TOPICAL REPORT SAFETY EVALUATION (TRSE)

BY THE OFFICE OF NEW REACTORS OF

TOPICAL REPORT APR1400-Z-M-TR-12003-P, REVISION 0,

“FLUIDIC DEVICE DESIGN FOR THE APR1400”

KOREA HYDRO & NUCLEAR POWER CO., LTD.

PROJECT NO. PROJ0782

CONTENTS

1.0 INTRODUCTION

In support of the application for the design certification for the Advanced Power Reactor 1400 (APR1400), Korea Hydro & Nuclear Power Co., Ltd., hereinafter referred to as the applicant, submitted Topical Report APR1400-Z-M-TR-12003-P, Revision 0, “Fluidic Device Design for the APR1400” (Reference 1). The APR1400 design uses pressurized safety injection tanks (SITs) installed with passive, flow controlling fluidic devices (FD) as a part of the emergency core cooling system (ECCS) design, otherwise referred to as the safety injection system (SIS). The APR1400 SIT with FD (SIT-FD) is designed on the operating experience of a conventional accumulator used for mitigating the consequences of loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWRs). Similar to the conventional accumulators used in the operating PWR plants, the SIT is an accumulator tank partially filled with borated water and pressurized with nitrogen. The APR1400 SIT design differs from the conventional accumulators in that it incorporates a flow controlling FD at the exit of the tank to provide a means for passive flow control. The SIT is attached to the primary system through a series of check valves and an isolation valve, and is aligned during normal plant operation to allow flow into the primary coolant system if the primary system pressure drops below the pressure setpoint of the SIT. The flow controlling FD can provide an extended injection flow rate without the need for any moving parts.

Emergency core cooling (ECC) during a LOCA is one of the primary functions of the ECCS. In a conventional nuclear plant, the ECCS consists of accumulators, the high-head SIS, and the low-head SIS to accomplish the ECC functions. During a large break LOCA (LBLOCA), the fuel cladding temperature increases due to the lack of liquid around the core. A LBLOCA generally includes blowdown, refill, reflood, and long-term cooling phases. After the initial blowdown, the ECCS is required to inject water into the core to limit the rise of fuel temperature in three steps. In the refill phase, the accumulators quickly inject water at a high flow rate to fill the lower plenum and downcomer of the reactor vessel. Subsequently, the core is reflooded by the water head in the downcomer, and the high-head SIS and low-head SIS inject flow to keep high water level in the downcomer to maintain reflooding of the core. In the long-term cooling phase after core reflood is completed, the low-head SIS provides water to remove decay heat and maintain the core in a flooded state.

In the APR1400 SIS design, the SIT switches its flow rate from large-flow injection to small-flow injection automatically and passively after the water level in the tank drops below the top of the standpipe. During a LBLOCA, it is necessary to start the SIS pumps prior to the end of accumulator injection. The SIT injects water for a longer period of time than a conventional accumulator, thereby allowing more time to start the SIS pumps.

Topical Report APR1400-Z-M-TR-12003-P, Revision 0, “Fluidic Device Design for the APR1400,” (Reference 1) describes the SIT-FD design, the principles of operation and important design features of SIT-FD, as well as full scale experiments confirming the performance of the SIT-FD.

2.0 REGULATORY BASIS

The staff's review of APR1400-Z-M-TR-12003-P, Revision 0, is based on conformance with the following regulatory requirements:

General Design Criterion (GDC) 35, "Emergency Core Cooling," in Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR) as it relates to the requirement of a system that would provide abundant ECC to satisfy the ECCS safety function of transferring heat from the reactor core following any loss of reactor coolant at a rate such that: (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.

Section 50.46 of 10 CFR, "Acceptance Criteria for Emergency Core Cooling Systems for Light-water Nuclear Power Reactors," as it relates to the ECCS equipment being provided that refills the reactor vessel in a timely manner for a LOCA resulting from a spectrum of postulated piping breaks within the reactor coolant pressure boundary. The ECCS cooling performance following postulated LOCAs must be calculated in accordance with an acceptable evaluation model to demonstrate conformance to the following acceptance criteria set forth in 10 CFR 50.46(b):

- The calculated maximum fuel element cladding temperature does not exceed 1200 degrees Celsius (°C) (2200 degrees Fahrenheit (°F)).

