AREVA

Project 728

October 6, 2005
NRC:05:059

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Framatome ANP Perspectives and Status Regarding Current Industry Issues with Channel Performance

Framatome ANP perspectives and status regarding current industry issues with channel performance are described in the attachment to this letter. The purpose of this letter is to keep the NRC informed of Framatome ANP activities in this area. The current industry issues are channel bow due to shadow corrosion (NRC Information Notice 89-69, Supplement 1) and elevated control blade insertion and withdrawal resistance.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
Site Operations and Regulatory Affairs

cc: M. C. Honcharik
F. M. Akstulewicz
S.-L. Wu
Project 728

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FRAMATOME ANP, INC. An AREVA and Siemens company
3315 Old Forest Road, P.O. Box 10935, Lynchburg, VA 24506-0935
Tel.: 434 832 3000 - Fax: 434 832 3840 - www.areva.com

FANP Perspectives and Status Regarding Current US Industry Issues with Channel Performance

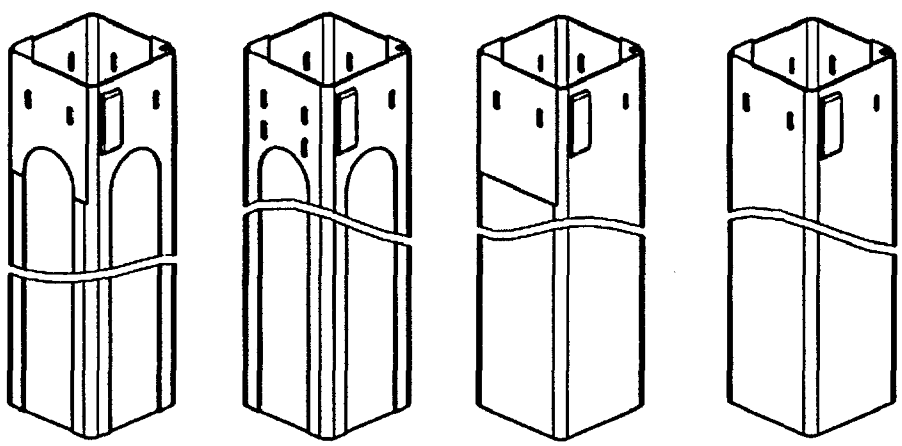
1. Channel Supply History

Since the late 1990's the supply of channels for BWR fuel assemblies has been an integrated part of all reload fuel supply contracts. Prior to that time, BWR operators procured fuel channels independent of reload fuel supply. For Framatome ANP (FANP), this resulted in FANP fuel bundles being combined with channels fabricated by either Global Nuclear Fuels (GNF) or Carpenter Specialty Products Corporation (CSPC).

The majority of FANP BWR fuel assemblies currently in operation utilize channels fabricated by CSPC from Zircaloy-2 and Zircaloy-4 sheet material produced by CEZUS. Both the product and material specifications for these channels are provided by FANP and the starting material and channels are then fabricated in accordance with FANP-approved processes. Most FANP fuel assemblies paired with GNF-supplied channels have now been discharged. Aside from the CSPC channels, channels from Kobe Steels Ltd. (KSL), added to FANP's Approved Supplier List in 2003, have now been introduced, though only in lead quantities in the US.

2. Current FANP Channel Supply

Even prior to the integration of channel supply under the scope of fuel supply contracts, FANP had begun extensive cooperative development efforts with CEZUS and CSPC, respectively to improve starting material and fabrication processes, to yield channels with enhanced performance characteristics. These cooperative efforts have been strengthened since FANP has become the supplier of record for the channels, assuring that all products meet FANP's own stringent specifications. As a result of these efforts, substantial improvements have been made in producing channels that exhibit greater dimensional stability and reduced corrosion with reduced variability between material and production lots.



Design (Type #)	Advanced (2)	Advanced (4)	Standard (5)	Standard (9)
Wall Thickness	0.114 in. @ corner 0.067 in. @ center	0.100 in. @ corner 0.075 in. @ center	0.100 in. uniform	0.080 in. uniform
Application	BWR/6	BWR/4 D (Sym) BWR/3,4,5 C	BWR/3,4,5 C	BWR/3,4,5 (phased out)

Currently, there are four FANP channel designs in use in the US market. These designs, illustrated above, are of either standard (uniform wall) design or the advanced channel design characterized by thick corners with thinner center panels.

