SOLUTIONS EVOLVED TO OVERCOME VARIOUS CHALLENGES IN THE DESIGN OF PIPING SYSTEMS FOR CRITICAL FACILITY

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ABSTRACT

In India, a low power Critical Facility has been installed and successfully commissioned at Bhabha Atomic Research Centre as a part of the over-all technology development program for thorium utilization in power production. Piping systems connecting various equipments to the reactor were required to be designed to take care of all kinds of loadings on the systems. Space constraints within reactor cavity, parallel running layouts outside reactor cavity and connection with components made of low strength aluminum material; all these factors posed major challenges in the design of these systems. Results of preliminary analytical exercises revealed the problems in fulfilling ASME codal requirements for a few of the layouts. This paper details the solutions evolved to overcome various challenges in the design of piping systems. This paper, with the help of a few case studies, also demonstrates that how the solutions have been evolved and how the same helped in tackling the various problems in the codal design of piping systems of the Critical Facility.

INTRODUCTION

Critical Facility has been installed and successfully commissioned at Bhabha Atomic Research Centre as part of the over-all technology development program for thorium utilization in power production aimed at achieving all-round capability in the entire thorium cycle. This facility will greatly contribute in the understanding and validation of the calculational models and nuclear data used in the design of thorium based Advanced Heavy Water Reactor. The Facility has been designed with the aim to carry out study of different core lattices based on various fuel types, moderator materials and reactivity control devices. This paper deals with the various challenges required to overcome in the design of piping system of this facility. It describes in details how solutions have been evolved to overcome various challenges in this effort. This has been demonstrated with the help of two typical layouts for which problems were observed during codal qualifications.

SYSTEM DESCRIPTION

The piping systems of critical facility connect various Dump Tanks, Freezer Driers, N_2 Gas Tank, Gas Heater etc to the reactor tank. Based on the layout arrangements and connectivity to equipment, the piping systems have been divided into following major loops under two distinct segments viz. within the reactor cavity and outside the reactor cavity in the following manner:

(a) Piping within Reactor Cavity
   (1) Heavy Water Line connecting reactor tank bottom to Embedded Part (EP),
   (2) Heavy Water Line connecting reactor tank to EP,
   (3) N_2 Gas line connecting reactor tank to square box and EP

(b) Piping outside Reactor Cavity
   (1) Line connecting EP End (outside Reactor Cavity) to Moderator Pump Suction and Dump Tanks 1, 2 & 3
   (2) Lines connecting EP End (outside Reactor Cavity) to Freezer Dryers 1 & 2 and Air Drier Package Units
   (3) Lines connecting EP End (outside Reactor Cavity) to Dump Tanks 1, 2 & 3 and subsequently to Gas Heater

MATHEMATICAL MODELLING OF THE LOOP

The piping systems both within reactor cavity and outside reactor cavity have been segregated in different loops based on anchor locations. Mathematical modeling has been carried out using piping analysis software CAESAR-II [1]. Within reactor cavity, Heavy Water lines and N_2 gas lines connecting reactor tank to Embedded Parts (EP) were modeled. Outside reactor cavity, the lines connecting the reactor cavity to moderator pump suction, Dump tanks, Freezer Dryers, Air Drier packages, gas heater & N_2 blowers have been modeled. The mathematical modeling has been carried out with the following considerations:

(1) Design Pressure & Temperature considered for N_2 Gas lines are 2 Kg/cm^2 & 80^{o}C within reactor vault and 3 Kg /cm^2 & 70^{o}C outside vault respectively.

(2) Design Pressure & Temperature taken for Heavy Water lines are 2 Kg/cm^2 & 80^{o}C within reactor vault and 5 Kg /cm^2 & 80^{o}C outside vault respectively.

(3) The Ambient temperature considered is 21 ^{o}C.

(4) The piping has been considered anchored at respective equipment locations.

METHOD OF ANALYSIS

The piping systems of the critical facility need to be designed to withstand various loadings including operating basis earthquake (OBE) as per ASME Section-III, Subsection NC [2]. The loadings have been categorized under the following three service levels:

(1) Design Conditions: weight, pressure and other sustained mechanical loads
(2) Level A: thermal expansion loadings
(3) Level B: weight, pressure, other sustained mechanical loads, seismic load (OBE)

Detailed Analyses have been carried out using piping analysis software CAESAR-II [1]. The stresses due to these loadings have been limited within the allowable limits as per the design code provisions [2] in the following manner:

Consideration of Design Condition

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of Eq.1:

$$S_{SL} = B_1\,(PD_o / 2t_n) + B_2\,(M_A / Z) \leq 1.5S_h \qquad (1)$$

Where

B_1 & B_2 - primary stress indices for the specific product under investigation,
P - Internal design pressure, D_o is outside diameter,
t_n - nominal wall thickness,
M_A - resultant moment due to weight and other sustained loads,
Z - section modulus and
S_h - basic material allowable stress at design temperature.

