Responses to the Second Request for Additional Information on WCAP-15942-P-A, Supplement 1, Revision 1, "Material Changes for SVEA-96 Optima2 Fuel Assemblies" (Non-Proprietary)

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RAI-3 GROWTH

Comment - *The response states that the growth between BWR* ***Low Tin ZIRLO™*** *[ ]a,c channels will be similar to [ ]a,c guide tubes. No data are provided to substantiate this claim. For example, the corrosion including shadow corrosion may be different for these two different reactor applications that would change the hydrogen pickup and subsequent growth due to hydrogen.*

Question 1 - Please provide the BWR and PWR [ ]a,c growth data to substantiate the claim that irradiation growth [ ]a,c between BWR **Low Tin ZIRLO™** [ ]a,c channels and [ ]a,c.

Answer Question 1: Figure 1 shows the experience of Zry-4 and [ ]a,c thimble tube growth in PWRs, along with data for **Low Tin ZIRLO™** channel growth in BWRs. Based on this data, **Low Tin ZIRLO™** channel growth in BWRs is similar to that for the standard [ ]a,c thimble tube growth in PWRs.

[ ]a,c

Question 2 – When will additional oxide and hydrogen data become available along with their projected burnup levels and how does this compare to the projected schedule for the first reload with **Low Tin ZIRLO™** channels in a US plant?

Answer to Question 2: Data on oxide thickness and hydrogen pick-up from [ ]a,c.

The first [ ]a,c of a similar program at [ ]a,c was finished in the summer of 2013, with channels seeing a burnup of [ ]a,c. Channel bow measurements obtained during this outage continue to show very good channel bow behavior at this burnup level. The channels were inserted in the core [ ]a,c. Measurement data from these channels will be obtained during the 2014 outage.

The first reload of **Low Tin ZIRLO™** channels in a US reactor is currently planned for 2014, which is consistent with when additional data from the [ ]^{a,c} will be available.

2) Comment - *Table 1 lists averaged measured hydrogen from one PIE examination of a fuel channel at [ ]^{a,c} and then estimates the average hydrogen level for **Low Tin ZIRLO™** channels at [ ]^{a,c}. Discussions in the submittal (WCAP-15942, Supplement 1, Revision 1) suggest that there are very large variations in oxide thickness and hydrogen levels both axially and for different sides (control blade versus non-control blade side) of the channel.*

Question 3 - How is average hydrogen measured for channel growth with such a large variation in measured oxidation and hydrogen in channels and what are the uncertainties in the hydrogen value for **Low Tin ZIRLO™**, for both the one PIE channel examined and the projected value at [ ]^{a,c}? .

Answer to Question 3: The hydride concentration on the specific **Low Tin ZIRLO™** channel is measured by [ ]^{a,c} The average hydride concentration is calculated as an average of the samples [ ]^{a,c} The uncertainty of the [ ]^{a,c} The projected value at [ ]^{a,c} is based on a total elongation of [ ]^{a,c} with a predicted irradiation growth of [ ]^{a,c}. Thus, the average hydrogen concentration in **Low Tin ZIRLO™** channels at [ ]^{a,c} will be much less than [ ]^{a,c}.

Question 4- How many samples were taken axially at which locations and how many per channel side at each axial location to determine the average hydrogen?

Answer Question 4: The average hydrogen content in the base material was detected by [ ]^{a,c}, the elevation of the samples at each side is shown presented in Table 1. The samples were neither taken in the longitudinal weld positions nor in shadow position.

Table 1: Elevation of samples at each side.

a,c

Question 5 - What are the uncertainties in the [ ]^{a,c} hydrogen for a channel given the small amount of data?

Answer to Question 5: The calculation of length increase due to the hydrogen content is based on the assumption that hydride contains [ ]^{a,c}.

Question 6 - Are there any differences in the data provided in Figure 4.2-1 of original submittal dated September 2010 and Figure 1 in the revised responses (also Figure 4.2-1 of August 2012 revision of submittal)? If so please describe the new data added including the material, equivalent burnup level and growth of the new data such that this additional data can be considered to determine if additional data are necessary to confirm **Low Tin ZIRLO™** performance at high burnup.

