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Your ref: Docket No. 52-006
Our ref: DCP/NRC1699

April 30, 2004

SUBJECT: Westinghouse Responses to ACRS Open Issues

This letter transmits Westinghouse responses to Issues 5-7 identified in the letter from the Advisory Committee on Reactor Safeguards dated March 17, 2004. A list of the responses transmitted with this letter is Attachment 1. The non-proprietary responses are transmitted as Attachment 2.

Please contact me at 412-374-4728 if you have any questions concerning this submittal.

Very truly yours,

for

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Attachments

1. List of the AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses transmitted with letter DCP/NRC1699
2. Non-Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated April 30, 2004

DCP/NRC1699

April 30, 2004

			Attachments
bcc:	Document Control	- US NRC, Rockville, MD	1 (original)
	C. B. Brinkman*	- Westinghouse, Rockville, MD	
	W. E. Cummins*	- Westinghouse, Pittsburgh, PA, EC E3	
	J. A. Gresham*	- Westinghouse, Pittsburgh, PA, EC E4-07A	
	J. P. Segala	- US NRC, Rockville, MD	6
	R. P. Vijuk	- Westinghouse, Pittsburgh, PA, EC E3-05	2
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* Letter only

April 30, 2004

Attachment 1

List of

Non-Proprietary Responses

Table 1 **"List of Westinghouse's Responses to ACRS Open Issues Transmitted in DCP/NRC1699"**	
ACRS ISSUE 5 ACRS ISSUE 6 ACRS ISSUE 7	

DCP/NRC1699
Docket No. 52-006

April 30, 2004

Attachment 2

AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: ACRS ISSUE 5

Original RAI Number(s): None

Summary of Issue:

In-Vessel Retention/Fuel-Coolant Interactions (FCI): The assessment of in-vessel retention has not included exothermic intermetallic reactions which have been shown by some prototypic experiments to be important. If these factors are properly accounted for, the associated energetics of any resulting ex-vessel steam explosions are likely to be greater than has been currently evaluated. We would like to review the FCI models used and see additional justification that the initial conditions related to intermetallic reactions will not give rise to an energetic FCI that could fail containment.

Westinghouse Response:

ACRS has questioned whether the ex-vessel steam explosion analyses performed for AP1000 and AP600 bounds a postulated steam explosion from a vessel breach at the bottom of the reactor vessel (reference 1).

The ex-vessel steam explosion analysis of record (reference 2) assumes that the vessel fails at the top of the oxide debris near the top of the lower head hemisphere.

A vessel breach at the bottom of the vessel head can be postulated to occur if bottom heavy metal layer of uranium, zirconium and iron forms in the debris bed and produces a thermal loading to the vessel wall that cannot be cooled by the boiling heat transfer at the lower head external surface. The thermal loading from the in-vessel debris bed is postulated to be produced by decay heat in the bottom metal layer and a potential exothermic chemical reaction that occurs as vessel wall steel is mixed into the zirconium/uranium rich bottom metal layer (reference 3). The critical heat flux, which defines the upper bound of cooling capacity, is smallest at the bottom of the reactor vessel (reference 4). Therefore, a high heat flux from the bottom metal pool may be postulated to exceed the critical heat flux at the bottom of the reactor vessel thus producing failure of the vessel wall. The vessel failure at the bottom of the vessel would release the molten bottom metal layer into the cavity water pool and potentially produce a steam explosion.

It is the Westinghouse position that, while such a debris bed configuration may be postulated, it is unlikely to produce vessel failure. Including a bottom vessel head failure in the AP1000 PRA will not significantly increase the risk of the plant. Therefore, the ex-vessel steam explosion analyses already performed bounds the consequences of a vessel failure at the bottom of the head.

To examine the likelihood of the formation of a bottom metal layer that challenges the lower head integrity can be decomposed into a series of questions and analyzed on a decomposition event tree (Figure 1):

1. Is the reactor vessel reflooded during the progression of the core damage sequence?
2. Does the in-vessel melt progression prevent mixing of a significant mass of zirconium with the molten oxide debris?
3. Given a bottom metal layer, does the bottom metal layer have less decay heat that it takes to melt the vessel wall?
4. Given a melting metal wall, does the chemical reaction produce less heat than required to exceed the critical heat flux at the external surface of the vessel?

