AP1000 Design Certification Review

Westinghouse Electric Company

Presentation to

Advisory Committee on Reactor Safeguards

June 3, 2004

BNFL Westinghouse

Safety Goal Risk Measures

- **NRC Safety Goal Policy Statement**
  - no significant additional risk to life and health
- **Quantitative Health Objectives - metrics for Safety Goal**
  - fatality and cancer risks < 0.1% of sum from other causes
- **Quantitative Health Objectives - numerics**
  - risk of prompt fatality < 5E-07 per reactor year
  - risk of latent cancer fatality < 2E-06 per reactor year
- **AP1000 PRA Results**
  - risk of prompt fatality 8.4E-11 per reactor year
  - risk of latent cancer fatality 8.6E-10 per reactor year

AP1000 Risk Quantification

- The AP1000 comparison to Safety Goal shows that additional uncertainties associated with severe accident analysis, such as those discussed today, can readily be tolerated without challenging the Safety Goal measures

Summary of Issue 5

- Exothermic intermetallic reactions could lead to a vessel failure and produce a fuel-coolant interaction (FCI) greater than currently evaluated.
- ACRS would like to review FCI models and see justification that such a FCI does not fail containment.

Ex-Vessel FCI in AP1000

- **FCI Analysis presented for AP600 using TEXAS concludes ex-vessel FCI does not fail containment**
- **AP600 analysis applied to AP1000**
  - Similar vessel lower head geometry
  - Similar lower plenum debris characteristics
    - materials
    - temperatures
  - Same vessel failure modes
  - AP1000 vessel closer to containment floor
- **This is consistent with NRC staff findings**

FCI in AP1000

- **Vessel bottom failure not the limiting case**
  - Bottom of vessel close to floor
  - Limited pre-mixing volume
  - Limited debris participating in the FCI
- **This is consistent with NRC staff findings**

Vessel Head Bottom Failure

- Decomposition Event Tree examines the potential for vessel failure at the bottom of the vessel head
- Four Nodes on the DET
  - Is the reactor vessel reflooded during the progression of the core damage sequence?
  - Does the in-vessel melt progression prevent mixing of a significant mass of zirconium with the molten oxide debris?
  - Given a bottom metal layer, does the bottom metal layer have less decay heat than it takes to melt the vessel wall?
  - 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?
- Vessel Failure not expected to result in bounding FCI

Vessel Reflooded?

- Many AP1000 severe accident sequences internally reflood the reactor vessel.
  - Vessel cooled inside and outside
  - Mitigates debris relocation inside vessel
  - Mitigates challenge to lower head
- Failure probability assigned = 0.5

Bottom Metal Pool?

- **In-vessel debris relocation prevents large-scale mixing of molten Zr with UO_2**
  - Zr frozen at top of support plate
  - Oxide crusts prevent mixing
  - No uranium formation
  - No bottom heavy metal pool
- **Failure probability assigned = 0.1**

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Melting Vessel Wall?

- **The decay heat in the bottom metal layer is not sufficient to melt the bottom vessel wall**
  - 20% of the fission products assumed to go into bottom layer with the uranium
  - Vessel wall in contact with bottom metal layer predicted to not melt
  - No mixing of Fe into the U-Zr rich metal layer
- **Failure probability assigned = 0.1**

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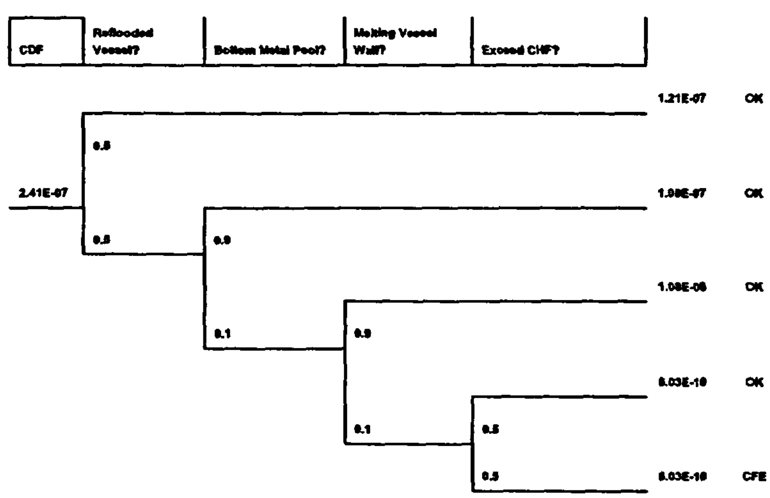
AP1000

Fe-Zr-U Reaction Exceed CHF?

- **Examination performed by UCSB predicts no runaway exothermic reaction**
  - Complex phenomena
- **Conservatively assigned a Failure probability = 0.5**

AP1000

Decomposition Event Tree



Results

- Base LRF = $2x10^{-8}$ per reactor year
- Increase to LRF = $6x10^{-10}$ per reactor year
- CCFP increases from 8.1% to 8.3%
- Conclusion
  - Inclusion of potential for bottom vessel head failure has negligible impact on the AP1000 PRA results

Summary of Issue 6

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.

