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of Colorado

16805 WCR 19 1/2, Platteville, Colorado 80651

April 12, 1984
Fort St. Vrain
Unit #1
P-84110

Mr. John Collins
Regional Administrator
U. S. Nuclear Regulatory Commission
Region IV
611 Ryan Plaza Drive
Arlington, Texas 76011

SUBJECT: Fort St. Vrain, Unit No. 1
Prestressing System

Dear Mr. Collins:

As a continuing followup on problems experienced with our PCRV prestressing system (originally reported to you on March 28, 1984, via telephone), we met with Messrs. Jim Miller, Dick Ireland, and Harold Polk at Fort St. Vrain on April 11 and 12, 1984.

The Nuclear Regulatory Commission representatives were given the opportunity to directly inspect the tendon system. In addition a complete review of the inspection test results as summarized on the attachments to this letter was presented.

Based on the program conducted to date it has been concluded that:

1. Although the prestressing tendons at Fort St. Vrain have exhibited individual wire strand failures, the lift off tests conducted clearly show that the tendon system is operable (i.e., capable of meeting its design intent).

2. Twenty-seven (27) tendons are continuously monitored by load cells with low point alarm in the control room. All load cells are operable and are indicating more than adequate load carrying capability of the tendon system.

3. Although the total inspection and evaluation program has not as yet been completed, the tests conducted to date demonstrate that the PCRV is functional and fully capable of meeting all design conditions for operation of Fort St. Vrain.

4. The PCRV design conditions and anlyses are presented in Section 5.3 of the Final Safety Analysis Report. The prestressing system design is presented in Section 5.6 of the Final Safety Analysis Report and design conservatisms of the prestressing tendons are provided in Appendix E Section E-14.2 of the Final Safety Analysis Report. The PCRV is designed to meet two primary requirements.

   A. Elastic response to operating, accident, and seismic loads.

   B. A margin of safety to account for design, construction, operating, and material deficiencies.

   For condition A the structural response of the PCRV up to Reference Pressure (845 psig) is to remain elastic.

   For condition B the design provides structural margins against failure at a hypothetical cavity pressure of 2.1 x Reference Pressure.

   Overpressure of the PCRV is positively prevented by means of safety valves. Two (2) redundant safety valves are provided either one of which is adequate to prevent exceeding Reference Pressure in the PCRV under design accident conditions.

   Without taking credit for the safety valves, however, with the testing done to date and the lift off loads of the tendons with failed wires as well as the continuous load cell readings on the 27 tendons, the tendon system at Fort St. Vrain is capable of meeting all of the above design criteria. Given these conditions there are no health and safety concerns.

On the basis of our tests to date, along with following continuing actions we request your permission to return to power operation from our present refueling outage.

1. Public Service Company will pursue the detailed analyses and engineering evaluations in order to provide timely solutions and/or corrective action.

2. Public Service Company will complete the additional tendon inspection program items regarding top cross head, bottom cross head, and circumferential tendons as expeditiously as possible.

3. Public Service Company will monitor the twenty-seven (27) tendon load cells on a monthly basis for trends of relaxation or load carrying capability.

4. Public Service Company will develop a semi-annual surveillance program for inspection of tendon terminations. It was agreed at our site meeting that the program would as a minimum require inspection of 33% of top head vertical tendon terminations. On this basis all top head vertical tendon terminations would be inspected over a refueling cycle. The program would also include some samples of circumferential, top cross head, and bottom cross head tendons. The sampling program will be developed to provide for inspecting some tendons with already identified wire failures as well as some new tendon terminations. The surveillance program will pre-establish inspection criteria such that if any significant degradation is noted the inspection program frequency would be increased to quarterly and successively to monthly if degradation should get serious enough to warrant such action.

5. As always, Public Service Company will keep the Nuclear Regulatory Commission abreast of the results of any continuing program results.

Based on the above Public Service Company would request your concurrence to begin our rise to power program as early as April 18, 1984.

Very truly yours,

Don W. Warembourg

Don W. Warembourg
Manager, Nuclear Production
Fort St. Vrain Nuclear
Generating Station

DWW/alk

Attachments

ATTACHMENTS TO P-84110

1. General Description PCRV Prestressing System
2. General Layout Drawings of Tendon System
3. Tendon Inspection Program
4. Results of Inspection Program to Date

ATTACHMENT 1

(P-84110)

GENERAL DESCRIPTION PCRV PRESTRESSING SYSTEM

EXCERPTS FSAR
Section 5.6
Section E.14.2

FORT ST. VRAIN PRESTRESSING SYSTEM

448 Tendons Total	27 Load Cells
310 Circumferential	17 Load Cells
90 Vertical	6 Load Cells
24 Top cross Head	2 Load Cells
24 Bottom Cross Head	2 Load Cells

Tendons consist of individual wire strands 1/4" in diameter button headed on each end and terminating in bearing washer. The tendons vary in size; the smallest being 152 wires and the largest being 169 wires.

The tendons were pregreased with a "no oxid" type grease. They were installed in pregreased tendon tubes. Tendons were sent to the site with one end already button headed (shop end). The other end (field end) was button headed after installation of the tendon in the PCRV.

The initial prestressing design was 0.7 GUTS.

For details of the prestressing system design see FSAR Section 5.6 and FSAR Appendix E, Sections E.14.2.1, E.18, and E.19.

$$E = (4.5)\ 10^6\ lb/in^2$$
$$I = 151{,}208\ in^4$$

$$\text{whence} \quad \lambda = \sqrt[4]{\frac{7500}{(4)(4.5)(10^6)(151{,}208)}} = 0.724 \times 10^{-2}$$

$$\text{and } \theta = (2)(777{,}000/7500)(0.724)^3\ 1^4 = 0.08 \times 10^{-3} \text{ radians}$$

whence the inner edge opens (0.88) 10^{-3} (108) = 0.0085 in. relative to the outer. However, as one side of the crack is bounded by the massive concrete head, the rotation is to be expected in the wall portion only. Thus, the cracks may be conservatively estimated to be narrower at the outer edge of the vessel than the inner edge by 0.016 in.

It may be noted that the above analysis was performed on a horizontal crack assumed to form at the haunch, and it may be postulated that a crack in this region could be inclined, with a maximum inclination of 45°. However, the analysis remains valid as the strain gradient over an inclined surface cannot be greater than that which occurs on a surface normal to the moment induced stresses, provided the magnitude of applied moment does not alter with surface inclination. In this structure the applied moment on any section decreases rapidly as the section under consideration moves from the junction between walls and heads, so the above analysis yields a conservative estimate of crack, shape, and consequently, the pressure gradient within the wall thickness.

Figure E.14-6 plots the force on the structure obtained as gas issues from a 1 ft. 0 in. horizontal liner crack with an internal pressure of 930 psig (1.1 RP) as a function of the flow geometry. It can be seen that the force on the structure increases as the flow angle increases. If the moment effect of the pressurized crack is plotted as a function of flow geometry as is shown in Figure E.14-7, the maximum moment effect is seen to occur with a flow angle of 140°, giving an applied moment of 6.1 x 10^8 lb/in and an uplift of 3.2 x 10^6 lbs.

E.14.2. Analysis Determining Permissible Number of Failed Tendons

E.14.2.1. Introduction

A quantitative analysis has been performed to establish the approximate number of tendons which could fail during operation of the reactor before a hazardous condition would exist. The results of this work are presented in this appendix and are directly related to the discussion in Section 5.6.3.2.

E.14.2.2. Vertical Tendons

By analyzing the prestress forces on a horizontal section through the vessel, it is shown that at least six adjacent vertical tendons can be lost during vessel operation before the design condition of zero average stress across the wall is violated. This analysis was performed by removing individual adjacent tendons on one side of the cross section until the centroid of the vertical prestressing shifted sufficiently to produce tension halfway through the wall thickness. This includes the assumption that vertical prestress losses are twice the predicted values.

Even if all vertical prestress forces were lost, the PCRV walls which are very heavily reinforced with continuous high strength bonded reinforcement still tie the two heads together. In order to assess various safety margins, the following information is submitted to show the cavity pressures which the PCRV could resist with only the rebars acting.

f_s [kip/in.^{2}]	A_s [in.^{2}]	$A_s f_s$ [kip]	$p = \frac{A_s f_s}{31^2 \times \pi/4} \times \frac{1}{0.144}$ [psig]
$0.9\ f_{sy} = 67.5$	1640	110,500	1020
$f_{sy} = 75$	1640	123,000	1135
$f_{sy} = 100$	1640	164,000	1515

The amount of reinforcement in the haunch areas and in the wall sections adjacent to the heads is considerably larger than the reinforcement at vessel midheight for which the analysis was performed. Concrete cracks and their effect on liner strains are still small even at 845 psig since the reinforcing steel has not yielded. About 75% of the vertical reinforcement consists of #18S and #11 bars which are spliced by mechanical means to develop the minimum guaranteed tensile strength of the bars. The bars are all anchored within the heads where the concrete is in compression; additionally, the #18S bars have anchor plates attached to their ends.

E.14.2.3. Circumferential Tendons

The loss of one "complete ring" of circumferential tendons which consists of 3 sets of six tendons each spaced over a wall height of about 5 ft. 0 in. has been analyzed without taking advantage of load redistribution to adjacent complete rings. The number of tendons that can be lost at any cross section of the ring is given below in relation to the internal pressure required to

produce failure. Of the total of 18 tendons, a minimum number of 12 pass any cross section. Reinforcing steel is taken into account.

Internal Pressure [psig]	Required No. of Tendons Passing Any 5 ft. Cross Section	No. of Tendons Allowed to Fail at Any 5 ft. Cross Section	Safety Factor
1690	9	3	2.0
1475	8	4	1.75
1265	6	6	1.50
1055	5	7	1.25
845	3	9	1.00

The results of this single evaluation indicate that all adjacent circumferential tendons can fail (i.e., all tendons anchored on one face of one pilaster, including head region) without reducing the safety factor against failure at 845 psig below 2.0.

Of the 210 circumferential tendons in the wall region about 30 tendons uniformly distributed could be lost before net tensile stresses would occur across the wall section at 845 psig assuming the predicted prestress losses of about 12% have occurred. On this same basis, of the 100 circumferential tendons in the heads, about 6 from each head could be lost.

E.14.2.4. Crosshead Tendons

All adjacent crosshead tendons on one face of the vessel represent 33% of the total crosshead prestress, or 8 out of 24 tendons. Loss of these adjacent tendons does not unbalance the remaining prestressing forces that help to counteract the cavity pressure applied to the heads because of the 120 degree orientation of the tendons. The large head depth also allows the unbalanced forces, caused by loss of adjacent tendons, to redistribute and still provide an almost uniform prestress force on the inside face of the vessel head.

The overall effect of the crosshead tendons has been demonstrated by overpressure tests on a 1/13 scale model of the Fort St. Vrain PCRV bottom head. Test pressures of 3300 psig could not cause failure of the heads. Since the crosshead tendons were tensioned to resist only approximately 300 psig of the internal pressure, the complete loss of all of these tendons would not reduce the head capacity below 1800 psig, which is approximately 2.1 times Reference Pressure (see Appendix E.21).

E.14.2.5. Discussions

The above analyses have not taken credit for the restraint provided by adjacent concrete mass or transverse prestress. It has been shown that the loss of a certain number of tendons in each type of adjacent tendons would not cause a hazard with respect to the reduction in the vessel saf ty factor or the loss of net compression across a section under operating conditions. The number of adjacent nonparallel tendons that could be lost is at least the same as the number of those determined for each individual group. For example, the lost adjacent vertical tendons and the lost circumferential tendons on one pilaster face or in one complete ring do not depend on each other in the analysis performed, i.e., their contribution to restraint is neglected. It is believed that more refined analyses are not justified in view of the large margin of vessel capacity available even with the loss of the significant number of tendons of each type.

A series of tests were conducted on PCRV Model 2 wherein several tendons were fully detensioned and the vessel behavior in the partially detensioned condition was evaluated with internal pressure. These tests were performed to provide experimental confirmation of the approximate analyses made above. The Model 2 tests are summarized in Appendix E.18.

The reactor is normally operated with all of the tendons tensioned, and with the tendon loads in the ranges specified by the design. However, it is possible at all times to operate with any one tendon detensioned and still comply fully with the design criteria for the PCRV. It is expected that operation with one tendon detensioned will occur at times when tendon load cells are being calibrated, and when a tendon is removed for inspection or replacement of the tendon itself, its anchor hardware, or its corrosion protection.

REFERENCES FOR APPENDIX E.14

1. Ferguson, P. M., J. E. Breen, and J. N. Thompson, "Pullout Tests on High Strength Reinforcing Bars," J. Am. Conc. Inst., August 1965, p. 942.

2. Shapiro, A. H., Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, Ronald Press Company, New York, 1953.

3. Hetenyi, Miklos. I., Beams on Elastic Foundation, University of Michigan, Ann Arbor, 1958.

5.6. PRESTRESSING SYSTEM

5.6.1. Description

The vessel is prestressed so that all major sections intersecting the interior cavity are subjected to a net compressive force under any pressure loading up to and including the Reference Pressure. The prestressing concept and the detailed arrangements of the PCRV prestressing system are shown in Appendix E.15. The figures in Appendix E.15 show the degree of redundancy provided by the prestressing system.

The stressing method used is known as post-tensioning. During construction, tendon tubes are embedded within the concrete for later insertion of tendon. The tendon is an assembly consisting of the required number and length of high-strength steel wires with a washer assembly at each end to support the buttonheaded wire anchorages. When the concrete has gained adequate strength, the tendons are tensioned. Each tendon is stressed using 1000 ton capacity jacks. The tensile force developed is transferred to the concrete by the end anchor assemblies.

Table 5.6-1 indicates the number of each type of tendon and the anchoring force applied to the PCRV

The distribution of tendons within the concrete is such that the distance between groups of tendons does not exceed the concrete thickness on which they exert their useful prestressing loads. In addition, the sum of the prestressing loads applied within that distance is sufficient to at least provide static equilibrium with the forces created by Reference Pressure acting within that distance.

5.6.2. Design and Design Evaluation

5.6.2.1. General

The stresses within the PCRV resulting from various loading conditions are discussed in Section 5.3.

The prestressing tendon size has been selected to satisfy the load needed after tendon losses have occurred and to fit within the physical space of the PCRV

Prestressing forces are applied throughout the vessel to counteract the internal pressures. The PCRV is prestressed sufficiently to prevent the occurrence of net tensile stress in the concrete at any cross section when loaded to the Reference Pressure.

The three types of tendon arrangements used to counteract the internal pressure are: (1) longitudinal, (2) circumferential, and (3) crosshead, as shown in the figures in Appendix E.15.

1. The longitudinal tendons are arranged uniformly across the wall section and concentrically around the vessel cavity to resist the internal pressure acting on the cavity area of the heads.

2. The circumferential tendons provide the necessary radial forces along the curvature of the wall and at anchor points on the vertical pilasters to counteract the internal pressure acting on the cavity wall. The degree of curvature is adjusted to compensate for the vertical pilaster stiffness. The total angle of curvature is determined primarily by the friction losses between the tendon and tendon tube.

3. The crosshead tendons passing between penetrations are curved in a vertical plane so that the induced bending moments are counteracting the internal pressure acting on the cavity heads.

Detailed information on the different components of the prestressing system is given in the following paragraphs.

5.6.2.2. <u>Wire Properties</u>

The "thermalized" low relaxation prestressing steel wire selected for use in the Fort St. Vrain PCRV prestressing system meets the requirements of ASTM A421 wire. The "thermalized" wire is manufactured by Richard Johnson & Nephew Ltd. (RJ&N), Manchester, England. (A typical stress-strain curve for the wire is shown in Figure 5.6-1.) The wire is produced by cold drawing and is subsequently thermalized by a continuous process to produce the following specified mechanical properties:

1. Static Properties

   a. Minimum ultimate tensile strength (f'_s) .... 240,000 psi

   b. Minimum yield strength (f_{sy}) (see Fig. 5.6-1) .... $0.85\ f'_s$

   c. Minimum elongation (10 in. gage length) at failure 4%

   d. Minimum buttonheaded wire strength........ minimum ultimate tensile strength of wire

   e. Diameter .... 0.25 in. ± 0.002 in.

   f. Chemical composition:

      The ladle analysis of the steel conforms to the following ranges:

      Carbon, % ....0.70 to 0.85
      Manganese, % ....0.50 to 0.80
      Phosphorus, maximum % 0.04
      Sulphur, maximum % 0.04
      Silicon, % ....0.15 to 0.30
      Tin, maximum % 0.020
      Copper, maximum % 0.20

2. Dynamic Properties

The effect of cyclic loads on the tensile properties of the buttonheaded wire specimens was evaluated by a test program conducted by RJ&N. The results of the fatigue tests are summarized in Table 5.6-2.

All of the specimens given in Table 5.6-2 survived the fatigue tests and did not exhibit degradation of the tensile properties. A few extra specimens were allowed to continue in the J_3 series fatigue test; failures in the wire occurred between 40 and 100 million cycles.

5.6.2.3. Tendons

The prestressing system adopted for use in the PCRV is a linear tendon post-tensioning system. Each tendon consists of up to 169 1/4-in.-diameter "thermalized" wires. The wires are anchored by means of cold deformed buttonheads to the washer assembly which then transfers and distributes the loads over split shims and a steel bearing plate into the concrete.

The allowable stresses listed in Paragraph 2606(a), ACI 318-63 were adopted in the design of the prestressing system. In addition, the maximum temporary jacking force is limited to

$$f_{sy} = \text{yield stress},$$

and the maximum stress after anchoring is limited to

$$0.9\ f_{sy}.$$

The prestressing system has been experimentally proven adequate as regard to the above stress levels both at temporary jacking force and at force after anchoring. The prestressing system efficiency has also been experimentally proven to exceed the required 100% for straight tendons and 95% for curved tendons. The prestressing system efficiency is defined as the actual ultimate tendon load divided by the minimum tendon GUTS.

The mechanical properties of the prestressing tendons used in the design are as follows:

1.	Minimum GUTS	240,000 psi
2.	Tendon load immediately after anchoring	168,000 psi
3.	Minimum yield strength @ 1% elongation (see Fig. 5.6-2)	180,000 psi

4. Modulus of elasticity of straight tendon — 27.7×10^6 psi

5. Friction factor (friction coefficient and wobble friction) (see Fig. 5.6-3 and Section 5.6.3.1) — 0.19

6. Total relaxation losses at 30-year design life at 120°F — 8%

The mechanical properties given above were derived from the test program described in Appendix E.19.

Additional discussion on tendon fabrication, installation, and stressing procedures is included in Section 5.11.4.

5.6.2.4. End Anchor Assembly and Tendon Tube

1. End Anchor Assembly

Each end anchor assembly consists of: (1) washer assembly (a composite washer or washer and nut combination), (2) split shims, and (3) bearing plate. Figure 5.6-4 shows the typical end anchor assembly of the PCRV prestressing system.

The end anchor assembly is required to resist without failing a force of 120% of the minimum tendon GUTS, which is determined by the number of wires multiplied by the minimum tensile strength of the individual wires.

Washer assemblies are made of AISI 4142 steel heat treated to have a hardness of Rc 38± 2, which is equivalent to a 163 ksi yield strength, 180 ksi tensile strength and a minimum elongation of 12% in a 2-in. gage length. Each production washer assembly has been proof loaded to the minimum tendon GUTS and inspected for evidence of deformation before acceptance and installation.

Table 5.6-3 shows results of 13 prototype tendon end anchor assembly tests. Test numbers one through ten were performed using the developmental anchor assemblies. Confirmatory test numbers 11, 12, and 13 were performed using the Fort St. Vrain PCRV production washer assemblies. All end anchor assemblies developed ultimate strengths greater than the specified 1.2 minimum tendon GUTS. The average capacity of end anchor assembly with respect to the minimum tendon GUTS was determined to be 1.54.

Several pieces of washer assembly have been used at least four times for various tendon ultimate load tests without showing any sign of deformation or strength reduction.

The split shims and bearing plates are made of carbon steel (ASTM A283 Grade D).

2. Tendon Tube

The tendon tubes are electric-resistance-welded carbon steel mechanical tubing per ASTM A513, Grade 1010. All tendon tube joints are welded to prevent leakage of grout and water.

Corrosion protection of end anchor assemblies and tendon tubes is provided as described in Section 5.6.2.5.

5.6.2.5. Corrosion Protection

The corrosion protection system for the prestressing components is considered to be more than adequate to assure that the required prestressing forces are sustained throughout the life of the plant.

