

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16530-NP "EVALUATION OF POST-ACCIDENT CHEMICAL

EFFECTS IN CONTAINMENT SUMP FLUIDS TO SUPPORT GSI-191"

PRESSURIZED WATER REACTOR OWNERS GROUP

PROJECT NO. 694

1.0 INTRODUCTION AND BACKGROUND

1.1 Background

By letter dated March 27, 2006 (Agencywide Documents Access Management System (ADAMS) Accession No. ML060890506), and supplemented by letters dated November 21, 2006 (ADAMS Accession No. ML063390128), April 3, 2007 (ADAMS Accession No. ML070950119), and September 12, 2007 (ADAMS Accession No. ML072570680), the Pressurized Water Reactor (PWR) Owners Group (PWROG) submitted for the U.S. Nuclear Regulatory Commission (NRC) staff review and approval the Westinghouse non-proprietary topical report (TR) WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," dated February 2006. TR WCAP-16530-NP provides an approach for plants to evaluate chemical effects that may occur in a post-accident containment sump pool.

For the purpose of this safety evaluation (SE), the issue of chemical effects involves interactions between the post-accident pressurized water reactor (PWR) containment environment and containment materials that may produce corrosion products, gelatinous material, or other chemical reaction products capable of affecting head loss across the sump strainer or components downstream of the sump strainers. This TR is applicable to PWRs only. TR WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid," evaluates potential chemical effects in the reactor vessel, so these effects are not addressed in TR WCAP-16530-NP nor in this SE. TR WCAP-16793-NP is being reviewed by the NRC staff and a separate SE will be provided for this report.

1.2 Introduction

In 2003, the Advisory Committee on Reactor Safeguards identified a need for an adequate technical basis to resolve concerns related to potential chemical reactions that may occur in a post-accident containment environment. Products formed from reactions between containment materials and the post-accident environment could increase head loss across the sump strainer or affect components downstream of the sump strainer. An initial scoping study was conducted by the Los Alamos National Laboratory (LANL) to evaluate potential chemical effects occurring following a loss-of-coolant accident (LOCA). This study assessed the potential for chemical products, if formed, to impede Emergency Core Cooling System (ECCS) performance (ADAMS Accession No. ML033230260). Although the LANL tests showed that gel formation with a significant accompanying head loss across a fibrous bed was possible, no integrated testing was performed to demonstrate a progression from initial exposure of metal samples to formation of chemical interaction precipitation products. In addition, the test conditions were not

intended to be prototypical of a PWR environment after a LOCA. Therefore, a more comprehensive test program was initiated to assess potential chemical effects in a more representative test environment.

An integrated chemical effects test (ICET) program was developed through a collaborative effort between the NRC staff and representatives of the nuclear industry. The test objective was to characterize any chemical reaction products, including possible gelatinous material that may develop in a representative post-LOCA PWR containment sump environment. Test conditions such as pH, temperature, and boron concentration were selected to simulate representative, but not necessarily bounding, plant conditions. The ICET series was conducted by the LANL at the University of New Mexico. Materials included in the ICET series included zinc (galvanized steel and inorganic zinc coatings), aluminum, copper, carbon steel, concrete, fiberglass, and calcium silicate insulation. Representative amounts of concrete powder, sand, and clay were also added to simulate latent debris in the containment building. Relative amounts of test materials were scaled according to plant data provided by the industry that were based on responses to a plant survey. Test coupons were either fully immersed or were placed above the test loop water line but subjected to a tank spray to simulate exposure to containment spray. The relative distributions of each material were determined based on plant estimated percentages of submerged material and material subjected to containment sprays following a LOCA.

Results from the ICET series, available in Volumes 1 to 6 of NUREG/CR-6914, "Integrated Chemical Effects Test Project" (ADAMS Accession No. ML071800338), indicated that chemical precipitates may form in representative environments. In particular, highly hydrated aluminum hydroxide and calcium phosphate precipitates were observed to form with specific combinations of plant materials and environments. The exact nature of the hydrated precipitates was difficult to characterize. Additional evaluations of aluminum hydroxide (ICET 1) type precipitates are provided in NUREG/CR-6915, "Aluminum Chemistry in a Prototypical Post-Loss-Of-Coolant-Accident Pressurized Water Reactor Containment Environment" (ADAMS Accession No. ML070160448).

Since evaluating head loss across a debris bed due to chemical precipitates was outside the scope of the ICET series, the NRC subsequently sponsored a head loss test program at the Argonne National Laboratory (ANL) to evaluate head loss effects from precipitates observed during the ICET tests. NUREG/CR-6913, "Chemical Effects Head-Loss Research in Support of Generic Safety Issue 191" (ADAMS Accession No. ML070090553), summarizes the results of vertical loop head loss testing and bench testing. The vertical loop head loss test results at ANL showed that some of the ICET chemical products can produce significant pressure drops across a fiber bed on a flat plate test section.

A peer review of NRC-sponsored chemical effects testing was performed following the ICET tests and during the time head loss testing was being performed at ANL. Five independent peer review panel members with a diverse set of expertise raised a number of technical issues related to GSI-191 chemical effects. These issues are documented in NUREG-1861, "Peer Review of GSI-191 Chemical Effects Research Program" (ADAMS Accession No. ML063630498). The peer review panel and the NRC staff developed a phenomena identification and ranking table (PIRT) of technical issues identified by the peer review panel. The NRC staff is working to resolve those issues identified in the PIRT. Part of the resolution process includes NRC-sponsored analyses being performed by Pacific Northwest National Laboratory.

The testing and chemical models contained within TR WCAP-16530-NP are intended to provide PWR plants a methodology to perform plant-specific chemical effects evaluations. The TR WCAP-16530-NP tests were performed at higher temperatures and for shorter durations compared to ICET. Additional plant materials were included in the tests described in TR WCAP-16530-NP.

TR WCAP-16530-NP is organized into the following sections:

- Report Overview - discusses the purpose of the TR and provides a summary of the various report sections.
- Introduction - presents the background of the chemical effects issue, discusses the ICET program, and discusses the objective of the PWROG chemical effects testing in relation to ICET.
- Containment Materials - provides the results of PWR plant containment material surveys, classifies the plant materials into 5 metallic and 10 non-metallic materials, and describes the material classes.
- Test Plan - explains the bench testing purpose and approach, and provides the plans for dissolution testing and precipitation testing.
- Bench Testing - documents the bench testing performed including the functional requirements, test procedures, materials tested, and the results from the dissolution tests and precipitation tests.
- Chemical Model - presents the chemical model developed from the results of the bench testing. The chemical model is contained in a spreadsheet that predicts the type and amount of material that dissolves based on material concentrations and chemical reactions in the environment. The model also predicts the quantity and type of precipitate that forms and is intended for use to determine the amount of plant-specific precipitate that may form in a post-accident environment.
- Particulate Generator - describes the qualification testing performed on chemical precipitate that is intended to represent the precipitate performed during bench testing. This section also provides directions for making the surrogate chemical precipitate that may be used during subsequent strainer head loss testing.
- Plant-Specific Application - provides the link between the TR WCAP-16530-NP tests and strainer vendor testing using plant-specific debris, including chemical precipitates. This section also provides guidance for plant-specific application of the chemical model contained in the TR.