1. Is the reactor vessel reflooded during the progression of the core damage sequence?

If the reactor vessel is reflooded, the reactor vessel wall is cooled from the outside and the debris bed is cooled from the inside. The mass of debris that relocates to the lower head is limited. Therefore, the challenge to the reactor vessel wall is mitigated. Approximately 50 percent of the AP1000 core damage frequency results in a reflooded reactor vessel from the progression of the severe accident sequence. Therefore, the failure probability at node 1 is assigned 0.5.

2. Does the in-vessel melt progression prevent mixing of a significant mass of zirconium with the molten oxide debris?

A bottom metal layer may be postulated only when a significant quantity of unoxidized zirconium mixes with steel and UO_2 in the oxide layer. However, the mixing of the constituents in the RASPLAV test is not considered to be applicable to the large-scale reactor relocation scenario (reference 5). In the melting and relocation analyses performed for the AP1000, it was shown that almost all of the unreacted zirconium in the damaged core is frozen at the top of the lower core support plate. The frozen zirconium does not participate in the formation of the lower head debris configuration until the lower support plate is subsumed and melted by the oxide debris from below. The melting temperature of the lower support plate and zirconium is much less than the oxide debris. Therefore, the formation of a significant bottom metal layer is considered to be unlikely. The failure of this node is assigned a probability of 0.1 on the decomposition event tree.

3. Given the formation of a bottom metal layer, does the bottom metal layer have less decay heat than it takes to melt the vessel wall?

A conservative analysis of the heat loading from a bottom metal layer is presented in reference 6. This analysis considers only the thermal loading from decay heat in the bottom metal layer and does not include any heat from a chemical reaction from mixing steel from the melting vessel wall into the uranium/zirconium rich bottom metal layer. The analysis considers 7000 kg of unoxidized zirconium, and 3000 kg of stainless steel reacting with the oxide to produce the bottom metal pool. The reaction is assumed to produce a bottom metal pool that is 40 weight-

percent uranium (reference 7). One hundred percent of the decay heat associated with an equivalent volume of oxide required to produce the uranium content of the bottom metal layer is mixed in with the uranium in the bottom metal pool along with the remaining iron and zirconium. The fraction of the decay heat is a very conservatively chosen upper bound value that was intended to cover all uncertainties such as the potential chemical reaction heat. The analysis shows that in this configuration, the resulting heat load to the lower head melts the inside vessel wall, but is not sufficient to exceed the critical heat flux. The lower head is predicted to not fail.

If the analysis is performed specifically including the potential heat of mixing the melting vessel wall into the uranium/zirconium rich bottom metal pool, it is appropriate to make the decay heat assumption in the pool a less conservative estimate. According to peer reviewer comments in reference 8, the actual upper bound of the decay heat that could be mixed in the metal pool is approximately 20 percent of the decay heat from the equivalent volume of uranium dioxide instead of 100 percent.

Based on reference 6, the maximum bottom metal layer volume is 1.53 m^3 with a thickness of 0.58m. With 100% of the associated decay heat, the volumetric heat density is 1.38 MW/m^3. Therefore, for the realistic upper bound value of 20%, the volumetric heat density is 0.28 MW/m^3. The total decay heat in the bottom metal layer is 0.43 MW. The area of the layer in contact with the reactor vessel is 7.34 m^2. The area upward to the oxide layer is assumed to be adiabatic. The thermal conductivity of the metal layer is high, so it is assumed to generate a uniform heat flux over the vessel wall. Therefore, the heat flux to the vessel is 58 kW/m^3. Given the vessel wall thickness of 0.1524 m and a thermal conductivity of 32 W/m-K, the inside wall temperature at this heat flux is 650°K, well below the melting temperature of the vessel wall.

The calculation of the inside vessel wall temperature assumes that the heat transfer from the oxide layer is negligible. Based on the volumetric heat density and the thickness of the heavy metal layer, the top surface temperature at the interface of the oxide layer and the heavy metal layer is approximately 2600°K, which is close to the temperature of the oxide crust layer. Therefore, the adiabatic top surface assumption is reasonable at this decay heat level.

In this case, with 20 percent decay heat, the analysis of the heat load to the vessel wall shows that the vessel wall does not melt. Therefore, the rate of mixing is limited to solid phase diffusion of the wall into the molten pool, which is quite slow. The heat of reaction is therefore very small, will not become a runaway reaction, and can be removed by the external vessel cooling.

Therefore, the reactor vessel is not expected to fail at the bottom metal layer. Node 2 is assigned a failure probability of 0.1.