All prestressing tendons and component parts are being handled from the point of manufacture through installation and prestressing to final closure in a manner to preclude corrosion. The following paragraphs summarize the materials and procedures being used for the protection of the several components comprising the prestressing system. Corrosion test summary is discussed in Appendix E.19. The postconstruction surveillance and inspection procedures are described in Section 5.13.8.

1. Tendon Tubes

After the tendon tubes were bent to the prescribed shapes, the inside surface was coated with No-Ox-Id 490 (product of Dearborn Chemical Division of W. R. Grace, Chicago) for corrosion protection. The outer surface is uncoated since a tightly adhering film of rust is desirable to develop a good bond between the tube and the embedding concrete. The No-Ox-Id 490 is a solvent cut-back grease which forms a thin film of corrosion -inhibiting compound on the metal. Each tube end is capped to exclude water, dirt, and debris during shipment and storage. When the tendon tubes are placed in the PCRV structure, the joints between the tube sections are fully welded to prevent leakage of grout and also to maintain tube alignment and structural strength. In addition, the welded joints are taped as a double protection against leaks.

Before the tendons are inserted, the inner surface of the tubes is coated with a continuous film of No-Ox-Id CM as the final corrosion protection.

No-Ox-Id CM is a petrolatum base corrosion-inhibiting compound originally designed as a casing filler, and recently used on the tendons of the secondary containments of nuclear reactor plants. It contains a micro-crystalline wax and surface active agents.

2. Tendon Wire

The wire is coated by the wire manufacturer with a calciumzinc phosphate (Meta Bond) and overcoated with Rustarest. The latter coating is a water emulsifiable oil which seals the pores of the phosphate and dries to leave a wax-like finish on the wire.

The coils of wire are spirally wrapped with a hessian backed vapor phase inhibited paper, which are then packed for overseas shipment in a doughnut-shaped metal container having a telescopic cover. These containers of wire are stored in a warehouse until the tendons are fabricated.

When the tendons are fabricated, they are coated with the No-Ox-Id CM and shipped to the site on a reel-type rack having a protective cover.

As the tendons are drawn into the tendon tubes they are recoated with a continuous film of No-Ox-Id CM as the final corrosion protection. In the period between installation and stressing and for the final closure, the tendon and end anchor assembly are capped to contain the corrosion-inhibiting compound and to exclude injurious environments from the prestressing system.

3. Buttonheads

The buttonheads formed during tendon fabrication are protected by a coating of No-Ox-Id CM for shipment to the site. The buttonheads formed on the leading end of the tendon after installation as well as those on the trailing end are coated with a continuous film of No-Ox-Id CM before the tendons are capped.

4. Washer Assembly

After inspection and acceptance, the finished washer assemblies are dip-coated with No-Ox-Id 500, a solvent cut-back wax containing corrosion inhibitors. Each item is then placed in a plastic bag to exclude water and dirt.

After the tendon is stressed, the washer assemblies are coated with a continuous film of No-Ox-Id CM as the final corrosion protection.

5. Split Shims

The mild steel split shims prescribed for the prestressing system are coated with a red oxide paint primer. After the tendon has been stressed, the exposed areas of the shims are coated with the No-Ox-Id CM.

6. Tendon End Anchor Assembly Cover

The steel covers are installed over the tendon end anchor assemblies and attached to the bearing plates. Before each cover is installed, all the

protruding portions of the tendon end anchor assembly within the cover are inspected to assure that the final corrosion protection requirements of each prestressing component are met.

The covers contain the corrosion-inhibiting compound and at the same time exclude injurious environments from contact with the tendon end anchor assemblies.

The covers incorporate a check valve to relieve any gas pressure developed as the reactor is brought to operating temperature and as the corrosion-inhibiting compound is irradiated.

The covers are coated with a red oxide paint primer and following installation, they are painted to conform with the prescribed decor of the PCRV externals.

5.6.2.6. Radiation Damage

The prestressing steel is protected from irradiation by the liner, by at least 6 in. of concrete and the tendon tubes, and therefore experiences a considerably lower dose than that described for the liner in Section 5.7 and for the reinforcing steel in Section 5.5. For those parts of the tendons passing nearest the liner, the predicted dose does not exceed 1×10^{17} nvt (> 1 Mev) during the life of the reactor vessel.

From the discussion (Section 5.5.2.4) concerning reinforcing steel, it may be surmised that irradiation will have a negligible effect on the tensile and impact properties of the prestressing steel. In addition, from the work of Bates et al. (Ref. 1), it is concluded that irradiation at the predicted dose level has an insignificant effect on the stress relaxation characteristics of the wire.

If the integrated flux were to exceed 10^{18} nvt, then the effect on the wire would be to increase the tensile properties and reduce the ductility (see References 2,3). The minimum specified ductility of the unirradiated "thermalized" wire tendon is 3% (in a straight tendon length). Results obtained from tests (Appendix E.19 and Reference 4) indicate that the ductility for "thermalized" wire tendon is about 4%. This is more than needed for the unbonded tendons to develop the ultimate strength of the PCRV, since the maximum predicted total strain is only 0.82% at 2.1 RP for the circumferential tendons at vessel midheight.

5.6.3. System Evaluation

5.6.3.1. Losses

The following major prestress losses are considered in the Fort St. Vrain PCRV prestressing system.

1. Transfer Losses

When the tendon load is transferred from the jack to the end anchor assembly and concrete, a loss in tendon load occurs. The split shims that are subject to stresses at this transfer tend to deform to a maximum of 0.0011 in./in., thus allowing the tendon to slacken slightly. In addition, the shim thickness required to hold the measured elongated wires in place vary within 0.031 in. The losses due to the above effects for various types of tendons are listed below. However, these losses are counterbalanced by slight over-tensioning during the jacking operation.

Longitudinal Tendons:	0.5% maximum
Crosshead Tendons:	1.6% maximum
Circumferential Tendons:	1.0% maximum

2. Friction Losses

When the prestressing steel rubs against the tendon tube as the tendon is tensioned, particularly in the case of the curved tendons, the resulting friction causes the tension in the tendon to become smaller as the distance from the jack becomes larger. Friction losses for the curved tendon design are computed by using the friction equation

$$T_x = T_o e^{-(\mu\theta+\kappa\ell)}.$$

where

T_x = the force at point ℓ feet from the jacking end

T_o = the force at the jacking end

e = base of the Napierian logarithm

κ = wobble friction

μ = coefficient of friction

θ = total angle change between the tangents to the tendon at end and at point ℓ in radians

ℓ = distance in feet from the jacking end to the point under consideration

The average coefficient of friction was experimentally found to be 0.149 during tensioning, as shown in Figure 5.6-3, computed by using κpa = 0.00027 obtained from tests. Substituting these values in the above equation for a typical circumferential tendon of ℓ - 100 ft., the average friction loss during tensioning is about 11.5%. Although a friction coefficient of about 0.15 was experimentally established, a value of 0.19, including the wobble effect, was used for the design to allow for construction variables. In this case, the average friction loss provided in the design is about 13%.

3. Steel Relaxation Losses

The prestressing tendon steel exhibits a phenomenon termed "relaxation" which is a reduction in the tendon force without change in tendon length. A relaxation loss of 8% of the initial load of 0.7 GUTS is used in the design at end of 30-year design life and at a temperature of 120°F.

The "thermalized" wire selected for use in the Fort St. Vrain PCRV prestressing system is characterized by its low relaxation property. For instance, the relaxation loss for a "thermalized" wire tendon was only approximately 7% of that measured for a stress-relieved wire tendon under similar test conditions after 1000 hours at 68°F and at an initial anchor load of 70% GUTS (Fig. 5.6-5). The relaxation loss for a "thermalized" wire tendon under 120°F temperature was measured at 3.2% after one year, and an extrapolation (see Fig. 5.6-6) shows that the relaxation will be less than the 8% loss which was used in the PCRV design and analysis.

Test data are compared for low relaxation ("thermalized" and stabilized) wire at various temperatures in Figure 5.6-6. Test data for "thermalized" wire tendon were obtained from General Atomic's prestressing test program. Test data for stabilized wire were obtained from Somerset Wire Company, Cardiff, Wales (Ref. 5).

The range of the total prestress loss due to steel relaxation in the PCRV tendons is shown in Table 5.6-3. The total prestress losses are measured in percentage of initial prestress of 0.7 GUTS. The prestress for the Fort St. Vrain PCRV was designed for losses that are at least 25% greater than the maximum predicted losses shown in Table 5.6-4. Thus the initial prestress forces are large enough to allow the above design losses to occur during the 30-year design life of the PCRV without retensioning.

4. Concrete Creep and Shrinkage Losses

Due to concrete shrinkage and creep after the tendons are tensioned, the distance between tendon anchors is reduced. The prestress losses due to creep and shrinkage effects between the period after prestressing and at end of design life are estimated from the viscoelastic creep analysis presented in

Appendix E.6. The range of prestress loss due to creep and shrinkage is shown in Table 5.6-4.

Creep and shrinkage characteristics of the PCRV concrete are discussed in Section 5.4.

5.6.3.2. Tendon Failure

Gross failure of the prestressing system without detection is highly improbable. Each tendon is independent of all others and the PCRV approach to failure must occur progressively. Since the prestressing tendon is ductile and unbonded, progressive approach to failure would cause cracking and dimensional changes in the reinforced concrete giving direct warning of structural changes in ample time for corrective action to be taken.

A sudden failure of a multiple wire tendon in such a way that the end anchor assembly becomes a potential missile is incredible because of the ductility of the tendon, the large number of wires and the unused stress capacity of the tendon which is loaded at the time of anchoring to only 0.7 GUTS. Since the tendons are not grouted into their tubes, they do not experience any high local strains imposed by the concrete. Only a complete failure of the washer assembly can cause sudden failure of a tendon. As discussed previously in Section 5.6.2.4, failure tests on prototype washer assemblies have experimentally established the load carrying capacity to be far in excess of the specified 1.2 times the minimum tendon GUTS. For a 169-wire tendon to develop a load of 1.2 times the minimum tendon GUTS, the wires must be tensioned to an average stress of about 290,000 psi. The maximum ultimate tensile stress of "thermalized" wire tendon obtained from test results (Appendix E.19) was only 247,000 psi. Therefore, failure of tendon must occur progressively by failing individual wire. This is the typical failure mode of all full-size tendons tested at General Atomic. However, individual wires or buttonheads could conceivably become projectiles. Restraint is provided to prevent any tendon wire or buttonhead from becoming a missile by means of an end anchor assembly cover attached to the bearing plate.

Fatigue Effect on Prestressing System. A full-size curved tendon was tested as part of the GA prestressing system test program by cyclic loading 1000 times between a load range of 1275 kips and 1525 kips (i.e., 0.7 GUTS ± 15 ksi) prior to testing to ultimate failure. An ultimate load of 2035 kips or 1.02 GUTS was measured. The stress cycling effect did not reduce the ultimate capacity of the full-size tendon. This test is more severe than the predicted cyclic conditions in the PCRV which are listed in Table 5.6-5. The number of cycles and the stress variations are so low that fatigue failure of tendon will not occur.

Missile Effect on Prestressing System. Tornado borne missiles as discussed in Section 5.10 have been considered with respect to their effect on the prestressing system. It is very unlikely that such missiles would cause

anchor failure of a prestressing tendon. The end anchor assemblies have a minimum design safety factor of 1.7 over the applied maximum tensile stress of 0.7 tendon GUTS. Consequently, the end anchor assemblies could withstand an additional static force of at least 1000 kips before failure would occur. Horizontal displacement of the assembly requires a static force of at least 300 kips. A friction factor of 0.3 between two steel plates is assumed in computing this value. There is no conceivable missile which has been listed that could produce the required energy to break the end anchor assemblies or move them.

Individual wires might fail if hit directly by a flying object. However, the buttonheads are protected by an end anchor assembly cover incorporating 3/8-in.-thick steel cover plate. The 3/8-in. steel plate will prevent missiles from hitting any buttonhead normal to the wire axis which is considered the critical impact direction. It is concluded that an end assembly failure caused by missiles is inconceivable.

However, if it is assumed that a whole end anchor assembly can fail, the following considerations show that the PCRV will remain safe: If it is assumed that a heavy object slides down the wall of the PCRV and produces failure of all tendon anchors on this wall, the loss of circumferential prestress is only 25%. This means the vessel will still have net compression in the wall for pressures up to 845 x 0.75 = 634 psig. The ultimate load capacity of the vessel will still be in excess of 0.75 x 2.1 x 845 = 1315 psi since the liner, tendon tubes, and rebars are unaffected by missiles.

It is difficult for any assumed missile to hit more than four head tendons at one time since each row of end anchor assemblies protects the lower row. This means that only 1/6 of the head prestress component counteracting the internal pressure can be lost, amounting to a prestress loss of about 16.7%. No significant reduction of the vessel strength will result from such an accident as discussed below. Even if all head tendons on one side fail (8 tendons out of 24 in each head) 66.7% of the prestress component counteracting internal pressure remains. The vertical prestress together with the reinforcement and tendon tubes provides a strength capacity equal to an ultimate internal pressure of about 3300 psig. Even if all vertical tendons were rendered useless by a missile, the ultimate pressure capacity still is about 1650 psig.

<u>Permissible Number of Tendon Failure</u>. A quantitative analysis has been performed to establish the approximate number of tendons which could fail during operation of the reactor before a hazardous condition would exist. The results of the analysis are presented in Appendix E.14.2. A representative number of tendons in Model 2 were fully detensioned and the vessel behavior in the partially detensioned condition was evaluated with internal pressure to confirm the above approximate analysis. Summary of the confirmatory test results is presented in Appendix E.18.

From the above considerations it can be seen that the PCRV is a very massive and redundant structure that is insensitive to accidental failures of prestressing tendons.

REFERENCES FOR SECTION 5.6

1. Bates, S. C., C. R. H. Corson, and A. T. Jeffs, "Prestressing Nuclear Pressure Vessels," Engineering, Vol. 197 (5111), 1964, pp. 492-495.

2. Trudeau, L. P., Radiation Effects on Toughness of Ferritic Steels for Reactor Vessels, AEC Monograph, Rowman and Littlefield, Inc., N. Y. 1964.

3. Cowan, A., and R. W. Nichols, "Effect of Irradiation on Steels used in Pressure Vessels," Conference on Prestressed Concrete Reactor Vessels, Group D, paper 20, 1967.

4. Northup, T. E., G. S. Chow, and J. F. Hildebrand, Testing Large Tendons for a Nuclear Reactor Vessel, USAEC report GA-9155, General Atomic Incorporated, December 27, 1968.

5. Cahill, R., and G. D. Branch, "Long-Term Relaxation Behavior of Stabilized Prestressing Wires and Strands," Conference on Prestressed Concrete Reactor Vessels, Group D, paper 19, 1967.

Table 5.6-1

PRESTRESSING SYSTEM DATA TABLE

Type of Tendon	Number of 1/4"ϕ Wires per Tendon	Anchor Force per Tendon* (kips)	Number of Tendons
1. Longitudinal	169	1395	90
2. Circumferential			
(a) Head	169	1395	100
(b) Wall	152	1255	210
3. Bottom Cross Head	169	1395	24
4. Top Cross Head	169	1395	24

*Anchor force at 0.7 of the minimum Guaranteed Ultimate Tensile Strength (GUTS) of the tendon

Table 5.6-2

FATIGUE TEST RESULTS OF "THERMALIZED" WIRES

Test Series	Stress[a] Conditions (ksi)	Cycles	Number of Samples Tested	Average Ultimate Tensile Strength Tested After Cycling	Standard Deviation
J_3	154 ± 16	1,000,000	7	254.4 ksi	±1.05 ksi
J_4	154 ± 16	2,000	7	254.0 ksi	±0.7 ksi
H_5	154 ± 4	100,000	7	256.7 ksi	±4.0 ksi

Note: [a] 60% GUTS is equal to 154.0 ksi.

Table 5.6-3
END ANCHOR ASSEMBLY TESTS

Test No.	Type of Test	Shims	Measured Load (P) in kips	Equivalent Ultimate Tendon Load (kips)	Safety Factor (S.F.)
1	Web-Shear	Yes	2613	3152[a]	1.57
2	Web-Shear	Yes	2682	3236[a]	1.61
3	Web-Shear	Yes	2586	3120[a]	1.56
4	Web-Shear	No	2541	3065[a]	1.53
5	Thread-Shear	No	2518	3038[a]	1.52
6	Thread-Shear	Yes	3378	3378	1.68
7	Thread-Shear	Yes	3561	3561	1.78
8	Thread-Shear	No	2922	2922	1.46
9	Thread-Shear	No	2930	2930	1.46
10	Thread-Shear	No	2745	2745	1.37
11	Thread-Shear	No	2764	2764	1.38
12	Web-Shear	No	2800)	No failure @ 1.4.S.F.	
13	Thread-Shear	No	2800)		

[a]For the web-shear test, the equivalent ultimate tendon load is adjusted from the measured load acting on the sheared plug area to an equivalent tendon load acting on the anchor area subjected to the reactions from the buttonheads.

Table 5.6-4

PREDICTED TOTAL PRESTRESS LOSSES

	Losses Due to Steel Relaxation (%)			Losses Due to Concrete Creep & Shrinkage (%)			Total Predicted Prestress Losses (%)			Total Design Losses (%)
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	
Longitudinal Tendons	8.0	1.4	4.7	2.0	0.0	1.0	10.0	1.4	5.7	20
Cross Head Tendons	8.0	1.4	4.7	4.0	0.0	2.0	12.0	1.4	6.7	15
Circumferential Tendons										
@ Mid-height	8.0	1.4	4.7	5.5	0.0	2.8	13.5	1.4	7.5	25
In Heads	8.0	1.4	4.7	4.0	0.0	2.0	12.0	1.4	6.7	15

Note: Losses are measured in percentages of initial prestress of 70% GUTS. Losses due to concrete creep and shrinkage are obtained from visco-elastic analysis in Appendix E.6.