2.1. Channel Fabrication

There are two primary approaches for fabricating the long square tube geometry of a fuel channel. The approach utilized by CSPC is to first roll a sheet wide enough to meet the final channel circumferential dimensions into a cylindrical tube. The sheet edges are seam welded together where they meet to close the tube and the weld is finished flush with the tubing wall. Prior to forming the tube, a blind weld is made in the center of the starting sheet along a line that will be directly opposite the actual closure weld. This assures symmetry in the heat affected regions of the finished channels, avoiding any potential differential irradiation growth rates of opposing faces due to asymmetric crystalline structure. In some applications additional blind welds have been included in the center of the faces perpendicular to the closure weld to further preserve symmetry. The welded tube is then drawn through a proprietary fixture to shape the basic square. After refining the shape through hot forming to near-final dimensions, the channel is fully annealed to remove all the cold work caused by the forming process. This eliminates the potential for bow and twist due to residual stress when the channel heats up in the reactor.

For advanced channels, after the channel has been formed, the center of each channel face is milled to the specified thickness using a machine developed by FANP and installed at CSPC facilities. The milling process eliminates reintroduction of cold work into the channel and the fixture assures that there is no dimensional distortion of the channel during the milling operation.

In the second channel fabrication approach, as employed by KSL and similar to that used by GNF, the channel is formed in two longitudinal halves which are then welded together. The process starts with the same starting material supplied to CSPC, except that the individual sheets are half as wide. These half sheets are taken from a common sheet of starting material and have been carefully marked to assure individual channels are fabricated from matched halves. This avoids issues of asymmetrical irradiation growth and creep characteristics of dissimilar halves in the finished channel. Each half sheet is formed into a "U"-shaped half channel and the edges are prepared for welding. Full-length seam welds at the center of opposing faces are then made to complete the square form. Thereafter, the process is similar to that employed by CSPC to produce the finished channels.

2.2. Channel Starting Material

The specifications and processes employed by FANP's channel suppliers assure that the delivered channels are straight and square to tight tolerances, free of residual stress, and have symmetric material microstructure. Aside from welding, none of the steps taken by the channel fabricator have any impact on the metallurgical properties of the channel material. Therefore, all in-reactor performance characteristics such as stress-induced creep, corrosion and hydrogen uptake, and irradiation-induced growth are essentially a function of the characteristics of the starting material sheet.

Both Zircaloy-2 (Zry-2) and Zircaloy-4 (Zry-4) have been used to fabricate channels currently in service and both materials have been shown to be satisfactory for meeting current operating demands. Variations in the sequence and nature of annealing steps employed during the processing of these zirconium alloys from the initial ingot to the final sheet can result in wide variations with respect to growth and corrosion rates and many other performance characteristics of finished components. This has been demonstrated through comprehensive controlled material development and irradiation programs and can also be seen in the significant differences observed between FANP and competitor products fabricated from material meeting the same ASTM specifications. The "pathfinder" programs employed by FANP to refine annealing sequences, both for Zry-2 and Zry-4, have resulted in production materials that exhibit very low corrosion and hydrogen uptake rates under irradiation. Further, when fully annealed to remove any residual stress and to create a uniform recrystalized grain structure in finished components, these materials also have low irradiation-induced growth and stress-induced creep rates.

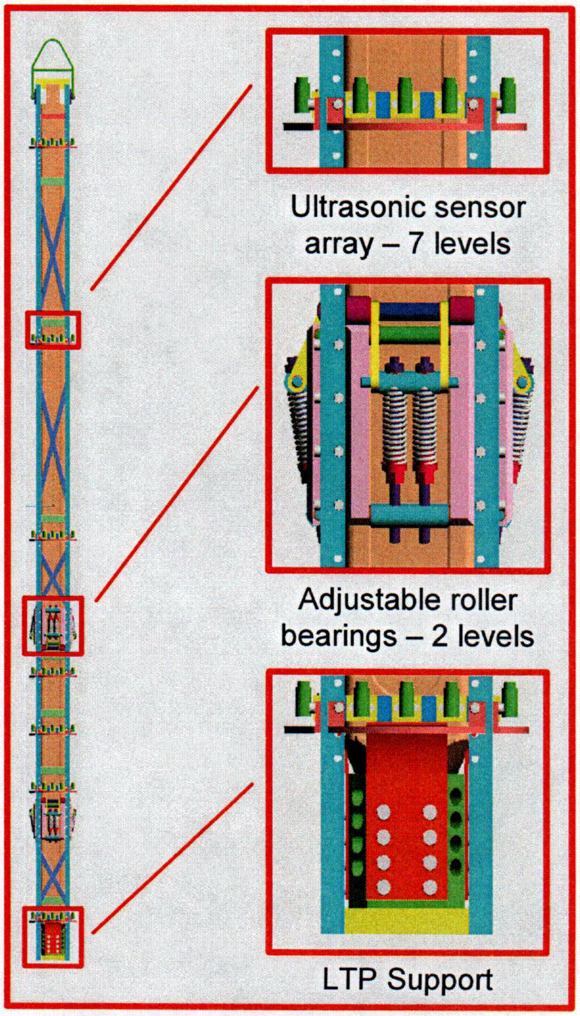
Comparisons between channels and spacers fabricated from Zry-2 and Zry-4 processed with optimized annealing sequences have shown Zry-2 to have lower corrosion levels on average than Zry-4 operating under the same conditions. Where control blades and instrument tubes in close proximity to channels have caused elevated corrosion in shadowed areas on the adjacent channel, Zry-2 channels have shown similar behavior as Zry-4 channels.