- The calculated total local oxidation of the cladding does not exceed 17 percent of the total cladding thickness before oxidation. Total local oxidation includes pre-accident oxidation as well as oxidation that occurs during the course of the accident.

- The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam does not exceed one percent of the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

- Calculated changes in core geometry are such that the core remains amenable to cooling.

- After any calculated successful initial operation of the ECCS, the calculated core temperature is maintained at an acceptably low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.

Section 50.46(a)(1)(i) of 10 CFR, also requires that for the realistic analysis of the ECCS cooling performance, the uncertainties in the analysis method and input must be identified and assessed so that the uncertainty in the calculated results can be estimated and accounted for.

The APR1400 SIS design, including the SITs, must comply with GDC 35, and the cooling performance will be evaluated through the safety analyses of LOCA for the full spectrum of break sizes (including LBLOCA and small break LOCA) to demonstrate that the above acceptance criteria are met. The staff's approval of the APR1400 SIS design requirements, which are intended to comply with GDC 35, are not documented in this safety evaluation report (SER), but instead, will be documented in the SER of the applicant's LBLOCA topical report (Reference 6).

The staff's evaluation of this topical report (Reference 1) includes the evaluation of the uncertainties and applicability of the experimental results to APR1400 as part of the LOCA evaluation models for the calculation of the APR1400 ECCS capability, as required by 10 CFR 50.46 and GDC 35.

3.0 TECHNICAL EVALUATION

The APR1400 SIS configuration includes four SITs connected to the reactor coolant system (RCS) via the direct vessel injection (DVI) nozzles. In addition, four safety injection pumps (SIPs) inject directly into the reactor vessel downcomer following a safety injection (SI) actuation signal.

Each SIT-FD consists of a tank partially filled with borated water and pressurized with nitrogen, and a FD inside the tank at the tank exit. The FD consists of a vortex chamber, a partition plate for segregating large and small flow, a standpipe connected to the supply port, control ports which are open to the liquid in the SIT at all times, an exit nozzle connected to the outlet port of the vortex chamber and the injection pipe. The configuration and typical flow pattern of the SIT-FD design is shown in Figure 2.2-1, "Structure of the APR1400 SIT installed with the Fluidic Device," Figure 2.2-2, "Structure of the Fluidic Device," and Figure 2.2-3, "Illustration of a Typical Flow Pattern inside the Vortex Chamber (a) Large Flow Rate Condition (b) Small Flow Rate Condition," (Reference 1).

When a LOCA occurs and pressure in the reactor vessel decreases below the SIT pressure, the check valves in the injection pipe open to permit the injection of the SIT injection water into the reactor vessel. With the initial water level in the SIT higher than the elevation of the inlet to the standpipe, water flows into the vortex chamber through the large-flow rate supply nozzles and small-flow rate control nozzles. These flows collide with each other at a design facing angle between the large flow and small flow inlet nozzles of the vortex chamber to decrease angular momentum, thus preventing a strong vortex formation in the vortex chamber. Consequently, the flow resistance in the vortex chamber is small, resulting in a large flow rate.

The large-flow injection phase continues until the water level in the SIT falls below the inlet elevation of the standpipe, and the flow in the standpipe decreases rapidly. The flow from the small-flow control ports enters the vortex chamber tangentially through only the control nozzles, which creates a strong vortex in the vortex chamber. The vortex in the chamber creates a large resistance to flow, and therefore, results in a small-flow injection rate. The switching from the large-flow to small-flow injection phase is thus accomplished passively without any moving parts.

