Resolution of Outstanding Chemical Effects PIRT Issues

Kerry Howe

February 09, 2012

During the Chemical Effects Summit held in the Nuclear Energy Institute offices on January 26 and 27, 2012, the NRC Phenomena Identification and Ranking Table (PIRT) was reviewed and general agreement was obtained regarding the items that need to be considered in a risk-informed approach to resolution of GSI-191.

The approach for addressing each of these items within the risk-informed approach can be divided into three categories. First, some items will be addressed by incorporating realistic experimental conditions within the test plan for the test at the University of New Mexico. The tests being planned include 30-day corrosion head-loss experiment (CHLE) tests, shorter-term head loss tests, and bench-scale tests; the PIRT items are addressed through the combination of these tests. Second, some PIRT items will be investigated through literature review and modeling to determine whether they need to be included in chemical effect testing. Depending on the outcome of the literature review and modeling, they will be addressed in bench-scale tests or the CHLE tests. Third, some PIRT items cannot be addressed within the chemical effect experimental testing and the approach for how they will be addressed is still being explored. The tables below summarize which approach is being followed for each PIRT item, and the following paragraphs provide additional detail about how each item is being addressed.

1. Addressed by incorporating realistic conditions in the experimental testing.

Item 1.1: RCS coolant chemistry conditions at break
Item 1.2: pH Variability
Item 1.4: Containment spray CO_2 scavenging and CO_2/O_2 air exchange
Item 1.5: Emergency Core Cooling System Injection of Boron
Item 3.2: Jet Impingement
Item 3.3: Debris Mix Particulate/Fiber Ratio
Item 3.4: Effects of Dissolved Silica from Reactor Coolant System and Refueling Water Storage Tank
Item 3.5: Containment Spray Transport
Item 3.6: Initial Debris Dissolution
Item 3.10: Alloying Effects
Item 3.11: Advanced Metallic Corrosion Understanding
Item 4.2: Heat Exchanger: Solid Species Formation
Item 4.5: Coprecipitation
Item 5.1: Inorganic Agglomeration

2. Addressed by modeling and literature investigation, with incorporation into experimental testing depending on the outcome of those efforts.

Item 2.1: Radiolytic Environment
Item 2.2: Radiological Effects: Corrosion Rate Changes
Item 2.5: Additional Debris Bed Chemical Reactions
Item 3.7: Submerged Source Terms: Lead Shielding
Item 3.8: Submerged Source Terms: Copper
Item 3.13: Reactor Core: Fuel Deposition Spall
Item 4.3: Reactor Core: Precipitation
Item 6.1: Break Proximity to Organic Sources
Item 6.2: Organic Agglomeration
Item 6.4: Coating Dissolution and Leaching
Item 7.3: Reactor Core: Fuel Deposition and Precipitation

3. Approach to address is still under investigation.

Item 3.1: Crud Release
Item 3.9: Concrete Material Aging
Item 3.12: Submerged Source Terms: Biological Growth in Debris Beds
Item 7.2: Heat Exchanger: Deposition and Clogging
Item 7.4: Reactor Core: Diminished Heat Transfer
Item 7.5: Reactor Core: Blocking of Flow Passages
Item 7.6: Reactor Core: Particulate Settling

Item 1.1: RCS coolant chemistry conditions at break

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.*

Resolution: Long-term (30-day) tests will be run representing 3 different LOCA scenarios (small, medium, and large). The quantities of materials in each test will be determined from the quantities of materials present in STP containment that are impacted by each size break, as determined by break modeling. The boron and lithium concentrations for each test will be selected by determining the concentrations in the RCS, RWST, and accumulators at STP and calculating the concentration based on the contribution from each source for each 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 (Visual MINTEQ). If the modeling indicate 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 with higher or lower concentrations of boron and lithium. The temperature will be varied over the 30-day duration to match the temperature profile of the selected break scenarios, with the exception that the effect of corrosion at temperatures higher than 185 °F will be addressed by including additional material in the corrosion tank for an appropriate period of time.

Item 1.2: pH Variability

The following root issue is contained in this item:

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

Resolution: The issue of pH variability over the fuel cycle is addressed by the selection of boron and lithium concentrations in Item 1.1.

Item 1.4: Containment spray CO_2 scavenging and CO_2/O_2 air exchange

The following root issue is contained in this item:

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

Resolution: The STP containment contains sufficient air space that the pool solution will be in equilibrium with the CO_2 and O_2 in the atmosphere (chemically, the solution behaves as an open system). The CHLE loop is not air tight, and the lid will periodically be removed during sampling, so the tests will have sufficient opportunity for air to interact with the solution and will also behave as an open system. Calculations will be performed to determine the dissolved gas concentrations that should be present in the solution in the STP containment. The impact of CO_2

from the atmosphere on the potential for carbonate precipitation will be evaluated using Visual MINTEQ. Furthermore, the dissolved O_2 (and possibly carbonate, if warranted) concentration will be measured during the CHLE tests. No special provisions will be performed to control the dissolved CO_2 and O_2 concentrations to ensure that the tests are comparable to the break scenario.

