D R A F T
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TENTATIVE BASIS FOR STRUCTURAL CONCRETE

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I. INTRODUCTION AND GENERAL INFORMATION

A. Objective and Scope

It is the objective of this document to detail requirements presently considered in the design and construction of reinforced and prestressed concrete nuclear reactor primary and secondary containment structures. These requirements are intended to ensure the containment meeting its functional performance objective. Safety, as applied to containment, relates to the potential adverse radiological affects on public health. Functional performance, as applied to containment, relates to the structures capability, within specified leakage limits, of preventing release to the environment any fission products that may be dispersed within its atmosphere in the event of a design basis accident.

It is specifically <u>not</u> the objective of this guide to supplant existing standards and codes. Throughout this document, wherever appropriate and deemed applicable, standards and codes have been referenced. In general, engineering practice as set forth in existing standards and codes, as augumented or amended by this document, shall be followed.

The provisions of this document apply to structures which, under design basis accident conditions, are subjected to the following environmental conditions:

a. Pressure - Ten to one hundred pounds per square inch (absolute)

b. Temperature - Minus twenty to plus 400 degrees Fahrenheit

The provisions of this standard are specifically directed to structures of cylindrical and spherical configuration and, to include in specific instances, flat slab foundation or base construction.

B. Definitions and Notation

(Not available)

C. Applicable Codes and Standards

In general, the provisions of ACI 318-63, Building Code Requirements for Reinforced Concrete, and ACI 301-66, Specifications for Structural Concrete for Buildings, will apply, unless specifically superseded by provisions of this criteria. For the containment liner, the provisions of the ASME Boiler and Pressure Vessel Code, Section III as pertain to Class B vessels will apply unless specifically superseded by provisions of this criteria.

II. FUNCTIONAL REQUIREMENTS

A. Operational Requirements

The structure shall be designed and constructed so that normal operating loads as the result of nuclear power plant operations shall not result in degradation of the structures load-bearing, leakage limiting, or shielding design capabilities.

B. Fault and Accident Requirements

The structure shall be designed and constructed to withstand up to and including its design basis accident in combination with all operational and abnormal environmental loadings.

C. Extreme Environmental Requirements

The containment structure shall be designed and constructed to withstand all extreme environmental loadings in such manner that these loadings will not be transmitted to interior components of the containment essential to safe shutdown or impare containment functional performance capabilities.

D. Acceptance Testing and Inservice Surveillance Requirements

1. The structure shall be designed so as to permit structural acceptance testing at design basis accident pressure at any time during a plant life of fifty years.

2. The structure shall be designed so as to permit leaktightness verification testing at design basis accident pressure at anytime during a plant life of fifty years.

3. A capability for continued structural surveillance (intermittent or continuous) other than full design basis accident pressure shall be provided.

4. A capability for continued leaktightness surveillance (intermittent or continuous) at full design basis pressure of all major potential sources of leakage shall be provided

III. STRUCTURAL LOADS

A. Operational and Normal Environmental Loads*

The following loadings shall be considered as simultaneous operational loadings and shall be combined in combination with other loads to load factors as specified in subsequent sections:

Construction weight

Shell dead weight

Buoyant water loading

Snow loading

Structural live loading (Internal Components)

Structural dead loading (Internal Components)

Normal thermal**

Differential settlement loading

Prestress loading**

Vacuum operating loading

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*Designated OP

**Prestressed structures only.

B. Fault and Accident Loads*

The following loadings shall be considered as simultaneous design basis accident or fault loadings and shall be combined in combination with other loads to load factors as specified in subsequent sections:

Design Basis Accident Pressure

Design Thermal Liner Transient

Design Thermal Concrete Transient**

Accident Vacuum Load

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* Designated DBA

** Prestressed Structures Only.

C. Abnormal Environmental Loads*

The following shall be considered as individual abnormal environmental loadings and shall be combined in combination with and to load factors as specified in subsequent sections:

Design Seismic

Design Wind Loading (100 year occurrence)

Design Flood (100 year occurrence)

*Designated AE

D. Extreme Environmental Loads*

The following loadings shall be considered individual extreme environmental loadings and shall be combined in combination with and to load factors as specified in subsequent sections:

Tornado***

Tsungmi***

Extreme Flood***

Maximum Earthquake**

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*Designated EE

**Treated Under IV D2

***Treated Under IV D1

E. Local Load Effects

The following loads shall be considered for isolated areas of the containment in combination with other loadings as is appropriate for the specific case:

External Missile Loading

Interior Missile Loading

Pipe Blowdown and Displacement Loading

Jet Impingement Loading

Dynamic Pressure Localization Loading

IV. Liner Load Consideration

A. Operational and Normal Environmental Loads*

The following shall be considered as simultaneous liner operational loadings and shall be applied within liner stress, strain, and cycle criteria as specified in subsequent sections:

Construction Weight

Shell Dead Weight

Buoyant Water Loading

Normal Thermal

Creep Loading

Shrinkage Loading

Vacuum Operating Loading

Prestress Loading**

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*Designated OP

**Prestressed Structures Only.

B. Fault and Accident Loads*

The following loadings shall be considered simultaneous design basis accident or fault loadings and shall be applied within liner stress and strain criteria.

Design Basis Accident Pressure**

Design Thermal Liner Transient

Design Thermal Concrete Transient***

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*Designated DBA

**Pressure load shall <u>not</u> be relied upon to help inhibit liner buckling effects.

***Prestressed Structures Only

C. Local Load Effects

The following loads shall be considered for isolated areas of the containment liner but in combination with other loadings as is appropriate for the specific case:

Hot Spot Loading

Pipe Reaction Loading

Jet Impingement Loading

Internal Missile Loading

Vibration Loading

Penetration Loading

V. STRUCTURAL AND LINER LOADING COMBINATIONS

A. Operational

$$C = 1.0\ \underline{OP}$$

B. Operational and Fault or Accident

$$C - 1.0\ \underline{OP} + 1.5\ \underline{DBA}$$

C. Operational and Fault or Accident and Environmental

$$C = 1.0\ \underline{OP} + 1.25\ \underline{DBA} + 1.25\ \underline{AE}$$

and

D. Operational/Extreme Environmental

$$C = 1.0\ \underline{OP} + 1.0\ \underline{EE}$$

$$C = 1.0\ \underline{OP} + 1.0\ \underline{DBA} + \underline{EE}\ \text{(Seismic Only)}$$

C. Construction Coefficients

To allow for small adverse variations in material, strengths, workmanship, dimensions, control, and degree of supervision which, while individually within either tolerance or the limits of good practice, may occasionally combine to result in undercapacity, the stress levels in the structure under designed loadscombinations shall not exceed the allowable stresses modified by the following factors (Ø values).

	0
Prestressing tendons (underflected or undrapped)	.95
Prestressing tendons (deflected or drapped)	.90
Reinforcing steel in tension	.95
Reinforcing steel in flexure or torsion	.90
Reinforcing steel in compression	.70
Fabricated structural steel	.90
Concrete in flexure	.90
Concrete in tension, diagonal tension, shear and in anchorage zones	.85

B. All Other Combinations

1. Concrete

Principal compressive stress	K_{fc}'
Membrane and principal tensile stress	(w/o reinforcement)
Excluding thermal effects	$3\sqrt{f_c'}$
Including thermal effects	$6\sqrt{f_c'}$
Bearing under tendon anchors	$.7\ f_c'\ \sqrt[3]{\frac{A'b}{Ab}}$

2. Reinforcing Steel

Compression	.95 fy
Tension	.95 fy

3. Prestressing Steel — .7 fs' or .9 fsy whichever is smaller

VI. STRUCTURAL ALLOWABLE STRESS REQUIREMENTS

A. Operational Combinations

1. Concrete

Principal compressive stress	$0.45\ K_{fc'}$
Membrane and Principal tensile Stress (w/o reinforcement)	$3\sqrt{f_c'}$
Under tendon anchors	$0.6\ f'_c\ \sqrt[3]{\frac{Ab'}{Ab}}$ but not greater than f_c'
Average bearing stress	$0.6\ f'_c$

2. Reinforcing Steel

Compression	.5 fy
Tension	.5 fy
Bond	$\frac{4.8}{D} f_c'$ but not greater than 500 psi

3. Prestressing Steel

Due to jacking	0.8 fs' or fsy whichever is smaller
Immediately after lock-off	.7 fs' or .9 fsy whichever is smaller
After losses	.6 fs' or .8 fsy whichever is smaller

VII. Liner Allowable

Stress, Strain and Cycle Requirements

Liner strain permissible will be one-half of the strain permitted by the fatigue requirements of the ASME Boiler and Pressure Vessel Code, Section III. The DBA load shall be considered as a ten cycle load. All other loads shall be considered at a realistic but conservative number of cycles.

