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Proj-704

Document Control Desk
U. S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Attention: Vanice Perin

Subject: Additional BWRVIP commitments to revise BWRVIP-139

The purpose of this memo is to provide a summary of additional revisions to BWRVIP-139 that will be made in response to NRC comments during a conference call on March 10, 2008.

The BWRVIP has previously submitted "BWRVIP-139: BWR Vessel and Internals Project, Steam Dryer Inspection and Flaw Evaluation Guidelines" for NRC review. NRC has provided Requests for Additional Information (RAIs) on these documents and BWRVIP has provided responses to these RAIs.

A conference call between BWRVIP and NRC representatives was conducted on March 10, 2008 to discuss BWRVIP responses to NRC RAIs on BWRVIP-139 (a list of participants is provided in Attachment 1). Based on this discussion, BWRVIP commits to the following actions to support NRC preparation of a Safety Evaluation on BWRVIP-139.

1. RAI No. 139-1. The BWRVIP committed to expand Section 1.0 of BWRVIP-139 to note that the final decision to install acoustic load mitigation devices at the Quad Cities 1 and 2 units was made as a result of damage incurred to relief valve actuators on the main steam lines that was attributed to acoustic resonances in the valve inlet stand pipes. Specifically, the 15th paragraph of Section 1.0 documented in the previous response to RAI 139-1 will be revised as follows (changed text is shown in bold):

    Because of differences in the valve stand pipe inlet diameters (inlet diameter determines the vortex shedding frequency) between the Quad Cities and Dresden units, the Quad Cities units are significantly more susceptible to this phenomenon

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than are the Dresden units at extended power uprate flow conditions. **In late 2005 damage to several Electromatic relief valve actuators was incurred. The damage was attributed to high vibration in the main steam lines resulting from fluctuating pressures induced by acoustic excitation in the relief valve inlet standpipes. As a consequence of the observed damage to the relief valve actuators, Exelon decided to develop and install acoustic load mitigation devices on the safety and relief valve stand pipes at both Quad Cities Units 1 and 2.** These devices were installed in early 2006 and effectively eliminated the high amplitude, high frequency pressure loading within the main steam lines and on the steam dryer.

2. RAI No. 139-6. Section 4.3 of BWRVIP-139 will be revised to incorporate the discussion of the dependency of steam dryer acoustic loading on main steam line configuration and system flows provided in the response to RAI No. 139-6. Specifically, 4.3.1 will be revised as shown below (changed text is shown in bold):

4.3.1 Reference Fluctuating Load Definition

Evaluation of the steam dryer's susceptibility to FIV is strongly tied to the assumptions regarding the fluctuating loads that the dryer experiences under normal operation. This is particularly true if an evaluation is performed to quantify stresses for a specific plant. The evaluations for the Quad Cities Unit 2 steam dryer identified that the fluctuating loads are directly related to the acoustic characteristics of the reactor dome/steam line/relief valve configurations. For the purposes of this evaluation, existing data was used to assess the fluctuating loads derived from previous measurements on instrumented dryers from three different plants. Future efforts based on industry steam dryer load definition model development activities will eventually improve the knowledge of the loads. Based on these plant data, a reference load definition was developed. It used all of the available in-plant pressure measurements from these instrumented steam dryers including measurements taken at a series of power levels up to 100% of the OLTP. The measured spectrums for several available sensors were also included. The maximum sensor readings were then plotted together to form a single overall spectrum after normalizing the data to the plant/condition steam velocities. This approach identifies possible pressure frequencies that could produce fluctuating loading on the dryer. Figure 4-1 displays the enveloping pressure spectrum based on this information. Figure 4-2 displays an enveloping response spectrum that was used as input to the 3-D finite element model that was used to determine the highest stress locations for use in defining the inspection locations.

This approach is intended to provide the general frequency content and amplitudes of the pressure loadings acting on steam dryers, based on the available instrumented dryer measurements. These measurements include examples of the SRV acoustic resonance peaks. The structural evaluation in Section 4 is intended to provide a general overview of the structural response of each of the basic dryer designs given the typical pressure loading characteristics described in Section 4.3. Accurate definition of steam dryer loading is very plant specific and is known to be dependent on the steam dryer design, the steam velocity, the plant specific geometry of local standoff piping at relief valves, and the flow field past the dryer outer hood and into the nozzles. These factors influence the frequency and magnitude of the fluctuating pressure loads on the dryer components. There are active efforts within the industry to develop plant specific load definition methodologies based on testing and analysis. Since the current inspection guidance in the report is based on an assessment of the structural characteristics of each of the basic dryer designs combined with the actual steam dryer experience observed within the industry, it is unlikely that this inspection guidance will change significantly in the future. However, as new information becomes available, it will be factored into future revisions of the report.

3. RAI No. 139-11. BWRVIP committed to discuss the recent steam dryer inspection findings (cracks on the interior of the steam dryer skirt) at the Clinton plant with Exelon to determine what (if any) additional inspections should be required in BWRVIP-139 to address these findings. In addition, BWRVIP has completed its assessment of the cracking recently observed on the interior of some curved hood dryers along their hood to base plate horizontal weld (as described in the original RAI 139-11 response). The results of these assessments are presented below:

   Cracking observed on the interior of Clinton Unit 1 steam dryer skirt

   Clinton Unit 1 received an EPU license to operate up to 120% of OLTP in 2002. Since that time the unit has been operating at 114-116 % of OLTP. Discussions with Exelon personnel indicate that during a January 2008 re-inspection of the Clinton Unit 1 steam dryer (a BWRVIP-139 inspection of the steam dryer was completed in 2006), cracking was observed on the exterior of the steam dryer skirt in the heat affected zone of fillet welds used to attach two of the six rectangular "seal plates" to the skirt interior just below the upper support ring at each seismic bracket location. The "seal plates" cover access holes used during construction to accurately locate the seismic brackets relative to the dryer supports on the vessel ID. These cracks extend from vertical welds attaching the external drain channels to the skirt to the heat affected zones of the welds attaching the seal plates to the skirt. One external crack had the appearance and characteristics of a fatigue crack and showed evidence of deposits indicating that the crack might be through wall. This crack had also been identified in the 2006 inspection. The examination indicated no apparent growth in the length of this crack between 2006 and 2008 (although the crack might have extended beyond the skirt to drain channel weld to a point behind the drain channel). The other external cracks appeared to be IGSCC in nature. The external cracks ranged in length from approximately 1 to 4 inches. Based on these findings and that the plant had increased its power output in recent years, the scope of the inspections was expanded to include the interior and exterior surfaces of the skirt base metal around all six seal plates. The internal inspection was conducted using a 'firefly" remote inspection vehicle. IGSCC cracking was observed on the interior surfaces in the heat affected zones of all six plates. The cracks were generally below and to the side of each seal plate and ranged in length from approximately 1 to 15 inches. The horizontal cracking observed on the exterior surface near the seal plate regions coincided with the interior cracks observed at three locations, which suggest that these cracks might be through-wall. IGSCC of the heat affected zone of the weld between the access hole cover and the skirt is very likely the initiating mechanism for the observed cracking in the seal plate regions. However, review of the inspection images suggest that some of these cracks might have extended by fatigue prior to 2006. The cracking was determined not to be structurally significant.

Based on this new OE, BWRVIP will add the following paragraph to Sections 5.3.2.3 and 5.3.3.3 of BWRVIP-139 (applies to slanted and curved hood designs):

> Cracking has also been observed in the heat affected zone of welds attaching seal plates to the dryer skirt below the seismic bracket locations and adjacent to vertical skirt to drain channel welds (See Figure 2-26). These vertical skirt-to-drain channel welds are already called out in BWRVIP-139 as locations requiring external inspection. This cracking is not considered structurally significant because the cracking observed to date appears to be limited and stable and thus, no additional inspections are required beyond those already specified in BWRVIP-139.

Note that reference to the inspections already specified in BWRVIP-139 will include the revisions being made to Section 5.3 as documented in the response to RAI 139-9. This includes 5.3(C), which states, "Cracks left in the "as found" condition shall be re-inspected at each subsequent scheduling refueling outage until it is demonstrated that the crack has stabilized."

Cracking observed on the interior and at the base of some curved steam dryer hoods

BWRVIP has determined that the short indications found on the interior side at the base of some curved steam dryer hoods appear to be stable based on their short length and even distribution along the weld length even after a significant operational period. Accordingly, these cracks are not considered structurally significant. Such cracking is likely to have been caused by the relief of residual stresses from initial fabrication and potentially the initial thermal expansion of the dryer. It is further expected that such cracks would become through wall and become visible on the exterior of the dryer long before they could become structurally significant. Current inspection guidance requires an external inspection at of each inner hood at the welds to the interior vertical reinforcement plates. The intersections of these vertical welds with the horizontal weld at the base of the hood are the highest stress locations along the length of the weld at the base of the hood. Accordingly, no additional inspections are required beyond those already specified in BWRVIP-139."

4. RAI No. 139-13. BWRVIP committed to review the actions taken by Exelon in evaluating and documenting the cracks identified on the interior of the dryer skirt in comparison to the flaw evaluation guidance provided in BWRVIP-139. The results of this review are provided below:

   Exelon identified cracking on the exterior of the Clinton Unit 1 steam dryer skirt below two of the seismic brackets in January 2008. Based on these observations and that the plant had increased its power output in recent years, Exelon expanded their investigation to include interior inspections of the dryer at all six "seal plate" locations. The inspections and scope expansion were consistent with the inspection guidance provided in Section 5 of BWRVIP-139 and the revisions to Section 5.2 documented in the response to RAI 139-18. Exelon conducted an evaluation of the observed cracking that was consistent with the flaw evaluation guidance provided in Section 6 of BWRVIP-139.

5. RAI No. 139-15. BWRVIP committed to provide the plant docket under which GE SIL 644-Rev 2 was submitted to NRC.

   For convenience, GEH SIL 644 Revision 2 is being provided to the NRC as part of this transmittal (Attachment 2).

6. RAI No. 139-15. BWRVIP committed to provide additional guidance in BWRVIP-139 for proactively monitoring existing plant instrumentation to detect the presence of high vibratory loading that could be the result of main steam line acoustic resonances. It was agreed that such guidance will be in the form of a

recommendation and will be designated a "Good Practice" as defined in BWRVIP-94 Rev 1. After review of existing guidance, BWRVIP has decided to add the following new Section 7.2 to the report as follows:

"7.2 Proactive Monitoring Guidance

Monitoring of steam moisture content as discussed in Section 7.1 can provide an indication of a dryer failure only after it has occurred. Proactive steps could also be considered to assess whether high acoustic loading might be present in the main steam lines that could adversely affect steam dryer integrity, however there are significant limitations to their application in practice.

Existing BWR on-line instrumentation is inadequate to provide early warning that high acoustic pressure loading might be present on the steam dryer. Such instrumentation could potentially include reactor water level ΔP and MSL venturi ΔP. Neither of these measurements is made with sufficiently high data acquisition rates to allow an assessment of fluctuating pressure levels in the main steam system. In addition, such measurements are hindered by long sensing lines and complex line manifolds between the pressure source and the measurement tap that can induce significant errors in measured pressure levels. Consequently, such measurements are not recommended as a means of identifying high acoustic pressure loading on the steam dryer.

BWRVIP considers the best approach for assessing whether high acoustic pressure loading might be present in the main steam system at the current operating power is to review maintenance and event records to determine if there is a history of the following:

- Main steam system instrumentation and small bore piping failures
- SRV and ERV actuator degradation/failures
- Out of tolerance SRV and ERV lift set points
- Observed high vibration levels of MSL components during plant walk downs

Such degradation and failure modes might be associated with high main steam line vibration that could be the result of high acoustic excitation. It is recommended that further engineering review be conducted in cases where a history of these types of failures is identified to assess the potential for high acoustic excitation. This recommendation is designated a "Good Practice" in accordance with NEI 03-08."

If you have any questions regarding the action/commitments discussed above, please contact Charles Wirtz at First Energy by telephone at 440.280.7665 or by e-mail at cjwirtz@firstenergycorp.com or Randy Stark at EPRI by telephone at 650.855.2122 or by e-mail at rstark@epri.com.

Sincerely,

Rick Libra

Rick Libra, Exelon
Chairman, BWR Vessel and Internals Project

c: BWRVIP Technical Chairs
BWRVIP EPRI Task Managers
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Attachment 1
List of Participants in
BWRVIP-NRC Conference Call on BWRVIP-139
March 10, 2008

Name	Organization
Chakrapani Basavaraju	NRC
Bob Carter	EPRI
Ganesh Cheruvenki	NRC
Ron Horn	GEH
John Hosler	EPRI
Dan Pappone	GEH
Vanice Perin	NRC
Patrick Sekerak	NRC
Tom Scarbrough	NRC
Jon Thompson	NRC
Chuck Wirtz	FENOC

BWR steam dryer integrity

SIL No. 644
Revision 2

August 30, 2006

SIL No. 644 ("BWR/3 steam dryer failure"), issued August 21, 2002, described an event at a BWR/3 that involved the failure of a steam dryer cover plate resulting in the generation of loose parts, which were ingested into a main steam line (MSL). The most likely cause of this event was identified as high cycle fatigue caused by a flow regime instability that resulted in localized high frequency pressure loadings near the MSL nozzles. SIL No. 644 Supplement 1, issued September 5, 2003, described a second steam dryer failure that occurred at the same BWR/3 approximately one year following the initial steam dryer failure. This second failure occurred at a different location with the root cause identified as high cycle fatigue resulting from low frequency pressure loading. SIL No. 644 included focused recommendations. For BWR/3-style steam dryers, it recommended monitoring steam moisture content (MC) and other reactor parameters, and for those plants operating at greater than the original licensed thermal power (OLTP), it recommended inspection of the cover plates at the next refueling outage. SIL No. 644 Supplement 1 broadened the earlier recommendations for BWR/3-style steam dryer plants and provided additional recommendations for BWR/4 and later steam dryer design plants planning to or already operating at greater than OLTP.

