CHEMICAL EFFECTS PIRT CONSIDERATIONS for Calvert Cliffs Nuclear Power Plant

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REVISION HISTORY Log

Revision	Description
0b	Issue for NRC Review
0c	Address Enercon, MPR, and S&L comments, various editorial comments such as changing “accumulators” to “Safety Injection Tanks, a minor enhancement to Item 2.1, and major revisions to Items 2.5 and 6.4
0d	Updated to reflect recent calculations, studies, and test plans. Final draft before owner acceptance and entry into FCMS for configuration management.

Contents

Resolution of Outstanding Chemical Effects PIRT Issues

In March 2011, the Office of Nuclear Reactor Regulation issued a document titled "Evaluation of Chemical Effects Phenomena Identification and Ranking Table Results". This document summarized 42 potentially significant issues that required further evaluation based on an original list of over 100 chemical effects phenomena identified in NUREG-1918, "Phenomena Identification and Ranking Table Evaluation of Chemical Effects Associated with Generic Safety Issue 191". The NRC provided an evaluation of the remaining 42 issues in the March 2011 report, and dispositioned each item as either having a negligible impact on the results or having been adequately addressed in the current plant-specific analyses. In several cases, issues that were not directly addressed by the industry were considered acceptable based on conservatisms in the methodology used for the plant-specific analyses.

In an effort to understand the true impact that chemical effects could have on long-term core cooling in a plant-specific post-LOCA environment, several plants are considering the option of performing chemical effects testing that is more realistic than previous tests. Since the testing will attempt to reduce or eliminate overly-conservative methods that were used previously, it is also necessary to consider potentially significant issues that were not directly addressed previously.

This document summarizes and provides a Calvert Cliffs-specific assessment of each of the 42 chemical effects PIRT issues. The purpose of this assessment is to provide discussion points for the NRC to reach agreement on the conditions that must be explicitly addressed in refined chemical effects tests.

The italicized text was copied directly from the NRC's March 2011 report describing the 42 issues.

1.0 UNDERLYING CONTAINMENT POOL CHEMISTRY

1.1 RCS coolant chemistry conditions at break

The reactor coolant system (RCS) coolant chemistry varies over the fuel cycle. Boron concentrations vary from approximately 2,000 to 4,000 parts per million (ppm) at the beginning of the fuel cycle. Therefore, the initial reactor water chemistry spewing out of the break and forming the containment pool will have variable boron concentration while the ratio of lithium to boron is approximately constant. The two-phase jet emanating from the break is initially at 315 degrees Celsius (C) (599 degrees Fahrenheit (F)) and then cools to 120 degrees C (248 degrees F). The main concern raised by the peer reviewers relates to how variations in the initial RCS chemistry will affect the interaction with containment materials and whether these variations have been appropriately addressed. Variations may influence corrosion rates of metals, leaching of species from nonmetallic materials, formation of chemical precipitates, and ultimately, plant-specific chemical effects.

The following root issues are contained in this item:

1. The break jet impacts different materials, and chemistry variations may have different effects.
2. Boron concentration in the RCS fluid varies over the fuel cycle.
3. Lithium concentration in the RCS fluid varies over the fuel cycle.
4. The temperature of the water exiting the break varies over the duration of the event.

The blowdown phase is brief (less than a minute for large break conditions), so chemical effects issues associated with impact by the break jet are negligible. After the blowdown phase ends, the water from the break would simply spill into the pool with minimal contact of containment materials.

Boron concentration is an important factor for chemical effects—partly due to potential chemical reactions, and partly due to its effect on pH. Therefore, a realistic boron concentration should be used to determine a realistic pH level, and an appropriate concentration should be added at the start of an integrated test. The RCS boron concentration at CCNPP ranges from approximately 2,700 ppm at the beginning of the fuel cycle to approximately 10 ppm at the end of the fuel cycle.

Lithium is not likely to be a major contributor to chemical effects since the concentration is generally low (ranging from negligible quantities to a few ppm). However, since it is relatively easy to include, a representative concentration of lithium should be added at the beginning of the refined chemical effects tests.

Temperature is an important factor since it has a direct effect on corrosion rates and solubility limits. Therefore, a realistic analysis should take into consideration temperature variations over the duration of the event.

CCNPP Resolution Plan

Long-term tests will be run representing the bounding LOCA scenario that produces the largest quantity of debris. The quantities of materials in the test will be determined from the quantities of materials determined to be in the CCNPP containment for the bounding break, as determined by break modeling. The boron and lithium concentrations for each test will be selected by determining the concentrations in the RCS, RWT, and SITs at CCNPP and calculating the concentration based on the contribution from each source for the LOCA scenario. The boron and lithium contributions from the RCS will be based on time-averaged concentrations. The impact of higher and lower concentrations of boron and lithium on the pH of the system will be evaluated using chemical equilibrium modeling. If the modeling indicates that changes in solution chemistry cause deviations in pH that significantly affect corrosion or precipitation rates, bench-scale tests may be performed to investigate the rate of corrosion and extent of precipitation rates with higher or lower concentrations of boron and lithium. The temperature will be varied over the duration of the refined tests to match the temperature profile of the break scenario, with the exception that the effect of corrosion at temperatures higher than 190 °F will be addressed by autoclave testing.

1.2 pH Variability

The normal operating pH of the RCS is typically in the range of 6.9-7.4. The pH adjusted to 25 degrees C (77 degrees F) changes during the course of the fuel cycle from acidic at the beginning of the cycle to closer to neutral by the end of a fuel cycle. There are implications similar to those discussed in Section 1.1 of this report with respect to how pH variations may affect the interactions between containment materials and the post-LOCA environment. These variations may influence corrosion rates of metals, leaching of species from nonmetallic materials, formation of chemical precipitates, and ultimately plant-specific chemical effects.

The following root issue is contained in this item:

1. pH level in the RCS fluid varies over the fuel cycle.

pH is an important factor since it has a direct effect on corrosion rates and solubility limits. Therefore, a realistic analysis should take into consideration pH variations in the RCS fluid and the resulting impact on the overall pH in the pool.

CCNPP Resolution Plan

The normal operating pH of the RCS at CCNPP is 7.1. The issue of pH variability over the fuel cycle is addressed by the selection of boron and lithium concentrations in Item 1.1.

1.3 Hydrogen Sources within Containment

Dissolved hydrogen may play a significant role in the containment pool water chemistry. Hydrogen sources within the containment include the RCS inventory; the corrosion of metallic materials, including the reactor fuel cladding; and the Schikorr reaction. Containment pool reduction-oxidation (redox) potential is a function of the dissolved hydrogen resulting from these sources. Higher H_2 *concentrations may decrease the redox potential. However, containment conditions are expected to foster* H_2 *evaporation, which could raise the redox potential. This issue could be important if* H_2 *concentrations have a significant effect on the redox potential in the post-LOCA containment water. The redox potential determines which materials will corrode or dissolve within the pool. A higher redox potential (i.e., more oxidizing) promotes metallic corrosion. As the concentration of dissolved constituents increases, so does the potential for solid species precipitation that could affect ECCS performance. The NRC or industry testing has not attempted to accurately simulate post-LOCA* H_2 *concentrations. However, the Schikorr reaction, by itself, may be beneficial by converting compounds that could form gelatinous-type chemical species into the mineral magnetite.*

The following root issue is contained in this item:

1. Dissolved hydrogen may increase corrosion or dissolution of materials in the containment pool.

As discussed in the March 2011 review, H_2 is considered insignificant since there will be limited amounts of H_2 in solution, and higher concentrations could actually reduce potential corrosion.