Item 1.5: Emergency Core Cooling System Injection of Boron

The following root issue is contained in this item:

1. *Boron concentration in the RWST will affect the pH in the pool.*

Resolution: The concentration of boron to be used in each test is addressed in Item 1.1.

Item 2.1: Radiolytic Environment

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 to form strong acids.*

Resolution: The quantity of acid formation due to radiolysis will be determined by modeling and the appropriate quantity of acids will be added during the tests. Decision whether to add all the acid at the beginning of the test or to add it periodically during the test to simulate acid formation over time will be decided based on the quantity of acid production and the effect of the acid on pH.

Item 2.2: Radiological Effects: Corrosion Rate Changes

The following root issue is contained in this item:

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

Resolution: The addition of acid to the tests to simulate radiolysis is addressed in Item 2.1.

Item 2.4: Conversion of N_2 to HNO_3

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.*

Resolution: The addition of acid to the tests to simulate radiolysis is addressed in Item 2.1.

Item 2.5: Additional Debris Bed Chemical Reactions

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.*

Resolution: An investigation of existing literature will be performed to evaluate the possible effects of radiolysis of materials trapped in the debris beds. In addition, this item may be explored in bench-scale testing if appropriate materials and a radiation source can be identified. This item will not be addressed in the 30-day CHLE tests.

Item 3.1: Crud Release

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.*

Resolution: This item will not be addressed in the 30-day CHLE tests. The crud is a source term for particulate debris and is not expected to affect the chemical environment. Crud release will be addressed by considering it as a potential additional source term for particulate debris that can contribute to head loss.

Item 3.2: Jet Impingement

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.*

Resolution: The approach for determining the quantity of materials during each test takes debris generation into account and is addressed in Item 1.1.

Item 3.3: Debris Mix Particulate/Fiber Ratio

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.*

Resolution: The mixture of debris to be used in each test is addressed in Item 1.1. The long-term tests will use a standard debris bed with a 5:1 ratio of particles to fibers to assess the relative impact of chemical effects under a standardized condition. Variations in the particle/fiber ratio and the impacts of that on chemical precipitate capture efficiency and debris bed head loss will be evaluated using short-term tests.

Item 3.4: Effects of Dissolved Silica from Reactor Coolant System and Refueling Water Storage Tank

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.*

Resolution: The quantity of silica present in the RCS, RWST, and accumulators at STP will be evaluated along with the boron and lithium as described in Item 1.1, and the contribution of silica from each source during each test will be calculated and added at the beginning of the test as described for boron and lithium in Item 1.1. The ratio of aluminum to silica and the effect of this ratio on corrosion will be investigated in bench-scale tests.

Item 3.5: Containment Spray Transport

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.*

Resolution: The CHLE tests will take into account debris transport due to containment sprays for each accident scenario. The amount of material transported to the pool versus the debris held up above the pool surface will be evaluated as part of the larger risk informed approach.

Item 3.6: Initial Debris Dissolution

The following root issue is contained in this item:

1. *Dissolution of debris can form chemical precipitates.*

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

Item 3.7: Submerged Source Terms: Lead Shielding

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.*

Resolution: The quantity of lead in STP containment is being determined. Literature is being consulted to evaluate the significance of lead-based precipitates. Chemical equilibrium modeling will also be performed to assess the potential presence of any lead-based precipitates. If these efforts reveal lead-based precipitates may be present, lead will be included in the CHLE tests in proportion to its presence at STP as described in Item 1.1 for other materials.

Item 3.8: Submerged Source Terms: Copper

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.*

Resolution: The ICET test results are being reviewed to evaluate the impact of copper in previous testing. If these efforts reveal that copper may have any effect on the outcome of the tests, copper will be included in the CHLE tests in proportion to its presence at STP as described in Item 1.1 for other materials.

Item 3.9: Concrete Material Aging

The following root issue is contained in this item:
1. *Aged concrete may release a larger quantity of calcium.*

Resolution: Concrete will be included in the CHLE tests in proportion to its presence at STP as described in Item 1.1 for other materials, but no effort will be made to age the concrete. Bench scale testing will be done to evaluate calcium leaching from concrete under the range of chemical conditions that may exist.