AP1000

Issue 6: Organic Iodine Production

- Formation of organic iodine as a result of radiolysis or organic materials involves the availability of elemental iodine (I_2).
- Elemental iodine can be produced from iodide (I^-) in water pools or films where pH is not controlled to be 7 or greater.
- AP1000 containment design includes TSP to control the pH of the water pool that collects in the lower compartment and reactor cavity following an accident.
- However, no specific pH control treatment for the condensate film draining down the containment dome and shell is provided.
- Cesium iodide can be deposited on the draining film and provide a source of I^- that could potentially be converted in the film to I_2 given the film was acidified.
- Film residence time depends on the steam condensation rate and limits the amount of film acidification and CsI deposition. A range of 40 to 260 seconds has been estimated for condensation rates of 29 to 2.3 kg/s.

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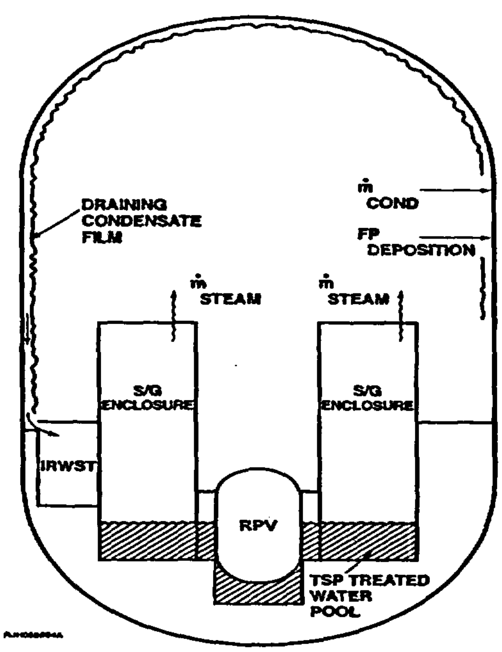

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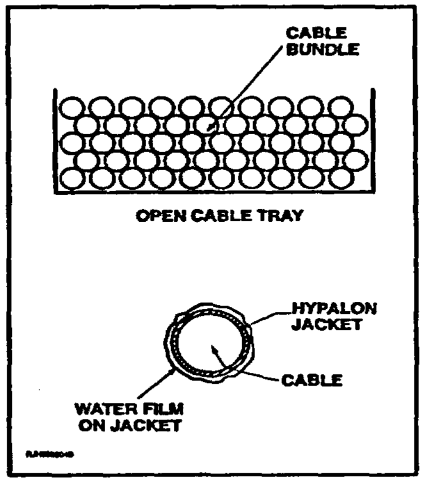
Issue 6: Organic Iodine Production

- Radiolytic decomposition of electric cable jacket material can produce HCl. If the HCl could escape the uncovered and covered cable trays, it could eventually mix with the containment atmosphere and be delivered to the draining film with the condensing steam.



AP1000

Issue 6: Organic Iodine Production

- **Draining film could be acidified by radiolytic formation of nitric acid or possibly deposition of other acids generated in containment.**
- **The radiation field in containment varies as the FPs are released and then removed by various deposition mechanisms.**
- **The estimated range of film pH due to nitric acid generation is 5.6 to 6.5 and 4.8 to 6.7 due to HCl deposition during the first 10 hr of the accident when $[I^-] \geq \sim 10^6$ g-mole/liter.**
- **A very small integral amount of CsOH (270 gram) from deposited aerosol fission products would be sufficient to neutralize all this nitric and hydrochloric acid for this 10 hour interval. Less than 0.1% of the potentially available CsOH in the core would completely neutralize the film.**

Issue 6: Organic Iodine Production

- It is known that a variety of fission product chemical species constitute the source term (ST). CsOH has been judged to be a dominant specie and used as a surrogate chemical specie for the balance of Cs available following CsI formation.
- If the balance of the core Cs is considered to be CsOH, an initial core inventory of approximately 373 kg of CsOH would be available for release. This is several orders of magnitude larger than that estimated to neutralize the draining film.
- Continuing ST research such as in the PHEBUS facility suggests multiple Cs compounds are formed and may be released as aggomerated aerosols of multiple fission product species. Thus, some uncertainty exists regarding the dominant chemical specie but it doesn't eliminate the existence of CsOH as one specie.
- Interestingly, the PHEBUS FTP1 test results indicate that the aerosols injected into containment do not possess a strong acidic character. A small increase in sump pH was measured when the deposited fission products were washed into the sump.

Issue 6: Organic Iodine Production

- The limited inventory of CsOH required to neutralize the film leads to the expectation that the draining condensate film pH will be 7 or greater.
- Significant conversion of the deposited iodide (I^-) would not be expected nor would the formation of additional organic iodine.

