Attachment A

Control Rod Friction Surveillance Recommendations for FANP Fuel Channels

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Definitions

EFID	Effective Full Insertion Days is a measure of time that a fuel channel is in proximity to a control rod.
EFID threshold	The EFID threshold is an EFID value above which the fuel channel is susceptible to abnormal bow.
EFPD	Effective full power days are the equivalent number of days at full power required to achieve a given core exposure.
Friction Cell	A control cell where the control rod does not settle within 30 seconds and the friction is attributed to channel deformation.
Exposure	The exposure of a fuel channel is equivalent to the accumulated exposure of the fuel bundle during the time the fuel channel resides on the bundle.
Exposure threshold	The exposure threshold is an exposure level above which the fuel channel is susceptible to abnormal bow.
Extended surveillance	Extended surveillance entails additional surveillance recommendations in the case where a Friction Cell is discovered.
Increased surveillance	Increased surveillance, beyond the Normal surveillance, involves periodic settle tests of control rods in a Susceptible core.
Normal surveillance	Normal surveillance requirements are contained in the plant Technical Specifications or plant operating procedures for control rod operability.
Suspect Cell	A Suspect Cell contains one or more suspect fuel channels.
Suspect fuel channel	A suspect fuel channel is one that is [ ] and exceeds both the exposure and EFID thresholds.
Susceptible core	A Susceptible core is a C- or S-lattice core that operates with FANP [ ] fuel channels and has Suspect Cells.

Control Rod Friction Surveillance Recommendations for FANP Fuel Channels

1.0 Introduction and Scope

Surveillance recommendations and bases are described as a means of avoiding excessive control rod interference with Framatome ANP, Inc. (FANP) BWR fuel channels. The recommendations address abnormal channel bow that is caused by early exposure to the control blades. The surveillance recommendations were conservatively derived from recent fuel channel bow measurements at Susquehanna Unit 1 and Grand Gulf. For utilities who already have implemented a control rod friction surveillance program, this document can serve as a basis for applying their existing surveillance program to FANP fuel channels.

As background, FANP recently issued a 10CFR Part 21 notification to the NRC on the impact of increased channel bow on the MCPR safety limit analysis for Susquehanna Unit 1 Cycle 14 (Reference 1). A number of slow control rods and several inoperable control rods resulted in a mid-cycle shutdown. Measurements were obtained on a large quantity of fuel channels and the cell friction problems were confirmed to be caused by excessive channel bow.

Fuel channel interference with the control rod, if unchecked, can slow scram insertion times, cause a stuck control rod, reduce margin to fuel lift, and increase loads on core internal components. If sufficient, channel bow can increase fuel rod power peaking and reduce margins to MCPR and LHGR operating limits. The surveillance program is formulated in a conservative manner to identify problem cell locations such that actions can be taken by the operators to help avoid control rod operability problems and to protect against exceeding fuel safety limits.

The surveillance recommendations provide a method to flag cells which could be vulnerable to increased channel bow and setting a surveillance interval to ensure cell friction is detected prior to exceeding allowable design limits (e.g., load limits for the fuel assembly, RPV internals, etc.). The vulnerability of the cells is determined from bow measurement data and the relation of abnormal bow to exposure, the degree of control rod insertion, and the number of channels in the cells that are vulnerable. The surveillance interval is estimated from bow measurement data to obtain a rate of increased channel bow (mils per day). This increased bow rate is used in combination with the calculated fuel assembly lateral stiffness and the allowed increase in the friction load to set a minimum frequency for testing.

Three levels of surveillance are defined depending on the susceptibility to abnormal channel bow and the detection of control rod friction:

1. Normal Surveillance: Perform normal control rod testing and scram insertion time testing as already required by Technical Specifications and/or plant operating procedures.
2. Increased Surveillance: Increased surveillance, in addition to the normal surveillance, using settle time tests for cells with fuel channels susceptible to abnormal bow.
3. Extended Surveillance: Extended settle time test sampling and frequency for cells identified with control rod friction and for Suspect Cells.

Figure 1.1 is flow chart that summarizes the decisions and actions for the three levels of surveillance.

