Phenomena Identification and Ranking

VHTR Cooperative Agreement

Program Review Meeting

February 25, 2009

Phenomena Identification and Ranking

- Crucial that the most important thermal-hydraulic phenomena of an accident scenario be identified.
  - Impossible to maintain complete similarity in reduced scale facilities.
- NGNP is still in the conceptual design stage and design activities are still ongoing.
  - Any conclusions based on the NGNP designs may change as the result of subsequent design changes to the VHTR.
- An NGNP PIRT was completed for the NRC in 2008.
  - Identified six general categories of postulated accident scenarios for the VHTR.
    - Pressurized loss of forced convection (P-LOFC or PCC),
    - Depressurized loss of forced convection (D-LOFC or DCC),
    - Depressurized loss of forced convection with air ingress,
    - Reactivity induced transient,
    - Steam-water ingress events, and
    - Process plant coupling events.

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Thermal Hydraulic Phenomena of Importance

- "Important TH parameters"
  - Consider in the scaling and design of the integral test facility.
  - High in importance (in PIRT).
  - Medium/low in knowledge (in PIRT).
  - Can be investigated using the HTTF.
- PIRT as a "living document".
  - Initial test program may reveal additional phenomena of importance.
  - PIRT could be revised at a later date.

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Loss of Forced Convection

- LOFC.
  - Loss of the forced flow of the helium coolant through the core.
  - Pertains to both pressurized and depressurized system events.
- Reactor cavity air circulation and heat transfer.
  - Affects upper cavity heating.
    - Radiation: primary method of heat removal during an LOFC event
    - Cavity Natural Circulation: may drive temperature distributions within the reactor cavity.
  - Importance: High.
  - Knowledge: Low.
- Reactor Cavity Cooling System (RCCS) behavior.
  - Phenomena.
    - RCCS fouling on the coolant side.
    - Failure of one or more RCCS channels.
    - RCCS forced-to-natural circulation transition.
    - Single phase boiling.
    - Parallel channel interactions.
    - Natural circulation in a horizontal panel.
    - Vessel to RCCS effective view factors.
    - RCCS spatial heat loadings.
  - Importance: high.
  - Knowledge: medium.

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Loss of Forced Convection

- Decay Heat Distributions
  - Temporal and spatial.
  - Represents a major factor in determining the maximum fuel temperature in the core during LOFC events.
    - HTTF can be used to determine the effects of various distributions on the maximum fuel temperature.
  - Importance: high.
  - Knowledge: low.
- Core Effective Thermal Conductivity
  - Affects the maximum fuel temperature during the LOFC event.
  - Conduction through the core is the primary means of heat transfer to the vessel walls in this event, for the prismatic block design.
    - Thermal conductivity of HTTF will be scaled to the most appropriate reference NGNP design.
  - Importance: high.
  - Knowledge: medium.
- Others.
  - Reflector properties (conductivity and annealing).
  - Core barrel emissivity.

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Pressurized LOFC

- P-LOFC (PCC).
  - Characterized by a loss of forced convection through the core.
    - System integrity is maintained so that the pressure during the event remains close to normal operating pressures.
  - Natural convection is the primary heat transfer mechanism within the core.
  - Upward coolant flow.
  - The hottest region of the vessel is the upper vessel head.
- Inlet plenum stratification and plumes
  - Temperature of the gas streams exiting the top of the core will determine the location of hot spots in the inlet plenum.
  - Importance: high.
  - Knowledge: medium.
- Core coolant flow distribution
  - Distribution of core flow affects the distribution of the core heat.
  - Phenomena.
    - Low flow correlations.
    - Flow reversal phenomena.
    - Core coolant bypass flow.
    - Coolant flow friction and viscosity effects.
  - Importance: high.
  - Knowledge: medium.
- Radiant heat transfer from the top of the core to the upper vessel head
  - Affect the upper vessel head temperatures.
  - Importance: high.
  - Knowledge: medium.

