Westinghouse

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066
USA

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

Direct tel: (412) 374-5130

e-mail: hosackkl@westinghouse.com

LTR-NRC-19-51

September 6, 2019

Subject: Submittal of Supplemental Comments on the Draft Safety Evaluation for Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3" (EPID L-2014-TOP-0002) (Proprietary/Non-Proprietary)

Enclosed are the proprietary and non-proprietary versions of the Submittal of Supplemental Comments on the Draft Safety Evaluation for Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3" (EPID L-2014-TOP-0002) (Proprietary/Non-Proprietary).

This submittal contains proprietary information of Westinghouse Electric Company LLC ("Westinghouse"). In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Nuclear Regulatory Commission's ("Commission's") regulations, we are enclosing with this submittal an Affidavit. The Affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to the proprietary aspects of the this submittal or the Westinghouse Affidavit should reference AW-19-4939 and should be addressed to Camille T. Zozula, Manager, Infrastructure & Facilities Licensing, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 1, Suite 165, Cranberry Township, PA 16066.

Korey L. Hosack, Manager
Product Line Regulatory Support

cc: Ekaterina Lenning (NRC)
Dennis Morey (NRC)

Enclosures:
1. Affidavit AW-19-4939
2. Proprietary Information Notice and Copyright Notice
3. Submittal of Supplemental Comments on the Draft Safety Evaluation for Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3" (EPID L-2014-TOP-0002) (Proprietary)
4. Submittal of Supplemental Comments on the Draft Safety Evaluation for Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3" (EPID L-2014-TOP-0002) (Non-Proprietary)

© 2019 Westinghouse Electric Company LLC. All Rights Reserved.

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

COUNTY OF BUTLER:

(1) I, Korey L. Hosack, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse).

(2) I am requesting the proprietary portions of LTR-NRC-19-51 be withheld from public disclosure under 10 CFR 2.390.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged, or as confidential commercial or financial information.

(4) Pursuant to 10 CFR 2.390, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse and is not customarily disclosed to the public.

(ii) Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

(5) Westinghouse has policies in place to identify proprietary information. Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

AFFIDAVIT

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (5)(f) of this Affidavit.

AFFIDAVIT

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 20190909

Korey L. Hosack, Manager
Product Line Regulatory Support

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and non-proprietary versions of a document, furnished to the NRC in connection with requests for generic review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the Affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

COPYRIGHT NOTICE

The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.390 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

Enclosure 4

Submittal of Supplemental Comments on the Draft Safety Evaluation for Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3"
(EPID L-2014-TOP-0002)

(Non-Proprietary)

September 2019

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

© 2019 Westinghouse Electric Company LLC
All Rights Reserved

After reviewing the Draft Safety Evaluation (SE) following the ACRS Subcommittee meeting on August 21, 2019, primarily for proprietary information, Westinghouse has identified several additional recommended changes. These changes are listed below and highlighted in the attached mark-up of the draft SE.

	SE Page	Comment
1.	34	In 3.2.1.1, 1st paragraph, modify text
2.	36	1st paragraph, modify text
3.	36	Replace 2nd paragraph with new text
4.	36	5th paragraph, modify text
5.	36	Remove first footnote
6.	38	In 3.2.2, 2nd paragraph, modify text
7.	42	4th full paragraph, remove bracketing on first three lines
8.	43	3rd paragraph, modify text

[

]a,c Because Westinghouse demonstrated that the D5 model was able to conservatively predict the transient behavior and that those transients were representative of the limiting AOOs which could be expected on SVEA96 SVEA-96 Optima 3 fuel, the NRC staff has determined that this goal has been met.

