

Role of Weld root Geometry – Backing rings in Flow Accelerated Corrosion (FAC): Radiography testing is an alternate NDT method for detection - An experience at Tarapur Atomic Power Station-1&2; Nuclear Power Corporation of India Limited, India

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Abstract

Tarapur Atomic Power Station (TAPS) is one of the vintage nuclear reactors operating in the world and belongs to earlier generation of Boiling Water Reactors (BWRs) has completed 40 years of successful, commercial and safe operation. TAPS was designed to generate 210MWe out of which 70% was from reactor primary steam and the remaining from Secondary Steam Generators (SSGs). These SSGs were isolated in the year 1984 and units are operating at rated capacity of 160Mwe since then. Of late it has been identified that Flow Accelerated Corrosion (FAC) is one of the degradation mechanisms with High Energy system piping components. The sudden failure of high energy (Enthalpy) piping components lead to loss of human lives as well as property loss in addition to the unplanned down times. The power industry is now reviewing their effectiveness of detection and monitoring programmes to identify & mitigate the consequences. The recent pipe rupture incidents in overseas NPPs in secondary cycle piping have alarmed Indian NPPs. This issue was reviewed in detail at TAPS-1&2 and corrective & measures have been formulated for timely detection of degradations. During these four decades TAPS has engineered many inspection methodologies to detect various degradation mechanisms such as IGSCC (Inter Granular Stress Corrosion Cracking), TGSCC (Trans-Granular Stress Corrosion Cracking), Erosion-Corrosion (EC), Stress Corrosion Cracking (SCC) and Flow Accelerated Corrosion (FAC). These degradation mechanisms were timely detected using various inspection methodologies developed time to time. The expertise gained from the Operation & Maintenance (O&M) of reactors for the past four decades has strengthened the capabilities of station inspection personnel to develop various inspection methodologies & their application in the field. One such inspection methodology was developed by the station QA group which has potential to detect the degradation of high energy system piping components vulnerable to FAC, especially the weld root inaccuracies. This inspection technique is established at site NDT facility with in-house expertise and effectively utilized to detect the piping components degradation due to FAC.

This paper gives a brief insight into the various inspection methodologies followed at TAPS for timely detection of degradation mechanisms avoiding catastrophic failure of High Energy system piping components. TAPS has effectively utilized these inspection methodologies and implemented to assess such component's integrity have also been briefly discussed.

Key Words: Erosion-Corrosion, Flow accelerated Corrosion, Visual Testing, Radiography testing, Backing rings.

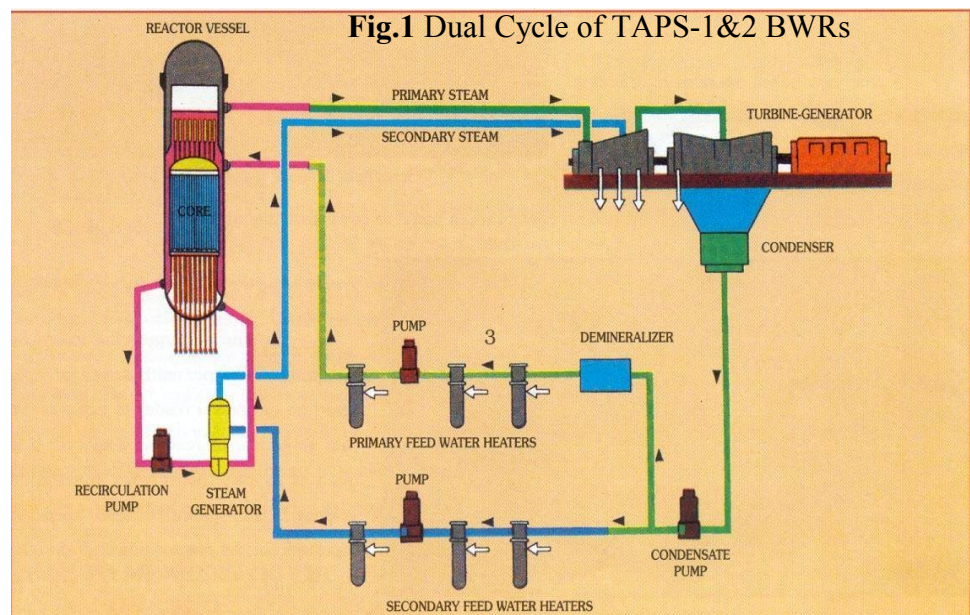
Tarapur Atomic Power Station-1&2 (TAPS) is one of the vintage Boiling Water Reactors (BWRs) operating in the world and belongs to earlier generation of BWRs. These units were commissioned in late 60's and have successfully completed 40 years of commercial and safe operation. During these four decades, TAPS has engineered many inspection methodologies to detect various degradation mechanisms such as IGSCC (Inter Granular Stress Corrosion Cracking), TGSCC (Trans-Granular Stress Corrosion Cracking), Erosion-Corrosion (EC), Stress Corrosion

Cracking (SCC) and Flow Accelerated Corrosion (FAC). These degradation mechanisms were timely detected using various inspection methodologies developed time to time. The expertise gained from the operation and maintenance of both the units for the past four decades has strengthened the capabilities of the station personnel to develop various inspection methodologies & their application in the field.

1.0 **INTRODUCTION:**

1.1 Of late it has been identified that Flow Accelerated Corrosion/Flow Assisted Corrosion (FAC) is one of the degradation mechanisms with High Energy system piping components. The sudden failure of high energy (Enthalpy) piping components lead to loss of human lives as well as property loss in addition to the unplanned down times. The power industry, especially nuclear is now reviewing their effectiveness of detection and monitoring programmes to identify & mitigate its consequences in a systematic manner. The recent pipe rupture incidents in overseas nuclear power plants in secondary cycle piping have alarmed Indian NPPs. Even though the incidents occurred in different type of reactors (PWRs) which operates under specified conditions, but the system under which the phenomenon occurred is common in every power plant. Therefore this phenomenon is applicable to both nuclear as well as fossil power plants systems.

