

November 21, 2007

Mr. Gordon Bischoff, Manager
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P.O. Box 355
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SUBJECT: DRAFT SAFETY EVALUATION FOR PRESSURIZED WATER REACTOR
OWNERS GROUP (PWROG) TOPICAL REPORT (TR) WCAP-16530-NP,
"EVALUATION OF POST-ACCIDENT CHEMICAL EFFECTS IN CONTAINMENT
SUMP FLUIDS TO SUPPORT GSI-191" (TAC NO. MD1119)

Dear Mr. Bischoff:

By letter dated March 27, 2006, as supplemented by letters dated November 21, 2006, April 3, 2007, and September 12, 2007, the PWROG submitted TR WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI [Generic Safety Issue]-191," to the U.S. Nuclear Regulatory Commission (NRC) staff for review. Enclosed for PWROG review and comment is a copy of the NRC staff's draft safety evaluation (SE) for the TR.

Twenty working days are provided to you to comment on any factual errors or clarity concerns contained in the SE. The final SE will be issued after making any necessary changes and will be made publicly available. The NRC staff's disposition of your comments on the draft SE will be discussed in the final SE.

To facilitate the NRC staff's review of your comments, please provide a marked-up copy of the draft SE showing proposed changes and provide a summary table of the proposed changes.

If you have any questions, please contact Sean E. Peters at 301-415-1842.

Sincerely,

/RA/

Stacey L. Rosenberg, Chief
Special Projects Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Draft SE

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DRAFT 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

1 testing was performed to demonstrate a progression from initial exposure of metal samples to
2 formation of chemical interaction precipitation products. In addition, the test conditions were not
3 intended to be prototypical of a PWR environment after a LOCA. Therefore, a more
4 comprehensive test program was initiated to assess potential chemical effects in a more
5 representative test environment.
6

7 An integrated chemical effects test (ICET) program was developed through a collaborative effort
8 between the NRC staff and representatives of the nuclear industry. The test objective was to
9 characterize any chemical reaction products, including possible gelatinous material that may
10 develop in a representative post-LOCA PWR containment sump environment. Test conditions
11 such as pH, temperature, and boron concentration were selected to simulate representative, but
12 not necessarily bounding, plant conditions. The ICET series was conducted by the LANL at the
13 University of New Mexico. Materials included in the ICET series included zinc (galvanized steel
14 and inorganic zinc coatings), aluminum, copper, carbon steel, concrete, fiberglass, and calcium
15 silicate insulation. Representative amounts of concrete powder, sand, and clay were also added
16 to simulate latent debris in the containment building. Relative amounts of test materials were
17 scaled according to plant data provided by the industry that were based on responses to a plant
18 survey. Test coupons were either fully immersed or were placed above the test loop water line
19 but subjected to a tank spray to simulate exposure to containment spray. The relative
20 distributions of each material were determined based on plant estimated percentages of
21 submerged material and material subjected to containment sprays following a LOCA.
22

23 Results from the ICET series, available in Volumes 1 to 6 of NUREG/CR-6914,
24 "Integrated Chemical Effects Test Project" (ADAMS Accession No. ML071800338), indicated
25 that chemical precipitates may form in representative environments. In particular, highly
26 hydrated aluminum hydroxide and calcium phosphate precipitates were observed to form with
27 specific combinations of plant materials and environments. The exact nature of the hydrated
28 precipitates was difficult to characterize. Additional evaluations of aluminum hydroxide (ICET 1)
29 type precipitates are provided in NUREG/CR-6915, "Aluminum Chemistry in a Prototypical
30 Post-Loss-Of-Coolant-Accident Pressurized Water Reactor Containment Environment" (ADAMS
31 Accession No. ML070160448).
32

33 Since evaluating head loss across a debris bed due to chemical precipitates was outside the
34 scope of the ICET series, the NRC subsequently sponsored a head loss test program at the
35 Argonne National Laboratory (ANL) to evaluate head loss effects from precipitates observed
36 during the ICET tests. NUREG/CR-6913, "Chemical Effects Head-Loss Research in Support of
37 Generic Safety Issue 191" (ADAMS Accession No. ML070090553), summarizes the results of
38 vertical loop head loss testing and bench testing. The vertical loop head loss test results at ANL
39 showed that some of the ICET chemical products can produce significant pressure drops across
40 a fiber bed on a flat plate test section.
41

42 A peer review of NRC-sponsored chemical effects testing was performed following the ICET
43 tests and during the time head loss testing was being performed at ANL. Five independent peer
44 review panel members with a diverse set of expertise raised a number of technical issues
45 related to GSI-191 chemical effects. These issues are documented in NUREG-1861, "Peer
46 Review of GSI-191 Chemical Effects Research Program" (ADAMS Accession No.
47 ML063630498). The peer review panel and the NRC staff developed a phenomena
48 identification and ranking table (PIRT) of technical issues identified by the peer review panel.

1 The NRC staff is working to resolve those issues identified in the PIRT. Part of the resolution
2 process includes NRC-sponsored analyses being performed by Pacific Northwest National
3 Laboratory.

4
5 The testing and chemical models contained within TR WCAP-16530-NP are intended to provide
6 PWR plants a methodology to perform plant-specific chemical effects evaluations. The TR
7 WCAP-16530-NP tests were performed at higher temperatures and for shorter durations
8 compared to ICET. Additional plant materials were included in the tests described in
9 TR WCAP-16530-NP.

10
11 TR WCAP-16530-NP is organized into the following sections:

- 12
13 • Report Overview - discusses the purpose of the TR and provides a summary of the
14 various report sections.
- 15
16 • Introduction - presents the background of the chemical effects issue, discusses the
17 ICET program, and discusses the objective of the PWROG chemical effects testing in
18 relation to ICET.
- 19
20 • Containment Materials - provides the results of PWR plant containment material
21 surveys, classifies the plant materials into 5 metallic and 10 non-metallic materials, and
22 describes the material classes.
- 23
24 • Test Plan - explains the bench testing purpose and approach, and provides the plans
25 for dissolution testing and precipitation testing.
- 26
27 • Bench Testing - documents the bench testing performed including the functional
28 requirements, test procedures, materials tested, and the results from the dissolution
29 tests and precipitation tests.
- 30
31 • Chemical Model - presents the chemical model developed from the results of the bench
32 testing. The chemical model is contained in a spreadsheet that predicts the type and
33 amount of material that dissolves based on material concentrations and chemical
34 reactions in the environment. The model also predicts the quantity and type of
35 precipitate that forms and is intended for use to determine the amount of plant-specific
36 precipitate that may form in a post-accident environment.
- 37
38 • Particulate Generator - describes the qualification testing performed on chemical
39 precipitate that is intended to represent the precipitate performed during bench testing.
40 This section also provides directions for making the surrogate chemical precipitate that
41 may be used during subsequent strainer head loss testing.
- 42
43 • Plant-Specific Application - provides the link between the TR WCAP-16530-NP tests
44 and strainer vendor testing using plant-specific debris, including chemical precipitates.
45 This section also provides guidance for plant-specific application of the chemical model
46 contained in the TR.

