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References:
1. Email from Billy Gleaves, Sr Project Manager dated 28 June 2011, "RE: Request to listen via teleconference [PUBLIC MEETING WITH WESTINGHOUSE ELECTRIC COMPANY ON THE AP1000 DESIGN CERTIFICATION - SHIELD BUILDING ROOF PASSIVE CONTAINMENT COOLING WATER STORAGE TANK ANALYSIS Thursday, June 30, 2011 9:00 a.m. - 11:30 a.m.]"
2. "Evaluation of the Effect of the AP1000 Enhanced Shield Building Design on the Containment Response and Safety Analysis", APP-GW-GLR-097, Rev. 1, submitted to the NRC as part of docket on AP1000 rulemaking, as enclosure 4 to DCP-NRC-002998, August 6, 2010.
3. "A Review -- Cooling by Water Evaporation Over Roof" by G. N. Tiwari, A. Kumar, and M. S. Sodha, in *Energy Conversion Management*, Vol. 22, pp. 143 to 153, 1982.
4. Letter from S G Sterrett to Billy Gleaves dated 7 July 2011 "Thermal loads and effects due to radiative heating and cooling of AP1000 shield building exterior surface, which are in addition to all thermal loads and effects due to ambient air temperature" (Written question submitted regarding PUBLIC MEETINGS WITH WESTINGHOUSE ELECTRIC COMPANY ON REV 19 OF THE AP1000 DCD that were held on June 30, 2011)

SUBJECT: **Question for ACRS Meeting on August 16th, 2011 (Rev 19 of AP1000 DCD) concerning whether solar radiation on the physical model was accounted for in interpretating experimental data in the "Large Scale Test" that was used to validate WGOTHIC, which is used in Rev 19 calculations for predicting heat and mass transfer aspects of the effectiveness of Passive Containment Cooling System in reducing containment pressure.**

1. Background to the Problem (from which the question about WGOTHIC validation using the PCS (Passive Containment Cooling System) Large Scale Test (LST) arises)

In the meetings about Rev 19 of the AP1000 DCD held on June 30, 2011, the topic of including thermal loads on the AP1000 shield building was discussed, and various sections of revision 19 of the AP1000 DCD were cited, including Appendix 3H. In an earlier letter addressed to the NRC's Billy Gleaves, (Ref. 4), which I attach to this letter for convenience, I discussed that issue as it related to the AP1000 nuclear safety accident analyses and analysis of the shield building

structure: It is clear from looking at the values of the thermal loads listed in Appendix 3H of Rev 19 of the AP1000 DCD that Westinghouse assumed the building exterior surface temperatures to be bounded by the ambient air temperatures. It is also a matter of very basic science that doing so is not correct.

The quantitative values of the neglected quantities are not small (~ 30 degrees F or more difference added onto the high end of the range; about half that added on the low end of the range). The data presented by Westinghouse in Appendix 3H of Rev 19 of the AP1000 DCD implies that Westinghouse and/or the NRC staff did not consider, and/or did not realize that it was relevant to take into account the fact that there can be radiative heating of an exterior surface due to the sun, and radiative cooling of an exterior surface due to radiation to the night sky. These temperature changes are distinct from, and in addition to, seasonal and daily temperature changes due to seasonal and daily temperature changes in the ambient air temperature.

The fact that Westinghouse made this error (neglecting the effect on building exterior surface temperatures due to radiative heat gains due to the sun (solar radiation) and radiative losses to the night sky) in the work done for the Rev 19 changes raises the question of whether there is a more fundamental problem with the safety analysis of the AP1000: if they really didn't know that they needed to consider the effect of heat of solar radiation for the Rev 19 calculations for the shield building exposed to the sun, did they know to do so when interpreting the test results of the Large Scale Test of the Passive Containment Cooling System? The steel containment as installed is inside the concrete shield building and is not exposed to the sun, so there would be a problem if the scale model of the steel containement was exposed to the sun during the test.