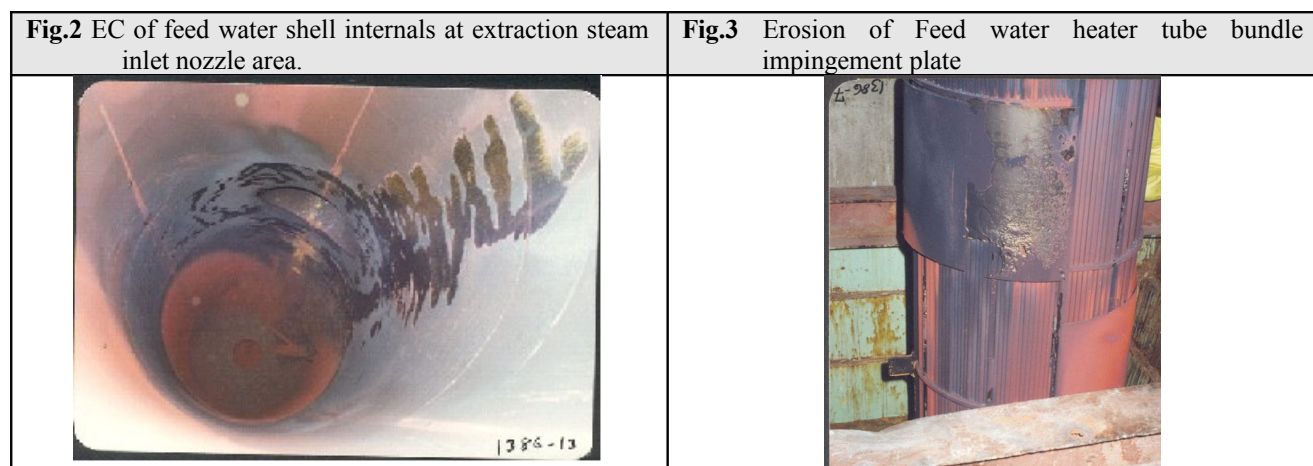
2.0 **HISTORY & BACKGROUND:** Tarapur reactors were built in late 60's and emphasis was given to optimize the design, selection of material etc., TAPS was initially designed for 210Mwe, with Dual-Cycle where-in 70% power was from Reactor and 30% of power is from



two-Secondary Steam Generators (SSGs). The system design is to have Load-following characteristics i.e., 30% of power can be varied without changing the reactivity mechanisms position. However, due to the problems associated with SSGs, the secondary Cycle was completely isolated in the year 1984 and both the units were re-rated to 160Mwe. Therefore, all the secondary cycle piping were isolated which are made of mainly Carbon Steel pipe fittings and the Heat Exchangers/Secondary Feed water heater tubes are made of copper alloys. Fig.1 shows Dual-Cycle of TAPS-BWRs which was in operation till 1985. The thermal cycle is "Regenerative Rankine" cycle with feed water heating. Like any other thermal power plant, TAPS also has a series of feed water heaters.

- 2.2 These feed water heaters utilize wet steam extracted from different stages of turbine for heating the condensate. One of the degradation mechanisms which are identified to be responsible for causing damage to turbine steam extraction piping is Erosion-Corrosion (EC). A portion of turbine steam extraction piping of various stages is made of carbon steel piping which carried wet steam is especially susceptible to EC. This phenomenon is applicable to both BWRs as well as PWRs. TAPS is one of the vintage reactors and systems of Turbine extraction system piping were also vulnerable to such degradation mechanism. Based on the feed back obtained from various study reports from ¹EPRI, TAPS has formulated inspection programme and systematically examined all the components of extraction system piping since early '80s. The contributory factors for EC are (a) Percent moisture (b) Material composition (c) pH and water chemistry (d) Temperature (e) Oxygen and (f) Flow path Geometry and velocity. The quality of steam output from reactor is 0.23% wet and hence this EC phenomenon is very well applicable to TAPS.
- 2.3 As per GE design/plant layout all the steam extraction piping from Turbine extraction nozzle up to Bleeder Trip Valves (BTVs) is made of Cr-Moly. Hence, EC degradation aspect was already taken-care by the designer. However, the remaining piping from BTVs and up to the respective Feed water Heaters used for “regenerative feed water heating” were made of Carbon steel material.
- 2.3 Failure to detect & repair EC degradation could result not only to plant personnel but also causes extensive damage to the plant equipment located in the vicinity, ultimately results in forced outages and revenue loss. The feedback from overseas reactors experience coupled with in-house practical experience on various inspection observations /results with practical experience, a systematic methodology-cum-guidelines were established for developing surveillance programme of monitoring. These vulnerable extraction systems piping of HP-LP turbines were prioritized based on the susceptibility to EC followed by identification of affected components by various NDE methods, especially by Ultrasonic Thickness gauging using “Band Method”. Earlier the concept of measuring thickness of components in specified “Grid Method” did not exist. Based on the practical experience the concerned areas vulnerable to this type of degradation could be identified with Band-Method.
- 2.4 Low Alloy Steels (LAS) such as 1-1/4Cr-1/2Mo (P11 grade); 2-1/4Cr-1Mo (P22 grade) is considered to be shown good resistance to EC in both operating systems and laboratory tests¹ in wet steam environment. TAPS has adopted the replacement of piping vulnerable to EC in the steam extraction system with EC resistant material 2-1/4Cr-1Mo in a phased manner completed by late early '90s. Recently, condition assessment of all the replaced components was assessed by plant surveillance programme, shown satisfactory results.
- 2.5 EC phenomenon was also observed in secondary pressure vessels such as feed water heaters of all the extraction stages of HP/LP turbines. In the primary feed water circuit TAPS-1&2 has HP, IP, LP feed water heaters and two drain coolers. Erosion of shell internals was a cause of concern in late '80s which results in many forced unit outages/reduced power operations for repairing the affected components. **Fig.2 & Fig.3** shows some of the observations with feed water heaters internals degradation. TAPS did a comprehensive review of various aspects such as layout, design and operating history and came out with many modifications.
- 2.6 EC related degradation has been addressed and all the feed water heaters were replaced in a phased manner by the year 2000. The major modifications introduced in the designs are (a) SS liner provided above & below the steam inlet nozzle at shell ID (b) SS impingement plates on