47
48 The NRC staff's evaluation for each of these sections is contained in Section 3.0 of this SE.
49
50

1 2.0 REGULATORY EVALUATION

2
3 The NRC regulations in Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.46,
4 require that the ECCS has the capability to provide long-term cooling of the reactor core
5 following a LOCA. That is, the ECCS must be able to remove decay heat so that the core
6 temperature is maintained at an acceptably low value for the extended period of time required by
7 the long-lived radioactivity remaining in the core.

8
9 Similarly, for PWRs licensed to the General Design Criteria (GDCs) in Appendix A to 10 CFR
10 Part 50, GDC-38 provides requirements for containment heat removal systems, and GDC-41
11 provides requirements for containment atmosphere cleanup. Many PWR licensees credit a
12 containment spray system (CSS), at least in part, with performing the safety functions to satisfy
13 these requirements, and PWRs that are not licensed to the GDCs may similarly credit a CSS to
14 satisfy related licensing basis requirements. In addition, PWR licensees may credit a CSS with
15 reducing the accident source term to meet the limits of 10 CFR Part 100 or 10 CFR 50.67.
16 GDC-35 is referenced in 10 CFR 50.46(d) and specifies additional ECCS requirements. PWRs
17 that are not licensed to the GDCs typically have similar requirements in their licensing basis.

18
19 The NRC staff's evaluation of post-accident chemical effects and TR WCAP-16530-NP is
20 developed within the context of resolution of GSI-191, "Assessment of Debris Accumulation on
21 PWR Sump Performance." In order to resolve GSI-191, the NRC staff needs to have
22 reasonable assurance that post-accident debris blockage will not impede or prevent the
23 operation of the ECCS and CSS in recirculation mode at PWRs during LOCAs or other high-
24 energy line break accidents for which sump recirculation is required. Following the completion of
25 a technical assessment of GSI-191, the NRC staff issued Bulletin 2003-01, "Potential Impact of
26 Debris Blockage on Emergency Recirculation During Design-Basis Accidents at Pressurized-
27 Water Reactors," on June 9, 2003. As a result of the emergent issues discussed therein, the
28 bulletin requested an expedited response from PWR licensees on the status of their compliance,
29 on a mechanistic basis, with regulatory requirements concerning the ECCS and CSS
30 recirculation functions. Licensees who chose not to confirm regulatory compliance were asked
31 to describe interim compensatory measures that have been implemented to reduce risk until the
32 analysis could be completed.

33
34 In developing Bulletin 2003-01, the NRC staff recognized that it might be necessary for licensees
35 to undertake complex evaluations to determine whether regulatory compliance exists in light of
36 the concerns identified in the bulletin and that the methodology needed to perform these
37 evaluations was not currently available. As a result, that information was not requested in the
38 bulletin, but licensees were informed that the NRC staff was preparing a generic letter that would
39 request this information. The information was subsequently requested in GL 2004-02, "Potential
40 Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents At
41 Pressurized-Water Reactors" issued on September 13, 2004, included, in part, the maximum
42 head loss postulated from debris accumulation on the submerged sump screen, including debris
43 created by chemical precipitates that may form due to chemical reactions in the post-LOCA
44 environment.

45
46 The NRC staff reviewed TR WCAP-16530-NP to determine whether it will provide an acceptable
47 technical justification for the evaluation of plant-specific chemical effects, as part of the
48 evaluations licensees are conducting to address GSI-191 concerns and to support supplemental
49 responses to GL 2004-02.

50

1 3.0 TECHNICAL EVALUATION

2
3 3.1 Containment Materials

4
5 This section of TR WCAP-16530-NP provides a compilation of containment materials based on
6 a survey of all 69 U.S. PWRs. This data formed the basis for selection of representative test
7 materials and their amounts for the bench tests. Ratios of plant material to water volume were
8 determined using the maximum amount of material and minimum water volume for each plant.
9 Plant materials from the survey were grouped based on composition into 10 non-metallic and
10 5 metallic material classes. Based on results from ICET indicating no significant interactions
11 with the environment (e.g., copper) or an analysis showing the amount of material in
12 containment would be insignificant (e.g., organics), no tests were performed on 5 material
13 classes. Materials were then selected from each material class for bench testing. Historical
14 data, ICET results, and chemical similarity of the different insulation brands were used to select
15 representative non-metallic (mineral wool, Interam, Durablanket, Nukon Fiberglass, MIN-K,
16 Temp-Mat high density fiberglass, calcium silicate, concrete) and metal (carbon steel,
17 galvanized steel, aluminum) samples for bench testing.

18
19 The NRC staff reviewed the selection of containment materials in the TR WCAP-16530-NP and
20 the assumptions used to determine the materials to be tested. The materials were identified in a
21 PWROG sponsored survey. While the NRC staff has not verified the survey results, the types
22 and amounts of materials appear reasonable. The NRC staff questioned (Request for Additional
23 Information (RAI) dated October 4, 2006, ADAMS Accession No. ML062440433) the TR
24 WCAP-16530-NP assumption that the amount of RCS oxides was not significant enough to be
25 included as a containment material in the TR tests. This NRC staff question is discussed in
26 greater detail in Section 3.8 of this SE. The NRC also sponsored some confirmatory tests to
27 verify the acceptability of the TR WCAP-16530-NP selections of representative materials for the
28 various non-metallic material classes. This is discussed further in Section 3.7 of this SE.

