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CONSOLIDATED EDISON COMPANY

INDIAN POINT UNIT 2

VISUAL INSPECTION ACCEPTANCE CRITERIA FOR IN-SERVICE INSPECTION(ISI) OF IP2 CONCRETE CONTAINMENT STRUCTURE

Revision 0

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1.0 EXECUTIVE SUMMARY

This report is prepared to establish the general In-Service Inspection (ISI) acceptance criteria for the concrete surface of the Indian Point 2 (IP2) Containment Structure (CS). The USNRC issued Final Rule in 1996 to mandate the requirements of the Subsection IWL of the ASME Code for inspection of Nuclear Power Plant Structures (Reference 8.1). The Indian Point 2 Containment Building is a PWR containment structure of cast-in-place reinforced concrete with a steel liner. The ISI acceptance criteria in this report are established based on the unique IP2 containment configuration, design basis and the IP2 environmental conditions.

The ISI acceptance criteria set the threshold values of the concrete degradation that the IP2 Containment Structure can tolerate without compromising its structural integrity. The criteria provided in this report cover the major items for concrete inspection as recommended by ACI 201.1R-68 (Reference 8.7). The actual scope of the In-Service Inspections should be determined by the Inspection Team Responsible Engineer.

The IP2 reinforced concrete containment with an inner steel liner, has been subjected to a structural integrity pressure testing, as required by the ASME Code, Section III, Division 2 requirements, upon completion. This test was performed at the internal pressure of 54 psi, which is by far the most severe loading that the IP2 Containment Structure has experienced to date. During the Structural Integrity Test (SIT), the containment was inspected for the presence and the extent of the resulting cracks. The results of these inspections are documented in Reference 8.11. Although the concrete surfaces exhibited the documented cracking, the reinforcing steel remained in the elastic range and with the depressurization of the internal test pressure, the containment "rebounded", as expected, and the cracks closed to essentially hairline cracks.

Since the structural integrity test, the containment has not been subjected to any major loading. Any post integrity test cracks on the containment surface may potentially result from the differential containment mat settlements and/or by drastic redistribution of loading (dead load, earthquake load, etc.) within the containment. As described in this document neither of these conditions occurred. Therefore the only potential (and visible) cracks that are present on the surface of the containment are non-stress related cracks, and if present, are due to the effects of relatively long term exposure to the environmental conditions and are not likely to be excessive nor are they expected to be continuous through the thickness of the containment concrete, i.e. through cracks. As such, these potential cracks caused by the environmental conditions do not impact the structural integrity of the containment. The structure, in general, is capable of safely resisting all postulated loads and their combinations, including Loss-of-Coolant-Accident (LOCA) loads, by the reinforcing steel.

Due to these considerations, and to facilitate the containment outer surface inspections, it is concluded that there is no need to provide a detailed mapping and recording of the cracks on the surface of the containment dome and cylinder in the areas not affected by the presence of large penetrations which cause discontinuity and a potential stress concentration. These areas, where no recording of cracks is required, are categorized as green and yellow zones, as further described in the body of this document. The ISI of these areas can be performed from remote locations utilizing appropriate optical equipment, in lieu of the close-up inspections specified by VT-3C in Subsection IWA 2213 of the ASME Code (Reference 8.3), to observe and record any signs of rebar rusting reflected on the surface. Rusting may indicate potential rebar area reduction that may potentially affect structural integrity that should be evaluated.

At transition areas, i.e. around the equipment and personnel hatches, penetrations and the intersection of the cylinder and mat which are easily accessible, mapping and recording of the cracks, in length and width, that are larger than the values provided in 7.1.2 are recommended. In addition any sign of rebar rusting should also be recorded for its effects on the structural integrity of the CS and for future engineering evaluations.

This report also provides a summary of the maximum stresses and design margins of the reinforcing steel in the IP2 Containment Structure. A review of the existing design documents confirmed that the IP2 Containment Structure has sufficient design margins in most of the areas. These margins allow some degree of concrete degradation while maintaining the original design functions of the structure. The steel liner will not be affected by the minor degradation of the concrete, and the leak tightness function of the steel liner is not compromised.

The following sections describe in detail the background, methodology, and steps taken in making the conclusion summarized above.

2.0 BACKGROUND

The USNRC found a large variation in the effectiveness of the programs, used to inspect steel and concrete containment structures by the Nuclear Power Plant Licensee, to detect degradation that affects the integrity of the structures. This finding was the result of a survey conducted in 1990. As a result, the USNRC imposed among other requirements, that a more detailed visual inspection requirements be imposed to ensure the detection of defects that may potentially compromise containment structural integrity and leak tightness.

On September 9, 1996, the USNRC issued a Final Rule (Reference 8.1) and amended 10CFR 50.55a (Reference 8.2) to incorporate requirements of the 1992 Edition and 1992 Addenda of ASME Code Section XI, Subsections IWE and IWL (Reference 8.3), with some specific exceptions, into the In-service Inspection Program for containment structures. Subsection IWE addresses the visual inspection of surfaces of metal containment structures, steel liners of the containment, pressure-retaining bolts, and seals and gaskets. Subsection IWL addresses the visual inspection of concrete pressure-retaining shells and shell components, and examination of unbonded post-tensioning systems.

Subsection IWL requires that VT-3C visual examinations be performed to determine the general structural condition of concrete surfaces of containment structures by identifying areas of potential concrete deterioration and distress, such as defined in ACI 201.1R-68 (Reference 8.7). Minimum illumination and maximum direct examination distance during the inspection are specified in IWA-2210. These requirements involve visual inspection of the concrete containment Structures at relatively close distances to their surface to identify and record the presence of cracks, which may include very small cracks, for evaluation of their effects, if any, on the structural integrity of the concrete containment.

3.0 PURPOSE

The purpose of the ISI acceptance criteria provided in this report is to provide guidelines for the inspection of the IP2 Containment Structure outer concrete surfaces. These guidelines are determined based on the review of available design data which includes the original design criteria, design calculations, licensing requirements, construction requirements, structural integrity test results and plant service environment, among others.

