Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381-2000

NOV 1 4 2001

10 CFR 50.9

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Gentlemen:

In the Matter of	)	Docket No.50-390
Tennessee Valley Authority	)	

SUBJECT: WATTS BAR NUCLEAR PLANT - RESPONSES TO RAI REGARDING SPENT FUEL POOL COOLING ANALYSIS METHODOLOGY (TAC NO. MB1884)

The purpose of this letter to provide TVA's response to NRC's request for additional information regarding the spent fuel pool cooling analysis methodology change requested by TVA's April 20, 2001 letter. NRC's request was provided in a letter dated November 8, 2001. The enclosure provides both the questions asked and the responses to those questions. These responses provide information both for the interface items related to the Spent Fuel Pool Cooling Analysis Methodology dated April 20, 2001, needed for the upcoming refueling outage and the interface items related to the Tritium License amendment dated August 20, 2001.

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There are no regulatory commitments made by this letter. If you have any questions about this letter, please contact me at (423) 365-1824.

Pursuant to 28 U.S.C. § 1746 (1994), I declare under penalty of perjury that the foregoing is true and correct.

Sincerely,

P. L. Pace
Manager, Site Licensing
and Industry Affairs

Enclosures
cc: See page 3

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cc (Enclosure):

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ENCLOSURE 1
TENNESSEE VALLEY AUTHORITY
WATTS NUCLEAR PLANT (WBN)
UNIT 1
DOCKET NO. 390
RESPONSES TO NRC REQUEST FOR ADDITIONAL INFORMATION

1. **TVA states in Section III of Enclosure 1 "Proposed Methodology Change - Description and Evaluation of the Proposed Change" that "Analyses have been performed that support the proposed change." Please provide these analyses or a summary of these analyses, including the methodology (e.g., equations, code, how to determine heat exchanger heat removal capability, etc.), important assumptions and results.**

<u>RESPONSE</u>

The purpose of the analysis "Development of SFP Hx Effectiveness Values with STER" was to develop Spent Fuel Pool Cooling and Cleaning System (SFPCCS) heat exchanger temperature effectiveness values and equations for design and off-design conditions. Performance Factors and the appropriate equations which relate fouling factors to Performance Factors were also developed. The analysis provided direct input to the Alternate SFP Decay Heat Analysis.

Heat Exchanger Effectiveness Values

The existing SFP Thermal-Hydraulic analysis of record ("Holtec Analysis") utilized the concept of Heat Exchanger Effectiveness. The benefit of utilizing this methodology is that for a fixed value for effectiveness, which is a function of coolant inlet and outlet temperature values and the hot stream inlet temperature, the system thermal balances can be easily written as a function of hot fluid stream inlet temperature and the coolant inlet temperature.

The equation for heat exchanger capacity was previously provided in the Holtec analysis as:

$$Q_{HX} = W_t * C_p * p * (T_{h,i} - T_{c,i})$$

where:

W_t = Coolant Flow Rate
C_p = Coolant Specific Heat
p = Temperature Effectiveness
$T_{h,i}$ = Hot (SFP) Inlet Fluid Temperature
$T_{c,i}$ = Coolant (CCS) Inlet Temperature

C_p varies minimally with small changes in temperature; therefore, the cold stream shell side inlet conditions are used to calculate C_p. The error introduced by this simplification is within the overall accuracy of this analysis.

The temperature effectiveness was previously defined as:

$$p = (T_{c,o} - T_{c,i}) / (T_{h,i} - T_{c,i})$$

where:

$T_{c,o}$ = Coolant Outlet Temperature

From data generated utilizing QA software Shell and Tube Heat Exchanger Rating program (STER), values for p can be determined for design and off-design conditions.

Holtec developed effectiveness values for the original SFP Thermal Hydraulic Analysis. The TVA analysis utilized the same methodologies as the Holtec analysis to develop similar effectiveness values; however, in the TVA analysis, parametric values were developed by varying certain input variables, specifically, CCS Temperature, SFP Temperature and allowable fouling factors. The Holtec analysis was based on design limiting conditions of 95°F CCS temperature and the 0.0005 hr*ft^2*°F/Btu design fouling factor. By developing new effectiveness values based on these variables, a revised analysis was developed by TVA which allows for off-design SFP evaluations.

