Evaluation of Safety Injection and Shutdown Cooling Piping applied to the graded approach for the APR1400

Revision 1

Non-Proprietary

May 2018

REVISION HISTORY

Revision	Date	Page	Description
0	July 2017	All	Standard Issue
1	May 2018	ABSTRACT NOMENCLATURE Pages 1, 9, 12, 15 , 16	The descriptions of environmental fatigue evaluation for DVI and SC piping subsystems are added by the response to piping audit “4/4/2017 piping audit questions and comments to be discussed with KHNP”
		Pages 4, 7	The “Class 1 piping” is changed to “Fatigue Evaluation” to describe the sentence clearly
		Pages 10, 11, 57, 58, 81, 82	The results of environmentally assisted fatigue analysis for DVI and SC piping subsystems are added by the response to piping audit “4/4/2017 piping audit questions and comments to be discussed with KHNP”
		Pages 84, 85	The referred documents in REFERENCE are added for environmentally assisted fatigue analysis

ABSTRACT

This report is in response to the Question No. 03.12-2 in RAI No. 35-7955, and provides summary information on the piping analysis approach and results as well as methodology of the piping analysis, necessary to support safety determination of the Safety Injection (SI) and Shutdown Cooling (SC) piping systems. To demonstrate that the subject piping, which has been structurally evaluated based on the graded approach described in DCD Tier 2, Section 14.3.2.3, conforms to the requirements of ASME B&PV Code, Section III, mandated by 10CFR50.55a, the following information is provided:

- A tabulated, quantitative summary of the calculated maximum stresses and fatigue usage factors (if applicable) with a comparison to ASME B&PV Code allowable for each Code equation.
- For equipment nozzles, a tabulated quantitative summary of the calculated reaction loads compared to the specific nozzle allowable values.
- For containment penetrations, quantitative maximum calculated results compared to the allowable values.

Additionally, environmental fatigue evaluation is performed by incorporating the life reduction of the metal components due to the effect of the light water reactor (LWR) environments. Environmentally Assisted Fatigue (EAF) analysis is performed for the DVI and SC piping subsystems in accordance with Regulatory Guide 1.207.

Based on the review of summary information and component design drawings provided in this report, it is concluded that the APR1400 Safety Injection and Shutdown Cooling piping that are included in the scope of Class 1 piping system design based on the graded approach, demonstrates the conformance to the requirements of ASME B&PV Code, Section III.

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1.0 INTRODUCTION

1.1 Graded Approach

Design of Class 1, 2 and 3 piping and components contained in the piping subsystems shall comply with the requirements of ASME Section III (Reference 10.1), subsections NB, NC and ND, respectively, for the conditions described in Section 5.0 of this report. In determination of the scope of piping system and component design for APR1400 DC, the concept of graded approach consistent with SECY-90-377 is taken as documented in DCD Tier 2, Subsection 14.3.2.3.

Piping subsystems analyzed for design certification are selected based on the safety significance. Piping subsystem for one SI piping with DVI (Direct Vessel Injection) and another for SC piping are selected as the representative Class 1 piping subsystems for the RCS (Reactor Coolant System) branch lines, based on the pipe size. The other lines are smaller in size and have no significant impact to RCS integrity. Out of the four direct vessel injection lines and the two shutdown cooling lines, which have symmetric arrangements, only one line for each system is analyzed as a representative case. This report summarizes the analysis results for RCS branch piping comprised of Class 1 and 2 piping based on the graded approach.

1.2 Scope of Report

The scope of this report consists of the documentation of Code (NB/NC-3650) compliance of the Class 1 and 2 piping components identified on the analytical drawings for the two representative piping subsystems, namely, SI101 and SI105 including fatigue analysis of Class 1 piping components for which usage factors are calculated using S-N curve provided in ASME Boiler and Pressure Vessel Code (Reference 10.1). Also, environmental fatigue analysis is performed using new S-N curve based on NUREG/CR-6909 (Reference 10.6) in accordance with USNRC Regulatory Guide 1.207 (Reference 10.7). Boundaries for subsystems SI101 and SI105 are described in Figure 1.3-1 and 1.3-2, respectively.

1.3 Piping Subsystem Description

1.3.1 SI101

The subject piping subsystem is routed from Reactor Vessel DVI nozzle to containment shell penetration . It also branches off to Safety Injection Tank Nozzle.

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Figure 1.3-1 Subsystem SI101 Boundary

1.3.2 SI105

This subject piping subsystem consists of the suction line of shutdown cooling system and the hot leg injection line of safety injection system. This subsystem is routed from the shutdown cooling system outlet nozzle on hot leg of reactor coolant system to containment shell penetrations.

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Figure 1.3-2 Subsystem SI105 Boundary

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

2.1 Conclusions

In this report, summary information on the piping analysis approach and results as well as methodology necessary to support safety determination of the Safety Injection (SI) and Shutdown Cooling (SC) piping are provided.

Based on the information provided in this report, it is concluded that the APR1400 SI and SC piping comprised of Class 1 and 2 piping and included in the scope of Class 1 piping system and component design, demonstrates the conformance to the requirements of ASME B&PV Code, Section III, mandated by 10CFR50.55a, based on the graded approach.

2.2 Fatigue Evaluation of SI101

The NB-3653 stress intensity ranges and usage factors calculated at the most highly stressed locations in the subsystem SI101 are listed in Table 2.2-1. The design of this subsystem meets all stress limitations specified in paragraphs NB-3653 and NB-3654. For all pairs of load sets, thermal stress ratchet is evaluated based on NB-3653.7 or NB-3222.5. The highest data points of thermal stress ratchet are listed in Table 2.2-2.

