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

ATTENTION: T. R. QUAY

SUBJECT: SUPPORT INFORMATION FOR ACCIDENT SPECIFICATION AND PHENOMENA EVALUATION FOR AP600 PASSIVE CONTAINMENT COOLING SYSTEM, WCAP-14811

REFERENCE:
1. Westinghouse Letter NSD-NRC-96-4921, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System, WCAP-14811," December 19, 1996.
2. Westinghouse Letter NSD-NRC-96-4790, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," August 8, 1996.

Dear Mr. Quay:

Reference 1 provided the revised Phenomena Identification and Ranking Table (PIRT) for the AP600 Containment Design Basis Analysis. To assist the staff review of the revised PIRT, pertinent information from the ongoing revision to the Containment scaling analysis is attached. The attached information is provided to NRC in advance of WCAP-14813, *Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents*, scheduled to be completed in February, 1997. The attachment contains values of scaling Pi groups which have been updated to reflect resolution of NRC informal review comments on Reference 2. These Pi group values are felt to be necessary for the NRC to more effectively review WCAP-14811.

Please contact John C. Butler on (412) 374-5268 if you have any questions concerning this transmittal.

B. A. McIntyre, Manager
Advanced Plant Safety and Licensing

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/jml

Attachment

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cc: T. Kenyon, NRC (w/o Attachment))
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Attachment to Westinghouse Letter NSD-NRC-97-4949

Pi Group Values from Scaling Analysis

The values and conclusions of the pi groups derived for scaling AP600 are presented in this section. The subscripts on the pi groups are defined in Section 7.0.

1.0 Heat Sink Surface Areas During Transients

Surface area is an important parameter for calculating the heat and mass transfer to the heat sinks. The surface area of some heat sinks change over time. The break pool volume, surface area and height increase with time, and the wetted area of the external shell initially increases, then varies with time as the source flow rate changes and the containment pressure causes the shell heat flux to change. Other areas are assumed constant over the time covered by the scaling analysis. The areas of heat sinks used in the scaling calculations are summarized in Table 1

Table 1 Heat Sink Areas During DECLG and MSLB Transients
(Units are ft^2)

Heat Sink	DECLG LOCA				MSLB
	Blowdown	Refill	Peak Press	Long Term	Blowdown
Drops	$9x10^7$	$9x10^7$	$9x10^7$	$9x10^7$	0
Break Pool	420	555	1933	1933	0
Steel	83,505	83,505	83,505	83,505	43,251
Concrete	23,883	23,883	23,883	23,883	23,883
Jacketed Concrete	28,237	28,237	28,237	28,237	8,382
Evaporating Shell	0	0	47,613	27,000	0
Dry Shell	52,662	52,662	3,600	24,077	52,662
Subcooled Shell	0	0	1449	1585	0

Conclusions of the heat sink area table are:

The zero value areas have zero value pi groups, since the pi values include the product of flux and area.

The large drop area produces close coupling between the drops and the gas atmosphere.

The pool and shell areas change significantly during the LOCA transient.

2.0 Energy Conductance Pi Groups

Table 2 presents pi values for the energy transfer conductances of each heat sink and shell region during each time phase. The basis for the conductance, h, is the familiar ralationship $q = hA\Delta T$. An equivalent conductance can be defined for the parallel and series conductances for radiation,

convection, mass transfer, and the liquid film. The conductance pi values are defined as the ratio of the equivalent conductance to the shell conductance, that is, $\pi_c = h_e/h_{sh}$. All the conductance values have been normalized to the coated shell conductance that includes the shell and the inner and outer inorganic zinc coatings. The value of coated shell conductance is h_{sh} = 216.58 B/hr-ft²-F. The coating conductance is 4840 B/hr-ft²-F, so has little effect on the shell conductance. Since the normalizing value is the same for all values in Table 2 the values can be compared both horizontally and vertically.