The NRC staff's evaluation for each of these sections is contained in Section 3.0 of this SE.

2.0 REGULATORY EVALUATION

The NRC regulations in Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.46, require that the ECCS has the capability to provide long-term cooling of the reactor core

following a LOCA. That is, the ECCS must be able to remove decay heat so that the core temperature is maintained at an acceptably low value for the extended period of time required by the long-lived radioactivity remaining in the core.

Similarly, for PWRs licensed to the General Design Criteria (GDCs) in Appendix A to 10 CFR Part 50, GDC-38 provides requirements for containment heat removal systems, and GDC-41 provides requirements for containment atmosphere cleanup. Many PWR licensees credit a containment spray system (CSS), at least in part, with performing the safety functions to satisfy these requirements, and PWRs that are not licensed to the GDCs may similarly credit a CSS to satisfy related licensing basis requirements. In addition, PWR licensees may credit a CSS with reducing the accident source term to meet the limits of 10 CFR Part 100 or 10 CFR 50.67. GDC-35 is referenced in 10 CFR 50.46(d) and specifies additional ECCS requirements. PWRs that are not licensed to the GDCs typically have similar requirements in their licensing basis.

The NRC staff's evaluation of post-accident chemical effects and TR WCAP-16530-NP is developed within the context of resolution of GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance." In order to resolve GSI-191, the NRC staff needs to have reasonable assurance that post-accident debris blockage will not impede or prevent the operation of the ECCS and CSS in recirculation mode at PWRs during LOCAs or other high-energy line break accidents for which sump recirculation is required. Following the completion of a technical assessment of GSI-191, the NRC staff issued Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Recirculation During Design-Basis Accidents at Pressurized-Water Reactors," on June 9, 2003. As a result of the emergent issues discussed therein, the bulletin requested an expedited response from PWR licensees on the status of their compliance, on a mechanistic basis, with regulatory requirements concerning the ECCS and CSS recirculation functions. Licensees who chose not to confirm regulatory compliance were asked to describe interim compensatory measures that have been implemented to reduce risk until the analysis could be completed.

In developing Bulletin 2003-01, the NRC staff recognized that it might be necessary for licensees to undertake complex evaluations to determine whether regulatory compliance exists in light of the concerns identified in the bulletin and that the methodology needed to perform these evaluations was not currently available. As a result, that information was not requested in the bulletin, but licensees were informed that the NRC staff was preparing a generic letter that would request this information. The information was subsequently requested in GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents At Pressurized-Water Reactors" issued on September 13, 2004, included, in part, the maximum head loss postulated from debris accumulation on the submerged sump screen, including debris created by chemical precipitates that may form due to chemical reactions in the post-LOCA environment.

The NRC staff reviewed TR WCAP-16530-NP to determine whether it will provide an acceptable technical justification for the evaluation of plant-specific chemical effects, as part of the evaluations licensees are conducting to address GSI-191 concerns and to support supplemental responses to GL 2004-02.

3.0 TECHNICAL EVALUATION

3.1 Containment Materials

This section of TR WCAP-16530-NP provides a compilation of containment materials based on a survey of all 69 U.S. PWRs. This data formed the basis for selection of representative test materials and their amounts for the bench tests. Ratios of plant material to water volume were determined using the maximum amount of material and minimum water volume for each plant. Plant materials from the survey were grouped based on composition into 10 non-metallic and 5 metallic material classes. Based on results from ICET indicating no significant interactions with the environment (e.g., copper) or an analysis showing the amount of material in containment would be insignificant (e.g., organics), no tests were performed on 5 material classes. Materials were then selected from each material class for bench testing. Historical data, ICET results, and chemical similarity of the different insulation brands were used to select representative non-metallic (mineral wool, Interam, Durablanket, Nukon Fiberglass, MIN-K, Temp-Mat high density fiberglass, calcium silicate, concrete) and metal (carbon steel, galvanized steel, aluminum) samples for bench testing.

The NRC staff reviewed the selection of containment materials in the TR WCAP-16530-NP and the assumptions used to determine the materials to be tested. The materials were identified in a PWROG sponsored survey. While the NRC staff has not verified the survey results, the types and amounts of materials appear reasonable. The NRC staff questioned (Request for Additional Information (RAI) dated October 4, 2006, ADAMS Accession No. ML062440433) the TR WCAP-16530-NP assumption that the amount of RCS oxides was not significant enough to be included as a containment material in the TR tests. This NRC staff question is discussed in greater detail in Section 3.8 of this SE. The NRC also sponsored some confirmatory tests to verify the acceptability of the TR WCAP-16530-NP selections of representative materials for the various non-metallic material classes. This is discussed further in Section 3.7 of this SE.

3.2 Dissolution Testing

The objective of the dissolution tests was to determine which materials would contribute significant dissolved mass to test solutions used to represent post-LOCA containment pool conditions. Plant survey data were used to determine limits for test parameters. For example, tests were performed with pH values of 4.1, 8, and 12 to bound the postulated post-accident pH values ranging from the initial, unbuffered, low pH solution in the containment pool to the maximum postulated high pH in the CSS during sodium hydroxide injection. All test solutions contained 4400 parts per million (ppm) boron as boric acid, and this boric acid concentration produced the pH 4.1 test solution. The pH 8 and pH 12 test solutions were produced by adding sodium hydroxide to the borated water to increase the pH. Test temperatures of 190 °F and 265 °F were selected to evaluate leaching of containment materials at high temperatures simulating early initial post-accident sump conditions.

Bench tests were conducted in either Teflon or stainless steel reaction vessels that were filled to a nominal fluid volume of 120 milliliters (ml) or 150 ml, respectively. The reaction vessels were placed on a rocking platform that was located in an oven that contained the solution reservoirs and reaction chambers. Samples of the reaction vessel solutions were taken at 30, 60, and 90 minutes. The solutions were analyzed using inductively coupled plasma spectroscopy (ICP) for the elements of interest including: aluminum, calcium, silicon, magnesium, phosphorous, sulfur, iron, zinc and titanium.

