Nuclear Power Plants Secondary Circuit Piping

Wall-Thinning Management in China

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Abstract. Research and field feedbacks showed that nuclear power plants secondary circuit steam and water piping are more sensitive than that of fuel plant to the attack of flow-accelerated corrosion (FAC). FAC, Liquid droplet impingement or cavitation erosion will cause secondary circuit piping local wall-thinning in NPPs. Without effective management, the wall-thinning in those high energy piping will cause leakage or pipe rupture during nuclear power plant operation, more seriously cause unplanned shut down, injured and fatality, or heavy economic losses. This paper briefly introduces the history, development and state of the art of secondary circuit piping wall-thinning management in China NPPs. Then, the effectiveness of inspection grid size selecting was analyzed in detail based on field feedbacks. EPRI recommendatory inspection grid, JSME code recommendatory grid and plant specific inspection grid were compared and the detection probabilities of local wall-thinning were estimated. Then, the development and application of NPPs Secondary Circuit Piping Wall Thickness Management Information System, developed, operated and maintained by our team, was briefly introduced and the statistical analysis results of 11 PWR units were shared. It was conclude that the long term, systemic, effective wall-thinning management strategy of high energy piping was very important to the safety and economic operation of NPPs. Furthermore, take into account the actual situation of China nuclear power plants, some advice and suggestion on developing effective nuclear power plant secondary circuit steam and water piping wall-thinning management system are put forward from code development, design and manufacture, operation management, pipeline and locations selection, inspection method selection and application, thickness measurement result evaluation, residual life predication and decision making, feedbacks usage, personnel training and etc.

Keywords: Piping, Wall-thinning, Nuclear Power Plants
1. **Introduction**

Since 1980s, secondary circuit piping wall-thinning incidents happened in nuclear power plants (NPPs) worldwide. Particularly Surry 2 and Mihama 3 accidents resulted from flow-accelerated corrosion (FAC), unplanned outage, huge fatalities and economic loss pushed whole industry to pay more attention on the wall-thinning problem. The following political shock even impacted the development of nuclear power industry. Continuous efforts, both on researches and practices, are put to build a systematic and effective method to control and mitigate the wall-thinning of secondary steam and water piping.

In fact, secondary circuit piping wall-thinning is the result of metal material loss of pipes which induced not only by FAC, but also other mechanical and electronic-chemical mechanisms, such as erosion, cavitation and liquid droplet impingement and so on. The consequence of wall-thinning is leaking or breaking of pipes, which leads to incidents or accidents.

2. **Management development in China**

2.1. **Before 2004 (Mihama 3 accidents)**

For China, before 2004, the management method of secondary piping mainly referred to technical supervision codes for metal in thermal plants. But the statistic data from Qinshan Phase 1 NPP (PWR) showed that by this method FAC sensitive pipe lines and locations cannot be selected effectively, as well as cannot be inspected pertinently. It’s too simple and not applicable for NPPs to make enough management because of the big difference of steam quality between nuclear and thermal power plants. The lower the steam quality, the easier FAC occurring. Without accurate selection and classification of sensitive pipe lines and locations, numerous inspections and replacements after failure are needed.

2.2. **After 2004 (Mihama 3 accidents)**

Based on Surry and Mihama’s experiences and under the technical support of EDF, from 2004, Daya Bay NPP (PWR) began to use BRT-CICERO™ software and related management techniques to build FAC Management Program and detailed inspection schedule and made secondary circuit steam and water pipe wall-thinning management as a part of plant ageing management. However, piping breaking events induced by FAC still occur because of some sensitive pipe lines which international feedbacks and experiences indicated not taking into account.

2006, After long time monitoring and investigation, Qinshan Phase 3 (CANDU) build BOP Pipe Wall Thickness Supervision Program which governed 13 steam and water pipe lines selected from both in and outside experiences and feedbacks.
2010, Tianwan NPP (VVER) completed the improvement of Conventional Island (CI) Metal Supervision Program which embodied domestic small bore pipes feedbacks. A primary management system of secondary piping was established.