Answer to Question 6: There are additional data in Figure 4.2-1 in the revised response compared to the submittal dated September 2010. The added data are from channels that have been inspection during the period from September 2010 and August 2012. In addition to new data being included, two **Low Tin ZIRLO™** channel points at [ ]^{a,c}. All other data points in the figures have been measured with qualified equipment.

The Table 2 below presents the additional data in the revised response for each material.

Table 2: New data since September 2010.

a,c

[ ]

The added data points are also visible in Figure 2 below, the basis for this figure is Figure 4.2-1 in the revised response from 2012 with the new data added marked.

New data at higher burnup for **Low Tin ZIRLO™** channels will be available in 2014. The projected burnup for these channels is approximately [ ]^{a,c} for channels that have operated for 24 month cycles and [ ]^{a,c} for channels that have operated in 12 month cycles.

a,c

Figure 2: Channel Growth

RAI-3 AND 6 CHANNEL BULGE AND CREEP

Comment – *[ ]^{a,c}. However, thermal creep does not always represent the characteristics of irradiation induced creep because there are different mechanisms involved. The response and submittal notes that niobium is known to decrease the creep rate but it is also known that reducing the tin level in zirconium alloys will also increase the creep rate. The tin content in* ***Low Tin ZIRLO™*** *is [ ]^{a,c} Therefore, it cannot be automatically assumed that a creep model for [ ]^{a,c} can be applied to* ***Low Tin ZIRLO™*** *because the effect of [ ]^{a,c} may increase the creep rate more than the niobium reduces the creep rate. Therefore, irradiation creep data are needed for* ***Low Tin ZIRLO™****.*

Question 7 - How and when will irradiation data be available to confirm the assumption that the [ ]^{a,c} creep model is applicable to **Low Tin ZIRLO™** and how does this compare to the schedule for the first reload with **Low Tin ZIRLO™** channels in a US plant?

Answer to Question 7: [ ]^{a,c} channels have been measured regarding creep deformation at an equivalent burnup of [ ]^{a,c}. [ ]^{a,c} were **Low Tin ZIRLO™** channels and [ ]^{a,c} were Zry-2 BQ channels. The creep deformation for the **Low Tin ZIRLO™** channels was about [ ]^{a,c} and of the calculated creep deformation, for the Zry-2 BQ channels the creep deformation was about [ ]^{a,c} of calculated values with current [ ]^{a,c} creep model.

RAI-4 DATA FROM LTAS

Question 1 - Are the [ ]^{a,c} data included in the latest revised submittal (August 2012) and responses? If so, please identify these data in the figures provided. If not, please explain.

Answer to Question 1: [ ]^{a,c} data is included in the figures in the revised submittal and responses. In Figure 3, Figure 4, Figure 5, and Figure 6 below, data from [ ]^{a,c} are marked in each plot [ ]^{a,c}.

Figure 2-15 from WCAP-15942-P-A, Supplement 1, Revision 1 and Figure 2 from response to the NRC's Request for Additional Information on WCAP-15942- P-A, Supplement 1 is presented in Figure 3 with data from [ ]^{a,c} marked in the plot.

a,c

Figure 3: Channel Bow.

Figure 4.2-14a from WCAP-15942-P-A, Supplement 1, Revision 1 (SVEA Channel oxide) is presented in Figure 4 and Figure 5 with [ ]^{a,c} data marked in the plots (two figures with oxide thickness in the control rod sides, 1 and 4, and on non control rod sides, 2 and 3).

a,c

Figure 4: Maximum Oxide Thickness side 1 and 4.

a,c

Figure 5: Maximum oxide Thickness side 2 and 3.

Figure 4.2-14b from WCAP-15942-P-A, Supplement 1, Revision 1 (SVEA Channel average oxide) is presented in Figure 6 with [ ]^{a,c} data marked in the plot.

a,c

Figure 6: Average Oxide Thickness.