The ICP results indicated that approximately 99 percent of the total mass released into solution during the leaching tests of containment materials was aluminum, silicon, and calcium. The amount of aluminum in the solution represented 75 percent of the total elemental mass released. The mass of aluminum released into solution was approximately 4 times greater than the mass of silicon released into solution and 15 times greater than the mass of calcium released into solution.

The amount of aluminum released into solution was a strong function of test solution pH. There is an order of magnitude increase in the total mass of aluminum released into solution at pH 8 relative to pH 4.1. The aluminum mass released increases by two orders of magnitude when the pH is increased from 4.1 to 12.

In terms of containment materials, aluminum, concrete, and calcium silicate released the most mass during testing. The amount of crushed concrete tested, however, was not scaled according to a representative surface area in a PWR containment since the surface area of the crushed concrete was not known prior to the start of testing. Afterwards, it was determined that the amount of concrete tested was much greater than the amount that would be representative of a U.S. PWR. The concentration of calcium due to dissolution of concrete would have been lower if the amount of concrete tested had been scaled to an upper bound of exposed concrete surface area in a PWR.

The NRC staff reviewed the test methods and results from the TR WCAP-16530-NP leaching tests and determined that the selection of pH and temperature was acceptable since the range of pH tested bounded the pH values that may be experienced by plant materials following a LOCA. The NRC staff found the TR test temperatures acceptable since greater dissolution is expected to occur at the elevated temperatures in the TR tests and this data complements the data obtained from the ICET series at 140 °F. The NRC staff found the use of ICP analysis to determine the concentration of elements that leached into solution to be acceptable since this a standard quantitative analytical method for determining the amount of a given element in solution.

3.3 Precipitation Testing

Following completion of the 90-minute leaching tests, solutions from the test reactors were transferred through a sintered stainless steel filter and small diameter stainless steel transfer lines located in a constant temperature water bath into settling cones. The water bath was maintained at 80 °F, and the solutions were visually inspected over time to look for evidence of precipitation caused by cooling the solution. In addition to the dissolution test solutions, additional precipitation test solutions were created by adding trisodium phosphate (TSP) or sodium tetraborate (STB) or by combining the solutions from different dissolution tests. More specifically, some of the pH 4.1 boric acid solutions were buffered to a pH 8 by addition of TSP or STB. In other cases, precipitation test solutions were created by combining pH 4.1 test solutions of one material (e.g., concrete) with pH 12 test solutions of a second material (e.g., aluminum).

Precipitates formed in a total of 17 experiments. Of these, 10 were single material, single test solution leaching experiments included in the precipitation test matrix. Another 2 precipitation experiments involved calcium-containing dissolution materials with subsequent additions of TSP. Mixing of solution from different leaching runs produced precipitate in 1 experiment. Finally, 4 additional experiments with single material, single test solution conditions produced precipitate.

These final 4 cases were from leaching test runs that were not included as part of the precipitation test matrix, but visual examination of the experiment detected the presence of precipitate.

Results from the leaching and precipitation tests indicated no recognizable correlation between the total amount of material in the solution during the dissolution tests and the amount of precipitate that subsequently formed during precipitation tests. The greatest volume of precipitate was formed with aluminum in a pH 12 solution. The complexity of the observed precipitation processes caused the PWROG to change the planned chemical model development such that the model does not rely on the precipitate mass measured during precipitation testing to determine the amounts of plant-specific precipitate. Instead, the model conservatively assumes all dissolved aluminum precipitates and all dissolved calcium in phosphate solutions precipitates. The TR WCAP-16530-NP also states that the precipitates formed do not settle quickly and thus cannot be discounted as a concern for sump screen performance.

Composition of the precipitates was determined by performing energy dispersive spectroscopy (EDS) on precipitate samples that were captured on filter paper and placed into a scanning electron microscope. Based on a best-estimate analysis from the EDS results, the TR concludes that the precipitates containing aluminum are predominantly aluminum oxyhydroxide and sodium aluminum silicates. EDS analysis also indicated that calcium phosphate formed in tests when dissolved calcium combined with phosphate in solution.

The NRC staff reviewed the test methods and results from the TR WCAP-16530-NP precipitation tests, and the NRC staff had some questions related these tests (see RAI dated October 4, 2006, ADAMS Accession No. ML062440433). One issue concerned whether the use of primarily single-material tests in the precipitation test matrix was appropriate considering the possibility that combined effects could result from the interaction of several materials. This issue is discussed in more detail in Section 3.8 of this SE. In addition, the NRC staff had questions concerning the limitations of the EDS technique used for the best estimate characterization of the TR WCAP-16530-NP precipitates. This issue is also discussed in greater detail in Section 3.8 of this SE. Overall, the NRC staff concluded that the use of an 80 °F water bath for cooling was appropriate since lower temperatures would typically favor the precipitation process for the aluminum-containing species, as was observed in the ICET 1 and ICET 5 tests. Post-LOCA sump pool temperatures would typically exceed 80 °F for most of the ECCS mission time. Therefore, with the exception of those items discussed in greater detail in Section 3.8 of this SE, the NRC staff concluded that the approach to precipitation testing was acceptable.

3.4 Precipitate Filterability Tests

Precipitate filterability studies were performed to measure the filter cake coefficients of the various precipitates produced in the chemical effects bench tests. In addition, precipitate filterability tests were performed on the surrogate precipitates developed in a particulate generator and intended to represent the precipitates observed during testing. Filterability of individual precipitates was assessed by pumping the precipitate solution through a 1 micron glass fiber filter using a peristaltic pump. The solution was pumped through the filter at different flow rates and the pressure drop across the filter was determined at different flow rates. Pressure drop was plotted as a function of flow rate. This slope was then combined with the water viscosity, solids weight, and effective filter area to determine an overall filter cake coefficient.

The NRC staff questioned some of the filterability model assumptions and the conclusion that the relative filterability of the aluminum oxyhydroxide and sodium aluminum silicate surrogate precipitates was similar. For example, one of the inputs used to calculate the filter cake coefficient is precipitate mass. In these tests, precipitate mass is obtained after the test is completed by drying the hydrated precipitate that was collected on the test filter. Differences in the degree of hydration between different precipitates or between different batches of the same precipitate could introduce significant error in the calculated filter cake coefficients.