CCNPP Resolution Plan

No action required.

1.4 Containment spray CO_2 scavenging and CO_2/O_2 air exchange

Air entrainment within the containment pool beginning soon after the LOCA will cause carbon dioxide (CO_2*) absorption within the containment pool. This entrainment increases the amount of* CO_2*, which could produce higher carbonate precipitate concentrations than would otherwise be present. These precipitates could also enhance nucleation and precipitation of other chemical species. Consequently, the air/liquid interactions within containment may increase the amount of chemical precipitates and degrade ECCS performance more than if these interactions were not considered.*

The following root issue is contained in this item:

1. Dissolved carbon dioxide may result in carbonate precipitates such as $CaCO_3$.

This is more of an issue for plants that do not use TSP as a buffer since dissolved calcium can react with the TSP to form calcium phosphate precipitates. As discussed in the March 2011 review, tests that are open to the atmosphere would generally have a higher concentration of dissolved CO_2 than an air-tight containment. Therefore, although this is a potentially significant issue that should be considered for air-tight tests, no additional analysis is required for tests that are not air-tight.

CCNPP Resolution Plan

The CCNPP chemical effects testing will be performed in a facility that is not air tight to ensure that potential formation of $CaCO_3$ will be appropriately represented in the test conditions.

1.5 Emergency Core Cooling System Injection of Boron

After a pipe break, RWST inventory with a boron concentration of approximately 2,800 ppm is injected into the RCS to cool the reactor core. This provides for a large boron source, which may affect chemical reaction products in the containment pool. Specifically, the boron source will serve as a pH buffer. This may influence corrosion rates of metals, leaching of species from nonmetallics, and ultimately formation of chemical precipitates.

The following root issue is contained in this item:

1. Boron concentration in the RWT will affect the pH in the pool.

Boron concentration is an important factor for chemical effects—partly due to potential chemical reactions, and partly due to its effect on pH. Therefore, a realistic boron concentration should be used to determine a realistic pH level, and an appropriate concentration should be added at the start of an integrated test. After a LOCA at CCNPP, the containment pool boron concentration ranges between ~2,600 and ~2,900 ppm for a range of break scensarios depending upon the total mass of borated water injected into the containment [Ref. 1].

CCNPP Resolution Plan

The concentration of boron to be used in the testing is addressed in Item 1.1.

2.0 RADIOLOGICAL CONSIDERATIONS

2.1 Radiolytic Environment

Radiolysis is the dissociation of molecular chemical bonds by a high energy radiation flux. The largest source of this radiation flux is the gamma radioactive decay of the reactor fuel. When the ECCS fluid passes through the reactor core, it is subjected to this radiation flux. Radiolysis reactions may change the pH of the ECCS containment pool, the fluid's redox potential, or both. Hence, chemical species which differ from those evaluated may form or the fluid may be more corrosive than that evaluated in all previous chemical effects testing.

The following root issues are contained in this item:

1. Radiolysis can affect pool pH through the creation of H_2O_2 and OH radicals.
2. Radiolysis can break down electrical cable insulation or dissolved nitrogen to form strong acids.

As discussed in the March 2011 report, the formation of H_2O_2 and OH radicals is not considered to be a significant issue based on previous analyses. The formation of strong acids due to the breakdown of cable insulation or dissolved nitrogen may have a non-negligible impact on the long-term pH, and therefore should be considered. As discussed in the March 2011 report, one licensee determined that acid formation would reduce the pH by 0.2.

<u>CCNPP Resolution Plan</u>

Design calculations are being prepared [Ref. 2] that compute the quantity of strong acids that could be formed and the rate at which the strong acids are formed long-term at CCNPP. The quantity of acids determined in these calculations will be introduced in the chemical effects tests at a conservative rate.

2.2 Radiological Effects: Corrosion Rate Changes

Radiolysis of water bearing the chloride ion (Cl^-) can elevate the post-LOCA corrosion rate through formation of hypochlorite (ClO^-) or hypochlorous acid (HOCl). The presence of these acids could increase the corrosion rate of metallic and nonmetallic species in containment, which in turn could alter the chemical byproducts formed. Hence, the chemical precipitates that form could differ from those previously evaluated. These different precipitates could subsequently affect ECCS performance in a manner that has not been considered previously.

The following root issue is contained in this item:

1. Radiolysis of water with chloride ions can create strong acids.

Chloride ions may be in solution primarily due to the breakdown of electrical cable insulation, but also due to potential leaching from coatings. As discussed for Item 2.1, the formation of strong acids may have a non-negligible impact on long-term pH, and therefore will be considered.

CCNPP Resolution Plan

The addition of acids to the tests to simulate radiolysis is addressed in Item 2.1.

2.3 Hydrolysis

Nickel oxide (NiO), as well as other oxides, resulting from the corrosion of stainless steel and Alloy 600 metals can become a catalyst for producing H_2 *from radiolysis of water. This process occurs more readily at higher water temperatures (i.e., hydrothermal environments). The hydrothermal hydrolysis of various organic/inorganic coating and insulation materials could partially depolymerize polymeric materials, producing materials ranging from small molecules to colloids. The colloids could subsequently aggregate into larger particles and gels. If this were to occur, the aggregated depolymerized materials may be more likely to transport to the sump strainer and affect pump performance or create chemical precipitates with different characteristics than those evaluated.*

The following root issue is contained in this item:

1. Hydrolysis may cause H_2 formation.

As discussed in the March 2011 report, hydrolysis is a chemical reaction that causes water molecules to split into hydrogen and hydroxide ions. Hydrolysis is more significant at higher temperatures (generally above boiling). Since the containment pool temperature would only be above 200°F for a few hours, and the formation of H_2 due to hydrolysis is a gradual process, this is an insignificant issue.

CCNPP Resolution Plan

No action required.

2.4 Conversion of N_2 to HNO_3

One panelist was concerned about the effects of nitric acid (HNO_3*) formed in the containment pool due to radiolysis of dissolved nitrogen (*N_2*). This panelist was mostly concerned that the* HNO_3 *concentration may overwhelm the buffering capacity and cause the containment pool pH to drop precipitously to a range within 1–3. If the containment pool pH were this acidic, the redox potential becomes strongly oxidizing and corrosive and would lead to significant metallic corrosion and leaching of inorganic ions from other materials (e.g., concrete). Most previous NRC and industry-*

sponsored research has evaluated the chemical effects and their implications associated within the neutral-to-alkaline pH range (i.e., 7–10) that is expected within the buffered post-LOCA containment pool. Therefore, if the containment pool pH were highly acidic (i.e., 1–3), the chemical effects that would occur may differ significantly from those previously evaluated. The implications of these effects on ECCS performance would also be largely unknown.