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Table 2.2-1 Location of Five Highest Usage Factor in SI101

Table 2.2-2 Location of Highest Thermal Stress Ratchet in SI101

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2.3 Fatigue Evaluation of SI105

The NB-3653 stress intensity ranges and usage factors calculated at the most highly stressed locations in the subsystem SI105 are listed in Table 2.3-1. The design of this subsystem meets all stress limitations specified in paragraphs NB-3653 and NB-3654. For all pairs of load sets, thermal stress ratchet is evaluated based on NB-3653.7 or NB-3222.5. The highest data points of thermal stress ratchet are listed in Table 2.3-2

Table 2.3-1 Location of Five Highest Usage Factor in SI105 TS

Table 2.3-2 Location of Highest Thermal Stress Ratchet in SI105

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2.4 Environmental Fatigue Evaluation of SI101 and SI105

Environmentally assisted fatigue evaluation has been performed for DVI and SC piping subsystems in accordance with the requirements of Regulatory Guide 1.207. Piping locations where CUFs exceed 1.0 using simplified method are further evaluated using detailed method. The eighteen highest EAF analysis results of DVI and SC piping subsystems are provided in Tables 2.4-1 and 2.4-2.

Table 2.4-1 Location of Eighteen Highest Environmental Fatigue Usage Factor in SI101

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Table 2.4-2 Location of Eighteen Highest Environmental Fatigue Usage Factor in SI105

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3.0 NOMENCLATURE

DVI	Direct Vessel Injection
SI	Safety Injection
SC	Shutdown Cooling
α	Coefficient of thermal expansion
C_1, C_2, C_3	Secondary stress indices
E	Modulus of elasticity of the material
K_1, K_2, K_3	Local stress indices
n_i	Number of cycles of load set
N_i	Allowable number of stress cycles
υ	Poisson's ratio
S_p	Peak stress intensity
ΔT_1	Absolute value of the range of the temperature difference between the temperature of the outside T0 and the temperature of the inside surface T1 of the piping product assuming moment generating equivalent linear temperature distribution.
ΔT_2	Absolute valve of the range for that portion of the nonlinear thermal gradient through the wall thickness not included in ΔT1.
S_m	Allowable stress intensity
S_y	Yield strength
P_m	General primary membrane stress intensity
y'	Maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength
S_n	Primary plus secondary stress intensity
S_e	Nominal value of expansion stress
F_{en}	Environmental fatigue correction factor
ε	Strain
$\dot{\varepsilon}$	Strain rate
$\dot{\varepsilon}'$	Transformed strain rate
DO	Dissolved oxygen contents of coolant water
O'	Transformed dissolved oxygen
T'	Transformed temperature
CUF_{en}	Cumulative usage factor in LWR environment

4.0 ASSUMPTIONS AND OPEN ITEMS

4.1 Assumptions

The vendor information in this report is assumed based on the reference plant.

4.2 Open Items

The small bore branch piping of the main line is not included in this analysis based on the decoupling criteria, which is not design in DC design stage. The small bore piping should be evaluated after the design is accomplished.

5.0 ACCEPTANCE CRITERIA

5.1 Primary Loads

The primary load combination definitions and acceptance criteria described in this article are used in conjunction with NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657. The specified condition/service loadings are described in terms of each individual pipe element response moments and the associated coincident internal pressure.

Associated with each loading condition is an acceptance criterion that limits the Equation 9 stress intensity to condition dependent allowable values as indicated below.

Table 5.1-1 Code Allowable

Source of Criterion	Allowable Stress Intensity	Condition
NB-3652	1.5 S_m	Design
NB-3654	1.8 S_m and 1.5 S_y (1)	Service Level B
NB-3655	2.25 S_m and 1.8 S_y (1)	Service Level C
NB-3656	3.0 S_m and 2.0 S_y (1)	Service Level D
NB-3657	1.35 S_y (2) 2.15 S_y - 1.2 P_m (3)	Test

Notes : (1) Lesser of the two quantities
(2) for $P_m \leq 0.67\ S_y$
(3) for $0.67\ S_y < P_m \leq 0.9\ S_y$

5.2 Fatigue Design

The allowable stress intensity range and usage factor acceptance criteria specified in paragraph NB-3653 are used to evaluate component designs covered by this report, for the design conditions itemized in this article.

Table 5.2-1 Allowable Stress Range

Source of Requirement	Acceptance Criteria
NB-3653.1 NB-3653.6 NB-3653.7	1. $S_n \leq 3.0\ S_m$ or 2. Eq. 12 (S_e) $\leq$ $3.0\ S_m$ and Eq. 13 $\leq$ $3.0\ S_m$ and Δ T1 range $\leq$ $y' S_y\ C4/\ 0.7E\alpha$
NB-3222.4 (e) NB-3653.5	Cumulative Usage (2) $U \leq 1.0$

Note : (1) See applicable Code paragraphs for nomenclature.
(2) Calculated per Reference 10.1.

5.3 Environmental Fatigue Design

The environmental fatigue usage factor acceptance criteria specified in USNRC regulatory guide 1.207 are used to evaluate component designs covered by this report.

The effects of reactor coolant water environments on the fatigue life of structural materials are expressed in terms of an environmental fatigue correction factor, F_{en}, which is defined as the ratio of fatigue life in air at room temperature ($N_{air,RT}$) to that in water at the service temperature (N_{water}):

$$F_{en} = N_{air,RT}/N_{water}$$

For Environmentally Assisted Fatigue(EAF), usage factor in air at room temperature is calculated in accordance with ASME Section III code with the new fatigue S-N curve provided in NUREG/CR-6909, Appendix. A Figure A.3 and multiplied by F_{en} to determine the usage factor in the LWR environment.