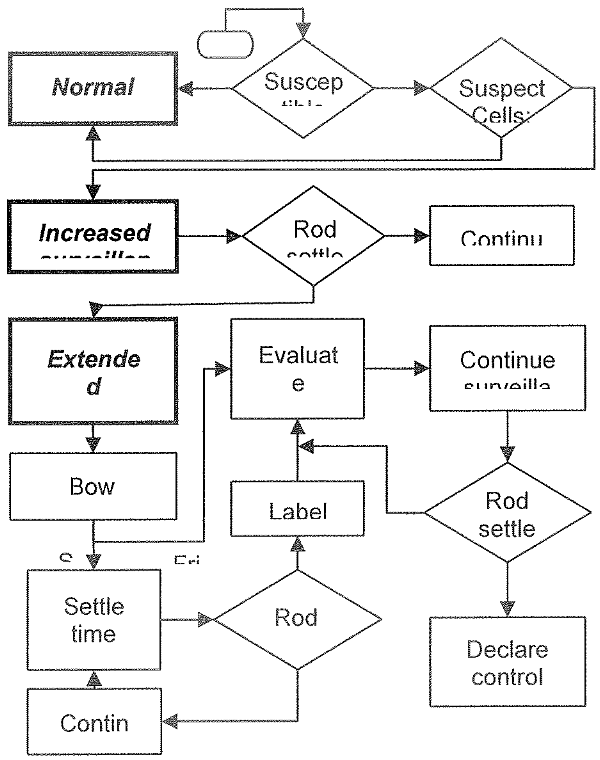

Figure 1.1 – Flowchart of Control Rod Friction Surveillance Recommendations

Increased surveillance of cell friction is recommended for plants with either C-lattice or S-lattice cell geometry and [ ] The recommended surveillance for plants with FANP fuel is shown in Table 1.1 below.

Table 1.1 – Recommendation of Plants for Cell Friction Surveillance

Plant	Core Lattice	Recommendation for Surveillance
Browns Ferry Unit 2	D-lattice	Normal
Browns Ferry Unit 3	D-lattice	Normal
Chinshan Unit 1	C-lattice	Increased
Chinshan Unit 2	C-lattice	Increased
Columbia Generation Station	C-lattice	Increased
Dresden Unit 2	D-lattice	Normal
Dresden Unit 3	D-lattice	Normal
Grand Gulf Nuclear Station	S-lattice	Increased
Kuosheng Unit 1	S-lattice	Increased
Kuosheng Unit 2	S-lattice	Increased
LaSalle Unit 1	C-lattice	Increased
LaSalle Unit 2	C-lattice	Increased
Quad Cities Unit 1	D-lattice	Normal
Quad Cities Unit 2	D-lattice	Normal
River Bend Station	S-lattice	Increased
Susquehanna Unit 1	C-lattice	Increased
Susquehanna Unit 2	C-lattice	Increased

The recommendations do not address the contribution of fast neutron fluence gradient to channel bow. Restrictions on fluence gradients are covered separately by core design guidelines.

In the case of a mixed core, the utility should consult with the other fuel vendor(s) and with FANP regarding the treatment of non-FANP fuel that is adjacent to FANP fuel.

The criteria and surveillance are described in Sections 2.0 and 3.0. Section 4.0 only needs to be read if an understanding of the bases for the surveillance is desired.

2.0 Criteria

To avoid excessive loads, the control rod friction force shall be limited to less than 600 lbf. The 600 lbf force limit is based on maintaining adequate margin to fuel lift. Fuel assembly and fuel channel structural integrity are also considered in establishing the 600 lbf limit. Normal operation, AOO and accident conditions are covered by the limit.

In addition, channel bow must remain within the assumptions of the safety analyses used to establish thermal operating limits. Control rod friction can be an indication of channel bow greater than assumed in the safety analyses and actions may be necessary to ensure that thermal operating limits remain conservative.

Other considerations for excessive friction load include the acceptability of loads on the control rod, the control rod drive mechanism, the top fuel guide and any other reactor internal structure that might be affected by the control rod-to-fuel channel friction. The utility should confirm that there are no load requirements for components other than the fuel that are more restrictive than the 600 lbf limit for fuel lift. If requirements that are more restrictive exist, then the utility should inform FANP so alternative recommendations can be provided.

In the case where non-FANP fuel is co-resident with FANP fuel, the utility should confirm with the non-FANP fuel vendor that the 600 lbf limit is acceptable.

A 250 lb weight is assumed for the control rod drive and connected drive hardware in deriving the test frequency. The value is an estimate of the wet weight and may vary from plant to plant. The utility should confirm with the applicable vendor(s) that 250 lb is a reasonable estimate.