Performance Factor Values

The use of effectiveness values is somewhat cumbersome when many different variables, such as fouling factors, tube plugging, CCS temperature, CCS flow rate, etc., are used. To simplify the use of effectiveness values within the spreadsheet based model, Performance Factor (PF) values were developed. PFs are ratios of the off-design effectiveness value to the established design effectiveness value. In equation form, the PF is defined as:

$$PF = p_{off\text{-}design} / p_{design}$$

The TVA analysis includes numerous cases for varying SFP temperature, CCS temperature, and SFP Hx fouling. Each case has a different effectiveness value when compared to the design condition of 95°F CCS temperature and SFP Hx fouling of 0.0005 $hr*ft^2*°F/Btu$.

The PFs developed by TVA calculation, and utilized in the Alternate SFP Decay Heat Analysis, are for variations in fouling factors only. A similar approach can be taken to develop PFs for tube plugging, CCS flow rate, SFP flow rate, etc. In these cases, multiple PFs can be used by multiplying each together into a combined PF for a specific off-design case. The combined PF can be multiplied by the established design effectiveness value to determine a combined effectiveness value:

$$p_{combined} = p_{design} * PF_{combined}$$

where:

$$PF_{combined} = PF_{ccs\ flow} * PF_{tube\ plugging} * PF_{fouling\ factor} * PF_{SFP\ flow} * \ldots$$

By developing Performance Factors, equation and computer modeling development is simplified in that values for Performance Factors can be developed for several varying inputs to calculate a combined PF for the specific off-design case. Note that the TVA analyses, after evaluation of benefits from changes in tube plugging, flow rates, etc, only developed and utilized PF's for fouling.

Method for Validation of Performance Factor Multiplication

This section explains the validation approach used which proved that the heat load Q_{Hx}, as derived by specific inputs into STER, are comparable to heat loads projected by methodologies which utilize Performance Factors. Setting subscript 1 to indicate STER methodology, and subscript 2 to indicate Performance Factor methodology, the following validation was developed.

The equation of effectiveness "p" was previously shown as:

Equation 1 (STER):

$$Q_{Hx} = W_t * C_p * p_1 * (T_{h,i} - T_{c,i})$$

To accommodate performance factors, p_2 is multiplied by Performance Factor (PF):

Equation 2 (Performance Factors):

$$Q_{Hx} = W_t * C_p * p_2 * (T_{h,i} - T_{c,i}) * PF_2$$

Rearranging Equation 2 yields:

$$Q_{Hx} / [W_t * C_p * (T_{h,i} - T_{c,i})] = p_2 * PF_2$$

Similarly, rearranging Equation 1 yields:

$$Q_{Hx} / [W_t * C_p * (T_{h,i} - T_{c,i})] = p_1$$

For the purpose of validating equivalency of two different methods of analysis, the input values for W_t, C_p and $(T_{h,i} - T_{c,i})$ are constant. Similarly, the resultant Q_{Hx} should also be constant, if the two methods result in the same value on the right side of the equation. Therefore, for method 1-STER and method 2-Performance Factors, the following equivalency required validating: Actual validation is described later in this summary.

$$p_1 = p_2 * PF_2$$

Design Effectiveness Values

The original Holtec Analysis utilized the methodology of heat exchanger effectiveness values as previously described. Multiple STER runs were completed which provided effectiveness values for various combinations of CCS shell side temperature and SFP tube side temperatures, at a design fouling factor of 0.0005 hr*ft^2*°F/Btu, for both tube and shell side, and 5% tube plugging. All values were developed using STER. Table 1 lists the design effectiveness values for the expected ranges of SFP and CCS temperatures under design fouling conditions:

TABLE 1
Design Effectiveness Values
(Fouling at 0.0005, Tube plugging at 5%, CCS Flow at 3000 gpm, SFP flow at 2300 gpm)

	CCS Temperature °F				
SFP Temperature (Shell Side Inlet)°F	95	93	90	85	80
100	0.3100	0.3100	0.3100	0.3087	0.3075
120	0.3140	0.3137	0.3130	0.3120	0.3110
140	0.3169	0.3166	0.3162	0.3155	0.3145
160	0.3198	0.3194	0.3189	0.3181	0.3174
180	0.3222	0.3221	0.3216	0.3208	0.3198

