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Integrated Chemical Effects Test Project: Test #1 Data Report

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Integrated Chemical Effects Test Project: Test #1 Data Report

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INTEGRATED CHEMICAL EFFECTS TEST PROJECT: TEST #1 DATA REPORT

ABSTRACT

A 30-day test was conducted in the Integrated Chemical Effects Test (ICET) project test apparatus. This was the first of a series of five tests. The test simulated the chemical environment present inside a pressurized water reactor containment water pool after a loss-of-coolant-accident. The initial chemical environment contained 15.14 kg of boric acid, 1.197 g of lithium hydroxide, and 5.87 kg of sodium hydroxide. An additional 2.27 kg of sodium hydroxide was added beginning at 30 minutes and lasting until 4 hours into the test. The test was conducted for 30 days at a constant temperature of 60°C. The materials tested within this environment included representative amounts of submerged and unsubmerged aluminum, copper, concrete, zinc, carbon steel, and fiberglass insulation samples. Representative amounts of concrete dust and latent debris were also added to the test solution. Water was circulated through the bottom portion of the test chamber during the entire test to achieve representative flow rates over the submerged specimens. The test solution reached a pH of 9.5 by the end of the NaOH injection and remained at approximately that level for the 30-day duration of the test. The test solution turbidity was initially about 12 NTU but decreased to less than 1 NTU within 72 hours. However, samples of the test solution cooled to 23°C showed an increase in turbidity from less than 20 NTU at Day 4 to about 130 NTU at Day 30. Total suspended solids (TSS) in the test solution varied somewhat during the test and were roughly in the range of 10 mg/L to about 30 mg/L for the solution at 60°C. End-of-test evaluations indicated TSS levels in the test solution of about 1800 mg/L at 22°C and 100 mg/L at 55°C. Precipitants were formed as the solution was cooled to room temperature. The precipitants were not apparent at the test temperature of 60°C. Analyses of the test solution indicated that high levels of aluminum were present, with levels rising from near zero at the beginning of the test to approximately 350 mg/L after 20 days of testing. Post-test evaluations indicated that the submerged aluminum coupons had lost about 25% of their weight during the test. Examinations of fiberglass taken from the test apparatus after 15 days of testing indicated evidence of chemical products and a web-like material that spanned individual fibers. After 30 days of testing, the web-like material was more prevalent and contiguous webbing appeared to span multiple fibers. Shear-dependent viscosity measurements indicated that the test solution was representative of Newtonian fluid. Samples from the second half of the test exhibited non-Newtonian behavior upon cooling to room temperature.

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research has developed a comprehensive research program to support resolution of Generic Safety Issue (GSI)-191. GSI-191 addresses the potential for debris accumulation on pressurized-water-reactor (PWR) sump screens with the consequent loss of emergency-core-cooling-system (ECCS) pump net-positive-suction-head margin. Among the GSI-191 research program tasks is the experimental investigation of chemical effects that may exacerbate sump-screen clogging.

The Integrated Chemical Effects Test (ICET) Project represents a joint effort by the U.S. NRC and the nuclear utility industry, undertaken through the Memorandum of Understanding on Cooperative Nuclear Safety between NRC and EPRI, Addendum on Integral Chemical Effects Testing for PWR ECCS Recirculation. The ICET Project simulates the chemical environment present inside a containment water pool after a loss-of-coolant-accident and monitors the chemical system for an extended period of time to identify the presence, composition, and physical characteristics of chemical products that form during the test. The ICET test series is being conducted by Los Alamos National Laboratory at the University of New Mexico, with the assistance of professors and students in the civil engineering department.

This report describes the ICET experimental apparatus and surveys the principal findings of Test #1. As an interim data report compiled during preparation for subsequent ICET tests, this description summarizes both primary and representative findings that were available at the time the report was prepared. It is anticipated that additional analyses will be conducted by the NRC and the nuclear power industry to enhance the understandings obtained from this test.

All of the ICET tests are being conducted in an environment that simulates expected containment pool conditions during recirculation. The initial chemical environment contains 2800 mg/L of boron, 100 mg/L of hydrochloric acid (HCl), and 0.7 mg/L of lithium hydroxide (LiOH). Tests are conducted for 30 days at a constant temperature of 60°C (140°F). The materials tested within this environment include representative amounts of submerged and unsubmerged aluminum, copper, concrete, zinc, carbon steel and insulation samples. Representative amounts of concrete dust and latent debris are also added to the test solution. Tests consist of an initial 4-hour spray phase to simulate containment spray interaction with the unsubmerged samples. Water is circulated through the bottom portion of the test chamber during the entire test to achieve representative flow rates over the submerged specimens.