In addition to optimization of the annealing sequence, the alloy composition of Zry-2 used by FANP has been refined within the ASTM specifications, notably to assure iron content is at the upper end of the allowable range. These alloy refinements have been shown to further reduce corrosion rates. As noted above, FANP has worked closely with CEZUS to develop these refined specifications and processes to assure starting material used in channels and other structural components will consistently yield the best achievable performance.

2.3 Recent Channel Measurements

Notices regarding GNF fuel exhibiting channel bow exceeding predicted levels at several plants added weight to interest in obtaining current dimensional performance data for FANP fuel channels operating in US reactors. Therefore, a decision was made to fabricate and deploy a portable channel measurement system. FANP undertook this project in cooperation with EPRI and its participating utilities. Design and fabrication of the measurement equipment, illustrated below, was the sole responsibility of FANP, while EPRI provided funding and support for the initial measurement campaigns.

In order to avoid the need for a heavy contact measurement system limited to installation in cask loading areas, FANP developed a system based on use of



ultrasonic transducers. The ultrasonic transducers allow accurate measurement of surfaces in close proximity to the sensor without requiring physical contact. This provided the freedom to use a readily transportable light weight frame usable in any open area of the spent fuel pool. Once the transducers are calibrated to a reference channel standard, they are able to take multiple readings within two minutes, allowing accurate measurements of the channel shape regardless of its position and orientation within the frame.

Five measurement campaigns have been conducted to date at two BWR/4 C-lattice plants, one BWR/3 D-lattice plant, one BWR/5 C-lattice plant and a BWR/6 S-lattice plant. The range of measurements included channels fabricated by both GNF and CSPC and also provided data for comparison of Zry-2 and Zry-4, advanced and standard channel geometries, and polished and etched/autoclaved surface finishes, as well as other physical variations. The selected channels also operated under a wide range of fluence gradient conditions as well as differing levels of controlled operation. The respective operational data for measured channels has been captured from core monitoring data for use in evaluating measured bow and bulge.

All measurements of CSPC channels to date have fallen within the uncertainties assumed in FANP channel methodology. Of the many physical variations covered by the measured channels, only the difference in channel supplier was observed to have a significant impact on channel performance. Bulge of CSPC channels was found to be lower than the level assumed in FANP channel analysis methodology. Channel bow for CSPC channels was shown to follow expected trends for bow resulting primarily from differential fluence-induced growth of opposing faces for the majority of fuel assemblies.

3. Response to Current Performance Issues

FANP continues to closely monitor the performance of channels it has supplied as well as performance reports for channels supplied by GNF. On a general level, FANP materials experts continue to assess reports of shadow corrosion-induced hydrogen uptake to determine if the proposed mechanism is reasonable and, if so, to what degree FANP-supplied channels might be susceptible. More specifically, observations of slow settling times at several plants, each with full or partial cores of FANP fuel, are being closely followed to determine if they are attributable to unexpected deformation of FANP-supplied fuel channels.

3.1. Review of Shadow Corrosion Effects on Zirconium Alloys

The NRC issued an information notice[1] to the BWR industry regarding the observation of unexpected channel bow in GNF channels attributed to shadow corrosion effects. Since the time of that notice, FANP has been informed that material samples taken from affected GNF channels have confirmed high concentrations of hydrides in the channel walls facing the control blade. Accumulation of hydrides above a threshold level has been identified as the cause of excessive growth in the affected channel faces, in some cases reversing channel bow from the direction that would be predicted by fluence gradients. Further, it is FANP's understanding that GNF has provided guidelines to operators regarding the need to actively monitor control blade settling times for channels based on threshold values of controlled operation.