The criteria provide the information for the inspection team to determine the incidences that need to be specifically recorded during the inspection in accordance with the requirements of VT-1C of IWA-2211 (Reference 8.3) for future engineering evaluations. It is determined in this report that the close-up inspection, as required by VT-3C of IWA-2213, will not be necessary for most of the areas on the outer concrete surfaces of the containment structure.

This report also provides the summary of the calculated design stresses in the reinforcing steel and the existing design margins. This information may be useful to the inspection team and the Responsible Engineer in evaluating the structural integrity of the reinforced concrete where the concrete degradation or the rebar corrosion indications are beyond the threshold values provided in the acceptance criteria.

The ISI acceptance criteria simplify the requirements for containment concrete surface inspection, minimize the unnecessary recording and engineering evaluation efforts, shorten the duration of inspection, reduce the record keeping and finally, reduce the cost of ISI without compromising the intent of the inspections in demonstrating the structural integrity of the CS.

4.0 JUSTIFICATIONS FOR THE ACCEPTANCE CRITERIA

- The IP2 containment is a reinforced concrete structure with a steel liner. As such, a minor degradation of the concrete will not affect the containment to function as a leak-tight structure. Based on the reasoning and justifications provided in section 6.5.1, the inner portions of the concrete are always in compression under normal operating conditions and therefore through cracks in the concrete are unlikely. Since through cracks in the concrete are not anticipated, yielding or rupture of the steel liner due to concrete crack induced strain is not an issue.

- The structural integrity of the IP2 Containment Structure is mainly maintained by the reinforcing steel. There are sufficient design margins of the reinforcing steel in most areas, as shown in Tables 3 and 4. Therefore, some degree of acceptability of the reinforcing steel area reduction due to rusting, though improbable, can be tolerated. This rusting may be postulated to occur due to possible migration of moisture through the surface cracks.

- Under normal operating conditions, the loads acting on the containment are the dead load, thermal load due to seasonal temperature change, snow load, and wind load. Under dead load and snow load the containment cylinder and dome are in compression. The thermal and wind loads could potentially crack the surface of the containment. Since the containment surface has cracks due to drying shrinkage and the structural integrity test, no additional cracks due to wind and thermal loads are expected. If anything, the existing cracks on the surface may open further due to thermal and wind loads. These cracks are of no concern and do not have any effect on the structural integrity of the containment.

- The IP2 Containment is founded on rock. Concrete fill was used in certain areas under the mat to level the rock to the elevation of the bottom of the mat. The rock and the fill are practically rigid. Settlement of containment mat, which is the only potential source of distress in the containment mat and cylinder under normal operating conditions, is not anticipated. In the unlikely event of yielding of the fill concrete, the distress of the containment will show at the intersection of the mat and the cylinder in the form of cracks, similar to what could be expected as a result of differential settlement. The effect on the general areas of the containment cylinder and dome is insignificant due to the continuity and overall rigidity of the containment shell.

- The IP2 Containment Structure has not been subjected to a DBE (Design Basis Earthquake with a peak ground acceleration of 0.15 g) event to date. However during the Structural Integrity test it was subjected to 54 psi internal pressure which is higher than a calculated peak pressure due to a LOCA of 41.12 psi. The maximum crack size anywhere on the surface before the test was measured to be 0.01". Inspection of the containment surfaces during the test showed that the maximum crack size was 0.03" at maximum test pressure and was reduced to 0.01" when the test was completed. This indicates, as also concluded in Reference 8.11 that the rebar remained in elastic range during the test. Following this test, there is no stress in the rebars, other than normal operating stress, which is very small, and there is no reason for any stress-related crack to develop in the general areas under normal operating conditions.

- There have been no reports in the industry of any major structural degradation of PWR reinforced cast-in-place concrete containment structures with liners that would affect the containment structural integrity (as recorded in the Documented Evaluation of the USNRC Final Rule, Reference 8.1). The IP2 plant is situated in an environment that does not have significant detrimental environmental elements that would potentially cause any concrete degradation to a higher extent than the other operating plants (See Section 5.3 for details). Therefore it is unlikely that the IP2 Containment Structure will have any major concerns that may be caused by the potential concrete degradation. Detailed inspection at a close range and recording of the existing cracks in the general area of the containment concrete surface is therefore not necessary.

- IP2 Containment Structure was built of cast-in-place reinforced concrete with a steel liner, without the use of pre-stressed concrete construction. Therefore, the inspection can be limited to the concrete surface of the containment. Many of the inspection requirements provided in the ASME Subsection IWL are for the prestressed concrete containment structures and are not applicable, nor necessary, for the IP2 Containment Structure.

5.0 METHODOLOGY

In order to develop the inspection acceptance criteria for the IP2 Containment Structure, the following steps were taken.

5.1 Review of the Containment Structural Integrity Test Report

In 1971, a Structural Integrity Test (SIT) for the IP2 Containment Structure was performed in accordance with the requirements of the ASME Code Section III, Division 2 (Reference 8.11). The maximum test pressure was 54 psi, which is 1.15 times the design pressure of 47 psi. The design pressure of 47 psi is more than the maximum pressure of a postulated Loss-of-Coolant Accident (LOCA) which is calculated to be 41.12 psi. Prior to the SIT, crack prediction calculations and pretest mapping of the concrete cracks of the containment outer face, including three white washed areas, i. e., equipment hatch, personnel lock and a 10' by 30' area at azimuth 310^0 above Elevation 43' was performed. During and following the pressure test, the resulting concrete surface cracks were examined. The following is a summary of those examinations:

5.1.1 Pretest Examinations

The following observations were recorded prior to the SIT:

- **i)** Horizontal cracks of widths less than 0.005" at construction joints were observed.
- **ii)** Spider cracks consisting of three or four cracks, less than 0.005" in width and approximately eight to ten inches long, at almost all the scaffolding insert holes were observed.
- **iii)** Vertical cracks observed were random in nature and occurred in general between Elevations 93'-0" and 168'-0". Below 93'-0" and above 168'-0", cracking was found to be much less prevalent. 99% of the cracks were found to be less than 0.005" in width and the

maximum crack width was 0.008". None of the cracks found were more than 4' long. Vertical cracks typically began at one construction joint and terminated at the next construction joint.

iv) Cracks observed in the dome, from spring line to apex were all less than 0.005" in width. Cracking generally occurred in all of the form crevices.

v) All cracks observed were considered to be associated with concrete drying shrinkage.