The acceptance criteria is that the cumulative usage factor in the LWR environment, CUFen, shall not exceed the limit of 1.0 as following;

$$CUF_{en} = U_1 \cdot F_{en,1} + U_2 \cdot F_{en,2} + U_3 \cdot F_{en,3} + U_i \cdot F_{en,i} \cdots + U_n \cdot F_{en,n} \leq 1.0$$

5.3.1 Environmental Fatigue Analysis Procedure

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5.3.2 Environmental Fatigue Analysis Method

NUREG/CR-6909 Appendix A, section A2 provides methodology for calculating the nominal environmental fatigue correction factor, $F_{en,nom}$, which is defined in Eq. A.1 of Reference 10.7. For Austenitic Stainless Steels, $F_{en,nom}$ is given by the following expression in Eq. A.9 of NUREG/CR-6909.

$$F_{en,nom} = exp(0.734- T' \cdot \dot{\varepsilon}' \cdot O')$$

where, T', $\dot{\varepsilon}'$ and O' are transformed temperature, strain rate, and dissolved oxygen (DO) level, respectively, defined as follow:

$T' = 0$	$T < 150°C$
$T' = (T -150)/175$	$150°C \leq T < 325°C$
$T' = 1$	$T \geq 325°C$
$\dot{\varepsilon}' = 0$	$\dot{\varepsilon} > 0.4\%/s$
$\dot{\varepsilon}' = ln(\dot{\varepsilon} /0.4)$	$0.0004 \leq \dot{\varepsilon} \leq 0.4\%/s$
$\dot{\varepsilon}' = ln(0.0004/0.4)$	$\dot{\varepsilon} < 0.0004\%/s$
$O' = 0.281$	*All DO Levels*

5.4 High Energy Line Pipe Break Postulation Criteria

In addition to the ASME Section III Code criteria described above, the portions of the subsystem designated as High Energy Lines requiring break postulation per Reference 10.10 are designed using the acceptance criteria specified below.

Table 5.4-1 Pipe Break Location

Source of Requirement	Acceptance Criteria
Reference 10.10	1. $S_n \leq 2.4\ S_m$ or 2. Eq. 12 (S_e) $\leq 2.4\ S_m$ and Eq. 13 $\leq 2.4\ S_m$
Reference 10.10	Cumulative Usage (2) $U \leq 0.1$

Note : (1) See applicable Code paragraphs for nomenclature.
(2) Calculated per Reference 10.1

6.0 LOAD AND LOAD COMBINATIONS

6.1 Design Basis for Primary Loads

6.1.1 Individual Mechanical Loadings

The individual mechanical loadings used for the primary load design of the subject piping are described below.

6.1.1.1 Normal Operation Weight Loading (WGHT)

Normal Operation Weight Loading is that loading due to the weight of the pipe metal, insulation and its contents during the subsystem normal operating service conditions, all valves and in-line equipment, and any significant support or restraint hardware that is directly supported by the pipe.

6.1.1.2 IRWST Hydro Dynamics Inertia Loading (IRWST)

IRWST Hydro Dynamics Inertia Loading is the inertia portion of the total loading induced by POSRV operation. The inertia loading is the result of excitation amplified by building response motion. (Reference 10.14 and 10.18).

6.1.1.3 Safe Shutdown Earthquake Inertia Loading (SSE)

Safe Shutdown Earthquake Inertia Loading is the inertia portion of the total loading induced by Safe Shutdown Earthquake excitation amplified by building response motion (Description in Reference 10.11 and 10.14).

6.1.1.4 RCS Branch Line Pipe Break Loading (BLPB)

Branch Line Pipe Break Loading is the total loading that is induced by the vibration of unbroken RCS branch line. The subject vibration is the result of excitations of reactor vessel, hot and cold legs, pressurizer and steam generator caused by a RCS branch line pipe break.

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Table 6.1-1 BLPB for Subsystem SI101

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Table 6.1-2 BLPB for Subsystem SI105

6.1.2 Coincident Pressure Loadings

Three coincident internal pressure loading cases are used for primary load design. These three cases are listed below. Specific descriptions concerning the combination of these pressure loading conditions with the individual primary loadings identified are contained in Article 6.1.3.

Table 6.1-3 Pressure

Load Abbreviation	Description
DPRE or PPRE	Individual component design pressure or peak pressure per Reference 10.6
OPRS	Individual component peak pressure coincident with service level being considered per Reference 10.6
HPRS	Individual component hydrotest pressure per Reference 10.6

6.1.3 Design Basis Combined Loadings

The combined loadings described in Table 6.1-4 are used as a design basis for all NB-3650 Equation 9 and NB-3657 primary load evaluations. These conditions address all requirements specified in Reference 10.6.

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Table 6.1-4 Load Combination

Combination No.	Condition	Load Combination
1	Design	DPRE + WGHT
2	Service Level B	PPRS(2) + WGHT + IRWST for SI101 PPRS(2) + WGHT + $[IRWST^2+FFTH^2]^{1/2}$ for SI105
3	Service Level C	N/A
4 (1)	Service Level D	PPRS(2) + WGHT + $[SSE^2 + IRWST^2 + DBE1^2]^{\frac{1}{2}}$
5	Test	HPRS + HWGT
6	NB-3656(b)(4)	TRNG + SSBD + SSHD

Notes : (1) Load combination shall repeated for each one of the branch line pipe break loadings (BLPB described in article 6.1.1.4 in place of DBE1

(2) PPRS is service level dependent.

