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Acceptance Criteria for the Use of Cast Iron Components in the CCSW and DGCW Systems Dresden Nuclear Power Station

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2.0	2-1 – 2-2			
3.0	3-1 – 3-5			
4.0	4-1 – 4-3			
5.0	5-1			

Table of Contents

1.0 INTRODUCTION

UFSAR Table 6.1-1 "Fracture Toughness Requirements" states that valves and fittings in the diesel-generator cooling water (DGCW) and containment cooling service water (CCSW) systems at Dresden Nuclear Power Station (DNPS) are constructed of carbon steel material. UFSAR Table 6.1-1 is based on correspondence with the NRC regarding SEP Topic III-1, "Quality Group Classification of Components and Systems". As stated in the introduction of the NRC's Safety Evaluation Report, the purpose of Topic III-1 was to review the classification of structures, systems, and components of plants designed and constructed from the late 1950's to late 1960's, to current appropriate classifications, codes, and standards for seismic and quality groups. In particular, significant changes in fracture toughness test requirements occurred in 1972. Under SEP Topic III-1, Dresden's safety-related systems, which were designed to USAS B31.1-1967, were evaluated against the fracture toughness and other requirements of ASME Section III, Classes 1, 2, and 3. At that time it was not known that the above two systems contained cast iron components.

Based on a recent review, most of the 2-1/2 inch and greater valves in the CCSW and DGCW systems are constructed from cast iron material. The CCSW pump casings are also made of cast iron. Cast iron has lower ductility and fracture toughness than other materials typically used in safety related piping systems. Although it is an acceptable material in USAS B31.1-1967, there are no material specifications for cast iron that are acceptable for ASME Section III, Class 3 components. The cast iron components' service conditions at Dresden, however, are not severe, and the original Code of construction does allow cast iron piping components in limited applications.

The purpose of this document is to establish an evaluation criteria to determine the acceptability of the use of cast iron piping components at Dresden Station to the original Code of construction, and to evaluate the fracture toughness considerations of the ASME Section III, Class 3 rules.

2.0 MATERIAL PROPERTIES OF CAST IRON

The acceptance criteria for use of cast iron components addresses two primary issues: what limitations to the service conditions that are specific to cast iron need to be applied, and what Code guidance exists for establishing allowable stresses and load combinations. In order to demonstrate that the criteria are appropriately conservative, the material properties of cast iron need to be understood.

The primary disadvantage of cast iron when compared to ferritic steel is that cast iron has much lower ductility and fracture toughness. The ASME Section III Code equations are based on the assumption that the material has sufficient ductility to deform plastically under high load, so as to provide an acceptable margin of safety between initial local yielding and ultimate fracture. The low fracture toughness makes castings vulnerable to shock loadings such as pressure spikes, thermal shock, and mechanical impact. However, these two issues can be addressed by limiting the design loads to below yield, and by placing restrictions on the system service to avoid shock loads.

The cast iron material that is in use in the CCSW and DGSW systems is ASTM Specification A 126 Class B [1]. The Specification references ASTM A 48 and shows the equivalent A 48 Class to be 30B. Specification A 126 [2] lists Class B cast iron as having a minimum tensile strength of 31 ksi. The tensile strength does not change significantly between 32°F and 450°F, with the tensile strength at 32°F being slightly higher than at 70°F [3].

In general, the compressive strength of cast iron is about 3.5 times the tensile strength, and the shear strength is about 1.4 times the tensile strength. Unlike carbon steels, the bending strength is higher than the tensile strength. The minimum bending strength can be determined from a transverse test. Following the method described in ASTM A 126, the minimum bending strength resulting from an acceptable transverse test is 58.4 ksi. Using a stress allowable based on tension and applying it to bending loads is very conservative for cast iron.

For cast iron, there is very little elongation prior to fracture. The elongation is only 0.6 % [3], and the yield stress is very close to the ultimate tensile stress. The design stresses must therefore be kept below yield. The fatigue endurance limit is 14 ksi for Class 30 cast iron [3], which is similar to carbon steel. The fatigue strength does not change appreciably between 32°F and 450°F [3]. The fatigue strength of grey cast iron is less sensitive to geometric discontinuities than carbon steel, as the fatigue strength already includes the effects of micro-notches that are present in the casting. Thus, stress intensification factors related to geometric discontinuities such as fillets and tapers, that are applied to the cast iron, are a source of conservatism.