29
30 3.2 Dissolution Testing

31
32 The objective of the dissolution tests was to determine which materials would contribute
33 significant dissolved mass to test solutions used to represent post-LOCA containment pool
34 conditions. Plant survey data were used to determine limits for test parameters. For example,
35 tests were performed with pH values of 4.1, 8, and 12 to bound the postulated post-accident pH
36 values ranging from the initial, unbuffered, low pH solution in the containment pool to the
37 maximum postulated high pH in the CSS during sodium hydroxide injection. All test solutions
38 contained 4400 parts per million (ppm) boron as boric acid, and this boric acid concentration
39 produced the pH 4.1 test solution. The pH 8 and pH 12 test solutions were produced by adding
40 sodium hydroxide to the borated water to increase the pH. Test temperatures of 190 °F and
41 265 °F were selected to evaluate leaching of containment materials at high temperatures
42 simulating early initial post-accident sump conditions.

43
44 Bench tests were conducted in either Teflon or stainless steel reaction vessels that were filled to
45 a nominal fluid volume of 120 milliliters (ml) or 150 ml, respectively. The reaction vessels were
46 placed on a rocking platform that was located in an oven that contained the solution reservoirs
47 and reaction chambers. Samples of the reaction vessel solutions were taken at 30, 60, and 90
48 minutes. The solutions were analyzed using inductively coupled plasma spectroscopy (ICP) for
49 the elements of interest including: aluminum, calcium, silicon, magnesium, phosphorous, sulfur,
50 iron, zinc and titanium.

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

7
8 The amount of aluminum released into solution was a strong function of test solution pH.
9 There is an order of magnitude increase in the total mass of aluminum released into solution at
10 pH 8 relative to pH 4.1. The aluminum mass released increases by two orders of magnitude
11 when the pH is increased from 4.1 to 12.

12
13 In terms of containment materials, aluminum, concrete, and calcium silicate released the most
14 mass during testing. The amount of crushed concrete tested, however, was not scaled
15 according to a representative surface area in a PWR containment since the surface area of the
16 crushed concrete was not known prior to the start of testing. Afterwards, it was determined that
17 the amount of concrete tested was much greater than the amount that would be representative
18 of a U.S. PWR. The concentration of calcium due to dissolution of concrete would have been
19 lower if the amount of concrete tested had been scaled to an upper bound of exposed concrete
20 surface area in a PWR.

21
22 The NRC staff reviewed the test methods and results from the TR WCAP-16530-NP leaching
23 tests and determined that the selection of pH and temperature was acceptable since the range
24 of pH tested bounded the pH values that may be experienced by plant materials following a
25 LOCA. The NRC staff found the TR test temperatures acceptable since greater dissolution is
26 expected to occur at the elevated temperatures in the TR tests and this data complements the
27 data obtained from the ICET series at 140 °F. The NRC staff found the use of ICP analysis to
28 determine the concentration of elements that leached into solution to be acceptable since this a
29 standard quantitative analytical method for determining the amount of a given element in
30 solution.

31 32 3.3 Precipitation Testing

33
34 Following completion of the 90-minute leaching tests, solutions from the test reactors were
35 transferred through a sintered stainless steel filter and small diameter stainless steel transfer
36 lines located in a constant temperature water bath into settling cones. The water bath was
37 maintained at 80 °F, and the solutions were visually inspected over time to look for evidence of
38 precipitation caused by cooling the solution. In addition to the dissolution test solutions,
39 additional precipitation test solutions were created by adding trisodium phosphate (TSP) or
40 sodium tetraborate (STB) or by combining the solutions from different dissolution tests. More
41 specifically, some of the pH 4.1 boric acid solutions were buffered to a pH 8 by addition of TSP
42 or STB. In other cases, precipitation test solutions were created by combining pH 4.1 test
43 solutions of one material (e.g., concrete) with pH 12 test solutions of a second material
44 (e.g., aluminum).

45
46 Precipitates formed in a total of 17 experiments. Of these, 10 were single material, single test
47 solution leaching experiments included in the precipitation test matrix. Another 2 precipitation
48 experiments involved calcium-containing dissolution materials with subsequent additions of TSP.
49 Mixing of solution from different leaching runs produced precipitate in 1 experiment. Finally, 4
50 additional experiments with single material, single test solution conditions produced precipitate.

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

5 Results from the leaching and precipitation tests indicated no recognizable correlation between
6 the total amount of material in the solution during the dissolution tests and the amount of
7 precipitate that subsequently formed during precipitation tests. The greatest volume of
8 precipitate was formed with aluminum in a pH 12 solution. The complexity of the observed
9 precipitation processes caused the PWROG to change the planned chemical model
10 development such that the model does not rely on the precipitate mass measured during
11 precipitation testing to determine the amounts of plant-specific precipitate. Instead, the model
12 conservatively assumes all dissolved aluminum precipitates and all dissolved calcium in
13 phosphate solutions precipitates. The TR WCAP-16530-NP also states that the precipitates
14 formed do not settle quickly and thus cannot be discounted as a concern for sump screen
15 performance.
16

17 Composition of the precipitates was determined by performing energy dispersive spectroscopy
18 (EDS) on precipitate samples that were captured on filter paper and placed into a scanning
19 electron microscope. Based on a best-estimate analysis from the EDS results, the TR
20 concludes that the precipitates containing aluminum are predominantly aluminum oxyhydroxide
21 and sodium aluminum silicates. EDS analysis also indicated that calcium phosphate formed in
22 tests when dissolved calcium combined with phosphate in solution.
23

24 The NRC staff reviewed the test methods and results from the TR WCAP-16530-NP
25 precipitation tests, and the NRC staff had some questions related these tests (see RAI dated
26 October 4, 2006, ADAMS Accession No. ML062440433). One issue concerned whether the use
27 of primarily single-material tests in the precipitation test matrix was appropriate considering the
28 possibility that combined effects could result from the interaction of several materials. This issue
29 is discussed in more detail in Section 3.8 of this SE. In addition, the NRC staff had questions
30 concerning the limitations of the EDS technique used for the best estimate characterization of
31 the TR WCAP-16530-NP precipitates. This issue is also discussed in greater detail in
32 Section 3.8 of this SE. Overall, the NRC staff concluded that the use of an 80 °F water bath for
33 cooling was appropriate since lower temperatures would typically favor the precipitation process
34 for the aluminum-containing species, as was observed in the ICET 1 and ICET 5 tests. Post-
35 LOCA sump pool temperatures would typically exceed 80 °F for most of the ECCS mission time.
36 Therefore, with the exception of those items discussed in greater detail in Section 3.8 of this
37 SE, the NRC staff concluded that the approach to precipitation testing was acceptable.
38