the tube bundles (c) SS sleeve designs adopted at drain inlet nozzle with a SS liner on the shell (d) Impingement SS solid rods on the tube bundle in front of steam extraction inlet nozzle (e) Tube Support plates/Baffles design changed to segmented baffles & gap between the baffles reduced to eliminate “Fretting Failure” (f) perforated plate introduced at feed water inlet of tube bundle inside channel to avoid inlet end erosion. With modified heaters designs all the replaced heaters have given trouble free operation till date, this EC phenomenon is addressed and mitigated at TAPS-1&2.

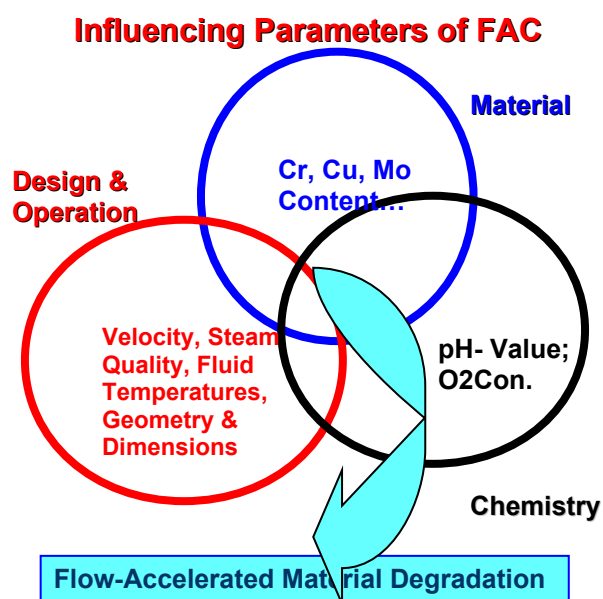


2.7 Systematic Corrosion monitoring programme exists at TAPS-1&2 and is being followed scrupulously and documented. So far no on-line failures have been experienced in these systems vulnerable to EC. Subsequent paragraphs indicates the inspection methodology being formulated and followed at TAPS to detect Single Phase corrosion (FAC) degradation in both primary and secondary Cycle High Energy System piping. The alternate inspection Methodology developed and implemented by TAPS to detect the material loss adjacent to the weld root is covered in detail. This paper describes the inspection methodology being followed at TAPS-1&2 in detecting the degradation due to FAC in High Energy System piping Components.

3.0 FLOW ACCELERATED/ASSISTED CORROSION (FAC):

3.1 FAC is a flow-accelerated increase in the corrosion rate of the material; increase of mass transfer under high flow or high turbulent condition. The phenomenon of FAC is a process where the protective layer on Carbon Steel dissolves in a stream of flowing water, two-phase mixture or wet steam. FAC is an electrochemical corrosion process dependent on various influential factors. These are (1) Trace Element Content (2) Geometry (3) Temperature (4) PH (5) Fluid Velocity and (6) Dissolved Oxygen content.

Fig.4. Influencing parameters of FAC



5.0 FAC-MANAGEMENT:

5.1 Wall thinning in steel piping due to flow-accelerated corrosion FAC has resulted in pipe ruptures in high-energy systems, resulting in forced unit outages and posing great concern for personnel and equipment safety. The rate of metal loss depends upon many parameters including water chemistry, hydrodynamics, and material composition. Systems frequently affected include feed water, heater drain, and extraction steam. Carbon steel piping components that carry wet steam are especially susceptible to flow-accelerated corrosion.

5.2 TAPS has identified Single-Phase FAC phenomenon in early '90s and inspection methodology was established to detect, monitor and assess the components conditions vulnerable to this type of degradation mechanism. However, the monitoring was being done only in limited areas in identified components vulnerable to EC/FAC. Subsequent to pipe rupture incident that took place in one of the overseas NPP, Surry Pressurized water Reactor (PWR) in the year 1986, the surveillance programmes of TAPS-1&2 were enhanced. In addition to these, various applicable code cases² and USNRC Generic Letter² on EC issue were taken into consideration for formulating surveillance programme.