Table 5.6-5

TENDON STRESS CHANGES

	Pressure Change (psia)	Cycles	Longitudinal Tendons $\Delta\sigma$ (ksi)	Circumferential Tendons at Midheight $\Delta\sigma$ (ksi)	Cross Head Tendons $\Delta\sigma$ (ksi)
Atmospheric to N.W.P.	688	125	1.1	5.3	1.5
Atmospheric to 1.15 R.P.	972	1	1.6	7.5	2.5
0.83 N.W.P. to P.W.P.	132	20,000	0.2	1.0	0.3
N.W.P. to 0.50 N.W.P.	344	400	0.6	2.7	0.7
Atmospheric to V.P.	12	10	---	---	---
N.W.P. to R.P.	157	10	0.3	1.2	0.3
Atmospheric to 2.1 R.P.	1770	---	$\Delta\varepsilon$ = 0.08%	$\Delta\varepsilon$ = 0.21%	$\Delta\varepsilon$ = 0.04%

Note: Tendons are initially stressed to 168.0 ksi (0.7 of guaranteed minimum tensile strength) which is equivalent to a strain of ε = 0.61%. Measured elasticity modulus of tendons is $E = 2.7 \times 10^3$ (ksi)

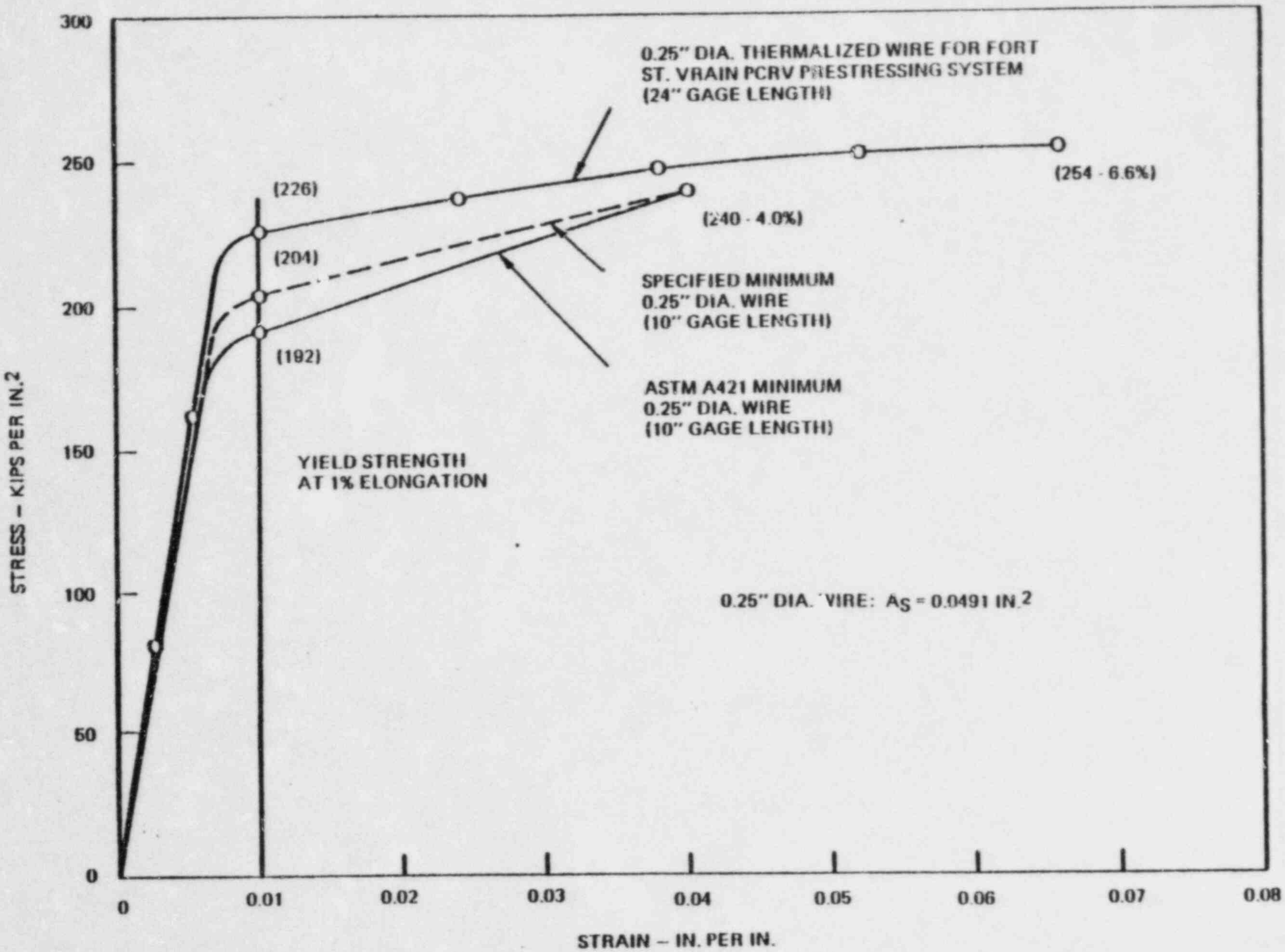


Figure 5.6-1 Typical Stress-Strain Curve of Wire

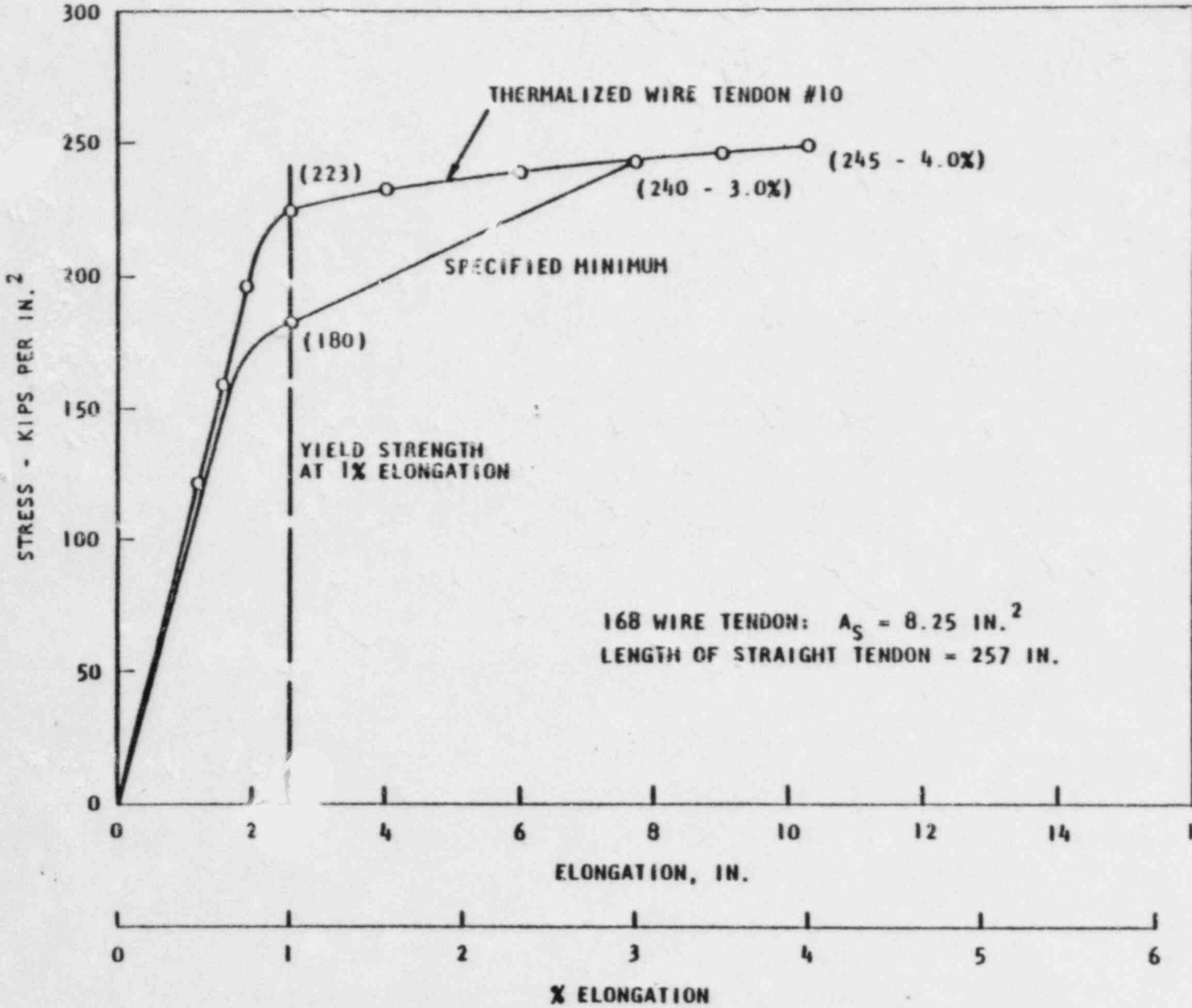


Figure 5.6-2 Typical Stress-Strain Curve of Straight Tendon

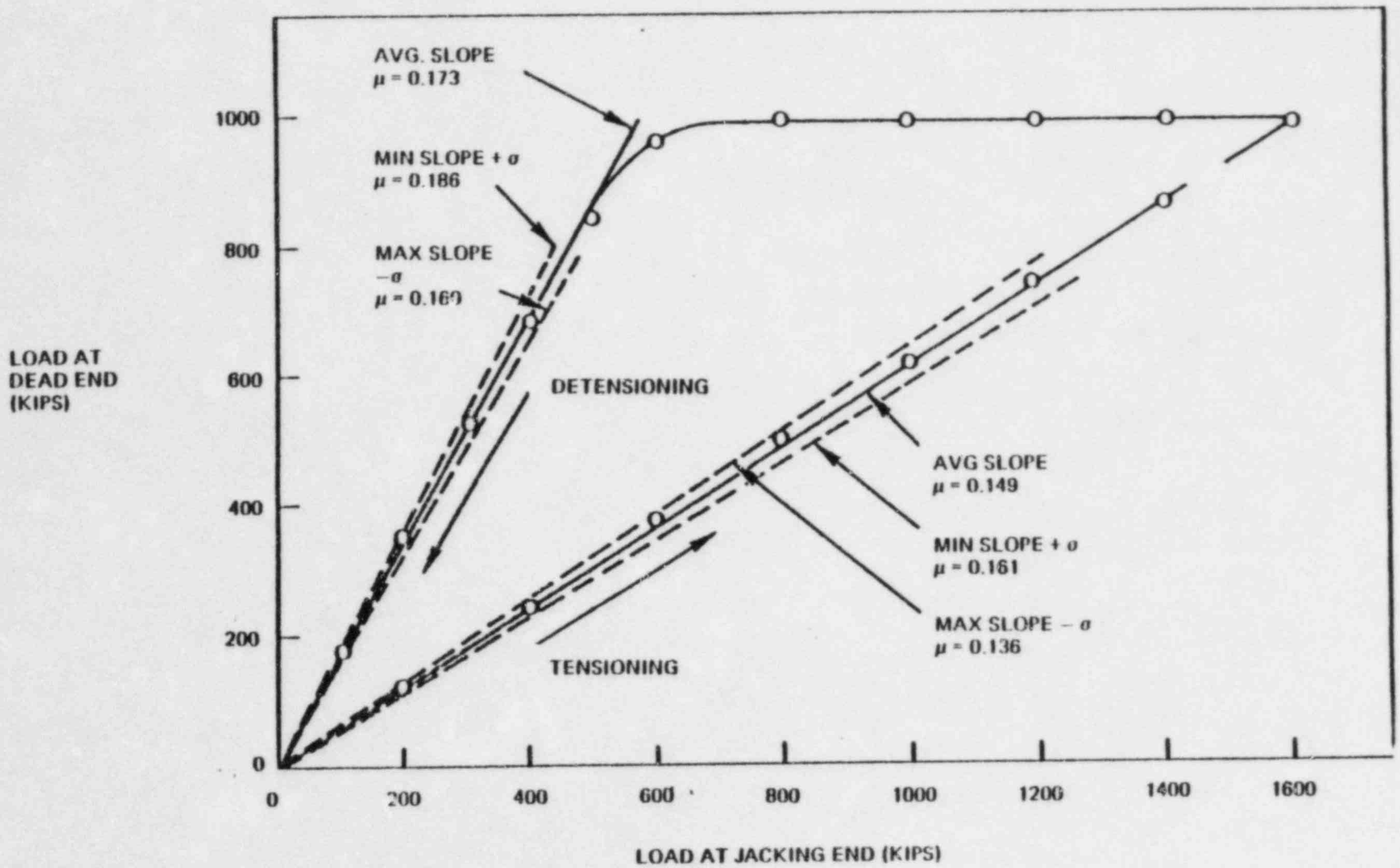
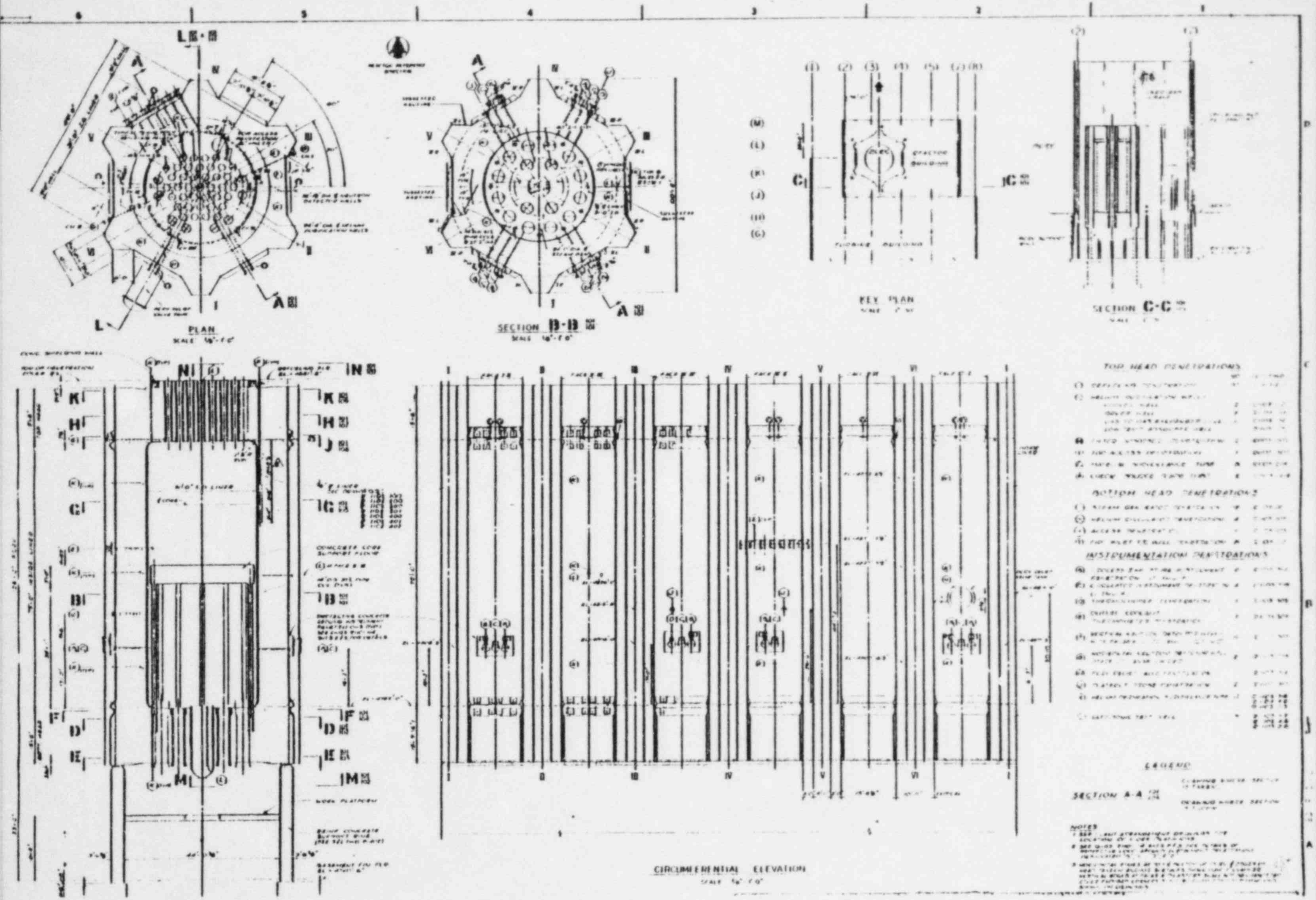


Figure 5.6-3 Typical Friction Curve of Prestressing Tendon

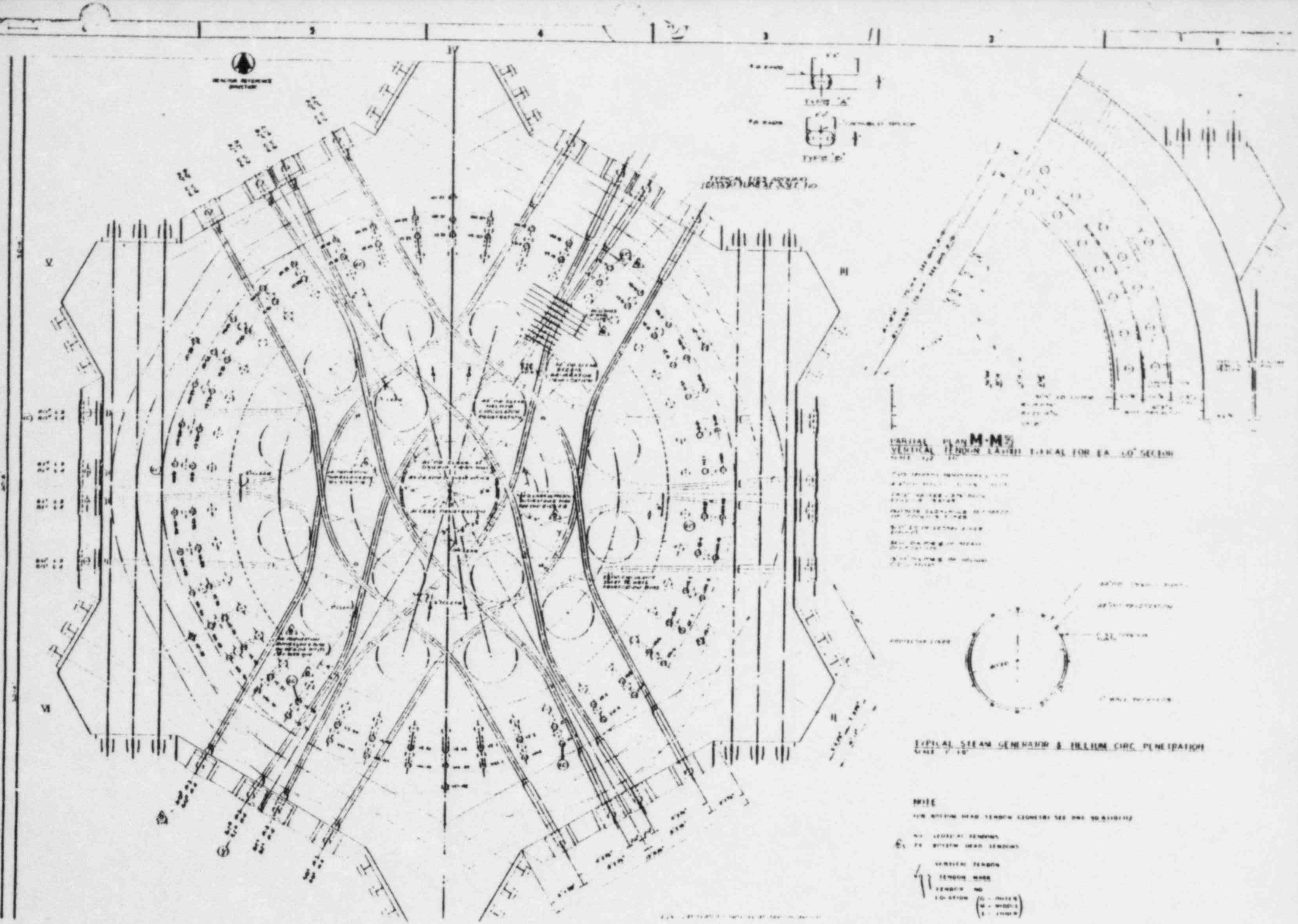
ATTACHMENT 2

(P-84110)