RAI-8 CHANNEL BOW

Comment - *There are several inconsistencies in the response, the submittal, and the original approval due to the concern of channel bow impeding control rod insertion:*

- *First inconsistency: The limit on channel bow is stated as [ ]^{a,c} standard deviation of [ ]^{a,c} for a symmetric lattice (response to RAI-8b and Figure 6). However, page 4-10 of the revised submittal (August 2012) states the standard deviation is [ ]^{a,c} for a symmetric lattice.*

- *Second inconsistency: In the approved methodology for evaluating clearance between the channel and blade to assure control rod insertion, the approved methodology is for [ ]^{a,c} the standard deviation. However, the analysis provided in the submittal to demonstrate adequate clearance between channel and blade used only [ ]^{a,c} standard deviation of [ ]^{a,c}.*

- *Third inconsistency: In the statistical level for calculating channel bow for determining control rod insertion, the approved methodology is intended to bound the data at a 95/95 level. Examination of the data demonstrates that [ ]^{a,c} (assuming standard deviation from page 4-10 of revised submittal) does not appear to bound the data in Figure 6 of revised responses at a 95/95 level for a symmetric lattice. This may suggest the standard deviation is incorrect.*

- *Furthermore, if a [ ]^{a,c} standard deviation value of [ ]^{a,c} is used, it appears to provide an interference fit that will restrict control rod movement given the minimum clearance of [ ]^{a,c} provided in the submittal that would impact control rod insertion*

Question 1 – Given the two different values of standard deviation quoted for a symmetric lattice, which value of standard deviation is used to determine channel clearance with the control blade at EOL?

Answer to Question 1: The historical [ ]^{a,c} database standard deviation of [ ]^{a,c} is still conservatively used for current [ ]^{a,c} and also **Low Tin ZIRLO™** channels when evaluating the combined effect of [ ]^{a,c} to the modified and approved criteria concerning maximum [ ]^{a,c} according to the response to RAI-15 of WCAP-15942-P-A. [ ]^{a,c} standard deviations i.e. [ ]^{a,c} are used in the evaluation.

Question 2 - Provide an example analysis using the value of standard deviation and the approved analysis methodology of [ ]^{a,c} standard deviation. For this analysis, [ ]^{a,c} along with a discussion on why [ ]^{a,c} will allow adequate control blade movement based on testing with various interference clearances.

Answer to Question 2: As described in the response to RAI-15 of WCAP-15942-P-A the largest range of channel bow experienced by SVEA fuel has been in the [ ]^{a,c}, for which a completely successful operating experience exist concerning compatibility with control rods, including ability to meet maximum [ ]^{a,c}.
According to the approved methodology, [ ]^{a,c} is thus used as a reference to bound a similar evaluation for each US application concerning the risk of control rod maneuvering issues with SVEA-96 Optima2 fuel.

The approved methodology according to the response to RAI-15 of WCAP-15942-P-A includes worst case combination of [ ]^{a,c}. The maximum bulge is, among other conservative assumptions, calculated with [ ]^{a,c}.

See sample analysis below for a BWR/6 C-lattice plant applying the approved methodology according to the response to RAI-15 of WCAP-15942-P-A:

a,c

[ ]

When conservatively assuming the historical [ ]^{a,c} channel bow also for current [ ]^{a,c} and **Low Tin ZIRLO™** channel materials, the BWR/6 C-lattice case results above are virtually identical to corresponding calculation of maximum interference with [ ]^{a,c} respectively for [ ]^{a,c} in the response to RAI-15 of WCAP-15942-P-A. When comparing maximum statistical [ ]^{a,c} channel bow for [ ]^{a,c} in Figure 6 in response to RAI-8 dated August 2012, with corresponding historical value for [ ]^{a,c} indicated in the same figure, it can further be concluded that the conservatism when using the historical [ ]^{a,c} channel bow in the analysis for modern [ ]^{a,c} and **Low Tin ZIRLO™** channel materials is several millimeters. The BWR/6 case, with [ ]^{a,c} and **Low Tin ZIRLO™** channel material, is thus clearly bounded by the [ ]^{a,c} reference case with [ ]^{a,c} channel material, both for the [ ]^{a,c}, and thus falls within the experience base for which control rod insertion has been demonstrated for the largest range of channel bow for SVEA channels.

Therefore, the extensive and completely successful operating experience in [ ]^{a,c} concerning control rod maneuvering with SVEA channels, including tests to verify fulfillment of maximum [ ]^{a,c} (results from [ ]^{a,c} are summarized in the response to RAI-15 of WCAP-15942-P-A) have proven that applications with **Low Tin ZIRLO™** as well as [ ]^{a,c} channel material, showing less [ ]^{a,c} than the reference case [ ]^{a,c} with historical [ ]^{a,c} material, will allow adequate control blade movement.