5.1.2 Examinations during Test

i) No new horizontal crack was observed.

ii) New cracks that developed during the test were mostly in the vertical direction. The maximum crack width was 0.02" in the white washed areas of equipment hatch interface between the containment wall and the thickened boss, and at the Azimuth 310^0 wall section. The crack length in the equipment hatch interface was approximately 6'. The crack spacing at the Azimuth 310^0 was about 15". The maximum crack width measured on the containment surface was 0.03", which occurred at the interface area of the containment wall and the thickened boss at the equipment hatch.

5.1.3 Examinations after Test

The containment structure was inspected and surveyed after the test. Cracks, which were "open" during the test, closed to nearly their original width. The largest cracks at the equipment hatch area had closed to approximately one-third of the maximum to about 0.01".

The details of these examined/measured cracks are contained in Reference 8.13.

5.2 Review of Design Documents

The following design documents, calculations, design reports and drawings were reviewed to obtain the stresses in the reinforcing steel in the containment structure, and other pertinent information necessary for the development of the inspection acceptance criteria:

5.2.1 Appendix 5A of Indian Point Nuclear Generating Unit No. 2 Updated Final Safety Analysis Report (UFSAR) (Reference 8.4), "Indian Point Unit 2 Containment Design Report", Revision 3 (Reference 8.13).

5.2.2 Book No. 16, Containment Structure – Volume No. 1 (Reference 8.14).

5.2.3 The Consolidated Edison Vendor Drawings Listed Below:

5.2.3.1 Containment South Section Seismic Reinforcing, Con. Edison Drawing No. A200069.

5.2.3.2 Containment Exterior Wall Elevations and Details, Con Edison Drawing No. A200070.

5.2.3.3 Containment Wall Reinforcing, N-E Quadrant – Elevation 43'-0" to 121'-9", Con. Edison Drawing No. A200078.

5.2.3.4 Containment Wall Reinforcing, S-E Quadrant – Elevation 43'-0" to 121'-9", Con. Edison Drawing No. A200079.

5.2.3.5 Containment Wall Reinforcing, S-W Quadrant – Elevation 43'-0" to 121'-9", Con. Edison Drawing No. A200080.

5.2.3.6 Containment Wall Reinforcing, N-W Quadrant – Elevation 43'-0" to 121'-9", Con. Edison Drawing No. A200081.

5.2.3.7 Containment Wall Reinforcing, NE & SE Quadrant – Elevation 121'-9" to 151'-0", Con. Edison Drawing No. A200082.

5.2.3.8 Containment Wall Reinforcing, NW & SW Quadrant – Elevation 121'-9" to 151'-0", Con. Edison Drawing No. A200083

5.2.3.9 Containment Wall Reinforcing, NE & SE Quadrant – Elevation 151'-0" to 191'-0", Con. Edison Drawing No. A200084

5.2.3.10 Containment Wall Reinforcing, NW & SW Quadrant – Elevation 151'-0" to 191'-0", Con. Edison Drawing No. A200085.

5.2.3.11 Containment, Reinforcing at Equipment Hatch Boss, Con. Edison Drawing No. A200086.

5.2.3.12 Containment, Dome Reinforcing, NE & SE Quadrant, Con. Edison Drawing No. A200087.

5.2.3.13 Containment, Dome Reinforcing, NW & SW Quadrant, Con. Edison Drawing No. A200088

5.2.3.14 Containment, Seismic Reinforcing From El. 134'-4" to 227'-1", All Quadrants, Con. Edison Drawing No. A200094.

5.2.3.15 Containment, Seismic Reinforcing From to El. 134'-4", NE Quadrant, Con. Edison Drawing No. A200102.

5.2.3.16 Containment, Seismic Reinforcing From to El. 134'-4", SE Quadrant, Con. Edison Drawing No. A200103.

5.2.3.17 Containment, Seismic Reinforcing From to El. 134'-4", SW Quadrant, Con. Edison Drawing No. A200104.

5.2.3.18 Containment, Seismic Reinforcing From to El. 134'-4", NW Quadrant, Con. Edison Drawing No. A200105.

5.2.3.19 Containment, Liner Details, Con. Edison Drawing No. A200168

5.3 Review of Environmental Conditions

The following aspects of the environmental conditions, which may have an effect on the concrete and reinforcing steel integrity, were reviewed:

5.3.1 Exposure to Atmosphere and Temperature Fluctuation

Indian Point No. 2 plant is situated in the southern part of New York State on the Hudson River, and away from the Atlantic Ocean. The plant is not subject to any extreme weather conditions nor is it subject to the salty air of ocean environment. There has been no record of any abnormal air quality or weather conditions during the years of plant operations. The daily and seasonal fluctuations of the temperature are considered to be within the expected environment for the original design of the concrete. Therefore, the degradation of the concrete beyond the normal expected rates is not anticipated. The reinforcing steel in the concrete containment is also anticipated to be in or close to the originally installed conditions and is expected to remain in that condition for the remaining plant life as presented by the study in Attachment A.

5.3.2 Ground Water Table

Since the base of the containment is at Elevation 43'-0" and the ground water level at the plant site is at Elevation 7'-3", no ground water is expected to be in contact with the outside face of the containment. Therefore the rate of concrete degradation would not be accelerated nor affected by the presence of the ground water.

5.3.3 Exposure to Chemical Substances

The lower portion of the containment is either buried in the earth backfill or is enclosed by adjacent buildings. The upper portion of the containment is exposed to the atmosphere where the air quality is generally free of chemical substance that may have detrimental effects on the structural integrity of the concrete. There are no systems nearby the containment outer surface that would disperse any chemical substances onto the containment surface. Deicing material or salt has not been used on the containment.

5.4 Review of Industrial Practices and Standards

The following documents related to the industrial practices and standards on concrete cracking were reviewed to obtain information on cracks in aged cast-in-place concrete.

5.4.1 EPRI NP-6695, "Guidelines for Nuclear Plant Response to an Earthquake" December 1989 (Reference 8.8). (On Page 5-21 of Table 5-1, under Reinforced Concrete Structures, the document recommends new open cracks of width larger than 0.06" be considered during the post earthquake inspection.)