Table 2 Heat Sink Energy Transfer Conductances Scaled to Shell Conductance

Heat Sink		Blowdown	Refill	Peak Press	Long Term	MSLB
Drops	$\pi_{c,d}$	141	165	149	202	--
Pool	$\pi_{c,p}$	231	0.02	1.38	1.51	--
Steel	$\pi_{c,st}$	0.31	0.39	0.41	0.62	0.37
Concrete	$\pi_{c,cc}$	0.25	0.39	0.37	0.54	0.29
Jacketed	$\pi_{c,jc}$	0.31	0.39	0.40	0.62	0.37
Dry Shell	$\pi_{c,ds}$	0.33	0.39	0.37	0.54	0.37
	$\pi_{c,dsx}$	0.01	0.01	0.01	0.02	--
Subcooled Shell	$\pi_{c,sc}$	--	--	0.39	0.58	--
	$\pi_{c,scx}$	--	--	3.88	3.88	--
Evaporat-ing Shell	$\pi_{c,es}$	--	--	0.37	0.60	--
	$\pi_{c,esx}$	--	--	0.10	0.52	--
Baffle	$\pi_{c,bf}$	0.03	0.03	0.05	-6.1	--
	$\pi_{c,bfx}$	0.01	0.01	0.01	0.02	--
Chimney	$\pi_{c,ch}$	0.03	0.03	0.03	0.06	--

Conclusions from the conductance scaling are:

Table 7-2 shows the conductances for the drops are extremely high, so the drops quickly reach thermal equilibrium with the gas and subsequently follow changes in the gas temperature with no significant lag.

The conductance to the pool during blowdown is very high because the break flow to the pool is assumed to flash to thermal and mechanical equilibrium with the average containment, as was assumed for the drops. Even after refill the pool conductance remains high due to the assumption that the source of break liquid is saturated at the containment total pressure.

The conductance of the outside surface of the subcooled shell is very high because heat is conducted directly from the shell to the subcooled liquid through the thin film thickness. Since the film is the heat sink, there is no additional evaporation, radiation, or convection conductance.

The conductances for the post-blowdown solid heat sinks, shell inside and evaporating shell outside all are high, in the range of 0.29 to 0.62, due to the high mass transfer conductance. The external conductance on the evaporating shell at the time of peak containment pressure is nearly equal to the internal conductance, and both are approximately 1/2 the shell conductance.

The remaining conductances range from 0.01 to 0.06 and are low mainly because mass transfer is not involved. The chimney operates with low conductances, even when condensate forms, due to the high noncondensable concentration. The dry shell external conductance is 1 to 2 orders of magnitude less than the internal conductance. The scaling analysis showed the baffle

inside and outside both operate dry and have low conductances.

The anomalously high negative baffle conductance resulted from a nearly zero-value, reversed baffle-riser temperature difference. Although the conductance is very high, the energy transfer is low, similar to the value during the preceding time phase.

3.0 Mass Pi Group Values

The containment and heat sink mass flow pi groups are presented in Table 3. Values greater than 10% are shaded.

Table 3 Containment and Heat Sink Mass Scaling Pi Group Values

Pi Group		Blowdown	Refill	Peak Press	Long Term	MSLB
Containment	τ_o (sec)	31	980	908	3309	392
	$\pi_{m,\tau}$	1.31	1.27	1.30	1.22	1.27
	$\pi_{m,brk}$	1.00	0.00*	1.00*	1.00	1.00
	$\pi_{m,f}$	1.50	0.00	2.00	0.00	0.00
Drops	$\pi_{m,flash,d}$	0.02	0.00	0.00	0.00	0.00
	$\pi_{m,evap,d}$	0.03	-0.05	0.01	0.00	--
Pool	$\pi_{m,p}$	0.04	0.00	0.03	0.07	--
Steel	$\pi_{m,st}$	-0.03	-0.86	-0.53	-1.02	-0.19
Concrete	$\pi_{m,cc}$	-0.01	-0.13	-0.06	-0.31	-0.10
Jacketed	$\pi_{m,jc}$	-0.01	-0.29	-0.18	-0.36	-0.04
Sc Shell	$\pi_{m,sc}$	--	--	-0.01	-0.04	--
Evap Shell	$\pi_{m,es}$	--	--	-0.43	-0.58	--
	$\pi_{m,esx}$	--	--	-0.02	-0.57	--
Dry Shell	$\pi_{m,ds}$	-0.02	-0.61	-0.03	-0.05	-0.27
Baffle	$\pi_{m,bf}$	0.00	0.00	0.00	0.00	--
Chimney	$\pi_{m,ch}$	0.00	0.00	0.00	0.02	--

* Refill was scaled with the same 200 lbm/sec flow rate used to normalize peak pressure.