The following root issues are contained in this item:

1. Radiolysis of dissolved N_2 may result in the formation of nitric acid.
2. Nitric acid may cause the pool pH to become strongly acidic.

As discussed in the March 2011 report, the formation of nitric acid due to radiolysis is expected to be relatively low due to the low solubility of N_2 in water. The assumption that the pool could become strongly acidic did not take into account the presence of the buffers. Therefore, the pool is not expected to become strongly acidic. However, similar to the other issues regarding the formation of strong acids, the effects on long-term pH due to the formation of nitric acid should be considered.

CCNPP Resolution Plan

The addition of acids to the tests to simulate radiolysis is addressed in Item 2.1.

2.5 Additional Debris Bed Chemical Reactions

The concentration of radionuclides, postulated to be hundreds of Curies, available within the sump strainer fiber bed acts as a "resin bed" or chemical reactor potentially altering the local chemical conditions, such as pH. A number of possible radiolytic reactions could occur which may directly alter the chemical byproducts formed. This effect may lead to the formation of different, or a larger quantity of, chemical products than those evaluated, which could have a different impact on head loss than that considered.

The following root issues are contained in this item:

1. Radionuclides trapped in the debris bed may change the local chemistry and cause precipitation.
2. Radionuclides trapped in the debris bed may cause the bed to break down.

As discussed in the March 2011 report, local changes in the chemistry (i.e. the formation of H_2O_2 due to radiolysis) will not have a significant effect since the constant flow through the debris bed will effectively flush it out. Also, the concern that the fiber bed may break down due to the radionuclides is not considered to be significant since materials similar to fiberglass insulation are routinely used as a filtration media for high activity particulate.

During the chemical effects summit, the NRC questioned whether other types of insulation or coatings debris besides fiberglass may break down in the debris bed due to the radionuclides.

CCNPP Resolution Plan

The non-fiberglass debris at CCNPP includes RMI, small quantities of mineral wool and marinite, and coatings debris. Radiation would not have any effect on the stainless steel RMI, the mineral wool, or inorganic zinc coatings debris. The marinite debris quantity at CCNPP is minor compared to the quantity of fiberglass debris. Therefore, even if radiolysis did have an effect on marinite particulate, it would not significantly change the structure or chemistry of the debris bed at CCNPP.

EPRI performed extensive design basis accident testing of epoxy and alkyd coatings, including exposure to high levels of ionizing radiation. The results of the irradiation testing indicated that irradiation resulted in some minor discoloration and had a minor impact on detachment from the substrate during DBA testing but no other affects such as dissolution or blistering were observed. Irradiation is not expected to have a chemical effects impact on coatings.

No additional evaluation of this issue is required.

3.0 PHYSICAL, CHEMICAL, AND BIOLOGICAL DEBRIS SOURCE TERMS

3.1 Crud Release

A PIRT panelist postulated that iron and nickel corrosion oxides up to 125 microns thick may exist on the interior of the RCS piping, fuel, and components. These oxides could be released by the hydraulic shock of the LOCA event. After release, the reduced Fe and Ni ions can be dissolved in the RCS (aided by radiolysis) and, when combined with air, can form oxides of hematite, maghemite, and magnetite. The crud release can create a localized radiolytic environment on materials caught on the sump screens, which could affect subsequent chemical reactions. The crud particles would also add to the debris concentration within the containment pool.

The following root issues are contained in this item:
1. The crud may influence the localized radiolytic environment.
2. A significant quantity of crud could be released as another source of particulate debris.

As discussed in the March 2011 report, the radiolytic effects of crud are insignificant compared to other sources. The March 2011 report estimated that the total quantity of crud in the RCS could be on the order of 400 kg. This is a potentially significant source of particulate debris, but it is not likely that 100% of the crud would be released by the thermal and hydraulic shock of a LOCA. The March 2011 report concluded based on transport considerations that this is not a significant issue.

At the chemical effects summit, the NRC questioned whether the RCS crud could transport and have a significant impact on head loss.

CCNPP performed an evaluation of crud release [Ref. 3] due to the thermal and hydraulic shock of a LOCA and determined the quantity of crud released would be on the order of 23 lbs which is less than the assumed latent debris particulate load.

CCNPP Resolution Plan

This item will not be addressed in the chemical effects tests. The crud is a source term for particulate debris and is not expected to affect the chemical environment.

3.2 Jet Impingement

The two-phase jet, and fine debris within the jet, will impact surfaces and could chip coatings, cause metallic erosion, or ablate materials like concrete. This phenomenon will govern the contributions of these materials in the early post-LOCA time period, before corrosion and leaching become important. Jet impingement could also initiate pitting corrosion, which could accelerate the corrosion of normally passivated materials like stainless steel. Most of the discussion from the peer review panel describes the jet interaction with materials as the primary source for post-LOCA debris. Jet impingement could result in a potential chemical effects debris source term that is greater than currently anticipated.

The following root issues are contained in this item:

1. Debris can be generated by the jet blast.
2. Pitting due to jet impingement could accelerate corrosion.

The generation of debris and subsequent effects of that debris in terms of both debris bed head loss and chemical effects is an important issue that should be considered.

As discussed in the March 2011 report, jet impingement during blowdown has a very short duration, and any pitting that occurs would be localized and have a minimal effect on the overall quantity of corrosion products. Also, CCNPP-specific evaluations account for jet interactions with coatings and other containment materials, such as thermal insulation and fire barriers. The amount of material released from metallic erosion, concrete ablation, or metallic pitting induced by jet impingement will be insignificant compared to the CCNPP design basis debris load used for strainer qualification.

CCNPP Resolution Plan

The issue of jet impingement need not be addressed in the CCNPP chemical effects testing and analysis. The approach for determining the quantity of materials during each test takes debris generation into account and is addressed in PIRT Item 1.1.

3.3 Debris Mix Particulate/Fiber Ratio

Breaks in different locations will create different debris characteristics with respect to the total mass of debris, debris constituents, and the ratio of particulates to fiber. Depending on the specific break location, significantly different types and quantities of debris (e.g., Cal-Sil and fiberglass insulations) can alter the type and quantity of chemical effects. Ultimately, the debris bed characteristics determine the chemical product capture efficiency and the total pressure drop across the sump screen strainer.

The following root issues are contained in this item:

1. Different mixtures of debris can have a different impact on chemical effects.
2. Variations in the particulate/fiber ratio impact the chemical precipitate capture efficiency.
3. Variations in the particulate/fiber ratio impact the debris bed head loss.

In an integrated environment, the presence of some materials may inhibit the corrosion or dissolution of other materials. For example, silicon that is released into solution from the dissolution of fiberglass may inhibit the corrosion of aluminum. In some cases, therefore, scenarios with lower quantities of certain types of debris could potentially result in more severe chemical effects.

Fiber beds act as very effective filters and can capture small particles. As the particulate to fiber ratio increases, the debris bed is compacted and the filtration efficiency increases (along with the head loss). Therefore, the particulate to fiber ratio is a significant parameter.

