Root Cause Analysis of Indications of Tube-to-Tubesheet Welds Rev. 1

1. Introduction
As a result of tube-to-tubesheet weld, the indications detected by high pressure Helium leak test for #2A and #2B RSG were more than those detected by low pressure Helium leak test for conventional SG. Therefore MHI performed a root cause analysis of these indications in order to achieve better welds and Helium leak test result of #3A and #3B RSG.

2. Contents
The contents of this report is listed below,

a) Helium leak test results for #2A and #2B RSG
b) Root cause analysis
c) Investigation of the location of indications on the tube-to-tubesheet weld
d) Comparison between high pressure and low pressure leak test
e) Conclusion

3. Helium leak test results for #2A and #2B RSG
   Official examination results are shown in Table-1a. Table-1a shows the Number of indications per each test and the rate of indication which is within a round bracket (%).

Table-1a. Helium leak test results for #2A and #2B RSG
MHI performed the low pressure and high pressure Helium Leak Test for #2B RSG.

4. Root Cause Analysis

Root cause analysis steps was performed as follows,

1. Listed potential factors of root cause and make a Factor Tree Analysis (FTA) chart (See Attachment-1)
2. Investigated each factor. Further investigations were performed for some specific factors (Cleaning, Shielding gas, Welder, Welding machine: See attachment-2, 3, 4)
3. Evaluated the investigation results for each factor.

Potential factors of root cause were listed in the FTA chart (Attachment-1).

At first, MHI checked the nature and characteristic of indications which were detected by Helium leak test including the sniffer check and PT.
Pin hole is a pass way of air or gas in weld pool, which is made in the final stage of solidification of weld metal and remained as a hole. There are many origins or resources of air and gas, such as air enclosed within a mating surface of tube OD and tubesheet hole ID, gases derived from contamination adhered on weld groove and fumed by weld heat, argon gas used as a shielding gas migrated into weld pool and come out during solidification. Potential sources of air and gas are listed below. These potential sources are shown in FTA chart (Attachment-1) as potential factors of root cause.
These potential factors of root cause were investigated and/or compared between SONGS and other past/existing projects. And these results of investigation are evaluated and described in FTA chart. Some investigations for some potential factors of root cause are conducted and described in the supplemental sheets as attachment-2, 3, 4. As a conclusion, there is no clear difference or evidence that shows [ ].

According to the investigation, [ ].

### 5. Investigation of the location of indications on the tube-to-tubesheet weld

The investigation regarding to the location of indications on the weld was conducted. Each tube-to-tubesheet weld joint is divided into 4 areas (A, B, C and D) for the investigation of the location of indications (See Fig.3). The result of its investigation is shown in Table-2 and Fig.4. [ ].
Table 2. The number of indications as for the location

Fig. 3. Welding sequence and divided area

Fig. 4. Rate of indications as for the location
This welding is performed with [   ] degree rotation by GTAW process (Machine). Tip of tungsten electrode aims at the boundary between tube and tubesheet. (See Fig.3) Welding starts from [   ], welding ends at [   ].

During welding, weld pool contains some amount of air or gas. Potential sources of air and gas are described in paragraph 4. As progression of welding, most of the cases, air or gas is released from the surface of weld pool or from a slight gap between tube and tubesheet.

When welding goes [   ].

According to Table-2 and Fig.4, [   ]. Therefore, [   ].

For direct corrective action to reduce the number of indications, there is two layer welding with groove and filler metal applied in the conventional heat exchangers, [   ].
6. Comparison between high pressure and low pressure leak test

Leak test sensitivity between high pressure and low pressure were compared. The result of this comparison is as follows and is already submitted to SCE as a letter “MHI Position for Helium Leak Test”.

1. Leak detectability by High-pressure test is much higher than Low-pressure test.
2. Estimated number of leaking welds for conventional SG by Low-pressure test is [ ], which is a reasonable number. Generation of indication, or tube-to-tubesheet weld quality, of SONGS RSGs are similar to the past [R]SGs.
3. Low pressure Helium Leak Test has still enough confidence level to assure leak tightness for hydrostatic test in accordance with MHI’s long experience.
4. According to the investigation results of other sections and above, the weld quality in #2A and 2B RSG are the same as conventional SGs, [ ].

7. Conclusion

1. Indications detected by Helium leak test and PT are [ ].
2. There is no clear difference or evidence that shows [ ].
3. Cleaning and welding process controls for tube-to-tubesheet weld were performed adequately. The extent of adequacy as for the control of cleaning and welding for SONGS is equal to or better than that for other past/existing project.
4. Most of the indications were existed at [ ]. This is the nature and the characteristic of this type of tube-to-tubesheet welding
5. From the comparison between high pressure and low pressure leak test, generation of indication, or tube-to-tubesheet weld quality, of SONGS RSGs are similar to the past [R]SGs.
6. Best achievable improvement of the welding process was studied. [ ].
Factor Tree Analysis Chart for root cause of indications on tube-to-tubesheet weld
Factor Tree Analysis Chart for root cause of defects on tube-to-tubesheet weld (2/2)
Table-3. Investigation of Cleaning Sequence/Procedure as for tube-to-tubesheet weld
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<th>Table-4-a. Dew Point Temp. of Argon at welding machine in [    ]</th>
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Table-5-a. Number of Indications per [ ] in #2A RSG.

Table-5-b. Number of Indications per [ ] in #2A RSG.

Fig.5-a. Rate of Indications per [ ] in #2A RSG.

Fig.5-b. Rate of Indications per [ ] in #2A RSG.
Welding Map [ ] for #2A RSG

Fig.6. Welding Map [ ] for #2A RSG
Welding Map [ ] for #2A RSG
Table-6-a. Number of Indications per [ ] in #2B RSG.

Table-6-b. Number of Indications per [ ] in #2B RSG.

Fig.8-a. Rate of Indications per [ ] in #2B RSG.

Fig.8-b. Rate of Indications per [ ] in #2B RSG.
Welding Map [ ] for #2B RSG

Fig.9. Welding Map [ ] for #2B RSG
Welding Map [ ] for #2B RSG

Fig.10. Welding Map [ ] for #2B RSG
Table-7-a. Number of Indications per [ ] for #2A & #2B RSG.

Table-7-b. Number of Indications per [ ] for #2A & #2B RSG.

Fig.11-a. Rate of Indications per [ ] for #2A & #2B RSG.

Fig.11-b. Rate of Indications per [ ] for #2A & #2B RSG.