From 2011, State NPP Service Company (SNPSC) is supporting Qinshan Phase 2 (PWR) to make CI Steam and Water Pipe Supervision Program and build a long term, systemic, effective wall-thinning management strategy.

For regulations, Chinese National Energy Administration and National Nuclear Safety Administration are formulating technical requirements and codes of secondary wall-thinning management. SNPSC also takes part in this job.

3. Application of thickness measurement (TM) records
SNPSC (former Nuclear Industry Non-destructive Testing Centre) as a technical service supplier has more than 20 years’ experiences on non-destructive testing of NPPs, which also include piping TM. SNPSC has been collecting a huge number of TM records which include 11 PWR units of all domestic in-operation NPPs.

Industry research and feedbacks indicate that only software is not enough for all secondary piping management (see figure 1). Expert judgements and operation experiences and feedbacks and related analyses are definitely essential for the efficiency of management activities. Therefore, SNPSC analyse these TM records as most direct field experiences and mainly apply the results to three aspects: forming engineering experiences and feedbacks, evaluating monitoring and inspection, building database for failure mechanisms research and information exchange and sharing.

*FIG 1. Classification of Secondary Piping with/without software management*
3.1. Engineering Experiences

Statistical analysis of 386 wall-thinning records of 11 units and 82 outages is carried out on large bore pipe and small bore pipe respectively. The results are shown in figure 2 and 3. It is shown that for large bore pipe, the most suspicious pipe lines are extraction lines, MSR lines and feedwater heater lines and the most dangerous locations are elbow and downstream straight pipe, over 80% wall-thinning events occurring at this area. One experience not shown here but should mentioned is that even stainless steel pipe occurring wall-thinning. It indicates that FAC is not the only cause of wall-thinning. Hence, other mechanisms which affect stainless steel or other high Cr content material should not be neglected.

To small bore pipes, the components are always made by carbon steel and much vulnerable in wet steam and water with high temperature and pressure. MSR lines, main feedwater lines and main steam drain lines are most sensitive lines. Elbow and downstream of valve are most sensitive locations. Periodical inspection on sensitive lines and repair by stainless steel components after detecting severe wall-thinning is a good management strategy which is justified by field engineering practices of Chinese NPPs.

FIG. 2. Large Bore (D≥50mm) Pipe Statistical Results
3.2. Inspection Grid Size

To monitor the selected sensitive pipe lines and components, ultrasonic TM is a fundamental activity. The effectiveness of TM is heavily affected by the grid size. Different Guidelines (such as JSME\textsuperscript{[1]} and EPRI\textsuperscript{[2]}) give different grid sizes, meantime some plant specific grid size are used. Here, three kinds of grids (shown in Table I) are compared with 32 wall-thinning records as benchmarking data. The probability of a localized wall-thinning be detected can be defined as the ratio of thinning area to grid area.

Benchmarking results list in Table II. From table II, we can see that, the bigger the grid size the more the risk. JSME code grid would miss most local thinning and the Chinese plant specific grid would miss least. It indicates that maybe the Japanese grid is too large to achieve enough effectiveness of inspection. Also Chinese plant’s grid may be too small and cost more inspection resource.

![Diagram of Pipelines](image1)

![Diagram of Components](image2)

\textit{FIG. 3. Small Bore (D<50mm) Pipe Statistical Results}

<table>
<thead>
<tr>
<th></th>
<th>JSME code\textsuperscript{[1]}</th>
<th>EPRI Guideline\textsuperscript{[2]}</th>
<th>A Chinese NPP</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>D\leq140 mm</td>
<td>D&gt;140 mm</td>
<td>D\leq100 mm</td>
</tr>
<tr>
<td>Circumferential</td>
<td>4 points</td>
<td>8 points</td>
<td>\pi D/12</td>
</tr>
<tr>
<td></td>
<td>(25mm~150mm)</td>
<td>(&lt;50 mm)</td>
<td>(25mm~150mm)</td>
</tr>
<tr>
<td>Axial</td>
<td>3 points</td>
<td>5 points</td>
<td>\pi D/12</td>
</tr>
<tr>
<td></td>
<td>(25mm~150mm)</td>
<td>(&lt;50 mm)</td>
<td></td>
</tr>
</tbody>
</table>
### Table II. Probability of not be detected