4. **Given melting of the vessel wall at the bottom metal layer, does the chemical reaction produce less heat than required to exceed the critical heat flux at the external surface of the vessel?**

Based on the analysis presented in reference 3, if the vessel wall is melting, the heat of mixing the steel into the heavy metal layer is not expected to produce a runaway reaction or fail the vessel wall. However, this phenomenon is considered to be complex. It is therefore conservatively assigned a failure probability of 0.5 on the decomposition event tree.

Failure at node 4 results in vessel failure. If the vessel fails into the reactor cavity, the containment is assumed to fail immediately from an ex-vessel steam explosion in the PRA. This assumption is carried through in this analysis. The initial conditions in this case are for a vessel failure that occurs close to the bottom of the reactor vessel. This type of vessel failure has not been investigated in the AP1000 PRA severe accident analyses. Therefore, it is appropriate to assume early containment failure for this vessel failure condition.

Quantification of the Decomposition Event Tree

The Decomposition Event Tree is quantified in Figure 1. The base large release frequency from the internal event at power PRA is $2x10^{-8}$ per reactor-year. The increase to the large release frequency from a steam explosion induced by the failure of IVR due to the formation of a bottom metal layer that dissolves the lower head is $6.0x10^{-10}$ per reactor-year, or a 3% increase. The conditional containment failure probability increases from 8.1 percent to 8.3 percent. This increase in large release frequency is considered to be negligible and does not impact the results of the PRA.

References

1. ACRS Letter Mario V. Bonaca, ACRS, to William D. Travers, USNRC, ACRS Reviews of the Westinghouse Electric Company Application for Certification of the AP1000 Plant Design – Interim Letter, March 17, 2004.
2. AP1000 PRA, revision 6.
3. Theofanous, T.G., Limits of Coolability in the AP1000 Related ULPU-2400 Configuration V Facility, CRSS-03/06, June 2003.
4. Westinghouse Response to RAI 720.047.
5. Scobel, J.H. The Potential for AP1000 Reactor Vessel Failure Induced by a Stratified Debris Bed with a Bottom Metal Layer During IVR, International Conference on Advanced Nuclear Power Plants (ICAPP), Cordoba, Spain, May 2003.
6. Rempe, J.L., et. al, Potential for AP600 In-Vessel Retention through Ex-Vessel Flooding, INEEL/EXT-97-00779, December 1997.
7. Theofanous, T.G., et. al., In-Vessel Retention and Coolability of a Core Melt, DOE/ID-10460, July 1995

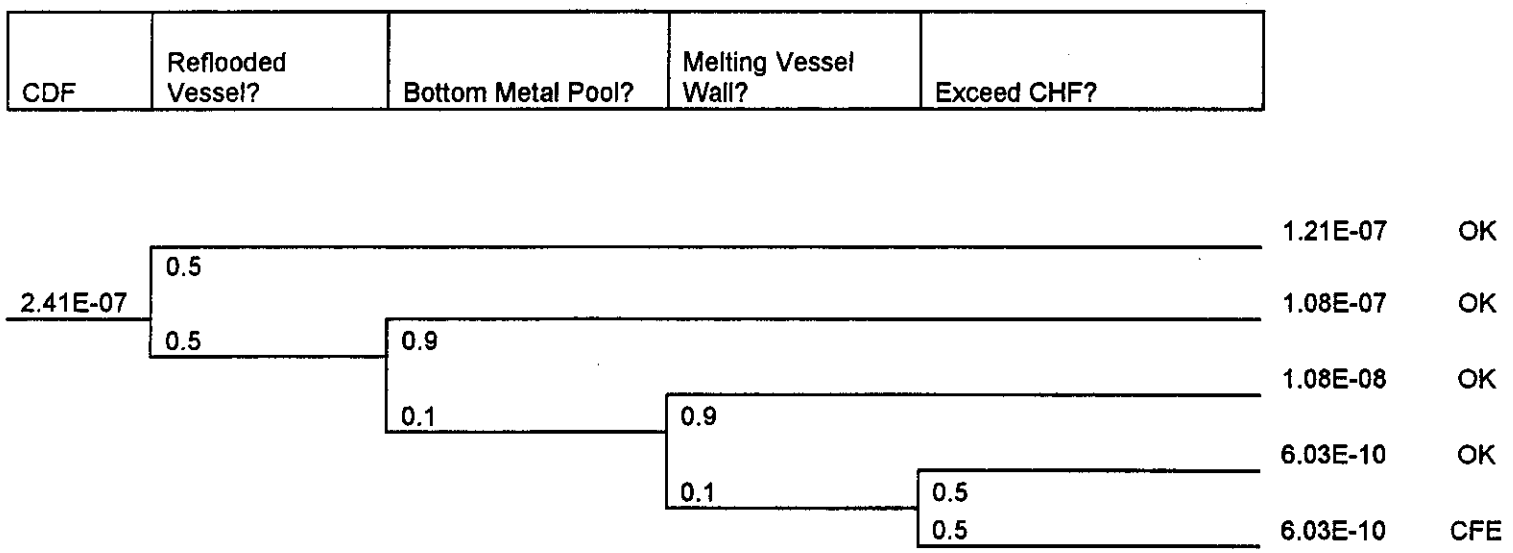
Design Control Document (DCD) Revision:

None

PRA Revision:

None

Figure 1
Decomposition Even Tree



Base LRF =	1.95E-08	per year
Increase to CFE =	6.03E-10	per year
Increased LRF =	2.01E-08	per year

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: ACRS ISSUE 6

Original RAI Number(s): None

Summary of Issue:

Organic Iodine Production: The acidification of containment water as a result of radiolysis of organic material could give rise to significant airborne fission product iodine in gaseous organic form. We need to review how Westinghouse and the staff have dealt with this potential

Westinghouse Response:

Our understanding of the concern is that the water film on the inside of the containment might become acidic due to the pickup of HNO3 and HCl which would result in the production of elemental iodine from the cesium iodine in solution. HNO3 may be produced in the water film during its drain time. HCl may be produced from the radiolytic decomposition of the HYPALON jackets on electrical cables in containment.

In actuality the water film is expected to be neutral or basic because of the following:

1. A representative AP1000 core melt sequence was selected, i.e. 3BE-1, which is a DVI LOCA with failure of more than one ADS stage 4 path. The condensate film thickness and velocity were obtained from the MAAP4 analysis of this sequence and were used to calculate the water film drain time. From the top of cylindrical shell section (>33 meter height) the drain time was determined to vary from about 1 minute at 1 hour to about 2.5 minutes at 10 hours. Note that some water will drain from higher up on the dome and some from lower on the shell. It is only during this limited time frame that acids (HNO3 and HCl) can be introduced into the water film. It is important to emphasize that the PCS feature results in the continuous generation of 'clean' steam that condenses on the dome and shell and transports the deposited fission products to the water pool in the bottom of the containment. The dome and shell are coated with inorganic zinc not an organic paint. Thus, the coatings on these surfaces would not provide a source of organic material for the generation of organic iodine.
2. CsI and CsOH are released to the containment atmosphere from the reactor as the core melts. Both CsOH and CsI are deposited on the water film on the containment shell. The deposition rate is related to the rate of steam condensation on the containment shell. Both CsOH and CsI are highly soluble chemicals and are rapidly taken up by the water film draining down the shell.
3. The CsOH is a strong base that tends to counteract the acidification of the film by HNO3 and HCl.
4. The rate of mass transfer of deposited CsOH and CsI into the draining film is quite high. Once deposited on the water film, they quickly drain into the lower containment volumes. Once the release for fission products from the RCS is over, the process of depositing fission products on the water film slows down and stops. The potential of iodine re-

evolution from the water film is only an issue for the early part of the sequence when a significant iodide concentration could be produced in the draining water film.

5. The AP1000 design provides sufficient TSP to the containment water pool to account for both HNO3 and HCl production. In the long term, the fission products are transported to the containment water pool.
6. Once the fission products are transported to the containment water pool, they will remain there since there is no containment recirculation spray capability and because the process of creating steam (either inside or outside the reactor vessel) will not re-introduce fission products or other chemical species into the containment atmosphere.

As a result, the pH of the containment water film would not be sufficiently acidic while there is iodine present in the film and iodine in the film would not re-evolve as elemental iodine.

We are in the process of calculating the pH that could exist in the water film on the containment wall. We will provide estimates of the film residence time on the shell, the concentrations of CsOH and CsI in the draining film, and the film's pH.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: ACRS ISSUE 7

Original RAI Number(s): None

Summary of Issue:

There is experimental evidence that a free-standing steel containment can fail in a catastrophic manner when its failure pressure is exceeded. Such a failure mode can lead to very rapid depressurization and, potentially, to resuspension of fission products that have been previously deposited or settled out. While the surrounding concrete structure of the AP1000 design may impede such a catastrophic depressurization, we would, nevertheless, like to see a sensitivity study on the fission product source term to assess the potential maximum effect on the risk of latent fatalities as compared to the Safety Goal.