In a Westinghouse document submitted as part of Rev 19, the following photograph of the Large Scale Test Facility is provided:

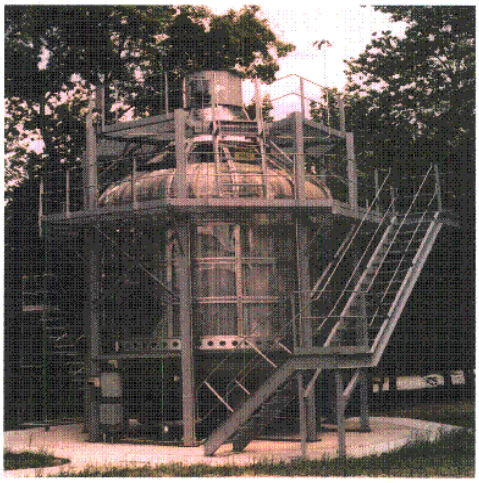


Figure 6-4: Large Scale Test Facility

If the above is a photograph of the site on which the test was performed (i.e., if the test was performed outdoors during the day), which I believe it is, then the wetted surface of the Large Scale Test (LST) of the Passive Containment Cooling System (PCS), was in the presence of the sun when the experimental test data was taken. The figure below, which is from an article in an engineering journal (Ref. 3) is applicable to that situation, and the factors depicted in it need to be taken into account when interpreting the test data:

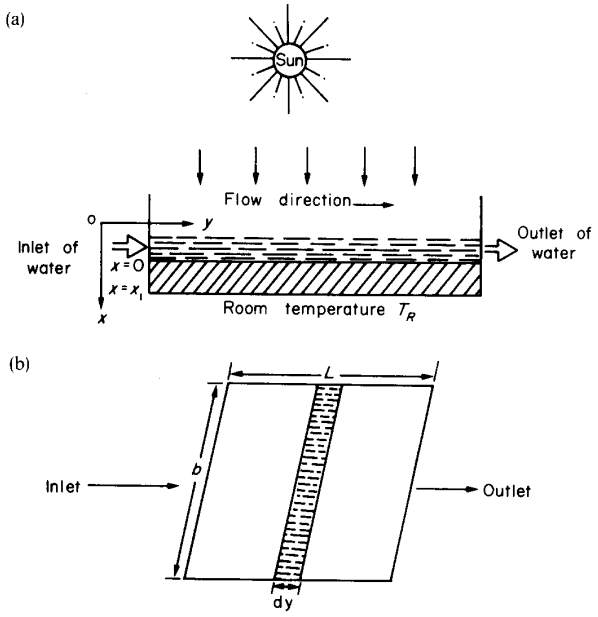


Fig. 1. (a) Schematic sketch of, "Flowing water over the roof" system. (b) Overside view of the flowing water system.

Now, compare the two situations: the PCS LST physical model in the outdoors, and the PCS under the conditions at which it is supposed to operate:

Large Scale Test (LST) -- Outdoors in Presence of Sunlight

> The above figure (Figure 1 of Tiwari 1981) correctly depicts the role of the sun in the **Large Scale Test situation** of the Passive Containment Cooling System (PCS) **LST**, which, it appears, was performed outdoors, in the presence of sunlight.
>
> In the LST model, which is a physical model, the baffle/shield building was represented, if at all, using a *transparent* material. **The physical model's being in the presence of sunlight thus aided evaporation in the PCS LST test.**

Conditions under which AP1000 PCS is designed to operate -- Inside shield building, largely shielded from Sunlight

> The **installed situation** for which the AP1000 Passive Containment Cooling System is to perform its safety function of heat removal from the steel containment is *inside* the concrete shield building, and the concrete shield building is *opaque* to solar insolation. Whatever the weather outdoors, the wetted surface of the steel containment from which evaporative losses are taken credit for in the AP1000 safety analysis is largely shielded from receiving the benefit of sunlight (solar insolation) in the situation in which the PCS operates, as installed in an AP1000 nuclear power plant.

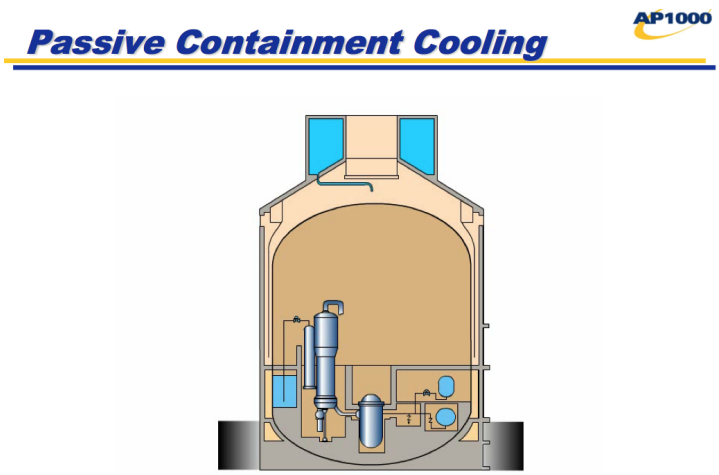
Thus there might well have been more evaporation, and more heat removal, earlier, in the LST experimental test situation than there will be in the situation in which the PCS is actually to operate when installed in an AP1000 nuclear power plant. At any rate, accuracy calls for considering the important relevant factors in a calculation, and the factor of whether or not a surface is in the presence of solar radiation or not is a relevant factor in the calculation of heat transfer.