These values were graphed to determine a best fit equation. The resulting equations are tabulated below for effectiveness "p" values relative to SFP temperature, T_{SFP}, at the listed CCS shell side temperatures between 95°F and 80°F, at design fouling of 0.0005 hr*ft²*°F/Btu and 5% tube plugging:

TABLE 2 Design Effectiveness Equations	
CCS Inlet Temperature (°F)	**Equation**
95	$p = 0.0206*\ln(T_{SFP}) + 0.2150$
93	$p = 0.0204*\ln(T_{SFP}) + 0.2160$
90	$p = 0.0198*\ln(T_{SFP}) + 0.2186$
85	$p = 0.0207*\ln(T_{SFP}) + 0.2134$
80	$p = 0.0212*\ln(T_{SFP}) + 0.2099$

These equations are used in the development of the Alternate SFP Decay Heat Analysis.

Performance Factors Based on Tube and Shell Fouling Factor Effectiveness Values

Tables of data were developed to provide effectiveness values for various combinations of fouling factors, CCS shell side temperature, and SFP tube side temperature. These values were developed using the computer code STER. The tabulated data tables also provided a ratio (Performance Factor) which was obtained by dividing the effectiveness at any given fouling factor by the specific design effectiveness value at the design fouling factor of 0.0005 hr*ft²*°F/Btu. This step was required since the original effectiveness values developed by Holtec and utilized in both the original SFP thermal analysis and the alternate SFP thermal analysis are all based on a design fouling factor of 0.0005 hr*ft²*°F/Btu.

An example of the tabulated data is provided in Table 3, for the case of T_{CCS} = 90°F. The specific design effectiveness values (based on fouling of 0.0005 hr*ft²*°F/Btu) for each pair of CCS and SFP temperatures are included as the first three rows. The remaining effectiveness values in the tables are off-design cases. In order to determine a PF, $p_{off\text{-}design}$ is divided by the p_{design} that has the same CCS and SFP temperatures.

The effectiveness values were calculated at Tube Side Inlet Temperatures of 100°F, 140°F, and 180°F. These temperatures were selected because they fall within the target operating range of the SFP.

TABLE 3
EXAMPLE
Performance Factors at a Constant CCS Temperature = 90°F

Shell Side Inlet Temperature (°F)	Tube Side Inlet Temperature (°F)	Tube and Shell Fouling Factor	WBN Effectiveness, p	Performance Factor ($p_{off-design}/p_{design}$)	Average PF
90 (design)	100	0.0005	0.310000	1.000000	
90 (design)	140	0.0005	0.316200	1.000000	1.000000
90 (design)	180	0.0005	0.321556	1.000000	
90 (off-design)	100	0.0004	0.323000	1.041935	
90 (off-design)	140	0.0004	0.330600	1.045541	1.044362
90 (off-design)	180	0.0004	0.336222	1.045609	
90 (off-design)	100	0.0003	0.338000	1.090323	
90 (off-design)	140	0.0003	0.345800	1.093612	1.092870
90 (off-design)	180	0.0003	0.352000	1.094677	
90 (off-design)	100	0.0002	0.354000	1.141935	
90 (off-design)	140	0.0002	0.362400	1.146110	1.145312
90 (off-design)	180	0.0002	0.369111	1.147890	
90 (off-design)	100	0.0001	0.371000	1.196774	
90 (off-design)	140	0.0001	0.380200	1.202404	1.201361
90 (off-design)	180	0.0001	0.387444	1.204904	

The resulting performance factor values for the different CCS temperatures are based on an average effectiveness value of three values of SFP temperature (100°F, 140°F and 180°F). The resulting Performance Factor values are tabulated below:

TABLE 4: Performance Factors For Varying Fouling Factors					
	CCS Temperature				
Fouling Factor	**95**	**93**	**90**	**85**	**80**
0.0005	1.000000	1.000000	1.000000	1.000000	1.000000
0.0004	1.045460	1.045703	1.044362	1.044786	1.045589
0.0003	1.095467	1.093384	1.092870	1.092766	1.093646
0.0002	1.147849	1.145481	1.145312	1.146084	1.145587
0.0001	1.202972	1.201870	1.201361	1.201430	1.201432