ICET Test #1 was conducted using NaOH to control pH, with a target pH of 10. Insulation samples consisted of scaled amounts of NUKON™ fiberglass material. In addition, 373 metal coupon samples and 1 concrete sample were contained within the test apparatus. Process control consisted of monitoring online measurements of recirculation flow rate, test solution temperature, and pH. Flow rate and temperature were controlled to maintain the desired values of 25 gpm and 140°F. Daily water samples were obtained to conduct pH, turbidity, total suspended solids, kinematic viscosity, and shear-dependent viscosity measurements, and for analytical laboratory evaluations of the chemical elements present. In addition, microscopic evaluations were conducted on water sample filtrates, fiberglass, coupons, sediment, and precipitated solids.

An initial amount of NaOH was included with the test solution and the other test chemicals before the test. The remaining NaOH was injected during the first 30 minutes of the 4-hour spray phase, and the amount of injected NaOH was determined so that the spray fluid pH did not exceed a value of 12 during the injection phase. At the end of NaOH injection, the test solution pH was approximately 9.5. The test solution pH decreased slightly during the test and was approximately 9.4 at the end of the test. The test

ran uninterrupted for 30 days, and the conditions were maintained within the accepted flow and temperature ranges.

Observations of the test solution indicated different behavior of the solution at room temperature vs test temperature. At 140°F, no chemical byproducts were visible in the water. However, at room temperature, precipitates were observed after 8 hours into the test and throughout the 30-day run. Turbidity and total suspended solids also increased from test temperature as the solution was cooled to room temperature.

Analyses of the test solution indicated that high levels of aluminum were present, with levels rising from near zero at the beginning of the test to approximately 350 mg/L after 20 days of testing. This effect was further indicated in posttest examinations of the submerged aluminum sample coupons, each of which lost approximately 25% of its pretest mass.

Examinations of fiberglass taken from the test apparatus after 15 days of testing indicated evidence of chemical products and a web-like material that spanned individual fibers. After 30 days of testing, the web-like material was more prevalent, and contiguous webbing appeared to span multiple fibers.

Daily measurements of the constant-shear kinematic viscosity revealed an approximately constant value at test temperature for both filtered and unfiltered samples. However, upon cooling to room temperature, the filtered and unfiltered sample viscosity started increasing after approximately 4 days of testing through approximately 23 days. Shear-dependent viscosity measurements indicated that the test solution was representative of Newtonian fluid. Samples from the second half of the test exhibited non-Newtonian behavior upon cooling to room temperature.

The ICET test series is being conducted under an approved quality assurance (QA) program, and QA procedures and project instructions were reviewed and approved by the project sponsors. Analytical laboratory results are generated under an EPA-approved quality control (QC) program, and other laboratory analyses are performed using standard practices as referenced in the body of this report.

ACKNOWLEDGMENTS

The principal authors of this report gratefully acknowledge the assistance of the following persons, without whom successful completion of the first Integrated Chemical Effects Test (ICET) could not have been accomplished. Graduate students Will Roesch and James Madrid of Los Alamos National Laboratory's (LANL's) Nuclear Design and Risk Analysis Group worked tirelessly to help design and construct the apparatus, manage all aspects of sample coupon preparation, and assist with daily water sampling. Mr. John Gisclon, the Electric Power Research Institute ICET Test Program Lead, contributed much practical, timely advice on preparation of the quality assurance (QA) program and experimental procedures and spent several weekends of personal time observing and helping to guide preparation of the test apparatus. Mr. Tim Andreychek of Westinghouse Electric Company, LLC, coordinated preparation of the ICET test plan and provided practical advice on the instrumentation and experimental procedures implemented for the test series. Dr. Al Csontos from the United States Nuclear Regulatory Commission (NRC) was instrumental in identifying the diagnostic methods and University of New Mexico resources needed for sample inspection and identification of gelatinous chemical reaction products. Mr. Michael Niehaus from Sandia National Laboratories provided a characterization of time-dependent strain-rate viscosity measurements for the circulating solution. Dr. William Kubic of LANL's Nuclear Design and Risk Analysis Group (D-5) performed initial literature reviews explaining the various precursor indications of gel formation and reviewed chemical engineering calculations critical to test performance quality. Mr. Luke Bartlein, also of Group D-5, contributed to the design and fabrication of the test tank and specification of equipment. Mr. James Young, of Group PS-1, provided valuable reviews and inputs to QA documentation and practices. The authors also express their gratitude for the contributions and continued participation of numerous NRC staff members who reviewed the QA program, test procedures, project instructions, and preliminary data to ensure relevance to plant safety, high-quality defensible results, and timely execution of this test.

Ms. Nancy Butner provided invaluable assistance with project management, budget analysis and reporting, contract administration, and final report preparation.