39 3.4 Precipitate Filterability Tests 40

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

1
2 The NRC staff questioned some of the filterability model assumptions and the conclusion that
3 the relative filterability of the aluminum oxyhydroxide and sodium aluminum silicate surrogate
4 precipitates was similar. For example, one of the inputs used to calculate the filter cake
5 coefficient is precipitate mass. In these tests, precipitate mass is obtained after the test is
6 completed by drying the hydrated precipitate that was collected on the test filter. Differences in
7 the degree of hydration between different precipitates or between different batches of the same
8 precipitate could introduce significant error in the calculated filter cake coefficients.
9

10 In response to the NRC staff's questions, the PWROG performed additional tests to study
11 filterability of sodium aluminum silicate and aluminum oxyhydroxide. Some of these additional
12 tests investigated the effects of cooling rates on precipitate properties. Based on the results
13 from these additional tests, the PWROG concluded that the TR WCAP-16530-NP aluminum
14 oxyhydroxide and sodium aluminum precipitates produced pressure drops equal to or greater
15 than precipitate formed in a representative post-LOCA environment. While the NRC staff agrees
16 that the data support the PWROG conclusions, the filterability model assumptions and the test
17 technique used to measure filterability in the additional studies had the same fundamental
18 weaknesses. Therefore, the NRC staff does not accept these test results to compare the
19 relative filterability of WCAP-16530-NP precipitates. Section 3.7 of this SE discusses some
20 NRC-sponsored testing that compares the relative filterability of TR WCAP-16530-NP
21 precipitates. Nonetheless, it is important to note that the filterability tests in the TR were
22 performed to permit relative comparison of the different surrogate precipitates and that these
23 filterability test results are not factored into the chemical model predictions.
24

25 3.5 Chemical Model

26
27 Regression analysis was performed on the bench test dissolution data to develop release rate
28 equations as a function of temperature, pH and concentration of the particular chemical species.
29 Release rate equations were developed for each predominant containment material for each
30 chemical species. For example, the amount of calcium released by calcium silicate insulation,
31 concrete, and other insulation materials containing calcium are determined by different
32 functions. Thus, bench test dissolution data are used to predict the amount of precipitate that
33 forms and the results from precipitate analysis are used to predict the type of precipitate that
34 forms. The model conservatively assumes all dissolved aluminum precipitates and all dissolved
35 calcium in phosphate solutions precipitates.
36

37 Since corrosion of aluminum resulted in the greatest mass released during the TR leaching
38 tests, the aluminum release rate incorporated into the chemical model is important. The TR
39 contains two aluminum release rate equations that were developed by fitting different aluminum
40 corrosion data sets, including the ICET series. The chemical model uses Equation 6-2 in the TR
41 that was fit to a greater number of data sets. The NRC staff questioned whether Equation 6-2
42 provided the most appropriate aluminum release rate and whether the ICET 1 aluminum
43 corrosion data were properly considered. The TR 16530-NP chemical model treatment of
44 aluminum corrosion is discussed further in Section 3.7 of this SE.
45

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

1 spreadsheet according to the amounts that are submerged or wetted by containment spray. The
2 amount of containment material that is transported to the pool and submerged will be dependent
3 upon the break location.
4

5 The output of the model is presented in a results table that shows the time-dependent amounts
6 of aluminum, calcium, and silicon released. The amounts of each precipitate predicted are also
7 provided as a function of time. Individual pages of the spreadsheet indicate the elemental
8 release and the precipitate formation on a plant-specific material basis to allow the user to
9 determine the potential benefits gained by reduction or removal of certain materials from their
10 plant.
11

12 Given that the chemical model assumes all aluminum in solution and all calcium in the presence
13 of phosphate precipitates, the NRC staff concludes that the model predictions for the amount of
14 plant-specific precipitate are conservative and are, therefore, acceptable. The assessment of
15 particular aspects of the model (e.g., the model's prediction of the relative amounts of surrogate
16 precipitate) and an overall assessment of the chemical model are contained in Sections 3.7 and
17 3.8 of this SE.
18

19 3.6 Particulate Generator 20

21 The purpose of the particulate generator is to create surrogate chemical precipitates with
22 representative properties that may be used during sump strainer head loss testing. Based on
23 plant-specific inputs, the chemical model spreadsheet predicts the amount of chemical
24 precipitates that would form in the post-accident environment. Since the precipitate filtration and
25 settlement properties are influenced by their amorphous and hydrated nature, the particulate
26 generator preparation is performed by mixing chemicals (e.g., water, aluminum nitrate
27 nonahydrate, and sodium hydroxide) in solution for a minimum of an hour prior to use. The
28 discussion in the particulate generator section of the report recognizes that representative
29 precipitate properties may not be achieved by the use of similar chemical formula solid material.
30 The NRC staff agrees that pre-manufactured particulate, e.g., calcium phosphate powder,
31 behaves differently than hydrated, amorphous, precipitate that was observed during the ICET
32 series. Therefore, the NRC staff does not consider addition of commercially manufactured
33 particulate with similar chemical composition to be an adequate simulation of chemical
34 precipitates.
35

36 During particulate generator qualification testing, the effects of precipitate concentration in the
37 mixing tank were evaluated, and it was observed that precipitate solutions prepared at higher
38 mixing tank concentrations settled at atypically high rates, even after subsequent dilution.
39 Figures 7.6-1 and 7.6-2 in TR WCAP-16530-NP show the effect of mixing tank concentration on
40 the settling rates of aluminum oxyhydroxide and calcium phosphate, respectively. The results
41 shown in these figures, that high concentrations favor formation of precipitate with faster settling
42 properties, is consistent with earlier test observations concerning precipitate concentration
43 effects on settling properties at ANL (NUREG/CR-6913). Therefore, TR WCAP-16530-NP
44 states that the maximum concentrations of aluminum oxyhydroxide and sodium aluminum
45 silicate in the mix tank should not exceed 11 grams per liter. The maximum mix tank
46 concentration for the calcium phosphate precipitate should not exceed 5 grams per liter.
47