Following this revised guidance, inspections were performed on plants operating at OLTP, stretch uprate (5%), and extended power uprate conditions. These inspections indicate that steam dryer fatigue cracking can also occur in plants operating at OLTP. Revision 1 to SIL No. 644, issued November 9, 2004 incorporated SIL No. 644 Supplement 1 and described additional significant fatigue cracking that had been observed in steam dryer hoods and provided inspection and monitoring recommendations for all BWR plants based on these observations.

The purpose of this Revision 2 to SIL 644 is to update the monitoring guidance in Appendix D. These updates reinforce the need for continuous "real time" monitoring of plant parameters.

The SIL material is presented in its entirety with the updates to Appendix D being the only change to the previously issued Revision 1.

SIL No. 644 Revision 2 voids and supercedes SIL No. 644 Revision 1.

Discussion

Instances of fatigue cracking in the steam dryer hood region have been observed recently in several BWR plants. The cracking has led to failure of the hood and the generation of loose parts in two BWR/3 plants. Details of the cracking in these plants are described below. These observations have potential generic significance for all BWR steam dryers that will be discussed in the generic implications section below.

BWR/3-Style Dryer Observations

Lower horizontal cover plate failure occurred in a BWR/3 in 2002. In this failure, almost the entire lower horizontal cover plate came completely loose, with some large pieces falling down onto the steam separators and one piece being ingested into the main steamline and lodging in the flow restrictor. This failure was accompanied by a significant increase in moisture content, along with changes in other monitored reactor parameters. The cause of this failure was attributed to the higher fluctuating pressure loads at extended power uprate (EPU) operation. In particular, there may have been a potential resonance condition between a high frequency fluctuating pressure loading (in the 120-230 Hz range) and the natural frequency of the cover plate. Appendix A provides a more detailed description of this event.

The same BWR/3 experienced extensive through-wall cracking in the outer bank hood on the 90° side in May 2003. On the opposite side of the steam dryer (270° side), incipient cracking was observed on the inside of the outer hood cover plate. Several internal braces were detached and found on top of the steam separators. No damage was found on the inner banks of the dryer. Again, the failure was accompanied by a significant increase in moisture content. Of the other monitored reactor parameters, only the flow distribution between the individual steamlines was affected. The cause of this failure was attributed to high cycle fatigue resulting from low frequency oscillating pressure loads (<50 Hz) of higher amplitude at EPU operation and the local stress concentration introduced by the internal brackets that anchor the diagonal internal braces to the dryer hoods. Appendix B provides a more detailed description of this event.

In November 2003, a hood failure occurred in the sister unit to the BWR/3 that had experienced the previously noted failures. This unit was also operating at EPU conditions. The observed hood damage and associated root cause determination were virtually the same as the May 2003 failure described above. During the event, the moisture content exceeded the previously defined action level. However, the monitored plant parameters (primarily individual steamline flow rates) showed only subtle changes and were well within the previously defined action levels for the plant. This failure resulted in the generation of loose parts from the outer vertical hood plate. In addition, inspections during the repair outage showed fatigue cracking in the inner hood vertical braces below where the lower ends of the diagonal braces were attached. The cracking of these braces was attributed to poor fit-up of the parts during the dryer fabrication. The diagonal braces should have terminated on the vertical braces where they were butted up against the drain trough, which would have transferred the diagonal brace loads directly to the drain trough. Instead, the diagonal braces terminated on the vertical braces above the top of the drain trough and the diagonal brace loads were transmitted through the unsupported section of the vertical braces, thus overstressing the vertical braces.

In October 2003 and December 2003, inspections were made of the steam dryers of the sister units to the BWR/3s described above at another site. These units had also been operating at EPU conditions. Incipient cracking was observed on the inside of the outer hood vertical plates on each of the outer dryer banks. At one location, the cracking had grown through-wall. The cracking was also attributed to high cycle fatigue resulting from low frequency pressure loading.

In March 2004, inspections were performed of the repairs made to the BWR/3 dryer in 2003. Incipient fatigue cracks were found at the tips of the external reinforcing gussets that were added as part of the 2003 repairs. Fatigue cracks were also found in tie bars that were reinforced during the 2003 repairs. The cracking in these repairs was attributed to local stress concentration introduced by the as-installed repairs. In both cases, the local stress concentrations had not been modeled in sufficient detail in the analyses that supported the repair design. Fatigue cracks were also found in perforated plate insert modifications that were made in 2002 as part of the extended power uprate implementation. These cracks were also attributed to the displacements and stresses imposed by the dryer banks that caused the tie bar cracking.

In April 2004, inspections were made of a BWR/3-style dryer (square hood) in a BWR/4 plant in preparation for implementing an extended power uprate during the upcoming cycle. This inspection found cracking at two diametrically opposed locations on the exterior steam dam near the lifting lug. Both cracks were similar in length. The cause of the cracking was not identified. It has been postulated that the crack initiation was due to high residual stresses generated during the dryer fabrication process. The structural analysis of the steam dryer for EPU conditions did not predict these locations as highly susceptible to fatigue cracking. Two other symmetrical locations in the steam dryer that experienced the same loading conditions did not exhibit any evidence of cracking. These observations point to the likelihood of the presence of an additional contributing factor aside from the pressure loads during normal operation. Specifically, the evidence indicates that a high residual stress condition was probably developed by the original dryer fabrication welding sequence. Other "cold spring" type loading could also have been generated during the fabrication process. After the cracking developed, the residual stresses would have been relieved and the crack growth would have subsided.

BWR/5-Style Dryer Observation

In March 2004, inspection of the steam dryer at a BWR/5 revealed a fatigue crack in the hood panel to end plate weld. The hood crack occurred in the weld joint between the 1/8" curved hood and the 1/4" end plate on the second dryer bank. This particular weld location is vulnerable to fatigue cracking because of the small weld size associated with the thin 1/8" hood material. Fabrication techniques (e.g., feathering the 1/8" plate during fit-up) may further reduce the weld size. Fatigue cracking has been observed in the second bank hood-end plate weld at several other plants with the curved BWR/4-5 hood design at OLTP power levels. An undersized weld was determined to be the root cause of the cracking observed in at least two of the plants. Incorporating lessons learned from the weld cracks at the other plants, the dryer for this BWR/5 was built with an additional 1/4" fillet weld on the inside of the hood-end plate joint. This weld extended as high up in the hood as was practical for the welder to make (approximately 50") and spanned the probable initiation location for the earlier cracks. The weld crack at the subject BWR/5 occurred in the upper part of the 1/8" weld, above this reinforced section.

The weld joint between the 1/8" curved hood and the 1/4" end plate on the second dryer bank is a known high stress location for the BWR/4-5 curved hood dryer design; therefore, periodic inspection of this location was recommended by SIL No. 644 Supplement 1. The hood cracks at the other four plants occurred early in plant life, within the first three or four cycles of operation. In-plant vibration testing of one of the cracked dryers showed that the dynamic pressure oscillations were high enough that the 1/8" hood to end plate weld was vulnerable to fatigue cracking at pre-uprate power levels. The hood crack at the subject BWR/5 occurred after approximately 16 years of operation, the last nine of which were at a 5% stretch uprate power level. While power uprate operation does increase the loading on the dryer, the length of operating time at uprated power levels before the cracking was observed indicates that the weld was not grossly overstressed and that power uprate was only a secondary factor in the cracking observed at the subject BWR/5.

BWR Fleet Operating History

Steam dryer cracking has been observed throughout the BWR fleet operating history. The operating environment has a significant influence on the susceptibility of the dryer to cracking. Most of the steam dryer is located in the steam space with the lower half of the skirt immersed in reactor water at saturation temperature. These environments are highly oxidizing and increase the susceptibility to IGSCC cracking. Average steam flow velocities through the dryer vanes at rated conditions are relatively modest (2 to 4 feet per second). However, local regions near the steam outlet nozzles may be continuously exposed to steam flows in excess of 100 feet per second. Thus, there is concern for fatigue cracking resulting from flow-induced vibration and fluctuating pressure loads acting on the dryer.

In addition to the recent instances described above, steam dryer cracking has been observed in the following components at several BWRs: dryer hoods, dryer hood end plates, drain channels, support rings, skirts, tie bars, and lifting rods. These crack experiences have predominately occurred during OLTP conditions, and are briefly described below.

Dryer Hood Cracking

As discussed above, outer hood cracking has occurred recently in square hood design dryers. Additionally, other hood cracking has occurred in the BWR operating fleet. Cracking of this type was first found in BWR/2s in the inner banks. These hood cracks were attributed to high cycle fatigue. Other cracking has since been observed in other types of dryers including BWR/4s and attributed to high cycle fatigue as well. Susceptible plants were typically reinforced with weld material or plates.

Dryer End Plate Cracking

Cracking has been detected in end plates of the dryer banks at several BWRs. These cracks have been attributed to IGSCC based on the location and morphology of the cracks. These cracks have been followed over several cycles and shown to be stable when operating conditions (power levels) are not changed. Typically no repairs have been necessary.

Drain Channel Cracking

Drain channel cracking has been found in all types of BWRs. This cracking has been primarily categorized as being attributable to fatigue, although many cracks have been attributed to IGSCC. The steam dryers were originally fabricated using Type 304 stainless steel, a material susceptible to sensitization by welding processes and prone to crack initiation in the presence of cold work. Drain channel cracking has been associated with at least 17 plants. The occurrence of the cracking prompted GE to issue SIL No. 474 ("Steam Dryer Drain Channel Cracking" issued October 26, 1988) after cracks were discovered in the drain channel attachment welds during routine visual examination of dryers at several BWR/4, 5 and 6 plants. The cracks generally were through the throat of vertical welds that attach the side of the drain channel to the exterior of the 0.25-inch thick dryer skirt. The cracks were as long as 21 inches. The cracks are thought to have originated at the bottom of the drain channel where there is maximum stress in the welds. The appearance of the cracking and analysis of potential sources of stress on the welds indicate that high cycle fatigue initiated the cracks in drain channel welds. With the internal dryer inspections performed following the issuance of SIL No. 644, similar cracking has been observed in the internal drain channels of BWR/3-type steam dryers. Typically, drain channel cracks have been repaired by replacing and adding reinforcement weld material, stop-drilling the crack tip, or by replacing the drain channels.

Support Ring Cracking

Support ring cracking has been found in many BWRs. Cracking has been found in at least 19 plants, ranging from BWR/4s to BWR/6s. The cause of cracking has been IGSCC with a potential contributor being the cold working of the support ring during the fabrication process. These cracks are typically monitored for growth. To date, no repairs have been necessary since cracks have reached an arrested state.

Skirt

Skirt cracking has been found along with drain channel cracking. These cracks are either due to IGSCC or could be related to fatigue due to imposed local loads on the dryer. The cracking has also been found in the formed channel section of the dryer. The complex structural dynamic mode shapes of the dryer skirt, the stiffness added by the drain and guide channels, and residual weld stresses all contribute to the cracking observed in these components. Cracking in the dryer skirt region has been observed in plants operating at both OLTP and uprated power levels. Typically, repairs have been implemented at the time that cracking was found.

Tie Bar Cracking

Fatigue cracking has been observed in tie bars of plants operating at both OLTP and uprated power levels. In most cases, the potential for cracking is related to the cross section of the tie bar itself because the tie bar must withstand the displacements and stresses imposed by the dryer banks. Typically, repairs have been implemented at the time that cracking was found.

Lifting Rod

Several plants have exhibited damage in the lifting rods. This cracking has often been in tack welds or in lateral brackets and has been attributed to fatigue.

Other Crack Locations

Other locations have also exhibited cracking. These locations include the level screws or leveling screw welds, seismic blocks, dryer bank end plates and internal attachment welds, vertical internal hood angle brackets and bottom plates.

Generic Implications

The steam dryer is a non-safety component. However, the structural integrity of the dryer must be maintained such that the generation of loose parts is prevented during normal operation, transients, and accident events. With the exception of the significant outer hood cracking at the two BWR/3 plants, the dryer cracking observed in the BWR fleet to date is unlikely to result in the generation of loose parts provided that a periodic inspection program is in place. However, given that the steam dryers operate in an environment that is conducive to crack initiation and that many plants are pursuing power uprates and operating license extensions, further cracking in steam dryers should be anticipated. Therefore, the material condition of the dryer should be actively managed to ensure that structural integrity is maintained throughout the life of the dryer.

The experience described above has several generic implications with respect to the susceptibility of steam dryers to fatigue or IGSCC cracking.

- Fatigue cracking may result from stress concentrations inherent in the design of the dryer. The design of the BWR/3-style steam dryers with a square hood and internal braces results in maximum stresses where the internal braces attach to the outer hood. The hood crack initiation at the BWR/3s described above occurred at these high stress locations. Also, the undersized hood-to-end plate welds on the BWR/5 curved hood dryers have cracked in several plants.
- The actual dryer fabrication may have introduced stress concentrations that may lead to fatigue cracking. The poor fit-up of the diagonal and vertical braces in the BWR/3 dryer led to the cracking of the vertical braces. Feathering of the 1/8" plate during fit-up, and the corresponding reduction in weld area, was considered a contributing factor in the through-wall cracking of the hood-end plate weld in one of the BWR/5-style dryers. Residual stresses or "cold spring" introduced during the fabrication sequence may also lead to crack initiation.
- The fabrication quality for each dryer may vary from one unit to the next, even if the dryers were built by the same fabricator to the same specifications.
- The design of dryer repairs and modifications should consider the local stress concentrations that may be introduced by the modification design or installation. Repairs and modifications to the dryer should be inspected at each outage following the installation until structural integrity of the repairs and modifications can be confirmed.
- Steam dryers are susceptible to IGSCC due to the material and fabrication techniques used in the dryer construction. Weld heat affected zone material is likely to be sensitized. Many dryer assembly welds have crevice areas at the weld root, which were not sealed from the reactor environment. Cold formed 304 stainless

steel dryer parts were generally not solution annealed after forming and welding. Therefore, steam dryers are susceptible to IGSCC.