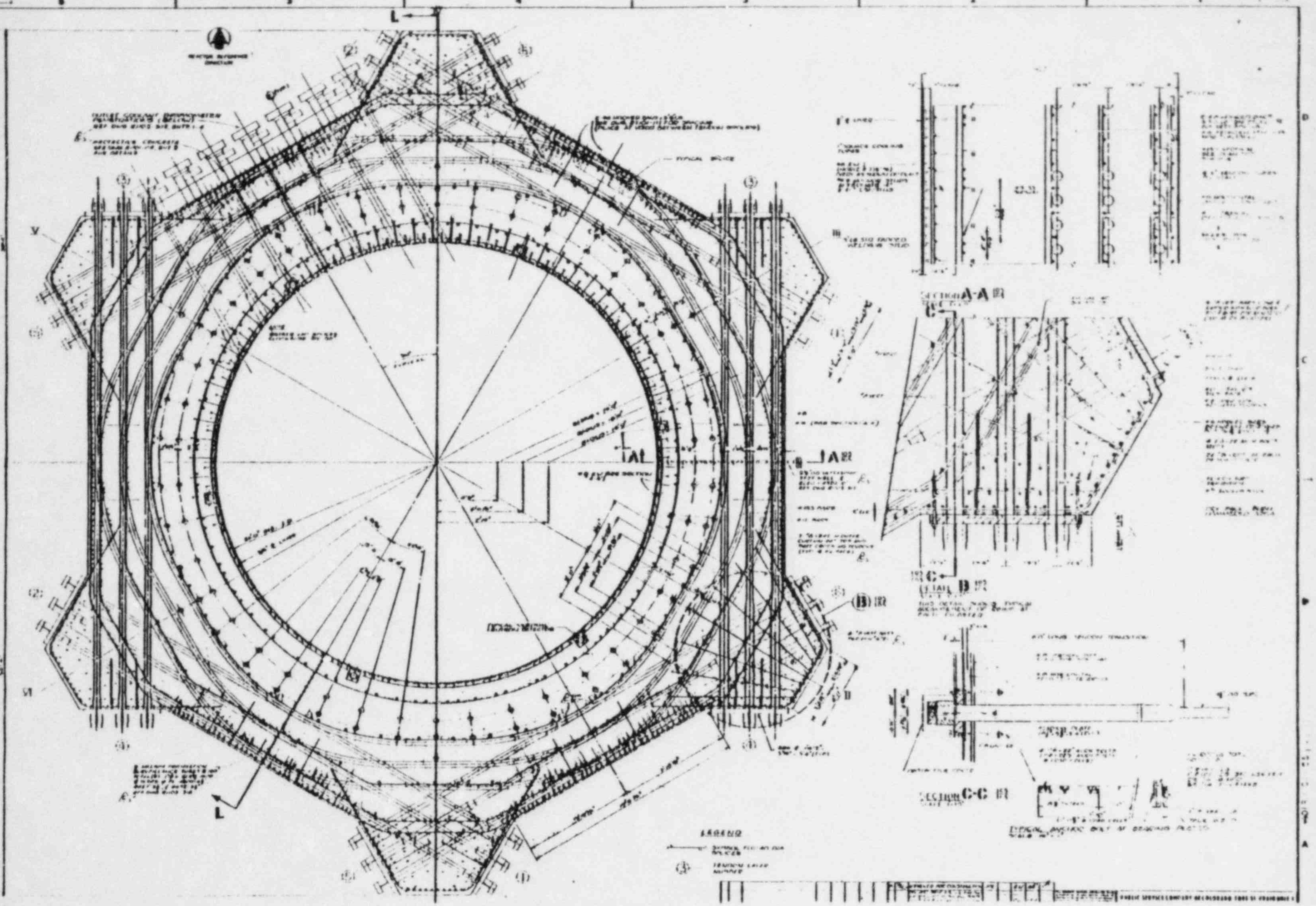
GENERAL LAYOUT DRAWINGS, TENDON SYSTEMS



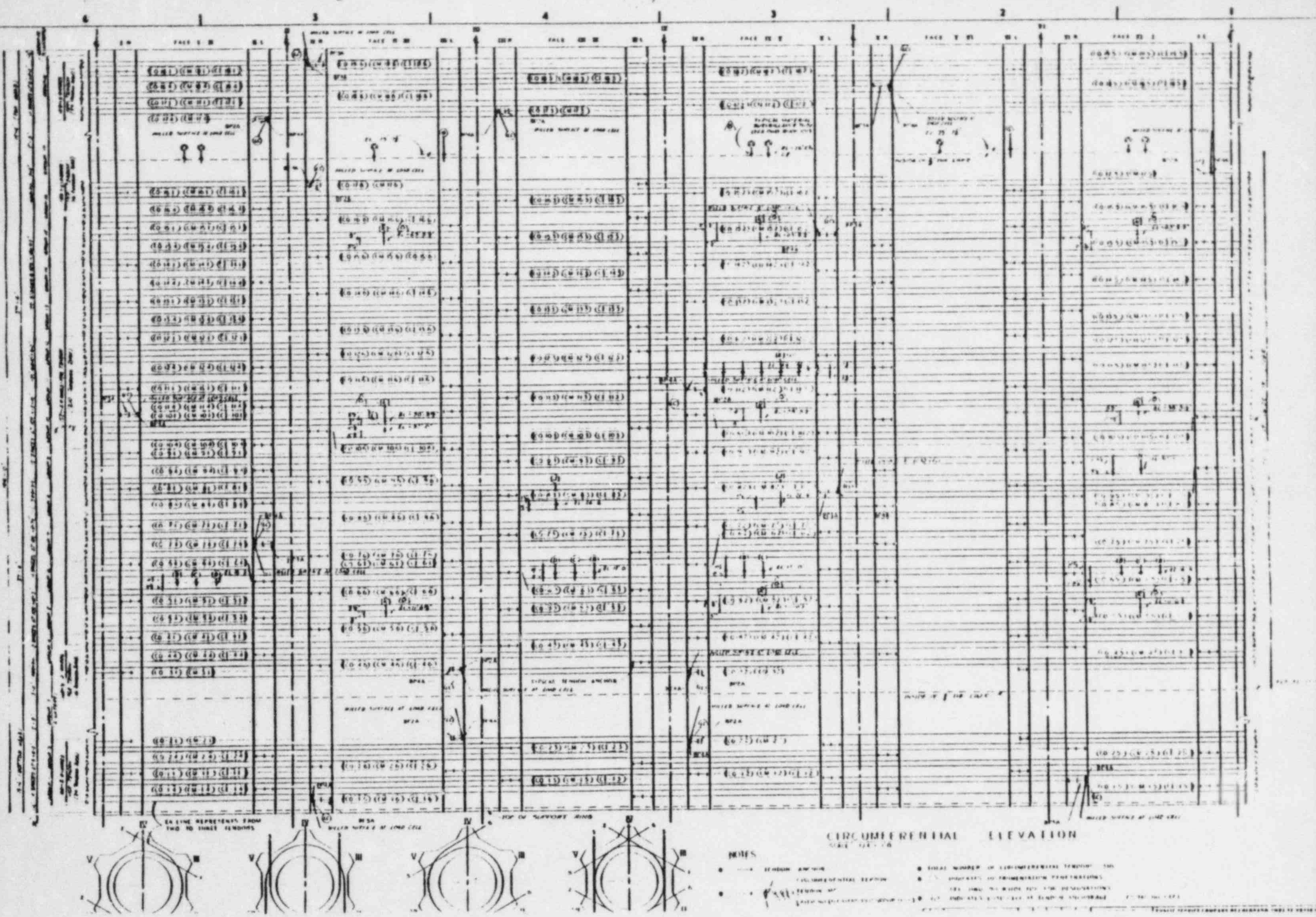
PCRV GENERAL ARRANGEMENT



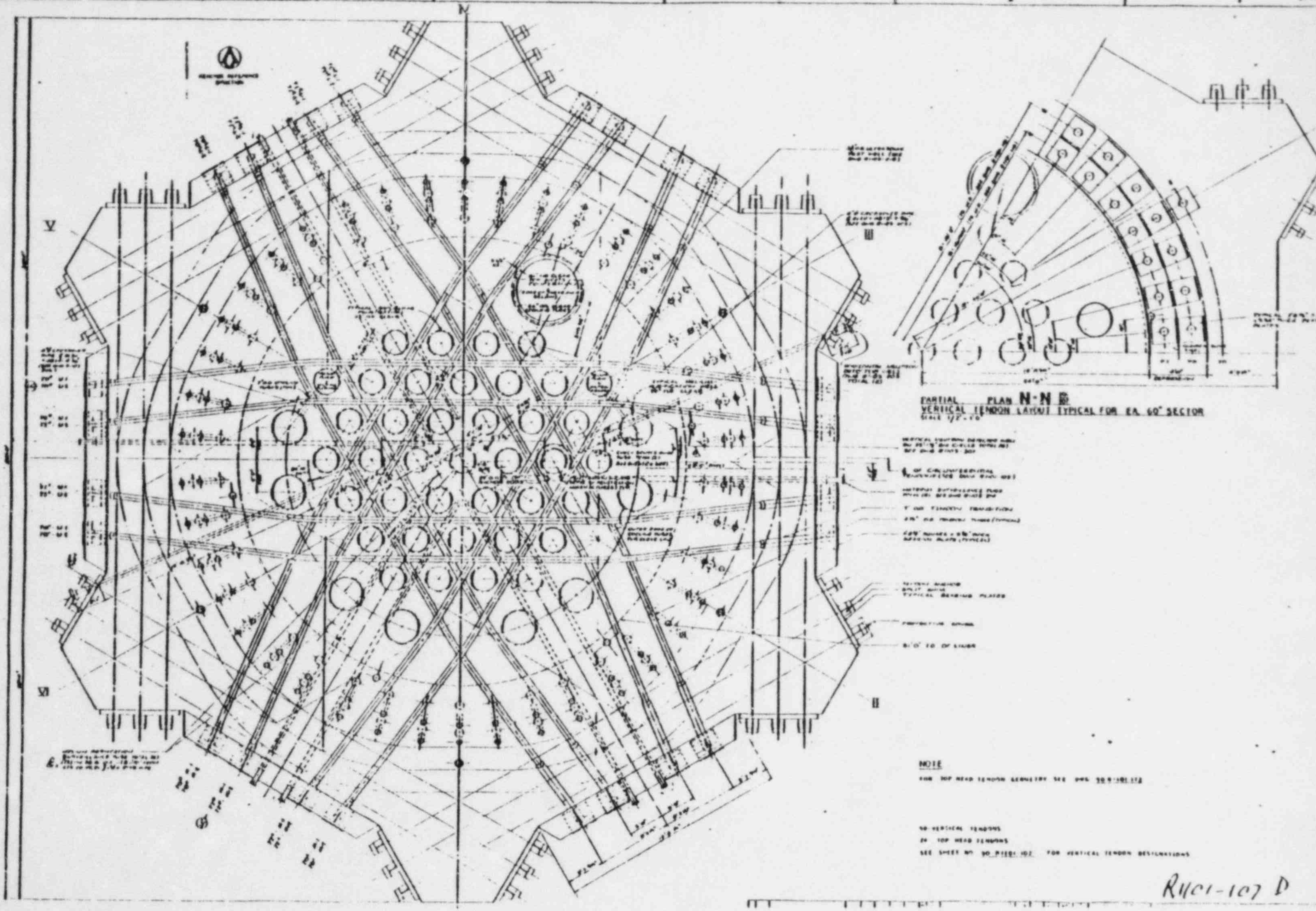
PCRV BOTTOM HEAD AND VERTICAL PRESTRESS



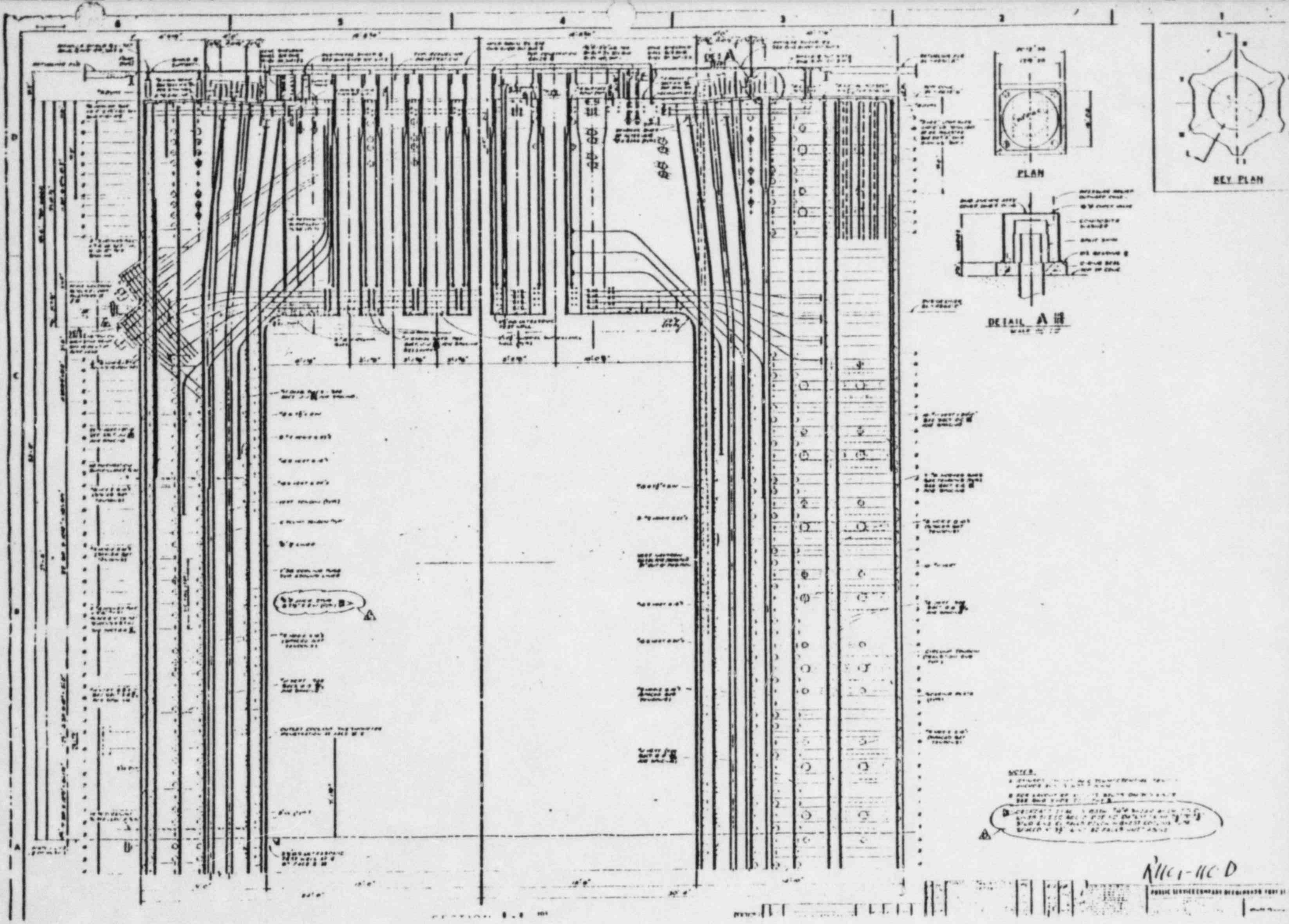
PCRV CIRCUMFERENTIAL PRESTRESS



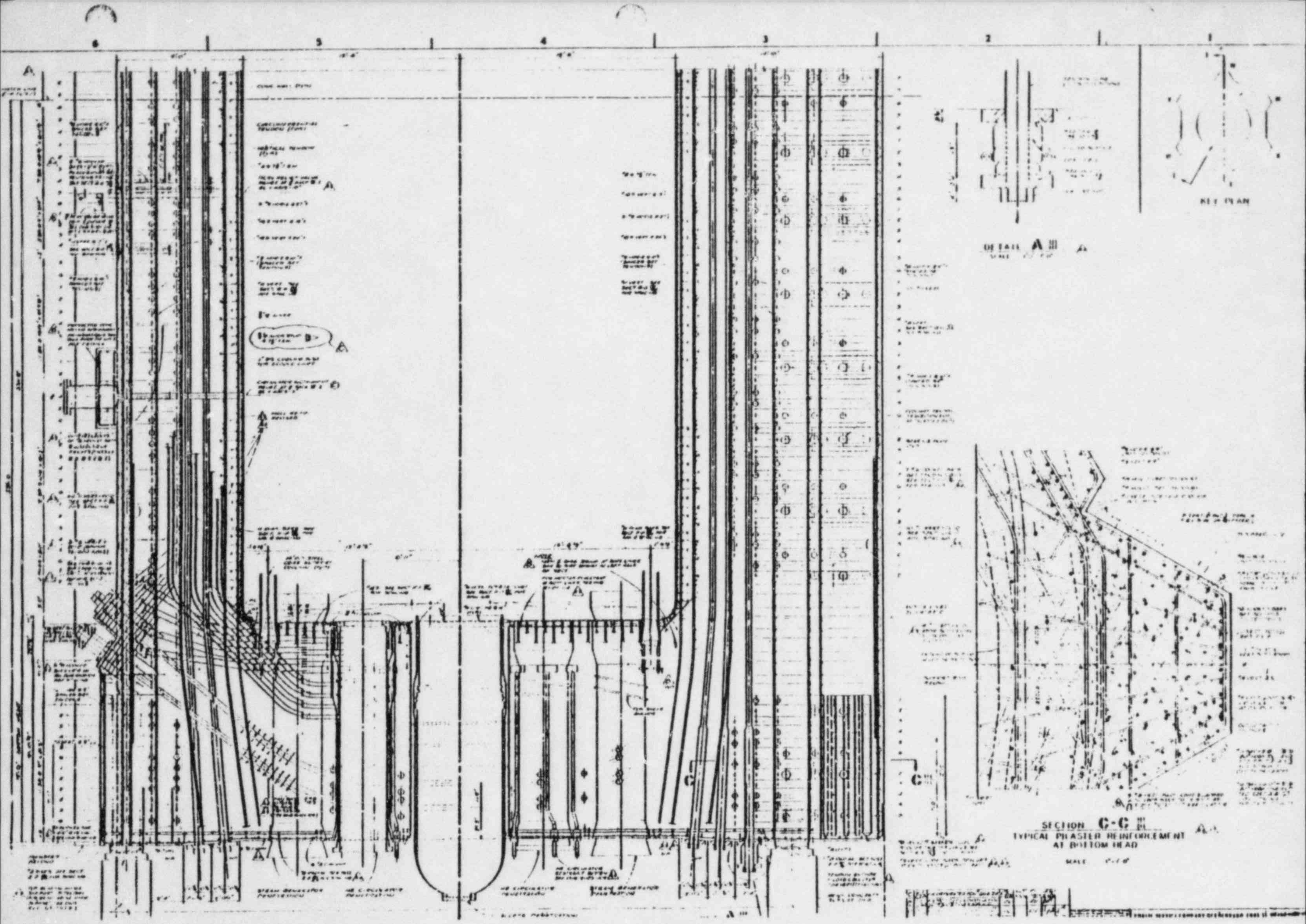
PCRV CIRCUMFERENTIAL PRESTRESS



PCRV, TOP HEAD AND VERTICAL PRESTRESS



PCRV TOP HALF VERTICAL SECTION



PCRV BOTTOM HALF VERTICAL SECTION

ATTACHMENT 3

(P-84110)

TENDON INSPECTION PROGRAM

TENDON INSPECTION PROGRAM

On March 15, 1984, our ISI program for the prestressing system under Technical Specification Surveillance SR 5.2.2c-5Y was started. The program basically calls for 5% of tendon termination to be inspected on a frequency of five (5) years.

Inspection work began on the top head on the vertical tendons. Early in the inspection a tendon was discovered with raised button headed wires which was a definite indication of broken wire strands.

The insepction sample was increased with the final inspection as follows:

TENDON TYPE	VISUAL INSPECTION	TENDONS WITH FAILED STRANDS	TENDONS WITH > 4 FAILED STRANDS
Vertical	89 Top Head	11	3
	2 Bottom Head	0	0
Top Cross Head	4	0	0
Bottom Cross Head	44	7	2
Circumferential	33	2	0

Lift off tests were conducted on those vertical tendons with load cells and results were compared to 1971 lift off data. Values are in kips:

Tendon	VI-38	VI-10	VM-3	VM-30
1971 Lift Off	1459	1509	1448	Not Done
Current Lift Off	1415	1444	1444	1296

TENDON INSPECTION PROGRAM

1.0 The following program was established to verify the operability of the prestressing system:

1.1 Lift off tests to be conducted on all vertical tendons with failed wires. Lift off tests to be conducted on adjacent tendons to those with failed wires. To date twenty lift off tests have been performed. Results are attached.

1.2 Load cell readings from all 27 load cell tendons to be taken. See results attached.

1.3 Detension VM-17. Perform visual inspection. Pull one good wire and one bad wire for engineering evaluation (metallurgical, pull tests, corrosion tests). This work is complete (Engineering evaluations are in progress).

2.0 In addition to the above the followup work was established as follows:

2.1 Perform lift off tests on all accessible tendons with failed wires. Presently plan to perform lift off tests on two circumferential tendons and the worst two bottom cross head tendons.

2.2 Detension one tendon in each of three remaining groups (Top Cross Head, Bottom Cross Head, and Circumferential). Perform visual inspection. Pull one good wire and one bad wire (if available) for engineering evaluation.

Items 2.1 and 2.2 require an additional hydraulic jack. An additional hydraulic jack from TMI arrived today (April 11, 1984). We understand that this jack is in need of repair and calibration, the extent of which in unknown. We would anticipate being able to complete Items 2.1 and 2.2 within the next 30 days.

	TENDON NUMBER	LIFTOFF IN KIPS	NUMBER OF FAILED STRANDS	
1)	VI-2	1348	5	
2)	VM-3	1445	0	Load Cell
3)	VM-8	1385	3	
4)	VI-10	1390	5	Load Cell
5)	VM-10	1344	3	
6)	VM-11	1380	1	
7)	VO-14	1380	4	
8)	*VM-17	1454	4	Load Cell
9)	VI-24	1430	0	Load Cell
10)	VI-29	1445	0	
11)	VM-29	1404	1	
12)	VI-30	1406	0	
13)	VM-30	1296	21	
14)	VI-31	1438	0	Load Cell
15)	VM-31	1429	0	
16)	VI-36	1459	0	
17)	VM-37	1443	1	
18)	VI-38	1456	0	Load Cell
19)	VM-38	1438	0	
20)	VM-42	1395	1	Load Cell
21)	VM-41	Ready to perform	0	

*Detensioned VM-17 - Visual Inspection
- Pulled One Good Wire
- Pulled One Bad Wire

TENDON LOAD CELL READINGS

The tendon load cells were read manually on March 26, 1984. The following is a list of the readings:

Tendon	Wires	Load (KIPS)	Low Nominal Alarm Point
**VM-17	169	1248	1160
**VI-10	169	1220	1160
VM-3	169	1229	1160
VI-24	169	1293	1160
VM-31	169	1252	1160
VI-38	169	1202	1160
TOR-U2	169	1210	980
TIR-M1	169	1003	980
BOR-L4	169	1191	980
BIR-M4	169	1155	980
CO-1.5	169	1185	980
CI-1.4	169	1178	980
CO-2.2	169	1231	980
CO-2.1	169	1167	980
CO-3.2	169	1303	980
CO-3.1	169	1147	980
CI-7.4	152	1021	980
CO-8.3	152	1072	980

TENDON LOAD CELL READINGS (continued)

Tendon	Wires	Load (KIPS)	Low Nominal Alarm Point
CI-10.1	152	1017	980
CO-11.2	152	1011	980
CI-15.3	152	1067	980
CO-17.6	169	1128	980
CO-17.5	169	1144	980
CO-17.4	169	1255	980
CO-17.3	169	1191	980
CO-18.5	169	1148	900
CO-19.6	169	1313*	980

*CO-19.6 had to be read locally at the load cell due to a cable problem. This problem is being investigated at present.