3.2 Single fuel rod failure and multiple v-shaped marks at Leibstadt NPP

In 2015, the NRC staff became aware of operating experience from the Leibstadt NPP, in which steady-state dryout was believed to have occurred and resulted in a fuel failure. The failure occurred in a SVEA-96 Optima2 fuel assembly, which is very similar design to the Optima3 fuel assembly and uses a correlation that is very similar to D5. Because dryout is supposed to be prevented by the minimum CPR (MCPR) safety and operating limits, the NRC staff evaluated this operating experience to determine if there were underlying issues with the CP correlation and/or the fuel design in use at Leibstadt NPP that could affect the acceptability of the D5 correlation.

3.2.1 Description of Circumstances

3.2.1.1 Initial Discovery of a Failed Fuel Rod

On July 5, 2014, towards the end of Cycle 30, reactor power at Leibstadt NPP was decreased from 100 percent to 80 percent in anticipation of a planned rod pattern adjustment and control rod integrity test. Due to operator error, after the reactor had successfully been powered down to 80 percent, the control system attempted to bring the reactor back to 100 percent power by quickly opening the recirculation system flow control valves. The resulting increase in flow collapsed steam voids in the core, leading to an increase in neutron flux. The measured neutron flux quickly reached 118 percent, resulting in an automatic reactor scram. During the transient, the maximum heat flux from the cladding to the coolant was believed to have only reached 87 percent of its rated value at full power. Plant operators subsequently restarted the reactor. Seven days after the reactor scram, on July 12, 2014, an increase in inert gas activity was detected consistent with fuel rod damage. **The area of the affected bundle was located and** ~~The control cell containing the affected bundle was located and its~~ the power **was suppressed with a control blade** in ~~a~~ **the** neighboring **control** cell ~~was suppressed with a control blade~~. The plant then continued operation until shutting down for a planned outage on August 11, 2014.

During the outage following Cycle 30, the affected fuel bundle was identified. Inspection of this fuel bundle found substantial localized oxidation of the zirconium cladding surrounding a cladding perforation on one rod, and a later inspection found what was believed to be increased localized oxidation on symmetric rod locations within the bundle. The affected bundle was not reloaded into the core when the plant was restarted for Cycle 31. Given the oxidation and the shape of the markings, it was initially assumed that dryout had occurred. However, the fuel assembly in question should have had substantial margin to dryout during normal operation [

]a,c

3.2.1.4 Post-Irradiation Examinations

Following Cycle 32, a number of fuel rods with V-shaped marks were subjected to further examination. In total, there were 205 visual inspections of fuel assemblies, **[ ]a,c** pool side inspections using the Frequency Scanning Eddy Current Technique (FSECT)**, diameter measurements performed on affected rods in the failed bundle**, and three rods sent for hot cell examinations at the Paul Scherrer Institute. The rods sent for hot cell inspection included **[**

]a,c

[

]a,c

[

]a,c

[

]a,c

Hot cell examinations and poolside measurements revealed that the vast majority of the observed V-shaped marks were not the result of excessive cladding oxidation, but instead were localized crud deposits. The crud was zinc-based (mainly ZnO and Zn_2SiO_4) and believed to be deposited by the repeated formation of dry patches or near dry patches (i.e., localized dryout/rewet of the coolant film). The crud was very water soluble and, as a result, crud could only be deposited in a region if the adjacent water film had a very high concentration of the chemical compounds present in the crud. While the crud could have been deposited when a dry patch formed, it could also have resulted from a thinning of the liquid film on the surface to a point that would allow the chemical compounds to be concentrated enough to come out of solution (without complete dryout). Given that there was some increase in oxidation for some of the fuel rods, dry patches must have formed

~~1~~ **[**

]a,c

on these rods at some point, and possibly many times[1]. Because only a small quantity of crud could be deposited during a single evaporation or near evaporation of the thin film, the same rod would have to experience multiple evaporation and rewet cycles to deposit the amount of crud observed from the hot cell testing.