Conclusions of the mass flow rate scaling are:

The mass flow pi groups show the break liquid mass flow rate is high, and the steel, concrete, jacketed concrete, dry shell, and evaporating shell have high scaled mass flow rates during some time phases.

The pool, drops, subcooled shell, baffle, and chimney always have small scaled mass flow rates.

During blowdown the break source flow rate is so high that even with significant energy absorption, none of the heat sinks have high scaled mass flow rates.

4.0 Energy Pi Group Values

The containment and heat sink energy flux pi groups are presented in Table 4. Values greater than 10% are shaded. Pi groups are normalized to different energy flow rates in each time phase, so cannot be compared between different time phases. The energy pi groups are all calculated relative to a zero energy reference for liquid water at 120 F inside containment and 115 F outside containment.

Table 4 Containment and Heat Sink Energy Scaling Pi Group Values

Pi Group		Blowdown	Refill	Peak Press	Long Term	MSLB
Containment	$\pi_{e,\tau}$	0.55	0.58	0.56	0.63	0.58
	$\pi_{e,brk}$	1.00	0.00*	1.00*	1.00	1.00
	$\pi_{e,f,work}$	0.00	0.00	0.00	0.00	0.00
Drops	$\pi_{e,q,d}$	0.00	0.00	0.00	0.00	--
	$\pi_{e,fg,d}$	0.05	-0.05	0.01	0.00	--
Pool	$\pi_{e,q,p}$	0.00	0.00	0.00	0.00	--
	$\pi_{e,fg,p}$	0.03	0.00	0.02	0.06	--
Steel	$\pi_{e,q,st}$	0.00	-0.05	-0.03	-0.03	-0.01
	$\pi_{e,fg,st}$	-0.03	-0.84	-0.50	-0.90	-0.19
	$\pi_{e,f,st}$	0.00	-0.02	-0.03	-0.12	0.00
Concrete	$\pi_{e,q,cc}$	0.00	-0.01	0.00	-0.01	-0.01
	$\pi_{e,fg,cc}$	-0.01	-0.12	-0.05	-0.27	-0.10
	$\pi_{e,f,cc}$	0.00	-0.01	0.00	-0.03	0.00
Jacketed Concrete	$\pi_{e,q,jc}$	0.00	-0.02	-0.01	-0.01	0.00
	$\pi_{e,fg,jc}$	-0.01	-0.28	-0.17	-0.32	-0.04
	$\pi_{e,f,jc}$	0.00	-0.01	-0.01	-0.04	0.00
Subcooled Shell	$\pi_{e,q,ss}$	--	--	0.00	0.00	--
	$\pi_{e,fg,ss}$	--	--	-0.01	-0.04	--
	$\pi_{e,f,ss}$	--	--	0.00	0.00	--
	$\pi_{e,q,ssx}$	--	--	-0.01	-0.05	--
Evaporating Shell	$\pi_{e,q,es}$	--	--	-0.02	-0.02	--
	$\pi_{e,fg,es}$	--	--	-0.41	-0.52	--
	$\pi_{e,f,es}$	--	--	-0.02	-0.06	--
	$\pi_{e,q,esx}$	--	--	0.00	-0.02	--
	$\pi_{e,fg,esx}$	--	--	-0.02	-0.52	--
Dry Shell	$\pi_{e,q,ds}$	0.00	-0.03	0.00	0.00	-0.02
	$\pi_{e,fg,ds}$	-0.02	-0.59	-0.03	-0.05	-0.27
	$\pi_{e,f,ds}$	0.00	-0.02	0.00	-0.01	0.00
	$\pi_{e,q,dsx}$	0.00	0.00	0.00	-0.02	--
Chimney	$\pi_{e,q,ch}$	0.00	0.00	0.00	0.00	--
	$\pi_{e,fg,ch}$	0.00	0.00	0.00	-0.02	--
	$\pi_{e,f,ch}$	0.00	0.00	0.00	0.00	--
Baffle	$\pi_{e,q,bf}$	0.00	0.00	0.00	-0.01	--
	$\pi_{e,q,bfx}$	0.00	0.00	0.00	-0.02	--

* Refill was scaled with the same pressure normalization used for peak pressure.