In response to the NRC staff's questions, the PWROG performed additional tests to study filterability of sodium aluminum silicate and aluminum oxyhydroxide. Some of these additional tests investigated the effects of cooling rates on precipitate properties. Based on the results from these additional tests, the PWROG concluded that the TR WCAP-16530-NP aluminum oxyhydroxide and sodium aluminum precipitates produced pressure drops equal to or greater than precipitate formed in a representative post-LOCA environment. While the NRC staff agrees that the data support the PWROG conclusions, the filterability model assumptions and the test technique used to measure filterability in the additional studies had the same fundamental weaknesses. Therefore, the NRC staff does not accept these test results to compare the relative filterability of WCAP-16530-NP precipitates. Section 3.7 of this SE discusses some NRC-sponsored testing that compares the relative filterability of TR WCAP-16530-NP precipitates. Nonetheless, it is important to note that the filterability tests in the TR were performed to permit relative comparison of the different surrogate precipitates and that these filterability test results are not factored into the chemical model predictions.

3.5 Chemical Model

Regression analysis was performed on the bench test dissolution data to develop release rate equations as a function of temperature, pH and concentration of the particular chemical species. Release rate equations were developed for each predominant containment material for each chemical species. For example, the amount of calcium released by calcium silicate insulation, concrete, and other insulation materials containing calcium are determined by different functions. Thus, bench test dissolution data are used to predict the amount of precipitate that forms and the results from precipitate analysis are used to predict the type of precipitate that forms. The model conservatively assumes all dissolved aluminum precipitates and all dissolved calcium in phosphate solutions precipitates.

Since corrosion of aluminum resulted in the greatest mass released during the TR leaching tests, the aluminum release rate incorporated into the chemical model is important. The TR contains two aluminum release rate equations that were developed by fitting different aluminum corrosion data sets, including the ICET series. The chemical model uses Equation 6-2 in the TR that was fit to a greater number of data sets. The NRC staff questioned whether Equation 6-2 provided the most appropriate aluminum release rate and whether the ICET 1 aluminum corrosion data were properly considered. The TR 16530-NP chemical model treatment of aluminum corrosion is discussed further in Section 3.7 of this SE.

The chemical model consists of a Microsoft Excel spreadsheet that contains algorithms based on the leaching and precipitation tests and uses linear sums of the individual test results to determine the total amount of material that is dissolved and precipitated. Plant-specific information is entered into the spreadsheet in several steps. The post-accident temperature and pH are entered as a function of time. The containment materials are entered into the spreadsheet according to the amounts that are submerged or wetted by containment spray. The

amount of containment material that is transported to the pool and submerged will be dependent upon the break location.

The output of the model is presented in a results table that shows the time-dependent amounts of aluminum, calcium, and silicon released. The amounts of each precipitate predicted are also provided as a function of time. Individual pages of the spreadsheet indicate the elemental release and the precipitate formation on a plant-specific material basis to allow the user to determine the potential benefits gained by reduction or removal of certain materials from their plant.

Given that the chemical model assumes all aluminum in solution and all calcium in the presence of phosphate precipitates, the NRC staff concludes that the model predictions for the amount of plant-specific precipitate are conservative and are, therefore, acceptable. The assessment of particular aspects of the model (e.g., the model's prediction of the relative amounts of surrogate precipitate) and an overall assessment of the chemical model are contained in Sections 3.7 and 3.8 of this SE.

3.6 Particulate Generator

The purpose of the particulate generator is to create surrogate chemical precipitates with representative properties that may be used during sump strainer head loss testing. Based on plant-specific inputs, the chemical model spreadsheet predicts the amount of chemical precipitates that would form in the post-accident environment. Since the precipitate filtration and settlement properties are influenced by their amorphous and hydrated nature, the particulate generator preparation is performed by mixing chemicals (e.g., water, aluminum nitrate nonahydrate, and sodium hydroxide) in solution for a minimum of an hour prior to use. The discussion in the particulate generator section of the report recognizes that representative precipitate properties may not be achieved by the use of similar chemical formula solid material. The NRC staff agrees that pre-manufactured particulate, e.g., calcium phosphate powder, behaves differently than hydrated, amorphous, precipitate that was observed during the ICET series. Therefore, the NRC staff does not consider addition of commercially manufactured particulate with similar chemical composition to be an adequate simulation of chemical precipitates.

During particulate generator qualification testing, the effects of precipitate concentration in the mixing tank were evaluated, and it was observed that precipitate solutions prepared at higher mixing tank concentrations settled at atypically high rates, even after subsequent dilution. Figures 7.6-1 and 7.6-2 in TR WCAP-16530-NP show the effect of mixing tank concentration on the settling rates of aluminum oxyhydroxide and calcium phosphate, respectively. The results shown in these figures, that high concentrations favor formation of precipitate with faster settling properties, is consistent with earlier test observations concerning precipitate concentration effects on settling properties at ANL (NUREG/CR-6913). Therefore, TR WCAP-16530-NP states that the maximum concentrations of aluminum oxyhydroxide and sodium aluminum silicate in the mix tank should not exceed 11 grams per liter. The maximum mix tank concentration for the calcium phosphate precipitate should not exceed 5 grams per liter.

In addition to the mixing tank concentration limits, TR WCAP-16530-NP provides maximum acceptable 1-hour precipitate settlement values to preclude atypical settling of the surrogate precipitate. The acceptable precipitate 1-hour settled volume criteria, shown in Table 7.8-1 of the TR, is greater than 4 ml for all three surrogate precipitates. In other words, when starting

with a 10 ml volume of cloudy surrogate precipitate, greater than 4 ml of solution should remain cloudy after one hour. Although the NRC staff understands that precipitate will settle slower during screen vendor testing due to bulk directional flow, the NRC staff questioned if the above settling criteria were adequate given the observations of slow precipitate settling reported in Table 5.3-1 in the topical report. The NRC staff position on acceptable precipitate settling criteria is discussed in Section 3.8 of this SE.

The NRC staff questioned whether the 1-hour settled volume criterion was sufficient for two reasons. First, a batch of aluminum oxyhydroxide prepared for head loss testing displayed a distinct change in properties over time even though the 1-hour settlement values met the acceptance criteria. Second, a modified strainer head loss testing approach, with the objective of settling all debris including chemical precipitate, was proposed by some licensees. This test approach is very different from an approach that intentionally uses agitation to keep chemical precipitate suspended to ensure it reaches the test strainer.

To address this shortcoming, the NRC staff reviewed the results from precipitate settling in the TR WCAP-16530-NP, specifically Figures 7.6-1 and 7.6-2 and Table 5.3-1, and results from other settling tests at ANL. The NRC staff also included a time-dependent criterion for settlement testing relative to head loss testing to preclude precipitate aging from significantly changing the surrogate precipitate properties before it is used. The NRC staff finds the following proposed modification (ADAMS Accession No. ML072570680) to the settling rates in TR WCAP-16530-NP to be acceptable:

1. For head loss tests in which the objective is to keep chemical precipitate suspended (e.g., by tank agitation):

Sodium aluminum silicate and aluminum oxyhydroxide precipitate settling shall be measured within 24 hours of the time the surrogate will be used and the 1-hour settled volume (for an initial 10 ml solution volume) shall be 6 ml or greater and within 1.5 ml of the freshly prepared surrogate. Calcium phosphate precipitate settling shall be measured within 24 hours of the time the surrogate will be used and the 1-hour settled volume shall be 5 ml or greater and within 1.5 ml of the freshly prepared surrogate. Testing shall be conducted such that the surrogate precipitate is introduced in a way to ensure transport of all material to the test screen.