48 In addition to the mixing tank concentration limits, TR WCAP-16530-NP provides maximum
49 acceptable 1-hour precipitate settlement values to preclude atypical settling of the surrogate
50 precipitate. The acceptable precipitate 1-hour settled volume criteria, shown in Table 7.8-1 of

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

8
9 The NRC staff questioned whether the 1-hour settled volume criterion was sufficient for two
10 reasons. First, a batch of aluminum oxyhydroxide prepared for head loss testing displayed a
11 distinct change in properties over time even though the 1-hour settlement values met the
12 acceptance criteria. Second, a modified strainer head loss testing approach, with the objective
13 of settling all debris including chemical precipitate, was proposed by some licensees. This test
14 approach is very different from an approach that intentionally uses agitation to keep chemical
15 precipitate suspended to ensure it reaches the test strainer.

16
17 To address this shortcoming, the NRC staff reviewed the results from precipitate settling in the
18 TR WCAP-16530-NP, specifically Figures 7.6-1 and 7.6-2 and Table 5.3-1, and results from
19 other settling tests at ANL. The NRC staff also included a time-dependent criterion for
20 settlement testing relative to head loss testing to preclude precipitate aging from significantly
21 changing the surrogate precipitate properties before it is used. The NRC staff finds the following
22 proposed modification (ADAMS Accession No. ML072570680) to the settling rates in TR WCAP-
23 16530-NP to be acceptable:

- 24
25 1. For head loss tests in which the objective is to keep chemical precipitate suspended
26 (e.g., by tank agitation):
27

28 Sodium aluminum silicate and aluminum oxyhydroxide precipitate settling shall be
29 measured within 24 hours of the time the surrogate will be used and the 1-hour settled
30 volume (for an initial 10 ml solution volume) shall be 6 ml or greater and within 1.5 ml of
31 the freshly prepared surrogate. Calcium phosphate precipitate settling shall be
32 measured within 24 hours of the time the surrogate will be used and the 1-hour settled
33 volume shall be 5 ml or greater and within 1.5 ml of the freshly prepared surrogate.
34 Testing shall be conducted such that the surrogate precipitate is introduced in a way to
35 ensure transport of all material to the test screen.
36

- 37 2. For head loss testing in which the objective is to settle chemical precipitate and
38 other debris:
39

40 Aluminum-containing surrogate precipitate that settles equal to or less than the 2.2 g/l
41 concentration line shown in Figure 7.6-1 of WCAP-16530-NP (i.e., 1-hour or 2-hour
42 settlement data on or above the line) is acceptable. The settling rate should be
43 measured within 24 hours of the time the surrogate precipitate will be used.
44

45 For testing that was performed prior to the time the PWROG notified licensees of a
46 revised precipitate settlement acceptance criteria, licensees should evaluate the
47 precipitate settlement of these tests considering the observations provided in the
48 response to NRC comment 7 provided in PWROG letter dated September 12, 2007
49 (ADAMS Accession No. ML072570680).
50

1 3.7 NRC-Sponsored Confirmatory Testing

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

12
13 The main purpose of the supplementary leaching studies performed at SwRI was to examine the
14 validity of the assumption in the TR that various non-metallic materials in the same class would
15 exhibit similar dissolution characteristics. A secondary objective was to characterize any
16 precipitate that formed. For the SwRI tests, five materials that had not been tested by the
17 PWROG were selected from various insulation classes to determine if the material tested by the
18 PWROG was representative of other materials in the same class. The SwRI test matrix included
19 E-glass materials (fiberglass, Alpha-Mat™, Temp-Mat A™), amorphous silica (Microtherm™),
20 calcium silicate (Marinite™), and aluminum silicate (Kaowool™). The test conditions were
21 selected by focusing on the test conditions that had provided the most concentrated leachate
22 solutions for each material class. Since the testing apparatus and procedures were similar but
23 not identical to that used for the topical report tests, some previously tested materials (calcium
24 silicate, Fiber Frax™, Durablanket™, and concrete) were also included to allow comparison
25 between the TR test results and the SwRI test results. Details of the test conditions and the test
26 results are provided in a SwRI letter report, "Supplementary Leaching Tests of Insulation and
27 Concrete for GSI-191 Chemical Effects Program" (ADAMS Accession No. ML063330573).

28
29 For leaching tests with similar times, temperatures, and pH, the concentration of elements in the
30 SwRI leaching tests were similar to or less than the concentrations from the TR tests. With the
31 exception of calcium silicate in certain test conditions, SwRI tests of the same insulation resulted
32 in lower elemental concentrations in solution compared to the TR tests. Significantly less silicon
33 leached from the fiberglass samples during the SwRI tests. The amount of calcium leached
34 from concrete was also lower in the SwRI tests, which was expected since the SwRI tests used
35 a concrete coupon with a scaled surface area representing the upper plant bound for uncoated
36 concrete. The TR WCAP-16530-NP tests used an amount of crushed concrete that exceeded
37 plant levels (see Section 3.2 of this evaluation).

38
39 No precipitates were observed to settle in any of the SwRI tests even when using the same
40 materials and same test conditions that produced precipitates in the TR WCAP-16530-NP tests.
41 Although the test conditions were similar, there were a few differences between the SwRI and
42 the TR test techniques that could have affected the results. For instance, the SwRI test
43 solutions were cooled over a 2-hour period during which time the test material remained in
44 contact with the test solution. In contrast, the TR test solution was immediately filtered and
45 transferred to the precipitation settling cones in the cooling water bath at the completion of the
46 dissolution test period. Therefore, the SwRI test materials remained in contact with solution for a
47 significantly longer periods, and the SwRI test solution was cooled at a significantly slower rate
48 compared to the TR test solution. The longer time for dissolution in the SwRI tests would
49 promote greater dissolution. This is offset by the greater agitation for the TR tests, where the
50 individual reaction vessels were placed on a rocking platform in the test oven. The slower