5.4.2 ACI 224R (Reference 8.10).

5.4.3 Properties of Concrete by A.M. Neville, Third Edition (Reference 8.12)

5.5 Stress Mapping

The stress map (Figure 2) was prepared based on the summary (Tables 1 and 2) extracted from the original design documents, Containment Design Report (Reference 8.13) and design calculations (Reference 8.14). The stress map shows the maximum stresses in the reinforcing steel in the various areas on the containment surface.

5.6 Design Margin Mapping

The design margin map (Figure 3) was prepared based on the summary of the stresses. The map shows the design margins in the reinforcing steel in various areas of the containment surface.

5.7 Determination of Inspection Acceptance Criteria

Based on the results from the steps described above, inspection acceptance criteria were developed. The acceptance criteria establish the guidelines for the major inspection parameters for the concrete outer surface of the containment. A map (Figure-4) was prepared to identify the guidelines for the measurement of the concrete cracks in various areas of the containment surface.

6.0 IP2 CONTAINMENT STRUCTURE

6.1 Function

Indian Point Unit No. 2 Nuclear Power Generating Station utilizes a Westinghouse Light Water Pressurized Water Reactor (PWR) NSSS system. The station was built in the late 1960's and completed in early 1970's.

The IP2 Containment Structure completely encloses the entire reactor and reactor coolant system and ensures that essentially no leakage of radioactive materials to the environment would result even if a loss of coolant accident (LOCA) with a gross failure of the reactor coolant system were to occur. The containment structure also provides biological shielding for normal and accident conditions. The containment structure is designed to withstand several conditions of loading and their credible combinations. The limiting extreme loading conditions are:

a) Occurrence of a gross failure of the reactor coolant system, which creates a high pressure and temperature, condition (Loss-of-Coolant Accident, LOCA) within the containment.

b) Coincident failure of the reactor coolant system with a maximum postulated earthquake (DBE) or the maximum wind effects

6.2 Description

The IP2 Containment Structure is a reinforced concrete vertical right cylinder with a flat base and a hemispherical dome. A steel liner with a minimum thickness of 3/8" is attached to the inside face of the containment wall and dome to insure a high degree of leak-tightness. The steel liner is attached to the inside face of the concrete shell by stud anchors and structural tees. The thickness of the liner on top of the base mat and on the walls of the cavities is 1/4". The thickness for the first three courses on the shell, starting from the base mat, is 1/2" except at penetrations where the thickness is 3/4". The thickness of the liner on the balance of the cylinder shell up to the spring line is 3/8" and on the dome is 1/2".

Attachment of the dome liner to the concrete is made by a combination of structural steel tee sections (ST 4 B 7.5#), welded to the exterior face of the dome liner in meridional and circumferential directions at approximately five foot intervals, and by stud anchors which are provided between the tees. The 3/8" thick liner on the cylinder shell is anchored to the concrete by stud anchors, welded to the liner at a 14" vertical spacing and a 24" circumferential spacing. The spacing of the studs for the 1/2" thick liner is 28" in the vertical direction and 24" in the circumferential. The studs are 1/2" diameter bent bars with a variable length (7" minimum and 7.5" maximum) and a 2" bent extension.

The containment cylindrical shell is 148' from the liner on the base to the spring line of the dome, and has an inside nominal diameter of 135'. The walls of the cylindrical shell and the dome are 4'-6" and 3'-6" thick, respectively. The inside radius of the dome is equal to the inside radius of the cylindrical shell so that the discontinuity at the spring line due to the change in thickness is on the outer surface. The thickness of the containment at the spring line gradually changes from 4'-6" to 3'-6".

The base mat is 9 feet thick with the bottom liner plate located and anchored to the top of this mat. The bottom liner plate is covered with a 3' structural slab of concrete, which carries the internal equipment loads and forms the floor of the containment. The internal pressure within the containment is self-contained in that the vector sum of the pressure forces is zero; therefore, there is no need for mechanical anchorage between the bottom mat and the underlying rock for the resistance of pressure loads. The base of the containment is supported directly on base rock and/or fill concrete.

The basic elements considered in the design of the containment structure are the base slab, cylindrical wall and dome acting as one structure under all possible loading conditions. The liner is anchored to the concrete shell by means of stud anchors so that it forms an integral part of the entire composite structure under all postulated loads. The reinforcing steel in the structure has an elastic response to all primary loads with controlled maximum strains to insure the integrity of the steel liner. The lower 20' of the cylindrical liner is insulated to avoid deformation of the liner due to restricted radial growth when subjected to a rise in LOCA temperature. Additional insulation was added, after a feedwater line broke in 1973, to extend the insulation from Elevation 64'-0" to approximately Elevation 82'-0". The insulation at the piping penetration areas was further extended to Elevation 90'-0" to reduce the thermal effects on the liner due to temperature change.

6.3 Design Basis

As discussed in Reference 8.13, Containment Design Report, the containment structure is designed for the following loads:

- Dead load (D)---This includes all structural self weight.
- Live load (L)---This includes all major equipment and personnel weights in the containment.
- Snow load (S)---Snow and ice loads of 20 lb/ft^2 were considered on the top of the dome.
- Construction loads (C)---50 lb/ft^2 on the top of the dome was considered.

- Wind Load (W)--- Wind load corresponding to a 30 lb/ft^2 (Reference 8.5) zone was considered in accordance with the requirements of Code A58.1-1955. In addition, the containment was also investigated for tornado wind pressure, differential pressure, and tornado-generated missiles.
- Operating temperature (T_o)--- The temperature inside the containment during the normal service condition is 130° F (Reference 8.5). The temperature on the containment wall outside surface varies depending upon the location of the walls. In consideration of the wall surface temperatures, the wall can be divided into three regions. In the first region, the wall is exposed to the atmosphere and the surface temperature varies from -5° F in winter to 95° F in the summer. The surface in this region experiences the largest fluctuation in temperatures. In the second region, the wall is built under ground and with soil temperature being steadier than the atmosphere. In the third region, the containment wall is formed as part of the walls of other adjacent structures, such as Electrical Rooms, Fan House and Fuel Storage Buildings and the wall surface temperature varies with the building room temperatures.
- Creep and Shrinkage loads --- The maximum stress induced in the steel reinforcement by these conditions are 4000 psi. Since the limiting case for the design is accident pressure load which effectively cracks the concrete and places the reinforcement into tension, creep and shrinkage induced stress was not a limiting factor in design.
- Operating Basis Earthquake Load (E) --- The response resulting from the earthquake with the ground accelerations in the horizontal and vertical directions of 0.1g and 0.05g, respectively.
- Design Basis Earthquake load (E')---The responses resulting from the earthquake with the ground accelerations in the horizontal and vertical directions of 0.15g and 0.1g, respectively.
- Accident Pressure Load (P)---The conservative design pressure is 47 psi.