The fracture toughness of grey cast iron is about 20 ksi $\sqrt{in}$ [4]. It does not have a transition temperature, so the fracture toughness does not reduce further at low temperatures. Although this value indicates reduced resistance to cracking from high strain rates, such as are associated with impact loads, the potential for brittle fracture can be controlled by limiting the service conditions to non-shock loading. Cast iron is commonly used in service water systems due to its wear resistance and the moderate service conditions.

3.0 CODE REQUIREMENTS

The original Code of construction for DNPS piping systems is USAS B31.1, 1967. The evaluation criteria for cast iron components address two Code compliance issues:

(1) The requirements of the original Code related to the use of cast iron in piping systems, including stress allowables and service limitations.

(2) The impact testing requirements contained in ASME Section III.

3.1 Requirements of the Original Code

The original Code of Construction, USAS B31.1-1967 [6], permits the use of cast iron in piping systems. In paragraph 123.2.4, it places a caveat on its use, that its low ductility should be recognized and use where shock loading can occur should be avoided. Table 126.1 lists the acceptable material specifications, which includes A 126 cast iron. Appendix A provides values for S, the stress allowable, for cast iron, by fabrication process. For sand mold cast, which is the most common process for valves and pump casings, the S value is 6.0 ksi for temperatures from -20°F to 400°F. Although B31.1-1967 gives some design guidance applicable to nuclear piping systems, it does not provide load combinations and allowable stresses for occasional loads, nor does it address valve and pump nozzle allowable stresses. In areas where B31.1 is silent, it is appropriate to obtain guidance from other ASME Codes.

The following requirements are specified in the 1989 Edition of ASME B31.1 regarding the use of cast iron in piping systems:

- Cast iron pipe may be used within the ratings established by the material Specifications listed, which include A-126 and A-48 (105.2.1(B)).
- Cast iron may be used in components meeting the Standards listed, which include B16.10 for cast iron valves. This Standard specifies minimum valve dimensions for each pressure rating.

- Table A-5 provides some stress allowables for cast iron materials. It lists an S value of 3.0 ksi for A-126 Class B, between -20°F and 400°F. However, Note (g) to the Table is significant, as discussed below.
- Cast iron pipe shall not be used for flammable, combustible, or toxic fluids.
- Possible shock loadings (pressure, temperature, or mechanical) and consequences of failure must be considered before specifying the use of cast iron (124.4).
- There are restrictions for the use of cast iron in boiler external blowoff and blowdown piping. This is not applicable to the CCSW and DGSW systems.
- Piping stress combinations, allowables, and stress intensification factors are provided (as they have been in Editions since 1973). These apply equally to cast iron.

Note (g) to Table A-5 of B31.1-1989 states that the allowable stresses provided are for use in designing components which are not manufactured in accordance with the referenced Standards. The cast iron valves in use at DNPS are all manufactured to the referenced Standard ASA B16.10. This Standard specifies minimum radii so as to minimize stress concentrations; a component that does not have these radii would presumably require a penalty factor in the allowable stress. B31.1-1989 does not state what the stress allowable is for components that do meet the Standard. 3.0 ksi would be a very conservative S value, as it is about 10 % of minimum tensile stress, in contrast to the Code basis for the S value, which is 25% of minimum tensile.

ASME Section IV, Subsection HC [7], which is for heating boilers, is significant in that it provides more comprehensive allowable stress guidance for cast iron. It specifies a design stress allowable in tension for cast iron of 6 ksi. It also specifies a bending stress allowable that is 1.5 times the allowable in tension, or 9 ksi, and an allowable in compression of 12 ksi. In the cast iron application at Dresden, which is in low pressure systems, nearly all of the stress in the Code piping stress qualification equations is bending stress.

In view of the above, the cast iron evaluation criteria at Dresden will use an allowable stress S of 6 ksi in the Code stress equations. This value is sufficiently conservative, is consistent with the original Code of construction, and will hold the stresses to magnitudes where the reduced ductility is not a concern.