Verification that the [ ]^{a,c} reference is still bounding is performed for every new US application with an analysis as described above as well as in the response to RAI-15 of WCAP-15942-P-A, using reactor specific input data and including the combined effect of [ ]a,c.

The improved channel bow behavior of **Low Tin ZIRLO™** channels will not reduce but rather add margin concerning control rod maneuvering.

Question 3 - Will **Low Tin ZIRLO™** channels also be applied to asymmetric lattice plants in the US? If so, please provide an example analysis for an asymmetric lattice plant similar to item a. above. Will Lead Test Assembly irradiations be performed in an asymmetric lattice prior to a reload because there is very little asymmetric data?

Answer to Question 3: Yes, **Low Tin ZIRLO™** channels will be applied to asymmetric lattice plants in the US. **Low Tin ZIRLO™** channel LTAs were inserted into [ ]a,c. [ ]a,c LTAs were inserted into each plant in locations with [ ]a,c.

See sample analysis below for a BWR/3 D-lattice plant (same bulge data used as in response 2 above), applying the approved methodology according to the response to RAI-15 of WCAP-15942-P-A (see also response 2 above concerning conservative assumptions in the analysis):

a,c

[ ]

The calculated [ ]a,c is bounded by the [ ]a,c case for both the [ ]a,c for historical [ ]a,c, and current [ ]a,c and **Low Tin ZIRLO™** channels, both showing an improved bow behavior compared to historical [ ]a,c. Therefore, the BWR-3 D-lattice sample analysis falls within the experience base for which control rod insertion has been demonstrated for the largest range of channel bow for SVEA channels and allowance of adequate control blade movement is thus proven.

Also note that extensive operation experience now exist with SVEA-96 Optima2 in US plants. More than [ ]a,c SVEA-96 Optima2 assemblies have been delivered to the BWR-3 D-lattice plants

[ ]^{a,c} and [ ]^{a,c} with [ ]^{a,c} of control rod maneuvering issues related to SVEA-96 Optima2 fuel.

The improved channel bow behavior of **Low Tin ZIRLO™** channels will not reduce but rather add margin concerning control rod maneuvering.

Question 4 - Also, when will additional channel bow data for asymmetric plants become available along with projected burnup levels and how does this compare to the schedule for a projected first reload for an asymmetric plant in the US?

Answer to Question 4: Additional **Low Tin ZIRLO™** channel bow data from asymmetric plants will be available in the upcoming years, especially for **Low Tin ZIRLO™** channels with long residence times irradiated in [ ]^{a,c}. These channels will be measured after each additional cycle and will be irradiated for [ ]^{a,c}

The main driving forces for channel bow are fluence gradient of the opposing channels sides and hydrogen pick-up (mainly from shadow corrosion from the control rod).

The fluence gradient in asymmetric and symmetric lattices are very similar, see Figure 7 below which presents the fluence gradient from an asymmetric lattice in [ ]^{a,c} and symmetric lattice in [ ]^{a,c}. The data is from a typical 24 month cycle core in both [ ]^{a,c}. The maximum fluence gradient is [ ]^{a,c}
However, due to the asymmetric design the average fluence gradient is [ ]^{a,c} for an asymmetric plant which also is seen in the measured average channel bow which is [ ]^{a,c} the control blade in an asymmetric plant.

a,c

[ ]

The effect from shadow corrosion on channel bow is mainly a function of distance between the control rod and fuel channel and the exposure time. The distance between the control rod and fuel channel is larger for asymmetric plants and consequently the effect of shadow corrosion induced bow will be less in asymmetric plants on channels with similar exposure time.

With respect to the channel bow from fluence gradient and shadow corrosion, the symmetric database will bound fuel channels operated in asymmetric plants in the case of channel bow towards the control rod.

Comment - *If the values of standard deviation provided in the submittal at [ ]^{a,c} are plotted on Figures 6 (of response) and 4.2-6 (of submittal), respectively, these values [ ]^{a,c} do not appear to bound their respective data at a 95/95 level. It is noted that there is very little channel bow data for asymmetric plants above an equivalent burnup of [ ]^{a,c}.*

Question 5 - If these values are used to determine the interference fit, please provide the number of data points at burnup intervals of [ ]^{a,c} along with how many data points are above the [ ]^{a,c} standard deviation value used (items a. and b. above) to demonstrate clearance for both symmetric and asymmetric plants in Figures 6 (revised responses August 2012) and 4.2-6 (revised submittal August 2012), respectively.