Issue 6: Organic Iodine Production

- As a sensitivity study, it can be assumed that no CsOH is deposited on the draining film.
- Regulatory design basis source term (ST) definition considers that 3% of the elemental iodine that is released from RCS is converted to organic iodine in containment. (Note: 5% of iodine released from RCS is taken as elemental so 0.03 x 0.05 = 0.15% of released iodine is in organic form per the ST definition.) This source term has been used in the AP1000 design basis dose assessments.
- Models have been formulated (NUREG/CR-5950) for estimating the fraction of I^- converted to I_2 in water as a function of the water's pH and the I^- concentration.
- Experimental studies indicate that when a threshold radiation dose to water is exceeded, the conversion will reach the steady-state value. Specifically, NUREG/CR-5950 states that for this model:
  - "Experimentally, it has been observed that at dose rates > ~0.3 Mrad/hr, steady state would be reached within a few hours."
- The draining film residence times are much shorter than an hour, which suggests that the steady-state conversion fractions would not be obtained.

Issue 6: Organic Iodine Production

- To estimate the potential dose impact of additional organic iodine generation due to the lack of specific pH control of these draining films, it will be assumed that the conversion model applies and conversion of iodine form occurs instantaneously.
- Based on the estimated ranges of film pH for either HNO_3 formation or HCl deposition and the range of iodide concentrations due to CsI deposition, the conversion fraction is estimated to vary between 0 and 0.5 over the 10 hour interval.
- As a conservatism, a conversion fraction of 1.0 is assumed to assess the potential dose impact.
- All the I^- in the deposited CsI, is assumed to be converted to elemental iodine in the draining film and also assumed to be in the equilibrium distribution of the aqueous, $(I_2)_{aq}$, and the gaseous, $(I_2)_{gas}$, molar concentrations.

Issue 6: Organic Iodine Production

- An expression for the iodine partition coefficient, PC (I_2), defined as the ratio of aqueous to gaseous concentrations is provided in NUREG/CR-5950 to be given as a function of the water temperature:

  $\log_{10} PC(I_2) = 6.29 - 0.0149\,T$

  where T is in °K
- The draining condensate film temperature is used to determine the iodine partition coefficient over the 10 hr interval. The fraction of $(I_2)_{gas}$ in the film is assumed to all be released as elemental iodine into the containment gas space. This corresponds to approximately 6.4% of the iodine aerosol released per the design basis ST.
- With the assumed 3% conversion to the organic form for the elemental iodine released to the containment atmosphere, the impact on the organic iodine source term is to increase it from 0.15% to 0.33%.
- The fraction of $(I_2)_{aq}$ that remains in the film is not expected to produce organic iodine since the containment dome and shell are coated with inorganic zinc that does not contain organic material.

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Issue 6: Organic Iodine Production

- This sensitivity study includes several significant conservatisms:
  - core melt,
  - conservative source that includes 3% conversion of elemental to organic iodine,
  - conservative containment leak rate,
  - conservative weather (χ/Q quantification),
  - zero CsOH release,
  - for control room no operation of HVAC nor re-supply of compressed air.
- The impact on the doses of the additional organic iodine is:

  Site Boundary 24.7 rem increases to 24.71 rem

  LPZ 22.8 rem increases to 23.16 rem

  Control Room 4.8 rem increases to 5.07 rem
- The sensitivity study results indicate that sufficient margin exists in the design basis dose assessment to accommodate these postulated consequences of no explicit pH control for the draining condensate films even if no CsOH deposition is considered.

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Summary of Issue 7

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.

Issue 7: Catastrophic Containment Failure

- Likelihood of catastrophic failure of the AP1000 steel containment due to overpressure is low, approximately 0.02, given failure of PCS cooling and no corrective operator actions.
- At least 24 hours are available for operators to take preventive actions. Any of the following actions could prevent the possibility of containment failure:
  - Climb up to the PCS values 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 Demin water.
  - Vent the containment to relieve the excess pressure.
- SAMG procedures that would guide operators to take these actions provide an additional level of protection against catastrophic failure and rapid containment depressurization.

Issue 7: Catastrophic Containment Failure

- The potential for rapid containment depressurization causing resuspension of deposited fission products for a set of LWR reference plants was evaluated as part of the IDCOR program.
- The range of containment volumes and catastrophic break sizes include the applicable AP1000 characteristics.
- The IDCOR report concludes that resuspension due to dispersion following catastrophic containment failure would be insignificant even for large failure areas (10 m^2) and dry particle deposits.
- Wetted deposits are harder to disperse than dry deposits (deposited and settled aerosols).
- The conditions inside the AP1000 containment with or without failure of the PCS to remove decay would remain wet with steam.

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Issue 7: Catastrophic Containment Failure

- The expected wet physical state of the deposited fission products greatly reduces the potential for resuspension.
- Thus, it is also concluded for AP1000 that catastrophic containment failure would not significantly enhance the fission product source term.
- The risk significance of any source term increase due to resuspension would be very small since the frequency of catastrophic failure induced releases is very low.
- This low frequency and the availability of preventive operator actions to potential catastrophic containment failure would prevent any discernible impact on compliance with the Safety Goal.

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