigated, then the steam generators are safe to operate safely for a further '10' years.

4.4 Tubes condition from plugged tube data:

Thermal hydraulic evaluation report [3] showed that about 6.183% (503 tubes) would be plugged up to 2006. Whereas the updated plugged tubes data until 2006 is that only 99 tubes are plugged. Considering it conservative, a new curve (Figure -1) is drawn, which shows that only 3.9% tubes would be plugged by 2019. KANUPP SGs shall be safe for operation at least for next ten years subject to verification of data by inspection of all units after every four years.

5.0 KANUPP STEAM GENERATOR DEGRADATION MECHANISM (Fig-3):

5.1 Comparison of SG Degradation in KANUPP with that of other CANDUs:

CANDU	KANUPP [1]
i Mechanical damage to tubes Location: Pre heater inlet, tube support structure, separator parts, fretting of tubes in outer U bend	i No reportable foreign objects/loose parts, which may cause mechanical damage to tubes is however ruled out.

region.	
ii Denting in tubes Location: 1st TSP region.	ii The most serious degradation problem is denting of tubes at first tube support plate. The cleaning of TSPs by water lancing is planned in next outage.
iii Pitting/Wastage Location: Under Sludge piles at TS and other tubes deposits.	iii Due to presence of comparatively small sludge pile in central region above tube sheet, degradation is evident but is likely to be contained after water lancing. Selected tubes shall be continuously examined.

CANDU type SGs	**KANUPP SGs**
iv Stress Corrosion Cracking (SCC) in tubes. Location: local high stresses on tubes by denting (i.e. 1st TSP region) and in roll transition area.	iv KANUPP SGs is at low risk from this mechanism due to exceptionally high resistance to SCC under normal operating conditions Based on experience on other CANDU SGs Monel-400 tubing is generally free of this mechanism and also ruled out.
v Intergranular Attack (IGA) Location: Under sludge pile	v Monel-400 has very high resistance to IGA and it is not expected to be a significant degradation mechanism at KANUPP.
vi Flow Accelerated Corrosion(FAC) Location: Carbon steel bundle support component.	vi The carbon steel bundle support components of KANUPP SGs are susceptible to this phenomenon, how ever due to environmental and hydraulic conditions, FAC has low probability as a degradation mechanism in CANDU SGs of similar design.

vi	Corrosion fatigue Location: Tubes	vi	There is no evidence that this mechanism has been active in CANDU SGs tube with Monel-400. Based on this experience and low vibration stresses, this mechanism is not expected to affect KANUPP SGs

5.2 STEAM GENERATOR DEGRADATION SURVEILLANCE AND CONTROL TECHNIQUES AT KANUPP:

5.2.1 Contingency plan for tube leaks:

In case of any tube leak, the first indicators are the radiation level and presence of PHT coolant in the secondary side. During 33 years of plant operation, a contingency plan to control the situation was first implemented in 1990 following an indication of radioactivity in the secondary side. The plant was handled safely leading to successful plugging of only one leaky tube and normalizing of the unit for service and plant restart.

5.2.2 Eddy Current (ET) inspection of tubes:

So far degradation mechanism pitting/ wastage is only observed above tube sheet under sludge pile region of hot leg. Up to 2006 15% to 30% tubes have been inspected. This data will be further expanded as per recommendations of condition assessment report [1].

5.2.3 Water lancing campaign in 2000 [5]:

In 2000 water lancing campaign, first time, a total of 18 nos. Hand Hole (HH) were installed in all six SG units with 3 in one SG (two of them above Tube Sheet and one above 1st Tube Support Plate). Location of HH is shown in enclosed (Fig-2). The lancing on tube sheet removed nearly 15-20% (~ 84 Kgs) of soft sludge by volume.

5.2.4 Plugging of dented tubes using stabilizer bar [6]:

The conservative approach to plug dented tube if tube does not allow passage to 0.250″ gauge, such tubes are plugged using stabilizer bars to avoid damage to neighboring tubes.

5.2.5 Vessel Integrity (primary & secondary side visual examination):

i) The remote visual examination was performed on TS and 1st TSP from the NTL and peripheral lane in 2000. (before & after lancing). This revealed following information:

Condition of sludge: It comprises of hard deposit in granular form, fine dust and sludge lumps.
Condition of tubes: The outer sides of tubes have fouling deposits and some flakes.

Location of sludge pile on TS: The location and approximate height of sludge is same as evaluated from eddy current data.
Lattice bar condition: Visual examination above and below 1st tubes support plate showed no blockade in no tube lane, where as blockage was seen in-bundle at tube support plate crevices.

ii) Based on repeat visual examination in 2006, no considerable change was found from the result of year 2000 after water lancing campaign.

iii) **Visual examination of primary side internals in 2006** revealed that divider plate assemblies (plates, bolts, nuts, locking tabs) are in intact in all SGs except few loose bolts that were tagged by welding.

iv) **Secondary side upper internals inspection:**

Inspection of upper internal of one SG was performed in 2006 from upper man way to U-bend including dismantling, inspection and reinstallation of dry pan, scrubber section, partition plate, cyclone and U-bend region, etc. Result revealed satisfactory condition of upper internal components. No noticeable degradation or flow accelerated corrosion was observed.