- Accident temperature load (T_a)---The temperature inside the containment during an accident varies with time and the maximum temperature is 260° F (Section 3.3.1 of Reference 8.5). This high temperature acts on the steel liner.

Based on Reference 8.5, the critical load combinations considering all loads discussed above are summarized below. Loads not contained in the load combinations are not governing the containment structure design.

a) $1.0\ D \pm 0.05\ D + 1.5\ P + 1.\ 0\ T_a$

b) $1.0\ D \pm 0.05\ D + 1.25\ E + 1.0\ T_a + 1.25\ P$

c) $1.0\ D \pm 0.05\ D + 1.0\ E' + 1.\ P + 1.0\ T_a$

In order to assess the structural behavior during the normal operating conditions, stresses in the reinforcing steel for the following load combination that includes dead load and normal operating temperature were also extracted from References 8.13 and 8.14 as:

d) $1.0\ D + 1.0\ T_o$

6.4 Reinforcing Steel Stress and Effect on Concrete Cracking

The stresses in the reinforcing steel at various elevations of the containment structure outer face for load combinations a) and d) are summarized in Tables 1 and 2. The relationships between the reinforcing steel stress and the concrete cracks are discussed below.

6.4.1 Areas Away from penetrations, Equipment Hatch and Personnel Lock

The stresses in the containment rebar, shown in Table 1 for given elevations of the containment structure, were based on the worst thermal gradient across the containment wall thickness. This worst condition is represented by the exterior wall temperature of –5° F in winter and the temperature at the inside steel liner in the normal operating temperature or the maximum accident temperature. However, the containment wall is partially underground near the equipment hatch area and partially surrounded by electrical penetration rooms, fan house and fuel storage building.

Therefore, concrete cracks are more of a concern in the areas exposed to the environment. The area exposed to weathering will potentially experience rainwater seepage, ice formation and temperature fluctuation which may result in degradation of concrete and may also potentially result in the corrosion of the reinforcing steel.

Normal Operating Service Condition

The maximum stress in reinforcing steel under normal operating service condition is 3.83 ksi near the spring line. The overall section in vertical direction is in compression due to the dead load and the overall section in the hoop direction is under nominal stresses. The reinforcing steel stress is due to temperature gradient across the wall thickness alone. The concrete section near the outer face is in tension but the inner part of the section close to steel liner is in compression. Therefore, the section, if cracks developed, will not be a fully cracked section. The resulting crack width and crack length is expected to be minimal. This condition is confirmed by the concrete crack survey, performed prior to the Structural Integrity Test of the containment, as discussed in Section 5.1.

Abnormal Condition

The maximum design stress in the outer face reinforcing steel under the abnormal condition is 38.7 ksi in the hoop direction between Elevation 117'-0" and the spring line at Elevation 191'-0". Part of this stress is due to the thermal gradient across the wall thickness. The stress, in the reinforcing steel and steel liner due to 1.5 times the 47 psi (design pressure) is 32.8 ksi (page 118, Book No. 16, Reference 8.14). The abnormal condition is a onetime occurrence in the plant life. Considering that the accident would happen at the end of 40 years life, and using the steel allowable stress of 0.9 Fy (54 ksi) as specified by the design code, the required area of the reinforcing steel can be calculated. Comparison of the required area with the actual area of reinforcing in the containment wall provides the amount of rebar that could be lost to possible corrosion without any impact on the structural integrity of the containment structure.

Based on "Handbook of Corrosion Data" by B. D. Craig, ASM International, 1989 Edition (Reference 8.9), the maximum corrosion rate in the first year of carbon steel exposed to atmosphere is 0.926 mils/year and 0.21 mils/year at the 16^{th} year. Considering the reinforcing steel exposed to the atmosphere for 40 years and the 0.926 mils/year corrosion rate as a constant over the entire period of time, the maximum reduction of the No. 18 bar (most exterior hoop bars) is 4.0-3.742=0.258 square inches, which is less than 10% of the original area. With this maximum postulated reduction in area, the stress in reinforcing steel will increase from 38.7 ksi to 42.6 ksi which is still well within the 0.9 Fy (54 ksi) allowable.

Based on the above discussion, corrosion of rebar due to potential cracks in concrete that allows access of exterior moisture to the rebar will not affect the structural integrity of the containment structure and its leak-tightness function under plant abnormal condition.

6.4.2 Containment Structure at Equipment Hatch, Penetrations, and Personnel Lock

The stresses in the rebar as tabulated in Table 2 for the equipment hatch are applicable to the areas where major penetrations and personnel lock are located. A review of these stresses, as listed in Table 4, shows that very limited or no design margins exist in these areas.

Therefore no corrosion of rebar is tolerated around equipment and personnel hatches and other penetrations. The acceptance criteria for the ISI on the crack size in these areas are based on this consideration.

7.0 INSPECTION ACCEPTANCE CRITERIA

The acceptance criteria for inspection of the IP2 Containment Structure outer surfaces are provided in this section. The criteria are based on the information and justifications noted in previous sections of this report. The inspection acceptance criteria are provided for the following concrete attributes in the sections noted.

- Cracks (7.1)
- Spalling (7.2)
- Scaling (7.3)
- Leaching (7.4)
- Staining (7.5)
- Exposed Rebar (7.6)

In addition, flow charts for the In-Service Inspection are provided in Section 7.7. The flow charts facilitate the decision making by the inspection team on the acceptability of the encountered conditions of concrete. It is to be noted that the scope of inspection is not bounded and/or limited to the attributes given in Sections 7.1 through 7.6. The Responsible Engineer of the inspection team should decide what attributes are to be inspected.