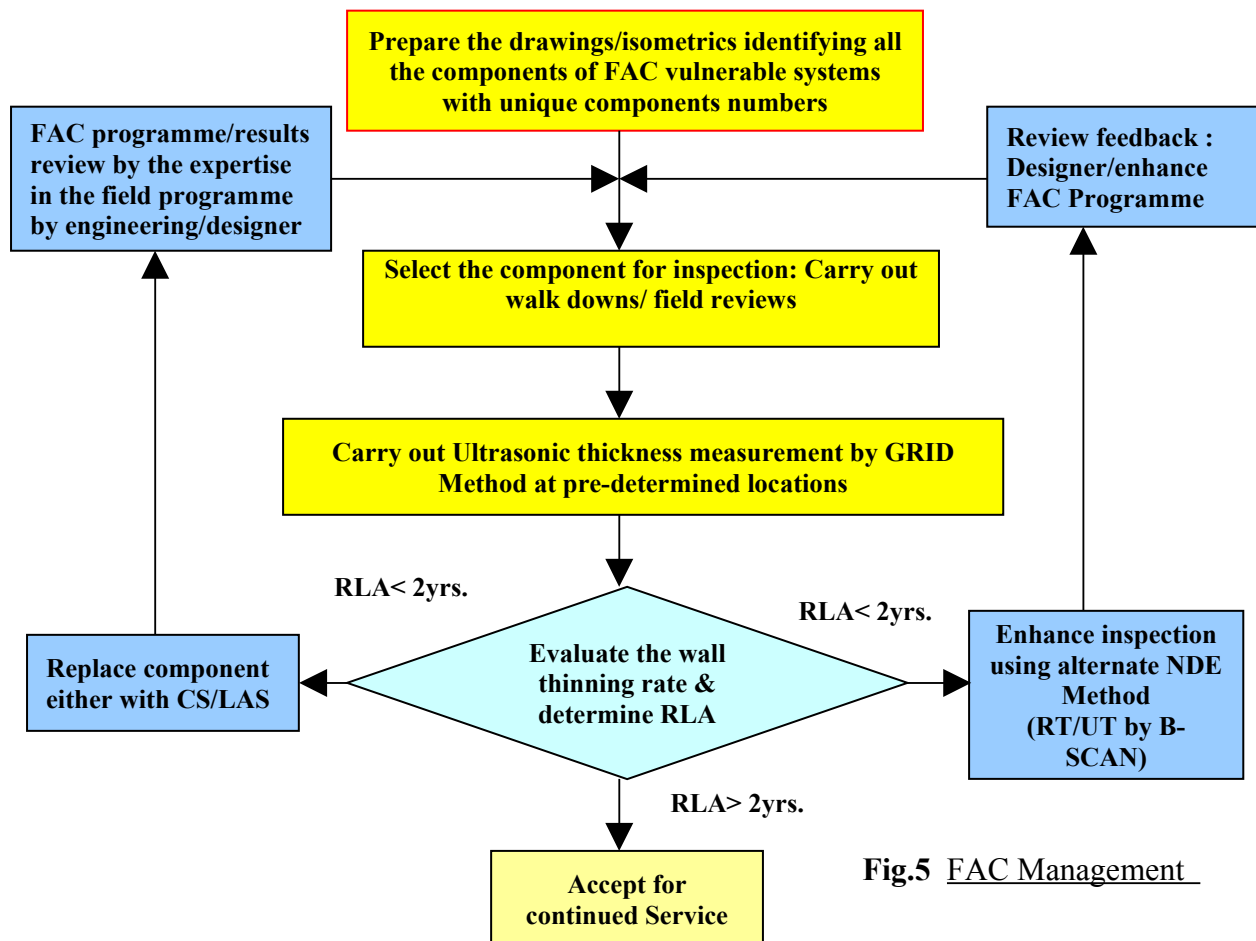


Fig.5 FAC Management

5.5. The systems vulnerable to single-phase FAC are given in As part of plant surveillance programme the primary system piping, also termed as conventional system piping are being examined by various NDE methods. The systems included are (a) Turbine Extraction system piping (b) Feed Water Drain lines (Cascade) (c) Condensate system (d) Feed Water System. The examinations of these components were being done to assess the condition with respect to

Erosion-Corrosion (EC) degradation mechanism and inspection programmes were formulated based on the feedback received time to time from overseas BWRs & EPRI study reports.

- 5.4 Based on the feed back received from overseas reactors (PWRs/BWRs) and experience from in-house operating units of NPCIL, the inspection/surveillance programmes have been enhanced to improve the detectability of degradation.
- 5.5 The areas vulnerable to FAC are different in BWRs compared to other Indian PHWRs (Pressurized Heavy water Reactors) and PWRs due to the differences in water chemistry. BWRs maintain oxygenated water chemistry with pH neutral & Dissolved Oxygen controlled in feed water is about 50ppb. TAPS-1&2 maintains 17ppb of dissolved oxygen content in condensate & feed water system. As indicated in the previous paragraphs Dissolved Oxygen (DO) is one of the influential parameters responsible for FAC. Studies have shown that 1ppb and above of DO is sufficient to mitigate FAC. In case of BWRs, DO can not be increased significantly as it affects primary system piping (welds) made of Austenitic Stainless Steels grade 304/316, which are susceptible to Stress Corrosion Cracking (SCC). Intergranular Stress Corrosion Cracking (IGSCC) is one of the generic phenomenon of BWRs.
- 5.6 The FAC programme is established from the operating practical experience of past four decades and coupled with the world wide nuclear industry experience. These programmes are made by conducting plant walk downs and physically verifying the lay out conditions. FAC monitoring programme undergoes a comprehensive review at corporate level. Corporate Guidelines exists to detect, monitor and mitigate FAC degradation mechanism in systematic manner. The corrosion monitoring is implemented as per the established programme vis-à-vis procedures. The results are evaluated by the design group to establish the Remaining Life Assessment (RLA). The feedback with regard to FAC findings, evaluation and reviews from one operating power plant is communicated to all other NPPs for strengthening the implementation FAC programmes.