FANP materials experts have reviewed the above notice and related information, internal and industry information regarding what is known of the physics of shadow corrosion,

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[1] NRC Information Notice 89-69, Supplement 1: Shadow Corrosion Resulting In Fuel Channel Bowing

and relevant data for the shadow corrosion behavior of FANP channel materials. Although there is no dispute that GNF has observed elevated hydrogen levels in controlled faces of its fuel channels, the attribution of cause to the shadow corrosion mechanism is not consistent with FANP's understanding of the phenomenon. The complete mechanism of shadow corrosion has not yet been explained, but there is general industry concurrence that it is a form of galvanic corrosion, classically attributed to close proximity of dissimilar metals in an oxygenated electrolyte. Since shadow corrosion is only observed under irradiation, an additional mechanism to the galvanic potential is also involved. Postulated radiolysis from beta-radiation has largely been disproved as this additional mechanism and attention is now directed to photoconductivity among suspected contributors.

Under galvanic corrosion in BWR water chemistry, hydrogen would be expected to be driven away from the oxidized component. Therefore, hydrogen levels would be lower than the local oxide thickness layers would suggest, contrary to GNF's observations of increased hydrogen levels. Limited data on hydrogen levels in FANP materials subjected to shadow corrosion have been consistent with the expectation of lower hydrogen levels. Data from FANP fuel rods exhibiting shadow corrosion at spacer elevations due to close proximity of nickel-alloy spacer grids indicate the hydride densities under shadowed areas are no greater than the levels seen between spacer spans, where only normal corrosion is occurring. Therefore, a mechanism other than shadow corrosion may be responsible for the observed elevated hydrogen levels.

In order to determine if there is any correlation between shadow corrosion conditions and the recent FANP channel measurements, the data has been analyzed to determine if there are any trends in channel bow data that would provide evidence of a mechanism other than fluence-induced growth influencing channel behavior. In particular, operational histories of measured channels were reviewed to quantify the degree and timing of controlled operation experienced by the measured fuel channels. Such controlled operation would be necessary to drive shadow corrosion in the fuel channel faces adjacent to the control blades. Plots of channel bow against measures of controlled operation have not shown any clear correlation. If shadow corrosion is a contributing factor, a strong trend in measured bow as a function of controlled exposure would have been expected.

Based on the assumption that controlled faces of fuel channels are affected by elevated hydride uptake, as reported by GNF, explanations other than shadow corrosion as the causal factor are possible. For example, it is known that deposition of certain metals, notably platinum, rhodium, and nickel on an oxide-free zirconium alloy surface will act as hydrogen windows, transporting free hydrogen in the coolant into the zirconium alloy component walls. It remains to be determined if there is a credible scenario for such deposition and, if so, for preferential effects on controlled faces.

Additionally, since this phenomenon is relatively new, various coolant chemistry and operational changes from before and after interference issues arose are being examined as potential contributing factors. For example, zinc injection has been introduced in several plants over the past several years. Industry presentations regarding the enhanced spacer shadow corrosion failures in ABB Atom fuel rods at the Leibstadt BWR in Switzerland circa 1997 cite a strong correlation of shadow corrosion sensitivity to iron-deficient coolant chemistry. Many US plants have inherently low iron content in the coolant, where zinc injection could be expected to reduce the Fe/(Ni+Zn) ratio commonly used as a measure of iron-deficient conditions. No causal mechanism has yet been identified that would indicate such zinc injection is a contributing factor, but it remains among a wide range of changes that have occurred.

3.2. Continuing Efforts

Additional channel measurements have been scheduled at plants exhibiting elevated control blade insertion and withdrawal resistance. Detailed evaluations of the data collected to date, particularly from the most recent BWR/6 campaign and pending measurements, are continuing to determine if there are any clear trends in the measured channel bow as a function of various differences in operational and fabrication histories.

4. Conclusion

The US measurement data for FANP channels collected to date has only identified a small minority of channels exhibiting bow significantly divergent from that readily explained by fluence-induced growth and normal statistical variance among measurements. Even in these cases, the variance has not been outside the range considered in FANP's empirically-based channel bow methodology. Measurements of bulge consistently show reduced levels from that assumed in FANP's channel analysis methodology. Therefore, the treatment of channel deformation within FANP design and licensing methodology remains bounding for current operational experience.

Evaluations of channel bow as a function of controlled operation, particularly early in life, have only indicated a general trend in a small minority of measurements. However, the overall correlation is poor with wide scatter in the data, indicative of a stochastic process. Further, measured channel bow in assemblies present in cells where elevated control blade insertion and withdrawal resistance was observed have not shown sufficient bow to fully explain the observations. Therefore, factors other than just channel bow are potentially contributing these interference conditions.