7.1 Cracks

A brief review of the guidance for the acceptability of the concrete structure crack sizes from the codes and standards and other related literature is provided in this section. In addition, the anticipated size of cracks due to shrinkage, and seasonal temperature change specific to IP2 containment and size of the cracks observed before, during and after Structural Integrity Test are provided. The purpose of this review is to provide further justification for the acceptance criteria that are given in Section 7.1.2.

ACI 318-95 (Reference 8.16) limits the crack size in the tension zone of the structural elements to 0.013" (0.33 mm) for exterior exposure and 0.016" (0.41 mm) for interior exposure at the design stage to assure protection of reinforcement against corrosion, and for aesthetic reasons. It states that many fine hairline cracks are preferable to a few wide cracks (Section 10.6 of Reference 8.16). ACI 349 (Reference 8.6) which is applicable to safety-related structures uses the same criteria as ACI 318.

ACI 207.3R (Reference 8.17), which provides information for In-Service Inspections of concrete structures, classifies cracks as fine, medium and wide. A fine crack has a width of less than 0.04" (1 mm), a medium crack is defined as having a width between 0.04" to 0.08" (1 to 2 mm),, and a wide crack width is defined as being more than 0.08" (2 mm).

EPRI NP-6695, "Guidelines for Nuclear Plant Response to an Earthquake" dated December 1989 (Reference 8.8), recommends that new cracks greater than 0.06" (1.5 mm) in width should be inspected after earthquake event. It states that cracks with widths greater than 0.06" (1.5 mm) are generally indicative of reinforcing steel overstress, therefore evaluation of the structural integrity is warranted.

After construction of the IP2 Containment Structure and before the Structural Integrity Test (SIT), a survey of the crack sizes on the outer surface of the containment was performed as noted in Section 5.1. The cracks were in general less than 0.005" (0.13 mm). Crack sizes up to 0.01" (0.25 mm) around the large openings were also measured. During the test, no new circumferential cracks were observed. New cracks that developed during the test were mostly in the vertical direction, as expected, with a nominal width of 0.02" (0.50 mm). The maximum crack width measured on the containment surface was 0.03" (0.75 mm), which occurred at the interface area of the containment wall and the thickened boss at the equipment hatch. The containment structure was again inspected and surveyed after the test. Cracks that were "open" during the test closed to nearly their original width. The largest cracks at the equipment hatch area had closed to approximately one-third of the maximum to about 0.01" (0.25 mm.). The spacing of the circumferential cracks was about 5' (spacing of construction joints) and the spacing of vertical cracks was approximately 15".

The crack sizes due to shrinkage and seasonal temperature change are calculated as part of this study. The size of drying shrinkage cracks in the vertical direction considering 15" spacing and using a maximum coefficient of 800 micro strain (Reference 8.18) is estimated to be 0.012" (0.3 mm). The maximum size of shrinkage cracks in the circumferential direction using 5' spacing will be 0.048" (1.2 mm).

The maximum calculated vertical crack size (spacing 15") due to change in temperature, using a coefficient of thermal expansion of 5.5×10^{-6} / °F and a conservative change in temperature of 75° F is 0.0124" (0.3 mm). This is calculated assuming conservatively that the inside surface of the containment shell is restrained and will not expand due to normal operating temperature of 130° F. The maximum circumferential crack size due to temperature change will be 0.05" (1.2 mm) using a 5' spacing.

Based on the above discussions, the total maximum temperature and shrinkage vertical crack size will be 0.024" (0.6 mm) and the circumferential crack size will be 0.1" (2.5 mm). It is to be noted that the calculated circumferential crack size is an upper bound value and is based on 5' spacing assuming that no other hair line cracks develop due the temperature change and shrinkage.

The size of a stress related crack, assuming an outer rebar reaches yield is estimated to be about 0.03" (0.75 mm). The calculated crack sizes discussed above are summarized in Table 5.

In order to provide guidance for the acceptance criteria for ISI observation/recording of the cracks, three crack zones are identified in Section 7.1.1. The guidance for each zone, which addresses the crack widths, lengths, orientations, spacing and numbers of cracks are provided in Section 7.1.2.

7.1.1 Crack Zones

The containment is composed of a cylindrical wall, a hemispherical dome, a steel liner and several major penetrations. Due to the different configurations and locations of these structural elements, the design stresses in the reinforcing steel vary. Therefore, based on the strength requirements and the structural configurations, the guidance for the ISI recording of the cracks is different for different locations. Three zones are identified to distinguish the guidance for the crack as shown in Figure 4 and described below:

Green Zone: This zone represents the areas of the cylindrical portion of the containment wall away from the penetrations. The design margins in the reinforcing steel in these areas have been shown to be adequate to accommodate the conservatively calculated steel area reduction, given in Section 7.6, due to the postulated corrosion. Therefore the surface crack mapping and crack size recording for these areas are not required unless the crack is determined to be stress-related. It is , however, required that these areas be carefully inspected by remote optical means for signs of any rebar corrosion as may be reflected on the surface. Areas exhibiting such indication of rusting should be identified and brought to the attention of the Responsible Engineer for further evaluation/disposition. Section 7.1.2.1 provides further guidelines for inspection and recording of stress-related cracks.

Yellow Zone: This zone represents the areas of the dome surface of the containment where the concrete is thinner than the cylinder and where the reinforcing steel is more susceptible to rusting due to migration of melted snow or rain through cracks. The dome rebars have a bigger cover than the cylinder and have sufficient design margins to accommodate the conservatively calculated steel area reduction, given in Section 7.6, due to the postulated corrosion. The concrete surface mapping and crack size recording for the cracks in this yellow zone are also not required unless the crack is determined to be stress-related. It is, however required that the yellow zone be carefully inspected by remote optical means for signs of any rebar corrosion as may be reflected on the surface. Areas exhibiting such indication of rusting must be properly mapped (by remote means) and brought to the attention of the Responsible Engineer for further evaluation and documented disposition. Section 7.1.2.1 provides further guidelines for inspection and recording of stress-related cracks.