6.0 INSPECTION METHODOLOGY:

- 6.1 The most common method for assessing the piping component's condition is by Ultrasonic thickness measurement by thickness gauging instrument which provides quantitative results. Ultrasonic thickness measurement was being carried out at TAPS-1&2 for the past three and half decades by "band method" (the present method: Grid method) till the year 2006. In this method the selected component thickness measured by scanning the entire area of the component. The minimum and maximum thickness values were being documented for future reference.
- 6.2 One of the drawback in this system is repeatability of measurement would be more difficult & hence condition monitoring will not be possible. **Table-1** gives the list of high energy systems covered in conventional systems and nuclear systems under FAC monitoring. Flow Accelerated Corrosion is one of the degradation mechanism related to these high-energy piping systems which are typically defined as those operating at temperature above 200°F (93°C) or/and pressure above 250Psig (176Kpa). Studies have shown that the single-phase FAC peaks at about 140°C (284°F) and therefore emphasis is given more to those systems which falls under this category and having MOC as carbon steel.

Table-1: Systems vulnerable to FAC

System Description	Design Pressure (Kg/cm ²)	Design Temperature (°C)	Piping Size	MOC
Main Steam Supply system	87.9	302	14"NB	ASTM A 106Gr.B/ 234Gr. WPB
Condensate & Feed water System (up to Primary Feed Pumps)	35/3.5	149/65	8"NB/10"NB/ 12"NB/16"NB/ 20"NB/30"NB	ASTM A 106Gr.B/ 234Gr. WPB
Condensate & Feed water System (beyond Primary Feed Pumps)	130	218	3"NB/6"NB/ 12"NB	ASTM A 106Gr.B/ 234Gr. WPB
Feed water Heater Drains & Vent system	22.8/8.8/3.5	232/171/149	6"NB/8"NB/ 10"NB/12"NB	ASTM A 106Gr.B/ 234Gr. WPB
Turbine Steam Extraction systems	22.8/8.8/3.5	232/176/149	4"NB/6"NB/ 8"NB/10"NB/ 12"NB/24"NB	ASTM A 335 Gr.P22/ 234Gr. WP22

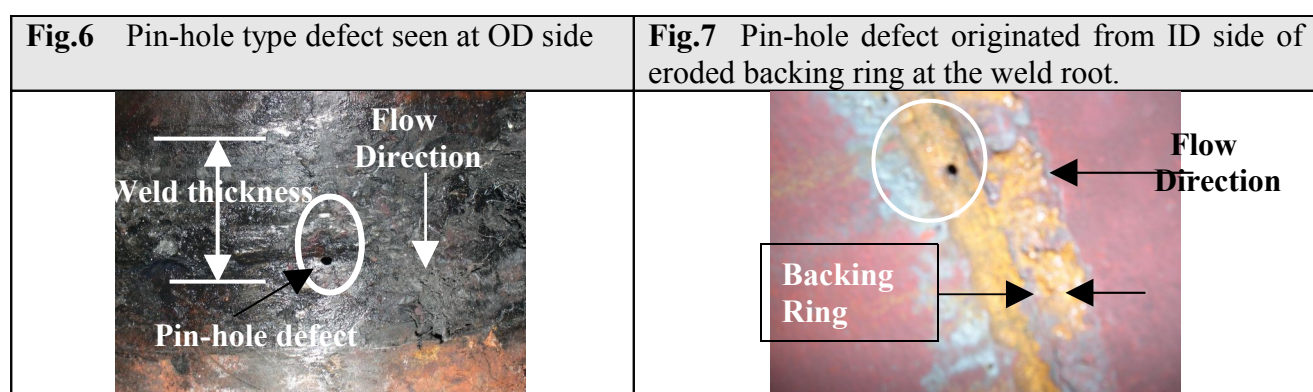
- 6.3 As per the inspection procedure, thickness measurement is carried out at pre-determined locations at grid intersection points. The grid spacing is also defined based on the size of component, ranging from 30mm up to 100mmNB pipe size; 50mm for 150-500NB and 100mm grid size for larger dia. piping components. Ultrasonic thickness measurement is generally done with calibrated instruments having probe size of 10mmØ; 5MHz frequency. The measurement starts from the weld following the flow direction axially and clock-wise direction circumferentially, to cover the full component. This is the standard established inspection methodology followed by all NPPs.
- 6.4 As the piping components are covered with either conventional/metallic mirror type of insulation, thickness measurement is possible after its removal. With the help of Grid mapping it is possible to monitor component's thickness at the location to the extent practical. Therefore, grid marking is done with **high temperature** marker pens which remain permanent & visible even after period of service. The grid measurement method is well established procedure and enhanced inspection need to be performed if reduction in thickness observed is more than the acceptable value, by close grid measurement depending upon the size of component.
- 6.5 In addition to the use of calibrated instruments and systematic measurement methods, the personnel performing inspection also must be qualified & certified in Ultrasonic Testing (UT) and in addition preferably in Visual Testing (VT) is an advantage. As the field observations are most important for enhancing/modification of the inspection programmes, hence it would be prudent that the personnel must possess valid qualifications in these inspection techniques. This inspection methodology is adopted by TAPS-1&2 since 2005 to detect monitor the condition of piping components vulnerable to single-phase FAC.