Answer to Question 5: These values are not used in the approved methodology according to the response to RAI-15 of WCAP-15942-P-A. The value still conservatively used for [ ]^{a,c} and also **Low Tin ZIRLO™** channels is [ ]^{a,c} the historical [ ]^{a,c} database standard deviation, [ ]^{a,c}, see Figure 6 in response to RAI-8 dated August 2012.

RAI-9

Question 1 - Provide references that [ ]^{a,c} do not dissolve in **Low Tin ZIRLO™** (as stated in revised responses) up to the fluence/burnup levels requested for the channels. Also, are there any other hydrogen pickup data at high burnup for **Low Tin ZIRLO™** other than the one data point in Table 1 at [ ]^{a,c} that demonstrates **Low Tin ZIRLO™** will continue to have a much lower hydrogen pickup than Zr-2 or Zr-4?

Answer Question 1: – Irradiation of **Low Tin ZIRLO™** material (Optimized ZIRLO cladding) in a PWR operation in three 18 month cycle up to [ ]^{a,c} was performed and examined for SPP sizes. The [ ]^{a,c} were still present and have an average size of [ ]^{a,c} in diameter for two examined samples. All [ ]^{a,c} have been diluted on [ ]^{a,c} and only [ ]^{a,c} are present after irradiation at [ ]^{a,c} with no increased hydrogen pick-up observed. Since the SPPs do not fully dissolve, no acceleration of the hydrogen pick-up is expected. Therefore the hydrogen content depends on the corrosion rate in the reactor environments.

Comment - *The irradiated mechanical property data provided are [ ]^{a,c} hydrogen levels compared to the hydrogen limits requested. In addition the NRC has irradiated data from [ ]^{a,c} cladding to suggest that its ductility is lower than for cold work stress relief annealed cladding at equivalent hydrogen levels. This could be due to the fact that the [ ]^{a,c} material has random orientation of hydrides such that some are orientated in the radial direction which could have a higher probability for crack initiation as the density of hydrides increases. Therefore, [ ]^{a,c} will need to be established for* ***Low Tin ZIRLO™*** *[ ]^{a,c} until data can be provided to substantiate a [ ]^{a,c}.*

Question 2 – Please provide a lower limit based on [ ]^{a,c} cladding with similar hydrogen orientation and distributions that exist in **Low Tin ZIRLO™** [ ]^{a,c} channels along with justification based on data. If additional, mechanical test data are to be provided for **Low Tin ZIRLO™** [ ]^{a,c} to demonstrate the higher hydrogen limit is valid, micrographs need to be provided that demonstrate the hydride distribution, orientation and length of the mechanical test data are prototypical of those found in **Low Tin ZIRLO™** [ ]^{a,c} channels. The mechanical response of Zirconium alloys has been found to be strongly dependent on hydride distribution, orientation and length of the hydrides as well as the stress state. In addition, provide data on the geometry and the stress state of the mechanical test specimens and relate these to the limiting stress state in BWR channels.

Answer Question 2: – The hydride orientation is dependent upon stresses in the material. Contrary to cladding tubes where hard contact with an expanding pellet results in mechanical stresses, the channel wall is only subjected to stresses resulting from thermal creep due to the internal pressure, i.e. bulge. An evaluation of the hydride orientation from an outer channel wall at [ ]^{a,c} elevation and the water cross material at [ ]^{a,c} show no occurrence of radial hydriding. Typical hydride orientation on the outer channel wall and water cross material subjected to thermal creep by the inside over pressure in the fuel bundle is shown in Figure 8 and Figure 9.

a,c

*Figure 8: **Low Tin ZIRLO™** [ ]a,c outer channel wall at [ ]a,c*

a,c

*Figure 9: **Low Tin ZIRLO™** [ ]a,c water cross at [ ]a,c*

The hydride orientation is typical for a [ ]a,c material and is similar to any Zry-2 [ ]a,c material with respect both to mechanical properties and hydride morphology. No differences in mechanical properties are expected between irradiated Zry-2, Zry-4 and **Low Tin ZIRLO™** material with equivalent hydrogen content, therefore the limit for Zry-2 is also applicable to **Low Tin ZIRLO™ material.**