VIII. Acceptable Analytical Procedures

A. Initial Shell Sizing

Normal pressure vessel design calculations neglecting secondary effects shall be permissible.

B. Design Analysis

General thin shell design procedures shall be acceptable for overall shell areas, provided:

Consideration is given to secondary and thermal effects

The shell thickness to radius ratio is less than one-tenth.

IX. Structural Design

A. Seismic Design

The applicant shall make a rigorous dynamic analysis of the containment by the "spectral response" or an equivalent method. With regard to use of the "spectral response" technique the following details shall apply:

1. The vertical component (g-loading) shall be considered, as a minimum, as two-thirds of the horizontal component.
2. The vertical and horizontal effects shall be combined to produce the worst effect stress wise in the structure.
3. Sufficient masses shall be assumed to accurately describe the mass distribution of the structure in the analysis.
4. The following damping values will not be exceeded without justification.
   a. For the design earthquake
      Prestressed concrete structure 2%
      Reinforced concrete structure 5%
   b. For the maximum earthquake
      Prestressed concrete structure 2%
      Reinforced concrete structure 5%

5. The response spectrum curve that will be used in the "response spectrum" analysis will be as follows:
   a. For foundations on aluvium: El Centro (appropriately scaled)
   b. For foundations in bed rock or relatively firm material: Taft (appropiately scaled)

6. At least three modes of vibration shall be considered. If more than the first three modes of vibration contribute over five percent, they shall also be considered.
7. The total loading on the structure shall be obtained by a direct summation of absolute values rather than by a sum of the squares addition of the modal participations.

B. Wind and Tornado Design

W Wind load design will be based on the final report of the ASCE Task Committee on Wind Faces (ASCE Paper No. 3269). The design wind load at the site for a 100 year period of recurrence shall be used (See Figure 1 (b) of the report). The records, experience and specifi site characteristic will be reviewed to insure that the basic values as specified in the figure are not inadequate. The designer shall specify and justify his selection of the following parameters.

a) Wind velocity distribution as a function of height and plan

b) Gust factor.

c) Drag and lift coefficients.

d) Dynamic pressure.

The tornado mean annual frequency for the one degree grid square containing the proposed site shall be calculated using the method of A.C.S. Therom, "Tornado Probabilities" in the Monthly Weather Review, 91, Nos. 10-12, pages 730-736. A minimum of twenty-five years shall be taken as the calculational basis. When the mean probability of a tornado striking any given point in the one degree grid sauare containing the site is equal to or greater tha 1×10^{-3}, the plant shall be designed for a tornado design wind of 300 mph in accordance with the procedures of 6.3.3.3.2 and the applicable design equations.

C. Penetration Design

1. Suitable cooling of penetrations will be provided to limit penetration concrete temperature to less than 150°F.

2. Shear or tension anchors will be provided to resist within allowables stresses all forces that may be transmitted to the penetration through the piping system or other attachments.

3. The penetration shall be design to withstand the local pressure buildup and jet impingment forces resultant from piping failure with the penetration.

4. Sufficient reinforcing steel shall be provided to:

   a. In a prestressed structure, resist within allowable compressive stress the stress concentrations caused by the opening.

   b. In a reinforced concrete structure, to replace the steel interupted by the opening and provide an orderly load transfer around it.

5. The penetration and any piping systems penetrating it shall be so designed that failure of the piping system must occur away from the liner-to-penetration leakage barrier.

D. Large Opening Design

NOT AVAILABLE

E.

NOT AVAILABLE

F. External Missile Design

NOT AVAILABLE

G. Internal Missile Design

NOT AVAILABLE

H. Anchorage Zone Design

The anchorage zone under prestressed concrete stress heads shall be investigated by the method of Guyon, Zielinski and Rowe, or Sievers. Spalling and bursting stresses indicated by the calculation shall be fully reinforced against by provision of mild steel reinforcement.