7.0 OPERATING EXPERIENCE FEEDBACK:

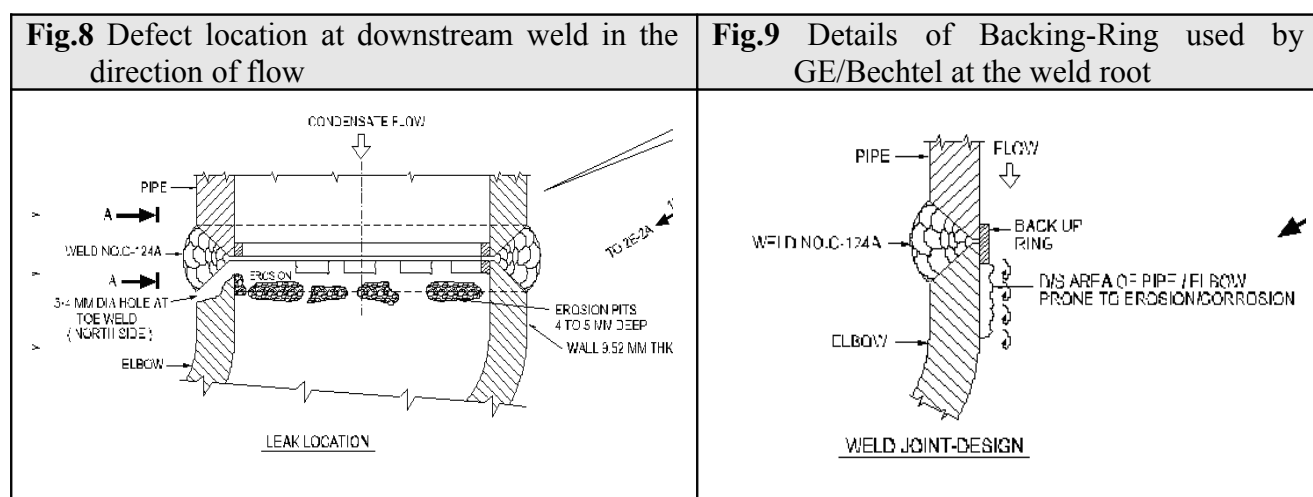
- 7.1 One of the component in condensate feed water system developed pin-hole leak at/adjacent to downstream of weld toe while the unit was at full power operation of 160MWe. This component is located at down stream of Low pressure Feed Water Heater. **Table-2** gives the component details. Detail failure analysis has been performed by the in-house expertise and flow turbulence/disturbance due to eroded backing ring at weld root is identified to be the root cause of failure. Various NDE methods were utilized to establish the detection capability of such degradation mechanism.

Table-2: Failed component details

Description	Details
Component	90° LR Elbow
Component Location	Down stream of LP heater.
Size	12"NB; Sch. Thickness 0.375" (9.52mm)
Design Pr. & Temperature	35 Kg/cm ² /149°C
Operating Pressure & Temperature	28 Kg/cm ² /102°C
Service	Condensate & feed water system
Material of Construction (MOC)	Carbon Steel ASTM-A-234 Gr.WPB
Defect location & size	@6'o clock position INTRADOS; 2mmØ



7.2 As per the GE's design, GE/Bechtel's welding procedure all the weld joints of condensate & feed water system are followed with back-up rings at the root (refer **Fig.8& 9** for details). This backing ring is of split-flat type and of similar material as that of the base material. It is fitted with spacers (knock-off pins/fusion nubs).



7.3 Conventional ultrasonic thickness gauging would miss to detect this type of degradation due to various factors such as (a) defect is at the weld toe (b) probe placement is not feasible at such location due to weld crown (c) measurement location may not be within the grid intersection point. Therefore, a comprehensive review of various inspection methodologies was carried out including (a) Ultrasonic testing of weld joint by conventional flaw detection technique and (b) Radiography testing of weld.

8.0 ALTERNATE INSPECTION METHOD – RADIOGRAPHY TESTING:

- 8.1 **Ultrasonic Thickness Gauging:** Ultrasonic thickness gauging is one of identified method to detect the degradation caused by FAC mechanism. Therefore, Ultrasonic thickness gauging of removed elbow was carried out as per standard FAC grid marking with thickness tester (Model No. DM-4) and also with through-paint thickness tester (Model: Cygnus-4). The measured thickness at all locations and values supports visual examination of eroded portion.
- 8.2 **At weld toe and 1 ½” either side of Weld:** The defect observed was at the weld toe and hence trails have been made whether degradation can be identified with conventional UT techniques of the material just adjacent to weld toe. The probe generally used for UT thickness measurement is of 10mmø normal beam probe. Reduction in thickness **could not be** detected with the conventional UT thickness measurement. In view of these observations, thickness measurement at the weld toe was measured with smaller diameter probe with grid spacing of 10 mm x 10 mm. The available minimum size probe diameter is 6mmø and thickness at 3 mm away from the weld toe only could be measured. No meaningful results obtained by this experiment.

From the above study it can be inferred that Suitable Ultrasonic thickness testers may have to be used with different size of probes to detect the degradation adjacent to the weld toe. It requires a detailed study on full-scale mock-up facility before applying in the field measurements.