Consideration of Normal Operating (Level-A) Condition

As per code [2], Service Loadings for which Level-A service limits are designated, the requirements of Eq.2 must be met. The effects of thermal expansion must meet the requirements of Eq.2 as follows:

$$S_E = (iM_C / Z) \leq S_A \qquad (2)$$

Where

M_C - range of resultant moments due to thermal expansion,
i - stress intensification factor,
S_A - allowable stress range for expansion stresses [2], given by Eq.3:

$$S_A = f\,(1.25\,S_c + 0.25\,S_h) \qquad (3)$$

Where

S_c - basic material allowable stress at minimum (cold) temperature and
f - Stress range reduction factor for cyclic conditions for total number N of full temperature cycles over total number of years of expected service period

Consideration of Upset (Level-B) Condition

As per code++ [2], the effect of loadings for which Level-B Service Limits are designated, must meet the requirements of Eq.4:

$$S_{OL} = B_1\,(P_{max}D_o / 2t_n) + B_2\,([M_A + M_B] / Z) \leq 1.8S_h \qquad (4)$$

Where

P_{max} - peak pressure,
M_B - resultant moment loading on cross section due to non-reversing dynamic loads;
S_y - material yield strength and
S_h - allowable stress respectively for temperature consistent with loading under consideration

++ **A**s per code version 2001 and onwards, the earthquake loading has been considered as reversing dynamic loads for which code permits higher allowable stress ($2S_A$) with use of Eq.11a. Results of present exercises have been limited to the Eq.9 limit (1.8 S_h which is on conservative side). This is as per pre-2001 versions of the code where earthquake was treated as non-reversing loading and was kept under occasional loads.

RESULTS AND DISCUSSION

The discussion on two typical layouts which posed major challenges in the design of piping systems are described below. For each case, the preliminary results obtained, the challenges observed in meeting codal requirements and the step-by-step methodology evolved to overcome the same is described in details.

Loop-1

This is heavy water line connecting EP End (outside Reactor Cavity) to Moderator Pump Suction and Dump Tanks 1, 2 & 3 (Fig. 1). The line size varies from 50 NB to 100 NB in different parts of the loop. The results showed that stresses exceeding allowable limits for Service Level-A at a few bends locations adjacent to the Dump Tanks with maximum stress equals 3.98 times of allowable at 1710 (Fig. 1).

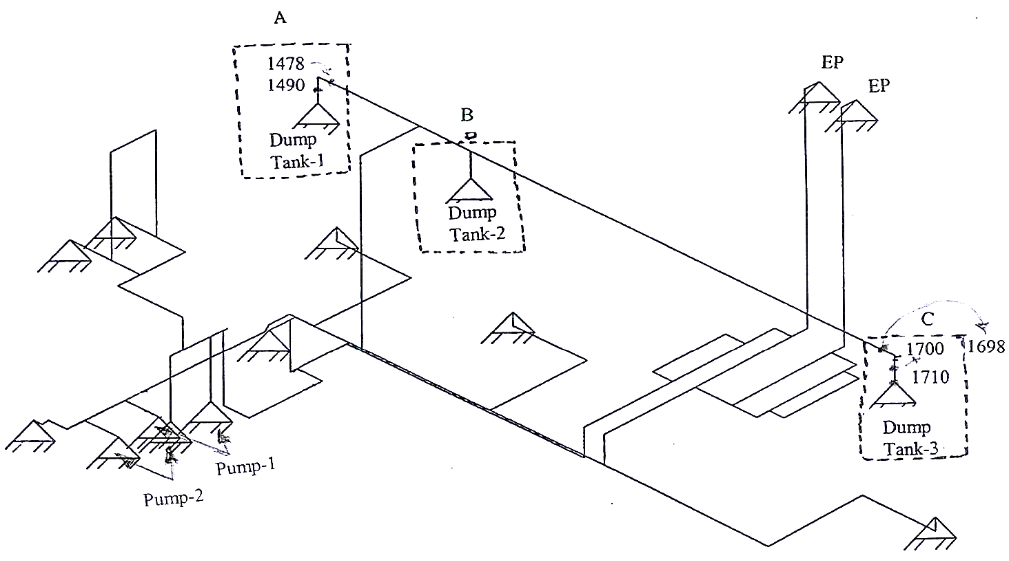

Fig. 1: Sketch Showing the High Stress Zones on Original Layout of Loop-1
(For better clarity, Supporting arrangements are not shown)