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Depressurized LOFC

- D-LOFC (DCC).
  - Characterized by a break in the pressure boundary of the system.
    - System depressurization.
  - Many potential variations.
    - Break size.
    - Break location.
  - Small breaks.
    - Low rate of depressurization.
    - Limited air ingress.
  - Challenge.
    - Ensure that the conduction through the core and radiation from the outer vessel wall to the RCCS are sufficient to remove the decay heat.
    - Radiation may also play a crucial role in heat transfer through the core for the pebble bed.
  - Event represents the design determinant for reactor maximum power level.
  - No high importance, low knowledge phenomena identified with the D-LOFC event.
    - PIRT panel concluded there are considerable uncertainties.
      - Core effective thermal conductivity.
      - Decay heat
      - RCCS performance.

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Depressurized LOFC with Air Ingress

- D-LOFC (DCC) with air ingress.
  - Characterized by a break in the pressure boundary of the system.
    - System depressurization.
  - Reactor cavity filled with air prior to any break.
  - For a large enough break with a high enough rate of depressurization, air ingress into the vessel may occur.
    - Single-ended or double-ended?
      - Single break scenarios there could be a long delay before significant air ingress flow would occur which would allow for a major shift in the core temperature profile.
  - Once a blowdown is complete the air/helium mixture in the reactor cavity may make its way into the vessel.
    - Potential for the oxygen in the air to oxidize the graphite inside the vessel.
      - Degrades structural integrity of the internal vessel structure and the core.
- Duct exchange flow
  - Stratified flow phenomenon leading to helium outlet and air inlet flow.
    - Difficult to calculate counter current natural circulation flow.
  - Can significantly reduce the time needed to allow a significant amount of air to enter the vessel itself.
  - May be a primary determinant to the onset of natural circulation and significant air ingress.
  - Importance: high.
  - Knowledge: medium.

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Depressurized LOFC with Air Ingress

- Molecular Diffusion in Air Ingress D-LOFC.
  - Relatively well understood under ideal conditions.
  - Uncertainties.
    - Operator actions.
    - Makeup of reactor cavity gas.
    - Position of break.
    - Circulation induced by the oxidation process.
  - Importance: high.
  - Knowledge: medium.
- Phenomena that effect cavity gas composition for air-ingress.
  - Determines oxygen concentration and thus the potential for oxidation of the graphite.
  - Processes may be very design or geometry dependent.
  - Importance: high.
  - Knowledge: medium.
- Others.
  - Predication of oxidation rates or oxidation effects.
    - Not explicitly included in scaling analysis.
    - Graphite temperature and oxygen concentration can be determined at the test facility.
      - Important to determining oxidation rates and effects.
  - Confinement to reactor cavity air ingress.
  - Cavity filtering performance.

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Normal Operations

- Normal Operations.
  - Not normally considered when examining accident conditions.
  - PIRT identified several phenomena that primarily occur during normal operation that could degrade the structure and components of the vessel and core to a point where these structures and components may not work as designed when challenged during an accident scenario.
- Outlet Plenum Flow Distribution
  - Gas exit temperatures vary from channel to channel.
  - Well mixed gas core outlet temperature is anticipated to be close to 1000°C.
  - Many channels may have temperatures significantly higher than that.
    - May lead to localized hot spots.
    - Potential structural problems with the lower plenum head or downstream components.
  - Problem may also be present in the pebble bed core design.
    - Uncertainty in the location of individual pebbles.
  - Not considered to be a major safety issue.
  - May impact performance of lower plenum and outlet duct during an accident scenario.
  - Importance: high.
  - Knowledge: low.
- Core Coolant Bypass Flow
  - Coolant not subject to direct core heating.
  - Cause.
    - Gaps between graphite blocks.
    - Pebble bed wall effects.
  - Determines active core cooling during normal operation and thus it will affect the maximum fuel temperature in the core during normal operations.
  - Importance: high.
  - Knowledge: low.