The hot cell testing along with FSECT measurements provided insights into the maximum temperatures that were likely obtained in the fuel. During normal operation, radiation damage progressively increases the hardness of the cladding and the cladding liner. The hardness saturates in about 6 months (Ref. 21). While the plant operates **with cladding surface temperature around 286°C (saturation temperature of water at 70 bars)**~~at temperatures around 325°C~~, the hardness due to radiation damage will begin to recover (i.e., the cladding will anneal) if the

[1] For cases in which oxidation did not increase, it is not possible to distinguish between if a fuel rod experienced a dry patch (complete dryout of the water film which deposited crud) or a near dry patch (extreme thinning of the water film allowing which deposited crud). Therefore, the term dry patch will be used for both instances.

As discussed in Section 3.2.1.4 above, the V-shaped marks were found to be composed of a zinc-rich crud that was very water soluble. Tests on the cladding and liner hardness carried out during the hot cell examinations concluded that even the most affected rods likely did not experience cladding temperatures in excess of 500°C (932°F).

Based on the operating characteristics of the Leibstadt NPP plant and core, the characteristics of the SVEA-96 Optima2 fuel, and the characteristics of the zinc-rich crud layer, the NRC staff concluded that the markings were probably created during the fuel's first cycle of operation, and likely towards the end of the cycle. The affected bundles were all operated at bundle powers of greater than 7.4 megawatts over the period during which the marks are believed to have been created. However, the affected bundles also had significant steady-state MCPR margin in their first cycle of operation, with a minimum CPR of 1.38 among affected bundles. In the cycles in which the marks are believed to have been created, the core flow was maintained above 97 percent for an extended period near the end of the cycle.

3.2.2 Evaluation

Though the inspections discussed above were carried out as the result of the failure of a fuel rod during Cycle 30 at Leibstadt NPP, the inspections uncovered very little about the ultimate cause of this failure, which is not definitively known. Inspections of numerous other rods apparently affected by the same phenomena found, as discussed above, at most limited degradation that remained well within Swiss regulatory limits.

V-shaped marks of the type observed at Leibstadt NPP were only found on SVEA-96 Optima2 fuel, of which full cores have been loaded at Leibstadt NPP since Cycle 28. Westinghouse has inspected **[ ]**^{a,c} Optima2 assemblies from **[ ]**^{a,c} other BWRs, including another BWR/6, and found no other similar marks. In total, over 12,000 Optima2 assemblies have been operated, many of which operated at lower CPRs than the assembly in which the fuel rod failure occurred, with no failures or ~~other indication of dryout~~**similar marks on the cladding**.

To determine the underlying phenomena that caused the fuel rod failure and dry patches at Leibstadt NPP, Westinghouse conducted a root cause investigation into the V-shaped marks observed at Leibstadt NPP, which concluded that the marks were the result of dry patches that formed due to the combined effect of bi-stable recirculation loop flow and the formation and dissipation of vortices at fuel assembly inlet orifices.

Over the course of this review, the NRC staff focused on three of those potential root causes which it considered to be the most significant. The first root cause considered was that dryout had occurred and the D5 CPR model had not predicted the margin correctly. The NRC also considered that an unanalyzed intra-bundle instability had occurred between the subchannels in the fuel bundle. The final root cause considered was that the dry patches were the result of local flow disturbances caused by vortex dispersal and reformation in front of SEO positions which itself was aggravated by high frequency bi-stable flow; this is consistent with the root cause proposed by Westinghouse. These root causes are all evaluated in the following sections.

3.2.2.1 Possibility of Error in D5 CPR Model

The NRC staff is aware of two previous events in which dryout occurred during operation of a NPP. In 1988 at Oskarshamn 2 (Ref. 27), one corner rod had failed in each of four fuel

were observed (above the 1/3 part-length rods) **[**
][a,c]

The NRC staff concluded based on a review of the experiments discussed above that step changes in the local flow conditions could momentarily disrupt a thick annular film, and that such a disruption would produce dry patches with the characteristics observed at Leibstadt NPP. Next, the NRC staff considered Westinghouse's explanation of what could cause such step changes to occur.