CCNPP Resolution Plan

The mixture of debris to be used in the tests is addressed in Item 1.1. The long-term tests will use a special debris bed with a pre-defined ratio of particles to fibers that will be used as a head loss detection instrument to assess the relative impact of chemical effects under a standardized condition.

3.4 Effects of Dissolved Silica from RCS and RWT

Dissolved silica is present in the water storage systems and the RCS during normal operation. This silica can react with other chemical constituents (most prominently magnesium, calcium, and aluminum) that form as a result of material dissolution or corrosion, or both, within the containment pool after the LOCA occurs. This reaction may result in a greater concentration of the chemical precipitates than would otherwise exist. The reaction may also alter the nature of the chemical precipitates by creating amorphous materials or gels or precipitates with retrograde solubility (i.e., they become more insoluble as temperature increases). The creation of additional chemical precipitates, amorphous materials, and retrograde soluble species could degrade ECCS performance by increasing head loss at the sump strainer or decreasing in the heat transfer rate from the reactor fuel if significant quantities of silica-containing precipitates are formed.

The following root issue is contained in this item:

1. The dissolved silica initially in the water may precipitate with other materials later in the event.

Silicon is an important factor for chemical effects. In some cases, it may help inhibit corrosion of aluminum, and also can contribute to precipitate formation. Therefore, the initial concentration of dissolved silica in the RCS, RWT, and SITs should be considered.

<u>CCNPP Resolution Plan</u>

The quantity of silica present in the RCS, RWT, and SITs at CCNPP is monitored and is approximately 1.2 ppm. CCNPP is a high fiber plant and the concentration of silica in the containment pool will be dominated by the dissolution of fiberglass insulation. Therefore, The quantity of silica present in the RCS, RWT, and SITs will not be addressed in the refined chemical testing.

3.5 Containment Spray Transport

Following a LOCA, the containment spray will tend to wash latent debris, corrosion products, insulation materials, and coating debris into the containment pool. This changes the containment debris sources (types, amounts, compositions) and chemical species reaching the containment pool environment which could affect the sump strainer debris bed and the formation of chemical precipitates.

The following root issues are contained in this item:

1. Corrosion products generated above the pool could be washed down into the pool.
2. Debris above the pool could be washed into the pool.

Both of these items are potentially significant and should be considered.

CCNPP Resolution Plan

CCNPP prepared conservative debris generation and transport calculations that specifically addressed latent debris, corrosion products, insulation materials, and coating debris. The results of the conservative debris generation and transport calculations will be addressed in the CCNPP chemical effects testing and analysis. Also, the corrosion of materials exposed to containment spray above the pool will be accounted for in the chemical effects tests.

3.6 Initial Debris Dissolution

Typical debris generated by the LOCA (within the first 20 minutes) includes Cal-Sil insulation, cement dust, organic fiberglass binders, and protective coatings. Initial debris dissolution could indicate potential important contributors to the chemical containment pool environment. It is possible that the dissolved, ionic species could react and precipitate to form new, solid phases that were not originally in the containment pool.

The following root issue is contained in this item:

1. Dissolution of debris can form chemical precipitates.

This is the chemical effects issue and should be appropriately modeled in realistic chemical effects tests.

CCNPP Resolution Plan

The relevant materials and debris determined to be present at CCNPP and contribute to chemical effects will be included in the test loop at the beginning of each test. Determination of the quantities of debris is addressed in Item 1.1.

3.7 Submerged Source Terms: Lead Shielding

Acetates present in the containment pool will corrode any submerged lead existing in containment, which could lead to formation of lead carbonate particulate or dissolved lead within the containment pool. Lead blanketing or lead wool is used to shield radiation hot spots during refueling outages and may remain in the containment building during the fuel cycle. In addition, several plants may still use small quantities of lead wool for insulation.

Lead carbonate contributions would provide additional particulate loading within the containment pool that could contribute to head loss at the sump strainer screen. Dissolved lead could also lead to cracking of submerged stainless steel structural components within containment. Neither the testing conducted to date nor do the licensee evaluations of ECCS performance consider these contributions. These omissions are potentially non-conservative if significant quantities of lead carbonate or dissolved lead are formed.

The following root issues are contained in this item:

1. Lead could dissolve and precipitate with other materials.
2. Dissolved lead may lead to cracking of submerged stainless steel components.

Generally, the quantity of lead exposed to the pool or sprays would be low. However, the dissolution of lead and subsequent precipitation is a potentially significant issue that should be considered.

As discussed in the March 2011 report, relatively low lead concentrations will not induce cracking in stainless steel components within the 30-day mission time.

CCNPP Resolution Plan

An evaluation of the sources of lead in containment at CCNPP has been performed [Ref. 4] and autoclave testing is being performed [Ref. 5] to determine whether there is a potential for significant lead quantities to be released into solution. Determination of the quantity of lead debris is addressed in Item 1.1.

3.8 Submerged Source Terms: Copper

Copper present in containment can accelerate or inhibit corrosion of other metals. One way in which Cu can alter the corrosion rate of other materials is by forming a galvanic couple. Galvanic effects can accelerate corrosion of less noble material while inhibiting corrosion of more noble materials. Dissolved copper can also enhance the rate of corrosion of other metals within an oxygenated environment. Different corrosion rates can impact the amount of corrosion products formed and therefore could have different effects on ECCS sump head loss.

The following root issues are contained in this item:

1. Galvanic couples can accelerate or inhibit corrosion of other metals.
2. Dissolved copper can enhance the corrosion rate of other metals by forming local galvanic cells.
3. Copper can inhibit corrosion of other metals by depositing and creating a passivation layer.

As discussed in the March 2011 report, the potential effect of galvanic couples in containment is insignificant. Local galvanic cells may enhance corrosion of aluminum, but this would only apply to the submerged aluminum. Also, as discussed in the March 2011 report, copper deposits were observed on aluminum samples in some of the ICET tests, which may have helped inhibit aluminum corrosion since the tests had negligible aluminum concentrations. Copper corrosion is expected to be relatively minor, but is a potentially significant issue that should be considered.

As discussed at the chemical effects summit, only the second root issue is important for chemical effects—potential enhancement of metal corrosion due to a local galvanic cell. The NRC also stated that the corrosion of zinc (from galvanized steel or other sources), and subsequent formation of zinc precipitates is a potentially significant issue that should be evaluated.

CCNPP Resolution Plan

An evaluation of the sources of copper and zinc in containment at CCNPP has been performed [Ref. 4] and autoclave testing is being performed [Ref. 5] to determine whether there is a potential for significant quantities of these metals to be released into solution. Determination of the quantity of copper and zinc is addressed in Item 1.1.

3.9 Concrete Material Aging

The PIRT panelists raised questions about the effect of aging on the leaching process for nonmetallic materials such as concrete. Neither the exposed concrete faces nor concrete dust in the containment building is likely to be fresh. After 30 years of exposure to the atmosphere, a substantial fraction of both the exposed calcium silicate hydrate (C-S-H) gel and the portlandite ($Ca(OH)_2$) constituents of the concrete would have been carbonated. Carbonation or other aging processes of concrete could affect the leaching rates and dissolved species as compared to relatively fresh concrete samples used in the ICET experiments and other research programs.