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Normal Operations

- Power and Flux Profiles
  - Sets initial conditions for accident scenarios.
  - Important in determining the maximum fuel temperature during the P-LOFC and D-LOFC events.
  - Importance: high.
  - Knowledge: medium.
- Others.
  - Pebble bed flow.
  - Pebble bed heat transfer coefficients.
  - General core coolant distribution
  - Effective fuel element thermal conductivity.
  - Shutdown cooling system startup transients during core heat-up.
  - Reactivity feedback coefficients.
  - Fuel performance modeling.
  - Ag-110m release and plateout.
  - RCCS heat removal.
    - Discussed under LOFC.

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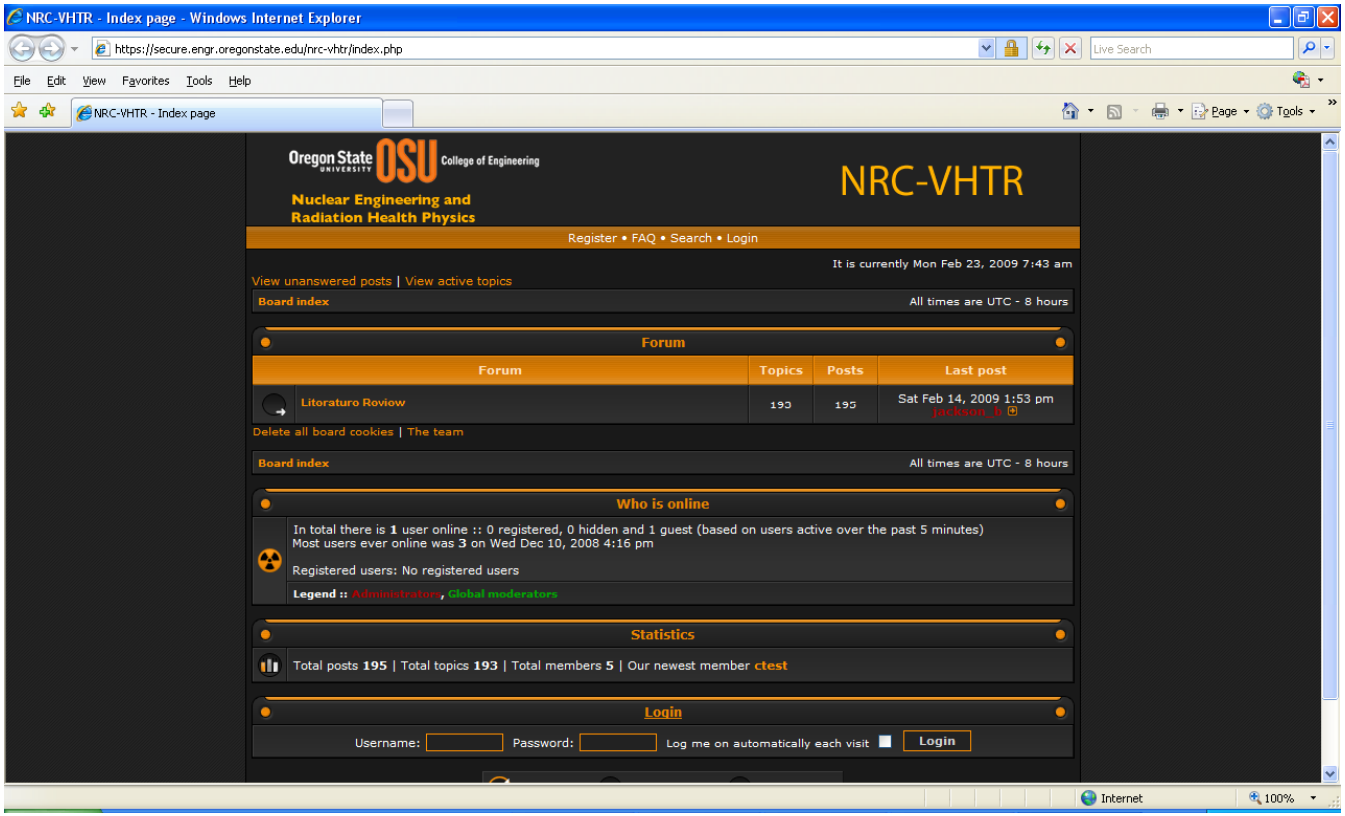