6.0 TUBE INTEGRITY:

6.1 Metallographic studies performed on steam generator removed tube (under sludge on tube sheet area) concludes that:

6.1.1 The material retains its characteristics microstructure as of Monel-400 tube material.

6.1.2 There was reasonable oxidation effect both inside as well outside surface of tube. This could gives rise to enhance pitting but so far based on monitoring by eddy current, not much evidence of accelerated pitting has so far being observed.

6.1.3 Mechanical tests were also performed on both new as well as removed tube material for comparison. The tensile strength gives evidence of material aging effects but nevertheless its value is well within the acceptable range.

6.2 The integrity of Monel-400 tube of KANUPP can be demonstrated as follows:

6.2.1 In view of the facts that no Monel-400 tube has so far ruptured neither at KANUPP, and the fact that the tubes are being monitored for degradation by NDE & that regular sampling for secondary side for sign of radiation contamination, the tubes are therefore meeting their designed intent. All tubes, whose degradation exceeds our acceptance criteria and proven experience, are immediately plugged.

6.2.2 During visual examination of pulled tubes (06 nos.) specifically in the areas of roll transition, we have not come across any evidence of cracking in material. This suggests that tubes are not experiencing cracking in the rolled transition area.

6.3 A distribution of degradation mechanism found so far in KANUPP SGs (Figure-3) in view of inspection data until 2006, no visible deviation has been observed. A regular (2-3 years) inspection programme has in place to keep a watch with assistance from OEF and COG.

6.4 During 33 years of operation, only one tube (R16, C25) leakage in SG # 3 (1989-90) occurred. This was known by sampling.

7.0 SHORT TERM ACTION PLAN (ACTION ON AREAS OF CONCERN):

7.1 Visual examinations of secondary side internals, to clean it from foreign or loose objects.

7.2 Secondary side cleaning of steam generator for sludge from tube sheet and corrosion products from crevices of 1st TSP.

8.0 LONG TERM ACTION PLAN

Based on the results of short-term action plan, the expected long-term plan includes the following depending upon the merit of each.

8.1 Monitor and control degradation in SG tubes at other locations by applying techniques of regular inspection & remedial measures such as cleaning and through OEF.

8.2 Perform a comprehensive visual examination of internals and repeat periodically.

8.3 Implement suitable or modify ‘Chemistry’ and ‘Plant Operational’ parameters to control degradations during the extended plant life.

8.4 Develop fitness-for-service (FFS) criterion for SG safe operation after water lancing campaign.

8.5 Acquire inspection facility in SG tubes specifically at dent and at rolled joints for safe operation in the extended life of plant.

8.6 Perform sludge cleaning on periodic basis on the other potential areas for corrosion related degradation.

8.7 Replacement of condenser tubes.

8.8 Feed train improvements on secondary side e.g. improve performance of WTP, hot soaks, etc.

8.9 Dented tubes profilometry to disposition dents based on the R&D findings and FFS criterion.

9.0 FITNESS FOR SERVICE ASSESSMENT

9.1 The condition assessment report [4] concluded that SGs can be operated safely for further ten years from year 2004 with remedial measures. Control measures such as chemistry control, continuous blow down, condenser tube plugging/re-tubing, regular surveillance and inspection have already in place. In 2006 outage, KANUPP has also completed recommendations regarding secondary side inspection of lower and upper internals and increased tubes inspection. The tubes and internal structure is acceptable as no immediate corrective action is needed except water lancing in next outage.

9.2 The degradation mechanisms effecting tubes is known to KANUPP and there is no evidence of any unexpected degradation up to next inspection.

9.3 Plug the defective tubes with wall loss ≥40% of wall thickness and **severely dented tubes with ID ≤0.250″ using stabilizer bars.**

9.4 Where doubtful signals exist and cannot be characterized for dis-positioning in the absence specialized techniques, plug the tubes on the basis of signal amplitude.

9.5 Plug the tubes, in which eddy current probe had stucked (i.e. U-bend area) and was removed forcibly. This is in view of any damage that probe could have done in to the tube.

9.6 Monitor the secondary side of boilers for any PHT leakage while in service and if one is detected, plan for plugging and subsequent tubes inspection of leaky boiler.

9.7 Monitor the chemistry of condenser and feed train to SGs and take appropriate action to limit the excursions of undesired elements according to the plant technical specifications.

10.0 CONCLUSION:

10.1 KANUPP has in place a regular surveillance and control measures programme and during 33 years of KANUPP SGs operation, only single tube was leaked in 1990, which was detected and plugged.

10.2 KANUPP FSAR-II report also concluded that multiple failure of SG tubes is most unlikely that may lead to comprising safety.

10.3 So far, there is also no evidence of circumferential defect in rolled transition area, which may cause to rupture of single tube.

11.0 FIGURES

12.0 REFERENCES

[1] life management program for KANUPP Steam Generators, special technical report # KANUPP-STR-03-02.

[2] Mechanical integrity evaluation for dented tubes of KANUPP steam generator, PK/ERD/RP/007 (Rev-A)

[3] Thermal hydraulic evaluation for KANUPP steam generator, PK/ERD/RP/008 (Rev-D).

[4] Condition assessment of KANUPP steam generator internals and tubing, B&W-155N-TR-01 (Rev-0).

[5] Water lancing of KANUPP steam generator, KANUPP-ISR-360-06.

[6] KANUPP steam generator tube denting and plugging criteria, KANUPP-STR-99-04.