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Executive Summary of Lessons Learned from Transitioning to Flexible Power Operations, 2014–2018

1 Purpose, Method, and Top Insights

This report summarizes for industry executives key results to date of the Electric Power Research Institute's (EPRI's) Nuclear Power Plant (NPP) Flexible Operations Program. Key research results and operating experiences are highlighted for executive-level attention when considering or transitioning to NPP flexible operations.

This executive summary is based on EPRI research and operational experience gathered during 2014–2018 from six North American companies (seven specific reactor sites) that are considering a transition, or have transitioned to, flexible power operations (FPO) from a prior state of operating primarily as base-loaded plants. Complete details of the program's results to date are presented in current EPRI reports, especially 3002010414, *Transitioning Nuclear Power Plants to Flexible Power Operations: Experience Report Summary and Update of Approach to Transition Nuclear Power Plants to Flexible Power Operations*.

The NPP Flexible Operations Program will continue to work with member utilities to gather global operating experience and research. Results will be communicated via future EPRI technical reports and updates as warranted.

This section provides a brief statement of each major insight. Section 2 provides additional background information. Section 3 comprises a current listing of EPRI research and development reports on FPO, where complete details of the NPP Flexible Operations Program results are available. Insights are grouped into three general topics:

- Insights related to planning or executing a transition to FPO
- Insights related to early implementation of FPO, primarily equipment reliability considerations
- Insights related to longer-term or programmatic aspects of FPO

The insights consist of typically observed results, good practices, or research-based recommendations.

1.1 Transitioning to FPO

- A multi-disciplinary transition team and change management plan is needed. (Good practice)
- A feasible initial flexible operating envelope is readily definable within existing procedures and operating practices that allow for some FPO with little additional effort. (Observation) Later expansion of the flexible operating envelope remains feasible by applying further analysis as necessary. (Research result)

- A well-defined communication and implementation protocol is needed between the independent system operator/transmission system operator (ISO/TSO) and each reactor's operating team. (Good practice)
- Following initiation of FPO, the impacts observed thus far are manageable within existing corrective action processes and ongoing performance improvement methods. Little reallocation of operations or maintenance resources has been necessary. (Observation)

1.2 Equipment Reliability Insights

- Fundamental craft practices, for example, tuning control systems, air-operated valve/motor-operated valve (AOV/MOV) packing, etc., need to be high quality to provide resilience to a flexibly operating plant. Experience shows if high-quality craft practices are found to be lacking, craft training as needed restores desired plant resilience. (Observation)
- Westinghouse baffle former bolts need plant-specific attention to assess inspection frequency and to verify acceptability of the initial FPO envelope. (Research result and Ongoing research)
- Flow-accelerated corrosion (FAC) wear rates increase for some components with lowering power output. Plant-specific susceptibility assessment is required. (Research result)

1.3 Programmatic Insights

- Corrosion product transport increases during power transients, and changes in boiling may change deposition patterns at reduced power, potentially changing the overall localized corrosion risk. (Research result and ongoing research)
- Primary-secondary leakage monitoring is affected, and steam generator tube integrity guidance is being improved. (Research result)
- Pressurized water reactor (PWR) pH control may require more resources when power is controlled by changing boron concentration. (Research result)
- Boiling water reactor (BWR) reactor water chemistry transients during power changes are observed that warrant increased sampling frequencies, for example, chloride and sulphate control, zinc injection. (Observation)