Red Zone: This zone represents the areas that contain major discontinuities such as the equipment hatch, personnel lock and large mechanical/electrical penetrations, as well as the area where the containment cylinder intersects the containment base mat. The reinforcing steel around the large penetration areas does not have any design margin to accommodate any steel area reduction due to the potential long term rebar corrosion. The mat-cylinder intersection is susceptible to stress-related cracks, such as cracks that may develop due to potential differential settlement. The concrete around hot penetrations is susceptible to degradation due to long term excessive heat. Therefore the concrete surface cracks in the areas of the red zone have to be inspected in accordance with the requirements and the acceptance criteria provided in Section 7.1.2.2 of this document.

7.1.2 Acceptance Criteria for Cracks

7.1.2.1 Green and Yellow Zones

The maximum crack width during the Structural Integrity Test was 0.03" and the maximum crack width after the test was approximately 0.01". The majority of the cracks on the containment surface were smaller than 0.005". The calculated maximum stress in the reinforcing steel under normal operating conditions was only 15.82 ksi (Table 2). During the years of operations of the Indian Point 2 Plant, there were no major environmental or LOCA events recorded that would induce any additional stress to the reinforcing steel. The feedwater line No. 22 broke in 1973, the break thermal effects locally buckled the steel liner plate but did not induce any significant load in the reinforcing steel (Section 4.3.4.5 of Reference 8.5).

The IP2 Containment is founded on rock. A 9'-0" thick mat supports the containment structure. Concrete fill was used in certain areas under the mat to level the rock to the elevation of the bottom of the mat. The rock and the fill can be considered to be rigid. The only potential source of distress in the containment mat and cylinder under normal operating conditions would occur from the mat settlement that is not anticipated. In the unlikely event of yielding of the fill concrete, which may have the same effect as a differential settlement, the distress of the containment will appear in the intersection of the mat and cylinder in the form of visible cracks. The effect of this on the general areas of the containment cylinder and dome is insignificant due to the continuity and rigidity of the containment shell.

ACI 224R (Reference 8.10) states that the maximum concrete cracks will not increase with time when the reinforcing steel stress is below 30 ksi. Therefore, large cracks due to stress are not anticipated for the IP2 Containment Structure. Any potential increase of the crack width therefore may only be due to the exposure to the environmental conditions and the quality of the concrete. The containment is in an environment free of any elements that are significantly detrimental to the concrete quality which was placed under controlled conditions. Therefore, only normal degradation of the concrete through the years of operations is anticipated.

Furthermore, the containment was designed to have extra concrete cover over the reinforcing steel, approximately 3 1/8" to 3 5/8" for dome and 2 7/8" to 3 3/8" for the cylindrical wall. This extra depth of concrete cover will reduce the possibility that the reinforcing steel is subject to the moisture and the resulting corrosion attack.

Due to the temperature difference at the inside and outside concrete surfaces during the operating conditions, the inner portion of the containment wall and the dome will always experience compression. Therefore it is unlikely that through cracks would develop in the concrete wall and dome under operating conditions. Corrosion of the steel liner plate due to the potential seepage of water through the cracks is, therefore, not a concern. Also, additional stress on the steel liner plate due to concrete cracks is not anticipated.

The general appearance of the Indian Point 2 containment outer face shows little signs of major concrete degradation or any cracks of excessive width after over twenty years of operating life. A walkdown in early July of 1999 of the accessible areas, where part of the containment is embedded in soil, confirmed that the cracks were small demonstrating that the degradation rate of the containment concrete at Indian Point 2 is relatively slow.

EPRI NP-6695, "Guidelines for Nuclear Plant Response to an Earthquake" dated December 1989 (Reference 8.8), recommended that new cracks of larger than 0.06" in width should be inspected after earthquake event. Cracks with width larger than 0.06" may be indicative of reinforcing steel overstress, therefore evaluation of the structural integrity may be warranted. The IP2 Containment Structure has not been subjected to a DBE (Peak ground acceleration of 0.15 g) event to date. However during the Structural Integrity Test it was subjected to 54 psi internal pressure which is much higher than the peak pressure due to a LOCA. It is therefore prudent to expect observation of some minor cracking in the green and yellow zones of the IP2 Containment Structure.

This is confirmed based on the review of the crack sizes shown in Table 5. The maximum non-stress related crack size (Shrinkage and temperature) that is anticipated for the IP2 containment is 0.024" for vertical cracks (15" spacing) and 0.1" for circumferential cracks (5' spacing). Considering an unlikely condition that the outer rebar are stressed to yield (Hypothetical) under normal condition, the maximum crack size will be 0.06" in the vertical direction and 0.125" in the circumferential direction. These cracks are tolerable in the green and yellow zones. It is to be noted that the 0.125" crack size is based on the assumption that there are no hairline cracks between construction joints, which are 5' apart. This is highly improbable.

Considering that several hairline cracks exist, the upper bound horizontal crack size will be closer to 0.06".

In the yellow and green zones there are abundant design margins in the reinforcing steel. A crack width of 0.06" or more with a crack depth of more than 5" may expose the rebars to moisture. Under this scenario, rebar will tolerate the corrosion rate without losing its original design functions. See Attachment A, for a report on effect of cracks on corrosion of rebar.

Based on the information provided in the preceding paragraphs, cracks in the areas designated as green and yellow are primarily due to temperature change, shrinkage and the Structural Integrity Test and are of no consequence. In these zones no stress-related cracks are anticipated. It is therefore concluded that a detailed mapping and recording of cracks, on the general surface of the containment dome and cylinder away from discontinuities is not necessary. The inspection should be limited to recording of any signs of rebar rusting, if any. However if a stress related cracks is identified, it has to be recorded.

A stress-related vertical crack in the dome and cylinder is defined as a continuous crack extending toward the containment mat and crossing several horizontal construction joints. Discontinuous vertical cracks that end at a horizontal construction joint are not stress-related. A circumferential stress-related crack is defined as a crack continuously extending about 180° around circumference with a size of 0.125" (3 mm) due to cantilever action of the containment under lateral loads. This type of crack is not expected to be detected anywhere in the green and yellow zones. Size, length, location of any circumferential or vertical stress-related cracks and any other relevant information that could help the Responsible Engineer should be recorded for further evaluation.