Item 3.10: Alloying Effects

The following root issue is contained in this item:
1. *Differences in alloys may affect dissolution and corrosion rates.*

Resolution: The specific alloys selected for the long-term CHLE tests will be those that are most representative of actual materials present in STP containment.

Item 3.11: Advanced Metallic Corrosion Understanding

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.*

Resolution: Synergistic effects and corrosion inhibition are address due to the selection of materials in the proper proportions relative to the STP containment, as described in Item 1.1. Acid formation is addressed in Item 2.1. Enhanced corrosion due to jet impingement will not be addressed in the CHLE tests.

Item 3.12: Submerged Source Terms: Biological Growth in Debris Beds

The following root issue is contained in this item:
1. *Biological growth in the post-LOCA environment may contribute to clogging issues.*

Resolution: This item will not be addressed in the 30-day CHLE tests. An investigation of existing literature will be performed to evaluate the possible impact of biological growth.

Item 3.13: Reactor Core: Fuel Deposition Spall

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.*

Resolution: An investigation of existing literature will be performed to evaluate the possible chemical reactions involving fuel cladding oxides (ZrO_2), and Visual MINTEQ will be used to identify whether the possible species can affect the chemistry of the system. The effect of activated particles on chemical effects due to radiolysis is considered to be insignificant and will not be considered in the CHLE tests. The possibility that spalling of fuel oxides could be a source term for particulate debris will not be incorporated into the CHLE tests because the CHLE tests are focused on chemical effects. Additional particulate debris source terms can be included in the quantities of debris used in head loss calculations.

Item 4.2: Heat Exchanger: Solid Species Formation

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.*

Resolution: The testing will include a loop in which the temperature of the solution will be decreased, passed through an analytical system to detect whether precipitation has occurred, and increased to determine whether temperature reduction will induce precipitation.

Item 4.3: Reactor Core: Precipitation

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.*

Resolution: Precipitation in the reactor core is outside the scope of the 30-day CHLE tests. An investigation of existing literature will be performed to evaluate the possible effects of retrograde solubility, and Visual MINTEQ will be used to identify possible species that may exhibit retrograde solubility. In addition, this item may be explored in bench-scale testing.

Item 4.5: Coprecipitation

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.*

Resolution: 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 STP, as described in Item 1.1.

Item 5.1: Inorganic Agglomeration

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.*

Resolution: No attempt to either stimulate or prevent agglomeration of particles will be incorporated into the CHLE tests. In the CHLE 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 CHLE tests will be similar to the STP system, so the formation and behavior of chemical precipitates will be similar, with particulate debris already present in the debris bed.

Item 6.1: Break Proximity to Organic Sources

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.*

Resolution: The presence of oil in the containment pool is outside the scope of the 30-day CHLE tests. An investigation of existing literature including previous experimental will be performed to evaluate the possible effects of oil in containment. If the literature review indicates that oil may have an effect on debris bed head loss, this item may be explored in short-term head loss testing. The issue of organic materials from coatings failure and organic binders in insulation debris is addressed in Item 6.4, below.

Item 6.2: Organic Agglomeration

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.*

Resolution: The resolution of this item is the same as Item 6.1.

Item 6.4: Coating Dissolution and Leaching

The following root issue is contained in this item:

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

Resolution: Existing literature will be reviewed to assess the rates of leaching from coated surfaces. If necessary, information from literature can be supplemented with data from bench-scale testing. If the literature or bench-scale testing indicates that leaching from coatings can affect the overall pool chemistry, appropriate materials will be included in the CHLE tests.

Item 7.2: Heat Exchanger: Deposition and Clogging

The following root issue is contained in this item:

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

Resolution: The efficiency of heat exchange and performance of the heat exchangers will not be monitored during the CHLE 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.

Item 7.3: Reactor Core: Fuel Deposition and Precipitation

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.*

Resolution: This item is the same as Item 4.3. Precipitation in the reactor core is outside the scope of the 30-day CHLE tests. An investigation of existing literature will be performed to evaluate the possible effects of retrograde solubility, and Visual MINTEQ will be used to identify possible species that may exhibit retrograde solubility. In addition, this item may be explored in bench-scale testing.

Item 7.4: Reactor Core: Diminished Heat Transfer

The following root issue is contained in this item:

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

Resolution: The resolution of this item is outside the scope of the CHLE tests. It will be addressed as part of the larger risk-informed approach.

Item 7.5: Reactor Core: Blocking of Flow Passages

The following root issue is contained in this item:

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

Resolution: The resolution of this item is outside the scope of the CHLE tests. It will be addressed as part of the larger risk-informed approach.

Item 7.6: Reactor Core: Particulate Settling

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.*

Resolution: The resolution of this item is outside the scope of the CHLE tests. It will be addressed as part of the larger risk-informed approach.