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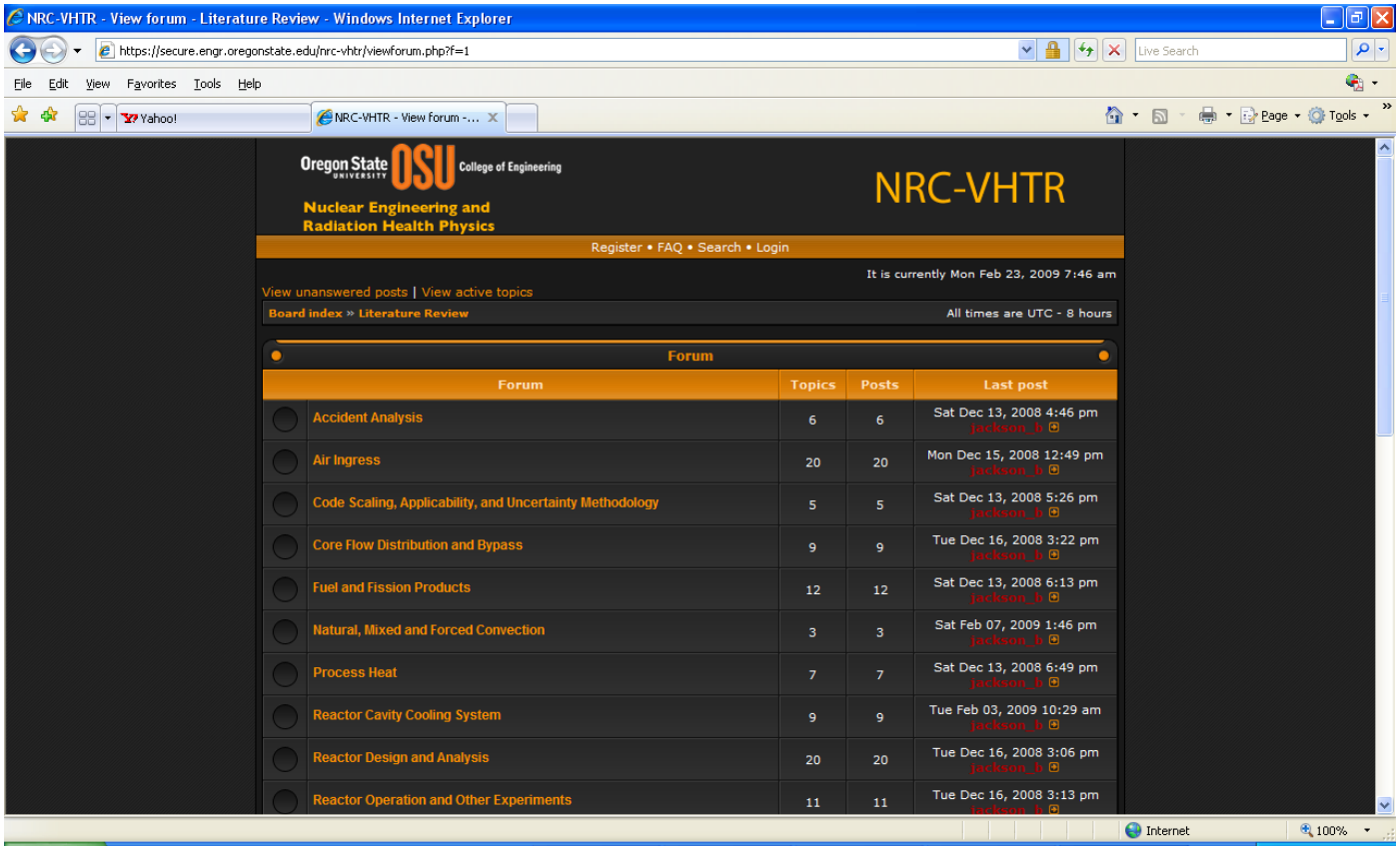