The APR1400 SIT is designed with two performance objectives: (1) immediately after the reactor coolant blowdown during a LBLOCA, the SIT injects borated water at a large flow rate for a limited duration of time to refill the reactor vessel lower plenum and downcomer, and (2) after the refill period, it injects water at a relatively small flow rate to establish the core reflooding condition by maintaining the downcomer water level. To achieve these performance objectives, Section 2.3, “Design Requirements of the SIT-FD,” (Reference 1) describes the determination of the design parameters for the large flow and small flow injection phases, respectively, based on a hypothetical LBLOCA sensitivity analysis. The water volume above the top of the standpipe in the SIT is the large flow injection water volume needed to refill the reactor vessel lower plenum and downcomer during the refill phase of a LOCA. The injection flow rates for the large-flow and small-flow injection phases, respectively, are designed to refill the lower plenum and downcomer as rapidly as possible and to provide a sufficient reflood rate to assure the peak cladding temperature is within the acceptance criteria during the worst case LOCA as evaluated in Reference 6.

The design requirement for the total pressure loss coefficient of the SIT-FD injection flow path for the large flow phase is calculated based on the refill injection rate requirement, the SIT pressure, and the RCS depressurization transient. The design requirement for the total pressure loss coefficient of the SIT-FD injection flow path for the small flow phase is calculated based on the requirements of the minimum flow rate and injection duration to keep the downcomer filled with water and to preclude the core boil-off rate from exceeding the SIP injection rate. The FD pressure loss coefficients for the large-flow and small-flow phases, respectively, are obtained by subtracting the pressure loss coefficient of the SI line from the SIT-FD nozzle to the DVI nozzle from the total pressure loss coefficient of the FD and SI line combined. The LBLOCA sensitivity study establishes the design requirements for the target FD pressure loss coefficients and water injection volumes for the large-flow and small-flow injection phases, respectively. The design specifications of the SIT-FD as summarized in Table 3.1-1, “Specification of the SIT,” of the topical report (Reference 1), includes additional margins from the results of the sensitivity analysis. Section 3.1, “Safety Injection Tank,” presents the detailed design of the “as installed” SIT with the structure of the SIT-FD depicted in Figure 3.1-1, “Drawing of the SIT (Side View),” and Figure 3.1-2, “Drawing of the SIT (Top View),” of the topical report (Reference 1).

3.1 Evaluation of SIT Performance

3.1.1 Full Scale Tests

The FD is designed to act as a passive flow controller where flow decreases rapidly as the water level in the tank decreases below the height of the standpipe entrance. The applicant conducted four series of full-scale performance verification tests at the Valve Performance Evaluation Rig (VAPER) test facility at the Korea Atomic Energy Research Institute to confirm the operational principles of the FD, and examine the performance of the SIT-FD. The full scale test facility, VAPER, consists of the SIT installed with the FD, a compressed air supply system, SIT water discharge pipe line and associated valves, SIT water supply and recirculation system, stock tank, and a data acquisition and control system as shown in Figure 4.1-1, “Schematic of the VAPER Facility,” of the topical report (Reference 1). The SIT of the VAPER facility was manufactured to have the same inner diameter, height, and volume of the APR1400 SIT. The stock tank, which receives the discharged contents of the SIT during the tests, is kept at atmospheric pressure. No scaling analysis was needed.

Two series of tests, identified as the Case-01 series and the Case-02 series, correspond to the standard FD tests; that is, the FD in these two series of tests has almost the same geometrical dimensions as the FD of the APR1400, but the Case-02 series has a slightly higher stand pipe than the Case-01 series in order to examine the effect of the stand pipe height on FD performance. The other two series of tests, identified as the Case-03 series and the Case-04 series, are sensitivity tests to evaluate the effects of manufacturing tolerances. The details of the test objectives, test apparatus, and test results for these tests are described in Section 4, "Performance Verification Tests," of the topical report (Reference 1).

Three Case-01 tests were performed at the reference test conditions, shown in Table 4.2-1, "Reference Test Conditions for the Performance Verification Tests of the VAPER SIT," of the topical report, (Reference 1), in order to check the repeatability of the test results. One additional Case-01 test was performed at approximately half of the reference pressure in order to evaluate the reliability of the pressure drop characteristics of the FD. The test conditions of Case-01 tests are summarized in Table 4.2-2, "Test Conditions of Case-01 Tests," of the topical report (Reference 1). A total of four tests were performed as a part of the Case-01 series.