Step changes in flow caused by vortex formation and dispersal

Early in the inspection process, it became apparent that the V-marks were strongly correlated to the SEO position. While V-marks were also observed in some SEO-2 positions, it was with much less frequency than V-marks observed in SEO-3 positions. V-marks were never observed in SEO-1 positions. This strong correlation to SEO position suggested that the V-mark formation could be related to another phenomenon which was also correlated to SEO position.

In 2002, the General Electric Company (GE) submitted a Part 21 notification to the NRC (Ref. 33) discussing the need to adjust the SEO loss coefficients due to the core support structure, as bundles adjacent to zero core support beams (SEO-1), one core support beam (SEO-2), or two core support beams (SEO-3), as these bundles had loss coefficients which were too low. SEO-2 positions should have had a loss coefficient about 20 percent higher than SEO-1 positions, and SEO-3 positions should have had a loss coefficient about 40 percent higher than SEO-1 positions. The overall impact of this correction to the CPR margin was approximated to be 0.01. This represented a very minor impact, but it was accounted for BWR/6 CPR values.

~~[~~Later testing provided some insights as to what could have caused the difference in the loss coefficients. Multiple tests (as well as computational fluid dynamics (CFD) analysis) demonstrated that vortices would form below SEO-3 and SEO-2 positions (Refs. 20 and 21). **[**

][a,c]

The NRC staff concluded based on a review of the experiments, analysis, and operation data discussed above that there are likely vortices which exist in the lower plenum next to SEO positions, that these vortices seem to have the most impact on SEO-3 positions, and these vortices would cause the step change in local flow conditions should the vortices suddenly form or dissipate. However, the presence of vortices alone would not cause step changes in local flow conditions. Therefore next, the NRC staff considered Westinghouse's explanation of what could cause the vortices to form and dissipate, resulting in a step change of flow conditions.

Vortex formation and dissipation caused by bi-stable flow

Based on experimental data, computational analysis, and plant data, Westinghouse postulated that vortices would form in the lower plenum of a BWR/6 under normal conditions, but that they could be dispersed by strong crossflows. Westinghouse further postulated that strong crossflows in the lower plenum were generated at Leibstadt NPP during the affected cycles by bi-stable flow conditions in the recirculation loops. Bi-stable flow is a phenomenon that is documented to occur in some BWRs (Refs. 29 and 30). It is related to the design of the recirculation system and occurs when the recirculation loop flow oscillates between two stable modes. **[**

][a,c]

Westinghouse believed that following a vortex dissipation caused by a bi-stable flow transition, the vortex would re-form (potentially in a different structure) with the resumption of a stable flow pattern in the lower plenum. They hypothesize that vortex dissipation and reformation would cause a sudden change in bundle flow conditions, which would then result in the temporary disruption of the waves in the annular film region where the dry patches were postulated to occur. **[**

][a,c]

The NRC staff concluded based on a review of the plant data, that bi-stable flow conditions at Leibstadt NPP could cause vortices to form and dissipate, that these conditions were prevalent when in cycles where V-shaped marks were observed, that when these conditions were avoided in later cycles V-shaped marks were no longer observed, and that **[**

][a,c]

<u>Summary</u>

In summary, the NRC staff concluded that Westinghouse's root cause provided a phenomenological explanation of the formation of the V-shaped marks and is supported by inspection data, experimental data, and computational analysis. The root cause explains why the V-shaped marks were determined to have formed at the end of the cycle, how the V-shape marks could form and rewet intermittently and repeatedly allowing crud to build up, and why fuel rod surface temperatures remained relatively low. The root cause explains why SEO-3 positions would be the most susceptible and what **[**
][a,c] Finally, the root cause explains why the Vshaped marks were observed in certain cycles and not observed in other cycles.

---

[1] **[**

][a,c]