2 Additional Background Information Regarding Major Insights

2.1 Additional Background Information Regarding Transitioning to FPO

- **Multi-disciplinary transition team and change-management plan.** Assigning a multi-disciplinary team has been effective during initial assessment or initial implementation of FPO. Various forms of such a multi-disciplinary approach have been successful for different utilities, consistent with the typical corporate practice for a given utility company. Such multi-disciplinary teams have conducted similar activities and reached similar decisions for initial transition to FPO as follows:
  - Within the EPRI guidance for transitioning to FPO, site-specific commitments and aggregate design changes since the original design need to be reviewed because past design change decisions could theoretically impose limits on the duration or frequency of operating at reduced power. Such restrictions might affect, for example, assumptions of transient analyses recorded in the final safety analysis report. Plant-specific analysis following the EPRI guidance or similar approaches at five diverse sites has resulted in the conclusion that FPO is possible and implementable within the current design of those nuclear power plants. To date, no site has reported a need to adjust prior commitments or accident analyses as a result of this possibility. However, license renewal commitments may need to be adjusted for plants desiring to start FPO following license renewal.
- **Initial flexible operating envelope.** Experience shows that a feasible initial flexible operating envelope that allows for some FPO is readily definable within existing procedure and operating practices with little additional effort. All sites embarking on FPO (to date) have remained within existing approved operating procedures for the initially determined flexible operating envelope. Incremental procedure or practice changes have been made to simplify and standardize the operational approach to raising and lowering power when needed. To date, initial flexible operating envelopes have been based on the desire to keep the full-power configuration of operating pumps, while avoiding known regions of power where the full-power operating configuration results in undesirable component vibration

or control instability. This restriction is not theoretically necessary, and international experience indicates that deeper load reductions are feasible. Engineering analysis is possible that would provide operational guidance for the sequencing of pump starts and stops if deeper load reductions become desirable.

- **Operating protocol with the ISO/TSO.** Establishing an operating protocol with the ISO/TSO has been effective. Key success elements of such an operating protocol are:
  - Allowed power ramp rates (megawatts per minute or hour), depth, duration, frequency of maneuvers, and time in core life are specified. In particular, power ramp rates and potential beginning-of-cycle exclusion of FPO should be based on fuel vendor recommendations (including fuel preconditioning requirements). End-of-cycle limitations such as those shown in Figure 1 (a result of boron dilution being limited by radwaste processing capacity) should be conveyed.

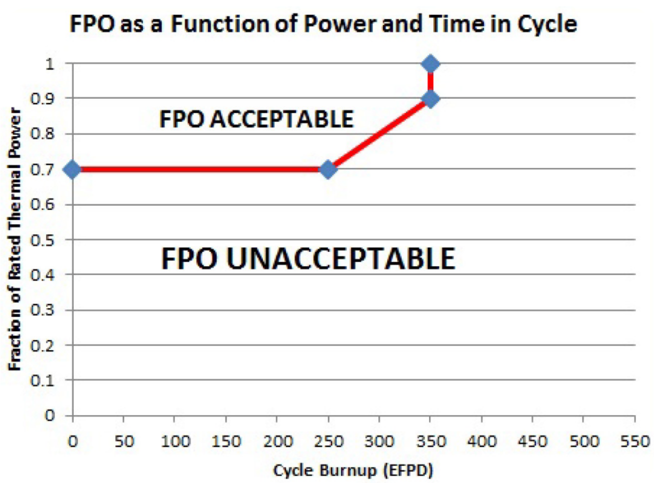

Figure 1 – Example of an FPO envelope that describes FPO acceptability throughout the fuel cycle for a PWR in terms of effective full-power days (EFPD) (Courtesy of Arizona Public Service Co.[1])

  - A simple and clear procedure for ISO/TSO communicating requested station output power changes to the operations crew is helpful.
  - The operations shift manager has the authority to opt out of FPO.
  - For companies operating multiple generation assets (for example, a fleet including both reactors and non-nuclear generation), an integrated process is useful for determining which generating resource to curtail when several resources are available to be curtailed. This provides additional responsiveness to grid demands.

- **Impacts of FPO initiation.** Following the initiation of FPO, impacts observed thus far are manageable within existing corrective action processes and ongoing performance improvement methods, guided by completed and ongoing research within the FPO program. Common details observed include the following:
  - Observation of four sites shows that little reallocation of operations or maintenance resources has been needed. For example, three visited sites have been successful with extensive FPO without reassigning personnel or changing budgets specifically to address FPO; instead, they have allowed some activities (for example, maintenance start times) to be temporarily delayed in order to meet FPO goals. Additional research insights on selected programmatic or long-term impacts are provided in Section 2.3.
  - Experience shows that if a degradation mechanism is (or could be) exacerbated by FPO, equipment failures are going to take time to present themselves. Two plants have adopted a good practice of using a unique trend code for FPO-related issues. This helps to ensure that issues are detected early and remain manageable within normal processes.