I. Foundation and Substructure Design

1. Piling

The piling will be designed for the following load combinations:

a. C = 1.0 OP + 1.5 AE

b. C = 1.0 OP + 1.0 EE

c. C = 1.0 OP + 1.5 DBA

Using these combinations the following limit stresses shall not be exceeded:

a. Concrete

Compression	0.85 fc'
Tension	0

b. Reinforcing Steel

Compression	0.95 fy
Tension	0.95 fy

c. Structural Steel

Compression	0.95 fy
Tension	0.95 fy

In addition, the connection of the pile into the base slab shall be designed as a full moment resisting connection. The pile system shall possess sufficient ductility to absorb a differential displacement between base slab and pile tip of twice the maximum ground movement due to the maximum earthquake. The vertical seismic effect and the overturning movement due to the horizontal seismic effect shall be considered together.

Pile capacity for compression, uplift and lateral loading shall be verified to transfer the design loading into the soil strata without non-linear displacement.

2. Rock Anchors

Rock anchor design shall be based, as a minimum, on the following criteria:

a. Rock anchor pull is resisted solely by the pull of the rock.
b. The rock breakout angle will be considered as 45 degrees from the vertical or less.
c. The apex of rock breakout will be the mid-point of initial (first stage) grout.
d. The rock core, the rock anchor bond development length, and the grout-to-rock shear strength shall be sufficient to develop the ultimate strength of the coupled or attached tendon system.
e. The bond stress and rock shear stress assumed shall be equal to or less than actual measured rock anchor test values by a factor of safety of two.
f. At least one on-site rock pullout test will be accomplished to verify the grouting technique, bond stress and shear stress values assumed.

3. Mat Foundations

For mat foundations, a factor of safety of three with respect to the total operational load and a factor of safety of two with respect to the load <u>combinations</u> shall be required.

4. Differential Settlement

The settlement of the containment structure in relation to its surrounding facilities (turbine building, auxiliary building, etc.) shall be analyzed. Sufficient flexibility shall be designed into piping and wiring and other connection runs to ensure functional performance of vital systems under such settlement.

5. The possibility of foundation liquefication shall be investigated through the media of dynamic testing when sandy deposits are present in the substructure foundation strata. Such tests will not be required, however, if the critical void ratio is not approached or exceeded and the standard penetration value of the strata is N = 30 or greater.

J. Corrosion Protection

1. Concrete Cover Requirements

Base Slab, Bottom Bars	4"
Base Slab; All Others	3"
Base Slab; Prestressing Ducts	4"
Cylinder; Outside Bars	3"
Dome; Outside Bars	3"
Cylinder; Prestressing Ducts	3"
Dome; Prestressing Ducts	3"

2. Cathodic Protection

A soil resistivity survey shall be made at the site. When the mean soil resistivity at a site falls below 20,000 ohm-centimeters cathodic protection shall be provided.

3.

X. Liner Design Details

A. Liner Plate Design

The applicant shall tabulate all loads that will be considered in the design of the liner, the number of cycles considered for each load, and the stress range for each load cycle. A fatigue analysis in accordance with Section III, ASME Boiler and Pressure Vessel Code shall be made. Strain and cycle allowables for individual loads shall be one-half the corresponding values in ASME Boiler and Pressure Vessel Code, Section III. The permissible usage factor shall be less than .5.

B. Anchorage Design

1. Steel Anchor Design (Stud Anchors)

   a. Minimum required length shall be nine times the shank diameter.

   b. Maximum stud diameter permitted shall be twice the plate thickness.

   c. The anchor shall be designed to resist the full shear load caused by maximum plate out-of-round, maximum plate yield strength variation and hot spot temperature

   d. The stud anchor shall be shown to develop adequate ductility to be capable of absorbing random failures without loss of anchor performance or breach of liner integrity

2. Steel Anchor Design (Channel Anchors)

   NOT AVAILABLE

C. Detailing Requirements

Particular design attention will be given to the following areas with the view that the leakage limiting function of the liner will not be neglected by poor design detailing. The following details are of special concern:

1. Verification of leaktightness of liner weld seams permanently embedded in concrete.
2. Transfer of load carrying reinforcing steel through the base slab.
3. The strain absorbing capability of the base slab-cylinder liner junction or "quarter-round."
4. Transfer of crane and other loadings through the liner at brackets.
5. Transfer of liner strains into and around penetrations.