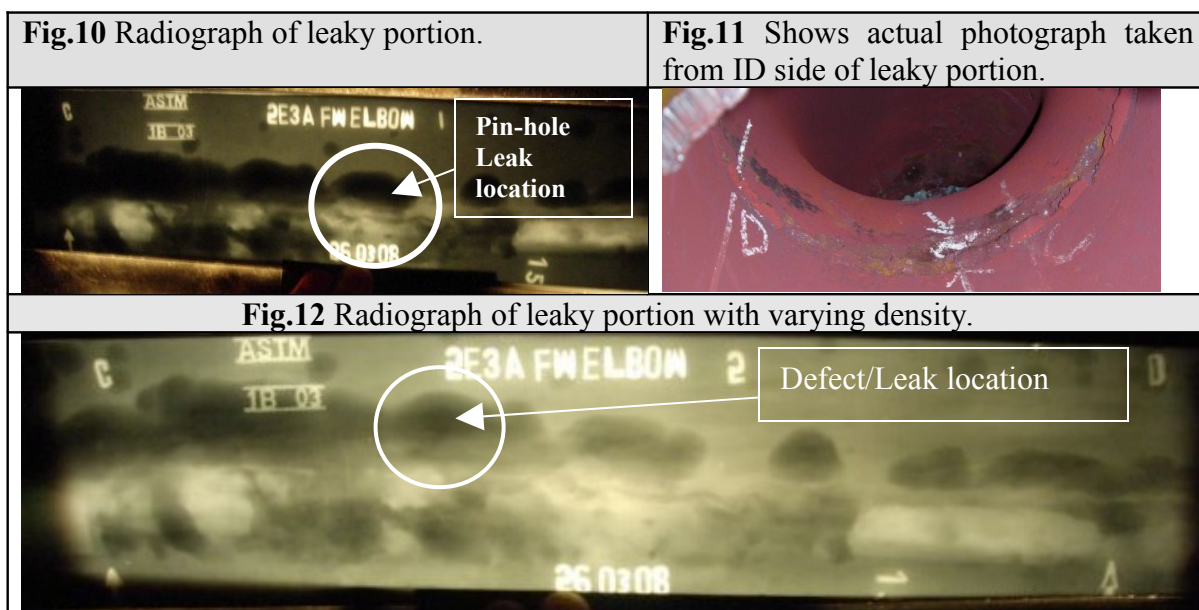
8.3 Ultrasonic Examination- using angle beam technique (as per In-Service Inspection procedure):

The reduction in thickness was noticed at the weld root as well as adjacent to the root. Therefore, an experiment was also done with angle beam ultrasonic examination technique to check whether this technique can detect the degradation or not. This has been performed as some of the weld joints were being covered in in-service inspection of Class-2 system components, as per ASME B&PV Code, Section-XI. Ultrasonic Examination was carried out with 2.25MHz with 45° and 60° angle beam probes. UFD equipment ESM-2 was used. No meaningful results could be obtained with 60° angle beam probe. Indication amplitude of 50% of reference was observed from 3 o'clock to 7 o'clock position with 45° angle beam probe. But with this data magnitude of erosion can not be established.

*From the above observations it can be inferred that the conventional ultrasonic examination (as is followed during in-service inspections) with angle beam technique **can not detect** this type of degradation.*

8.4 Radiography Testing- An alternative volumetric examination to detect material loss/ material wastage:

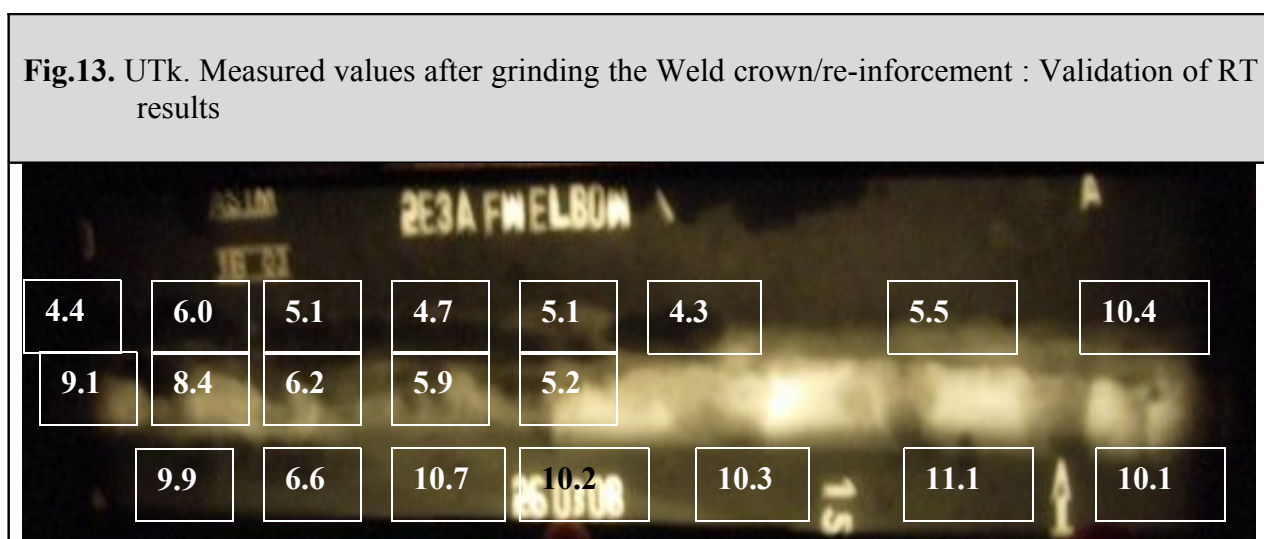
- 8.4.1 Some of the overseas nuclear power plants have indicated in their FAC detection & monitoring programmes that Radiography Testing (RT) can be one of the NDT methods that can be used to detect the degradation. Therefore, an experiment was made to correlate the data vis-à-vis visual observations. In radiography testing, change in density would give qualitatively about the condition of piping component (ID) and weld condition at & adjacent root. Radiographs were exposed at varying densities. From the review of radiographs it can be interpreted the material loss at the root & also at adjacent to the weld root. Fig.10 to Fig.11 shows the radiographs and actual photographs for comparison purpose.



8.4.2 Radiography testing of base material was also taken up to study the erosion pattern. The erosion could be identified and are compared with respect to the visual examination observations. The density of films at weld varies from 2.0 to 3.0 and it was observed that the indications are interpreted with a reasonable confidence level at an average optical density of 2.0.