2. For head loss testing in which the objective is to settle chemical precipitate and other debris:

Aluminum-containing surrogate precipitate that settles equal to or less than the 2.2 g/l concentration line shown in Figure 7.6-1 of WCAP-16530-NP (i.e., 1-hour or 2-hour settlement data on or above the line) is acceptable. The settling rate should be measured within 24 hours of the time the surrogate precipitate will be used.

For testing that was performed prior to the time the PWROG notified licensees of a revised precipitate settlement acceptance criteria, licensees should evaluate the precipitate settlement of these tests considering the observations provided in the response to NRC comment 7 provided in PWROG letter dated September 12, 2007 (ADAMS Accession No. ML072570680).

3.7 NRC-Sponsored Confirmatory Testing

During the NRC staff's review of TR WCAP-16530-NP, the NRC staff determined that some confirmatory testing was necessary in order to independently assess certain aspects of TR WCAP-16530-NP. In general, the NRC staff was interested in: (1) supplementary and confirmatory dissolution and precipitation experiments for insulation materials and concrete, and (2) testing to evaluate the properties of surrogate precipitates prepared using the instructions provided for the particulate generator in the TR. Therefore, the NRC staff sponsored additional dissolution and precipitation testing at the Southwest Research Institute (SwRI). In addition, the NRC sponsored bench testing and head loss testing of TR WCAP-16530-NP chemical surrogate at ANL.

The main purpose of the supplementary leaching studies performed at SwRI was to examine the validity of the assumption in the TR that various non-metallic materials in the same class would exhibit similar dissolution characteristics. A secondary objective was to characterize any precipitate that formed. For the SwRI tests, five materials that had not been tested by the PWROG were selected from various insulation classes to determine if the material tested by the PWROG was representative of other materials in the same class. The SwRI test matrix included E-glass materials (fiberglass, Alpha-Mat™, Temp-Mat A™), amorphous silica (Microtherm™), calcium silicate (Marinite™), and aluminum silicate (Kaowool™). The test conditions were selected by focusing on the test conditions that had provided the most concentrated leachate solutions for each material class. Since the testing apparatus and procedures were similar but not identical to that used for the topical report tests, some previously tested materials (calcium silicate, Fiber Frax™, Durablanket™, and concrete) were also included to allow comparison between the TR test results and the SwRI test results. Details of the test conditions and the test results are provided in a SwRI letter report, "Supplementary Leaching Tests of Insulation and Concrete for GSI-191 Chemical Effects Program" (ADAMS Accession No. ML063330573).

For leaching tests with similar times, temperatures, and pH, the concentration of elements in the SwRI leaching tests were similar to or less than the concentrations from the TR tests. With the exception of calcium silicate in certain test conditions, SwRI tests of the same insulation resulted in lower elemental concentrations in solution compared to the TR tests. Significantly less silicon leached from the fiberglass samples during the SwRI tests. The amount of calcium leached from concrete was also lower in the SwRI tests, which was expected since the SwRI tests used a concrete coupon with a scaled surface area representing the upper plant bound for uncoated concrete. The TR WCAP-16530-NP tests used an amount of crushed concrete that exceeded plant levels (see Section 3.2 of this evaluation).

No precipitates were observed to settle in any of the SwRI tests even when using the same materials and same test conditions that produced precipitates in the TR WCAP-16530-NP tests. Although the test conditions were similar, there were a few differences between the SwRI and the TR test techniques that could have affected the results. For instance, the SwRI test solutions were cooled over a 2-hour period during which time the test material remained in contact with the test solution. In contrast, the TR test solution was immediately filtered and transferred to the precipitation settling cones in the cooling water bath at the completion of the dissolution test period. Therefore, the SwRI test materials remained in contact with solution for a significantly longer period, and the SwRI test solution was cooled at a significantly slower rate compared to the TR test solution. The longer time for dissolution in the SwRI tests would promote greater dissolution. This is offset by the greater agitation for the TR tests, where the individual reaction vessels were placed on a rocking platform in the test oven. The slower

cooling rates in the SwRI tests would be more similar to the fluid cooling of the containment sump pool following a LOCA. The more rapid cooling in the TR tests may be more similar to cooling that would occur as fluid from the sump passes through a residual heat removal (RHR) heat exchanger. The TR test solution cooling would not be prototypical of cooling in an ECCS system, however, since fluid that passes from the sump through a RHR heat exchanger would be reheated as it passes into the reactor vessel or spills out a break and returns to the post-LOCA pool on the containment floor. This effect would increase the solubility of some precipitates since reheating may cause the precipitates to go back into solution.

Overall, results from the SwRI dissolution and precipitation tests did not contradict the TR WCAP-16530-NP assumptions concerning leaching from representative materials in different classes. In addition, no precipitates were formed with the new test materials. Therefore, the NRC staff finds the TR classification of materials and the selection of representative test materials to be acceptable.

While the NRC-sponsored tests at SwRI were intended to verify some of the TR assumptions related to representative materials and to repeat some of the dissolution and precipitation tests, the goal of NRC-sponsored tests at ANL was to evaluate the surrogate chemical precipitate prepared using the instructions in the TR. Tests at ANL included bench testing to study the TR precipitate characteristics and vertical loop head loss testing to evaluate the head loss properties of the precipitate (see ANL Technical Letter Report, ADAMS Accession No. ML070580086). These tests focused on the aluminum oxyhydroxide and sodium aluminum silicate precipitates since these are the predominant precipitates predicted by the TR chemical model and ANL had previously performed extensive testing with the calcium phosphate precipitate, as reported in NUREG/CR-6913.

The TR procedure for preparing surrogate chemical precipitate recognizes that the precipitate concentration in the mixing tank will affect the size and settling properties of the precipitate. Therefore, the procedure limits the maximum concentration of the mixing tank and provides criteria for acceptable one-hour settling volumes. ANL evaluated precipitates prepared according to the TR instructions and also prepared precipitates by deviating from the TR guidelines to evaluate the potential effects on the precipitate properties. Overall, the TR precipitate preparation specifications seem effective at producing fine precipitate that is most probably finely crystalline, although no clear diffraction pattern was obtained due to the small particle size. Bench testing also showed that precipitate settling rates were slower for aluminum oxyhydroxide precipitate produced according to the TR directions. X-ray diffraction of the precipitates prepared outside the bounds of the TR instructions indicated a crystalline structure (bayerite). This precipitate, however, did not meet the TR settlement acceptance criteria.