**VM-17 and VI-10 visually inspection and given lift off test.

ATTACHMENT 4

(P-84110)

TENDON INSPECTION PROGRAM RESULTS

TENDON INSPECTION PROGRAM RESULTS TO DATE

Some tendons, predominantly the vertical tendons have experienced individual wire strand failure due to corrosion.

The corrosion has been on the shop end of the tendons and the corrosion has been observed very near the end of tendons.

Detailed evaluations are in progress on the corrosion mechanism, wire failures, etc.

Lift off tests have been conducted on all vertical tendons with wire failures as well as several other vertical tendons. All lift off test data indicates that the tendons are more than capable of meeting design requirements.

Although some further lift off tests have yet to be completed, lift off tests that have already been done certainly bound those to be done.

All 27 tendon load cells are operable and are giving more than acceptable readings. All 27 load cells are alarmed into the control room.

It would appear that the corrosion we are seeing originates from original construction. It is felt that during installation the shop end washer could have slid back and forth on the tendons effectively wiping the grease applied to the shop end next to the bearing washer.

There is no indication in construction procedures that the shop end was ever regreased during installation of the tendons, where as the field end required regreasing in the field. The PCRV was exposed to varying weather conditions after post tensioning as the reactor building was open to the atmosphere. Changing temperatures and adverse weather could have created a moisture ingress and condensation problem. With the shop end possibly having minimum grease (the shop end is top head end of the vertical tendons) and the natural tendency for grease to flow from the top end, corrosion probably started.

It should be noted that the above is only a theory. We do not have the results of detailed analysis a yet to either support or refute the theory.

Given that possibility, however, we are proceeding to regrease the top end of all accessible vertical tendons.

Our final conclusion based on our efforts to date would be that the tendon system is completely operable and capable of performing its design function. Twenty-seven (27) of the tendons are being continuously monitored (complete with alarms) to ensure load carrying capability. Although the long term effects and solutions cannot be identified as yet, the PCRV is functional and fully capable of meeting all design conditions for operation of Fort St. Vrain.

In terms of the future, PSC intends to pursue the detailed analyses and engineering evaluation in order to provide timely solutions and/or corrective action.

In the interim PSC operations will monitor the load cells on the twenty-seven (27) tendons on a monthly basis for trends of relaxation or load carrying capability.

PSC will develop a semi-annual surveillance program of the tendon terminations wherein a sample of tendon terminations, including a sample of those presently identified with failed wires, will be inspected to establish any further degradation trends. Should any degradation trends be discovered the surveillance program will be structured to increase surveillance frequency to insure such trends are adequately monitored.

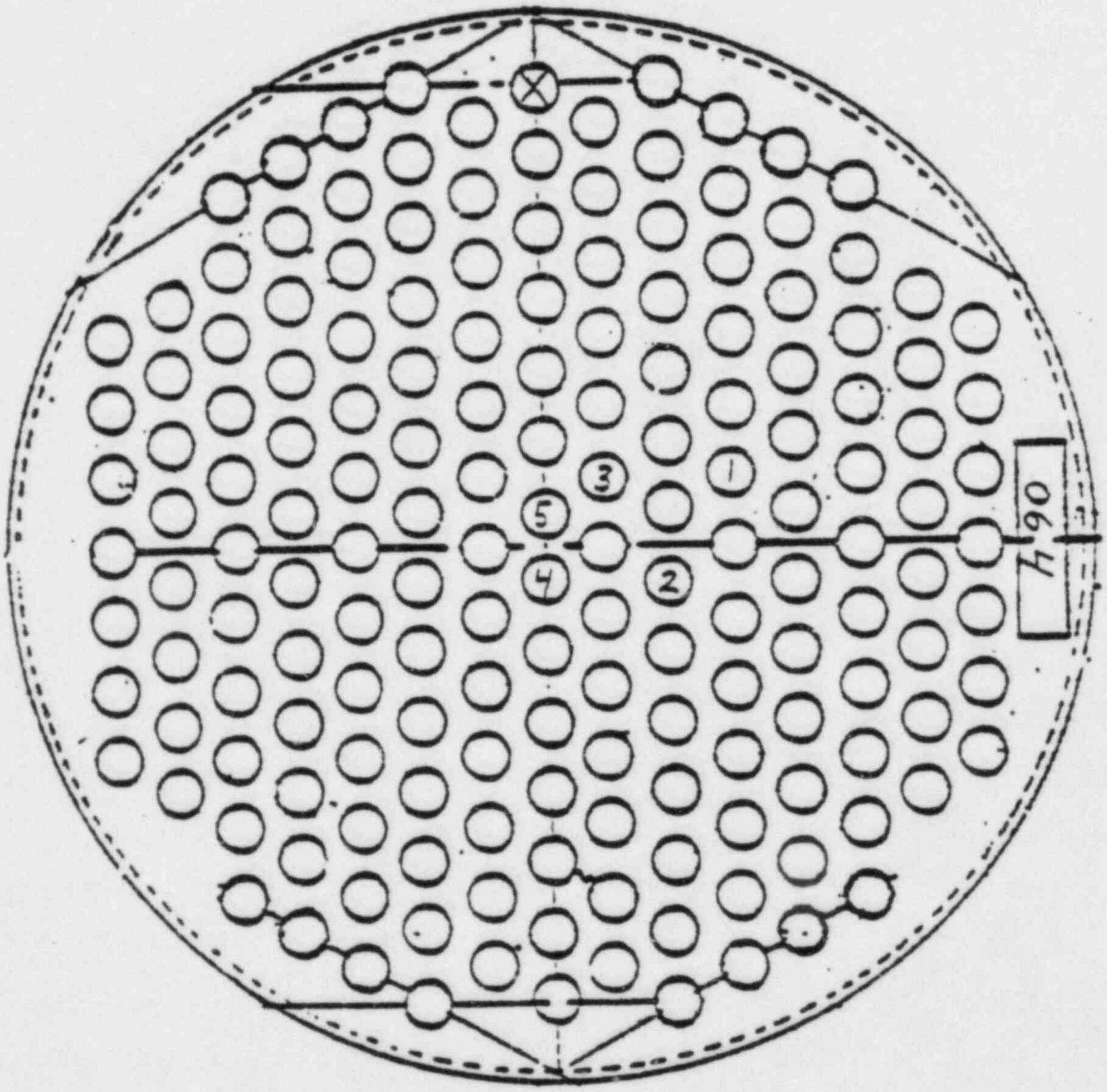
Public Service Company will keep the Nuclear Regulatory Commission abreast of the results of our on-going inspection programs.

Attachment 4

SUMMARY OF TENDON INSPECTION

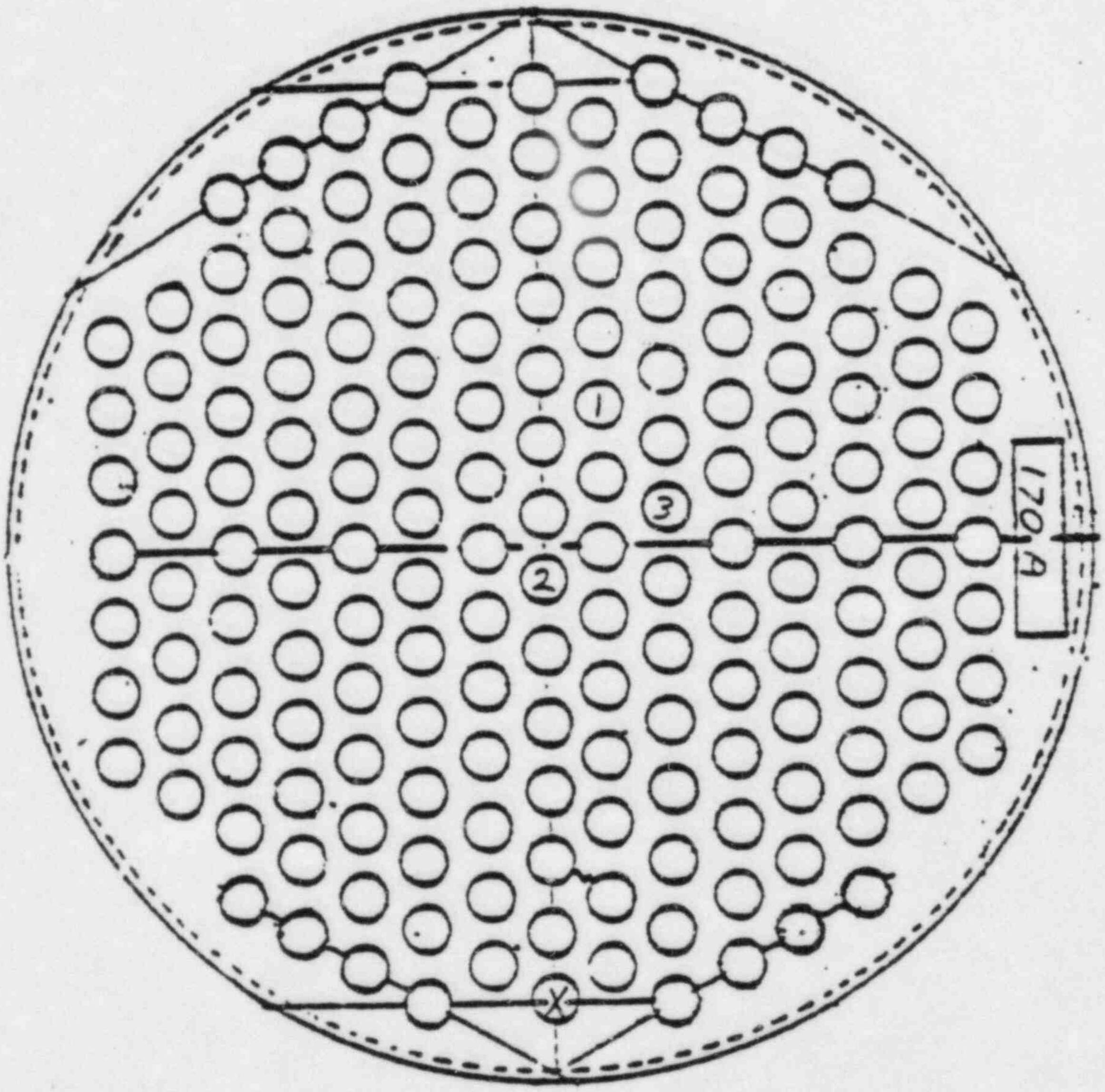
TENDON	TYPE	# OF INDICATIONS (BUTTONHEAD RISEN)	TOTAL
VI-2	Vertical	5	89 of 90 vertical top head anchor assemblies were inspected. 11 were found with indications of wire failure.
VM-8	"	3	
VI-10	"	5	
VM-10	"	3	
VM-11	"	1	
VO-14	"	4	21 Tendons were tested for lift-off force including all vertical tendons with indications. All were found to be well within the acceptance criteria.
VM-17	"	4	
VM-29	"	1	
VM-30	"	21	
VI-37	"	1	
VM-42	"	1	
$BI^{L}U4$	BottomHead	17	44 of 48 bottom head anchor assemblies were visually inspected. 7 were found with indications of wire failure. Liftoff testing is under way at this time.
$BI^{R}U3$	"	12	
$BO^{L}U4$	"	3	
$BO^{L}L4$	"	2	
$BO^{L}M3$	"	1	
$BO^{R}M4$	"	1	
$BO^{L}M4$	"	1	
CO 2.5	Circumferential	3	33 circumferential anchor assemblies were visually inspected. 2 were found with indications of wire failure. Liftoff testing is underway at this time.
CO 1.1		2	
			4 top head anchor assemblies were inspected, no indication of corrosion or wire failure was noted.
			2 vertical bottom head anchor assemblies were inspected, no indications of corrosion or wire failure were noted.