Westinghouse Response:

The likelihood of a catastrophic failure of the AP1000 steel containment with the passive containment cooling system (PCS) due to over pressure is very small; if the PCS water drain valves all fail (2 AOVs and 1 MOV) and the operators do nothing, the reduced effectiveness of air only cooling causes the containment pressure to exceed design pressure such that the probability of the containment failing is approximately 0.02.

In addition, the operators have several actions that they could take that would prevent the possibility of containment failure and they have at least 24 hours to take one of those actions. The actions include:

- Climb up to the PCS valves and manually crank open one of the PCS drain valves that failed to open remotely.
- Align another water supply to the outside surface of the containment; connections are provided for PCS Ancillary Water, Fire Water and Demineralized water.
- Vent the containment to relieve the excess pressure.

The SAMG procedures that would guide the operator to take these actions provide an additional level of protection against catastrophic containment failure. Thus, rapid containment depressurization due to catastrophic containment shell failure is highly unlikely.

The potential for rapid containment depressurization causing the resuspension of fission products that have been previously deposited or settled out has been evaluated for a set of LWR reference plants as part of the IDCOR program (IDCOR, 1984). The range of containment volumes and catastrophic break sizes considered in the IDCOR study include the applicable AP1000 characteristics. Several major conclusions from this evaluation were made and include:

- Thin layers of particulate held by electrostatic forces are so tightly bounded that even very high velocities would not strip them off the surface.

- Thicker particulate layers, like those that could be found on horizontal surfaces could be resuspended but only after a long time of high velocities. Considering the blowdown character of the containment, either high velocities for short times or low velocities over long times, it can be concluded that resuspension throughout the containment volume would be insignificant even for large rupture sizes.

- Evaluation of potential debris accumulation in close proximity to localized penetration failures shows that the velocities over the top of the debris would be too small to resuspend the particles.

- Experiments on the physical state of cesium iodide and cesium hydroxide show that contact with water would essentially eliminate their potential for dispersion even if the water should eventually dryout.

- Experiments on debris dispersion show this phenomenon can be represented by simple physical models. These experiments also show that rapid depressurizations would be required to resuspend a debris accumulation and to maintain the suspended state.

- Evaluation of the resuspension potential for the various containment designs considered in the IDCOR reference plant analyses shows that even if large rupture areas and dry particle beds are assumed, resuspension due to dispersion would be insignificant.

The physical state of the deposited and settled aerosols is the controlling attribute regarding the potential for resuspension. Wetted deposits require very large velocities and dissolved deposited would require entrainment of the water film or pool containing the dissolved fission products. Since the AP1000 containment uses a PCS, the long term removal of decay heat results in wet internal containment surfaces. Containment failure due to overpressure would require the failure of the PCS to remove decay heat. However, conditions inside containment would remain wet with steam. Thus, the expected physical state of the deposited and settled fission product aerosols is wet and not dry. This physical state in combination with the high solubility of the key dose significant fission product aerosols (CsOH and CsI) severely reduces the potential for resuspension.

A range of containment conditions were evaluated in the IDCOR study. It included a large dry PWR containment with a volume of 74,000 m^3 and a catastrophic containment failure area of 10 m^2. For AP1000 the containment volume is 60,800 m^3 and sequences that include its catastrophic containment failure used a failure area of 1.0 m^2. These AP1000 attributes fall within the range of conditions that were used to evaluate the potential for resuspension of deposited aerosol in the IDCOR study. The physical state was conservatively assumed to be dry aerosol. The upper bound particle size limit for dispersion of a bed of settled (dry) particles following the rapid depressurization of the AP1000 containment is estimated to be of the order

of 0.1 μm. Like the IDCOR reference plants, this is smaller than the particle sizes that dominate the settling process. If one assumed a ten times larger failure area, the upper bound limit on the particle size that could be re-suspended would increase by a factor of about three to about 0.3 microns and the same conclusion would apply. Consequently, even if the wet physical state of the deposited fission product aerosols is ignored and the particle bed is assumed to be dry, the potential for resuspension of a settled particle bed is also insignificant for the AP1000 design.

Thus, it is concluded that the fission product source term for the AP1000 containment with its PCS is insensitive to the postulated catastrophic containment failure due to excessive overpressure.

Reference

IDCOR, 1984, "Technical Report 11.6 Resuspension of Deposited Aerosols Following Primary System or Containment Failure," August.

Design Control Document (DCD) Revision:

None

PRA Revision:

None