Results of the Detailed Investigation

Detailed Investigations revealed that the main reason for observed high stress was the axial displacement due to the thermal expansion of approximately 12 meters long 50 NB line. This line connects the nozzles of Dump Tanks 1,2 & 3 through 224 mm long pipe between bend and flanged valve (Figs. 1&2)

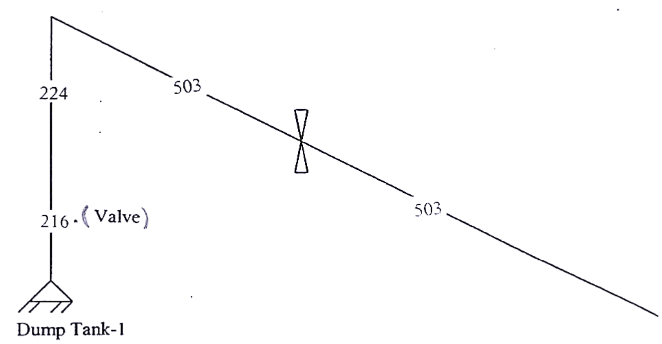

Fig. 2: Details "A" (Fig. 1) Showing Length of Piping near Nozzle Location Connecting Dump Tank-1

Exercises to Arrive at the Feasible Supporting Arrangements

A few alternative supporting arrangements were evolved to control the stresses. Discussion with the site revealed that due to site constraints, installation of the evolved supports at the site locations will not be feasible. Thus layout change emerged as inevitable option.

Exercises for Layout Modification

The feasible layout change options have been explored. The optimized solution emerged was inclusion of extra pipe lengths to add flexibility. Addition of horizontal distance of 405 mm (Fig. 3) was not enough as the maximum stress was still exceeding allowable limit by 51%. Further increase in length of the pipe from 224 mm (Fig. 2) to 399 mm (Fig. 3) brought thermal stresses well within the code allowable limits (Table 1).

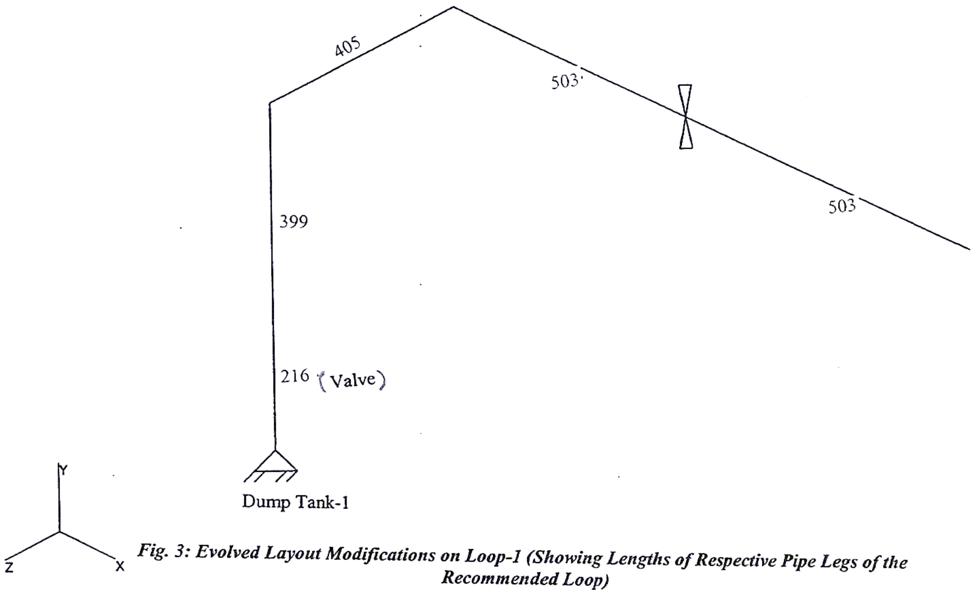

Fig. 3: Evolved Layout Modifications on Loop-1 (Showing Lengths of Respective Pipe Legs of the Recommended Loop)