1 cooling rates in the SwRI tests would be more similar to the fluid cooling of the containment
2 sump pool following a LOCA. The more rapid cooling in the TR tests may be more similar to
3 cooling that would occur as fluid from the sump passes through a residual heat removal (RHR)
4 heat exchanger. The TR test solution cooling would not be prototypical of cooling in an ECCS
5 system, however, since fluid that passes from the sump through a RHR heat exchanger would
6 be reheated as it passes into the reactor vessel or spills out a break and returns to the post-
7 LOCA pool on the containment floor. This effect would increase the solubility of some
8 precipitates since reheating may cause the precipitates to go back into solution.
9

10 Overall, results from the SwRI dissolution and precipitation tests did not contradict the TR
11 WCAP-16530-NP assumptions concerning leaching from representative materials in different
12 classes. In addition, no precipitates were formed with the new test materials. Therefore, the
13 NRC staff finds the TR classification of materials and the selection of representative test
14 materials to be acceptable.
15

16 While the NRC-sponsored tests at SwRI were intended to verify some of the TR assumptions
17 related to representative materials and to repeat some of the dissolution and precipitation tests,
18 the goal of NRC-sponsored tests at ANL was to evaluate the surrogate chemical precipitate
19 prepared using the instructions in the TR. Tests at ANL included bench testing to study the TR
20 precipitate characteristics and vertical loop head loss testing to evaluate the head loss
21 properties of the precipitate (see ANL Technical Letter Report, ADAMS Accession No.
22 ML070580086). These tests focused on the aluminum oxyhydroxide and sodium aluminum
23 silicate precipitates since these are the predominant precipitates predicted by the TR chemical
24 model and ANL had previously performed extensive testing with the calcium phosphate
25 precipitate, as reported in NUREG/CR-6913.
26

27 The TR procedure for preparing surrogate chemical precipitate recognizes that the precipitate
28 concentration in the mixing tank will affect the size and settling properties of the precipitate.
29 Therefore, the procedure limits the maximum concentration of the mixing tank and provides
30 criteria for acceptable one-hour settling volumes. ANL evaluated precipitates prepared
31 according to the TR instructions and also prepared precipitates by deviating from the TR
32 guidelines to evaluate the potential effects on the precipitate properties. Overall, the TR
33 precipitate preparation specifications seem effective at producing fine precipitate that is most
34 probably finely crystalline, although no clear diffraction pattern was obtained due to the small
35 particle size. Bench testing also showed that precipitate settling rates were slower for aluminum
36 oxyhydroxide precipitate produced according to the TR directions. X-ray diffraction of the
37 precipitates prepared outside the bounds of the TR instructions indicated a crystalline structure
38 (bayerite). This precipitate, however, did not meet the TR settlement acceptance criteria.
39

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

1 In these tests, a standard fiberglass debris bed was formed using NUKON fiberglass fibers that
2 had been shredded and processed in a blender to produce individual fibers. A fiberglass debris
3 bed was formed and a baseline pressure drop was measured before addition of surrogate
4 precipitate. The first test used the TR aluminum oxyhydroxide precipitate in an amount
5 equivalent to what would be produced if 5 parts per million (ppm) of dissolved aluminum from the
6 119-liter vertical head loss loop volume were to transform into precipitate. This amount of TR
7 precipitate resulted in a rapid increase in pressure drop across the fiber-covered screen, and the
8 pressure drop capacity of the test loop was exhausted almost immediately.

9
10 Given the rapid increase in pressure drop with the initial test of the TR aluminum oxyhydroxide
11 precipitate, an additional head loss test with this precipitate was performed using smaller
12 incremental additions, equivalent to 0.5 ppm of dissolved aluminum in the test loop transforming
13 into precipitate. Using these reduced precipitate additions, the system's pressure drop capacity
14 was exceeded with a total addition equivalent to 1.5 ppm of dissolved aluminum in the loop
15 transforming to precipitate.

16
17 ANL also performed vertical loop head loss testing with the TR sodium aluminum silicate
18 precipitate. An initial head loss test in deionized water revealed that the sodium aluminum
19 silicate precipitate was dissolving over time. Small additions of precipitate would produce an
20 initial increase in pressure drop comparable to the aluminum oxyhydroxide precipitate, however,
21 the pressure drop would decrease over time. After adding an amount of aluminum equivalent to
22 5 ppm of dissolved aluminum in the vertical loop transforming into sodium aluminum silicate
23 precipitate, the head loss was near the loop capacity but still exhibited the pressure drop decay
24 behavior over time. Subsequent bench testing with deionized and potable water indicated that
25 approximately 2 ppm of sodium aluminum silicate dissolves in deionized water and that the pH
26 of deionized water becomes more alkaline compared to potable water for a given amount of
27 sodium aluminum silicate addition. Therefore, if deionized water were to be used for strainer
28 head loss testing, the solubility of sodium aluminum silicate shall be accounted for when
29 determining the appropriate amount to be added to the test.

30
31 Since strainer vendors that add TR surrogate precipitate to larger scale integrated head loss
32 tests use potable water, not deionized water, a second sodium aluminum silicate head loss test
33 was conducted with potable water in the vertical head loss test loop. With potable water, the
34 system's pressure drop capacity was exceeded with a total sodium aluminum silicate addition
35 equivalent to 2.2 ppm of dissolved aluminum in the loop transforming to precipitate. In addition,
36 the pressure drop across the debris bed remained stable for greater than 10 hours after an
37 equivalent 2 ppm of dissolved aluminum as sodium aluminum silicate was introduced. Although
38 there were some small differences in the vertical loop head loss test results, the vertical loop test
39 results indicate that small quantities of both these TR surrogate precipitates are effective at
40 causing significant pressure drop across a fiber bed.

41 3.8 Overall Staff Technical Evaluation

42
43
44 There are a number of different technical issues embedded within the TR WCAP-16530-NP
45 methodology. In this section, the NRC staff discusses important technical issues and provides
46 an overall staff evaluation of TR WCAP-16530-NP.