ANL also conducted vertical head loss loop tests of the aluminum oxyhydroxide and sodium aluminum silicate precipitates to evaluate their filterability. The NRC staff was interested in evaluating the relative filterability of these two precipitates since the TR chemical model predictions assume, based on thermodynamic equilibrium predictions, that sodium aluminum silicate precipitate will form before aluminum oxyhydroxide precipitate if sufficient silicate is present. Although the chemical model conservatively assumes that all aluminum in solution precipitates, based on the information provided in the TR, the NRC staff was not able to conclude that the model predictions for the relative amounts of aluminum oxyhydroxide and sodium aluminum silicate that form are accurate. Therefore, the NRC staff sponsored head loss testing at ANL to compare the relative filterability of sodium aluminum silicate and aluminum oxyhydroxide precipitates.

In these tests, a standard fiberglass debris bed was formed using NUKON fiberglass fibers that had been shredded and processed in a blender to produce individual fibers. A fiberglass debris bed was formed and a baseline pressure drop was measured before addition of surrogate precipitate. The first test used the TR aluminum oxyhydroxide precipitate in an amount equivalent to what would be produced if 5 parts per million (ppm) of dissolved aluminum from the 119-liter vertical head loss loop volume were to transform into precipitate. This amount of TR precipitate resulted in a rapid increase in pressure drop across the fiber-covered screen, and the pressure drop capacity of the test loop was exhausted almost immediately.

Given the rapid increase in pressure drop with the initial test of the TR aluminum oxyhydroxide precipitate, an additional head loss test with this precipitate was performed using smaller incremental additions, equivalent to 0.5 ppm of dissolved aluminum in the test loop transforming into precipitate. Using these reduced precipitate additions, the system's pressure drop capacity was exceeded with a total addition equivalent to 1.5 ppm of dissolved aluminum in the loop transforming to precipitate.

ANL also performed vertical loop head loss testing with the TR sodium aluminum silicate precipitate. An initial head loss test in deionized water revealed that the sodium aluminum silicate precipitate was dissolving over time. Small additions of precipitate would produce an initial increase in pressure drop comparable to the aluminum oxyhydroxide precipitate, however, the pressure drop would decrease over time. After adding an amount of aluminum equivalent to 5 ppm of dissolved aluminum in the vertical loop transforming into sodium aluminum silicate precipitate, the head loss was near the loop capacity but still exhibited the pressure drop decay behavior over time. Subsequent bench testing with deionized and potable water indicated that approximately 2 ppm of sodium aluminum silicate dissolves in deionized water and that the pH of deionized water becomes more alkaline compared to potable water for a given amount of sodium aluminum silicate addition. Therefore, if deionized water were to be used for strainer head loss testing, the solubility of sodium aluminum silicate shall be accounted for when determining the appropriate amount to be added to the test.

Since strainer vendors that add TR surrogate precipitate to larger scale integrated head loss tests use potable water, not deionized water, a second sodium aluminum silicate head loss test was conducted with potable water in the vertical head loss test loop. With potable water, the system's pressure drop capacity was exceeded with a total sodium aluminum silicate addition equivalent to 2.2 ppm of dissolved aluminum in the loop transforming to precipitate. In addition, the pressure drop across the debris bed remained stable for greater than 10 hours after an equivalent 2 ppm of dissolved aluminum as sodium aluminum silicate was introduced. Although there were some small differences in the vertical loop head loss test results, the vertical loop test results indicate that small quantities of both these TR surrogate precipitates are effective at causing significant pressure drop across a fiber bed.

3.8 Overall Staff Technical Evaluation

There are a number of different technical issues embedded within the TR WCAP-16530-NP methodology. In this section, the NRC staff discusses important technical issues and provides an overall staff evaluation of TR WCAP-16530-NP.

Role of RCS Oxides

One of the potential material source terms that was judged to be insignificant in TR WCAP-16530-NP is potential reactor coolant system (RCS) oxides released during a LOCA. In letters dated October 4, 2006, and March 23, 2007 (ADAMS Accession Nos. ML062440433 and ML070810208), the NRC staff requested additional information from the PWROG related to the amount of RCS oxides that could be released during a LOCA and the potential effects of these oxides on chemical effects. In letters dated November 21, 2006, April 3, 2007, and September 12, 2007 (ADAMS Accession Nos. ML063390128, ML070950119, and ML072570680), the PWROG provided information supporting its conclusion that the amount of crud released during a LOCA would be insignificant compared to the other debris that is included in strainer head loss testing. Based on the additional information provided in the RAI responses, conservatism in other parts of the chemical model (e.g., all aluminum in solution precipitates), and considering the amounts of other particulate debris included in strainer testing, the NRC staff finds that the amounts and effects of RCS oxides can be considered insignificant for strainer head loss testing. Therefore, the NRC staff concludes that it is acceptable that RCS oxides are not included in the TR WCAP-16530-NP head loss testing source term.

Aluminum Release Rates

Corrosion of aluminum resulted in the greatest mass released during the TR WCAP-16530-NP dissolution tests. Therefore, the aluminum release rate incorporated into the chemical model is important. The aluminum release rate was determined by considering a number of test results, including the ICET series. The fit to the ICET data is based on an average 30-day aluminum corrosion rate, but measurement of aluminum in solution during the ICET 1 test indicated an active phase of aluminum corrosion during the initial half of the test followed by aluminum passivation during the second half of the test. By using an averaged value, the TR chemical model release rate under-predicts aluminum release by about a factor of 2 for the active corrosion part of ICET 1. The NRC staff finds this acceptable since licensees using the TR WCAP-16530-NP surrogate precipitate typically add the amount predicted for a 30-day mission time while using a first-day pump net positive suction head (NPSH) margin acceptance criteria. If a licensee performs strainer head loss tests with TR WCAP-16530-NP surrogate precipitate and applies a time-based pump NPSH margin acceptance criteria (i.e., timed precipitate additions based on TR model predictions), the NRC staff expects the licensee to use an aluminum release rate that does not under-predict the aluminum concentrations during the initial 15 days of ICET 1. In this case, aluminum passivation may be considered during the latter parts of the ECCS mission time.