Parameter monitoring programs had been previously recommended with the intent of detecting structural degradation of the steam dryer during plant operation. The experience described above also has generic implications with respect to monitoring reactor system parameters during operation for the purposes of detecting steam dryer degradation.

- The November 2003 BWR/3 hood failure demonstrated that monitoring steam moisture content and other reactor parameters does not consistently predict imminent dryer failure nor will it preclude the generation of loose parts. Monitoring is still useful in that it does allow identification of a degraded dryer allowing appropriate action to be taken to minimize the damage to the dryer and the potential for loose parts generation.
- Monitoring the trends in parameter values may be more important than monitoring the parameter values against absolute action thresholds. An unexplained change in the trend or value of a parameter, particularly steam moisture content or the flow distribution between individual steamlines may be an indication of a breach in the dryer hood, even though the absolute value of the parameter is still within the normal experience range.
- Statistical smoothing techniques such as calculating running averages using a large quantity of samples may be necessary to eliminate the process noise and allow the changes in the trend to be identified.
- An experience base should be developed for each plant that correlates the changes in monitored parameters to changes in plant operation (rod patterns, core flow, etc.) in order to be able to distinguish the indications of a degraded dryer from normal variations that occur during the operating cycle.

Recommended Actions:

GE Nuclear Energy recommends that owners of GE BWRs consider the following:

A. For all plants:

A1. Perform a baseline visual inspection of all susceptible locations of the steam dryer within the next two scheduled refueling outages. Inspection guidelines showing the susceptible locations for each dryer type are provided in Appendix C.

a. Repeat the visual inspection of all susceptible locations of the steam dryer at least once every two refueling outages.

b. For BWR/3-style steam dryers with internal braces in the outer hood that are operating above OLTP, repeat the visual inspection of all susceptible locations of the steam dryer during every refueling outage.

c. Flaws left "as-is" should be inspected during each scheduled refueling outage until it has been demonstrated that there is no further crack growth and the flaws have stabilized.

Note: This recommendation does not supercede the inspection schedules for existing flaws for which plant-specific evaluations already exist.

d. Modifications and repairs to cracked components should be inspected during each scheduled refueling outage until the structural integrity of the modifications and repairs has been demonstrated. Once structural integrity of any modifications and repairs has been demonstrated, longer inspection intervals for these locations may be justified.

Note: This recommendation does not supercede the inspection schedules for existing modifications or repairs for which plant-specific evaluations already exist.

A2. Implement a plant parameter monitoring program that measures moisture content and other plant parameters that may be influenced by steam dryer integrity. Initial monitoring should be performed at least weekly. Monitoring guidelines are provided in Appendix D.

A3. Review drawings of the steam dryer to determine if the lower cover plates are less than 3/8 inch thick or if the attachment welds are undersized (less than the lower cover plate thickness). If this is the case, and the plant has operated above OLTP, review available visual inspection records to determine if there are any pre-existing flaws in the cover plate and/or the attachment welds.

B. In addition, for plants planning on increasing the operating power level above the OLTP or above the current established uprated power level (i.e., the plant has operated at the current power level for several cycles with no indication of steam dryer integrity issues), the recommendations presented in A (above) should be modified as follows:

B1. Perform a baseline visual inspection of the steam dryer at the outage prior to initial operation above the OLTP or current power level. Inspection guidelines for each dryer type are provided in Appendix C.

B2. Repeat the visual inspection of all susceptible locations of the steam dryer during each subsequent refueling outage. Continue the inspections at each refueling outage until at least two full operating cycles at the final uprated power level have been achieved. After two full operating cycles at the final uprated power level, repeat the visual inspection of all susceptible locations of the steam dryer at least once every two refueling outages. For BWR/3-style steam dryers with internal braces in the outer hood, repeat the visual inspection of all susceptible locations of the steam dryer during every refueling outage.

B3. Once structural integrity of any repairs and modifications has been demonstrated and any flaws left "as-is" have been shown to have stabilized at the final uprated power level, longer inspection intervals for these locations may be justified.

To receive additional information on this subject or for assistance in implementing a recommendation, please contact your local GE Energy Nuclear Representative.

This SIL pertains only to GE BWRs. The conditions under which GE Energy Nuclear issues SILs are stated in SIL No. 001 Revision 6, the provisions of which are incorporated into this SIL by reference.

Product reference

B11 — Reactor Assembly
B13 — Reactor System

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Appendix A

2002 BWR/3 Event

On June 7, 2002, while operating at approximately 113% of OLTP, the BWR/3 experienced a mismatch between the "A" and "B" reactor vessel level indication channels, a loss of approximately 12 MWt, and a reactor pressure decrease. Following the event, measurement indicated that the moisture content had increased by a factor of 10 (to a value of 0.27%). The reactor pressure decrease, reactor vessel level indication mismatch, and increase in moisture content comprised a set of concurrent indications suggesting a possible failure of the steam dryer. It was evaluated that there were no safety concerns associated with the observed conditions, and the plant continued to operate after implementing several compensatory measures (e.g., reactor water level setpoint adjustments, increased frequency of moisture content measurements).

Following the initial event, additional short duration (several minutes to ½ hour) perturbations occurred and the moisture content continued to increase. When the moisture content increased to approximately 0.7%, the power level was reduced to approximately 97% of OLTP. At this reduced power, the frequency of the plant perturbations decreased, along with the moisture content. Given the stable plant response at this lower power, the power was increased to 100% OLTP approximately one week later.

On June 30, subsequent to the power reduction to the OLTP level, a step change increase in the reactor steam dome pressure was noted. No changes in turbine control valve positions or pressure in the turbine steam chest were observed. Several additional perturbations occurred over the following week with the reactor steam dome pressure continuing to increase (to a total of 15 to 20 psi above normal conditions) along with a divergence of the measured total main steam line (MSL) flows compared to the total feedwater flow. The plant was shut down on July 12 to inspect the steam dryer.

Inspection Results:

Inspection of the steam dryer revealed that a ¼-inch stainless steel cover plate measuring approximately 120" x 15" had failed near the MSL "A" and "B" nozzles (Figure A-1). The failure of this cover plate allowed steam to bypass the dryer banks and exit through the reactor MSL nozzles, causing the observed increase in moisture content. The majority of the cover plate was found as a single piece on top of steam separators. However, a piece of the cover plate (approximately 16"x 6") had failed and was found lodged in and partially blocking the MSL "A" flow venturi contributing to the MSL flow imbalance and water level perturbations. Several smaller loose pieces (believed to have come from a startup pressure sensor bracket which may have been knocked off by the cover plate) were located at the turbine stop valve strainer basket. Minor gouges and scratches from the transport of foreign material were noted in the "A" steam nozzle cladding, the main steam piping and the MSL "A" flow venturi. All loose pieces were recovered. No collateral damage to other reactor vessel components was observed.

The cover plate was welded in place as part of the original equipment dryer assembly. No known prior repairs had been made to the cover plate. The cover plate is not connected or adjacent to the dryer modification performed at the previous outage; all flow distribution plates installed as part of the dryer modification were intact in the as-installed condition.

Metallurgical Evaluation:

Preliminary laboratory analysis has been completed. The main crack originated from the bottom side of the cover plate and propagated upward through both the plate base metal and weld metal. The transgranular, as opposed to intergranular, nature of the fracture surface and the relative lack of crack branching indicated that the failure was not caused by stress-corrosion cracking. The lack of macro and micro ductility features in and near the fracture indicated the cracking occurred over a period of time and not due to a mechanical overload. Additionally, there was no evidence that the failure was a result of an original manufacturing defect. Based on the available evidence, the most probable cause of the cover plate cracking was mechanical, high cycle fatigue.

Root Causes:

The results of the metallurgical analysis confirmed that the failure mechanism is high cycle fatigue. The cause of this high cycle fatigue is believed to be flow induced vibration. At this time there are two probable root causes of the cover plate failure:

1. Increased pressure oscillations on the steam dryer due to the increased steam flows at extended power uprate conditions, aggravated by the potential presence of a pre-existing crack in the cover plate.
2. A flow regime instability that results in localized, high cycle pressure loadings near the MSL nozzles. When the natural frequency of the installed cover plate coincides or nearly coincides with the frequency of the cyclic pressure forcing function, and the acoustic natural frequency of the steam zone, the resulting resonance or resonances can lead to high vibratory stresses and eventual high cycle fatigue failure of the cover plate.

Corrective Actions:

The cover plates on both sides of the dryer have been replaced with ½-inch continuous plates (this eliminates two intermediate welds on the original plates). The fillet weld connecting the plate to the support ring was increased to ⅜-inch and the weld to the vertical face of the dryer hood was increased to ½-inch. The plant has been returned to service with interim, enhanced monitoring of moisture content, reactor steam dome pressure, MSL flow rates and reactor water level. As an additional measure, the plant has implemented dynamic response monitoring of the MSLs to determine if higher flow induced vibration occurs as the steam flow is increased.

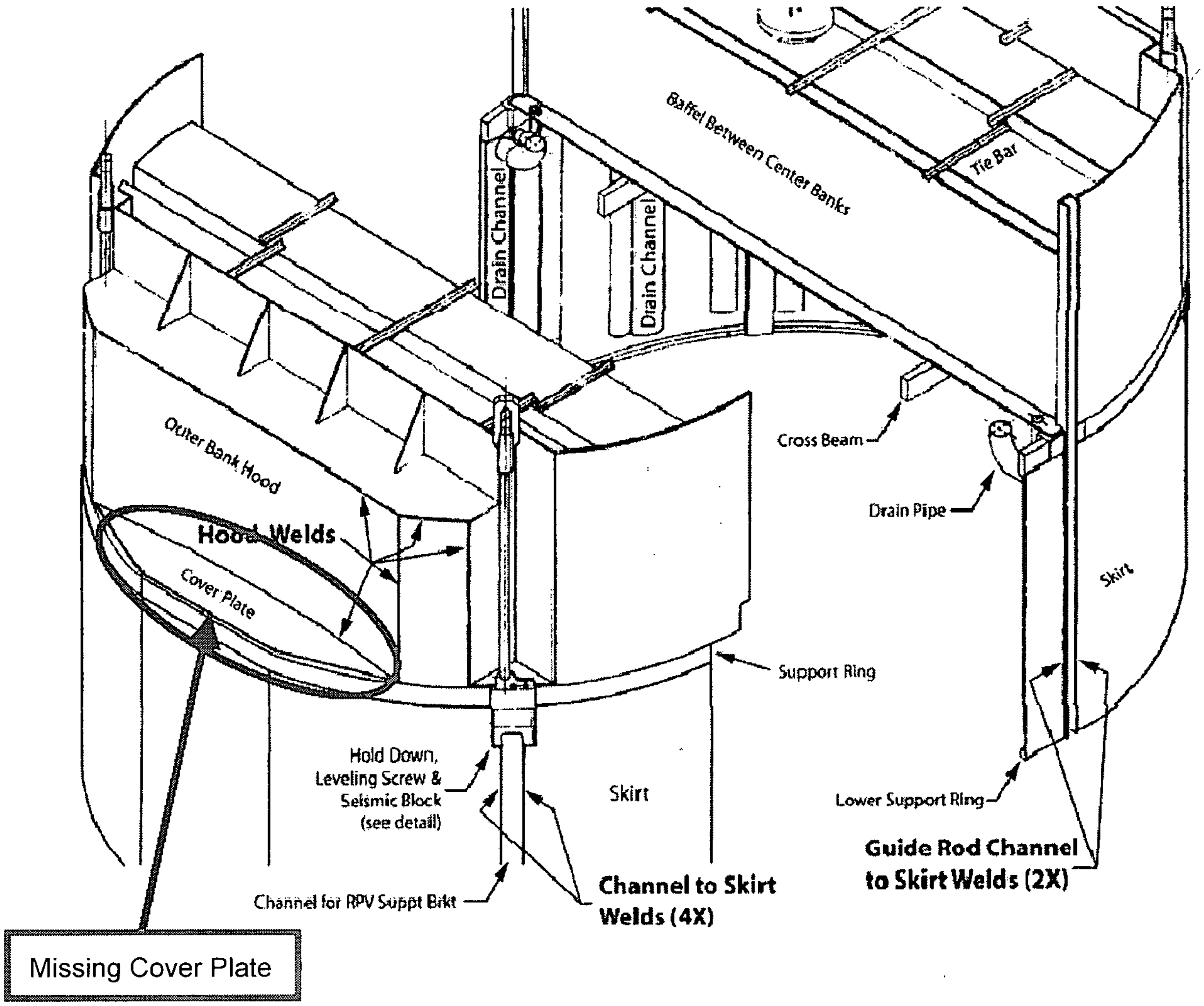


Figure A-1: Location of the 2002 Lower Cover Plate Failure

Appendix B

2003 BWR/3 Event

On April 16, 2003, with the plant operating at extended power uprate (EPU) conditions, an inadvertent opening of a pilot operated relief valve (PORV) occurred. The unit was shut down and the PORV replaced. On May 2, 2003, following return to EPU conditions, a greater than four-fold increase in the moisture content was measured. The moisture content continued to gradually increase until it exceeded a pre-determined threshold of 0.35% on May 28, 2003. The power level was reduced to pre-EPU conditions that resulted in a moisture content reduction to 0.2%. The moisture content remained steady at this value following the power reduction with no significant changes in other reactor operating parameters observed by the operators.

A detailed statistical evaluation of key plant parameters concluded that a subtle change in the MSL flows had occurred following the April 16, 2003 PORV event. Based on this information, concurrent with the moisture content increase, the utility elected to shut down the unit on June 10, 2003 and perform a steam dryer inspection.