A close inspection of the data listed above reveals a very close similarity between the Performance Factors for each given fouling factor, but it does not reveal a definite trend to aid in identifying the most conservative case. The graphs of these values match very closely for each CCS shell side temperature. An equation was developed to relate fouling factors to Performance Factors based on this data. The resulting equation is as follows:

$$\mathbf{PF = 1.2564 * e^{(-458.37 * \text{fouling factor})}}$$

Validation of Performance Factor Multiplication

The use of effectiveness values is difficult when many different variables are used. To provide simplifying equations, Performance Factor (PF) values were developed. The analysis utilized the validation technique explained above to prove methodology equivalency.

As previously shown, for the method 1-STER and method 2-Performance Factors, the following equivalency requires validating:

$$p_1 = p_2 * PF_2$$

The following value for p_1 from a STER analysis is based on 90°F CCS temperature, 140°F SFP temperature, and a 0.0003 $hr*ft^2*°F/Btu$ fouling factor.

$$p_1 = \mathbf{0.345800 \text{ (from Table 3)}}$$

The design equation of the effectiveness value, p_2, for 90°F CCS shell side temperature, and a design fouling factor of 0.0005 $hr*ft^2*°F/Btu$ was determined to be:

$$p_2 = 0.0198*\ln(T_{SFP}) + 0.2186 \text{ (from Table 2)}$$

Using a SFP temperature of 140°F, the effectiveness value is:

$$p_2 = 0.0198*\ln(140) + 0.2186 = \mathbf{0.316445}$$

From the equation derived previously, the Performance Factor value, PF_2, for a fouling factor of 0.0003 $hr*ft^2*°F/Btu$ is:

$$PF_2 = 1.2564 * e^{-458.37 * \text{fouling factor}}$$

$$PF_2 = 1.2564 * e^{-458.37 * 0.0003} = \mathbf{1.09498}$$

Multiplying p_2 and PF_2:

$p_2 * PF_2 = 0.316445 * 1.09498 =$ **0.346501**

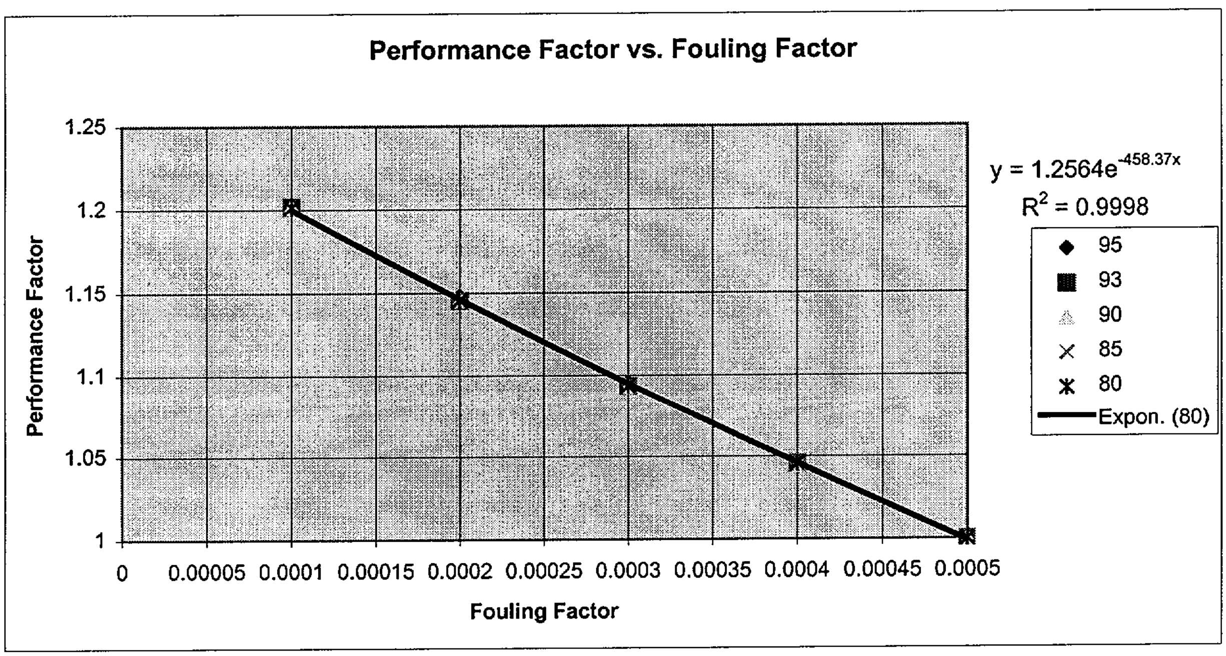
The ratio of $p_2 * PF_2$ to p_1 is:

$0.346501 / 0.345800 =$ **1.002**

A ratio of $p_2 * PF_2$ to p_1 equaling 1 would show perfect agreement between the two methodologies. The result obtained from the ratio above demonstrates that there is excellent agreement between the STER and Performance Factor methods.

The following figure depicts the relationship of Performance Factor to fouling factor, and also shows the independence of fouling factor to changes in CCS temperature. Note that all data for varying CCS temperature from 95°F to 80°F is superimposed on the graph as shown in Figure 1, clearly demonstrating that the performance factor for fouling is independent of CCS temperature.

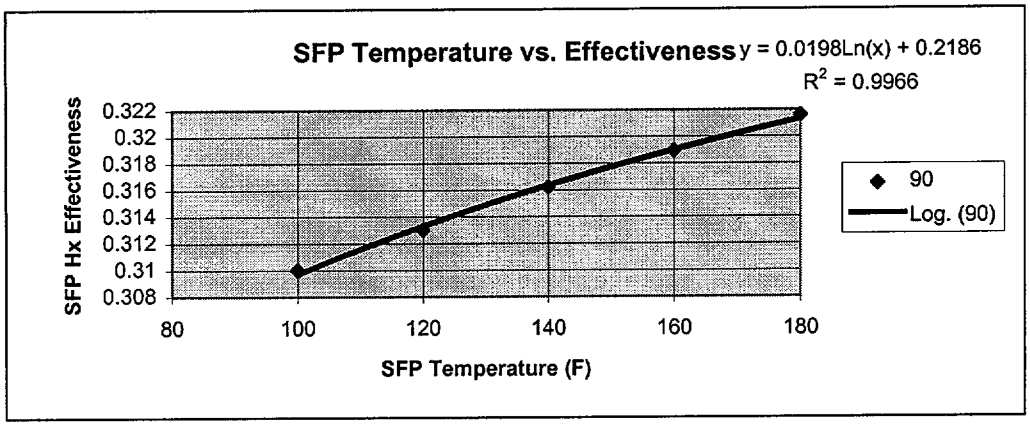
FIGURE 1



The following figure is an example of SFP Hx effectiveness "p" plotted as a function of SFP temperature.

90°F CCS Shell Side Temperature
Fouling Factor = 0.0005 $hr*ft^2*°F/Btu$

FIGURE 2



Results

The following equations were determined in the analysis to accurately calculate Spent Fuel Pool heat exchanger effectiveness values for the CCS shell side temperatures listed between 95°F and 80°F:

TABLE 5	
CCS Inlet Temperature (°F)	**Equation**
95	$p = 0.0206*\ln(T_{SFP}) + 0.2150$
93	$p = 0.0204*\ln(T_{SFP}) + 0.2160$
90	$p = 0.0198*\ln(T_{SFP}) + 0.2186$
85	$p = 0.0207*\ln(T_{SFP}) + 0.2134$
80	$p = 0.0212*\ln(T_{SFP}) + 0.2099$

The following equation was developed in the analysis to accurately relate fouling factors to Performance Factors for the CCS temperatures listed above:

$$PF = 1.2564 * e^{(-458.37 \, * \, \text{fouling factor})}$$

Conclusions

The purpose of the TVA analysis was to develop SFPCS heat exchanger temperature effectiveness values and equations for design and off-design conditions. Performance Factors and the appropriate equation which relates Performance Factors to fouling factors were developed in the analysis. The results shown above have been proven to be adequate for the application, and consistent with the calculation purpose and system design requirements.