The following root issue is contained in this item:

1. Aged concrete may release a larger quantity of calcium.

Concrete surfaces in containment are generally coated, which would prevent carbonation due to aging. However, this may be a significant issue for plants with large uncoated concrete surfaces; especially if the plant uses a TSP buffer. CCNPP has little uncoated concrete and does not use TSP as the buffer.

During the chemical effects summit, the NRC stated that the difference in dissolution between aged and fresh concrete is not significant and it is not necessary to use aged samples for chemical effects testing.

CCNPP Resolution Plan

CCNPP plans to use concrete from original plant construction in the refined chemical effects testing.

3.10 Alloying Effects

Another issue raised by the PIRT is the effect of different alloys on the quantity of corrosion products. Corrosion rate data exhibit wide variability depending on the specific corrosion conditions and the nature of the alloy being subject to corrosion. Alloying could affect dissolution and corrosion rates, thereby affecting the solid species precipitates that are formed.

The following root issue is contained in this item:

1. Differences in alloys may affect dissolution and corrosion rates.

As discussed in the March 2011 report, alloys would generally exhibit lower corrosion rates than pure metals. In realistic testing, it may be beneficial to use the actual alloys that exist in containment. Regardless, it is important to appropriately justify all surrogate materials (including metal coupons) that are used in chemical effects tests.

At the chemical effects summit, the NRC stated that there is not a large difference between corrosion rates for pure materials and alloys. However, it is appropriate to use materials that are representative of what is in containment.

CCNPP Resolution Plan

Commercially pure aluminum (SA 1100) will be used for chemical effects testing on the basis that aluminum alloys are typically more corrosion resistant than pure aluminum [Ref. 7]. Galvanized steel used in containment will be of a manufacturing method and zinc coating thickness representative of materials used in containment at CCNPP. Zinc from IOZ will be represented by a appropriately applied and cured IOZ coated coupons.

3.11 Advanced Metallic Corrosion Understanding

The PIRT panel raised several other issues related to the understanding of metallic corrosion in the post-LOCA environment. These issues include enhanced Al corrosion caused by hypochlorite or other *catalytic effects (e.g., jet impingement), synergistic effects on corrosion, and corrosion inhibition. These effects could substantially affect corrosion rates and therefore could have different effects on ECCS sump head loss.*

The following root issues are contained in this item:

1. Enhanced corrosion due to acid formation.
2. Enhanced corrosion due to pitting from jet impingement.
3. Synergistic effects on corrosion.
4. Corrosion inhibition.

As discussed previously, the long-term effects on pH due to acid formation may be an important factor that should be considered. Also as discussed previously, pitting from jet impingement is considered to be an insignificant factor due to the localized impact of the jet. Generally, synergistic effects tend to inhibit corrosion, but both synergistic effects and corrosion inhibition are inherently considered in integrated testing.

CCNPP Resolution Plan

Synergistic effects and corrosion inhibition are being addressed in autoclave testing [Ref. 5].

3.12 Submerged Source Terms: Biological Growth in Debris Beds

The PIRT considered the propensity for bacteria or other biota to grow in preexisting debris beds located on the sump strainer screen or elsewhere within the ECCS system. Significant bacterial growth may be important if it creates additional debris that contributes to sump screen clogging or detrimental performance of downstream components like pumps and valves.

The following root issue is contained in this item:

1. Biological growth in the post-LOCA environment may contribute to clogging issues.

As discussed in the March 2011 report, most microorganisms cannot survive under high temperature, low or no light, and high radiation conditions. Any microorganisms that do survive would be highly unlikely to experience significant growth under the harsh post-LOCA conditions. Therefore, biological effects can be reasonably neglected for a realistic chemical-effects analysis.

CCNPP inspected the containment sumps and observed no biologic growth. One of the radiation protection individuals at CCNPP has inspected containment sumps at multiple plants and cleaned two of them. In none of these cases was biologic growth observed.

CCNPP Resolution Plan

This item will not be addressed in chemical effects tests.

3.13 Reactor Core: Fuel Deposition Spall

Spall of reactor fuel cladding oxides (ZrO_2) and deposited chemical products could be a potential source of activated materials that could affect chemical reactions in the post-LOCA containment pool. Also, precipitates of post-LOCA chemical products (organics, Al, B, Ni, Fe, Zn, Ca, Mg, silicates (SiO_3^{2-} and SiO_4^{4-}), and CO_3^{2-}-based products) could deposit on the fuel clad and spall, contributing either to clogging within the reactor core, or head loss across the sump strainer.

The following root issues are contained in this item:

1. Spall of activated fuel cladding oxides could affect chemical reactions in the containment pool.
2. Precipitation and spall of chemical products on the fuel could contribute to fuel or strainer clogging.

As discussed previously, the effect of activated particles on chemical effects due to radiolysis is considered to be insignificant. However, this debris could contribute to the source term for particulate debris with an effect on the overall head loss across the strainer or fuel channels. This issue is addressed in Item 3.1.

Some precipitates, particularly certain calcium precipitates, exhibit retrograde solubility. As water flows through the reactor vessel, the high temperature in the vicinity of the fuel rods may cause some of these materials to precipitate. The precipitates may form on the fuel rods themselves, or in solution where they can be swept out of the reactor vessel and potentially contribute to strainer clogging. This is a potentially significant issue that needs to be addressed for materials that exhibit retrograde solubility.

CCNPP Resolution Plan

The effects of chemical precipitation on the fuel rods has been previously addressed in a conservative manner for CCNPP using the LOCADM software. Materials with retrograde solubility have generally been calcium-based precipitates or phosphate-based precipitates. Calvert Cliffs does not anticipate precipitants of these types in containment.

4.0 SOLID SPECIES PRECIPITATION

4.1 Polymerization

The PIRT panelists expect polymerization to occur after molecular precipitation as a precursor to solid species agglomeration in post-LOCA environments. Molecular precipitation refers to the formation of bonds between metallic species and oxygen to form monomers. Polymerization is the ripening of these bonds to form covalent bonds and the growth of the monomers through one of many types of polymerization reactions. Chain polymerization, which is the most common, consists of initiation and propagation reactions and may include termination and chain transfer reactions. Step-growth and condensation polymerization are two additional mechanisms. Polymerization occurs until approximately nanometer-sized particles have formed. These particles can then continue to grow to larger sizes through agglomeration mechanisms.

The PIRT panelists expect polymerization is needed to form large enough particles to tangibly affect ECCS performance. The fact that chemical precipitates have formed during testing to simulate post-LOCA conditions provides evidence that polymerization is likely occurring. The issue is important only if the differences in polymerization mechanisms in the simulated and actual post-LOCA environments are significant enough to alter head loss or downstream effects associated with the chemical precipitates.

The following root issue is contained in this item:

1. Polymerization processes may cause initial precipitate growth.

As discussed in the March 2011 report, polymerization is expected to be an important process in the formation of precipitates, but is appropriately represented in testing and does not need to be further evaluated.

CCNPP Resolution Plan

No action required.