Three Case-02 tests were also performed at the reference test conditions to check the repeatability of the tests. Case-02 tests utilized a stand pipe which was approximately 12.87 inches higher than the stand pipe in Case-01. The test conditions for Case-02 are summarized in Table 4.2-3, "Test Conditions of Case-02 Tests," of the topical report (Reference 1). A total of three tests were performed as a part of the Case-02 series.

In addition, three Case-03 and three Case-04 sensitivity tests were performed at the reference test conditions to ensure repeatability of the tests. Case-03 tests utilized vortex chamber height reduction and Case-04 tests utilized vortex chamber height reduction as well as control nozzle width enlargement to assess the effect of maximum expected manufacturing tolerances. A total of three tests were performed as a part of the Case-03 series and a total of three tests were performed as a part of the Case-04 series.

Overall, these tests were performed with the objective of confirming the following characteristics:

- Principle and performance of SIT-FD.
- Passive injection flow control performance.
- Independence of pressure loss coefficient of the FD from initial pressure, height of stand pipe, and expected manufacturing tolerances.

A total of 13 tests were conducted as a part of the applicant's full-scale testing program for the SIT-FD system.

The staff reviewed the test facility setup, test cases, quality assurance program (QAP), and experimental procedures associated with the SIT-FD full scale testing program. The staff noted that the applicant designed the test cases to cover the major phenomena associated with the SIT-FD, such as, stand pipe height and initial internal pressure. The staff determined that the number and variety of test cases proposed by the applicant would be sufficient to validate whether or not the SIT-FD evaluated in the full-scale testing program could satisfy the design requirements of the APR1400. The staff noted that the QAP for the FD Performance Verification Tests were developed in accordance with 10 CFR Part 50 Appendix B and American National Standards Institute/American Society of Mechanical Engineers NQA-1-1994. The staff also noted that the experimental procedures associated with the SIT-FD full-scale testing program contained provisions for testing the repeatability of the experiments.

During a review of the applicant’s full-scale test facility schematics, the staff discovered a discrepancy between the discharge pipe inside diameter of Figure A-5, “Drawing of the Discharge Pipe connected to the Exit Nozzle,” and descriptions of the discharge pipe provided in Section 4.1.3, “Subsidiary Components,” and Section 5.1, “Representative Pipe Area for the Fluidic Device K-Factor.” Therefore, the staff issued Request for Additional Information (RAI) 2-7371, Question 13 (ADAMS Accession No. ML14100A668), to address this issue. In its response to RAI 2-7371, Question 13 (ML14104A001), the applicant stated that the figure was incorrect. In addition, the applicant provided the staff with the correct figure. In its revised response to RAI 2-7371, Question 13 (ML15166A379), the applicant showed the staff how the topical report (Reference 1) will be updated with the correct figure. Therefore, RAI 2-7371, Question 13, is being tracked as a confirmatory item pending the incorporation of the corrected figure into the topical report (Reference 1).

The staff accepts, pending the inclusion of the corrected figure into the topical report (Reference 1), that the applicant’s full-scale test facility setup and testing procedures provide a sufficient and adequate means for testing the SIT-FD to validate whether or not it satisfies the APR1400 design requirements.

3.1.2 Performance of the FD during Large and Small Flow Phases

During a LOCA, there is initially large flow injection from the accumulator when the check valve in the injection pipe opens in response to the decrease in RCS pressure below the SIT pressure setpoint. The flow decreases, as the water level in the SIT decreases and the level reaches near the entrance to the standpipe. The large flow injection phase occurs as the combination of flow from the standpipe and the flow from the small-flow control ports. Due to the supply nozzle injection in conjunction with the control nozzle injection into the vortex chamber, no strong vortex is allowed to form and the net flow is radial in the vortex chamber, thus allowing for a small flow resistance. As the flow in the standpipe decreases, the majority of flow into the vortex chamber comes from the tangential control nozzles, thus forming a strong vortex with a large increase in flow resistance resulting in a lower injection flow rate. During the switching of flow from the large-flow to the small-flow injection phase, the water level in the standpipe undergoes a transient due to inertial effects. When the water level of the SIT drops below the top of the stand pipe, the water level in the stand pipe decreases abruptly and reaches the lowest level, from which it slightly recovers thereafter. Finally, the water level in the SIT decreases gradually due to the increase in flow resistance.