6.1.4 Functional Capability Criteria

These piping subsystems (or a portion of this piping subsystem) are designated as "Required for Safe Shutdown" per Section 902 of the system PSDS(Reference 10.6). The requirements for assurance of functional capability are provided in Section 902 of the general PSDS(Reference 10.6).

a. Piping functional capability is assured by verifying that the maximum stress in Eq.(9) of ASME B&PV Code, Section III NB/NC-3650, regardless of service level, does not exceed Service C limits.

b. Based on NUREG-1367, functional capability of a piping system is assured by meeting the present code(ASME B&PV Code, Section III NB/NC/ND-3650) Eq.(9), Level D, stress limit of 2Sy, provided that:

   - Dynamic loads are reversing. This includes loads due to earthquake and pressure wave loads(not slug-flow fluid hammer).
   - Dynamic moments are calculated using an elastic response spectrum analysis with ±15% peak broadening and not more than 5% damping.
   - Steady-state(e.g., weight) stresses including non-reversing dynamic loads do not exceed 0.25 Sy.
   - Do/t(pipe outer diameter divided by thickness) does not exceed 50.
   - External pressure does not exceed internal pressure.

6.2 Fatigue Design Basis

The definitions, loading combinations, and acceptance criteria described in this article are used as a design basis for the fatigue evaluation required by paragraphs NB-3653 and NB-3654. The design basis consists of the following sets of data:

a. A design basis Pressure-Temperature-Transient History (PTTH) for the subsystem.
b. A design basis Dynamic Loading History (DLH) for the subsystem.
c. The acceptance criteria used to evaluate the design.

6.2.1 Design Basis Dynamic Loading History (DLH)

The design basis DLH for the subsystem is a history of dynamic loading conditions that are used, in combination with the design basis PTTH, for the fatigue design of the subsystem. The design basis DLH consists of a number of loading conditions that are described in terms of each individual excitation. All loading conditions designated as ASME Code Service Levels A and B are addressed. The resulting individual piping excitation response associated with that dynamic excitation event includes both primary and secondary response components, which has its own cyclic range reversals as well.

6.2.1.1 Individual Loadings

The individual excitation response loading used for the fatigue evaluation of the subject piping subsystem is described in this article. The excitation consists of three independent components. These three components are combined before use in the fatigue evaluation. They are listed in the Table below.

Table 6.2-1 Individual Excitation Load

	Component	Classification	Description
1	Inertia Component	Primary	Inertia loading induced by building and RCS header excitation
2	Building Displacement Component	Secondary	Loading induced by relative movement of attachments of building structure
3	RCS Header Displacement Component	Secondary	Loading induced by movement of branch connections to external headers

The following individual excitation response loadings are used for the fatigue design.

(a) Safe shutdown earthquake inertia loading (SSE)
(b) Seismic anchor motion loading (SAM)

Seismic anchor motion is consisted with Safe shutdown earthquake building displacement loading (SSBD) and RCS header displacement loading (SSHD).

Safe shutdown earthquake building displacement loading is that loading induced by relative movement between the piping system’s attachment points to the main building structure

Safe shutdown earthquake RCS header displacement loading is that loading induced by dynamic movement of external pipe header that the subsystem may be attached to at its terminal points. The movement of the header is a result of safe shutdown earthquake excitation. If the subject subsystem does not terminate at a branch connection to a larger header, this loading is not applicable.

(c) IRWST hydro dynamics Inertia loading (IRWST)

6.2.2 Design Basis Number of Occurrences

6.2.2.1 Earthquake Inertia and Seismic Anchor Motion Loading

Two SSE events with 10 maximum stress cycles per event (20 full cycles) are considered (Reference 10.8).

Alternatively, equivalent number of SSE fractional earthquake cycles to that of 20 full SSE cycles may be used (but with an amplitude not less than one-third of the maximum SSE amplitude) as following (Reference 10.8). A total of 120 cycles (12 events with 10 cycles) for 1/2 SSE which are equivalent of 20 maximum stress cycles

6.2.2.2 IRWST Hydro Dynamics Inertia Loading

2010 IRWST events (Service level A and B) are occurred during the life of plant (Reference 10.6). And 10 cycles per event are assumed. Therefore, 20100 cycles are considered.

6.2.2.3 Fluid Force Time History Loading

The Fluid Force Time History Loading is induced by the hydrodynamic loading due to the LTOP valve actuation in subsystem SI105. Fluid Force Time History Analysis is performed in accordance with Reference 10.19.

Not applicable for the subsystem SI101

6.2.3 Fatigue Design Load Combinations

The loading combinations identified in the table below are used for fatigue design of the subsystem using the NB-3653 design rules.

Table 6.2-2 Load Combination for Fatigue of SI101

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Table 6.2-3 Load Combination for Fatigue of SI105

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7.0 DESIGN EVALUATION

7.1 PRIMARY LOAD DESIGN EVALUATION

7.1.1 Procedure

A primary load evaluation of all piping products, used in the design of this subsystem, is performed in accordance with the design rules specified in Articles NB-3652, NB-3654, NB-3655, NB-3656 and NB-3657. The design basis and acceptance criteria itemized in Section 5.0 of this report are used as a basis for the calculations. The evaluation is performed using the following procedure.

7.1.2 Structural Analysis

A structural analysis of the subsystem is performed for each one of the individual mechanical loadings identified in Reference 10.6. These calculations result in a set of internal loadings (Bending Moments) for each individual mechanical load. The procedures used to perform the structural analyses are described in Section 5.0 of this report.