Conclusions of the energy scaling pi groups are:

The sensible heat transfer terms (q subscripted) are always small.

The energy carried away by the liquid film (f subscripted) is generally 10% or less of the energy transferred into the heat sink by condensation (fg subscripted).

The outside shell surface scaled energy transfer is small during blowdown, refill, and peak pressure. However, the inside of the dry shell during refill, and the inside of the evaporating shell during the peak pressure phase have large values of scaled energy transfer, indicating the

significant shell energy storage capacity.

Post-blowdown heat sink mass transfer pi groups (fg subscripted) have high values.

Energy interactions with the baffle and chimney are always small.

5.0 Pressure Pi Group Values

The containment and heat sink pressure pi groups are presented in Table 5. Values greater than 10% are shaded. The negative signs in Table 5 indicate pressure decrease terms, while the positive values indicate pressure increase terms.

Table 5 Containment and Heat Sink Pressure Scaling Pi Group Values

Pi Group		Blowdown	Refill	Peak Press	Long Term	MSLB
Containment	$\pi_{p,\tau}$	0.76	0.76	0.77	0.76	0.76
	$\pi_{p,brk,work}$	1.00	0.00*	1.00*	1.00	1.00
	$\pi_{p,brk,enth}$	0.03	0.03	0.03	0.02	0.03
	$\pi_{p,f,work}$	0.00	0.00	0.00	0.00	0.00
Drops	$\pi_{p,q,d}$	0.00	0.00	0.00	0.00	--
	$\pi_{p,enth,d}$	0.00	0.00	0.00	0.00	--
	$\pi_{p,work,d}$	0.05	-0.05	0.01	0.00	--
Pool	$\pi_{p,q,d}$	0.00	0.00	0.00	0.00	--
	$\pi_{p,enth,d}$	0.00	0.00	0.00	0.00	--
	$\pi_{p,work,d}$	0.04	0.00	0.03	0.07	--
Steel	$\pi_{p,q,st}$	-0.01	-0.16	-0.08	-0.08	-0.04
	$\pi_{p,enth,st}$	0.00	0.00	0.00	0.00	0.00
	$\pi_{p,work,st}$	-0.03	-0.86	-0.53	-1.02	-0.19
Concrete	$\pi_{p,q,cc}$	0.00	-0.02	0.01	-0.03	-0.02
	$\pi_{p,enth,cc}$	0.00	0.00	0.00	0.00	0.00
	$\pi_{p,work,cc}$	-0.01	-0.13	-0.06	-0.31	-0.10
Jacketed Concrete	$\pi_{p,q,jc}$	0.00	-0.05	-0.03	-0.03	-0.01
	$\pi_{p,enth,jc}$	0.00	0.00	0.00	0.00	0.00
	$\pi_{p,work,jc}$	-0.01	-0.29	-0.18	-0.36	-0.04
Evaporating Shell	$\pi_{p,q,es}$	--	--	-0.07	-0.05	--
	$\pi_{p,enth,es}$	--	--	0.00	0.00	--
	$\pi_{p,work,es}$	--	--	-0.43	-0.58	--
Subcooled Shell	$\pi_{p,q,ss}$	--	--	0.00	0.00	--
	$\pi_{p,enth,ss}$	--	--	0.00	0.00	--
	$\pi_{p,work,ss}$	--	--	-0.01	-0.04	--
Dry Shell	$\pi_{p,q,ds}$	0.00	-0.10	-0.01	0.00	-0.05
	$\pi_{p,enth,ds}$	0.00	0.00	0.00	0.00	0.00
	$\pi_{p,work,ds}$	-0.02	-0.61	-0.03	-0.05	-0.27

* Refill was scaled with the same pressure normalization used for peak pressure.

Table 5 provides the basis for the following conclusions:

All heat sinks, except the drops and pool, reduce pressure during the time phases considered.

The drops produce a small pressure increase during blowdown, and thereafter are either a pressure sink or a negligible pressure source.

The pool is always a small pressure source that increases to 7% at the time of peak containment pressure.

During the blowdown phase, the internal heat sinks and shell reduce the rate of pressure change by less than 7% of the source work.

The work due to mass removal is the most significant pressure reduction process; heat transfer processes (radiation plus convection) are typically less than 20% of the flow work.

The enthalpy pi groups for both the source and heat sinks are always small.