Inspection results

A detailed visual inspection of the accessible external and internal areas of the steam dryer revealed significant steam dryer damage. The damage was most severe on the 90-degree side of the steam dryer, the side that was closest to the PORV that had opened. On the 90-degree side, a through-wall crack approximately 90 inches long and up to three inches wide was observed in the top of the outer hood cover plate and the top of the vertical hood plate (refer to Figures B-1 and B-2). Three internal braces in the outer hood were detached and one internal brace in the outer hood was severed. The detached braces were found on top of the steam separator. All detached parts were accounted for and retrieved. On the opposite side of the steam dryer (270-degree side), incipient cracking was observed on the inside of the outer hood cover plate and one vertical brace in the outer hood was cracked. No damage was found in the cover plates that had been replaced following the first steam dryer failure in 2002.

Three tie bars on top of the steam dryer connecting the steam dryer banks were also cracked. Tie bar cracking has been observed on several other steam dryers (including plants that have not implemented EPU); therefore, tie bar cracking is believed to be unrelated to the other damage noted above.

Root cause of steam dryer failure

Extensive metallurgical and analytical evaluations (e.g., detailed finite element analyses, flow induced vibration analyses, computational fluids dynamics analyses, $1/16^{th}$ scale model testing and acoustic circuit analyses) concluded that the root cause of the steam dryer failure was high cycle fatigue resulting from low frequency pressure loading. There are two potential contributing factors to the failure:

1. Continued operation for approximately 1 month following the failed cover plate in 2002 which resulted in additional stress loading on the vertical hood plate, and
2. Inadvertent opening of the PORV resulting in a decompression wave, which subjected the steam dryer to two to three times the normal pressure loading. (It is believed that there was incipient cracking in the steam dryer and the PORV event caused the cracks to open up).

The root cause identified in the first steam dryer failure was high cycle fatigue cause by high frequency pressure loading. The low frequency pressure loading was identified as the dominant cause in this failure. The low frequency pressure loading may have also been a significant contributing factor in the first failure.

Corrective Actions:

The following repairs and pre-emptive modifications were made to both the 90 and 270-degree sides of the steam dryer:

1. replaced damaged ½ inch outer hood plates with 1 inch plates
2. removed the internal brackets that attached the internal braces to the outer hood
3. added gussets at the outer vertical hood plate and cover plate junction
4. added stiffeners to the vertical welds and horizontal welds on the outer hood

The combined effect of these modifications was to increase the natural frequency of the outer hood, reduce the maximum stress by at least a factor of two, and reduce the pressure loading by reducing the magnitude of vortices in the steam flow near the MSLs.

Following the steam dryer modifications, the unit was returned to service on June 29, 2003.

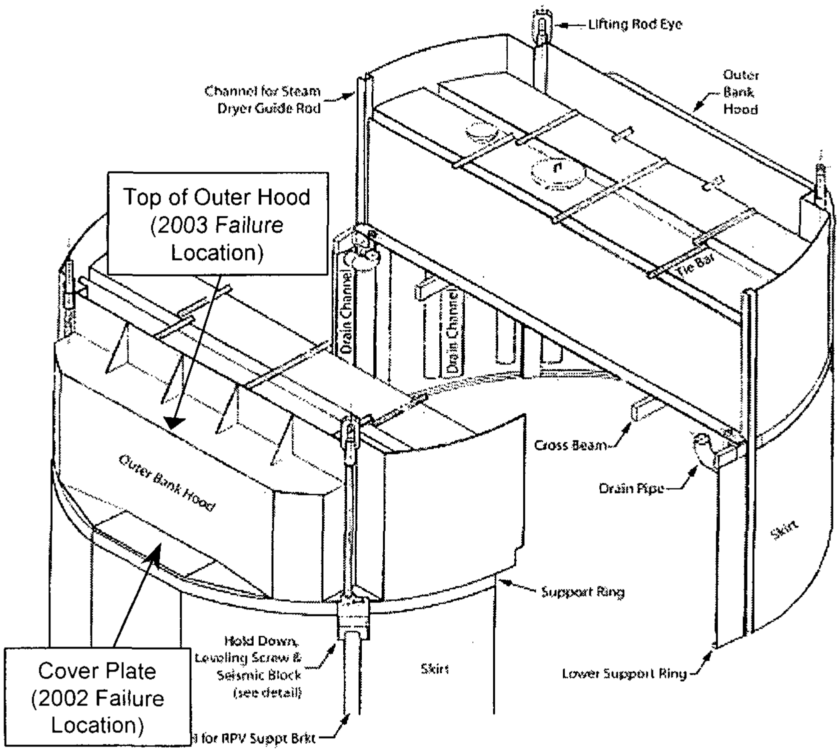


Figure B-1: Location of the 2003 Outer Hood Failure

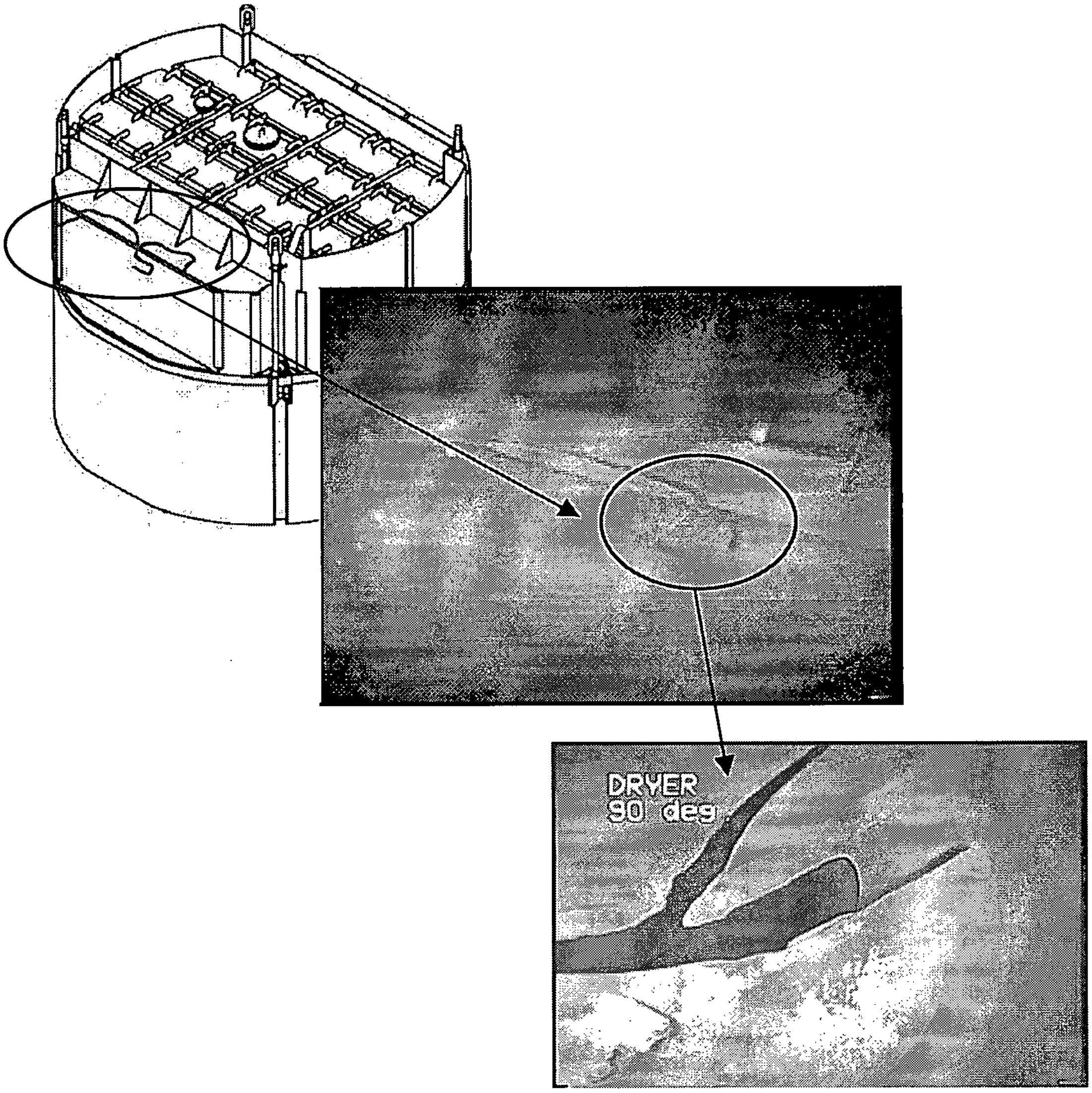


Figure B-2: Steam Dryer Damage 90 Degree Side

Appendix C
Inspection Guidelines

Overview

The steam dryers have been divided into four broad types with fourteen sub-groups: BWR/2 design, square hood design, slanted hood design and the curved hood design. The focus of the inspections for each dryer type is divided into two categories. The first category is directed at the outer surfaces of the dryer that are subject to fluctuating pressure loads during normal operation and are potentially susceptible to fatigue cracking. The second category is directed at the cracking that has been found in the drain channels and in inner bank end plates. These latter locations are not associated with any near term risk of loose part generation. They have often been associated with IGSCC cracking in the heat-affected-zones of stainless steel welds.

Inspection Techniques

Based on the current experience in inspecting the dryer components, VT-1 is the recommended technique to be employed for the inspections. VT-1 resolution, distance, and angle of view requirements should be maintained to the extent practical. In instances where component geometry or remote visual examination equipment limitations preclude the ability to maintain the VT-1 requirements over the entire length of the different weld seams, "best effort" examinations should be performed. In that cracking will be expected to have measurable length (several inches), field experience has confirmed that "best effort" approaches are sufficient to find the cracking that is present.

Steam Dryer Integrity Inspection Recommendations

The recommendations are divided into three categories: BWR/2 and square hood taken together, slanted hood and curved hood steam dryers. The inspection recommendations for each type of dryer will be detailed using schematics of the outer dryer structure. The key weld seams that must be inspected are outlined in red or green. High stress locations associated with structural integrity are outlined in red. Locations associated with field dryer cracking experience are outlined in green. Typical horizontal and vertical welds are shown thereby providing guidance for establishing a plant specific inspection plan. The weld numbering approach shown in the figures is only given as an example. Due to the many welds and size differences, each plant should employ their own weld numbering system. If an indication is detected, care should be exercised when inspecting the symmetrical locations on the dryer. If an indication is detected on the external surface of a plate or weld, consideration should be given to inspecting the location from the inside of the dryer in order to determine if the indication is through-wall.

Square Hood Design: applicable to BWR/2 plants and BWR/3 plants

Several square hood dryers were built with interior brackets and diagonal braces. These structures produce stress concentration locations, which have been found to aid in the initiation of fatigue cracking. These brackets exist in both the outer and the inner dryer banks. The recommended inspections follow.

Steam Dryer Bank Inspections

Figure C-1 provides the overview of the square dryer design. These dryers will require both an external and internal inspection. All dryers are symmetrical from this perspective. Outlined in red are the key weld seams that must be inspected. These welds, both horizontal and vertical outline the outer dryer bank. These locations considered as high stress locations. Figure C-2 displays a cross-section of the BWR/2 steam dryer with the outer bank peripheral welds highlighted. This configuration has no lower cover plate. However, the external locations that match those shown in Figure C-1 need to be inspected in a similar fashion to the other square hood dryers. Figures C-3 and C-4 provide the details of the weld seams as viewed from the dryer bank interior. As shown in Figure C-3, the outer bank welds need to be inspected from both the dryer exterior and the dryer interior. In addition, for the dryers where there are interior brackets that were present in the original design and are still present, the interior inspection must be conducted of the weld region where the bracket is joined to the hood vertical and top plates. Figure C-3 shows these locations for the outer banks hoods. Figure C-4 shows the brackets for the inner hood. In addition, Figure C-5 provides a cross section of the bracket-diagonal brace substructure. The intersection locations between the bracket and the top and outer hood are also outlined in red in these figures. In that the concern is primarily fatigue cracking, several inches of base material adjacent to welds should be examined as well as any obvious discontinuity, e.g., the exterior base material should be examined in the general area where there is an internal weld. This inspection examination region includes the heat-affected-zone and will therefore detect any IGSCC cracking. This figure also shows locations in green that exhibited cracking in the field. The region of inspection should be the same.

Tie Bar Inspections

In addition to the outer bank and interior bracket locations, tie bars also require inspection. Figure C-6 provides a schematic of the tie bars. These are located between each set of dryer banks.

Inspections Based on Field Experience

The other locations of interest are primarily associated with IGSCC in drain channels (shown for information in Figures C-7 and C-8). These components will be part of the internal examination. While these indications have been historically associated with BWR/4 through BWR/6 plants (SIL No. 474 "Steam Dryer Drain Channel Cracking" issued October 26, 1988), recent findings indicate that cracking can occur in these locations in square hood dryers. The additional weld seams associated with the outer side of the next set of inner banks should also be inspected in that this represents a steam path through the dryer. These areas are shown in green in Figure C-1. Cracking has been detected in these end panels in later design dryers. Finally, cracking at the steam dams as indicated in green in Figure C-6 has occurred in one BWR/4. These locations need to be included in the inspection plan for all of these plants. Finally, bank inner surface welds have cracked in the BWR/2. These locations, shown in Figure C-2 in green, also need to be inspected.

Slanted Hood Design: applicable to BWR/4 plants

The slanted hood steam dryers fall into three categories for which the primary difference is diameter and the number of banks. These dryers use 2 or 3 stiffener plates to strengthen each dryer bank. All inspections are on the external surface of the dryer. However, if an indication is detected on the external surface of a plate or weld, consideration should be given to inspecting the location from the inside of the dryer in order to determine if the indication is through-wall. The recommended inspections follow.

