

ISSUE STATEMENT

Worldwide, a number of boiling water reactor plants (primarily BWR/4 and /5 designs) are experiencing jet pump degradation associated with flow induced vibration. The primary causes for jet pump degradation from flow-induced vibration are thought to be turbulent flow through the jet pumps, slip joint leakage flow instability, and pressure pulsations from pump vane passing. Jet pump degradation is generally characterized by wedge and rod wear, but one plant recently experienced substantial cracking in a jet pump riser extending 240 degrees around the circumference. The rate and severity of observed jet pump degradation is increasing. Further, the power uprates being pursued by many plants can lead to increased flow-induced vibration loads on the jet pump assembly.

DRIVERS

There are a number of factors that drive the need for timely resolution of the jet pump flow induced vibration issue, including:

Asset Management

Asset management is the primary driver associated with the management of jet pump flow-induced vibration. Jet pump degradation has become one of the most costly BWR material issues, with industry costs currently exceeding \$20 million. Several plants have experienced wedge and rod wear even after installing clamps, auxiliary wedges or labyrinth seals. In 2008, a BWR/5 plant experienced a significant fatigue crack in a jet pump riser that resulted in several months of downtime and required a temporary repair. Currently, the plant is only allowed to operate for a single cycle at reduced power.

Anticipated Growth in the Extent and Severity of Degradation

As more plants pursue power uprates, the potential for more widespread and severe jet pump degradation increases. Power uprates result in higher back-pressure on the jet pumps, which can exacerbate jet pump degradation if mitigation techniques are not available and implemented.

Safety Impact

The integrity of the jet pump assembly is of paramount importance to safe plant operations. The jet pump ensures reflooding to at least 2/3 core height in the event of a concurrent recirculation pipe break, and for some BWRs, the jet pump assembly provides a flow path for low-pressure injection.

Potential for Regulatory Action

Although the Nuclear Regulatory Commission (NRC) has not taken action to-date in response to observed jet pump degradation, increased regulatory scrutiny is possible if such degradation is not addressed by industry, particularly if another significant jet pump fatigue crack is identified.

RESULTS IMPLEMENTATION

Results of BWRVIP testing to investigate jet pump phenomena will allow utilities to assess their relative susceptibility to jet pump degradation based on jet pump design and plant operating conditions. The results will also provide the basis for defining a “demonstration test protocol” to be used during testing to assess the effectiveness of proposed flow-induced vibration mitigation solutions.

Demonstration test results will be provided to BWRVIP utilities in BWRVIP reports and can be used to inform decisions on potential implementation of one or more jet pump mitigation solutions.

Jet pump inspection guidance (BWRVIP-41) and repair guidance (BWRVIP-51) will be updated, where applicable, applying lessons learned baseline BWRVIP-41 inspections, during the test program and from insights gleaned from the jet pump degradation and operational history review. Nuclear plant owners will implement the revised jet pump inspection and repair guidance in accordance with NEI-08 implementation guidelines.

PROJECT PLAN

The jet pump degradation management research program includes compilation of plant data on jet pump degradation, plant operation and repair histories to understand relationships between plant operation, configuration and degradation, sub-scale testing to study the slip joint leakage flow instability phenomenon, and full-scale testing of prototypical jet pump assemblies to assess the effectiveness of

vendor-proposed flow-induced vibration mitigation solutions. In addition, lessons learned from testing will be factored into revisions to jet pump inspection and repair guidelines.

Accomplishments to date include compilation and publication of jet pump degradation and operational history information, sub-scale testing at 1/5th and 1/2 scale to better understand the slip joint instability phenomena, testing using a full scale mock-up of a typical slip joint configuration to assess the relationship between slip joint flow and differential pressure, and fabrication of a full-scale test facility that includes a BWR/5 jet pump assembly. Tests completed to date have reproduced the BWR/5 slip joint leakage flow (SJLF) instability phenomenon and highlighted the need for on-line measurement of the slip joint gap and well as remote control of the alignment between the mixer and diffuser to provide repeatable test results. Other tests have shown that the full scale, full-flow test facility meets all flow, pressure, and temperature requirements; has defined the relationship between slip joint ΔP and M-Ratio; assessed the effect of recirculation pump vane passing frequency on system resonances; and has demonstrated the effects of variation in operating parameters such as set screw gaps, mixer-diffuser concentricity alignment, water temperature, and drive flow. The results of phenomenological tests conducted in the full flow test facility with a BWR/5 jet pump design are documented in BWRVIP-263.

In addition, two vendor proprietary conceptual designs for improved lateral support of the jet pump mixer/diffuser have been developed and are documented in BWRVIP-207 and BWRVIP-210. These designs hold promise to significantly reduce the potential for flow-induced vibration (FIV) damage to jet pump components.