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ABBREVIATIONS

BSE	Back-Scattered Electron
CPVC	Chlorinated Polyvinyl Chloride
DAS	Data Acquisition System
DHR	Decay Heat Removal
ECCS	Emergency Core-Cooling System
EDS	Energy-Dispersive Spectroscopy
EPRI	Electric Power Research Institute
ICET	Integrated Chemical Effects Tests
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectroscopy
IOZ	Inorganic Zinc
LANL	Los Alamos National Laboratory
LCS	Lab Control Spike
LOCA	Loss-of-Coolant Accident
MB	Method Blank
MD	Matrix Duplicate
MS	Matrix Spike
MSDA	Matrix Spike Duplicate Accuracy
NRC	Nuclear Regulatory Commission
NTU	Nephelometric Turbidity Unit
ppt	Precipitate
PVC	Polyvinyl Chloride
PWR	Pressurized-Water Reactor
QA	Quality Assurance
QC	Quality Control
RO	Reverse Osmosis
SEI	Secondary Electron Image
SEM	Scanning Electron Microscopy
SS	Stainless Steel
T1	ICET Test #1
TEM	Transmissive Electron Microscopy
TSP	Trisodium Phosphate
TSS	Total Suspended Solid
UNM	University of New Mexico
U.S.	United States
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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1.0 INTRODUCTION

The Integrated Chemical Effects Test (ICET) Project represents a joint effort by the United States (U.S.) Nuclear Regulatory Commission (NRC) and the nuclear utility industry[1] to simulate the post-loss-of-coolant-accident (LOCA) chemical environment present inside a containment structure and to monitor the chemical system for an extended period of time to identify the presence, composition, and physical characteristics of chemical products that may form. Among the many secondary objectives (not addressed by the ICET Project), should products of this nature be found during the ICET series, are interests in determining the cause and potential quantity of the products and to characterize their head-loss properties in combination with fibrous debris. The ICET test series is being conducted by Los Alamos National Laboratory (LANL) at the University of New Mexico (UNM), with the assistance of professors and students in the civil engineering department.

This report describes the ICET experimental apparatus and procedures and surveys the principal data and observations from Test #1. As an interim data report compiled during preparation for subsequent ICET tests, this exposition summarizes both primary and representative findings, but it cannot be considered comprehensive. For example, only a small selection out of several hundred photographs is presented here. In addition, this report focuses on the presentation of observations and data without in-depth analyses or interpretations. Observed trends and typical behaviors are noted. Section 2 of this report presents more thoroughly the objectives and background of the ICET test series. Section 3 describes the experimental apparatus, the analytic methods used to characterize samples, and the quality assurance (QA) process that governs the performance of these tests. Section 4 presents key results in both graphical and narrative form. Section 5 addresses some of the practical lessons learned during Test #1 and makes recommendations for minor changes to the experimental procedure to improve subsequent tests.

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2.0 BACKGROUND AND OBJECTIVE

Containment buildings of pressurized-water reactors (PWRs) are designed to accommodate the energy release following a postulated accident. They also permit recirculation of reactor coolant and emergency-core-cooling-system (ECCS) water to the decay heat removal (DHR) heat exchangers. The water collected in the sump from the reactor coolant system, the safety injection system, and the containment spray system is recirculated to the reactor core to remove residual heat. The sump contains a screen that protects system structures and components in the containment spray and emergency-core-cooling-system (ECCS) flow paths from the effects of debris that could be transported to the sump. Concerns have been raised that fibrous insulation material could form a mat on the screen, which would obstruct flow, and that chemical reaction products such as gelatinous or crystalline precipitates could migrate to the screen, causing further blockage and increased pressure-head losses across the debris bed. Other adverse chemical effects include the possibility of increased bulk fluid viscosity that also would increase flow losses through a debris bed.

The ICET test series was conceived as a limited-scope suite of five different tests containing different constituents, with each test lasting between 15 and 30 days. A complete rationale for the selection of these test conditions is provided in Ref. 2, but in brief, the ICET apparatus consists of a large stainless-steel (SS) tank with heating elements, spray nozzles, and associated recirculation pump and piping to simulate the post-LOCA chemical environment. Samples of structural metals, concrete, and insulation debris are scaled in proportion to their relative surface areas found in containment and in proportion to a maximum test dilution volume of 250 gal. of circulating fluid. Representative chemical additives, temperature, and material combinations are established in each test; the system then is monitored while corrosion and mixing occur for a duration comparable to the ECCS recirculation mission time.

The primary objectives for the ICET test series are to (1) determine, characterize, and quantify chemical reaction products that may develop in the containment sump under a representative post-LOCA environment; and (2) determine and quantify any gelatinous material that could be produced during the post-LOCA recirculation phase. For the purpose of this report, the term “gelatinous material” generically refers to any observed sample constituent with amorphous, hydrated, or noncrystalline physical characteristics. This adjective is sufficient to distinguish from chemical products that are crystalline in nature, but it is not intended to imply any specific head-loss behavior. The ICET series is not presently designed to test the head-loss characteristics of chemical products that might be observed.