Steam Dryer Bank Inspections

Figure C-9 provides the overview of the slanted dryer design. All dryers are symmetrical from this perspective. Outlined in red are the key weld seams that must be inspected from the external surface. These welds, both horizontal and vertical outline the outer dryer bank as well as the cover plate between the outer hood vertical plate and the support ring. Additional red lines represent the outside projected location where the stiffener plates are welded to the outer hood vertical plate. These locations are considered as high stress locations. The man-way welds (on one side) are also shown as locations requiring inspection.

Tie Bar Inspections

In addition to the outer bank and interior bracket locations, tie bars also require inspection. Figure C-10 provides a schematic of the tie bar locations joining the tops of each set of banks. The primary concern is the presence of fatigue cracking through the bar base material cross-section at axial location where the tie bar is attached to the bank.

Inspections Based on Field Experience

Cracking has been detected in these end panels in later design dryers. Therefore, these additional weld seams associated with the outer side of the inner banks should also be inspected in that this represents a steam path through the dryer. These areas are shown in green in Figure C-9. Cracking has been observed in these locations in dryers of this design. The other locations of interest are primarily associated with IGSCC in drain channels (refer to SIL No. 474 "Steam Dryer Drain Channel Cracking" issued October 26, 1988), support ring, and lifting rod attachments.

Curved Hood Design: applicable to BWR/4-BWR/6 and ABWR plants

The curved hood steam dryers fall into five categories for which the primary differences are diameter and inner bank hood thickness. Similar to the slanted hood dryers, these dryers also have 2 or 3 interior stiffener plates to strengthen each dryer bank. All inspections are on the external surface of the dryer. However, if an indication is detected on the external surface of a plate or weld, consideration should be given to inspecting the location from the inside of the dryer in order to determine if the indication is through-wall. The recommended inspections follow.

Steam Dryer Bank Inspections

Figure C-11 provides the overview of the curved hood dryer design. All dryers are symmetrical from this perspective. Outlined in red are the key weld seams that must be inspected from the external surface. These welds, both horizontal and vertical outline the outer dryer bank as well as the cover plate between the outer hood vertical plate and the support ring. Additional red lines represent the outside projected location where the stiffener plates are welded to the outer hood vertical plate. Inspection locations also include outer plenum end plates and inner hood vertical weld seams for BWR/4 and BWR/5 plants with 1/8 inch thick hood plates on the inner banks. The location shown is the region where these thinner hood plates are attached to the stiffeners. All of these locations are considered as relative high stress locations. The man-way welds (on one side) are also shown as locations requiring inspection.

Tie Bar Inspections

In addition to the outer bank and interior bracket locations, tie bars also require inspection. Figure C-11 provides a schematic of the tie bar locations joining the tops of each set of banks. In that the attachment of the tie bars may have employed high heat input welds, the inspection should also include the entire welded region to assess the presence of IGSCC on the bank top plate. This region is adjacent to the region shown in red around the end of the inner bank tie bars.

Inspections Based on Field Experience

Cracking has been detected in the end panels in later design dryers. Therefore, these additional weld seams associated with the outer side of the inner banks should also be inspected in that this represents a steam path through the dryer. These areas are shown in green in Figure C-11. Cracking has been observed in these locations in dryers of this design. The other locations of interest are primarily associated with IGSCC in drain channels (refer to SIL No. 474 "Steam Dryer Drain Channel Cracking" issued October 26, 1988) and lifting rod attachments.

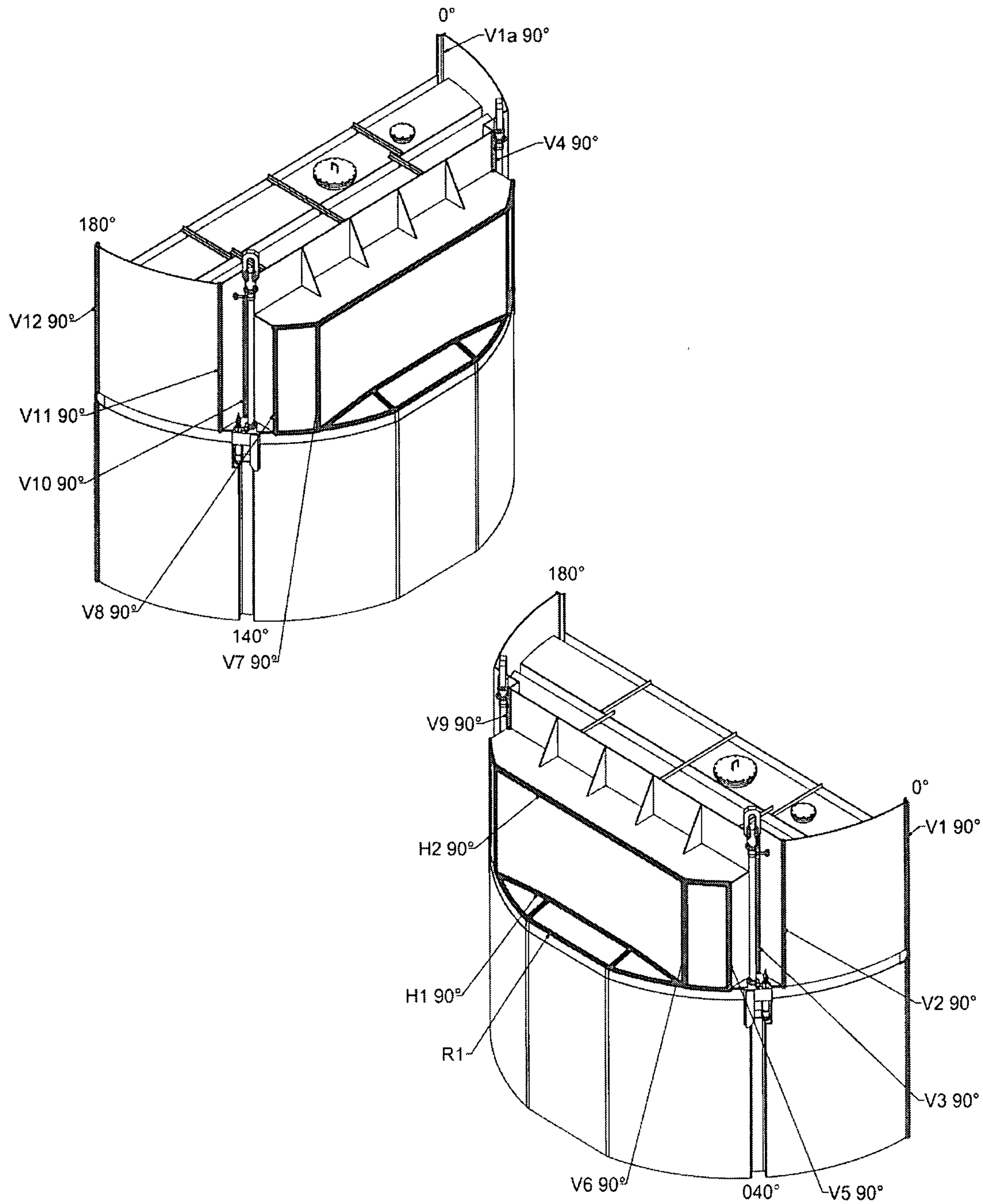


Figure C-1: Inspections: Outer Dryer Hood and Cover Plate (Square Hood Dryer)

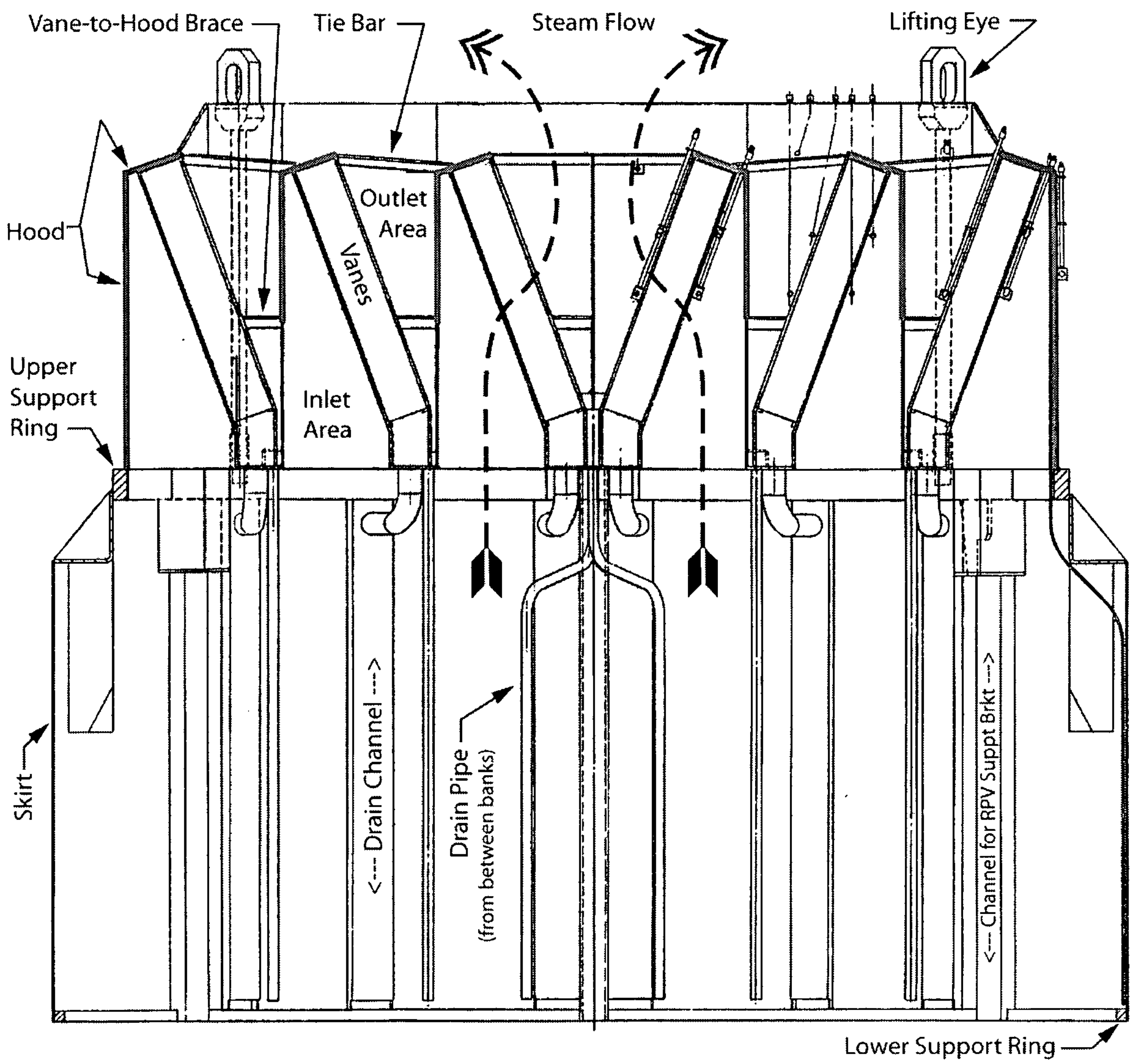


Figure C-2: Cross-Section of BWR/2 Steam Dryer

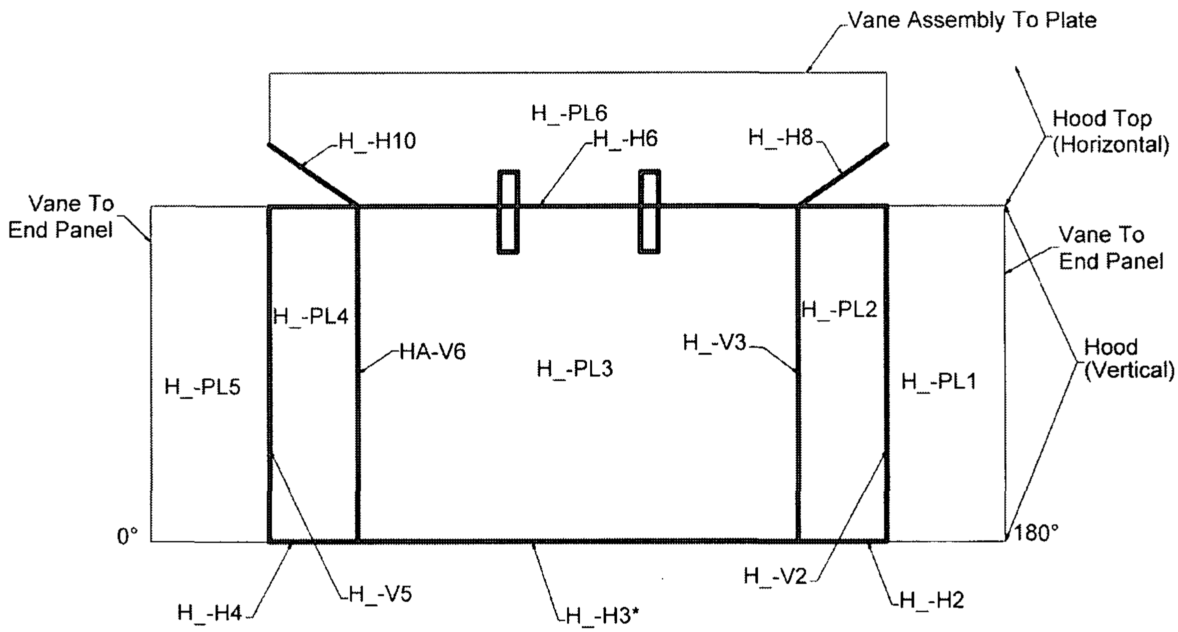
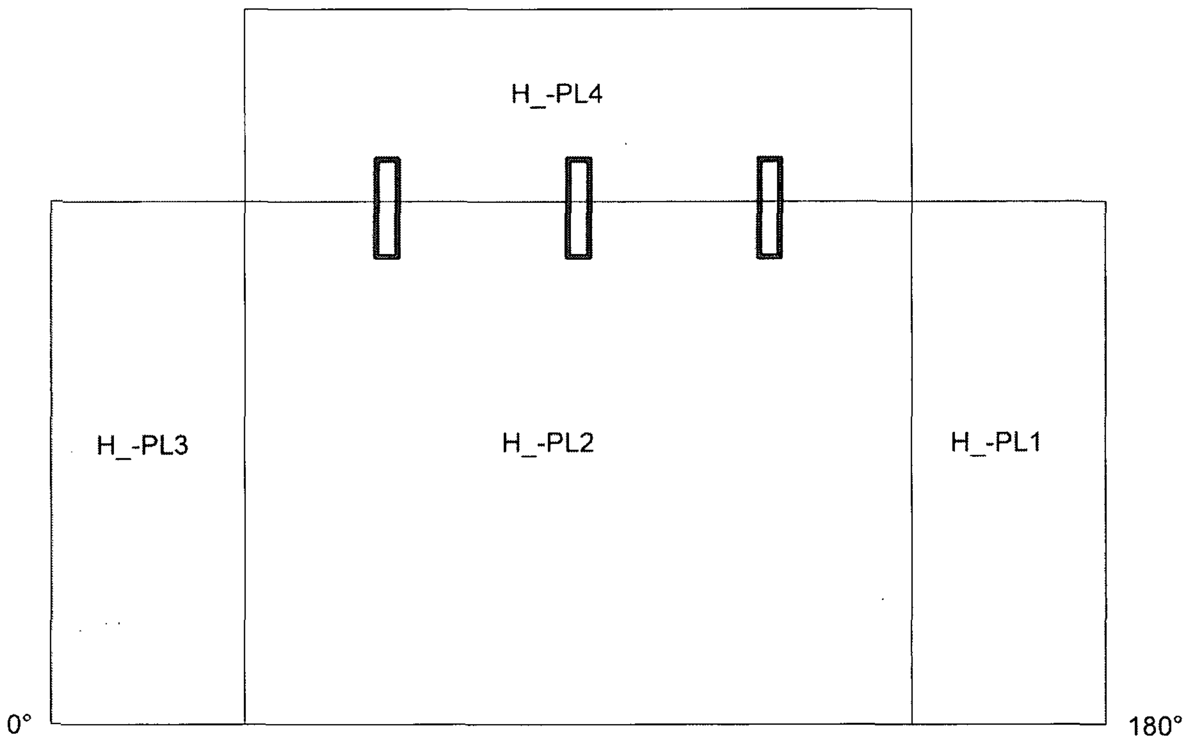