Identification of Precipitate Types

Amorphous, hydrated precipitates, such as those that formed in ICET and those that appeared to form in the TR WCAP-16530-NP tests, are difficult to characterize. Some of these precipitates, such as the aluminum hydroxide type precipitates, may initially form as an amorphous material and then change into a crystalline structure over time as a result of an aging process. The EDS technique used to analyze the precipitates that formed during the TR WCAP-16530-NP tests is not definitive, and the EDS analysis was not sensitive to either boron or carbon that may have been contained in the precipitate. The NRC staff notes that TR WCAP-16530-NP aluminum oxyhydroxide surrogate

precipitate is prepared by adding aluminum nitrate to water followed by sodium hydroxide. This results in formation of precipitate at a lower pH compared to a post-LOCA environment where this type of precipitate would most probably form after the pH was greater than 7. The NRC staff cannot conclude that the TR WCAP-16530-NP surrogate precipitates are identical to those that formed in ICET and in the TR tests, because of (1) the limitations in the EDS technique used to identify the TR WCAP-16530-NP precipitates, (2) the fact that prediction of sodium aluminum silicate precipitate formation in the TR is somewhat based on thermodynamic calculations, and (3) the surrogate precipitate preparation sequence that adds aluminum nitrate before adjusting the pH with sodium hydroxide. Nevertheless, the technical approach used in the TR WCAP-16530-NP does not rely on making the exact precipitates that formed during testing but rather surrogate precipitates that have representative properties such as precipitate settlement and filterability. Therefore, the NRC staff review focused on determining if the predicted types, filterability, and amount of surrogate precipitates were either representative or conservative when compared to those precipitates that may form in the post-LOCA plant environment. Based on its review, the NRC staff concludes that the surrogate precipitate that is prepared in accordance with the TR WCAP-16530-NP directions provides adequate settlement and filterability characteristics to represent post-LOCA chemical precipitates in strainer head loss tests.

Amount of Precipitate

With respect to the total amount of precipitate, TR WCAP-16530-NP assumes all dissolved calcium, in the presence of phosphate, and all dissolved aluminum form precipitates. This is a reasonable assumption for calcium dissolved in a TSP-buffered solution, since a calcium phosphate precipitate forms and calcium, not phosphate, is expected to be the limiting reactant. The assumption that all dissolved aluminum forms a precipitate is clearly a conservative assumption when compared to literature values and measured values of dissolved aluminum in alkaline, borated test solutions at LANL and ANL. The solubility of aluminum is dependent on the temperature and the pH of the sump pool following a LOCA. One indication that not all dissolved aluminum precipitates is shown by the room temperature (49 mg/L) concentration of aluminum in the ICET 1 test fluid supernate four months after the completion of the test. However, this value should not be assumed to be a solubility limit since sub-micron suspended aluminum hydroxide particles that are not visible have been shown to cause head loss in tests at ANL. The NRC staff concludes that the chemical model prediction on the total amount of precipitate, i.e., that all dissolved aluminum precipitates, is acceptable since this results in a conservative amount of precipitate.

Single Effects vs. Multiple Material Tests

Dissolution and precipitation evaluations in the TR WCAP-16530-NP are based mostly on single-effects testing. Although single-effects testing complements the ICET tests and may produce conservative amounts of dissolved materials in some instances, this testing approach could miss some important combined effects from multiple materials. Combined effects may or may not be conservative relative to projections from separate effects testing. For example, silicates are known to inhibit aluminum corrosion. The chemical model in TR WCAP-16530-NP may significantly over-predict the amount of silica released from fiberglass since the TR WCAP-16530-NP tests did not consider the potential effects of dissolved aluminum inhibiting leaching of silica from fiberglass.

Therefore, TR WCAP-16530-NP may be conservative in some plant-specific environments with respect to the amount of silica leaching from fiberglass, but non-conservative if the predicted pool silica levels are then used in an attempt to credit passivation of aluminum. Although single effects testing results in greater uncertainty compared to integrated testing, the NRC staff finds this acceptable since other conservative assumptions in the chemical model offset uncertainties associated with single effects tests. Examples of those assumptions include: (1) all aluminum that goes into solution forms a precipitate, (2) the topical report takes no credit for phosphate inhibition of aluminum corrosion in TSP environments, and (3) the topical report takes no credit for inhibition of aluminum corrosion by silicates. In addition, test results from the ICET series and some limited long-term tests with representative post-LOCA temperatures and pH values have shown that the TR WCAP-16530-NP chemical model does not under-predict chemical precipitates.

Form of Aluminum Precipitates

TR WCAP-16530-NP surrogate precipitate composition is based on "best estimate" analysis of precipitate formed during bench testing. As previously mentioned in Section 3.6 of this SE, the NRC staff questioned the model's ability to accurately predict the relative amounts of aluminum oxyhydroxide and sodium aluminum silicate precipitates that could form in a plant-specific environment. The NRC-sponsored head loss tests at ANL were designed to compare the head loss test results of aluminum precipitating as an aluminum hydroxide to aluminum precipitating as a sodium aluminum silicate. The tests at ANL confirmed that small quantities of each TR surrogate precipitate produced significant pressure drop across a Nukon fiber bed. Therefore, even though the NRC staff cannot conclude that the model predictions for relative amounts of aluminum hydroxide and sodium aluminum silicate are accurate, the ANL tests have shown that the effects of the two surrogate precipitates are similar. Therefore, the NRC staff finds the TR WCAP-16530-NP predicted amount of precipitate to be acceptable since all aluminum is assumed to precipitate and small quantities of each precipitate are effective at producing significant head loss across a fiber bed.

Precipitate Settlement Criteria

Precipitate settlement is another important surrogate precipitate characteristic that was reviewed by the NRC staff. Precipitate that formed during cooling of ICET solutions and during the TR WCAP-16530-NP bench tests was observed to settle slowly. During the surrogate precipitate development stage, TR WCAP-16530-NP tests showed that the surrogate precipitate mixing tank concentration affected the settling properties. Therefore, TR WCAP-16530-NP recommends a maximum mixing concentration to achieve reasonably prototypical settling behavior. In addition, TR WCAP-16530-NP provides criteria for physical characteristics of acceptable surrogate precipitates, including criteria for a 1-hour settled volume. As a condition on the use of this TR, licensees must implement the additional settlement criteria described in response to NRC comment 7 of the September 12, 2007 letter (ADAMS Accession ML072570680), for proper use of the surrogate precipitate materials. These criteria are provided in Section 4.0 of this SE.

Based on the considerations above, although there are uncertainties associated with the actual formation of chemical products in a post-LOCA plant environment, the NRC staff finds the

overall technical approach in TR WCAP-16530-NP to be acceptable for plant-specific chemical effect evaluations since this approach predicts a conservative amount of chemical precipitate and the surrogate precipitate filterability is either representative or conservative compared to precipitate that may be expected to form in a post-LOCA environment.