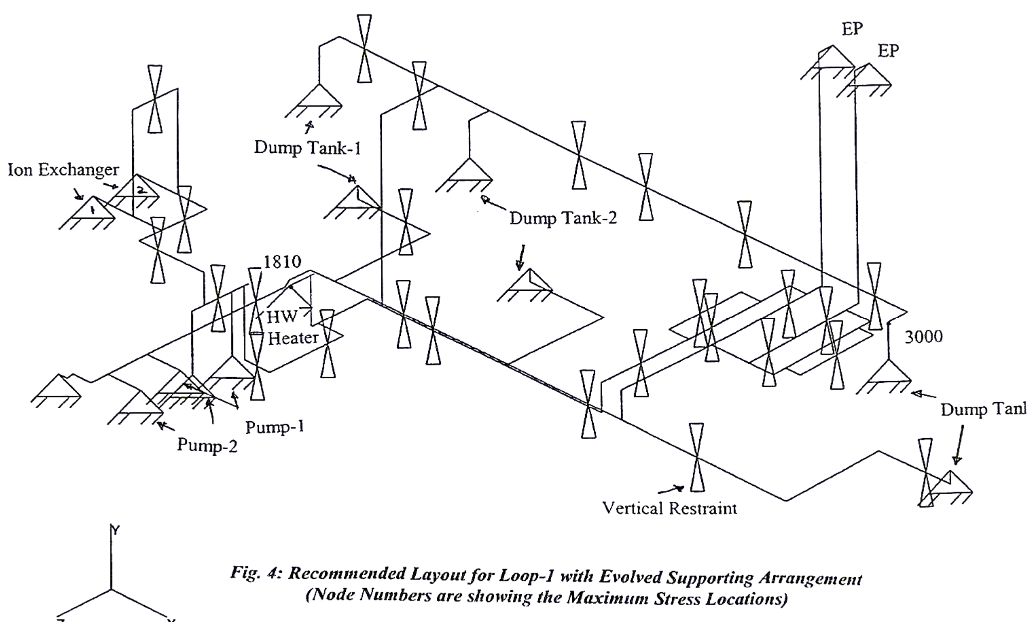

Fig. 4: Recommended Layout for Loop-1 with Evolved Supporting Arrangement (Node Numbers are showing the Maximum Stress Locations)

Finalization of Supporting Arrangements

Further the seismic qualification was carried out with incorporation of minimum required number of seismic supports as shown in Fig. 4. A typical spectrum used for seismic qualification is shown in Fig. 5. In consultations with site, all supporting arrangements were located at the available EP locations at the site. With the evolved supporting arrangements, the loop was qualified for Design condition, Level-A and Level-B service loading conditions. The stresses at various locations are found to be well within code permissible limits (Table 1).

Table 1: Results for the Modified Layout for Loop-1 (with evolved supporting arrangements)

Load Case No.	Loading Condition	Node No. (Fig.6)	Maximum Stress (Kgf/mm^2)	Allowable Stress (Kgf/mm^2)	Maximum stress as % of allowable
1.	Design Condition	1810	2.941	17.612	17%
2.	Level-A	600	21.29	29.24*	73%
3.	Level-B	1210	10.59	21.13	50%

* Code allowable stress for eq.11 as per NC-3653.2 [2]