Figure C-3: Weld layout for interior of outer banks (Square Hood Dryer)

The brackets shown only exist in those plants where they were part of the original design and were not removed as part of dryer modifications.



H_-PL# = Plate (Bank B, C, D or E) (Ex. HB-PL1)
Internal View - View Is Looking Away From Vane Assembly

Figure C-4: Weld Rollout – Inner banks with internal brackets (Square Hood Dryer)

The brackets shown only exist in those plants where they were part of the original design and were not removed as part of dryer modifications.

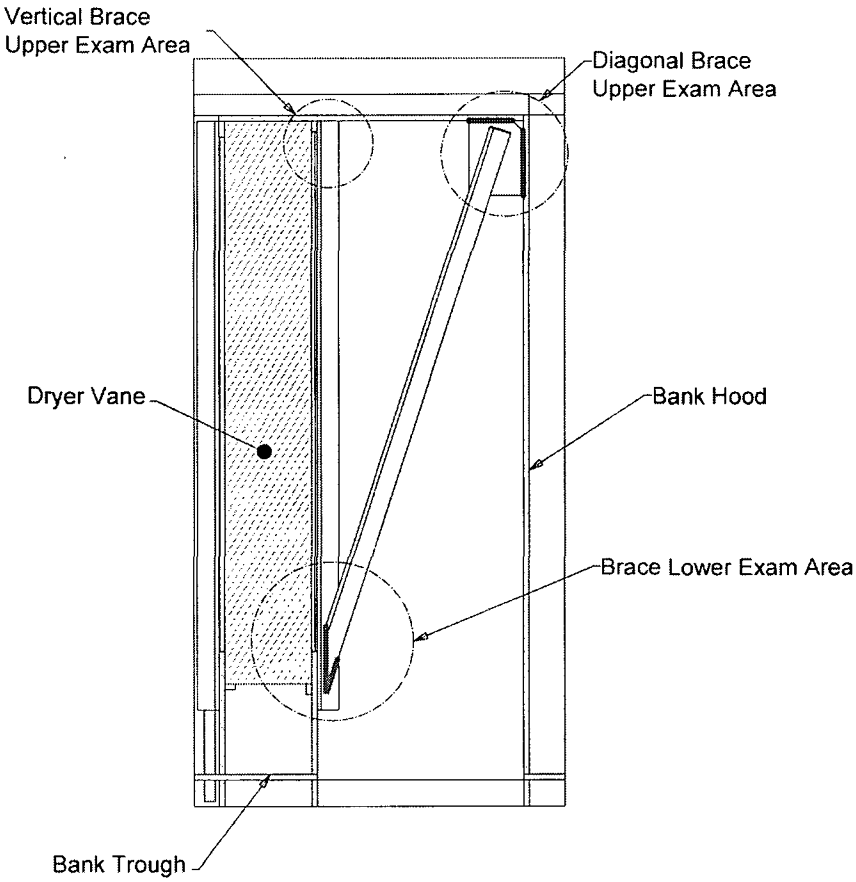


Figure C-5: Dryer Brace Detail (Square Hood Dryer)

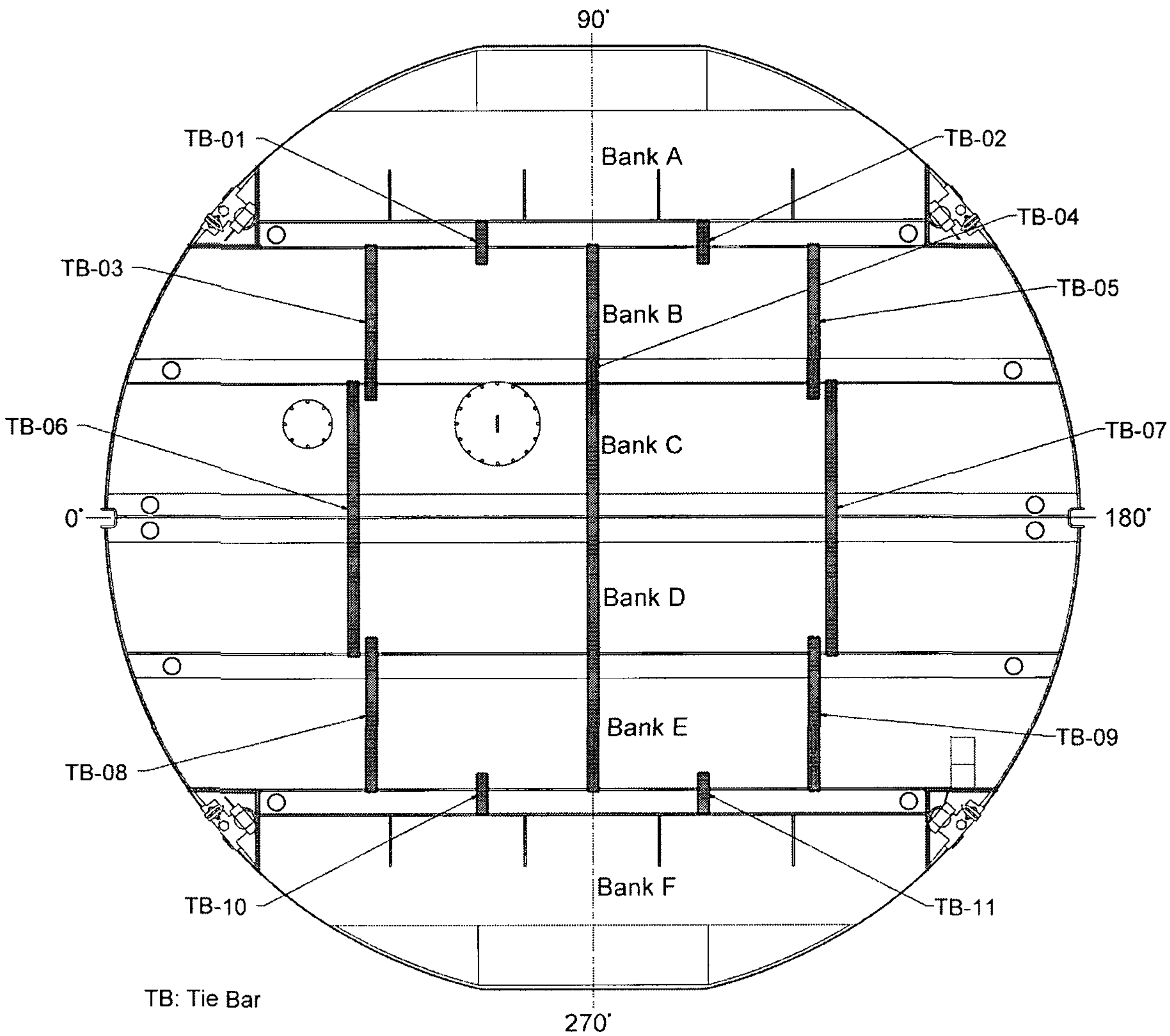


Figure C-6: Inspection Locations: Tie Bars and Steam Dam Inspections (Square Hood Dryer)

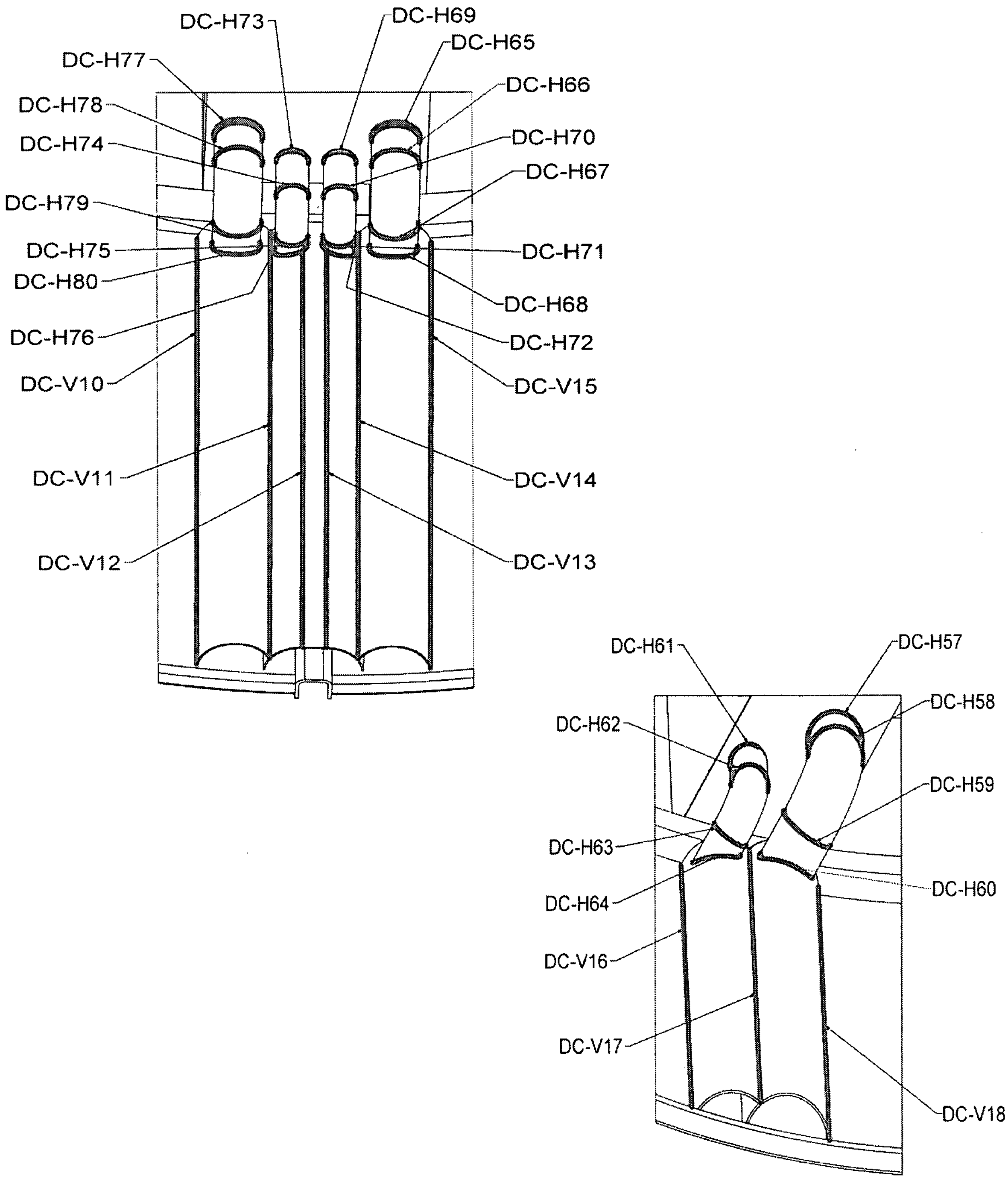


Figure C-7: Drain Channel Locations (Square Hood Dryer)