The facility has been used to develop a worst case “demonstration test protocol” for use in evaluating vendor-developed flow-induced vibration mitigation solutions. The test facility has been used by participating vendors at their cost to assess the effectiveness of their solutions in mitigating BWR/5 jet pump flow-induced vibration loading. Demonstration testing has been completed for one vendor’s FIV solutions and the results are documented in BWRVIP-264. Developmental testing to investigate BWR/5 FIV solutions for three additional organizations has been completed. The results of developmental testing are the property of the respective testing organization and not reported to BWRVIP members. All testing on the BWR/5 jet pump design has been completed.

The full scale test facility has been modified to allow full flow testing of a BWR/4 full scale jet pump assembly up to 550 psia and 300°F. Jet pump FIV phenomenological testing with the BWR/4 jet pump configuration was completed in April 2015. One FIV mitigation solution vendor conducted developmental testing on the BWR/4 configuration in May 2015. The results of BWR/4 testing indicated a need to expand the test program to investigate the effect of potential wear at the interface between the mixer and diffuser at the slip joint. Testing with simulated slip joint wear were completed in November 2015. The facility should be available for additional mitigation solution vendor testing by March 2016.

RISKS

The program is thought to have a sound technical basis; however, there is potential risk in the following areas:

- Initially, there was a concern that testing conducted at non-prototypical temperature (320 vs 532°F) and pressure (600 vs 1000 psia) conditions may not result in prototypical results. The difference in pressure was not considered significant. Temperature, however, affects the kinematic viscosity which influences the onset of the slip joint instability phenomenon. Since the kinematic viscosity at 320°F is very close to that at 532°F, this effect was considered small and manageable. Testing has now demonstrated that the facility can readily reproduce the slip joint instability phenomena.
- Initially, testing of only one of the 12 jet pump designs in the fleet was funded (Typical BWR/5 251” design). The BWR/4 251” jet pump design has also experienced degradation, but was initially not funded for testing. A technical review was conducted in July 2013 to determine whether BWR/4 testing is needed. The review team unanimously concluded that BWR/4 testing was needed and funding to complete BWR/4 jet pump testing was approved in 2013.
- To obtain repeatable results, extreme care must be taken to ensure consistent slip joint concentricity between tests. The test facility will include a specialized system for remote measurement and control of slip joint concentricity. Initially, there was concern that the planned concentricity control system may not be effective in producing repeatable results. Tests to date have shown that the system for concentricity control has been very successful in producing repeatable results.
- Initially, there was concern that the FIV solutions developed by vendors and tested in the facility may not be effective in mitigating jet pump vibration. Tests to date have demonstrated successful FIV solutions.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

REVISION	DESCRIPTION OF CHANGE
0	<p>Original Issue: August 2011 Roadmap Owner: Randy Stark</p>
1	<p>Revision Issued: August 2012 Roadmap Owner: Randy Stark</p> <p>Changes: Updates to "Project Plan" that include project progress and accomplishments since original issue. Updates to Project Risks based on project progress over the last year.</p> <p>Editorial changes throughout the document.</p>
1	<p>Revision Issued: December 2012 Roadmap Owner: Andy McGehee</p>
2	<p>Revision Issued: January 2014 Roadmap Owner: John Hosler</p> <p>Changes: Updates to "Project Plan" that include project progress and accomplishments over the last year. Updates to "Risks" based on project progress to date. References to NRC review of BWRVIP-41 and BWRVIP-51 deleted as such reviews are not required nor currently planned. Changed roadmap owner to John Hosler</p>
3	<p>Revision Issued: August 2014 Roadmap Owner: John Hosler</p> <p>Changes: Updates to "Project Plan" documenting completion of BWR/5 jet pump testing including FIV solution testing by four (4) organizations as well as conversion of the test facility to allow testing the BWR/4 jet pump design. In addition an update to "Risks" documenting completion of a technical review concluding that testing with the BWR/4 jet pump design was needed.</p>

REVISION	DESCRIPTION OF CHANGE
4	<p>Revision Issued: August 2015 Roadmap Owner: John Hosler</p> <p>Changes: Updates to status of facility modifications to the BWR/4 configuration and BWR/4 jet pump testing completed to date. Results indicated a need to expand the test program to investigate the effect of potential wear in the slip joint. Defined schedule for planned additional testing in late 2015.</p>
5	<p>Revision Issued: August 2015 Roadmap Owner: John Hosler</p> <p>Changes: Updates to status of facility modifications to the BWR/4 configuration and BWR/4 jet pump testing completed to date. Results indicated a need to expand the test program to investigate the effect of potential wear in the slip joint. Defined schedule for planned additional testing in late 2015.</p>