TENDON # VI-2



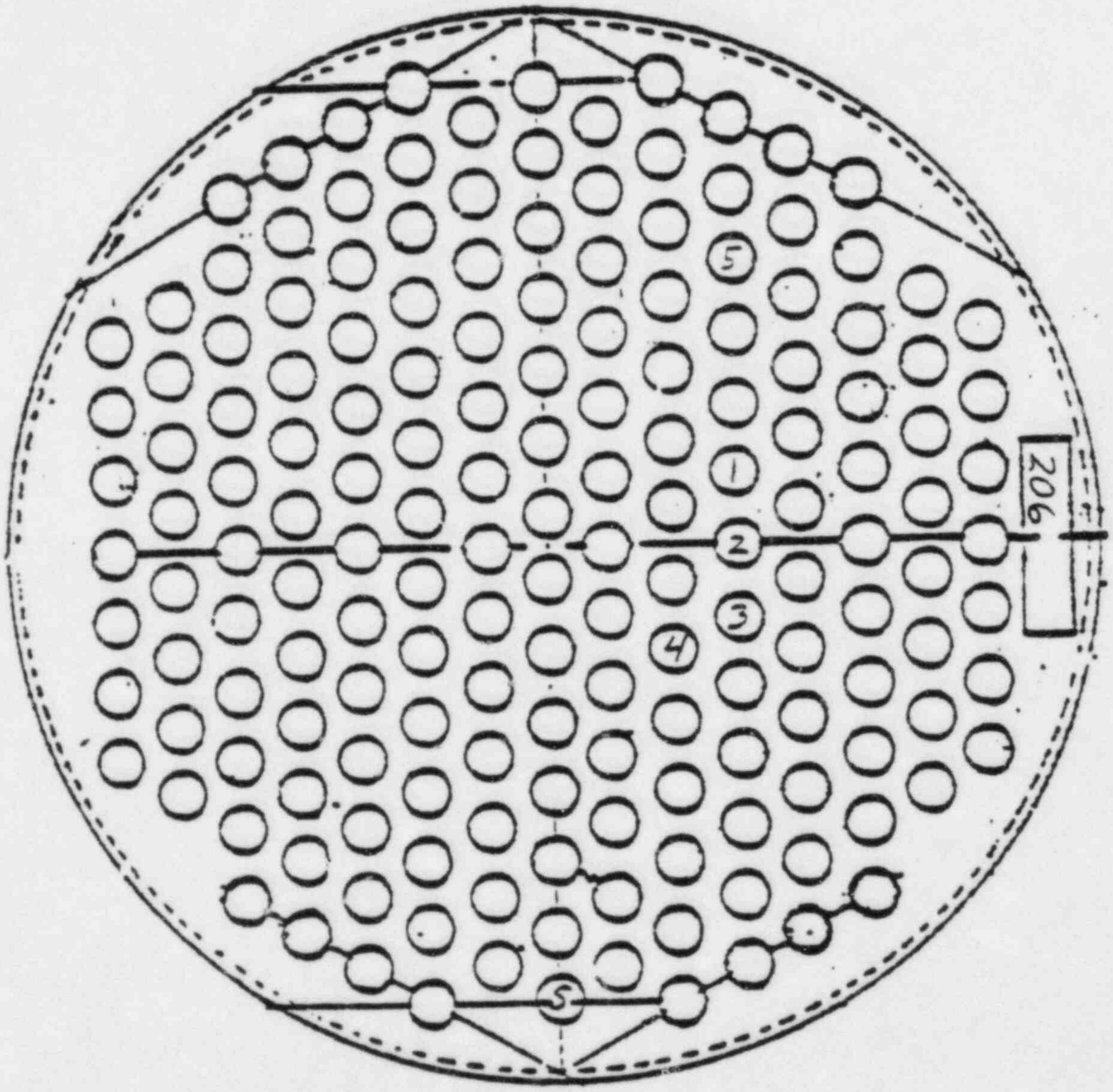
X: MISSING
#: RAISED

TENDON # VM-8



X = MISSING
# = RAISED

TENDON # VI-10

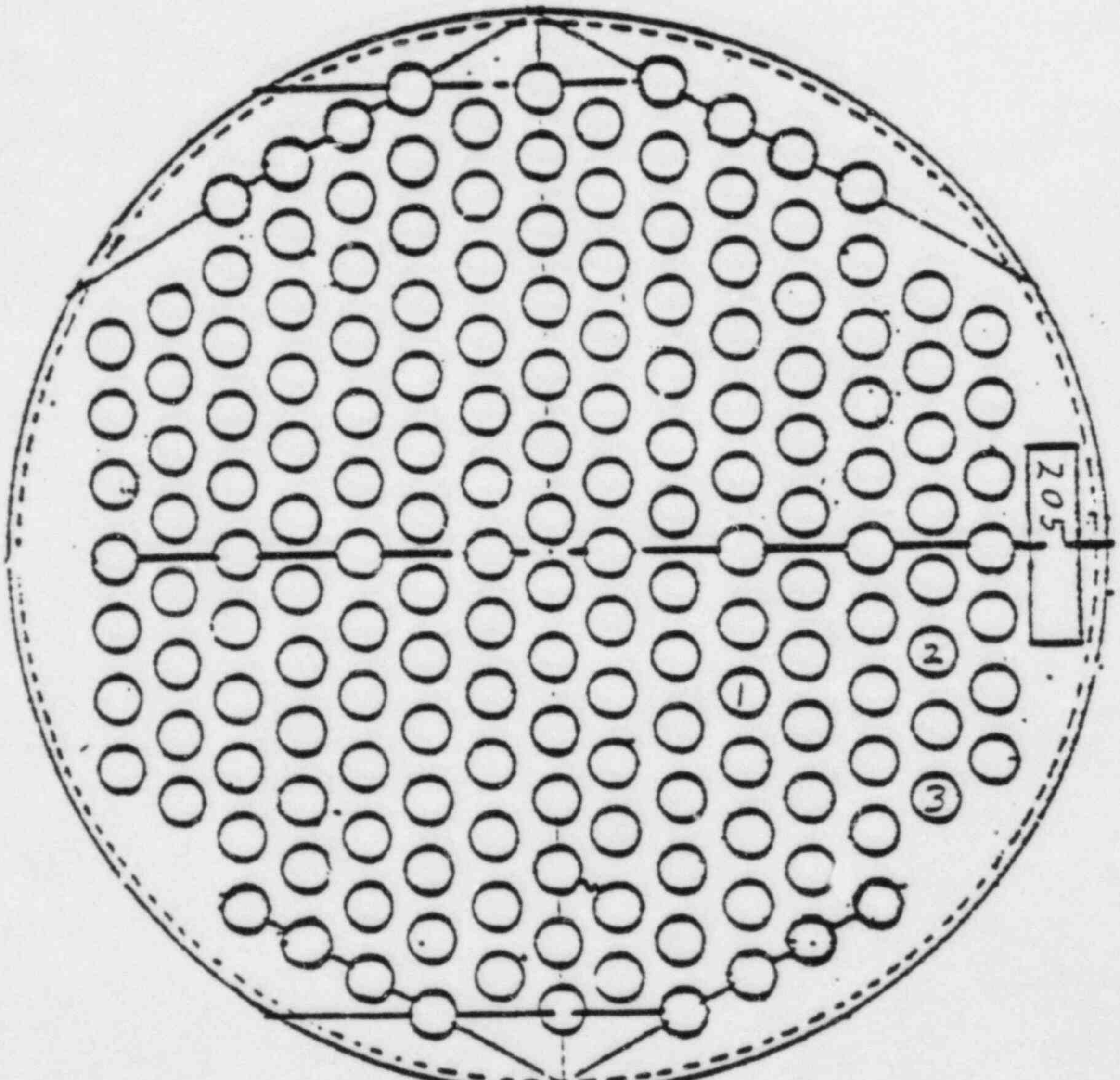


X = MISSING

= RAISED

S = Sample wire

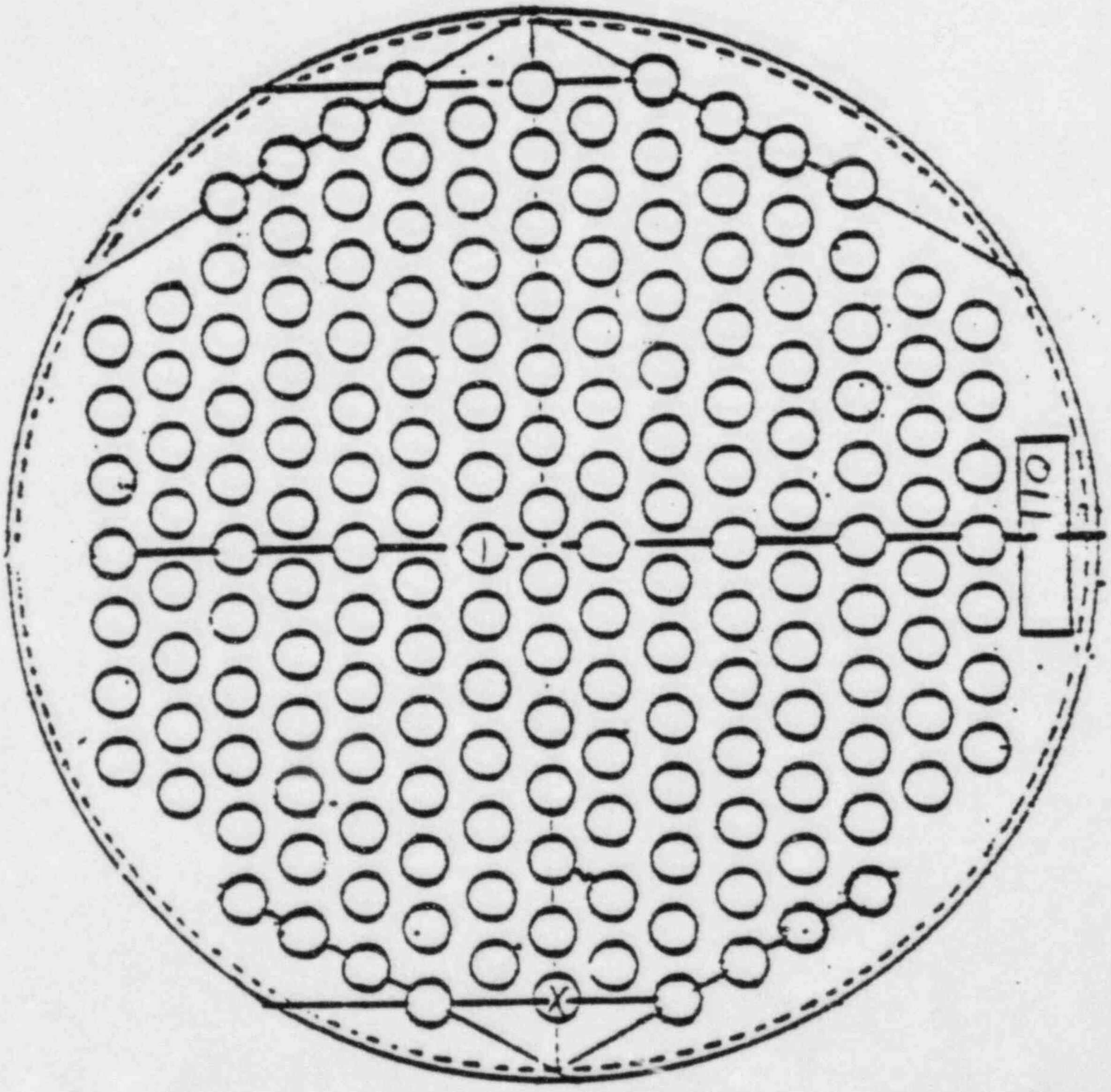
TENDON # VM-10



X = MISSING

= RAISED

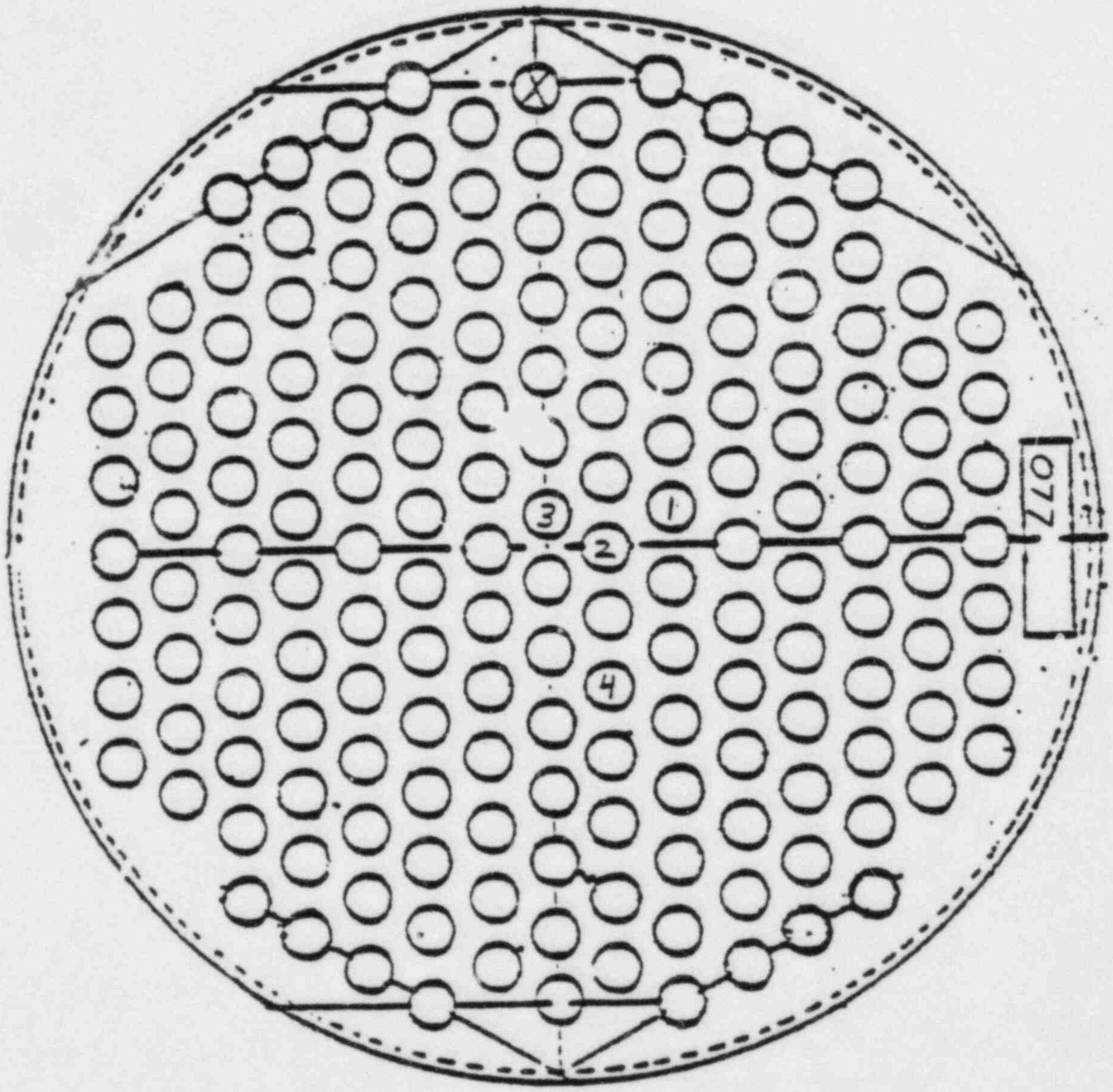
TENDON # VM-11



X = MISSING

= RAISED

TENDON # VO-14



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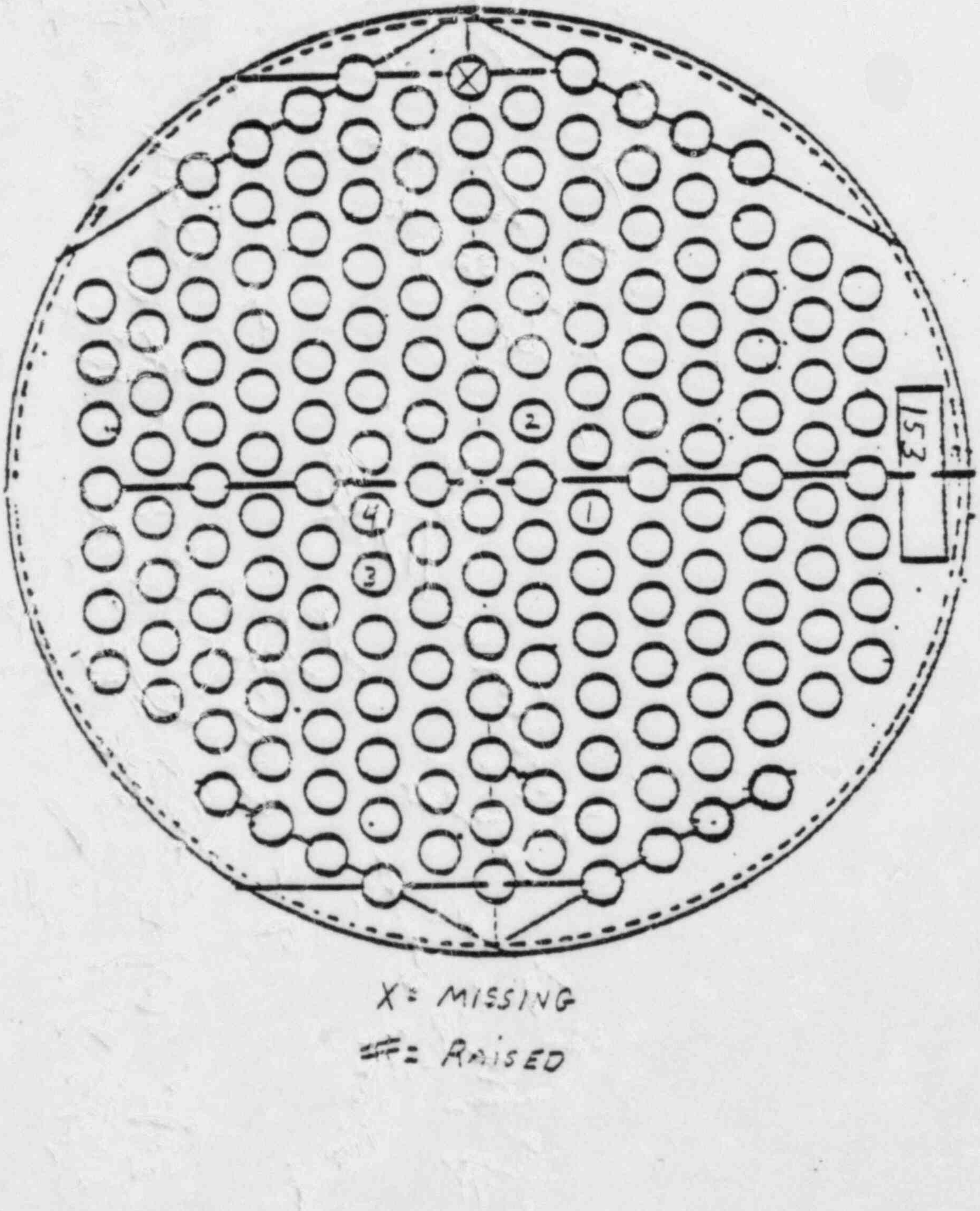
= RAISED

TENDON # VM-17



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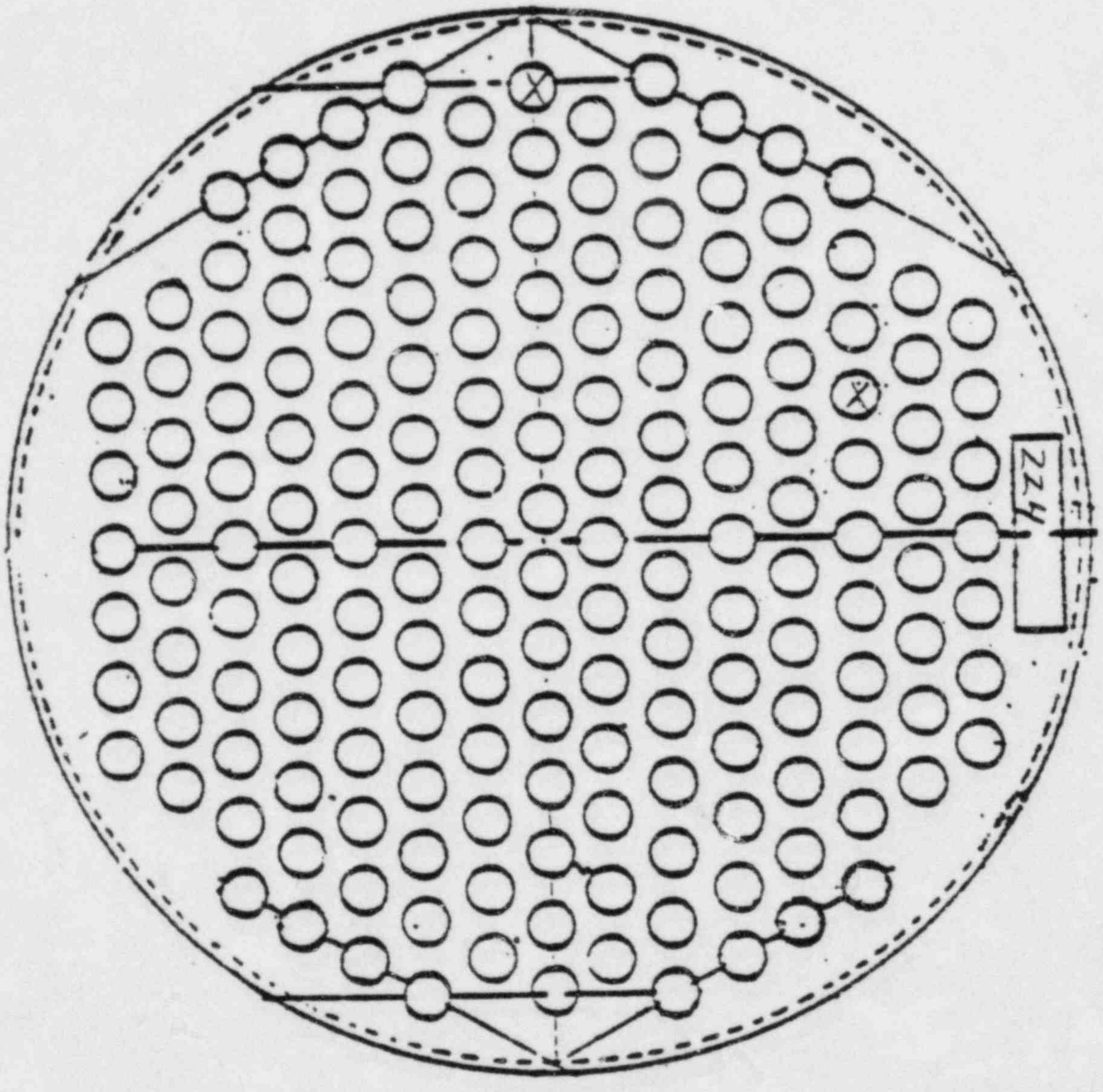
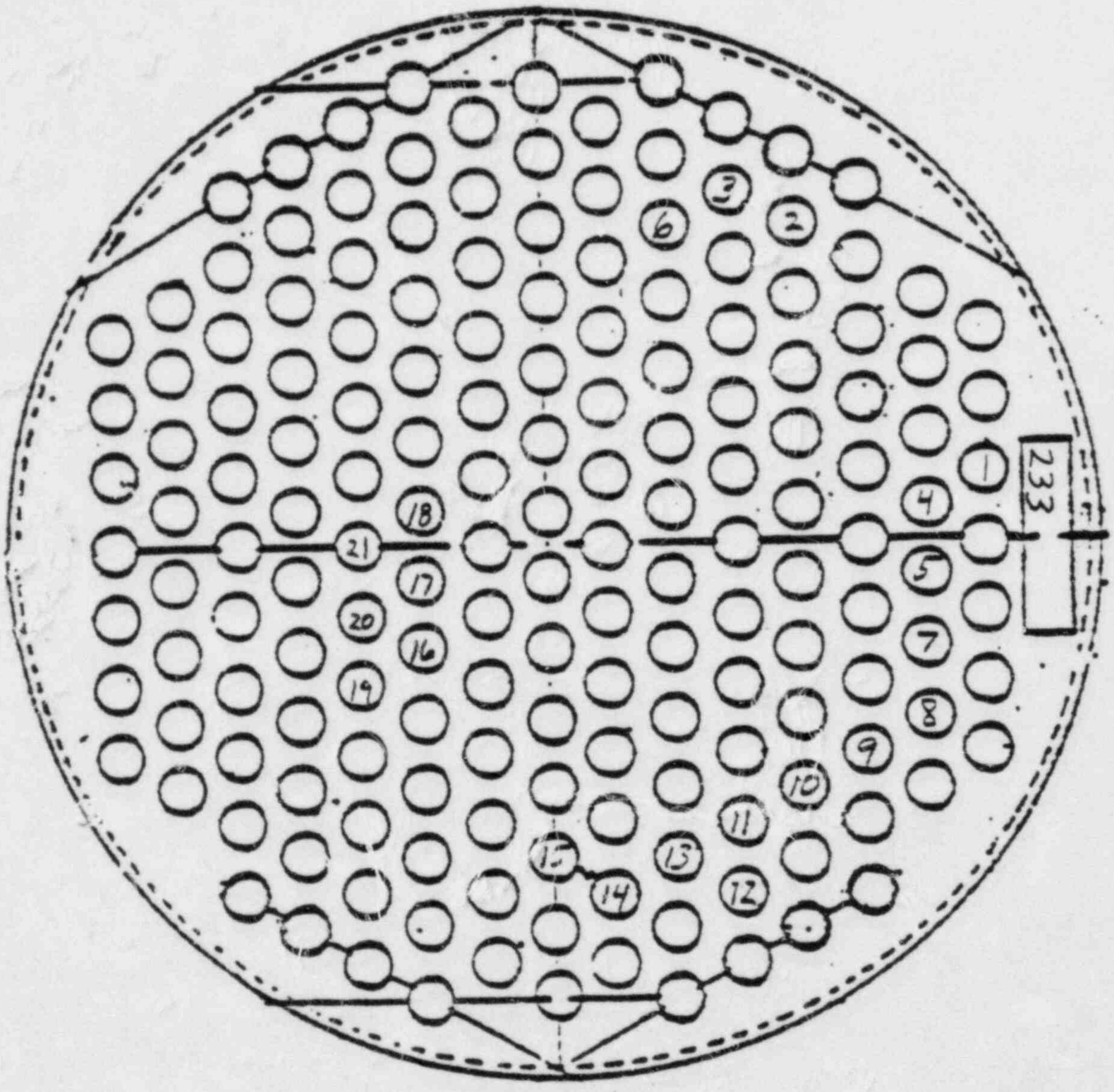
= RAISED