D. Insulation

Where liner insulation is employed the following will be required:

1. The insulation shall limit mean liner temperature rise to no more than $2^{o}F$ to the time when the design basis pressure is a maximum.
2. In making steady state and/or transient heat flow calculations the change in conductivity due to long range humidity effects and the compressibility effect because of pressure and temperature change during design basis accident conditions shall be considered.
3. The material shall be capable of withstanding periodic compression under structural acceptance test loading throughout its life.
4. Insulation material to include required adhesives and joint fillers shall be chemically and physically compatable with the liner plate and insulation sheet covering under all conditions within containment.
5. The permeability factor shall be such that the humidity effect shall not cause deterioration of the material.

XI. Materials of Construction

A. Concrete Materials

NOT AVAILABLE

B. Reinforcing Steel Materials

Reinforcing bar material will meet the standard ASTM specificati requirements. Where mechanical splicing of main load carrying reinforcing is required the splicing shall meet the criteria that (1) the strength of 95 percent of the mechanical splices will be greater than 125 percent of the minimum yield strength for the bar size and specification and (2) the average of all splices will equal or exceed the miminum ultimate strength for the particular bar size and ASTM specification.

Where welding splicing is specified, the carbon and manganese content of the reinforcing bar shall be limited to less than the 0.35 percent and 0.90 per cent, respectively, and subjected to periodic bend tests to assure ductility and weldability. Welding will be performed in accordance with AWS specification D-121. Preheat and interpass temperatures 100 degrees F greater than those listed in AWS D-12.1 shall be used and completed welds shall be wrapped with a protective insulating blanket to aboid rapid cooldown. The recommendation of ACI Committee 315 with regard to reinforcing details shall be adhered to and as an additional precaution against brittle fracture, a minmum ductility of ten percent shall be required of all reingorcing steel.

C. Prestressing Steel Materials

1. Wire Materials

When prestressing wire is used, mill tests will be required on each reel. The manufacturer's mill test reports will be reviewed for conformance to specification and be maintained on file during the construction.

Where button head type units are used, a test coupon will be cut from each end of each reel and tested to destruction. These tests shall verify that individual wire rupture is (for the tested button head) in the wire and not through the head and, also, that the wire develops its guaranteed minimum ultimate tensile strength. Coupons (and the reels they represent) not meeting this specification will be rejected. In addition, all accepted button heads will have a cutting tolerance, split specification and dimensional specifications based on the considerations of the design.

Prior to its usage, the relazation properties of the prestressing steel shall be determined on the basis of at least one-thousand hour relaxation testing at temperatures that brackets those that are calculated to be experienced by the wire or strand during the plant's operating life. Based on log-strain-rate vs log-time extrapolation of these values, conservative relaxation values will be indicated and justified.

Z. Strand Materials

NOT AVAILABLE

D. Prestressing Hardware Materials

Anchorage assemblies for unbonded prestressing tendon units shall meet the following performance requirements:

1. Assembly efficiency of not less than 95 percent at two percent wire failure.
2. Full sized unit elongation under miximum curvature of two per cent at two two per cent wire failure.
3. Verification of dynamic performance without two per cent wire failure at twice the maximum stress range and twenty times the total cycles at a calculated mean stress level and for a cyclic total including all cycles except earthquake and design basis accident.
4. Verification of dynamic performance without two percent wire failure at four times the maximum stress range (under the critical load combination) for one thousand cycles and at the calculated mean stress level at which this critical loading (in combination with DBA) is calculated to occur.

The tendon anchorages shall be capable of developing the ultimate strength of the tendon (as determined by testing of strand or wire samples) without exceeding the yield strength of the anchorage hardware. Howerwe, if each tendon anchorage is proof-loaded to tendon ultimate strength prior to installation, the tendon anchorage may be designed for an ultimate strength of no less than 1.2 times the ultimate strength of the tendon.

E. Sheathing and Corrosion Inhibiting Materials

Sheathing shall have a Brinel (or equivalent) hardness value of not greater than 200. When corrosion inhibiting materials are use their properties shall be fully demonstrated as having acceptable general application. In addition, all corrosion inhibiting materials shall be verified as free of chloride, sulfide, and other substances of possible deleterious effect on prestressing wire or strand.