7.1.2.2 Red Zone

In the hatch and penetration areas where nominal or no design margin in the reinforcing steel is available to tolerate corrosion, any crack that would pose potential passage for moisture should be recorded. The maximum crack width in these areas prior to the plant operations was approximately 0.01" and the tolerable crack width recommended by ACI report 224R (Reference 8.10), ACI 318 (Reference 8.16), and ACI 349 (Reference 8.6) is 0.013".

Considering that the IP2 Containment Structure has extra concrete cover beyond the ACI 349 code requirements (Reference 8.6), the threshold value for the acceptable crack width in the hatch and penetration areas is set at 0.03" (larger than 0.013").

Cracks with the width larger than 0.03" (0.75 mm) should be recorded and evaluated regardless of the crack length. The 0.03" is adapted based on the review of Table 5, considering maximum temperature and shrinkage effects and the crack spacing of more than 15".

At the intersection of the mat and cylinder, any crack larger than 0.06" (1.5 mm) regardless of length should be recorded for evaluation.

7.1.2.3 Definition of Crack Width

The crack width is defined as the gap between two adjacent concrete bodies being separated by the crack, not the flared (widened) opening at the surface of the concrete at the location of the crack. Where the cracks flare at the concrete surface, the crack width shall be the narrowest gap between the two separated concrete bodies.

7.1.2.4 Summary

Based on the discussions noted above the following acceptance criteria for each containment surface zone are recommended and are shown in Figure 4.

Green and Yellow Zones

Detailed mapping and recording of cracks, on the general surface of the containment dome and cylinder away from discontinuities are not necessary. The inspection should be limited to recording of any sign of rebar rusting, if any, and recording any potential stress-related cracks. Stress related cracks are defined in Section 7.1.2.1

Red Zone

- The maximum acceptable crack width is 0.03" (0.75 mm) around penetrations, equipment hatch and personnel airlock.
- The maximum acceptable crack width is 0.06" (1.5 mm) at the intersection of the cylinder and mat.

It is to be noted that crack sizes larger than the threshold values provided for inspection do not necessarily indicate any structural distress in the containment and may not affect the load carrying capacity of the structure during LOCA. These cases, however, shall be recorded as outliers for the purpose of engineering evaluation, future observation and possible corrective action to protect rebars.

7.2 Spalling

Any spalling of the concrete surface should be recorded. If any of the spalled areas exhibit signs of rebar rusting, close inspection of the spalled areas should be implemented. Spalling may be an indication of possible rebar corrosion.

7.3 Scaling

General scaling is acceptable since the Indian Point 2 containment is designed to have minimum concrete cover of approximately 2 7/8" which is more than the minimum concrete cover required by ACI Code 349 (Reference 8.6) which is 2". Maximum acceptable depth of scaling is 1". At the protruding edge of the containment surface, scaling of 2" depth is also considered acceptable. Holes up to 2" deep are acceptable.

7.4 Leaching

Leaching at the concrete surface may be the sign of concrete degradation associated with cracks. Since it is difficult to see the crack width behind the leaching, it is required that the areas of concrete showing leaching be inspected in detail to determine the crack configurations. Engineering evaluation is needed if the cracks are beyond the threshold values defined above.

7.5 Staining

Staining of concrete at the cracks, which may indicate potential corrosion of steel reinforcement, needs to be recorded for engineering evaluation. Any sign of staining that is judged to be from the rusting of the attachments to the containment structure such as lightning rods, HVAC duct supports, etc. is considered acceptable and does not have to be recorded.

7.6 Exposed Reinforcing Steel

The concrete in the area where reinforcing steel is exposed, and the condition of the corroded reinforcing steel, should be recorded for engineering evaluation. Repair to the concrete surface is recommended for good engineering practice even though the loss of the corroded reinforcing steel in some areas may be tolerable. It is to be noted that the exposed metal is not necessarily reinforcing bar. The reinforcing bars are deformed #18S and are easily identifiable. Any exposed metal, judged not to be reinforcing bar, such as shims, metal spacers, etc., should be recorded and accepted "as is" without further engineering evaluation.

Based on the calculations provided in Attachment B, loss of one rebar in every 4'-6" width and 3'-6" width for the cylindrical and dome of the containment respectively is tolerable.

7.7 Inspection Flow Charts

Inspection flow charts to facilitate the inspection effort and evaluation are provided in Figure 1 through Figure 1b.

8.0 REFERENCES

8.1 USNRC Final Rule, September 9, 1996.

8.2 Code of Federal Regulation, CFR 50.55a.

8.3 ASME Code Section XI, Division I, Subsections IWA & IWL, 1992 Edition With 1992 Addenda.

8.4 Consolidated Edison Company Of New York, Indian Point No. 2, Updated Final Safety Analysis Report (USAR).

8.5 Consolidated Edison Company Of New York, Indian Point No. 2, Design Basis Document for the Containment Building, Document # CB DBD, Rev. 0.

8.6 ACI 349-85, Code Requirements for Nuclear Safety-Related Containment Structures.

8.7 ACI 201.1R-68, Guide for Making a Condition Survey of Concrete in Service.

8.8 EPRI Report NP-6695, Guidelines for Nuclear Plant Response to an Earthquake, December 1989.

8.9 Handbook of Corrosion Data by B. D. Criag, ASM International, 1989 Edition.

8.10 ACI 224R-90, Control of Cracking in Concrete Structures.

8.11 Containment Structural Integrity Test Report for Indian Point 2, 1971.

8.12 Properties of Concrete by A. M. Neville, 3rd Edition.

8.13 IP2 Containment Design Report, March 1969.

8.14 IP2 Containment Structure Design Calculations Book #16 by United Engineers and Constructors.

8.15 IP2 Containment Design Drawings (See Section 5.2.3).

8.16 ACI 318-95, Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95).

8.17 ACI 207.3R-79, Practices for Evaluation of Concrete in Existing Massive Structures for Service Conditions.

8.18 Concrete Repair and Maintenance Illustrated, by Peter H. Emmons, R. S. Means Company, Inc.