In the event a control rod must be declared inoperable due to excessive friction, additional consideration is required for Technical Specification limits on the allowed quantities and locations of slow or inoperable control rods.

3.0 Surveillance Recommendations

The surveillance recommendations are organized in the following steps:

1. Identification of Suspect Cells.
2. Increased Surveillance - cell friction criteria, test frequency and sampling.
3. Extended Surveillance – evaluation of thermal operating limits, cell friction criteria, test frequency and sampling for cells exhibiting friction.

Refer to Figure 1.1 for the decisions and actions on surveillance. More details on the identification of Suspect Cells and the testing are provided below.

3.1 *Identification of Suspect Cells*

The identification of Suspect Cells is based on the fuel channel exposure and the exposure of the fuel channels to the control rod. The fuel channel exposure is in units of MWd/kgU and it is the accumulated bundle exposure during the time the fuel channel resides on the fuel assembly. The exposure to the control rod is time-based and it is characterized as Effective Full Insertion Days or EFID.

The EFID is calculated as a summation of the fraction of control rod insertion multiplied by the interval of time for the control rod position:

$$\text{EFID} = \Sigma\, F * (\text{fraction of control rod insertion})_i * (\text{days of operation at insertion fraction})_i$$

The factor, F, is defined as:

[

]

A control fraction of 1.0 is taken to coincide with notch position 00. Days of operation are calendar days at temperature. However, EFPD can be judged as a reasonable approximation of time if the plant is operating at a high capacity factor.

Threshold levels for fuel channel exposure and EFID vary by channel type as listed in Table 3.1.

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A cell is considered a "Suspect Cell" if one or more [ ] fuel channels in the cell exceed both the exposure threshold and the EFID threshold. Suspect Cells are subject to the Increased surveillance outlined in the following sections.

3.2 *Increased Surveillance - Test Frequency and Sampling*

The goal of the Increased surveillance is to identify any control rods that are experiencing the onset of friction such that further actions can be taken to help avoid operational or safety issues.

3.2.1 Test Criteria

A cell is considered to be experiencing friction if the control rod settle time, from the start of the "settle function" (i.e., when the settle light goes out) to the observation of the target notch position, is greater than 30 seconds for a change of a single notch. The control rod settle times can be measured anywhere in the range of near-full insertion down to a point above half insertion (i.e., notch positions 04 to 20).

If cell friction is observed, then additional evaluation is recommended to attempt to discount causes of cell friction other than channel bow (e.g., stroke time testing or settle time tests at intermediate notch positions).

If the control rod has a settle time greater than 30 seconds and evaluations do not rule out friction caused by channel deformation, then the cell is identified as a "Friction Cell."

Plant Technical Specifications should be consulted regarding control rod operability. In addition to Technical Specification requirements, the maximum control rod axial friction force shall not exceed 600 lbf. If the friction force is equal or greater than the 600 lbf limit, the control rod must be declared inoperable.

If the control rod remains operable, the Friction Cell is subject to the Extended surveillance described in Section 3.3.

3.2.2 Test Frequency

For Suspect Cells, cell friction testing should be conducted by sampling at a frequency interval of no more than [ ] of operation.

3.2.3 Test Sampling

At a minimum, [ ] Suspect Cells should be tested. If there are [ ] or fewer cells, then all Suspect Cells should be tested. Suspect Cells should be prioritized for sampling in descending order of [

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The Suspect Cells are acceptable if none fail the test criteria. If one or more cells fail the test criteria, then the sampling described for Extended surveillance applies to all Suspect Cells along with the identified Friction Cell(s).

3.3 ***Extended Surveillance***

Extended surveillance applies when Friction Cells are discovered. The Friction Cells are tested with increased frequency along with a load criterion. The remaining Suspect Cells are also subject to a larger sample size as described below. Refer to Figure 1.1 for a summary of the Extended surveillance.

3.3.1 Impact on Thermal Operating Limits

In addition to initiating the extended surveillance, compensatory actions may be required to ensure the adequacy of current thermal operating limits as impacted by increased channel bow.

Following the first discovery of a Friction Cell, additional plant specific evaluations should be performed to determine if sufficient conservatism exists in the safety limit MCPR (SLMCPR) analysis to eliminate or reduce the need for additional MCPR margin to compensate for the increased channel bow. In the absence of plant specific evaluations, administrative restrictions should be initiated to ensure that the margin to the operating limit MCPR remains greater than [ ] is sufficient for the increased channel bow observed to date based on evaluations performed at several plants (see Section 4.3).