7.1.3 Primary Stress Evaluation

Using the bending moments produced in Section 5.1, NB-3650 Equation 9 and NB-3657 stress intensity values are calculated for each of the design basis loading conditions specified in Reference 10.6. These values are then reviewed against specified acceptance criteria (Section 2.1).

Table 7.1-1 Locations of Ten Highest Primary Stress in SI101 Design Condition

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Table 7.1-2 Locations of Ten Highest Primary Stress in SI101 Service Level B Condition

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Table 7.1-3 Locations of Ten Highest Primary Stress in SI101 Service Level C Condition TS

Table 7.1-4 Locations of Ten Highest Primary Stress in SI101 Service Level D Condition

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Table 7.1-5 Locations of Ten Highest Primary Stress in SI105 Design Condition

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Table 7.1-6 Locations of Ten Highest Primary Stress in SI105 Service Level B Condition TS

Table 7.1-7 Locations of Ten Highest Primary Stress in SI105 Service Level C Condition

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Table 7.1-8 Locations of Ten Highest Primary Stress in SI105 Service Level D Condition TS

7.2 FATIGUE DESIGN EVALUATION

7.2.1 Procedure Used

A fatigue design evaluation of all piping products used in the design of this subsystem is performed in accordance with the design rules specified in paragraphs NB-3653 and NB-3654.

7.2.2 Structural Analysis

A structural thermal expansion analysis is performed for the thermal expansion modes. A dynamic structural analysis and static forced displacement analysis, as appropriate, are performed for each individual excitation loading. These calculations produce the internal bending moments required for NB-3653 stress intensity range calculations.

7.2.3 NB-3653 Stress Range Check and Fatigue Analysis

The thermal transient stress, along with structural stress data described above, the loading combination definitions and the acceptance criteria described in Section 5.0 and 6.0 are used to perform all design calculations required by paragraphs NB-3653 and NB-3654 for the subsystem. The procedures specified in Reference 10.1 are used to perform the calculations. The calculations for standard piping products are performed using the PIPESTRESS computer program (Reference 10.7).

7.3 STRUCTURAL ANALYSIS

A structural analysis of the subsystem is performed for each one of the individual static dead weight, thermal expansion and dynamic excitation loadings identified in Sections 6.0 of this report. The analyses are performed to determine the response bending moments for use in Code calculations, and to calculate interface loadings that are used for the design of components that interface with this subsystem. Table 7.3-1 contains a listing of those loadings and the procedures used to analyze them. The procedures used are described below. All structural analyses calculations are performed using the PIPESTRESS computer program (Reference 10.7).

7.3.1 Dead Weight Analysis

To determine the subsystem response to its dead weight loading, the entire subsystem, with its suspension system (Constant and Rigid Hangers and Rigid Restraints), is modeled as connected finite beam elements and analyzed using the stiffness matrix frontal solution method. The following weight loadings are accounted for :

a. The weight of the pipe and its fluid contents.
b. Insulation weight.
c. The weight of all valves, fittings and the fluid contents.
d. The weight of any in-line equipment and its fluid contents.
e. Significant restraint hardware weight directly supported by the pipe.

7.3.2 Thermal Expansion Analysis

To determine the effects of thermal expansion loading, the entire subsystem, with its restraint system (Rigid Hangers and Rigid Restraints) is modeled as connected finite beam elements and analyzed using the stiffness matrix frontal solution method. Consistent thermal forces, based on the temperature distribution within the model are calculated and applied to the model. The following effects are taken into account for each operating mode analyzed.

a. Thermal expansion growth of all piping assemblies based on the temperature distribution of the subsystem associated with the operating mode being analyzed and Code material coefficients of thermal expansion and the elastic modulus, ASME Section II Part D, 2007 Edition with 2008 Addenda.
b. The thermal expansion displacements and rotations of the piping system's anchors that are associated with the operating mode being analyzed.
c. The thermal stratification loads are associated with the operating mode being analyzed.

7.3.3 Uniform Response Spectra Analysis

The procedure described below is used to determine the inertia (primary) response of all base excitation dynamic loadings.

a. The entire subsystem, with its restraint system (Rigid Hangers and Rigid Restraints) is modeled as multi-degree of freedom finite beam elements.

b. Subsystem modal analysis is performed to determine the dynamic model characteristics of this subsystem.

c. The response of the subsystem to each one of three mutually perpendicular excitations are calculated (North-South, East-West, Up-Down). The three excitations are constructed by enveloping the individual response spectra associated with all points of attachment to the building structure. The response of the system to the three directional excitations is combined using the Square Root of the Sum of the Squares (SRSS) (Reference 10.16) to determine the final design response associated with the loading.

d. The responses of the individual modes are combined using the Der Kiureghian Method (Reference 10.16). Rigid modes are combined using the Left out force method. The resultant response due to the flexible and rigid modes is calculated by using the Absolute Sum method

7.3.4 Forced Displacement Analysis

7.3.4.1 RCS Header Displacement Analysis

The procedure described below is used to determine the header displacement (Secondary) effects of the SSE base excitation dynamic loadings,

a. The entire subsystem, with its restraint system (Rigid Hangers and Rigid Restraints) is modeled as connected finite beam elements.

b. Six static forced displacement analyses are performed for each header connection. Each analysis determines the effects of forcing the displacement amplitude along one of the six degrees of freedom at the header connection.

c. The results of the individual analyses (for each degree of freedom amplitude) are combined using the Square Root of the Sum of the Squares Method to determine the final design response.