1
2 Role of RCS Oxides
3

4 One of the potential material source terms that was judged to be insignificant in TR
5 WCAP-16530-NP is potential reactor coolant system (RCS) oxides released during a
6 LOCA. In letters dated October 4, 2006, and March 23, 2007 (ADAMS Accession Nos.
7 ML062440433 and ML070810208), the NRC staff requested additional information from
8 the PWROG related to the amount of RCS oxides that could be released during a LOCA
9 and the potential effects of these oxides on chemical effects. In letters dated
10 November 21, 2006, April 3, 2007, and September 12, 2007 (ADAMS Accession Nos.
11 ML063390128, ML070950119, and ML072570680), the PWROG provided information
12 supporting its conclusion that the amount of crud released during a LOCA would be
13 insignificant compared to the other debris that is included in strainer head loss testing.
14 Based on the additional information provided in the RAI responses, conservatism in other
15 parts of the chemical model (e.g., all aluminum in solution precipitates), and considering
16 the amounts of other particulate debris included in strainer testing, the NRC staff finds
17 that the amounts and effects of RCS oxides can be considered insignificant for strainer
18 head loss testing. Therefore, the NRC staff concludes that it is acceptable that RCS
19 oxides are not included in the TR WCAP-16530-NP head loss testing source term.
20

21 Aluminum Release Rates
22

23 Corrosion of aluminum resulted in the greatest mass released during the TR WCAP-
24 16530-NP dissolution tests. Therefore, the aluminum release rate incorporated into the
25 chemical model is important. The aluminum release rate was determined by considering
26 a number of test results, including the ICET series. The fit to the ICET data is based on
27 an average 30-day aluminum corrosion rate, but measurement of aluminum in solution
28 during the ICET 1 test indicated an active phase of aluminum corrosion during the initial
29 half of the test followed by aluminum passivation during the second half of the test. By
30 using an averaged value, the TR chemical model release rate under-predicts aluminum
31 release by about a factor of 2 for the active corrosion part of ICET 1. The NRC staff finds
32 this acceptable since licensees using the TR WCAP-16530-NP surrogate precipitate
33 typically add the amount predicted for a 30-day mission time while using a first-day pump
34 net positive suction head (NPSH) margin acceptance criteria. If a licensee performs
35 strainer head loss tests with TR WCAP-16530-NP surrogate precipitate and applies a
36 time-based pump NPSH margin acceptance criteria (i.e., timed precipitate additions
37 based on TR model predictions), the NRC staff expects the licensee to use an aluminum
38 release rate that does not under-predict the aluminum concentrations during the initial 15
39 days of ICET 1. In this case, aluminum passivation may be considered during the latter
40 parts of the ECCS mission time.
41

42 Identification of Precipitate Types
43

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

1 The NRC staff notes that TR WCAP-16530-NP aluminum oxyhydroxide surrogate
2 precipitate is prepared by adding aluminum nitrate to water followed by sodium
3 hydroxide. This results in formation of precipitate at a lower pH compared to a post-
4 LOCA environment where this type of precipitate would most probably form after the pH
5 was greater than 7. The NRC staff cannot conclude that the TR WCAP-16530-NP
6 surrogate precipitates are identical to those that formed in ICET and in the TR tests,
7 because of (1) the limitations in the EDS technique used to identify the TR WCAP-
8 16530-NP precipitates, (2) the fact that prediction of sodium aluminum silicate
9 precipitate formation in the TR is somewhat based on thermodynamic calculations, and
10 (3) the surrogate precipitate preparation sequence that adds aluminum nitrate before
11 adjusting the pH with sodium hydroxide. Nevertheless, the technical approach used in
12 the TR WCAP-16530-NP does not rely on making the exact precipitates that formed
13 during testing but rather surrogate precipitates that have representative properties such
14 as precipitate settlement and filterability. Therefore, the NRC staff review focused on
15 determining if the predicted types, filterability, and amount of surrogate precipitates were
16 either representative or conservative when compared to those precipitates that may form
17 in the post-LOCA plant environment. Based on its review, the NRC staff concludes that
18 the surrogate precipitate that is prepared in accordance with the TR WCAP-16530-NP
19 directions provides adequate settlement and filterability characteristics to represent post-
20 LOCA chemical precipitates in strainer head loss tests.

21 Amount of Precipitate

22
23
24 With respect to the total amount of precipitate, TR WCAP-16530-NP assumes all
25 dissolved calcium, in the presence of phosphate, and all dissolved aluminum form
26 precipitates. This is a reasonable assumption for calcium dissolved in a TSP-buffered
27 solution, since a calcium phosphate precipitate forms and calcium, not phosphate, is
28 expected to be the limiting reactant. The assumption that all dissolved aluminum forms a
29 precipitate is clearly a conservative assumption when compared to literature values and
30 measured values of dissolved aluminum in alkaline, borated test solutions at LANL and
31 ANL. The solubility of aluminum is dependent on the temperature and the pH of the
32 sump pool following a LOCA. One indication that not all dissolved aluminum precipitates
33 is shown by the room temperature (49 mg/L) concentration of aluminum in the ICET 1
34 test fluid supernate four months after the completion of the test. However, this value
35 should not be assumed to be a solubility limit since sub-micron suspended aluminum
36 hydroxide particles that are not visible have been shown to cause head loss in tests at
37 ANL. The NRC staff concludes that the chemical model prediction on the total amount of
38 precipitate, i.e., that all dissolved aluminum precipitates, is acceptable since this results
39 in a conservative amount of precipitate.

40 Single Effects vs. Multiple Material Tests

41
42
43 Dissolution and precipitation evaluations in the TR WCAP-16530-NP are based mostly
44 on single-effects testing. Although single-effects testing complements the ICET tests
45 and may produce conservative amounts of dissolved materials in some instances, this
46 testing approach could miss some important combined effects from multiple materials.
47 Combined effects may or may not be conservative relative to projections from separate
48 effects testing. For example, silicates are known to inhibit aluminum corrosion. The
49 chemical model in TR WCAP-16530-NP may significantly over-predict the amount of
50 silica released from fiberglass since the TR WCAP-16530-NP tests did not consider the

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

15 Form of Aluminum Precipitates

16
17 TR WCAP-16530-NP surrogate precipitate composition is based on "best estimate"
18 analysis of precipitate formed during bench testing. As previously mentioned in
19 Section 3.6 of this SE, the NRC staff questioned the model's ability to accurately predict
20 the relative amounts of aluminum oxyhydroxide and sodium aluminum silicate
21 precipitates that could form in a plant-specific environment. The NRC-sponsored head
22 loss tests at ANL were designed to compare the head loss test results of aluminum
23 precipitating as an aluminum hydroxide to aluminum precipitating as a sodium aluminum
24 silicate. The tests at ANL confirmed that small quantities of each TR surrogate
25 precipitate produced significant pressure drop across a Nukon fiber bed. Therefore,
26 even though the NRC staff cannot conclude that the model predictions for relative
27 amounts of aluminum hydroxide and sodium aluminum silicate are accurate, the ANL
28 tests have shown that the effects of the two surrogate precipitates are similar. Therefore,
29 the NRC staff finds the TR WCAP-16530-NP predicted amount of precipitate to be
30 acceptable since all aluminum is assumed to precipitate and small quantities of each
31 precipitate are effective at producing significant head loss across a fiber bed.