TENDON # VM-29



X = MISSING

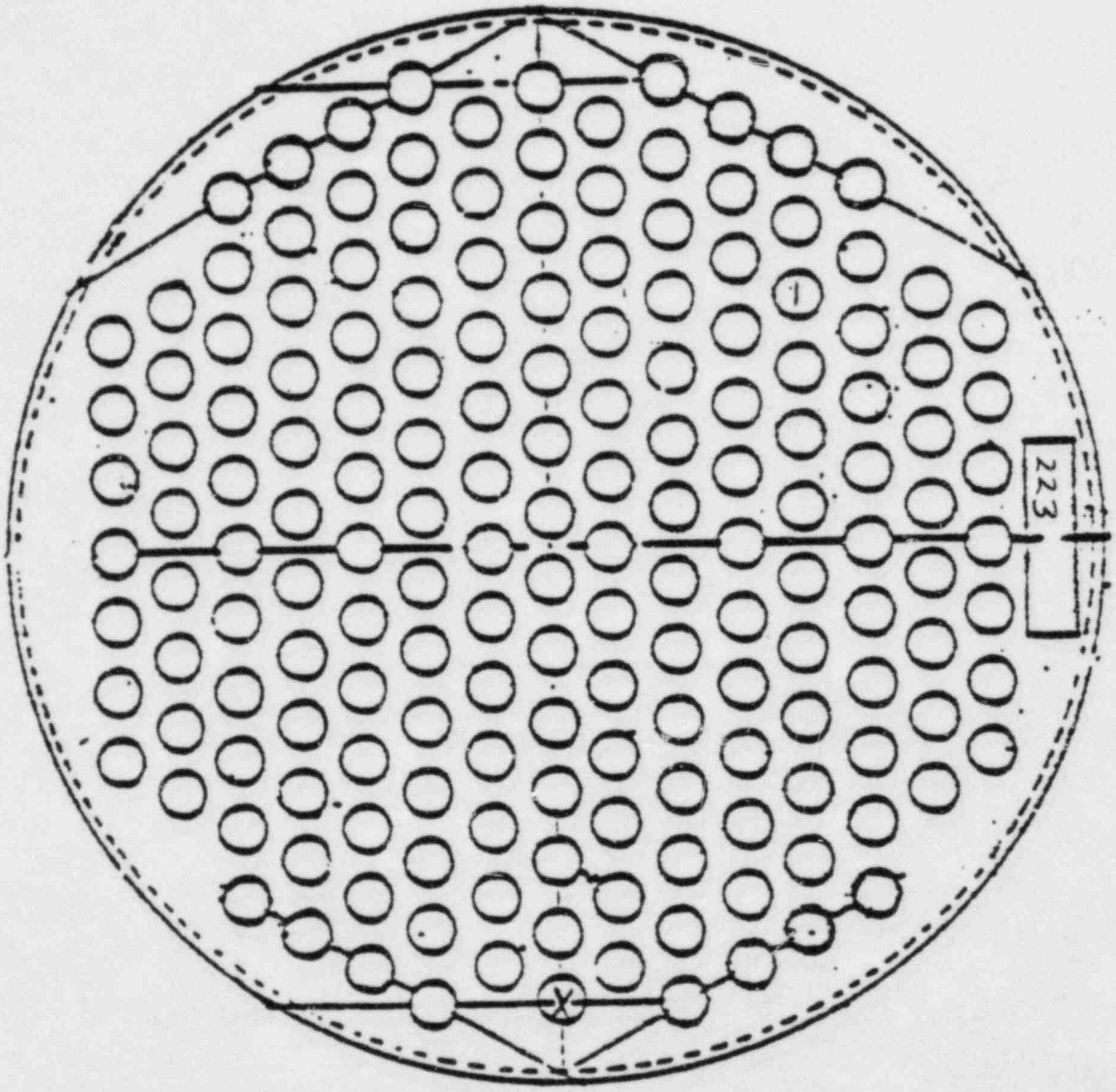
TENDON # VM-30



X = MISSING

= RAISED

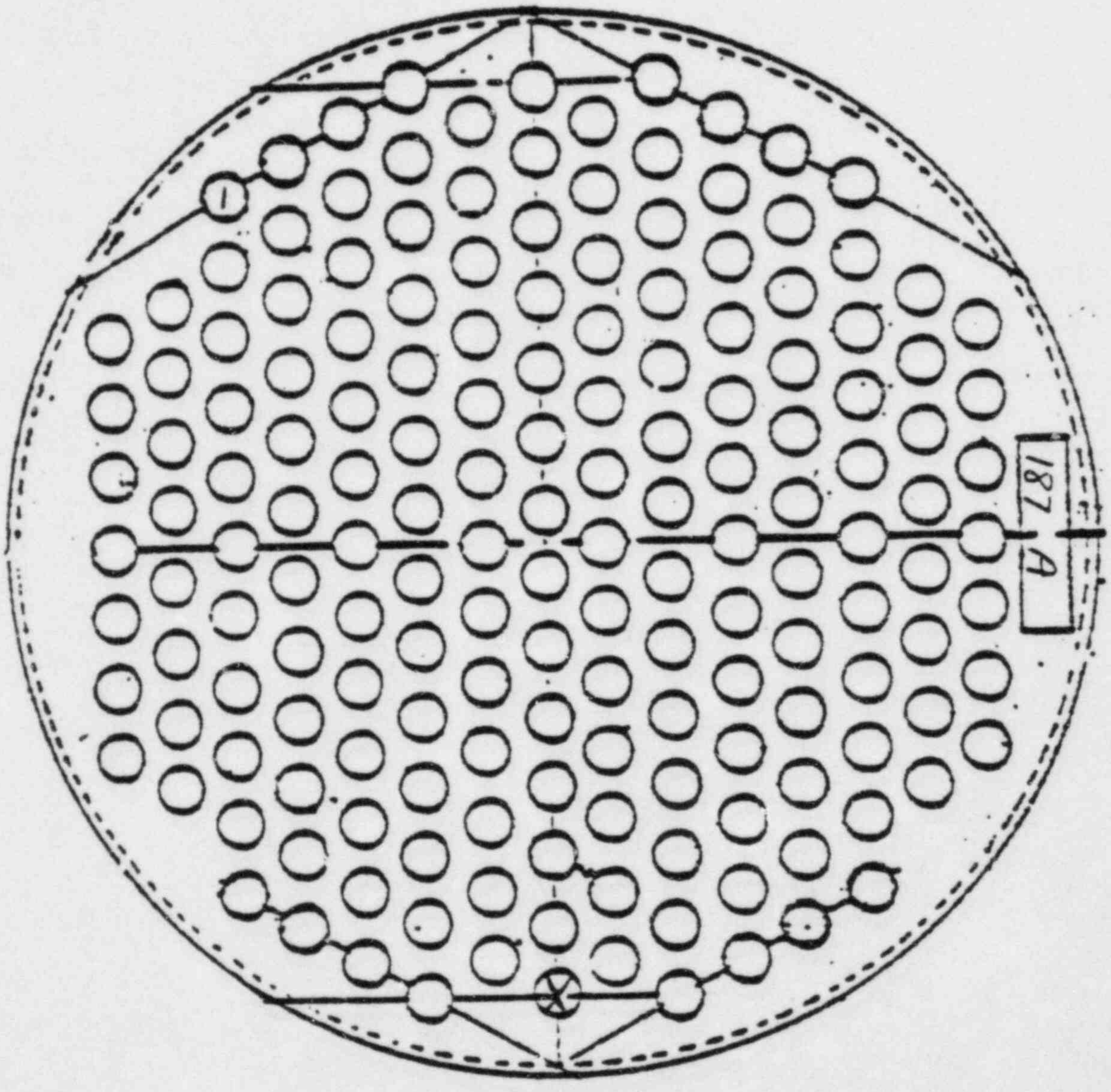
TENDON # VM-37



X = MISSING

= RAISED

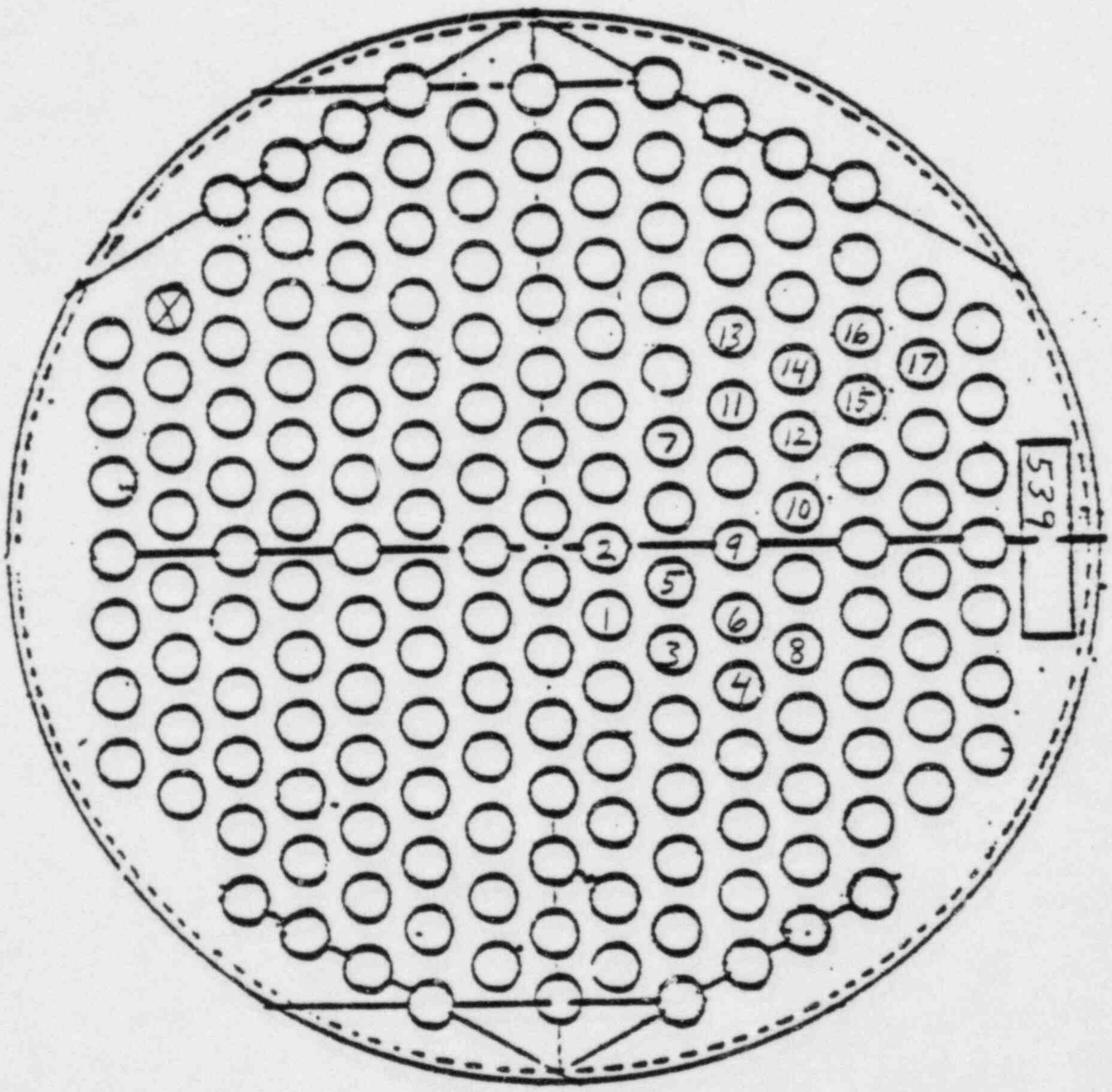
TENDON # VM-42



X = MISSING

= RAISED

TENDON # BI^L U4

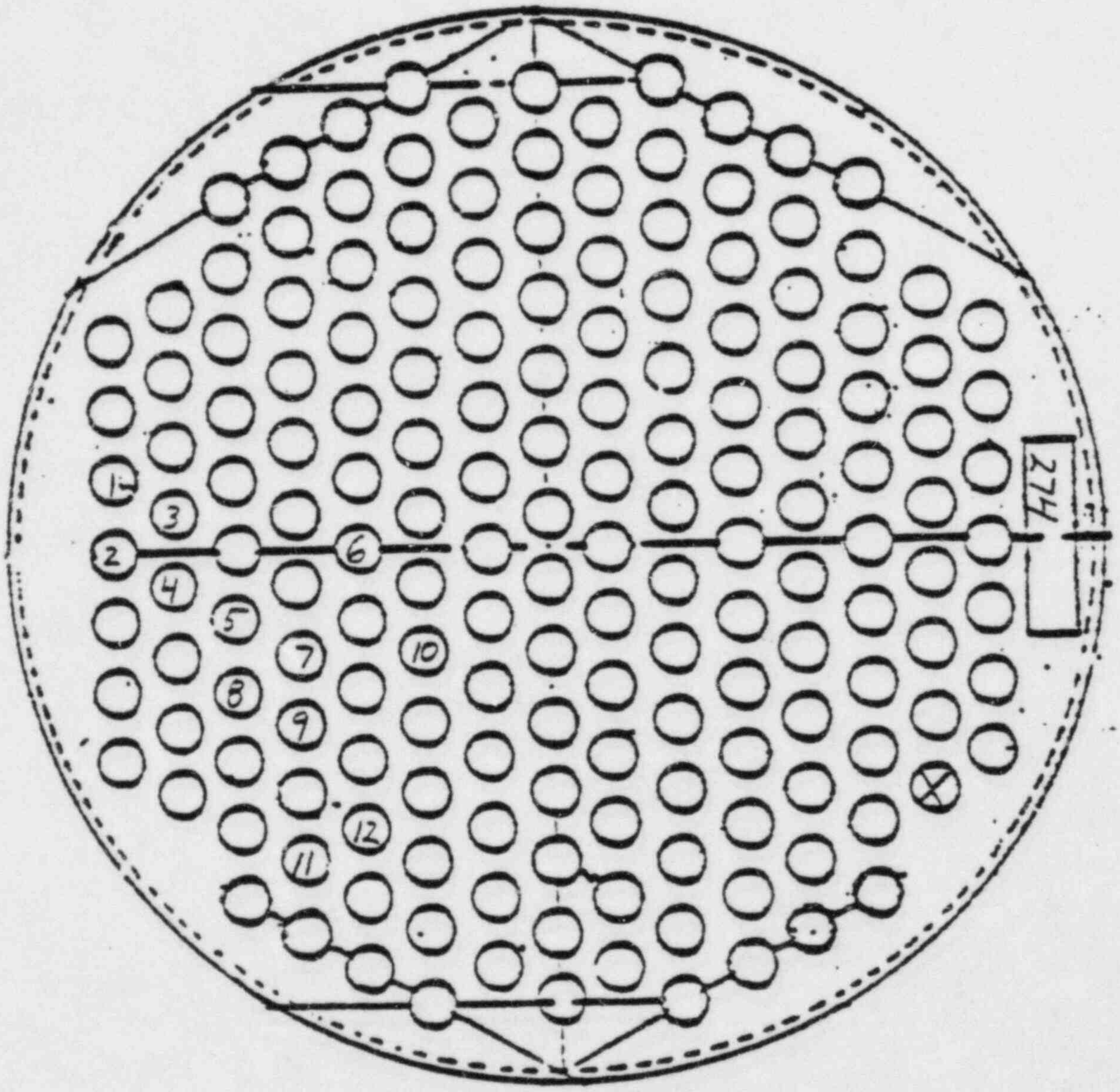


X = MISSING

= RAISED

FACE I - II

TENDON # BI^R U3

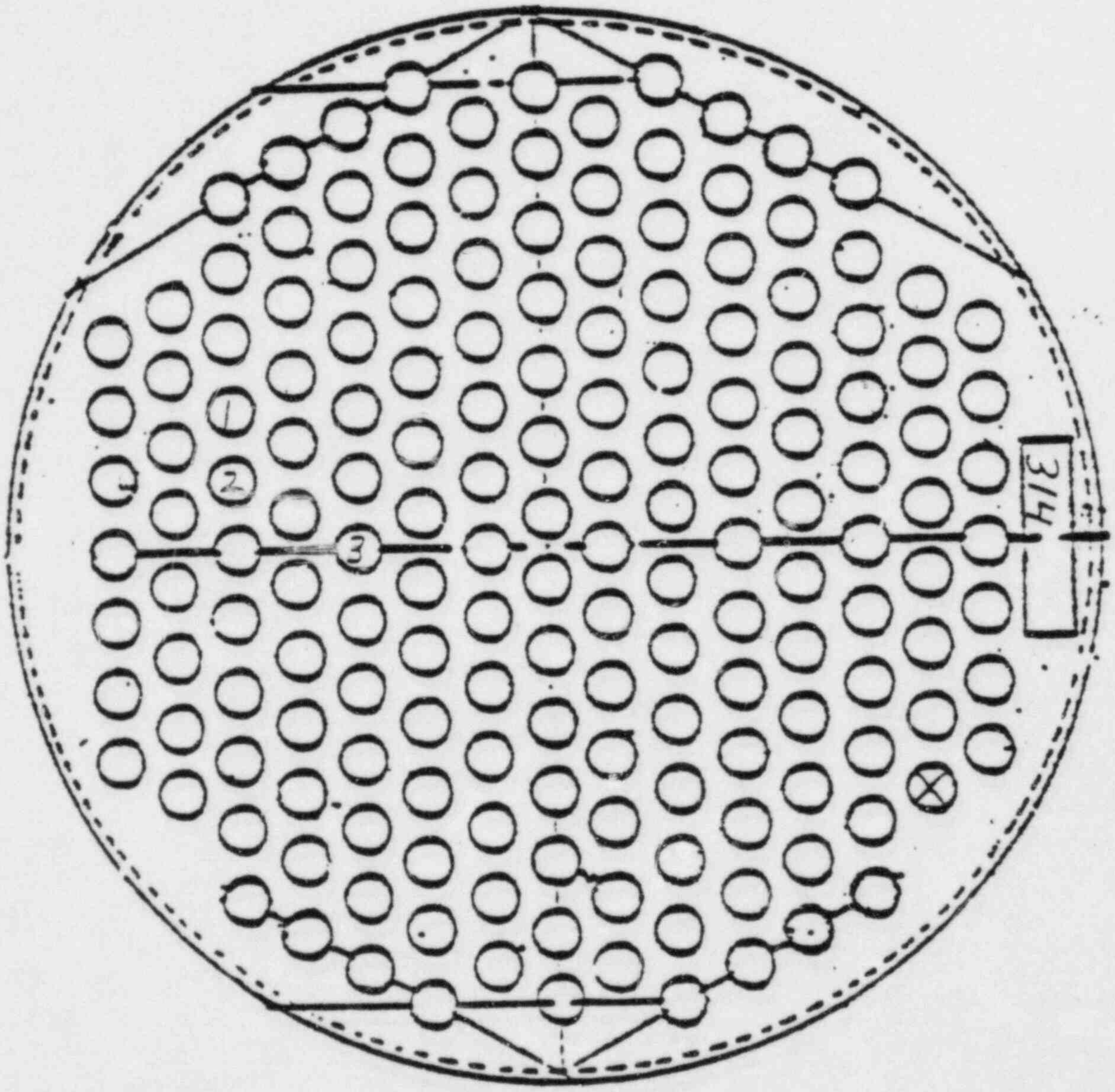


X = MISSING

= RAISED

FACE IV - V

TENDON # BO-U4

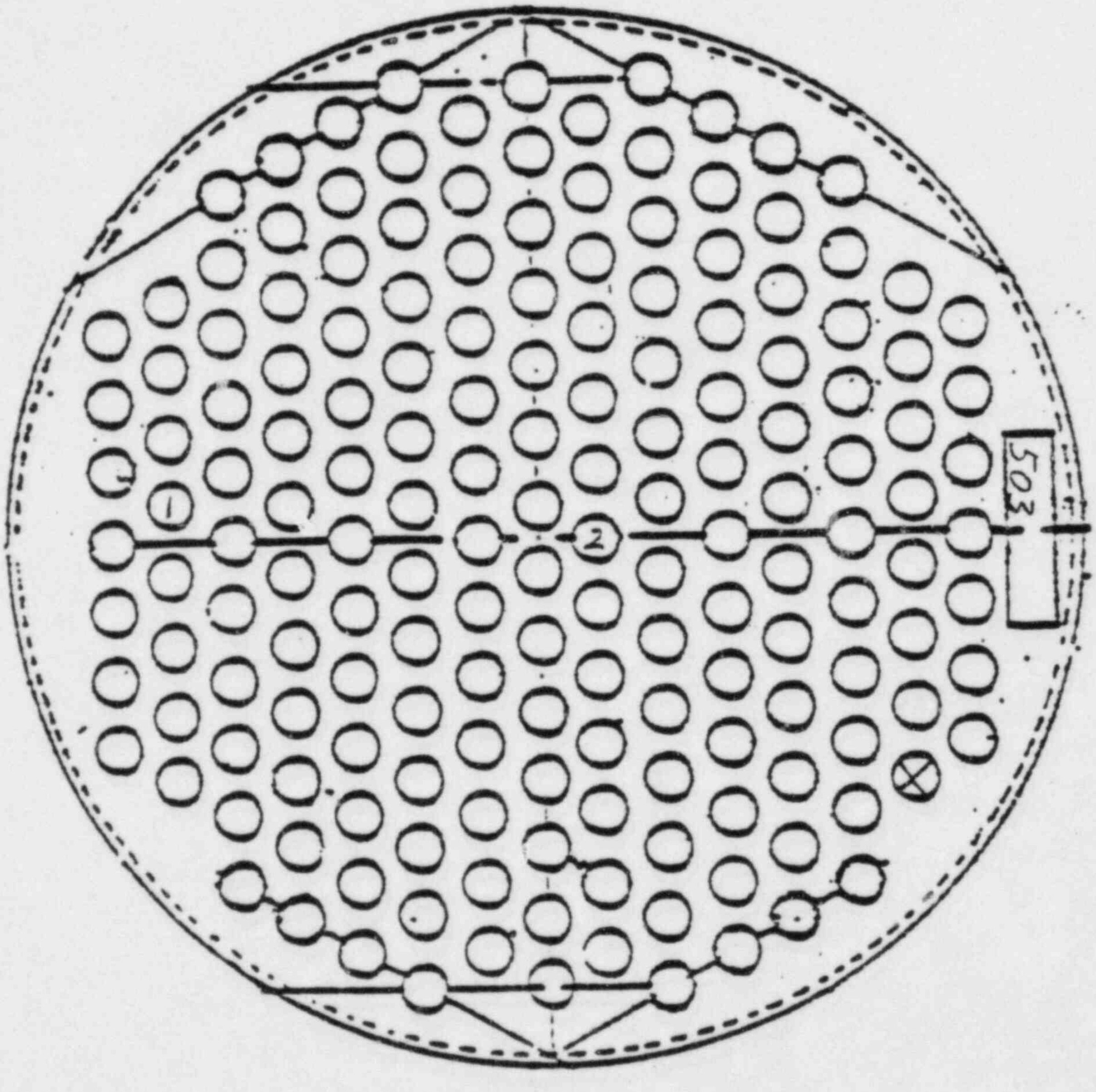


X = MISSING