7.3.4.2 Building Displacement Analysis

The procedure described below is used to determine the building displacement (secondary) effects of the SSE base excitation dynamic loadings.

a. The entire subsystem, with its restraint system (Rigid Hangers and Rigid Restraints) is modeled as connected finite beam elements.

b. A static forced displacement analysis is performed for each restrained degree of freedom. Each analysis determines the effect of forcing the maximum displacement amplitude regardless of time, along one of the restrained degree of freedom at each restrained node point.

c. The results of the individual analyses (for each restrained degree freedom amplitude) are combined using the Square Root of the Squares Method to determine the design response.

7.3.5 Support Excitation Time History Analysis

The procedure described below is used to analyze the subsystem for each RCS branch line pipe break loading case. Both the primary and secondary components of the loading are accounted for in the calculations.

a. The entire subsystem, with its restraint system (Rigid Hangers and Restraints) is modeled as multi-degree of freedom finite beam elements.

b. Unique displacement-time histories due to RCS branch line pipe break are assigned as boundary conditions at each unbroken RCS branch nozzle modeled as an anchor in the subsystem.

c. The response of the piping system resulting from the excitation is calculated based on modal super position techniques for time dependent excitations. The 4% critical damping per Regulatory Guide 1.61, Rev.1 is used for the calculations described in Reference 10.4.

7.3.6 Forced Vibration Time History Analysis

The procedure described below is used to analyze the subsystem for LTOP valve transient loading case during operation.

Both the primary and secondary components of the loading are accounted for in the calculation.

a. The entire subsystem, with its restraint system (Rigid Hangers and Restraints) is modeled as multi-degree of freedom finite beam elements.

b. Force-time histories resulted from RELAP analysis is applied on each pipe segment along the discharge flow path.

c. The response of the piping system resulting from the excitation is calculated based on direct integration method with proportional damping for time dependent excitations.

Table 7.3-1 Load Abbreviation

	Load Abbreviation	Description	Article Describing Procedure
1	WGHT	Dead Weight	7.3.1
2	TH	Thermal Expansion	7.3.2
3	IRWST	POSRV Operation Inertia Loading	7.3.3
4	SAM	SSE Header Displacement Loadings and Relative Building Displacement Loadings	7.3.4.
5	SSE	SSE Inertia Loading	7.3.3
6	BLPB	RCS Branch Line Pipe Break Loadings (See Table 6.1-1 and 6.1-2)	7.3.5
7	FFTH	LTOP Valve Actuation Transient Loading for Subsystem SI105	7.3.6

8.0 ANANYSIS RESULT

8.1 SI101

8.1.1 Subsystem Plot

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Figure 8.1-1 Subsystem SI101 Plot

8.1.2 Pipe Data Sheet

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Figure 8.1-2 Subsystem SI101 Pipe Data Sheet

8.1.3 Piping Stress Evaluation Results

8.1.3.1 Nozzle Load

The purpose of this evaluation is to check the loads at safe-end of the reactor vessel DVI nozzle and safety injection tank actual nozzle against maximum nozzle load criteria.

8.1.3.1.1 R/V DVI Nozzle Load Check (Class 1 Piping)

TS

Table 8.1-1 Criteria Check at R/V DVI Nozzle in SI101

Based on the above evaluation, it can be concluded that loads on the reactor vessel DVI nozzle safe ends in Subsystem 1SI101 are acceptable.

8.1.3.1.2 Safety Injection Tank Actual Loads Check (Class 2 Piping)

TS

Table 8.1-2 Criteria Check at Safety Injection Tank Actual Nozzle in SI101

Based on the above evaluation, it can be concluded that loads on the Safety Injection Tank Nozzle in Subsystem 1SI101 are acceptable.

8.1.3.2 Head Plate Penetration Anchor (Class 2 Piping)

The stresses at the head plate penetration anchor are listed in Table 8.1-3. The stress for each Code equation is tabulated below. The stresses at the head plate penetration anchor meet all stress limitations specified in paragraphs NC-3650.

Table 8.1-3 The Stress at the Head Plate Penetration Anchor

TS

8.1.3.3 Branch Pipe Connection

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the branch pipe connection are listed in Table 8.1-4. The stress intensity ranges and usage factors calculated at the branch pipe connection meets all stress limitations specified in paragraphs NB-3653, NB-3654 and NB-3656(b)(4).

Table 8.1-4 Usage Factor at the Branch Pipe Connection

TS

For the Class 1 piping, the primary stresses at the branch pipe connection are listed in Table 8.1-5. The primary stresses calculated at the branch pipe connection meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

Table 8.1-5 Primary Stress at the Branch Pipe Connection

TS

For the Class 2 piping, the stresses at the branch pipe connection are listed in Table 8.1-6. the stresses at the branch pipe connection meet all stress limitations specified in paragraphs NC-3650.

Table 8.1-6 The Stress at the Branch Pipe Connection

TS

8.1.3.4 Pipe Support

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the pipe support location are listed in Table 8.1-7. The stress intensity ranges and usage factors calculated at the pipe support location meets all stress limitations specified in paragraphs NB-3653, NB-3654 and NB-3656(b)(4).

Table 8.1-7 Usage Factor at the Pipe Support Location

TS

For the Class 1 piping, the primary stresses calculated at the pipe support location are listed in Table 8.1-8. The primary stresses calculated at the pipe support location meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

TS

Table 8.1-8 Primary Stress at the Pipe Support Location (1/2)

TS

Table 8.1-8 Primary Stress at the Pipe Support Location (2/2)

For the Class 2 piping, the stresses at the pipe support location are listed in Table 8.1-9. The stresses calculated at the pipe support location meet all stress limitations specified in paragraphs NC-3650.