<table>
<thead>
<tr>
<th>Component</th>
<th>Pipe Size</th>
<th>Local thinning</th>
<th>EPRI</th>
<th>JSME</th>
<th>A Chinese NPP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (mm)</td>
<td>t (mm)</td>
<td>Cir.</td>
<td>Axi.</td>
<td>Prob. (%)</td>
</tr>
<tr>
<td>Tee</td>
<td>273</td>
<td>7.1</td>
<td>60</td>
<td>100</td>
<td>16.47</td>
</tr>
<tr>
<td>Elbow</td>
<td>377</td>
<td>8.0</td>
<td>50</td>
<td>80</td>
<td>6.46</td>
</tr>
<tr>
<td>Elbow</td>
<td>377</td>
<td>8.0</td>
<td>100</td>
<td>110</td>
<td>14.29</td>
</tr>
<tr>
<td>Elbow</td>
<td>279</td>
<td>6.3</td>
<td>40</td>
<td>80</td>
<td>31.31</td>
</tr>
<tr>
<td>S.P. A. E.</td>
<td>279</td>
<td>6.3</td>
<td>40</td>
<td>80</td>
<td>31.31</td>
</tr>
<tr>
<td>Elbow</td>
<td>377</td>
<td>8.0</td>
<td>50</td>
<td>100</td>
<td>35.06</td>
</tr>
<tr>
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<td>324</td>
<td>8.0</td>
<td>50</td>
<td>80</td>
<td>2.42</td>
</tr>
<tr>
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<td>8.0</td>
<td>50</td>
<td>50</td>
<td>21.38</td>
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<tr>
<td>S.P. A. V.</td>
<td>377</td>
<td>8.0</td>
<td>100</td>
<td>150</td>
<td>9.09</td>
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<tr>
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<td>7.1</td>
<td>40</td>
<td>40</td>
<td>19.06</td>
</tr>
</tbody>
</table>

#### 3.3. Management Information System

Based on the collection and analysis of numerous TM records, engineering experiences and field feedbacks, SNPSC developed an information exchange and sharing platform on secondary wall-thinning management and research: *Secondary Circuit Wall-Thinning Research and Management Platform*. This is the first information system focused on secondary piping wall-thinning issue in China and paves a standard way to exchange and share experiences for whole industry. Now in this platform, about 400 records are included. It is not only a database, but also contains SNPSC’s analysis, advice, guidance and consultation on research, management, engineering and regulation codes. Domestic NPPs may also exchange and share new field experiences on this platform. Figure 4 gives a picture of its homepage.

![FIG 4. Homepage of Information Exchange and Sharing Platform](image-url)
4. Conclusion and Suggestion
Since only software is not enough for secondary piping wall-thinning management, a long
term, systemic and effective management strategy with full use of experiences and feedbacks
should be adopted. To fulfil this goal, a whole process from pipe lines and locations selection,
then effective inspection, then evaluation of TM results and residual lifetime prediction to
repair and replacement decision making, which governed by a secondary piping supervision
program should be established and implemented.

In China, several NPPs and technical support organizations have been taking efforts on
secondary piping wall-thinning issue and have gotten some experiences and capabilities to
handle this problem. Based on this, SNPSC is now taking part in the industry technical
guidelines formulation about this issue.

From the above analyses and experiences, it is obvious that an appropriate grid should be
chose under the consideration of safety, inspection resource, plant specific operation
condition and pipe features.

Meantime, besides FAC, other wall-thinning mechanisms cannot be neglected. Do not treat
stainless steel as invulnerable. Cr content and operation condition must be analysed carefully.
Locations with different Cr content, such as dissimilar metal welds, should be taken more
attentions. Field Cr content checking is essential for the sensitive pipe lines and suspicious
locations.

Finally, field experiences and feedbacks exchange and sharing is an efficient way to use the
information because of the similarity of secondary circuit in all NPPs. SNPSC’s information
system make a good practice on solving this problem.
References