2.2 Additional Background Information Regarding Equipment Reliability Insights

- **Quality of fundamental practices.** Several stations experienced minor issues with balance-of-plant equipment during implementation of FPO. Examples included valve packing leaks on AOVs or MOVs, heater level control operation throughout the full range of reduced power requiring recalibration of controllers, and operational control of steam-driven pumps during ramps. In the cases encountered thus far, training craft technicians or operators on the applicable fundamental practice has corrected or controlled the equipment issues.
- **Westinghouse-designed reactor baffle former bolts.** Plant-specific analysis of Westinghouse-designed reactors is needed to address a degradation mechanism from FPO that affects baffle former bolts (a core internals component). Analysis shows that the baffle former bolts experience thermal cycling driven by gamma heating variations during power changes. Prior Nuclear Regulatory

1 Arizona Public Service Co, "Palo Verde Nuclear Generating Station Flexible Power Operation Scoping Assessment R1." 2016, with permission.

Commission- (NRC-) approved guidance for inspections (MRP-227-A) to manage this degradation mechanism assumed base-load operation as the basis for the recommended inspection intervals. Research is underway to provide guidance applicable to plants operating flexibly. Plant-specific analysis of Westinghouse plants is needed because the propensity for damage is affected by individual plant design.

- **Flow-accelerated corrosion (FAC).** Wear rates increase for some components with lowering power output. Although FAC rates will decrease for most components, rates can increase significantly for others. Plant-specific review of prior FAC program strategies is needed to address the following two issues. Piping that is not susceptible to FAC at 100% power may become susceptible at reduced power, requiring a unit-specific update to the FAC system susceptibility evaluation (SSE). This requires an update to any FAC software model being used (for example, CHECWORKS™) and Susceptible-Not-Modeled (SNM) risk ranking so that appropriate next scheduled inspections can be determined.

2.3 Additional Background Information Regarding Programmatic Insights

- **PWR crud-induced power shift (CIPS) and crud-induced localized corrosion (CILC).** Corrosion product transport may increase during power transients, and changes in boiling may change deposition patterns at reduced power, potentially changing the overall localized corrosion risk. Currently, cycle core analyses bound the impacts of these phenomena. EPRI research is continuing to combine utility data with EPRI Fuel Reliability Program simulations to assess the changes in risk associated with CIPS and CILC.
- **Primary-to-secondary leakage monitoring for non-steady-state powers.** If a PWR plant is operating flexibly and develops a primary-to-secondary leak (PSL), that plant should perform an evaluation prior to returning to full power based on guidance from EPRI's Steam Generator Management Program. If operating flexibly with a leak, how the leak rate is measured during power level changes will likely be more complicated. EPRI's Steam Generator Management Program is working to develop additional steam generator tube integrity guidance.
- **PWR reactor coolant system (RCS) pH control.** The industry has implemented restrictive control bands for RCS lithium concentrations in order to maintain pH within limits and optimize corrosion and radiation dose concerns. Changes to plant power levels implemented by changing boron concentration require additional effort to manage the RCS lithium concentration, including increased use of lithium.
- **BWR chemistry monitoring.** Using online chemistry monitoring, significant reactor water chemistry transients during a power change have been observed. The impact of power changes on chemistry parameters has been variable (sometimes improving a parameter, sometimes worsening a parameter). Chemistry control methods for injecting zinc or controlling aggressive anions such as chlorides or sulfates may need increased sampling frequency if only traditional grab samples are available. This could have impacts for water treatment systems, plant material, fuel, dose, etc. Research is ongoing toward improved guidance in support of FPO.

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Contact Information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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