32 Precipitate Settlement Criteria

33
34
35 Precipitate settlement is another important surrogate precipitate characteristic that was
36 reviewed by the NRC staff. Precipitate that formed during cooling of ICET solutions and
37 during the TR WCAP-16530-NP bench tests was observed to settle slowly. During the
38 surrogate precipitate development stage, TR WCAP-16530-NP tests showed that the
39 surrogate precipitate mixing tank concentration affected the settling properties.
40 Therefore, TR WCAP-16530-NP recommends a maximum mixing concentration to
41 achieve reasonably prototypical settling behavior. In addition, TR WCAP-16530-NP
42 provides criteria for physical characteristics of acceptable surrogate precipitates,
43 including criteria for a 1-hour settled volume. As a condition on the use of this TR,
44 licensees must implement the additional settlement criteria described in response to
45 NRC comment 7 of the September 12, 2007 letter (ADAMS Accession ML072570680),
46 for proper use of the surrogate precipitate materials. These criteria are provided in
47 Section 4.0 of this SE.
48
49

1 Based on the considerations above, although there are uncertainties associated with the actual
2 formation of chemical products in a post-LOCA plant environment, the NRC staff finds the
3 overall technical approach in TR WCAP-16530-NP to be acceptable for plant-specific chemical
4 effect evaluations since this approach predicts a conservative amount of chemical precipitate
5 and the surrogate precipitate filterability is either representative or conservative compared to
6 precipitate that may be expected to form in a post-LOCA environment.

7
8 4.0 LIMITATIONS AND CONDITIONS

- 9
10
11 1. A peer review of NRC-sponsored chemical effects testing was performed and a number
12 of technical issues related to GSI-191 chemical effects were raised by the independent
13 peer review panel members (NUREG-1861). The peer review panel and the NRC staff
14 developed a PIRT of technical issues identified by the peer review panel. The NRC staff
15 is working to resolve the technical issues identified in the PIRT. Part of the resolution
16 process includes NRC-sponsored analyses being performed by PNNL. Although the
17 NRC staff has not developed any information related to the PIRT issues resolution that
18 would alter the conclusions of this evaluation, some issues raised by the peer review
19 panel were not completely resolved at the time this evaluation was written. An example
20 of such an issue is the potential influences of organic materials on chemical effects.
21 Therefore, it is possible that additional analysis or other results obtained during the
22 resolution of the remaining peer review panel issues could affect the conclusions in this
23 evaluation. In that event, the NRC staff may modify the SE or take other actions as
24 necessary.
25
- 26 2. This evaluation does not address TR WCAP-16785-NP, "Evaluation of Additional Inputs
27 to the WCAP-16530-NP Chemical Model." The NRC staff will provide comments on
28 WCAP-16785-NP separate from this evaluation. In addition, a separate SE will address
29 a related TR, WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering
30 Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." Chemical effects in
31 the reactor vessel are not addressed in WCAP-16530-NP or in this SE. Therefore, the
32 approval of this TR does not extend to chemical effects in the reactor vessels.
33
- 34 3. If a licensee performs strainer head loss tests with surrogate precipitate and applies a
35 time-based pump NPSH margin acceptance criteria (i.e., timed precipitate additions
36 based on topical report model predictions), they must use an aluminum release rate that
37 does not under-predict the initial 15 day aluminum concentrations in ICET 1, although
38 aluminum passivation can be considered during the latter parts of the ECCS mission
39 time in this case.
40
- 41 4. For head loss tests in which the objective is to keep chemical precipitate suspended
42 (e.g., by tank agitation):
43
44 Sodium aluminum silicate and aluminum oxyhydroxide precipitate settling shall be
45 measured within 24 hours of the time the surrogate will be used and the
46 1-hour settled volume shall be 6 ml or greater and within 1.5 ml of the freshly
47 prepared surrogate. Calcium phosphate precipitate settling shall be measured
48 within 24 hours of the time the surrogate will be used and the 1 hour settled
49 volume shall be 5 ml or greater and within 1.5 ml of the freshly prepared
50 surrogate. Testing shall be conducted such that the surrogate precipitate is
51 introduced in a way to ensure transportation of all material to the test screen.

- 1
2 5. For head loss testing in which the objective is to settle chemical precipitate and other
3 debris:

4
5 Aluminum containing surrogate precipitate that settles equal to or less than the
6 2.2 g/l concentration line shown in Figure 7.6-1 of WCAP-16530-NP (i.e., 1-or 2-
7 hour settlement data on or above the line) is acceptable. The settling rate shall
8 be measured within 24 hours of the time the surrogate precipitate will be used.
9

- 10
11 6. For strainer head loss testing that uses TR WCAP-16530-NP sodium aluminum silicate
12 and is performed in a de-ionized water environment, the total amount of sodium
13 aluminum silicate added to the test shall account for the solubility of sodium aluminum
14 silicate in this environment.

15 5.0 CONCLUSION

16
17 The NRC staff has reviewed WCAP-16530-NP and the supplemental information that was
18 transmitted by letters dated November 21, 2006, April 3, 2007, and September 12, 2007, and
19 has found that the TR, as modified and clarified to incorporate the NRC staff's
20 recommendations, and subject to the conditions and limitations in Section 4.0 of this SE,
21 provides an acceptable technical justification for the evaluation of plant specific chemical effects
22 related to GSI-191. The supplemental information that was provided in response to the NRC
23 staff's RAIs shall be incorporated into the approved version of TR WCAP-16530-NP. In
24 addition, where this SE states that a change to the TR is needed, such changes shall also be
25 incorporated in the approved version.
26

27 6.0 REFERENCES

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