The pi groups clearly show the importance of mass transfer as the process that dominates the rate of pressure change after blowdown.

6.0 Momentum Pi Group Values

The time constant and pi groups for the PCS air flow path are presented in Table 6. The ratio of the branch buoyancy to the total buoyancy, G/G_o is presented to show the relative contribution of the downcomer, riser, and chimney to the total buoyancy. The PCS operation is not considered for scaling the MSLB, due to the relatively short duration of the transient.

Table 6 PCS Air Flow Path Momentum Scaling Groups

	Blowdown	Refill	Peak Press	Long Term
τ_{ri}	70	58	15	7.0
$\pi_{mv,in}$	0.13	0.13	0.13	0.11
$\pi_{mv,buoy}$	1.00	1.00	1.00	1.00
$\pi_{mv,res}$	1.00	1.00	0.97	0.86
$\pi_{mv,dc}$	0.00	-0.04	-0.03	-0.16
$\pi_{mv,ri}$	0.48	0.46	0.46	0.58
$\pi_{mv,ch}$	0.52	0.58	0.58	0.58
$Ra_dD/L)_{dc}$	--	247,000	$7.6x10^6$	$2.2x10^8$
$Re_{d,dc}$	16,100	19,500	74,100	152,000
$Ra_dD/L)_{ri}$	7,600	19,000	333,000	271,000
$Re_{d,ri}$	16,600	20,100	77,200	164,000
$Ra_dD/L)_{ch}$	$3.3x10^{11}$	$3.4x10^{11}$	$1.9x10^{11}$	$1.2x10^{11}$
$Re_{d,ch}$	27,400	33,100	128,000	282,000

The following conclusions are drawn from the momentum scaling:

The pi groups show the inertial effect is relatively small, and the effect of the downcomer on the net buoyancy is relatively small.

The air flow Reynolds number is high even during blowdown due to the assumed initial condition of 120 °F shell temperature and 115 °F riser air.

The free/mixed/forced convection regime of the flow in the downcomer, riser, and chimney can be determined from the Reynolds and Rayleigh (RaD/L) numbers.

7.0 PI Group Subscripts

The subscripts on the pi groups identify the scaled parameter, the heat sink, and the phenomena.

Scaled Parameter

The first subscript on each pi group defines whether it is a ratio that scales:

c	=	conductances,
m	=	mass flow rates
e	=	energy flow rates
p	=	pressure rate of change
mv	=	momentum.

Heat Sinks and PCS Volumes

The following pi group subscripts specify the heat sink or component. The heat sinks inside containment are:

d	=	drops
p	=	break pool
st	=	steel heat sink
cc	=	concrete heat sink
jc	=	jacketed concrete

For the drops, mass scaling requires an additional level of subscripting to specify the fraction that flashes (flash) and the fraction that evaporates (evap). This distinction is not used for scaling drop conductance, energy, or pressure effects.

The subscripts for the shell are associated with both inside and outside containment shell surfaces:

sc	=	subcooled shell inside
scx	=	subcooled shell outside
es	=	evaporating shell inside
esx	=	evaporating shell outside
ds	=	dry shell inside
dsx	=	dry shell outside

Subscripts for heat sinks and components outside the shell are:

bf	=	baffle inner surface (facing the shell)
bfx	=	baffle outer surface (facing the shield building)
ch	=	chimney surface
dc	=	downcomer volume
ri	=	riser volume
ch	=	chimney volume

<u>Other Subscripts</u>

τ	=	the pi group that multiplies the transient term, for example, ? $_{\tau}dm^*/dt^*$.
brk	=	the break source
f	=	liquid. When used on containment groups f indicates all liquid sources including drops, films, and pools. In energy pi groups, f indicates the excess enthalpy of the condensed liquid that runs off the heat sink.
work	=	Pv work associated either with gas flowing in or out of the control volume (break, condensation, or evaporation), or with a change in the volume of the gas control volume due to liquid displacement.
q	=	sensible energy (heat) transfer by radiation or convection.
fg	=	phase change energy: the difference between h_g - h_f for condensation, or h_{fg} for evaporation.
enth	=	Excess enthalpy associated with the gas flowing in or out of the control volume (break, condensation, or evaporation)
in	=	inertia
buoy	=	buoyancy
res	=	resistance