Valve Stresses

B31.1 does not specify stress allowables for valves. ASME Section III, ND-3521 [5] provides guidance for Class 3 valves. It states:

- Valves with extended structures must satisfy the stress allowables of Table ND-3521-1. All of the cast iron valves in service at DNPS are manually operated valves with rigid, compact bodies, with no extended structures.
- If there is no extended structure, the valve must only meet the pressure rating of the Specification, and must be able to withstand the piping end loads. The valve is considered adequate to withstand piping end loads if (1) the valve nozzle section modulus is at least 10% greater than that of the attaching pipe, and (2) the stress allowable of the valve material is equal or better than the attaching pipe. Condition (1) is inherently met if the valve conforms to the B16.10 Standard. Condition (2) is not inherently met, but the intent can be met by restricting the allowable stress in the pipe material, at the pipe to valve connection, to the valve material stress allowable.

Pump Stresses

The adequacy of the cast iron CCSW pump casing to withstand design loads consists of three considerations:

(1) The service conditions must be within the pressure-temperature rating of the pump.
(2) The external loads applied at the nozzle by the attached piping do not overstress the region of the nozzle/shell junction.
(3) The pump supports meet component support criteria.

Meeting the pressure-temperature rating of the pump satisfies item (1). Item (3) is met by applying the DNPS generic component support design criteria; the fact that the pump casing is made of cast iron does not affect the pump supports, which are made of steel.

B31.1 does not specify stress allowables for the pump nozzle loads. ASME Section III, ND-3410 [5] provides guidance for Class 3 pumps. Table ND-3416-1 gives the stress limits for the various service levels in terms of S. The S value defined above will be conservatively used in these equations. The pump nozzle stress combination equations differ from the B31.1 piping equations in that thermal expansion loads are combined with other primary mechanical loads, but stress intensification factors are not applied.

3.2 ASME Section III Fracture Toughness Requirements

The ASME Section III Code [5] requires that the materials be one of the approved Specifications of Section II. Neither the SA-126 nor SA-48 Specifications are listed in Section II. Under SEP Topic III-1, Dresden's safety-related systems, which were designed to USAS B31.1-1967, were evaluated against the fracture toughness requirements of ASME Section III, Classes 1, 2, and 3. This evaluation did not recognize that cast iron materials were used in the DGSW and CCSW systems. B31.1-1967 does not require impact testing to verify adequate fracture toughness. It merely includes a caveat that the low ductility of cast iron should be recognized and the use of cast iron where shock loading may occur should be avoided.

ASME Section III [5] requires that under certain conditions where fracture toughness may be a concern, impact testing be performed to assure adequate ductility and energy absorption. ND-2311 specifies the impact testing requirements for materials in Class 3 systems. It provides a series of exemptions from impact testing, one of which is for pump and valve material connected to piping of nominal wall thickness of 5/8" or less. The cast iron components at Dresden are all connected to pipe of wall thickness below 5/8". This exemption from impact testing is regardless of material (some materials are exempt altogether). ND-2332 requires that impact testing be done at the lowest service temperature. The lowest service temperature in the DGCW and CCSW systems is 32°F. There are a number of Section III approved materials that at 32°F are close to their lower shelf fracture toughness, such as SA-216 and SA-352 annealed or normalized cast carbon steel [3]. At the lower shelf, these materials are not much different than cast iron in their fracture toughness, however they are still exempt from impact testing (when used as pump or valve material) if the connecting pipe wall thickness is less than 5/8". Thus it is inferred that the cast iron components in the CCSW and DGCW systems at Dresden do not require impact testing.

From a practical standpoint, fracture toughness is a concern only in applications which involve shock loading. Paragraph ND-3622 of ASME Section III requires that impact loads, whether internal or external, be considered in design. The use of cast iron at Dresden is exclusively in service water systems, which are not subject to thermal, pressure, or mechanical shocks. These systems are not subject to water hammer as they are kept full, there is no change of phase of the contained liquid, and there are no rapidly closing valves or rapidly starting pumps. Although these systems are designed for seismic loading, the seismic loads do not produce impact loads in the cast iron components. This is because the use of cast iron is limited to valve bodies and pump casings. The valve bodies are not enclosed in pipe supports, and therefore do not impact the support members during seismic motion. The pump casings also do not impact against other components during an earthquake.