= RAISED

FACE IV - V

TENDON # BO-L4

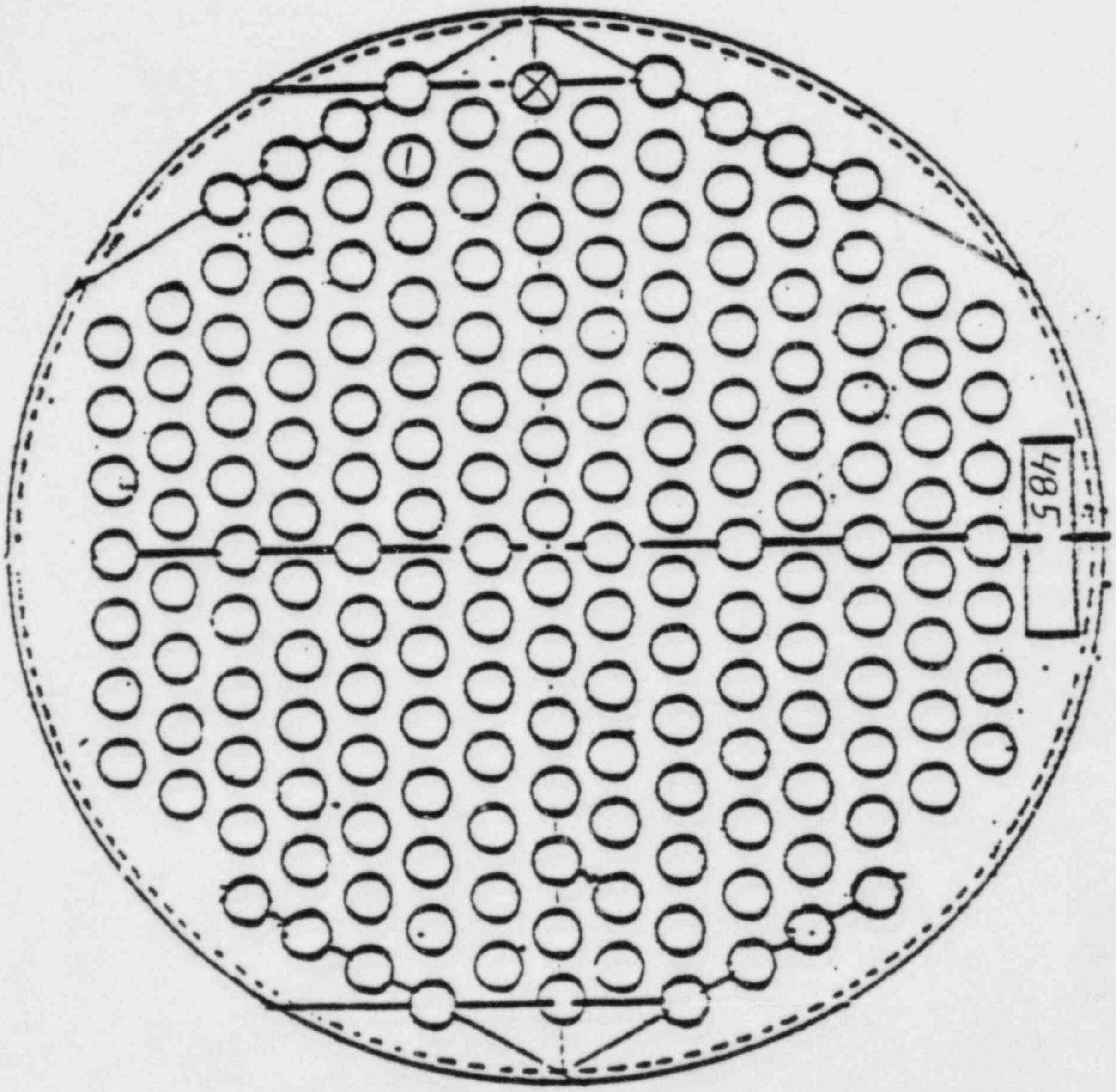


X = MISSING

= RAISED

FACE III - IV

TENDON # BO^L M3

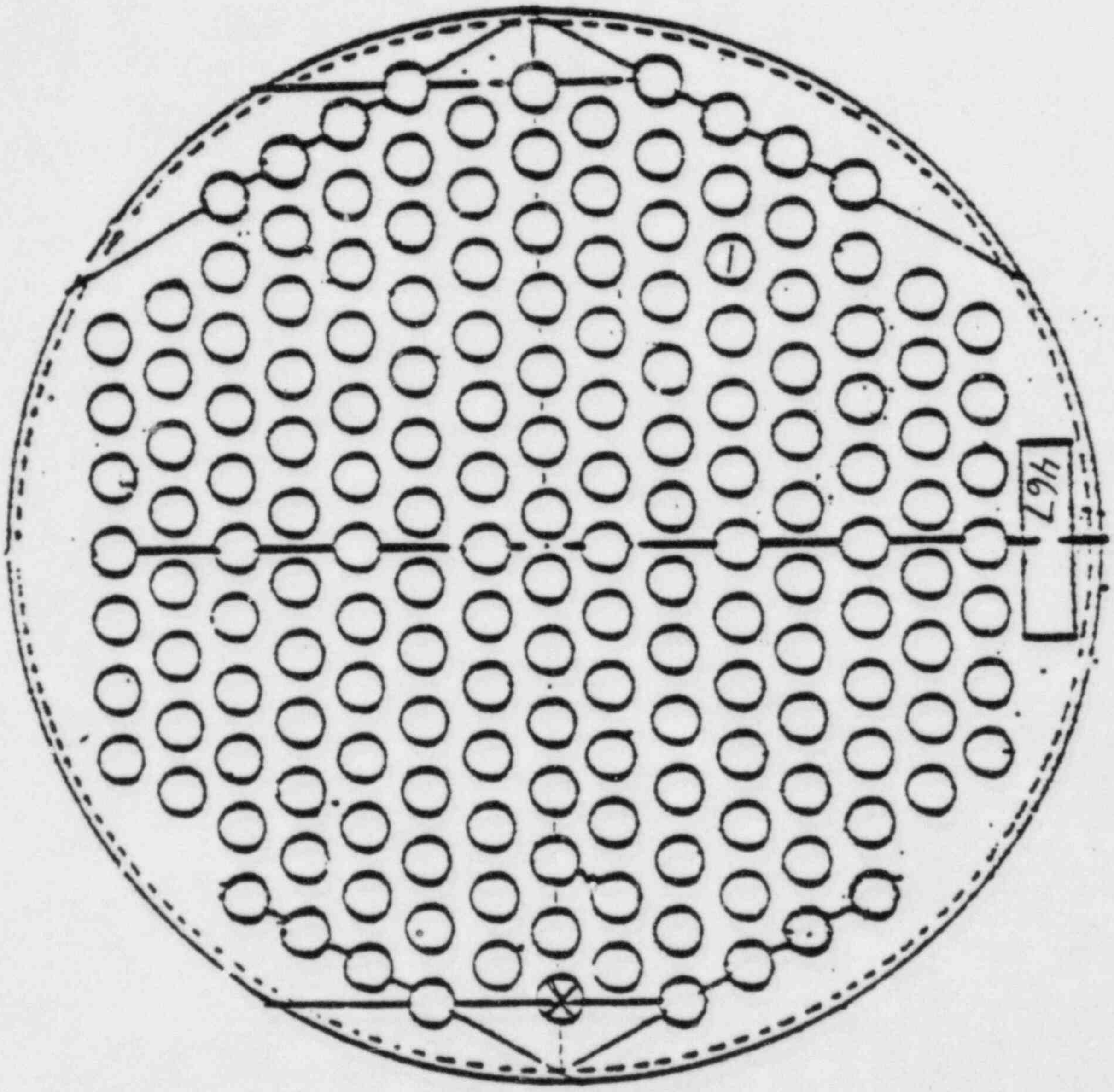


X = MISSING

= RAISED

FACE III - IV

TENDON # $BO^{R}M4$

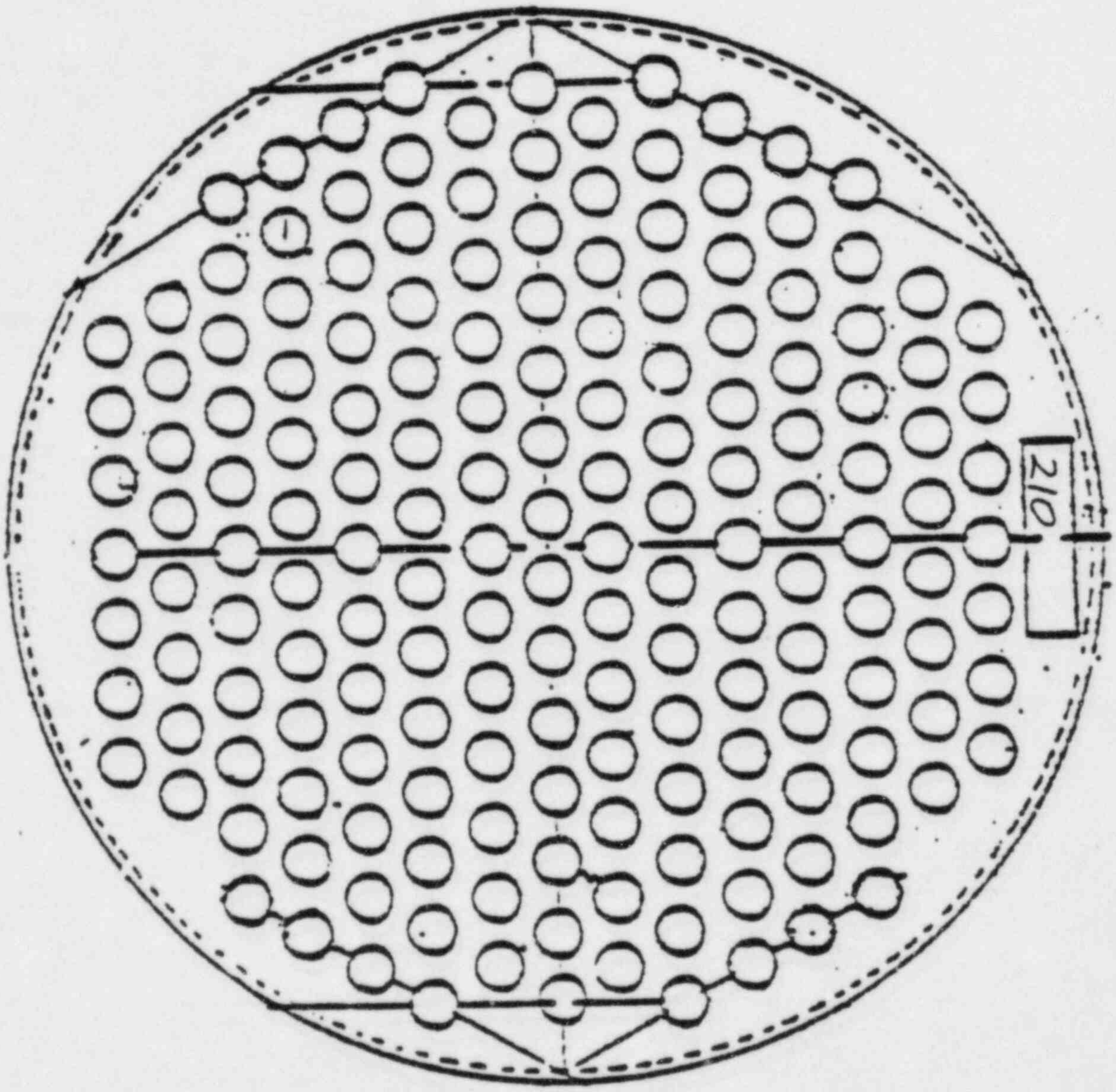


X = MISSING

= RAISED

FACE III - IV

TENDON # 60' M4

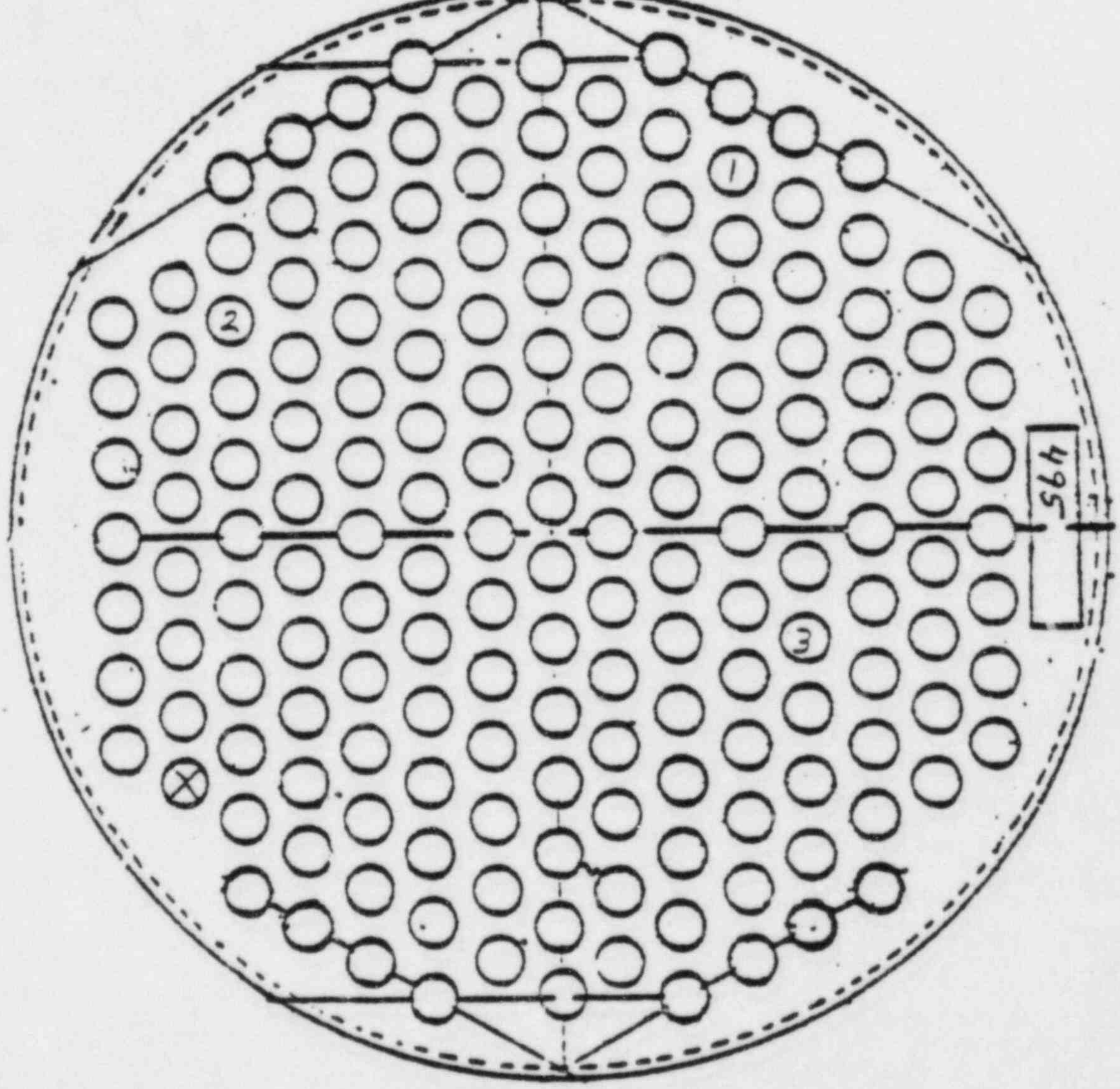


X = MISSING

= RAISED

FACE V - VI

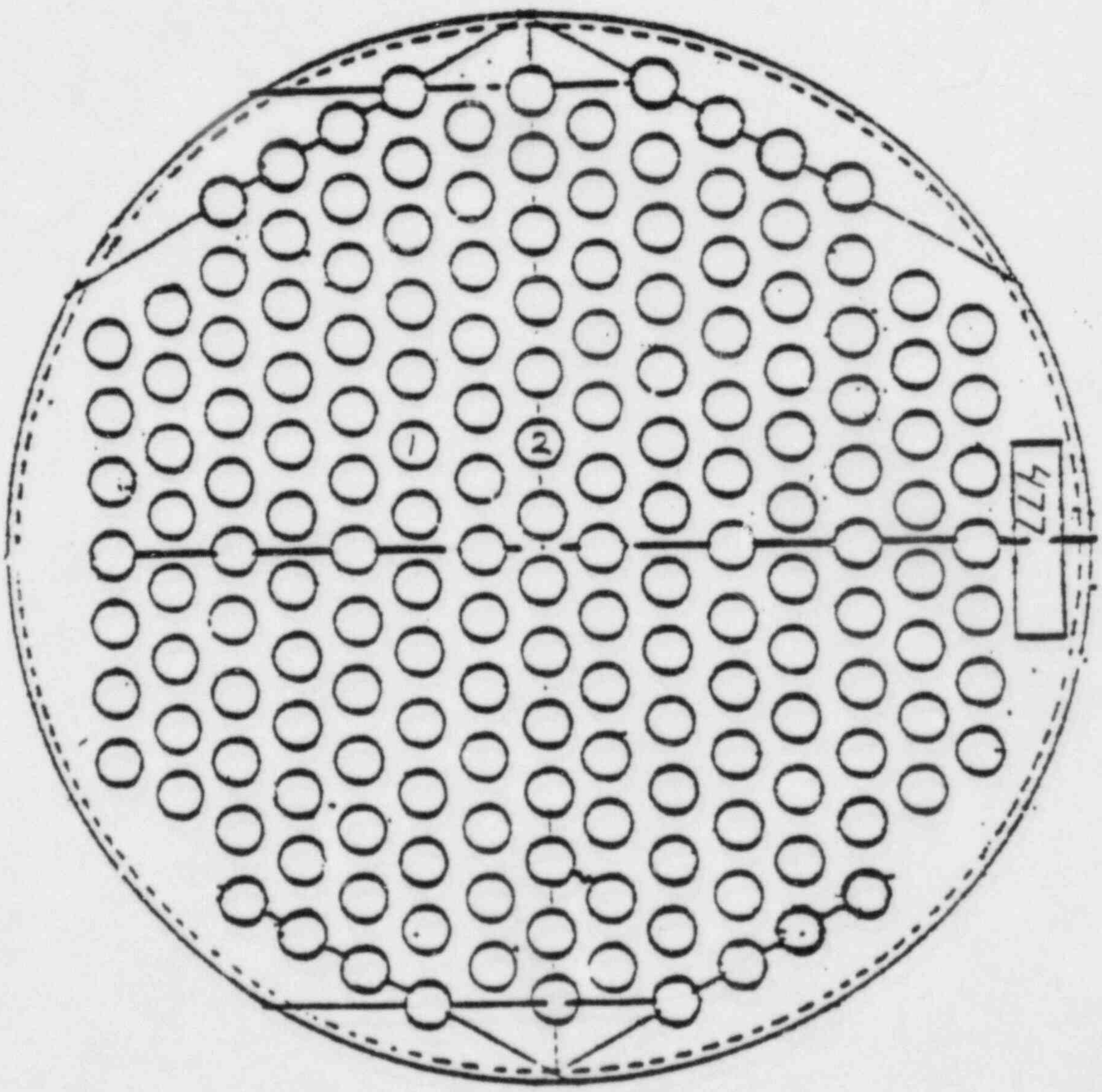
TENDON # CO 2.5



X = MISSING

= RAISED

TENDON # CO1.1



X = MISSING
# = RAISED