I have so far not run across any discussion of the fact that the test model of the steel containment shell was located in the sun whereas the actual containment is located within the shield building, largely shaded from sunlight.

2. Technical Discussion of the Problem

2a. WGOTHIC Validation of Indoor Systems Using Outdoor Test

The problem is that it appears that in the test situation (PCS LST) against which the computer code WGOTHIC was compared, the wetted surface was exposed to solar insolation (i.e., radiative heating from sunlight was present), whereas the situation WGOTHIC is being used to make predictions about is one in which it is not: inside the shield building, which is where the PCS delivers the water film over the steel containment. The interior is largely shielded from sunlight. The Westinghouse presentation at an NRC meeting on 30 June 2011 presented this figure:



It was also stated that the computer code WGOTHIC was used in the safety analysis for the AP1000 to predict PCS effectiveness in removing heat from the containment, and thus to predict its effectiveness in reducing containment pressure. Per the docket materials submitted describing the analysis performed in calculating containment pressure for Rev 19 changes, the computer code was validated by comparing the results that WGOTHIC predicted for the LST test with the results obtained experimentally in the LST test.

Since the LST test was conducted in the presence of sunlight, and the WGOTHIC model of the PCS performance was validated against it, won't the WGOTHIC model of the AP600/AP1000 containment response tend to *overestimate* the evaporative losses that will occur when the PCS operates as installed in the AP1000 plant? I ask this because, in the AP1000 plant, as in the AP600 plant, the wetted containment surface is indoors, in the dark, inside the shield building. Since evaporative losses *reduce* containment pressure, doesn't this mean that, unless the effect of the sunlight is quantified and accounted for in some way, using this approach to validate a computer code such as WGOTHIC results in a computer code that *underestimates* the containment pressure ?

2b. Some Points of Basic Physics

The symbol for solar radiation in the cited paper (Tiwari 1981) is H_s , as indicated in the nomenclature list on the first page of the paper. H_s occurs in the general energy balance equation for figure 1(b) in Tiwari 1981's paper (reproduced above). The general energy balance is equation (2) of the Tiwari 1981 paper; **the energy balance is basic physics and not a matter of controversy or interpretation**.

Refering to Fig. 1b, the energy balance equation for water moving over the roof along y-direction is

$$\left(bd\rho_w c_w \frac{\partial T_w}{\partial t} + \dot{m}_w c_w \frac{\partial T_w}{\partial y}\right) \mathrm{d}y = [\tau_1 H_s - Q_r - Q_e - Q_c + h_0(\theta|_{x=0} - T_w)]\, b\, \mathrm{d}y \quad (2)$$

where

I would like to emphasize something I said as a participant via telephone in the NRC public meeting that was held on the morning of June 30th, 2011: that *neither the effect of radiative heat gains (via solar radiation) nor the effect of radiative heat losses (via radiation to the night sky) is captured by considering the effect of ambient air temperature.*

To get this point across, I draw your attention to the portion of Tiwari's paper on cooling by water evaporation over roofs that makes a general comment about the cycles of solar radiation and cycles of temperature change due to daily night-and-day cycles. This paragraph of the paper (p. 146) makes clear that they are two distinct factors. H_s is the symbol for solar radiation, and T_a is the symbol for ambient air temperature:

On account of their periodic natures, solar insolation and ambient air temperature can be Fourier analysed in the form

$$H_s = a_0 + \sum_{n=1}^{\infty} a_n \exp(in\omega t) \qquad (7a)$$

and

$$T_a = b_0 + \sum_{n=1}^{\infty} b_n \exp(in\omega t) \qquad (7b)$$

To put this in nontechnical terminology: The *difference between ambient air temperature in night and in day* is one thing *(diurnal cycling, indicated by (7b)),* and *the difference due to the very presence or absence of solar insolation* is another thing. The *presence or absence of solar insolation* is the difference between *being in the shade* and *being in direct sunlight, at the same ambient air temperature* (indicated by (7a)).