4.0 LIMITATIONS AND CONDITIONS

1. A peer review of NRC-sponsored chemical effects testing was performed and a number of technical issues related to GSI-191 chemical effects were raised by the independent peer review panel members (NUREG-1861). The peer review panel and the NRC staff developed a PIRT of technical issues identified by the peer review panel. The NRC staff is working to resolve the technical issues identified in the PIRT. Part of the resolution process includes NRC-sponsored analyses being performed by PNNL. Although the NRC staff has not developed any information related to the PIRT issues resolution that would alter the conclusions of this evaluation, some issues raised by the peer review panel were not completely resolved at the time this evaluation was written. An example of such an issue is the potential influences of organic materials on chemical effects. Therefore, it is possible that additional analysis or other results obtained during the resolution of the remaining peer review panel issues could affect the conclusions in this evaluation. In that event, the NRC staff may modify the SE or take other actions as necessary.
2. This evaluation does not address TR WCAP-16785-NP, "Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model." The NRC staff will provide comments on WCAP-16785-NP separate from this evaluation. In addition, a separate SE will address a related TR, WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." Chemical effects in the reactor vessel are not addressed in WCAP-16530-NP or in this SE. Therefore, the approval of this TR does not extend to chemical effects in the reactor vessels.
3. If a licensee performs strainer head loss tests with surrogate precipitate and applies a time-based pump NPSH margin acceptance criteria (i.e., timed precipitate additions based on topical report model predictions), they must use an aluminum release rate that does not under-predict the initial 15 day aluminum concentrations in ICET 1, although aluminum passivation can be considered during the latter parts of the ECCS mission time in this case.
4. For head loss tests in which the objective is to keep chemical precipitate suspended (e.g., by tank agitation):

Sodium aluminum silicate and aluminum oxyhydroxide precipitate settling shall be measured within 24 hours of the time the surrogate will be used and the 1-hour settled volume shall be 6 ml or greater and within 1.5 ml of the freshly prepared surrogate. Calcium phosphate precipitate settling shall be measured within 24 hours of the time the surrogate will be used and the 1 hour settled volume shall be 5 ml or greater and within 1.5 ml of the freshly prepared surrogate. Testing shall be conducted such that the surrogate precipitate is introduced in a way to ensure transportation of all material to the test screen.

5. For head loss testing in which the objective is to settle chemical precipitate and other debris:

Aluminum containing surrogate precipitate that settles equal to or less than the 2.2 g/l concentration line shown in Figure 7.6-1 of WCAP-16530-NP (i.e., 1-or 2-hour settlement data on or above the line) is acceptable. The settling rate shall be measured within 24 hours of the time the surrogate precipitate will be used.

6. For strainer head loss testing that uses TR WCAP-16530-NP sodium aluminum silicate and is performed in a de-ionized water environment, the total amount of sodium aluminum silicate added to the test shall account for the solubility of sodium aluminum silicate in this environment.

5.0 CONCLUSION

The NRC staff has reviewed WCAP-16530-NP and the supplemental information that was transmitted by letters dated November 21, 2006, April 3, 2007, and September 12, 2007, and has found that the TR, as modified and clarified to incorporate the NRC staff's recommendations, and subject to the conditions and limitations in Section 4.0 of this SE, provides an acceptable technical justification for the evaluation of plant specific chemical effects related to GSI-191. The supplemental information that was provided in response to the NRC staff's RAIs shall be incorporated into the approved version of TR WCAP-16530-NP. In addition, where this SE states that a change to the TR is needed, such changes shall also be incorporated in the approved version.

6.0 REFERENCES

1. PWROG Letter WOG-06-113, "Submittal of WCAP-16530-NP, 'Evaluation of Post Accident Chemical Effects in Containment Sump Fluids to Support GSI-191' for Formal Review," dated March 27, 2006 (ADAMS Accession No. ML060890506).
2. WCAP-16530-NP, Revision 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," dated February 2006 (ADAMS Accession No. ML060890509).
3. NRC Letter to PWR Owners Group, "Request For Additional Information Re: Westinghouse Owners Group Topical Report WCAP-16530-NP, Evaluation of Post Accident Chemical Effects in Containment Sump Fluids To Support GSI-191," dated October 4, 2006 (ADAMS Accession No. ML062440433).
4. PWROG Letter OG-06-387, "Responses to NRC Request For Additional Information (RAI) on WCAP-16530, 'Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191,'" dated November 21, 2006 (ADAMS Accession No. ML063390128).
5. NRC Letter to PWR Owners Group, "Request For Additional Information Re: Westinghouse Owners Group Topical Report WCAP-16530-NP, Evaluation of Post Accident Chemical Effects in Containment Sump Fluids To Support GSI-191," dated March 23, 2007 (ADAMS Accession No. ML070810208).

6. PWROG Letter OG-07-129, "Responses to the Second Set of NRC Requests For Additional Information (RAI) on WCAP-16530, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," dated April 3, 2007 (ADAMS Accession No. ML070950119).
7. PWROG Letter OG-07-408, "Responses to NRC Requests For Clarification Regarding WCAP-16530, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," (PA-SEE-0275), dated September 12, 2007 (ADAMS Accession No. ML072570680).
8. Los Alamos National Laboratory Report LA-UR-03-6415, "Small Scale Experiments: Effects Of Chemical Reactions On Debris Bed Head Loss," dated November 2003 (ADAMS Accession No. ML0033230260).
9. NUREG/CR-6914, "Integrated Chemical Effects Test Project: Consolidated Data Report," dated December 2006 (ADAMS Accession No. ML071800338).
10. NUREG/CR-6915, "Aluminum Chemistry in a Prototypical Post-Loss-Of-Coolant-Accident Pressurized Water Reactor Containment Environment, dated December 2006 (ADAMS Accession No. ML070160448).
11. NUREG/CR-6913, "Chemical Effects Head-Loss Research in Support of Generic Safety Issue 191," dated December 2006 (ADAMS Accession No. ML070090553).
12. NUREG-1861, "Peer Review of GSI-191 Chemical Effects Research Program," dated December 2006 (Accession No. ML063630498).
13. Southwest Research Institute Letter Report IM20.12130.01.001, "Supplementary Leaching Tests of Insulation and Concrete For GSI-191 Chemical Effects Program," dated November 2006 (ADAMS Accession No. ML063330573).
14. Argonne National Laboratory Technical Letter Report "Follow-On Studies in Chemical Effects Head Loss Research; Studies of WCAP Surrogate and Sodium Tetraborate Solutions," dated February 15, 2007 (ADAMS Accession No. ML070580086)

Principle Contributor: Paul Klein

Date: December 21, 2007