The staff reviewed the applicant’s tests results to verify the performance of the FD during large and small flow injection phases. The staff noted that when the SIT water level was above the top of the standpipe, the injection flow rate was substantially larger than when the SIT water level was below the top of the standpipe. The staff also noted that the small flow injection phase lasted substantially longer than the large flow injection phase. Based on the review of the test results, the staff determined that the measured FD K-factors confirmed the injection flow rates, observed in both the large flow and small flow injection phases.

Based on the test results, the staff was unable to gather an understanding for cavitation at the throat of the exit nozzle of the FD. Therefore, the staff issued RAI 2-7371, Question 15 (ML14100A668), requesting that the applicant consider the effects of cavitation on the FD performance, since the performance of the SIT-FD can be affected by vaporous pocket formations impeding flow. In its partial response to RAI 2-7371, Question 15 (ML14104A001), the applicant committed to providing a subsequent technical report of a computational fluid dynamics (CFD) analysis with an evaluation of the effects of cavitation on FD performance. In its full response to RAI 2-7371, Question 15 (ML14164A169), the applicant submitted APR1400-K-A-NR-14005-P, Revision 0, “CFD Analysis of Fluidic Device,” (Reference 2) which fulfilled this commitment. The CFD analysis qualitatively confirmed vaporous cavitation occurrence in the center of the exit nozzle in both large and small flow modes. The applicant’s response included justification that the full-scale VAPER test results inherently include any effects due to cavitation. The staff evaluated the CFD analysis and confirmed the qualitative confirmations of vaporous cavitation occurrence. The staff accepts the conclusion that the full-scale experimental tests capture the effects of cavitation. Therefore, RAI 2-7371, Question 15, is resolved and closed.

Test Case-03 and Test Case-04 were conducted to analyze the effects of manufacturing tolerances on the FD K-factor. The staff noted that the experimental results show that the manufacturing tolerances, associated with Case-03 and Case-04, have an insignificant effect on the measured FD K-factor. The staff issued RAI 2-7371, Question 17 (ML14100A668), asking the applicant about how the facing angle uncertainty of the nozzle design in the FD might affect the FD K-factor. The CFD analysis (Reference 2) also analyzed the effect of this manufacturing tolerance by varying the nominal facing angle. In its response to RAI 2-7371, Question 17 (ML14164A169), the applicant showed that the APR1400 design requirement range for the SIT-FD K-Factor bounds the CFD results. The staff evaluated the CFD analysis on the effect of the manufacturing tolerance of the facing angle and confirmed that the design requirements for the APR1400 SIT-FD, bound the computational results. Furthermore, the staff concluded that since the manufacturing tolerance uncertainties, as evaluated in the full scale tests, have an insignificant effect on the measured K-Factor, then the manufacturing tolerance of the facing angle will exhibit the same behavior; and ultimately, the design requirements for the SIT-FD will remain bounding. In addition, the random uncertainty included in the uncertainty analysis as part of the final K-Factor values accounts for manufacturing tolerances. Therefore, RAI 2-7371, Question 17, is resolved and closed.

The staff evaluated the full scale testing results and confirmed that the performance of the SIT-FD during large and small flow injection phases behaves as intended by the applicant’s design. The results of these tests showed that a large flow rate manifests when the tank water level is above the standpipe; and when the water level in the tank falls below the inlet of the standpipe, the injection flow rate decreases significantly. The accompanying CFD analysis qualitatively confirms vortex formation inside the FD as well as cavitation effects during large and small flow injection phases. The staff’s evaluation concludes that the design requirements of the APR1400 SIT-FD bound all full-scale experimental and computational results of the applicant’s test program, and that cavitation is inherently accounted for in the full-scale testing. The staff’s evaluation also confirmed the design principle of passive flow control by the FD.