Both diurnal *thermal cycling* (due to ambient air temperature daily cycles) and daily temperature variation due to *solar insolation* can be periodic for a particular engineering project, and both are in some manner due, ultimately, to the heat of solar radiation. They are, however, two *distinct*, quantifiable effects whose variation does not coincide in time and place, and neither includes the other.

2.c. Conclusion of the above considerations: The effects of solar insolation (sunlight hitting the surface of something) that were present in the Large Scale Test of the Passive Containment Cooling System (and so aided evaporation), but which are not going to be present in the actual situation to which the safety analysis applies (since the wetted surface from which evaporation is supposed to take place is indoors, shielded from sunlight), should be quantified and subtracted from the LST test results before comparing it to the WGOTHIC analysis. The question is: was this done? Did the ACRS check whether it was done when they approved the designs based upon the analyses using the computer models whose validation appealed to this test? The difference between the test situation and the situation for which WGOTHIC is to be used for prediction needs to be taken into account in some manner. Otherwise, the LST does not serve to validate the WGOTHIC analysis for the PCS as it will perform when it is installed and used in the AP1000 plant.

The photograph of the Small Scale Test Facility, also taken from material submitted for rev 19 of the AP1000 DCD, likewise portrays it outdoors, so agreement between the small scale test experiments run on this facility, and the large scale tests cannot be appealed to in order to dismiss the significance of the test being performed outdoors:

Figure 6-3: Small Scale Test Facility

3. <u>Question to the NRC ACRS about WGOTHIC validation for Rev 19 Containment Pressure Calculations</u>

QUESTION: Did the NRC review how the difference between:

(i) the Passive Containment Cooling System Large Scale Test (PCS LST) test situation, in which solar insolation (the presence of sunlight, i.e., solar radiation) aided evaporation,

and

(ii) the situation to which the AP1000 computer-based safety analysis (using the WGOTHIC computer code) applies, in which the wetted surface is not exposed to sunlight and solar insolation does *not* aid evaporation,

is accounted for when appealing to the PCS LST experimental test results to validate the use of the WGOTHIC computer code analyses for predicting the effectiveness of the PCS in reducing containment pressure? Radiative effects act in addition to convection and conduction, and affect the calculated peak containment pressure.

I note that the analysis for Rev 19 shows that the margins on containment pressure have been further narrowed to the point of almost vanishing, even after much so-called "pencil sharpening" (taking credit for things for which credit was not previously taken).

Can the ACRS Committee members say whether, and, if so, how, the effects of solar insolation were quantified and subtracted from the LST test results when using the PCS LST to validate the WGOTHIC results for use in the AP1000 design certification? Or, whether this dissimilarity between the test and the situation about which WGOTHIC is being used to make predictions in the safety analysis is accounted for in some other way? If not, can you indicate what the NRC staff ought to do (or require of the applicants) concerning quantifying these effects to determine how they would change the NRC's safety evaluation of Rev 19 of the AP1000 safety analysis?

4. <u>Concluding remark on significance of the question</u>

Put briefly, the question above arises because it appears that on the AP1000 a scale model test of evaporative effectiveness performed outdoors in sunlight was used to validate predictions for a process that does not occur in the presence of sunlight. (I.e., a computer program was validated for the purpose of predicting quantitative values arising from a physical process *in which evaporation is important* and that occurs in the *absence* of sunlight, using a scale model test that was performed in the *presence* of sunlight.) I emphasize that the factor that was neglected is a matter of basic science, not a matter of interpretation or analysis methodology.

Put in terms of an everyday example, it seems to me that this would be akin to validating computer model predictions for a device that its manufacturer claims will rapidly dry clothing indoors in a darkened room, by constructing a physical model of the device and setting it outdoors in sunlight. That is, saying that the PCS LST scale model test validates the predictions of a WGOTHIC computer analyses of the effectiveness of the PCS in removing heat via evaporative heat losses is analogous to referring to the experimental tests of a clothes-drying device from data collected on a model of it used while outdoors in the sun, and then saying: look, my computer predictions were confirmed and I have thus proved how speedily this device works! My computer model calculations predicting how quickly water will evaporate when using this device indoors in the dark are now validated!

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Attachment -- Reference 4 is an attachment to this letter.