4.2 Heat Exchanger: Solid Species Formation

Chemical species having normal solubility profiles may be dissolved in the containment pool at higher temperatures. However, these chemical species may precipitate in the heat exchanger because of a drop in temperature of approximately 30 degrees F. Some possible solid species that could form include $Al(OH)_3$*, FeOOH, and amorphous* SiO_2*. The lower temperature at the heat exchanger outlet could also facilitate the development of macroscale coatings or suspended particulates, or both, that can continue to transport in the circulating fluid. Possible implications of this scenario include (1)* *species remain insoluble at higher reactor temperatures and affect the ability to cool the reactor core, (2) solid species formed may clog the reactor core and degrade heat transfer from the fuel, (3) species remain insoluble at higher containment pool temperatures and cause additional head loss upon recirculation, and (4) particulates act as nucleation sites for other compounds to precipitate.*

The following root issue is contained in this item:

1. The temperature drop at the heat exchanger may reduce the solubility limit sufficiently to cause precipitate formation.

This is a potentially significant issue that should be evaluated in the chemical effects testing. Timing is an important factor here. Early in the event while the pool temperatures are hot, the temperature drop across the heat exchangers may be significantly higher than 30°F. Since it takes time for containment materials to corrode and dissolve, precipitation may not be possible until much later in the event when the concentration in the pool starts to approach the solubility limit. Timing may also be important with respect to the kinetics of precipitate formation since the duration that coolant flow is exposed to lower temperatures downstream of the heat exchangers is relatively brief.

CCNPP Resolution Plan

The CCNPP chemical effects head loss loop includes a heat exchanger in which the process fluid if cooled and turbidity monitored to observe for precipitation. The cooled fluid is then returned to the test loop so that any precipitates that form will flow through the debris bed. Also, the final portion of the refined chemical effects head loss tests will be used to investigate low temperature chemical effects by reducing the temperature in stages until room temperature is achieved while continuously monitoring debris bed head loss.

4.3 Reactor Core: Precipitation

The increased temperature in the reactor vessel (i.e., 70 degrees C higher than the containment pool) and retrograde solubility of some species (e.g., Ca silicate, Ca carbonate, zeolite, sodium calcium aluminate) causes precipitation and additional chemical product formation. This could result in the following: (1) additional precipitate could be created and transported to the sump screen that would then contribute to head loss and (2) precipitate or spall (see Section 3.13 of this report) passing through the sump screen may degrade the performance of ECCS components downstream from the screen.

The following root issue is contained in this item:

1. High localized temperatures in the reactor vessel may cause precipitation of materials with retrograde solubility.

This is a potentially significant issue that should be evaluated in chemical effects testing. It should be noted, however, that the bulk flow temperature in the reactor vessel would generally not be 70˚C (158˚F) higher than the pool temperature. It is possible for local temperatures within the core (i.e. next to the fuel cladding) to be significantly hotter than the pool, which could result in localized precipitation. Also, under certain scenarios (such as a cold leg break during cold leg injection), it is possible for the water in the core to boil. Even under these conditions, however, the maximum bulk temperature in the core would be limited to the saturation temperature, which would never approach a level that is 158˚F hotter than the pool. Therefore, the focus of this issue should be on localized high temperatures in the reactor vessel rather than overall high temperatures in the bulk flow.

CCNPP Resolution Plan

Materials with retrograde solubility have generally been calcium-based precipitates or phosphate-based precipitates. Calvert Cliffs does not anticipate precipitants of these types in containment.

4.4 Particulate Nucleation Sites

Particles within containment create the nucleation sites required for chemical precipitation. Examples of particles that could serve as nucleation sites include irradiated particles, dirt particles, coating debris, insulation debris, biological debris, and other materials within the post-LOCA containment pool. These particles then grow through polymerization (see Section 4.1 of this report) and agglomeration (see Sections 5.1 and 6.2 of this report) into solid species that are large enough to possibly degrade ECCS performance.

This issue identifies a fundamental aspect of the formation of solid species. Implications only arise if the nucleation sites in the post-LOCA environment are not appropriately simulated in testing. That is, the quantities and types of nucleation sites used in testing should be representative of the post-LOCA environment to ensure that solid species formation is not suppressed.

The following root issue is contained in this item:

1. Heterogeneous nucleation sites are required for precipitation to occur.

As discussed in the March 2011 report, both containment and test conditions contain numerous nucleation sites. Therefore, this is not a significant issue.

CCNPP Resolution Plan

No action required.

4.5 Coprecipitation

Coprecipitation occurs when a normally soluble ion becomes either included or occluded into the crystalline structure of a particle of insoluble material. Precipitation of one species could lead to increased precipitation of another species (which, if taken separately, are each below their solubility limit). Thus, more solid species could form, which could lead to a greater concentration of chemical precipitates at the sump strainers or downstream of the strainers. Additionally, the species that form could differ in size from those observed in the ICET tests (i.e., 1 to 100 microns) such that they affect the head loss at the sump strainer more significantly.

The following root issue is contained in this item:

1. Precipitation of one material may result in precipitation of another material that would not otherwise have precipitated.

Coprecipitation does not reduce the solubility limit of precipitates, and therefore would not cause precipitation of two materials that are both below their solubility limit as suggested above. Although it is a potentially significant issue, in an integrated test environment, the various reactive materials are present together and coprecipitation can occur naturally. Therefore, this issue is inherently included in an integrated test.

CCNPP Resolution Plan

The issue of coprecipitation is addressed by inclusion of all materials that participate in chemical reactions in the same proportions that they are present at CCNPP, as described in Item 1.1.

5.0 AGGLOMERATION AND SETTLING: CHEMICAL EFFECTS

5.1 Inorganic Agglomeration

Inorganic agglomeration is the formation of larger clumps of smaller particulates. This phenomenon depends upon the pH of the point of zero charge (PZC) of the species and the ionic strength (the higher the ionic strength, the smaller the distance for agglomeration) of the fluid. This phenomenon is *sensitive to many factors, including particle shape factors, and maximum particle size. Inorganic agglomeration of small particles into larger sized particulates could degrade strainer performance.*

The following root issue is contained in this item:

1. Agglomeration of chemical precipitates, insulation particulate, and/or latent particulate may form larger particles that would be more easily captured in a debris bed.

In general, agglomeration of particles will make the debris less transportable. Also, as shown in NUREG/CR-6224, smaller particles have a larger impact on head loss due to the larger surface-to-volume ratio. Therefore agglomeration of particulate debris with each other or chemical precipitates is not a significant issue.

CCNPP Resolution Plan

No attempt to either stimulate or prevent agglomeration of particles will be incorporated into the chemical effects tests. In the chemical effects tests, particulate debris will be pre-deposited in the debris beds and will not be circulating in the solution in significant quantities. The solution chemistry in the chemical effects tests will be similar to the CCNPP system, so the formation and behavior of chemical precipitates will be similar, with particulate debris already present in the debris bed.

5.2 Deposition and Settling

Chemical products formed in the post-LOCA containment environment could either settle within the containment pool or be deposited on other surfaces. Chemical species which attach to or coat particulate debris may enhance settling. Examples are aluminum coating on NUKON® fiber shifting the PZC or formation of a hydrophobic organic coating. This could result in less particulate debris and chemical product transporting to the sump screen and either accumulating on or passing through it. The possible implications of this issue are that the chemical precipitates added to the plant-specific chemical effects tests could result in increased settling during the tests compared to actual plant conditions.