3.1.3 Effect of Dissolved Nitrogen

Fluid in the SIT of the APR1400 is in contact with nitrogen and over time nitrogen will dissolve and diffuse throughout the liquid phase. In the limiting case, water becomes saturated with nitrogen at equilibrium. A potential impact of dissolved gas on the performance of the FD thus exists. As the fluid particles move through the FD, subject to a pressure drop, the dissolved nitrogen gas will emerge out of solution and potentially affect the flow resistance of the FD.

The applicant utilized compressed air as the cover gas and liquid water as the injection fluid. The staff noted that there was no attempt to test dissolved gas in equilibrium with the injection liquid. However, to evaluate the effect of dissolved nitrogen gas on the FD K-factor, the applicant provided an estimate of the dissolved nitrogen flow rate out of solution during the whole injection period. First, the applicant calculated the solubility of nitrogen in the SIT water for SIT water temperatures of 0 °C (32 °F) and 40 °C (104 °F) using the empirical correlation from “Prediction of Nitrogen Solubility in Pure Water and Aqueous NaCl Solutions up to High Temperature, Pressure, and Ionic Strength,” (Reference 5). The staff noted that boron solubility was ignored in the applicant’s analysis. The applicant assumed that the nitrogen gas content in the SIT water reaches the equilibrium state of the solubility given by the empirical correlation during the fast pressure transient process across the FD. Using data obtained from Case-01-01 data, the mass release rate of nitrogen from solution was computed over time for two different temperatures of 0 °C (32 °F) and 40 °C (104 °F). Due to the higher nitrogen gas solubility in water during the large flow rate period, the mass release rate of nitrogen gas was larger during this time compared to the small flow rate period. In the applicant's experiments, it was observed that the air discharged through the empty stand pipe had little effect on the pressure loss coefficient. The applicant concluded that since the air discharge rate peaked at a higher rate than what was obtained from the dissolved nitrogen gas release rate calculation and that the air discharge had little effect on the pressure loss coefficient, then dissolved nitrogen released during the SI period would also have an insignificant effect on the observed pressure loss. The staff reviewed the applicant's dissolved nitrogen calculation and confirmed the applicant's conclusion based on the calculation results.

The staff identified a discrepancy in Table 5.2-1, "N_2 Solubility (kg/kg_{water}) in Pure Water at 0 C," and in Table 5.2-2, "N_2 Solubility (kg/kg_{water}) in Pure Water at 40 °C" (Reference 1). Both tables contained errors in the calculated nitrogen solubility. Therefore, on March 30, 2015, the staff had a clarification phone call with the applicant regarding the errors discovered in the tables. Subsequently, the applicant submitted a revised response to RAI 2-7371, Question 16 (ML15113A290), which corrected the errors in Tables 5.2-1 and 5.2-2. Therefore, RAI 2-7371, Question 16, is being tracked as a confirmatory item pending the incorporation of the corrected nitrogen solubility calculations into Table 5.2-1 and Table 5.2-2 (Reference 1).

Based on the review of the applicant's dissolved nitrogen effect calculation, the staff determined that the calculation's results are acceptable, pending the inclusion of the corrected nitrogen solubility calculations, and approves the applicant's conclusion regarding the insignificance that dissolved nitrogen has on the pressure loss coefficient.

3.1.4 Uncertainty Analysis

The total uncertainty of the pressure loss coefficient developed from the full-scale testing of the FD was computed by systematically evaluating uncertainty contributions from many parameters including, but not limited to, water injection flow rate and pipe cross sectional area. The uncertainties were analyzed at a 95 percent confidence level.

The systematic uncertainty of the SIT water injection flow rate was evaluated by a propagation of the elemental uncertainty sources (water density, SIT cross-sectional area, and SIT water level). The systematic uncertainty of the pressure loss coefficient of the FD was also evaluated through a propagation of the elemental uncertainty sources (FD pressure drop, water density, pipe cross sectional area, and water injection flow rate). The random uncertainty of the pressure loss coefficient of the FD was evaluated by multiplying the coverage factor of the student *t*-distribution with a degree of freedom of 12 (13 total test cases minus 1) with the standard deviation of the pressure loss coefficients from all the test cases. The random uncertainty accounts for the effects of process unsteadiness, differences in test conditions, and manufacturing tolerances. Finally, the total uncertainty of the pressure loss coefficient of the FD was estimated by the root sum square of the systematic and random uncertainties. The applicant's uncertainty analysis concluded that the experimental test results plus uncertainty fall within the design requirement ranges for the APR1400. The staff reviewed and accepts the applicant's uncertainty analysis and confirms that the APR1400 design requirements bound the test results plus uncertainty.