2. **TVA states in Section III of Enclosure 1 that "Procedures are in place to assure that at no time during core off-loading activities will the design basis limits of the SFPCCS [spent fuel cooling and cleanup system] be exceeded." Please explain these procedures.**

RESPONSE

For each outage at approximately 6 months, one month, and one day prior to shutdown, TVA determines the combined SFP and Reactor core decay heat values utilizing the computer code "DHEAT". These decay heat values are compared to the design allowable SFP decay heat values and the overall outage plan for initiation and duration of core offloading is developed. The pre outage determination of heat loads documents the decay heat values and a conclusion is made relative to meeting the design allowable value. The current value is 32.6 MBtu/hr. The proposed change will allow varying of the allowable SFP decay heat between 32.6 and 47.4 MBtu/hr, consistent with CCS temperatures and known fouling of the SFP heat exchangers.

As part of TVA's plan for implementation, after receipt of NRC approval of the requested methodology change, changes to outage management procedures (and other related procedures) will be identified and revised as necessary to reflect both the revised methodology and the increase in allowable SFP heat load.

3. **Please provide the data used to calculate the "time to boil", "SFP [spent fuel pool] heat-up rate", "boil-off rate", and "time until 10 feet of water over racks" (e.g., amount of water in the SFP, the heat capacity of the SFP and other structures, etc.).**

RESPONSE

The following data was utilized in the SFP thermal analysis:

Design Input Parameter	Value
SFPCCS Flow per HX	$1.14*10^6$ lbm/hr
CCS Flow per SFP Hx	$1.49*10^6$ lbm/hr
Design Fouling Factor (Tube & Shell Side)	0.0005 $hr*ft^2*^\circ F/Btu$
Design Tube Plugging	5%
Maximum CCS Temperature - refueling	95° F
Earliest Start Time for Core off-loading	100 hours

Design Input Parameter	Value
Maximum Residual SFP Decay Heat	1.8 MWt
Volume of Water in SFP	4.979 E04 ft^3
WBN SFP Heat Capacity	3.05 E06 Btu / °F
Maximum No. of TPBAR Fuel Assemblies	96
Maximum Allowable SFP Temperature - 1 Train operation	159.24 °F
Maximum Allowable SFP Temperature - 2 Train operation	129.30 °F
Maximum Steady State Heat Load Rejection to CCS	16.213 E06 Btu / hr.
Maximum (Design) Allowable SFP Decay Heat	32.6 E06 Btu / hr.
Maximum (Off-Design) Allowable SFP Decay Heat (1)	47.4 E06 Btu / hr.
Elevation of SFP Floor	709.23′
Height of SFP Fuel Storage Rack	177″
Minimum SFP Low Water Level	748′ - 11.5″
Minimum SFP Makeup water Flow	55 gpm
SFP Length	474″
SFP Width, Cask Pit Width	380.5″
Cask Pit Length	144″
Minimum allowed water depth over active fuel	10 feet
Maximum Ultimate Heat Sink Temp (ERCW)	85 °F

Note 1: 47.4 MBtu/hr is the basis for all heat-up rates, time-to-boil, boil-off rate, etc., determinations.

4. **The first paragraph of Enclosure 2 "UFSAR [Updated Final Safety Analysis Report] Markups," states that "to assure that the spent fuel pool temperature does not exceed 150°F." However, the table in Enclosure 1 shows the maximum SFP temperature to be 159.24°F. Please explain this discrepancy.**

<u>**RESPONSE**</u>

Please see the response in TVA letter dated October 29, 2001, to Section 1.5.11, Question 1.c "Specific SFP Thermal Analysis". The temperature of 159.24°F is the worst case SFP temperature assuming single failure of an entire train of spent fuel pool cooling. The 150°F is a temperature that will not be exceeded for normal offloads with operable (two trains) equipment.

5. **In Sections 1.5.8 and 1.5.9 of Enclosure 3, TVA states that "the increase in allowable decay heat associated with the reduced SFP heat exchanger fouling factors and lower CCS [cooling and cleanup system] temperatures is approximately 14 MBTU/Hr." However, this increase is stated to be 10 MBTU/Hr in the same sections of TVA's May 1, 2001 submittal. Please explain the discrepancy.**

   Please see response in TVA letter dated October 29, 2001, to Section 1.5.11, Question 2.a.