The following root issue is contained in this item:

1. Chemical precipitates may settle or enhance settling of other particulate in the containment pool.

Given their small size, chemical precipitates can readily transport under relatively low flow conditions, and it is not expected that significant settling would occur. Therefore, this is not considered to be a significant issue.

CCNPP Resolution Plan

No action required.

5.3 Quiescent Settling of Precipitate

Quiescent flow regions within the containment pool promote settling. The low flow rate within most of the containment pool also allows larger size, more stable particles and precipitates to form, which promotes settling. Settling of nonchemical debris and precipitate could be beneficial with respect to the pressure drop across the sump strainer.

The following root issue is contained in this item:

1. Chemical precipitates may settle or enhance settling of other particulate in the containment pool.

As discussed above, this is not considered to be a significant issue.

CCNPP Resolution Plan

No action required.

5.4 Transport Phenomena: Precipitation and Coprecipitation

Precipitation or coprecipitation and ripening of solid species within the containment pool would create solid species which are less likely to transport. Decreased transportability will result in less product migrating to or through the sump screen.

The following root issue is contained in this item:

1. Chemical precipitates may settle in the containment pool.

As discussed above, this is not considered to be a significant issue.

CCNPP Resolution Plan

No action required.

6.0 ORGANICS AND COATINGS

6.1 Break Proximity to Organic Sources

The pipe break location plays an important role in debris generation. If the break occurs in close proximity to organic sources, it could introduce a significant amount of organic materials into the containment pool. Organic sources could then affect the nature, properties, and quantities of chemical byproducts that form in the post-LOCA containment environment. The scenario evaluated by the PIRT considered failure or leakage of oil and other organics from either the RCP oil collection tanks or lube oil systems resulting from LOCA-induced damage. If the pipe break occurs in close proximity to the organic sources, up to approximately 250 gallons of oil may be released to the containment pool. If this should occur, head loss and downstream effects may be altered, either beneficially or negatively, by these organic materials.

The following root issues are contained in this item:

1. Certain breaks may result in a significant quantity of oil being released into the containment pool.
2. Other organic materials may be present due to failure of coatings and the organic binders in insulation debris.

As discussed in the March 2011 report, one licensee added a large quantity of oil (representative of the quantity from one RCP motor) to an integrated chemical effects head loss test. The oil addition had no impact on the head loss, and is not considered to be a significant factor.

Similarly, the presence of smaller quantities of organic material from other sources is not expected to have a significant effect on the pool chemistry conditions.

<u>CCNPP Resolution Plan</u>

The cases where a significant quantity of oil would be introduced to the containment pool would be limited to a few larger breaks in the vicinity of one of the RCP motors. Since the majority of break cases would not have significant quantities of oil, oil will not be included in the 30-day chemical effects tests. The issue of organic materials from coatings failure and organic binders in insulation debris is addressed in Item 6.4, below.

6.2 Organic Agglomeration

Organic agglomeration is the process of small organic colloidal particles (1 to 100 nanometers in size) joining together, or coagulating, to form larger particles and precipitates. Coagulated particles can collect on sump strainers, decreasing ECCS flow; they could also collect on other wetted surfaces, such *as walls or structural steel, and decrease the debris loading on the sump screen. Hence, head losses and downstream effects could differ from those evaluated during plant-specific testing.*

The following root issue is contained in this item:

1. Organic agglomeration may form larger particles that would be more easily captured in a debris bed.

As discussed in the March 2011 report, this issue is similar to the issue of inorganic agglomeration, and is not considered to be a significant factor.

CCNPP Resolution Plan

No attempt to either stimulate or prevent agglomeration of particles will be incorporated into the chemical effects tests. In the chemical effects tests, particulate debris will be pre-deposited in the debris beds and will not be circulating in the solution in significant quantities. The solution chemistry in the chemical effects tests will be similar to the CCNPP system, so the formation and behavior of chemical precipitates will be similar, with particulate debris already present in the debris bed.

6.3 Organic Complexation

Organic complexing agents act to inhibit agglomeration either by adsorption onto solid surfaces or by interaction in solution with metal ions. Organic surface complexation occurs if organic molecules (i.e., amines, acids, and heterocycles) adsorb on surfaces of ions or solids and inhibit the subsequent precipitation or growth of those species. The implications of organic complexation are counter to those associated with organic agglomeration. Organic complexation could reduce the effects associated with chemical precipitates and therefore may be beneficial to ECCS performance if this phenomenon is not credited or addressed during plant-specific testing.

The following root issue is contained in this item:

1. Organic complexation may inhibit agglomeration.

Since both inorganic and organic agglomeration are not considered to be significant issues, organic complexation would be an insignificant factor also.

CCNPP Resolution Plan

No action required.

6.4 Coating Dissolution and Leaching

Coatings existing within containment represent possible additional physical debris sources. Generally conservative guidance for considering the effects of physical coating debris is provided for the evaluation of ECCS performance. However, dissolution and leaching of coatings can impact the chemical effects that occur within, or are transported to, the ECCS cooling water. Both inorganic (e.g., zinc-based) and organic (e.g., epoxy-based) coatings exist within containment. One concern is that these coatings leach chemicals as a result of being submerged in the containment pool environment after the LOCA. Coatings may create additional chemical species (e.g., chlorides or organics) within the containment pool that could potentially increase sump screen head loss or promote more deleterious downstream effects.

The following root issue is contained in this item:

1. Materials may leach from coatings affecting the overall pool chemistry.

As discussed in the March 2011 report, the amount of material that dissolves or leaches from coatings is expected to be relatively low. However, this is a potentially significant issue and should be appropriately addressed in realistic testing.

<u>CCNPP Resolution Plan</u>

DBA testing of epoxies has indicated that no coatings debris smaller than 1/32 inch in face dimension is produced, no organic compounds are released, and the pigments that are released do not dissolve or leach. Epoxy coatings destroyed due to jet impingement may fail as smaller particles but this is not expected to change the dissolution or leaching of these coatings.

Zinc-based coatings similar to those in containment at CCNPP will be included in the tests to account for failed zinc-based coatings.

The potential for dissolution and leaching of alkyd coatings is being addressed through bench-top autoclave testing [Ref. 5].

7.0 CHEMICAL EFFECTS ON DOWNSTREAM SYSTEM PERFORMANCE: PUMPS, HEAT EXCHANGERS, AND REACTOR CORE

7.1 Emergency Core Cooling System Pump: Seal Abrasion and Erosion or Corrosion

Abrasive wearing of pump seals (e.g., magnetite—high volume or concentration of mild abrasive) creates additional materials that contribute to containment pool chemistry. In addition, chemical byproducts cause erosion or corrosion of pump internals, especially close-clearance components (e.g., bearings, wear rings, impellers). The possible implications of these phenomena are (1) additional particles could contribute to reactor core clogging, (2) particles could add additional sump screen loading, (3) particles could affect chemical species formation, and (4) pump performance degrades, possibly to the point of being inoperable.