4.0 ACCEPTANCE CRITERIA FOR CAST IRON COMPONENTS AT DRESDEN

Cast iron valve bodies and pump casings shall be considered acceptable for service at Dresden Nuclear Power Station provided they meet the following requirements:

4.1 Compliance with Code of Construction

4.1.1 General

1. The Containment Cooling Service Water and the Diesel Generator Service Water system piping are designed to USAS B31.1, 1967 Edition.

2. All cast iron valves and the CCSW pump meet the manufacturers specified pressure and temperature service ratings.

3. The design temperature is not higher than 400°F, and not lower than 32°F.

4. The material of the cast iron components meets ASTM Specification A 126 or A 48.

5. All cast iron valves are manually operated, and meet the ANSI B16.10 Standard.

6. The cast iron components are not used with flammable, combustible, or toxic fluids.

7. The cast iron components are not subject to water hammer or rapid thermal or pressure transients. Mechanical impact such as hammering to disassemble flanged joints is not permitted.

8. There are no pipe supports at the cast iron valves.

9. Welding to cast iron components is not permitted.

4.1.2 Valve Nozzle Stresses

The valve nozzle stresses caused by the connecting piping end moments meet the following stress limits (see Notes, below):

Sustained Loads:

Pressure Stress + Deadload Stress ≤ 1.0 S_{CI}

Level B Loads:

Pressure Stress + Deadload Stress + OBE Stress ≤ 1.2 S_{CI}

Level D Loads:

Pressure Stress + Deadload Stress + DBE Stress ≤ 2.4 S_{CI}

Thermal Expansion plus Sustained Loads:

Pressure Stress + Deadload Stress + Thermal Expansion Stress ≤ 2.5 S_{CI}

Notes:

1. Definition of the stress terms is per ASME B31.1, 1989 Edition.
2. S_{CI} = 6.0 ksi.
3. The Level D allowable is per Code Case 1606-1.
4. The thermal expansion plus sustained load allowable assumes fewer than 7000 thermal transient cycles. For cast iron, $S_c = S_h$.

4.1.3 Pump Nozzle Stresses

The pump nozzle stresses caused by the connecting piping forces and moments meet the following stress limits (see Notes, below):

Level B Loads:

General Membrane Stress ≤ 1.1 S_{CI}

General or Local Membrane Stress + Bending Stress ≤ 1.65 S_{CI}

Level D Loads:

General Membrane Stress ≤ 2.0 S_{CI}

General or Local Membrane Stress + Bending Stress ≤ 2.4 S_{CI}

Notes:

1. Definition of stress terms is per ASME Section III, ND-3416, 1989 Edition.
2. Level B general membrane stress is due to pressure, and axial forces from deadload, OBE, and thermal expansion.
3. Level B bending stress is due to deadload, OBE, and thermal expansion. No stress intensification factors are applied.
4. Level D general membrane stress is due to pressure, and axial forces from deadload and DBE.
5. Level B bending stress is due to deadload and DBE. No stress intensification factors are applied.
6. S_{CI} = 6.0 ksi.

4.2 Fracture Toughness Acceptance Criteria

1. All cast iron components are connected to piping of wall thickness 5/8" or smaller.
2. The lowest service temperature is not lower than 32°F.
3. The cast iron components are not subject to water hammer or rapid thermal or pressure transients. Mechanical impact such as hammering to disassemble flanged joints is not permitted.
4. There are no pipe supports at the cast iron valves. Displacements of the cast iron components are limited such that they do not contact other components in a seismic event.
5. Welding to cast iron components is not permitted.

5.0 REFERENCES

1. General Work Specification K-4080, Dresden Piping Design Table "O". SI File CECO-62Q-201.
2. ASTM Standard Specification for Grey Iron Castings for Valves, Flanges, and Pipe Fittings, A 126-93, 1993.
3. ASM Metals Handbook, Volume 1, "Grey Cast Iron", Tenth Edition, ASM Int., 1990.
4. ASM Metals Handbook, Volume 19, "Fatigue and Fracture Properties of Cast Iron", ASM International, 1996.
5. ASME Boiler and Pressure Vessel Code, Section III, Subsection ND, 1989 Edition.
6. ANSI / ASME B31.1 Power Piping Code, 1967 and 1989 Editions.
7. ASME Boiler and Pressure Vessel Code, Section IV, Subsection HC, 1989 Edition.