Table 8.1-9 The Stress at the Pipe Support Location

TS

8.1.3.5 Valve

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the valve location are listed in Table 8.1-10. The stress intensity ranges and usage factors calculated at the valve location meets all stress limitations specified in paragraphs NB-3653, NB-3654 and NB-3656(b)(4).

Table 8.1-10 Usage Factor at the Valve Location(1/2)

TS

Table 8.1-10 Usage Factor at the Valve Location(2/2)

TS

For the Class 1 piping, the primary stresses calculated at the valve location are listed in Table 8.1-11. The primary stresses calculated at the valve location meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

Table 8.1-11 Primary Stress at the Valve Location

TS

For the Class 2 piping, the stresses at the valve location are listed in Table 8.1-12. The stresses calculated at the valve location meet all stress limitations specified in paragraphs NC-3650.

Table 8.1-12 The Stress at the Valve Location (1/2) TS

Table 8.1-12 The Stress at the Valve Location (2/2)

TS

8.1.3.6 Flanged Connection

There is no flanged connection in this piping subsystem.

8.1.4 Environmental Fatigue Evaluation Results

Table 8.1-13 shows the results of eighteen highest CUF_{en} using simplified method in DVI piping subsystem. And the data points where CUF_{en} using simplified method exceed 1.0 are further evaluated using detailed method. The EAF analysis results using detailed method. Table 8.1-14 shows the results of fifteen highest CUF_{en} using detailed method in DVI piping system.

Table 8.1-13 Results of Eighteen Highest CUF_{en} using Simplified Method TS

Table 8.1-14 Results of fifteen Highest CUF_{en} using Detailed Method

TS

8.2 SI105

8.2.1 Subsystem Plot

TS

Figure 8.2-1 Subsystem SI105 Plot

8.2.2 Pipe Data Sheet

TS

Figure 8.2-2 Subsystem SI105 Pipe Data Sheet

8.2.3 Piping Stress Evaluation Results

8.2.3.1 Nozzle Load

The purpose of this evaluation is to check the loads at safe-end of the shutdown cooling outlet nozzle against maximum nozzle load criteria.

8.2.3.1.1 H/L Shutdown Cooling Outlet Nozzle Load Check

TS

Table 8.2-1 Criteria Check at H/L Shutdown Cooling Outlet Nozzle in SI105

8.2.3.1.2 Conclusion

Based on the above evaluation, it can be concluded that loads on the shutdown cooling outlet nozzle safe ends in Subsystem 1SI105 are acceptable.

8.2.3.2 Head Plate Penetration Anchor (Class 2 Piping)

The stresses at the head plate penetration anchor are listed in Table 8.2-2. The stresses at the head plate penetration anchor meet all stress limitations specified in paragraphs NC-3650.

TS

Table 8.2-2 The Stress at the Head Plate Penetration Anchor

8.2.3.3 Branch Pipe Connection

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the branch pipe connection are listed in Table 8.2-3. The design of the branch pipe connection meets all stress limitations specified in paragraphs NB-3653, NB-3654 and NB-3656(b)(4).

TS

Table 8.2-3 Usage Factor at Branch Pipe Connection (1/2)

Table 8.2-3 Usage Factor at Branch Pipe Connection (2/2) TS

For the Class 1 piping, the primary stresses calculated at the branch pipe connection are listed in Table 8.2-4. The primary stresses calculated at the branch pipe connection meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

TS

Table 8.2-4 Primary Stress at Branch Pipe Connection (1/2)

Table 8.2-4 Primary Stress at Branch Pipe Connection (2/2)

TS

For the Class 2 piping, the stresses at the branch pipe connection are listed in Table 8.2-5. the stresses at the branch pipe connection meet all stress limitations specified in paragraphs NC-3650.

Table 8.2-5 The Stress at Branch Pipe Connection

TS

8.2.3.4 Pipe Support

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the pipe support location are listed in Table 8.2-6. The stress intensity ranges and usage factors calculated at the pipe support location meets all stress limitations specified in paragraphs NB-3653, NB-3654 and NB-3656(b)(4).

Table 8.2-6 Usage Factor at Pipe Support Location (1/2)

TS

Table 8.2-6 Usage Factor at Pipe Support Location (2/2)

TS

For the Class 1 piping, the primary stresses calculated at the pipe support location are listed in Table 8.2-7. The primary stresses calculated at the pipe support location meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

Table 8.2-7 Primary Stress at the Pipe Support Location (1/3)

TS

Table 8.2-7 Primary Stress at the Pipe Support Location (2/3)

TS

Table 8.2-7 Primary Stress at the Pipe Support Location (3/3)

TS

For the Class 2 piping, the stresses at the pipe support location are listed in Table 8.2-8. The stresses calculated at the pipe support location meet all stress limitations specified in paragraphs NC-3650.

TS

Table 8.2-8 The Stress at Pipe Support Location

8.2.3.5 Valve

For the Class 1 piping, the NB-3653 stress intensity ranges and usage factors calculated at the valve location are listed in Table 8.2-9. The stress intensity ranges and usage factors calculated at the valve location meets all stress limitations specified in paragraphs NB-3653 and NB-3654.

Table 8.2-9 Usage Factor at Valve Location (1/2)

TS

Table 8.2-9 Usage Factor at Valve Location (2/2)

TS

For the Class 1 piping, the primary stresses calculated at the valve location are listed in Table 8.2-10. The primary stresses calculated at the valve location meets all stress limitations specified in NB-3652 Equation 9, articles NB-3652 and NB-3654 through NB-3657.