IV. CONSTRUCTION TECHNIQUES AND CONTROL

A. Concrete Construction

1. Concrete shall be sampled and tested during construction in accordance with ACI 318-63 and the ACI 301-66 to ensure compliance with the design specifications. All sampling and testing shall be performed by an independent testing laboratory not in the employ of or in any way affiliated with the containment construction contractor. The testing laboratory shall submit the results of its testing to the on-site engineer representing the owner.

2. It shall be the responsibility of the owner acting through his on-site engineer to ensure that all construction specifications have been achieved. In addition to the requirements referenced above, the following requirements shall be met:

   a. The design mix shall be such that the average twenty-eight day compressive strength will not be less than the compressive strength specified in the design plus two times the standard deviation of the design mix. The standard deviation of the design mix should not exceed 750 pounds per square inch. Whenever field test samples indicate that this strength is not being met, the mix shall be adjusted.

   b. A minimum of three test groups per day or one test group for each seventy-five cubic yards of concrete placed per day, whichever is greater, shall be taken during each day of concrete placement. The method of cylinder construction shall conform to ASTM C31. Each test group should be comprised of a minimum of four test specimens.

c. One cylinder from each test group taken shall be tested at three days. One cylinder from each test group shall be tested at seven days. The remaining cylinders shall be tested at twenty-eight or ninety days. The percentage of three-day and seven-day compressive strength specimens below the specified three day and seven day design strength should not exceed twenty and ten percent, respectively. If any of these limits be exceeded, the on-site engineer shall direct the mix to be readjusted to place it back within the limits specified as (a) above.

d. Slump tests should be made at random with a minimum of one test for each ten cubic yards of concrete placed and one test on each concrete batch used for test cylinders.

e. In the event that concrete is placed during freezing weather (with proper protection), an additional cylinder should be made for each test group, cured under the same conditions as the part of the structure which is represented, and tested at seven dayss

f. Where laboratory tests of the cured cylinders indicate that the structural concrete does not meet the specified strength at twenty-eight or ninety days, the on-site engineer shall:

(1) Require adjustment of the mix to increase its strength,

(2) Require additional tests of specimens cured under the existing field conditions,

(3) Require improvded procedures for protecting the concrete, as needed, and

(4) Require at least three representative drilled cores from each member or area of concrete in place that is considered potentially deficient. Such cores will be tested air dry.

g. If the cores mentioned in f(4) above fail to verify that the concrete strength is in excess of 110 percent of its required compressive strength, the on-site engineer shall require removal and replacement of the deficient concrete.

Where reinforced or prestressed concrete is considered in the design basis accident to provide shielding, density control sampling should be frequently and routinely undertaken during the construction. Two sets of samples per day is recommended. Testing procedures should be in accordance with ASTM C138.

In use of cement grout, particular attention shall be given to its compositional control. In particular, grout mixing water shall be limited to less than fifty ppm chloride ion and shall generally be free of other deleterious substances such as organics. Control of grout shrinkage shall be given particular attention. The "Tentative Recommended Practices for Grouting Post-tensioned Concrete" will be followed.

B. Reinforcing Steel Construction

The steel reinforcing bar quality control tests specified by the applicable ASTM specification for reinforcing for normal construction will apply. In addition, bend tests and tensile tests shall be conducted at the construction site or at the fabricators shop (testing or reinforming bar stock prior to bending is acceptable). One of each type of test shall be made for each size of reinforcing bar in each heat of material.

Unmarked reinforcing bars of the 50,000 psi grade will not be permitted where less than complete heats of materials are purhhased from the manufacturer's platn.

For reinforcing bar strength splicing, sufficient initial testing will be conducted to insure that the splicing method proposed will develop the required strength.

Splices will be made by qualified splicing crews that have been qualification tested before making production splices. All splices will be subjected to visual examination and randomly tested to destruction according to the following schedule for each position, bar size, and grade of bar:

Two out of the fi st ten splices

Four out of the next hundred

Two out of the next one hundred and subsequent one hundred splices.

As a minimum, one-half of the tested splices shall be taken from the structure itself.