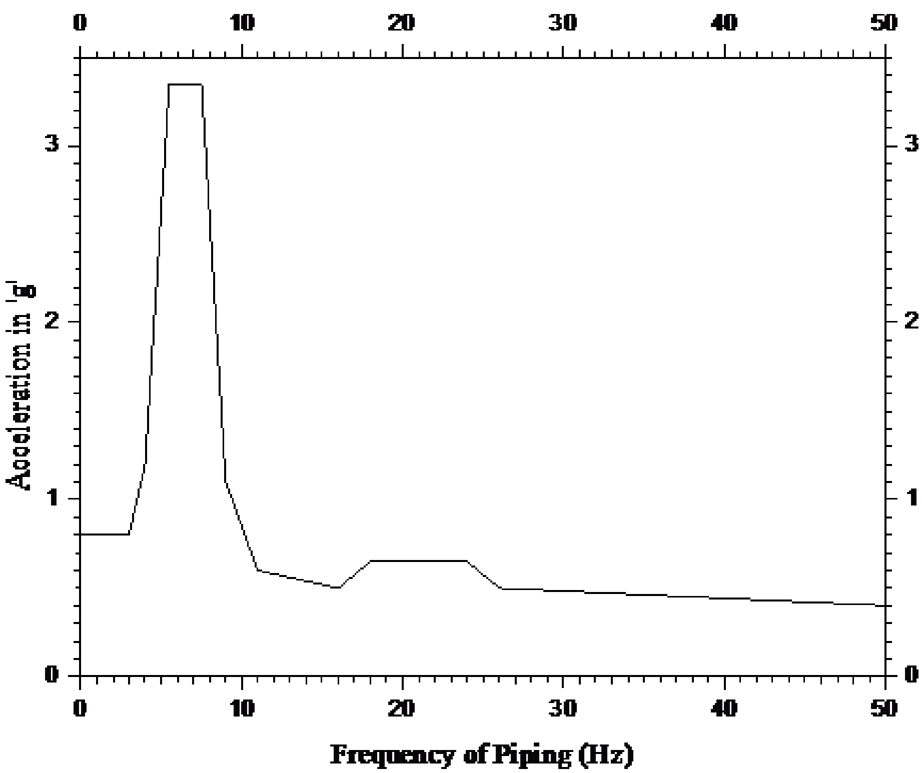

Fig. 5: A Typical Spectrum in Horizontal Direction at the Top of the Reactor Cavity (EL. 108.07 M)

Loop-2

This 100 NB heavy water line located within reactor cavity connects the reactor tank bottom to EP. In this loop a small length, fabricated integral with the reactor tank, is made of aluminum. Based on the preliminary exercises, following challenging aspects were observed:

(1) The load at the nozzle connecting reactor tank (node no. 10, Fig.6) was high.

(2) The stress at adjacent bend (node no. 20) was exceeding the allowable limits.

(3) The line between node nos. 10 to 50 is made of aluminum. The problem observed in codal qualification was due to lower allowable limits of aluminum [3].

(4) Since it is integral part of the reactor tank, option of layout change was ruled out.

(5) Space constraint further ruled out option of incorporation of any support on loop.

Methodology Evolved to Tackle the Above Challenging Situation

After elaborate discussions with the site, the only feasible option emerged was provision of a bellow just after flange where aluminum pipe connects to stainless steel pipe (i.e. after node no. 50, Fig.5). Exercises were performed to finalize a suitable bellow [4] which will help in reduction of the

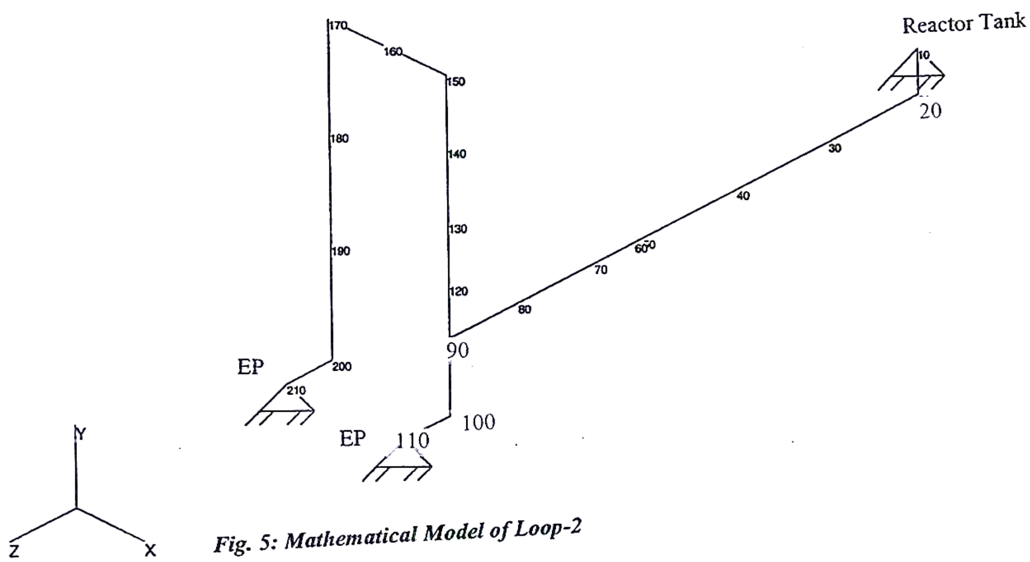

Fig. 5: Mathematical Model of Loop-2

loads on the nozzle (at node no. 10) to the maximum. Loads could be further reduced with provision of two clamp supports on either ends of the bellow (Fig. 6), without compromising the flexibility of the system. The results with final recommended scenario (Table 2) showed that the stresses for all the service conditions are well within code allowable limits. Though the aluminum material is not permitted in Class-2 piping, this portion has been qualified as Class-3 piping using the provision of ASME Section-III subsection ND [3].