The analyses used to establish the LHGR and MAPLHGR operating limits include sufficient conservatism to offset the impact of the increased channel bow observed to date; therefore, no compensatory actions are required for these operating limits based solely on observing control rod friction.

3.3.2 Extended Test Criteria

Test criteria for control rod friction are as described previously in section 3.2.1. In addition to satisfying Technical Specifications and/or plant procedures for operability as projected to the end of the test interval, the projected cell friction force limit (600 lbf) should not be exceeded at the end of the test interval. If the estimated friction force is less than 525 lbf, then the time interval should be reduced to [ ]. If the friction force is less than 600 lbf but greater than

525 lbf, then the interval should be reduced to ensure the 600 lbf limit is not exceeded by at the end of the interval by accounting for a force rate increase [ ].

Guidelines from the NSSS supplier should be consulted for estimating the control rod friction force based on specific hydraulic parameters.

3.3.3 Extended Test Frequency

The maximum test interval for a Friction Cell is reduced from [ ]. The test interval should be reduced if the estimated friction force is greater than 525 lbf as described in the preceding section.

Testing on Suspect Cells can continue at a [ ].

3.3.4 Extended Test Sampling

One hundred percent of the Friction Cells should be tested at the reduced time interval.

Increase the sample size to [ ] for the Suspect Cells. Or, test 100% if the quantity of Suspect Cells is [ ] or less. If an additional Suspect Cell fails the test criteria (Section 3.2.1), then test 100% of the Suspect Cells.

4.0 **Bases**

The bases for the identification of Suspect Cells, the test frequency and sampling are described here. Also, background is provided on the evaluation of the thermal operating limits in the case of cell friction.

The Increased surveillance in Section 1.0 is restricted to plants with C-lattice or S-lattice cores based on industry experience. To date, abnormal bow only has been observed for fuel channels [ ] in C-lattice and S-lattice cores.

While channel bow problems have not been observed [ ] at D-lattice plants, it is prudent to monitor for abnormal channel bow. The Normal surveillance for control rod operability that is required by the plant Technical Specifications or plant operating procedures should be sufficient to detect the onset of a general problem.

4.1 ***Identification of Suspect Cells***

Channel bow measurements from a sample of channels at two plants were evaluated to derive a measure for determining which channels are susceptible to abnormal bow. Signs of abnormal bow have been observed at Susquehanna Unit 1 (SUS1) in Cycle 14. A small quantity of channels was also observed to have unusual bow at GGNS (Grand Gulf Nuclear Station) at EOC 14.

Based on the operating experience of 80-mil fuel channels at SUS1, signs of friction were observed at fuel channel exposures of approximately [ ]. At GGNS, where the [ ] AFC (advanced fuel channel) is used, no abnormal bow was observed except above [ ]. A thinner wall thickness could explain the lower exposure threshold for the 80-mil design. Following this line of thought, the 100-mil FC (fuel channel) design is assumed to behave similar to the [ ] AFC. Hence, exposure threshold values were established at [ ] for the 80-mil FC, the 100-mil FC and the [ ] AFC, respectively.

To determine a measure for identifying abnormal bow due to control rod exposure, the data were fitted in such a way to segregate channels with abnormal bow. Figure 4.1 shows the measurements from the two plants.

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Figure 4.1 – Channel Bow Deviation versus EFID

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4.2 *Friction Test Sampling and Frequency*

The time interval for testing is established such that a channel with abnormally high bow is detected before excessive friction loads occur. Although a large number of channel measurements have been made in the last two years, data is lacking on the rate of excessive bow. For this reason, some assumptions are necessary to derive a test interval.

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Figure 4.2 – Estimation of Inspection Interval

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Figure 4.3 – Beam Model of Fuel Assembly For Stiffness Calculation

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Table 4.1 – Axial Friction Force per Deflection by Fuel Channel Type

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4.3 *Impact on Thermal Operating Limits*

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5.0 References

1. Letter, R. L. Gardner (FANP) to USNRC, "10 CFR Part 21 Notification of an Error in BWR Safety Limit," NRC:05:069, December 5, 2005.
2. ISO 2859-1 : 1989(E), "Sampling Procedures for Inspection by Attributes, Part 1: Sampling Plans Indexed by Acceptable Quality Level (AQL) for Lot-by-Lot Inspection," International Organization for Standardization, First Edition, 1989.