4.0 CONCLUSION

The staff reviewed APR1400 Topical Report APR1400-Z-M-TR-12003-P, Revision 0, “Fluidic Device Design for the APR1400,” (Reference 1), as well as the responses to the staff’s RAIs. As a result of its review, the staff reached the following conclusions:

a) The full-scale test facility provides a sufficient and adequate means for testing the SIT- FD to validate whether or not it satisfies the APR1400 design requirements.

b) The full scale tests demonstrate and confirm that the SITs injection flow is passively controlled by a FD.

c) The performance and design of the SIT-FD evaluated in the full-scale VAPER test facility satisfies the design requirements of the APR1400 SIT-FD, which are intended by the applicant to meet the criteria provided in GDC 35 and 10 CFR 50.46.

d) The applicant has shown that manufacturing tolerances and dissolved nitrogen provide an insignificant effect on the observed pressure loss coefficient of the FD.

e) The applicant has shown that the design requirements of the APR1400 bound all full-scale experimental and computational results with uncertainties.

RAI 2-7371, Questions 13 and 16, are being tracked as confirmatory items pending the incorporation of a corrected figure and a corrected table in the topical reports (Reference 1). Overall, the staff considers the design, testing, and evaluation of the SIT-FD acceptable with limitations identified below.

5.0 LIMITATIONS

The staff’s approval of the APR1400 SIS design requirements, which are intended by the applicant to comply with GDC 35 and 10 CFR 50.46(b), is not documented in this SER, but instead, is pending the approval of the applicant’s LBLOCA topical report (Reference 6). The safety evaluation conducted by the staff and presented herein approves the applicant’s development of the SIT-FD in conformance with a specific set of design and performance requirements of the APR1400.

6.0 REFERENCES

1. “Fluidic Device Design for the APR1400,” APR1400-Z-M-TR-12003-P, Revision 0, issued December 2012 (ML13018A194).

2. “CFD Analysis of Fluidic Device,” APR1400-K-A-NR-14005-P, Revision 0, issued June 2014 (ML14164A170).

3. ANSYS CFX 14.5 Documentation, “Theory Guide,” issued November, 2011.

4. ANSYS CFX-Solver Theory Guide, Release 12.1, issued November, 2009.

5. R. Sun, W. Hu, Z. Duan, “Prediction of Nitrogen Solubility in Pure Water and Aqueous NaCl Solutions up to High Temperature, Pressure, and Ionic Strength,” Journal of Solution Chemistry, Vol. 30, No. 6, pp. 561-573, issued 2001.

6. “Realistic Evaluation Methodology for Large-Break LOCA of the APR1400,” APR1400-F-A-TR-12004-P, Revision 0, issued December 2012 (ML13023A081).

7.0 LIST OF ACRONYMS

ADAMS	Agencywide Documents Access and Management System
APR1400	Advanced Power Reactor 1400
CFD	Computational Fluid Dynamics
CFR	Code *of Federal Regulations*
DVI	Direct Vessel Injection
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System
FD	Fluidic Device
GDC	General Design Criteria
LBLOCA	Large Break Loss-of-Coolant Accident
LOCA	Loss-of-Coolant Accident
NRC	U. S. Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
QAP	Quality Assurance Program
RAI	Request for Additional Information
RCS	Reactor Coolant System
SER	Safety Evaluation Report
SI	Safety Injection
SIP	Safety Injection Pump
SIS	Safety Injection System
SIT	Safety Injection Tank
SIT-FD	Safety Injection Tank with Fluidic-Device
VAPER	Valve Performance Evaluation Rig