The following root issue is contained in this item:

1. Particulate debris generated by abrasive wearing of pump seals may cause additional downstream problems.

As discussed in the March 2011 report, the quantity of particulate material generated by wearing of the pump seals is insignificant compared to other particulate sources. Also, the pump materials are not unique, and the surface area of similar metals and materials in containment are large enough that the impact of the pump internals on chemical effects is considered to be negligible. Therefore, this issue is insignificant.

<u>CCNPP Resolution Plan</u>

No action required.

7.2 Heat Exchanger: Deposition and Clogging

Solid species which form in the heat exchanger lead to surface deposition or clogging, or both, within close-packed heat exchanger tubes (5/8-inch in diameter). This could cause decreased flow through the heat exchanger core or diminished heat transfer between the ECCS and heat exchanger cooling water, or both. Diminished cooling of the ECCS water could ultimately decrease the capacity of the ECCS water to remove heat from the reactor core.

The following root issue is contained in this item:

1. Precipitation within the heat exchanger may affect the heat exchanger performance.

As discussed in the March 2011 report, chemical precipitates would not have enough shear strength to block flow through the heat exchanger tubes. It's possible that some precipitates could create a thin coat on the tube walls. However, since the precipitates would generally form later in the event when the heat exchangers have ample margin, any slight degradation in performance due to the precipitates is negligible.

CCNPP Resolution Plan

The CCNPP chemical effects head loss loop includes a heat exchanger in which the process fluid is cooled and turbidity monitored to observe for precipitation. The cooled fluid is then returned to the test loop so that any precipitates that form will flow through the debris bed. The efficiency of heat exchange and performance of the heat exchanger will not be monitored during the chemical effects tests. However, if the heat exchanger used in the test can be disassembled, the heat exchanger tubes will be visually inspected for the presence of precipitates or scale formation, and if precipitates or scale is present, a sample of the precipitates will be scraped from the surfaces and analyzed using the techniques used for precipitate analysis.

7.3 Reactor Core: Fuel Deposition and Precipitation

The increased temperature (+70 degrees C from containment pool) and retrograde solubility of some species (e.g., Ca silicate, Ca carbonate, zeolite, sodium calcium aluminate) causes scale buildup on the reactor core. Zn, Ca, Mg, and CO_2*-based deposits, films, and precipitates may form at higher temperatures within the reactor core. This may lead to (1) a decrease in heat transfer from the reactor fuel, (2) localized boiling due to insufficient heat removal, and (3) spallation of deposits, creating additional debris sources which could clog the reactor core or contribute to sump screen head loss.*

The following root issue is contained in this item:

1. High localized temperatures in the reactor vessel may cause precipitation of materials with retrograde solubility.

As discussed previously, precipitation of materials with retrograde solubility on the fuel surfaces or in solution within the core is a significant issue that needs to be addressed.

CCNPP Resolution Plan

Materials with retrograde solubility have generally been calcium-based precipitates or phosphate-based precipitates. Calvert Cliffs does not anticipate precipitants of these types in containment.

7.4 Reactor Core: Diminished Heat Transfer

Physical and chemical solid debris within the ECCS coolant water could diminish the fluid's heat transfer capacity and degrade the ability of the coolant to remove heat from the core.

The following root issue is contained in this item:

1. Concentrated materials in the reactor vessel may reduce the water's heat removal capacity.

The highest debris concentrations would occur under cold leg break conditions during cold leg injection since the water entering the core would boil off raising the concentration of boron, other dissolved materials, and suspended solids. As discussed in the March 2011 report, the relatively dilute concentration of dissolved solids would not significantly affect the rate of boiling and rate of heat removal. The effects of high boron concentration on heat removal are not fully understood, but a PWROG program investigating this issue is currently in progress and is expected to be completed by 2015. Although the outcome of the PWROG research may change the acceptable limit for boron concentration in the reactor vessel, it would not affect the physical processes that must be evaluated in realistic chemical effects testing. Therefore, the PWROG progress should be monitored for potential plant modifications that may be required (i.e. timing for switchover from cold leg to hot leg injection), but is not a significant issue for realistic chemical effects testing.

At the chemical effects summit, the NRC announced that the boron precipitation issue must now be addressed as part of the overall resolution of GSI-191.

<u>CCNPP Resolution Plan</u>

The resolution of the boron precipitation issue will not be addressed in the CCNPP chemical effects test program. This issue will be addressed as part of the overall resolution of GSI-191 at CCNPP.

7.5 Reactor Core: Blocking of Flow Passages

Fuel deposition products and precipitated retrograde soluble chemical species spall and settle within the reactor vessel. Settling can be potentially deleterious if flow passages to the fuel elements are either globally or locally impeded. Reduced flow within the RPV, if significant, has the potential to diminish heat transfer from the fuel.

The following root issue is contained in this item:

1. Debris may spall and settle within the reactor vessel causing blockage.

As discussed previously, precipitates that form due to retrograde solubility within the reactor vessel must be properly addressed. This item raises an additional issue of the potential settling of precipitates or other debris spall under low flow conditions within the reactor vessel. During cold leg injection, the flow would move upward through the core and would tend to lift the debris and transport it out of the reactor vessel. If the settling velocity is high enough for the debris to settle, it would not be expected to create any significant head loss since the flow would simply have to overcome the “weight” of the debris to continue injecting into the core. During hot leg injection, the flow would move downward through the core in the same direction that settling debris would be moving. The debris could accumulate in various locations where it could form a bed and cause higher head losses. However, this issue would occur regardless of debris settling. Therefore, debris settling concerns are insignificant for realistic chemical effects testing.

CCNPP Resolution Plan

No action required.

7.6 Reactor Core: Particulate Settling

Relatively low, upwards flow (for cold leg injection) within the reactor causes particulates to settle. Compacted deposits form and may impede heat transfer and water flow, especially for lower portions of reactor fuel.

The following root issue is contained in this item:

1. Particulate debris may settle during cold leg injection causing flow path blockage or inhibiting heat transfer.

As discussed previously, debris that settles during cold leg injection would not result in significant head loss. Also, as discussed in the March 2011 report, the higher flow through the core for a hot leg break, and the turbulence due to boiling for a cold leg break would be expected to keep the particulate debris from blocking heat transfer to the lower portions of the fuel. Therefore, debris settling concerns are insignificant for realistic chemical effects testing.

CCNPP Resolution Plan

No action required.

8.0 REFERENCES

1. Design Calculation CA08048, Rev. 000y, GSI-191 Containment Pool Boric Acid Calculation, MPR Calculation No. 0090-0267-01, Probabilistic Distribution of Boric Acid Concentration in Containment Building Sump Pool.
2. CA08049, Rev. 000y, GSI-191 Strong Acids Calculation
3. CA08051, Rev. 000y, CCNPP Crud Debris Generation Calculation
4. CA08045, Rev. 000y, Calvert Cliffs Debris Generation Calculation
5. CA08074, Rev. 000y, Westinghouse Autoclave Chemical Effects Test Report
6. CA08046, Rev. 000y, CCNPP GSI-191 Copper And Galvanized Steel Quantity Calculation
7. WCAP-16530-NP-A, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191”, March 2008.