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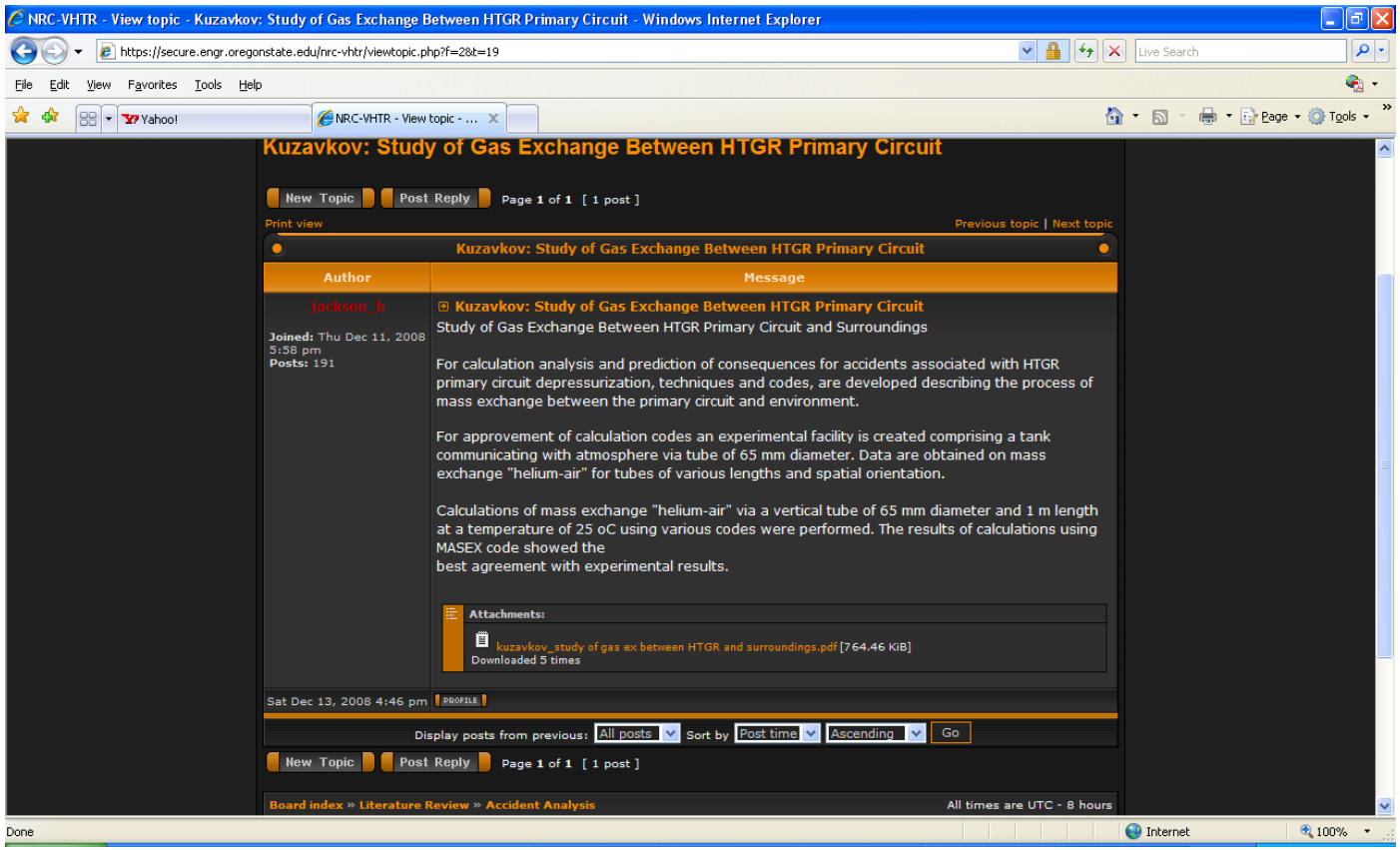

Questions?

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