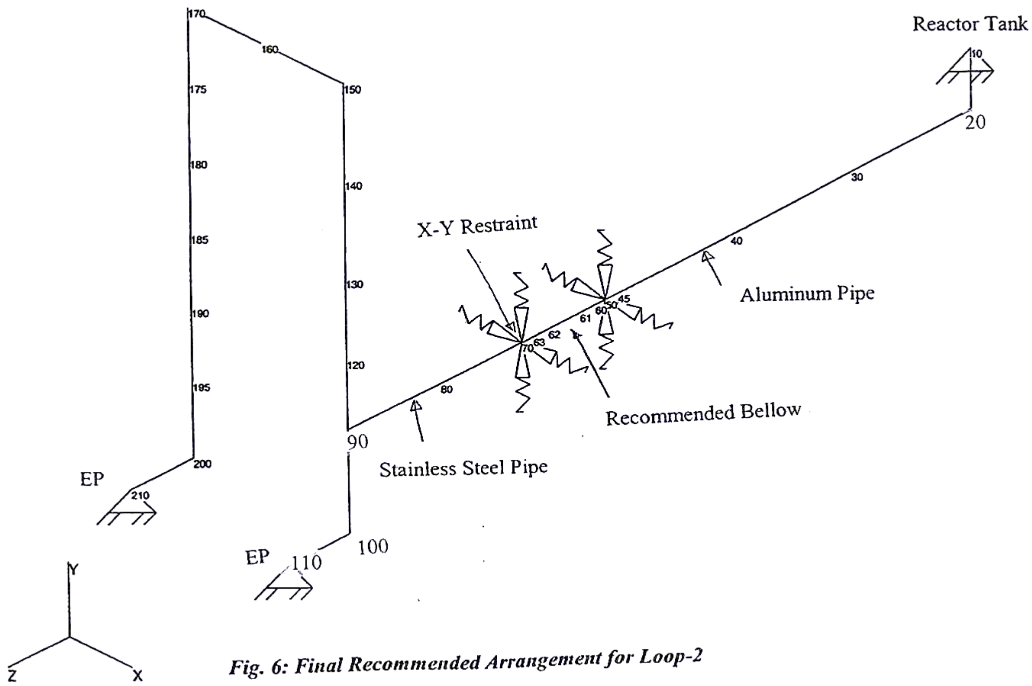

Fig. 6: Final Recommended Arrangement for Loop-2

Table-2: Results for Loop-2 with provision of recommended bellow

Load Case No.	Loading Condition	Node No. (Fig.1)	Maximum Stress (Kgf/mm^2)	Allowable Stress (Kgf/mm^2)	Maximum stress as % of allowable
1.	Design Condition	20	0.47	1.68**	28%
		110	0.73	17.61	4%
2.	Level-A	90	0.87	17.61	5%
		20	0.14	1.68**	8%
3.	Level-B	20	0.57	2.02**	28%
		100	1.68	21.13	8%

** showing stress value on aluminum portion of the piping loop.

CONCLUSIONS

The challenges in the design of piping systems of the critical facility and the step-by-step solutions evolved to overcome the challenges are presented in the form of two typical case studies in this paper. Based on the outcome of the exercises presented for typical two cases in this paper, the following conclusions can be drawn:

(i) Problems were observed in Level-A qualification of Loop-1. Site feasible solution was evolved in the form of optimized layout modifications.

(ii) In Loop-2, stresses were high on the aluminum pipe. In absence of feasibility of any other option, a bellow was recommended at the flange joint.

This paper demonstrates that how engineering solutions can be evolved despite several site constraints.

REFERENCES

(1) Piping Analysis Software CAESAR-II version 4.20
(2) Boiler and Pressure Vessel Code ASME Section-III, Subsection NC
(3) Boiler and Pressure Vessel Code ASME Section-III, Subsection ND
(4) Flexonics/Pathway Bellows Expansion Joint Catalogue Database