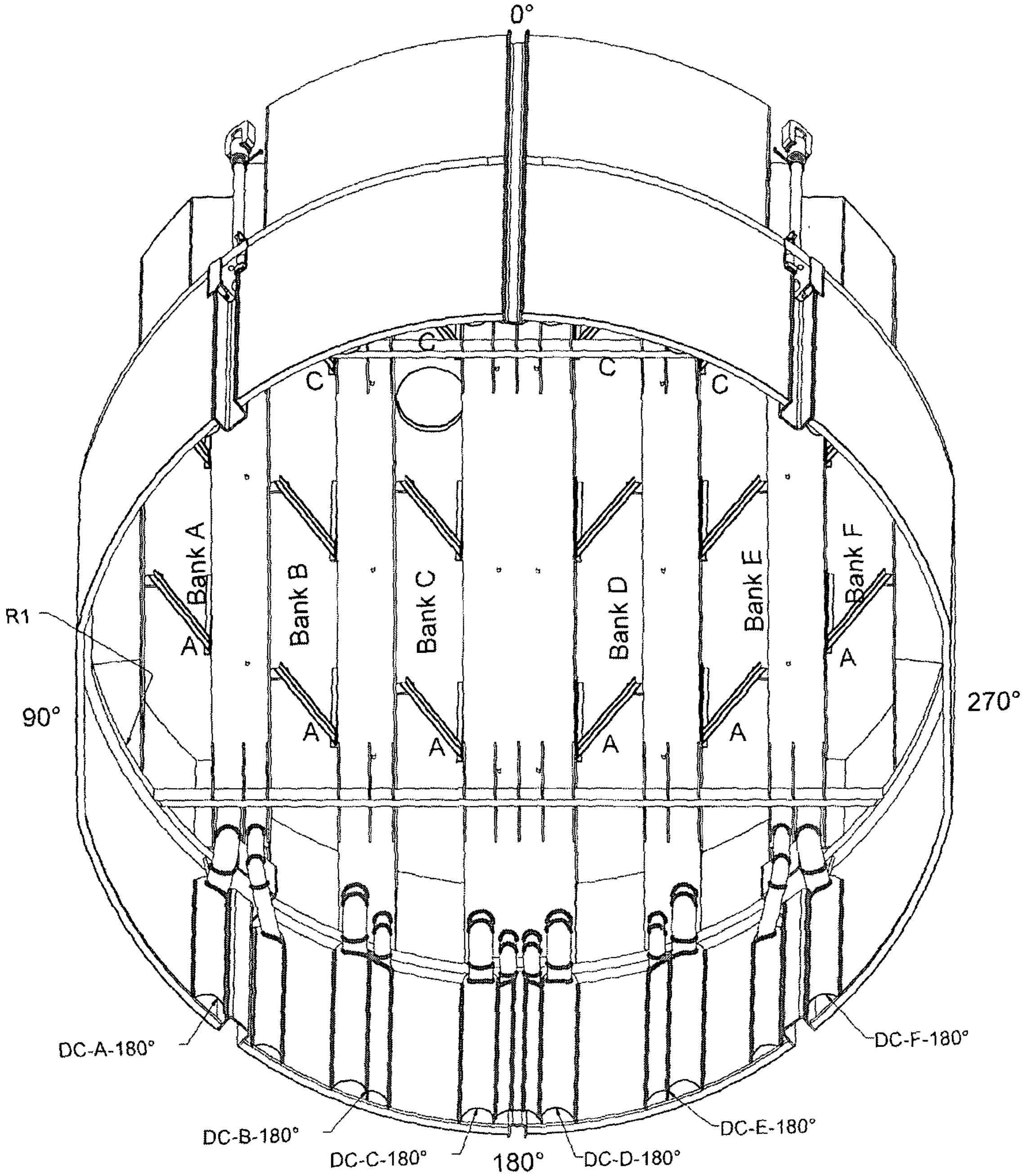


Figure C-8: Dryer Drain Channel, Guide channels and Guide Rod - Bottom View (Square Hood Dryer)

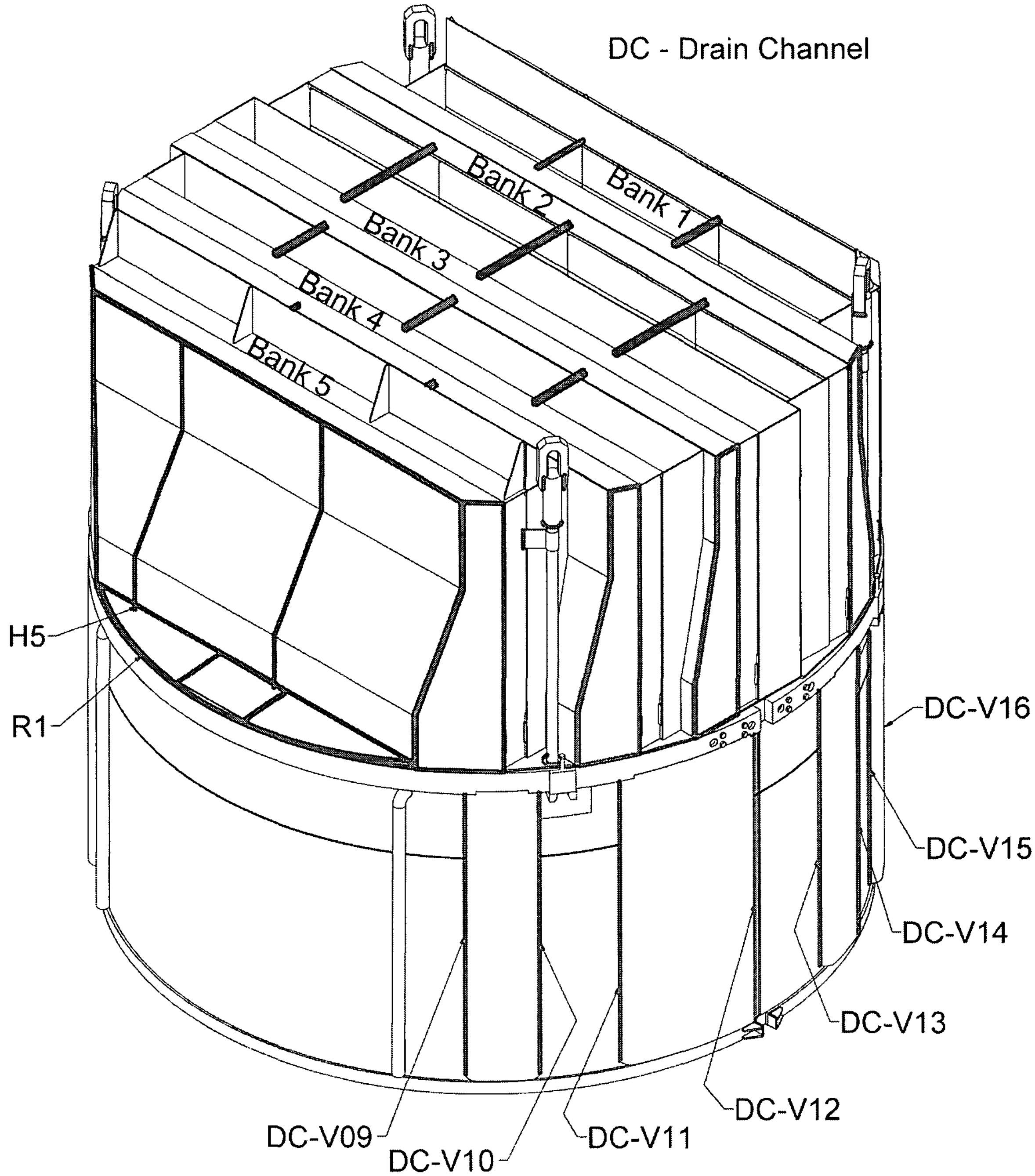


Figure C-9: Inspection Locations (Slanted Hood Dryer)

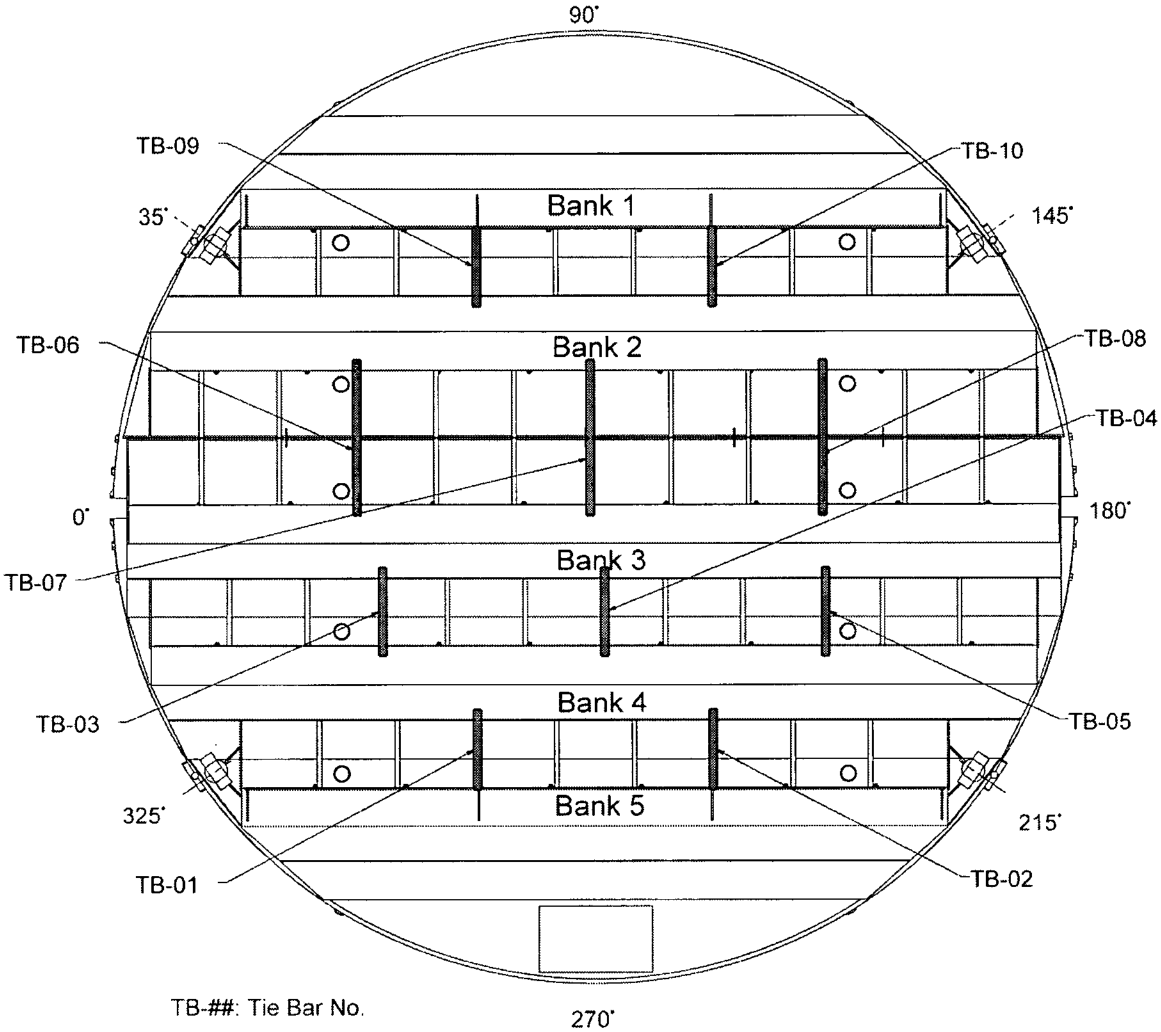


Figure C-10: Tie Bar Locations (Slanted Hood Dryers)

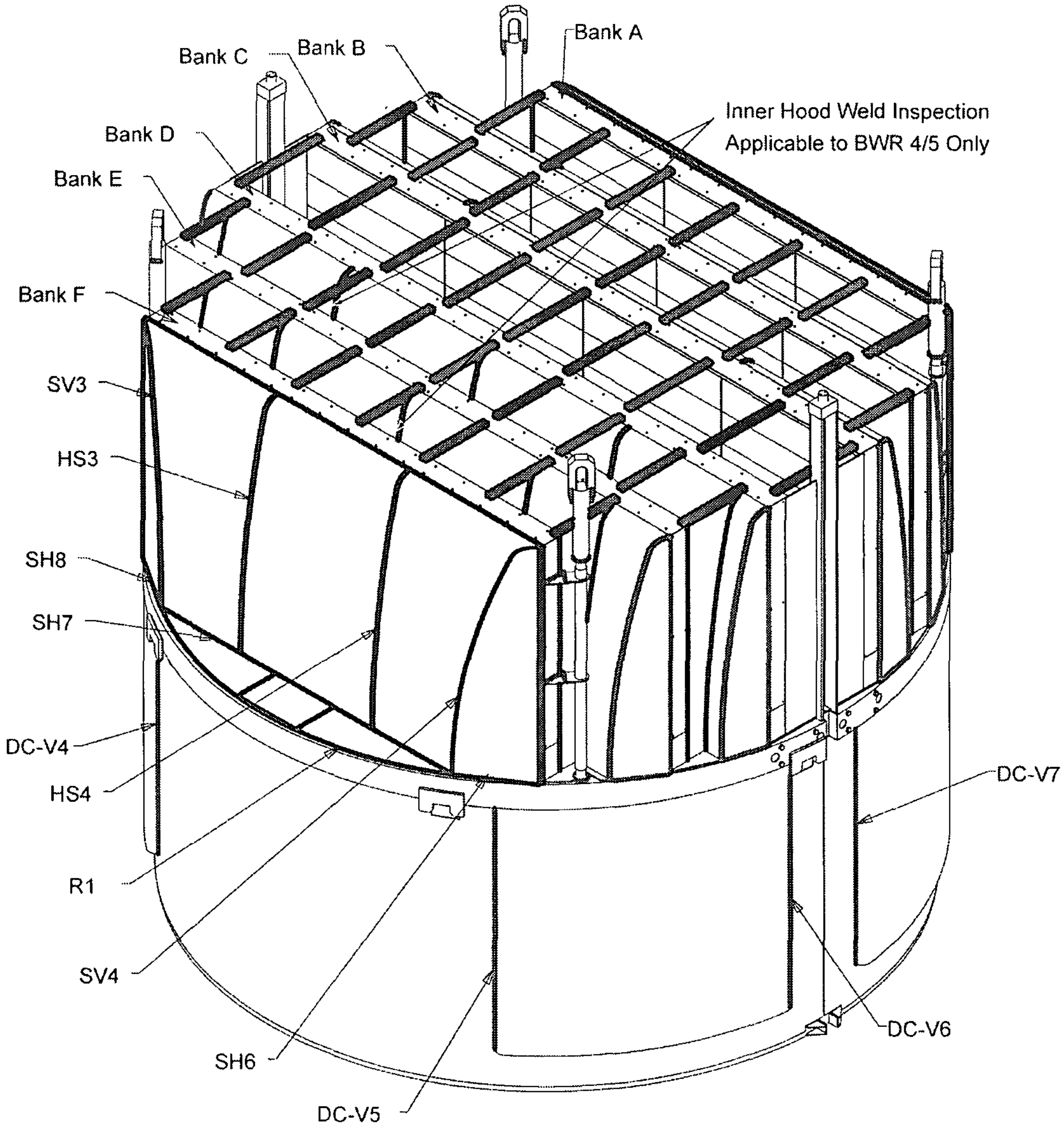


Figure C-11: Inspection Locations (Curved Hood Dryer)

Appendix D
Monitoring Guidelines

Applicability

In general, it is good practice to have access to as much performance data as practicable in order to make informed operational decisions. Therefore, GE recommends that all BWRs determine moisture carryover (MCO) baseline data and implement the moisture carryover and operational response guidance described here. Plants that have sufficient MCO baseline-data and operating experience may elect to consider a less stringent monitoring program.