C. Prestressing Installation and Control

1. Wire and Strand

Each reel of prestressing wire or strand shall be tested in accord with ASTM Specification A416 or A421, as appropriate, under the direct surveillance of a representative of the owner. In addition, where button heading is employed, coupons will be cut from each end of each reel, formed as button heads and tested in tension to destruction. For reel acceptance, the buttonhead test must verify that the wire develops its minimum tensile strength and that rupture of the wire occurs prior to button head rupture.

Each size of wire from each mill heat and strand from each manufactured reel to be shipped shall be assigned an individual lot number and tagged in a manner so as to enable accurate job site and/or fabrication shop idenfification.

2. Tendon Assemblies and Anchorages

When BBRV anchorage hardware is used each anchor assembly shall be tested for correct hardness, thread dimensional compliance and hole dimensional compliance. The cut and buttonheaded wires shall be within ±1/16 inch of specified length. Button heads shall be checked at random for dimensional and split tolerance.

As additional prestressing hardware comes into general use, further quality control requirement will be developed that relative to the hardware.

As additional assurance of production tendons meeting performance requirements, two tendons using the production fabrication procedures and of a minimum five foot length shall be tested to destruction. In addition, where curvature is involved in the tendon system layout, at least one additional tendon assembly will be tested to destruction on the maximum curvature demanded in the design.

3. Prestressing

All jacking devices utilized should have incorporated a serviceable load cell accurage to five percent. The calibration of the jacking devices should be verified by the on-site testing laboratory prior to prestressing operations and at weekly intervals thereafter during the prestressing.

The on-site engineer should maintain full records of all tensioning operations to include actual measured extensions of each tendon as verified by the inspector approving the tensioning, the hydraulic pressure gage or load cell readings at each anchorage at each stage of tensioning and the amount of pull-in at each anchorage.

For a minimum of one percent of the total tendons at random, the on-site engineer should require pickup of load by rejacking and verification that the design load had been achieved.

D. Liner Construction

1. Liner Plate Construction

Liner plate material properties shall be under continuous surveillance. One tension, one bend, and one homogeneity test shall be made of each liner plate as rolled. In addition, impact testing of each plate in accordance with ASTM 300 shall be accomplished for liner plate for reinforced concrete structures. All testing will be conducted under direct surveillance of a representative of the owner.

Liner plate butt welding shall be of the full penetration, multipass type. A minimum of two percent spot radiography shall be accomplished. In addition, for twenty percent of the plates welded, a coupon of plate material shall be attached, welded and the weld run incorporated into the coupon. The coupon will then be cut out, radiographed and bend and Charpy tested. The plate welding shall, also, be one-hundred percent visual and vacuum box tested. Dye penetrant or magnetic particle inspection shall be used to closely examine all welds judged to be of questionable quality on the basis on initial visual inspection.

2. Liner Anchorage Construction

Detailed welding procedures and personnel training shall be accomplished prior to start of liner attachment welding. The Welding procedures shall be qualified by using metallographic examination, bend, and tension tests as well as visual standards.

At beginning of operation for stud attachment welding, each welder shall be required to make three welds at actual location on test plates. These weldments shall be bent to ninety degrees in one direction and the weld areas observed for fractures. One out of each nine of these test plates shall be sectioned longitudinally and observed for bond, heat affected zone, and weld. In addition, mill check tests and chemical control tests under the surveillance of the owner shall be requirdd of each heat of stud stock material. Eahh production heat (where studs are used) shall be tensile tested and visually inspected. Any stud not showing a full 360° weldment shall be struck with a hammer and bent 15 degrees opposite the lack of weld.

E. Construction Inspection

All field construction related to erection of the containment structure should be accomplished with the on-site presence of a licensed professional engineer who was directly associated with its design. In addition, each site of formwork construction; reinforcing and/or prestressing steel placement; concrete batching; and contrete placement and curing should be under the direct inspection of a competent inspector responsible only to the on-site engineer. In the performance of their inspectionn duties, the on-site engineer and his inspectors should assure that the construction plans and specifications are met. They should be guided by the recommended practice set forth in the ACI Manual of Concrete Inspection, the ACI Standard Specification for Structural Concrete for Buildings, and other pertinent references.

The on-site engineer shall keep a record of the quantity and quality of concrete materials; the mixing, placing, and curing of concrete;

the placing of reinforcing steel and wire strand; and the sequence of erection and connection of precast members. He shall daily certify on record that all construction has been in conformance with the design drawings and specification. Where deviations are observed, they should be noted in his daily report.