9.0 Validation of RT Observations-by Ultrasonic Thickness Gauging after “GRINDING” the weld crown portion:

9.1 Erosion was noticed at the weld centerline as well as at the weld toe from ID. Thickness measurement at weld toe **could not** be carried out due to the presence of weld crown/reinforcement. To facilitate UT thickness gauging on weld and weld toe, some portion of the weld was ground flush with the parent metal at OD. Thickness measurement at a span of 25 mm was carried out and the results are as follows:



9.2 Thickness measurement was carried out with DM-4 thickness tester. After grinding, thickness could be measured at weld centre and weld toe successfully. These values are comparable and co-related with the observations made in the RT (Density variation due to material loss).

From the above experiments and study it can be inferred that after carrying out Radiography Testing (RT) the thickness reduction indication areas have to be further examined by “Ultrasonic Thickness Measurement” after suitably grinding the affected areas/locations (weld crown portion/re-enforcement). The above study has demonstrated these aspects and this methodology would give sufficient confidence level to assess the component’s degradation.

10.0 ENHANCED INSPECTION TECHNIQUES:

10.1 In addition to the above, B-Scan facility has been successfully utilized in detecting the material loss of carbon steel piping components. This technique is being used once the area of concern is detected & identified by either RT and/or ultrasonic thickness gauging. Further scanning the area with closed grid spacing, with UT instrument having B-Scan facility is an added advantage to monitor the component condition for fit-to-service evaluation. Some of the components were monitored with this enhanced UT technique and could detect the component degradation effectively. This technique will be employed in critical areas in future inspections.

Fig.15 B-Scan technique for corrosion mapping

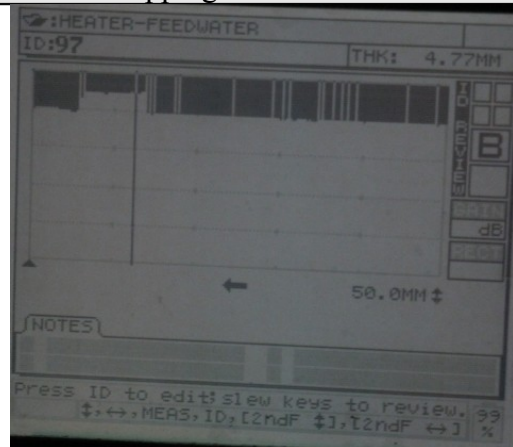


Fig.16 RT Calibration reference with known material loss data (20%; 40%; 60%; 80% & 100%)



11.0 REPAIR, REPLACEMENT AND PRE-SERVICE INSPECTION (PSI):

The component to be replaced should also under go detailed thickness measurement for base-line data. At location it is also required to examine the connected piping components visually at upstream and down stream to assess the general condition of the components. Based on the detailed study and failure analysis, root cause of defect was established as “erosion of backing rings-creates further turbulence at down stream piping component” resulted in such defects. Therefore, it has been decided that future replacements of piping and fittings in condensate and feed water system will be replaced ***without backing rings*** at the weld root. Therefore if the backing ring is eliminated, no flow turbulence would take place thus no erosion of piping component, eliminates the root cause. In order to eliminate the flow disturbance/ change flow

pattern at the root, especially in the fittings, the welding procedure also has been revised by incorporating root pass welding with GTAW process.

12.0 FUTURE COURSE OF ACTIONS-SURVEILLANCE, INSPECTION & TESTING:

12.1 In view of the generic phenomenon as detailed above, all the piping components in condensate & feed water system are having weld configuration as explained above have been identified in both the units. **Priority** has been given for those components which are **not isolable** during unit operation. These components have been selected for detailed examination during scheduled unit outages using inspection methods such as UT thickness gauging and RT.

12.2 Based on the radiography result and difference in optical density, thickness measurement has been employed specifically at the suspected portion after grinding the weld to co-relate radiography results. Subsequently, replacement of some of the components has also been taken up based on evaluation. The above inspection methodology has been worked out by in-house expertise and is being followed scrupulously.

13.0 CONCLUSION:

13.1 Backing rings have been used by GE/Bechtel in Condensate Feed water system (other than condensate pump suction) as well as in primary feed water heaters vents & condensate drain lines. Due to the presence of backing ring, flow induced eddies are formed causing erosion of backing ring from the weld and also erosion at the weld toe. Therefore, RT of vulnerable areas proved to be beneficial in identifying the material loss qualitatively and subsequently confirmed by UTG. **Preference** has been given to weld joints which are **non-isolable**.

13.2 Use of backing rings **has been eliminated**, instead GTAW process has been incorporated for better weld quality at the root to eliminate flow disturbances, thus material loss by erosion, one of the influential factors of FAC.

13.3 Conventional ultrasonic thickness measurement **can not detect** this type of degradation mechanism of root defects/material loss at the root/weld toe. UT Technique has been studied/developed & an alternate NDE method/procedure has established on full-scale mock up facility.

13.4 Ultrasonic thickness measurement using angle beam probes also **does not give meaningful results** as the thickness loss is not uniform and the defect is having very rough surface.

13.5 Radiography testing would give qualitative results of material degradations with reasonable confidence level. However, it may not be possible to estimate the thickness reduction exactly. To establish this, a sample Radiography of known thickness block with "Flat Bottom Holes" (with diameter Ø12mm and a depth of 2mm, 4mm, 6mm, 8mm and through hole representing 20%, 40%, 60%, 80% and 100% of base material wall thickness) has been done to compare the material loss.

13.6 Erosion adjacent to backing ring is a new phenomenon found at TAPS -1&2 which is **not detectable** by **existing FAC programme**. However, the detectability of this degradation mechanism has been established, enhanced and implemented successfully at TAPS-1&2 with a combination of RT, UTG and UTG with B-SCAN facility.

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