Background

A moisture carryover greater than 0.1 weight% (wt.%) at the licensed power level is an indication of potential steam dryer damage, unless a higher threshold has been established based on dryer/separator design and normal operating experience for the plant. A higher threshold may be warranted for a BWR with an unmodified square dryer hood (i.e., no addition of perforated plates) and/or operating with MELLLA+ at off-rated core flow.

Reliance on only the threshold value of 0.1 wt.% to assess the condition of the steam dryer is not recommended. Monitoring the trends in reactor parameter values (e.g., reactor water level, individual steamline flow rates) may be more important than monitoring the parameter values against absolute action thresholds. An unexplained change in the trend or value of a parameter, particularly steam moisture content or the flow distribution between individual steamlines, may be an indication of a breach in the dryer hood even though the absolute value of the parameter is still within the normal experience range. To be effective parameter trend monitoring must be done continuously, rather than retroactively evaluating the trends once a threshold has been reached. Trending provides a significant advantage over use of a threshold value in that it allows time for a cross-functional team (operations, engineering, fuels, chemistry, and other experts such as the original equipment manufacturer) to evaluate the data prior to reaching a threshold that would prompt a plant shutdown decision.

If plants are reporting measured moisture carryover values of "less than" a value because of inability to measure Na-24 in the condensed steam sample and the "less than" value is greater than 0.025 wt.%, then the moisture carryover measurement process should be modified to reduce the minimum detectable threshold (preferably such that "less than" values are never reported). Without quantitative data, the plant staff will be unable to develop operational recommendations based on statistically valid moisture carryover and other plant data.

While monitoring for indications of steam dryer cracking is important, it is equally important to be aware that individual apparent indications of steam dryer cracking may be due to other factors. BWR moisture carryover may be impacted by: (1) reactor power level, (2) core flow and power distributions, (3) localized "hot spots", (4) core inlet sub-cooling (which is related to final Feedwater temperature), and (5) reactor water level.

> Moisture carryover is very sensitive to power level. Therefore, data should be collected during steady state operations at the highest possible power levels.
>
> Moisture carryover has increased in cases where steam flow is increased towards the center of the core.

Moisture carryover has increased in cases where core inlet sub-cooling is decreased (i.e., final Feedwater temperature is increased).

Moisture carryover has increased in cases where reactor water level is increased (due to degraded separator performance).

Moisture carryover has increased due to changes in the core power distribution associated with an increased radial peaking factor.

Note that the standard deviation of moisture carryover measurements is not expected to change significantly following power distribution changes. However, if a significant condenser tube leak occurs, then the standard deviation of moisture carryover measurements may change significantly due to the resulting increased Na-24 concentrations.

If abnormal indications appear in the parameters being trended for dryer integrity, confirm that the instrumentation is in calibration and is operating properly. Ensure that there are no unusual environmental or equipment operating conditions present that may affect the instrument response and indications.

If fuel leakage is known to be present or is suspected, or if high fission background is present, then site chemistry should be made aware of the need to differentiate the Na-24 measurement (for the determination of moisture carryover) from the secondary I-135 peak. The secondary gamma peak for I-135 (associated with a fuel leak) is very close to the gamma peak for Na-24 (used to measure MCO). Therefore, if caution is not exercised in interpreting the sample, a fuel leak can be misinterpreted as high MCO.

For trending purposes sampling Na-24 from the feedwater heater drains rather than the hotwell will provide more effective data. MCO is determined by measuring the amount of Na-24 in the reactor steam condensate and comparing it to the Na-24 in the reactor water. The only way that Na-24 can be present in the reactor steam is if it is carried over as droplets of reactor water (which is the moisture carryover). The water in the hotwell is primarily condensed reactor steam. However, the hotwell can receive reactor water (and Na-24) through a number of other pathways (Reactor Water Clean Up, sample lines, etc.). These paths must be isolated and sufficient time allowed for the hotwell Na-24 concentration to reach equilibrium based on the steam alone (typically several hours). The feedwater heaters usually receive only reactor steam (either directly or as extraction steam from the turbine) and are usually not susceptible to being "contaminated" by reactor water. However, the heater drains may be relatively inaccessible, which may make taking samples at the drains difficult.

Plants are recommended to accurately determine the flow distribution between individual steam lines. If significant steam dryer damage occurs, steam line flow distribution changes may result.

It may be helpful to measure the pressure at each main steam flow element (venturi) to better understand the pressure drops and possible pressure changes due to moisture content changes in the steam line flow. This pressure data would have been beneficial previously at a BWR/3 plant to help identify the flow blockage upstream of the flow element following significant steam dryer damage. Note that flow element performance calculations are based on the RPV steam dome pressure.

An increased feed-to-steam mismatch (i.e., total Feedwater flow plus CRD flow minus total steam flow, with reactor water level constant) may validate an increase in moisture carryover. Plant application has confirmed this correlation exists when the initial moisture carryover value is low (~0.01 wt.%), however the correlation showed significant scatter at higher initial moisture carryover values (0.04 wt.% to 0.10 wt.%).

Baseline Data

Collect baseline data for MCO and pertinent plant operating parameters daily for at least five (5) days to establish the MCO baseline data.

> NOTE
>
> Data should be collected during steady state operations at the highest possible power levels.

Moisture Carryover

Statistically evaluate the moisture carryover data (e.g., determine the mean and standard deviation for the data) to determine if there is a significant increasing trend. Qualitatively review the data to ascertain if there is a significant increasing trend. If there is an increasing trend in moisture carryover, review the changes in plant operational parameters to determine if there is an operational basis for the trend.

If an unexplained increasing trend is evident, then collect additional moisture carryover data with consideration for increasing the measurement frequency (e.g., from "once per day" to "once per 12 hours").

If an unexplained increasing trend is not evident, then this is considered to be acceptable baseline data to support the collecting and evaluation of periodic data for moisture carryover.

Plant Operational Parameters

> NOTE
>
> Most pertinent plant operational data is available from the process computer. This process computer data can normally be exported for analysis and storage using plotting and graphing tools such as EXCEL.

The following parameters should be measured during collection of moisture carryover data:

Reactor power (MWt)

Core flow (Mlb/hr)

Core power distribution (radial peaking factor, core map of relative bundle power peaking)

Core inlet sub-cooling (deg F)

Reactor water level, average of at least 1000 data points over a one to three hour time period.

Individual main steam line flows (Mlb/hr), average of at least 1000 data points over a one to three hour time period. Include pressure data at each MSL flow element (venturi), if available.

Total Feedwater flow (Mlb/hr), average of at least 1000 data points over a one to three hour time period.

CRD flow (Mlb/hr), average of at least 1000 data points over a one to three hour time period.

Periodic Data and Operational Response

> NOTE
>
> Data should be collected during steady state operations at the highest possible power levels.
>
> If a moisture carryover measurement is suspect (e.g., less than "mean minus 2-sigma"), then repeat the moisture carryover measurement to verify sampling and analysis were performed correctly. Consider eliminating data shown to be incorrect/invalid.

Measure moisture carryover and pertinent plant operational parameters weekly. The reactor parameter trends for the entire week should be evaluated, particularly if operating conditions changed during the week. The changes in reactor parameter trends should be consistent with the change in operating conditions. Following are recommendations for evaluating the data and determining if an operational response is appropriate.

Data Evaluation

The following specific applications of the general trending recommendations within INPO 97-011 should be incorporated into the plant's trending program;

> Determine normal values for each trended parameter from past station experience of desired performance.
>
> Past experience has shown Na-24 MCO indications to vary without an associated cause. To provide for useful trending the data can be assumed to be normally distributed, allowing a station to examine the standard deviation of the readings to determine if the trend is not random.
>
> Use rolling averages to smooth out data that is subject to a large variation over a short time and to help recognize a possible trend. If plant operation has been constant, linearly interpolating between points of "good data" may be used to bridge short computer outage periods. This will allow a continuous rolling average to be used without having to reestablish the average.

Statistical smoothing techniques such as calculating running averages using a large quantity of samples may be necessary to eliminate the process noise and allow the changes in the trend to be identified. Additionally, an experience base should be developed for each plant that correlates the changes in monitored parameters to changes in plant operation (rod patterns, core flow, etc.) in order to be able to distinguish the indications of a degraded dryer from normal variations that occur during the operating cycle.

Use data that has been recorded periodically (e.g., once every 5 seconds, once a minute) on the plant process computer. Avoid using data that has been recorded "by exception" (e.g., when the parameter value changes by more than a threshold value). Reconstruction of the parameter trends from data recorded using these techniques does not have the resolution necessary to identify changes that may indicate potential dryer integrity issues.

Statistically evaluate the moisture carryover data and qualitatively determine if there is a significant increasing trend that cannot be explained by changes in plant operational parameters.

Operational Response

If there are no statistically significant changes in moisture carryover for an operating cycle, then decreasing the moisture carryover measurement frequency (e.g., from "once per week" to "once per month") may be considered, provided the highest operating power level is not significantly increased.

An unexplained change in the trend or value of a parameter, particularly steam moisture content or the flow distribution between individual steamlines may be an indication of a breach in the dryer hood, even though the absolute value of the parameter is still within the normal experience range.

If an unexplained increasing trend is evident, then collect additional moisture carryover data with consideration for increasing the measurement frequency (e.g., from "once per week" to "once per day").

> If the latest moisture carryover measurement is greater than "mean plus 2-sigma" and this increase cannot be explained by changes in plant operational parameters, then obtain a complete set of data for the plant operational parameters (identified above). Convene a multi functional team, which includes operations, engineering, plant chemistry, reactor engineering, and other experts such as the original equipment manufacturer. Compare the current plant operational data with the baseline data to explain the increased moisture carryover (i.e., is there significant evidence of potential steam dryer damage).
>
> It is strongly suggested that the original equipment manufacturer be contacted as early as possible if an adverse MCO trend is suspected so that industry wide experience and detailed design information can be assessed.
>
> If an increase in moisture carryover occurs immediately following a rod swap, additional moisture carryover data should be obtained to assure that an increasing trend does not exist. Note that occurrence of steam dryer damage immediately following a rod swap would be highly unlikely as opposed to a new fuel leak.
>
> If the increasing trend of moisture carryover cannot be explained by evaluation of the plant operational data, then initiate plant-specific contingency plans for potential steam dryer damage. These contingency plans may include increased frequency of MCO monitoring, reducing core thermal power, or establishment of limitations on core power distribution (i.e. reduce core radial power peaking). If the evaluation of plant data confirms that significant steam dryer damage has most likely occurred, then initiate a plant shutdown.

As part of the evaluation of adverse trends, consideration must be given to non-dryer related causes for increased MCO or anomalous parameter indication.

> The observed trends should be evaluated against plant activities on a timeline. As with any apparent adverse plant condition the indication should be validated. During one recent event, a leak in stem packing for a valve in the region of the water level variable leg piping heated the water in the piping. The change in water density drove the instrument out of calibration, resulting in a water level indication that was similar to the water level indications observed during one of the dryer failure events.
>
> If fuel leakage is known to be present or is suspected, or if high fission product background activity is present due to previous fuel failures, then site chemistry should be made aware of the need to differentiate the Na-24 measurement (for the determination of moisture carryover) from a secondary I-135 peak. One of the many smaller secondary gamma peaks for I-135 (associated with fuel leakage) is very close in energy to the sole gamma peak for Na-24 (used to measure MCO).

Therefore, if caution is not exercised in interpreting the sample, a fuel leak can be misinterpreted as high MCO.

INPO OE22177 addresses this particular interference and provides direction to remove the interference from the Na-24 gamma analysis by selectively concentrating the cation species in the samples and to change the gamma isotopic library to include this energy of I-135 as interference for Na-24 and to evaluate all single energy isotopes for similar situations.

Certain combination of symptoms could typically be interpreted as potential steam dryer structural integrity concerns

High MCO that is not otherwise explainable

Steam flow mismatch. This is based on the reduction of steam flow in one line that could indicate a flow blockage due to a dislodged piece of a damaged steam dryer.

Damage to the dryer skirt or hood in the region of the reference leg vessel tap could permit flow through the annular area around the skirt. In the presence of the vessel level instrumentation this flow has the potential to induce a Bernoulli effect indication error that may affect both the water level and reactor pressure indications. This phenomenon was observed during the BWR/3 lower horizontal cover plate failure in 2002.