When the temperature falls below 45°F or rises above 90°F, an additional record of temperatures and the protection given to the concrete while curing should be maintained.

Records of inspection as referred to in the above paragraph should be kept available during progress of the construction and permanently thereafter in the files of the owner. They should be made available, if requested, to the regulatory authority having jurisdiction at the site.

Where deviations are observed which, in the judgment of the on-site engineer, could affect the ability of the structure to meet its designed functional performance, the on-site engineer should stop the construction until the noted deviation is corrected. Where any observed deviations are left uncorrected, a written analysis signed and bearing the seal of the engineer responsible to the owner for the design should attest to the fact that the uncorrected deviation will, in fact, not limit the structure in achieving its designed functional performance.

XIII. TESTING AND INSERVICE SURVEILLANCE

A. Structural Acceptance Testing

1. Pressure Test Level

The selection of a suitable acceptance test pressure level will be the responsibility of the designer. It will be the goal of the acceptance test to furnish a high degree of verification that the structure has been designed properly, that it has been constructed in accordance with the design, and that a high degree assurance exists as to the structure's capability to achieve its load carrying functional performance. As a guide toward achieving these objectives, it is considered mandatory that the following criteria be met:

(a) The test pressure be high enough that structural action under design basis accident conditions be simulated by the acceptanee test.

(b) The deformations of the structure during the test are measureable and of sufficient magnitude to permit comparison with predicted values.

(c) Permanent deformations affecting continued structural performance cannot occur.

The first goal generally implies, in a reinforced concrete structure, that the pressure level will be high enough for cracked sections to exist under the acceptance test pressure and that the reinforcing steel to be placed in full action. The second criteria demands of the design a complete comparison of structural strains and deformations under test and design basis accident conditions and a careful selection of measurement means. Likewise, the third criteria implies, typically, that the acceptance test pressure be kept below a level where unacceptable liner tensile stresses are developed in the structure.

2. Performance Prediction

Prior to acceptance testing the designer shall have developed in detail, using the same analysis techniques that he has employed in the design, the strains and overall deformations in the structure and liner under acceptance test conditions. In addition, he shall have estimate crack size, spacing, and pattern.

3. Instrumentation and Testing

When a general structural concept is being used for the first time, a detailed instrumentation program for the structure shall be developed. Areas that will be monitored will include:

a. Liner strains in dome, cylinder, base, and reactor sump.
b. Liner strains at typical penetrations and discontinuities.
c. Liner strains around large openings.
d. Overall diametral and longitudinal growth of the structure on at least two meridional axes.
e. Reinforcing bar strains at general locations throughout the structure and around typical openings and penetrations.
f. Tendon load changes in each of the major load carrying systems (Prestressed Structures Only).
g. Displacement and rotation of the base-cylinder junction
h. Cracking patterns in areas where significant concrete tensile stress is predicted to occur.

When the structural design is identical to a previous design in all aspects except minor variations diameter, height, and opening size, the instrumentation program may be reduced considerably. In such cases general deformational measurements of the overall structure and large openings shall be considered as adequate conformation that the structure has been constructed in accord with the intent of the design.

B. Leaktightness Acceptance Testing

Leaktightness acceptance testing will consist of two phases, an initial component leaktightness phase and an overall leaktightness phase. In the initial phase the leaktightness of all individual penetration assemblies and liner seam welds shall be verified. Subsequently in the second phase, it shall be required that an integrated leakage acceptance test be conducted at design basis accident pressure.

C. Inservice Structural Surveillance

Measures shall be provided for continued long term verification of structural performance. A capability to repeatly acceptance test, the structure at intervals of no less than once a year shall be a mandatory capability of all structural concrete containments. For reinforced concrete structures, the initial performance of the structure at reduced pressures, particularly those identified for future leaktightness testing, shall be made a matter of record during the initial accdptance testing phase. Subsequent overall leaktightness testing shall include monitoring of structural capability and sufficient installed instrumentation shall be provided to achieve this purpose.

For ungrouted prestressed and partially prestressed concrete containments, the main prestressing elements of ungrouted systems shall be monitored for loss of prestress and onset corrosion. For grouted systems, repeated structural acceptance testing at five year intervals at design basis accident pressure shall be mandatory or will be continuously monitored