TS

Table 8.2-10 Primary Stress at the Valve Location (1/2)

Table 8.2-10 Primary Stress at the Valve Location (2/2)

TS

For the Class 2 piping, the stresses at the valve location are listed in Table 8.2-11. The stresses calculated at the valve location meet all stress limitations specified in paragraphs NC-3650.

TS

Table 8.2-11 The Stress at Valve Location (1/2)

Table 8.2-11 The Stress at Valve Location (2/2)

TS

8.2.3.6 Flanged Connection

The purpose of this evaluation is to check flanged joints with strength bolting moments with respect to the allowables.

8.2.3.6.1 Flanged Joint with High Strength bolting check

Table 8.2-12 Flanged Joint with High Strength bolting check in SI105

TS

8.2.3.6.2 Conclusion

All flanged joints are per ANSI B16.5 flanges with high strength bolts. Based on the above evaluation, the loads at each flanged joints are acceptable.

8.2.4 Environmental Fatigue Evaluation Results

Table 8.2-13 shows the results of eighteen highest CUF_{en} using simplified method in SC piping subsystem. And the data points where CUF_{en} using simplified method exceed 1.0 are further evaluated using detailed method. The EAF analysis results using detailed method. Table 8.2-14 shows the results of eleventh highest CUF_{en} using detailed method in SC piping system.

Table 8.2-13 Results of Eighteen Highest CUF_{en} using Simplified Method

TS

Table 8.2-14 Results of Eleventh Highest CUF_{en} using Detailed Method

TS

9.0 COMPUTER CODE

9.1 PIPESTRESS 3.9.0

PIPESTRESS is a piping analysis program that is applied to the static and dynamic analyses including response spectra and time-history analyses. PIPESTRESS is used for the analysis of ASME Section III, Class 1, 2, and 3 as well as ASME B31.1 and B31.3 piping systems.

9.2 ANSYS 13.0

ANSYS is a general-purpose linear and nonlinear finite element program with structural and heat transfer capabilities. Finite element analyses of reactor internal structures such as flanges and the lower support structure are performed the ANSYS to determine vertical and lateral stiffness. The program is also used to perform the static and dynamic analyses of the reactor internals to determine its structural stress responses.

10.0 REFERENCE

1. ASME B&PV Code Section III, 2007 Edition with 2008 Addenda.

2. APR1400 DC Piping Stress Reports for Subsystem 1SI101 and 1SI105
   Calculation No. 1-313-P397-SI101, Rev. 7, dated 05/15/17.
   Calculation No. 1-312-P397-SI105, Rev. 6, dated 04/20/17.

3. Environmentally Assisted Fatigue Evaluation Summary of Safety Injection and Shutdown Cooling Piping Applied to the Graded Approach for The APR1400, 1-310-P462-003, Rev.0, dated 08/04/16.

4. Piping and Instrumentation Diagram for SI/SC System and RC System:
   Drawing No. 1-441-N105-001, Rev. 1, dated 02/09/17.
   Drawing No. 1-441-N105-002, Rev. 1, dated 02/09/17.
   Drawing No. 1-441-N105-003, Rev. 1, dated 02/09/17.
   Drawing No. 1-441-N105-004, Rev. 1, dated 02/09/17.
   Drawing No. 1-431-N105-004, Rev. 1, dated 09/30/13.

5. USNRC Regulatory Guide 1.61, Rev. 1.

6. Regulatory Guide 1.207, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components due to the Effects of the Light-Water Reactor Environment for New Reactors”, U.S Nuclear Regulatory Commission., March 2007.

7. NUREG/CR-6909, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials, U.S Nuclear Regulatory Commission., February 2007.

8. Piping Design Tables and Standard Details, 1-037-P443-001, Rev. 4, dated 08/25/15.

9. Piping System Design Specification (PSDS) :
   General PSDS, 1-037-N407-001, Rev. 1, dated 12/30/14
   IRWST System PSDS, 1-447-N407-001, Rev. 1, dated 02/28/12
   SI/SC System PSDS, 1-441-N407-001, Rev. 2, dated 12/30/14
   RC System PSDS, 1-431-N407-001, Rev. 1, dated 02/28/12

10. PIPESTRESS Computer Program / KEPCO E&C Register No. : E-P-PD-1338-3.9.0/DC, and User’s Manual.

11. IEEE Std. 344-2004, “Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generation Stations”, Institute of Electrical and Electronics Engineers, 2005

12. Thermal and Hydraulic Responses to Design Basis Events,
    Reactor Coolant System, 11A60-SA-DE022-01, Rev. 1, dated 10/16/12.
    Safety Injection/Shutdown Cooling System, 11A60-FS-DE022-02, Rev. 0, dated 10/16/12

13. Standard Review Plan, Section 3.6.2, Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping.

14. Containment BLDG Seismic Analysis Report,
    Report No., 1-310-C455-001, Rev. 2, dated 05/11/17.

15. Interface Requirements for RC System Branch Line Piping Nozzles,
    11A60-ME-IR222-00, Rev. 1, dated 08/16/13.

16. Design Criteria Manual, Doc. No. 0-037-B401-001, Rev.2, dated 05/28/13.

17. USNRC Regulatory Guide 1.92, Rev. 3.

18. Piping ISO DWG. No.
    Drawing No. 1-313-P193-SI012, Rev. 2, dated 07/31/15.
    Drawing No. 1-314-P193-SI012, Rev. 1, dated 07/31/15.

19. RCB Floor Response Spectra (FRS) by IRWST Hydro Dynamic Loads,
    DIT No. DIT-C-0003-00, dated 05/15/13.

20. Hydrodynamic Loads of SC Line due to LTOP Valve Actuation,
    DIT No. DIT-N-0014-01, dated 04/03/13.