SUMMARY OF EXISTING AND PLANNED WORK FOR ACTIVATION VERIFICATION

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Work Performed by: [signature] 4/12/91
Date

Approved by: [signature] 4/12/91
Date

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I. INTRODUCTION

Although there are many potential sources contributing to the uncertainty of the results from any activation analysis, the two most important sources are the accuracy of the thermal neutron flux predictions (the majority of all activation reactions occur at the thermal flux level) and the accuracy of assumptions used for material composition, including any trace elements. PSC has developed an action plan to assess the accuracy and sensitivity of these parameters and the impact to the overall activation analysis results. This action plan, designed to validate the neutron flux and verify the material composition assumptions, will provide additional confidence that the activation analyses results are very reasonable in terms of component activity and resulting dose rates. The efforts are divided into two sections: 1) the verification of the neutron flux predictions through comparison of predicted activities and measurements taken from activated samples of known composition, and 2) verification of the trace element assumptions used for the PCRV concrete and the sensitivity of the trace element abundances on activity levels.

II. NEUTRON FLUX VERIFICATION

PSC has removed wire and Charpy specimens from the PCRV top head which were used to verify thermal neutron flux predictions from the ANISN (Reference 1) calculations and to assess the conservatisms of cobalt impurity assumptions used in carbon steel. At the suggestion of the NRC, PCRV tendon wires have also been removed from one vertical PCRV tendon (located 8" inches beyond predicted concrete removal depth), analyzed, and the results compared to analytical activity predictions (preliminary results provided).

A. Wire Specimens

The data available to validate the neutron flux came from the three wire specimens, located in the top head directly above the core, adjacent to the PCRV liner (See Figures 1 and 2). The wire specimens were originally designed as radiation monitors to be used in conjunction with the Charpy specimens which were to be used to monitor neutron irradiation effects on the liner material.

The wires were removed from the top head and were radiochemically analyzed for their specific isotopic activities. The results of the radiochemical analysis were compared to the analytical predictions from the 1-D neutron flux and activation calculations (Reference 2) and are summarized below.

One wire, composed of 99.5% aluminum and 0.5% cobalt, was judged to provide the best data for validating the thermal neutron flux. The

Co-60 isotope, produced from the thermal reaction of Co-59 + n -- Co-60, was selected for comparison since its cobalt composition was known with accuracy. The radiochemical analysis resulted in an average Co-60 specific activity of 14.5 microCi/gram. The 1-D ANISN/REBATE (Reference 3) calculations predicted a Co-60 specific activity of 14.0 microCi/gram. The comparison between the experimental data and analytical predictions is excellent, indicating that the estimates of the thermal flux in the top head is reasonable. Similar results are expected for the thermal neutron flux predictions, at the same distance from the core, in the radial direction since the same analytical methods and assumptions were used to generate the radial neutron flux. Better results may also be expected due to the homogeneity (less streaming paths, simple geometry) of materials in the radial direction.

The two remaining wires were used for comparing the fast neutron flux. The isotope Mn-54, produced from the fast reaction Fe-54(n,p)Mn-54, was used as the comparison isotope. The two wires were composed of: 1) 99.55% Vanadium + 0.45% Fe (88% enriched Fe-54) and 2) 100% natural Fe. Trace element compositions for elements such as cobalt and tantalum were not known, although their presence was determined during the radiochemical analysis. The radiochemical analysis of the two wires resulted in a Mn-54 specific activity of 3.43E-02 microCi/gram and 2.68E-03 microCi/gram, respectively. The 1-D ANISN/REBATE calculations predicted a specific activity for wires 1 and 2 of 1.81E-02 microCi/gram and 5.50E-04 micro Ci/gram, respectively. Although the predicted versus the actual results were not as close as for the thermal flux case (varying from a factor of 2 to 5 lower), the results are reasonable with consideration of the possible variables involved:

1) The fast flux varies more rapidly as a function of position than the thermal flux and the precise location of the specimens (within the holding tray) was not known.

2) The effects of fast flux neutron streaming in the core/reflector are not easily determined in a 1-D analysis and can therefore introduce more error than for the more isotropic thermal flux.

3) Any error in the assumed material composition would affect the analytical predictions.

It should also be noted, as mentioned previously, that the majority of all activation reactions occur at the thermal flux level; the contribution of the fast flux toward overall activation is minimal.

B. Charpy Specimens

In addition to the wire samples, carbon steel Charpy V-notch specimens, from the same top head location as the wires, were analyzed using gamma spectroscopy. The exact composition (trace

elements) of the specimens was not known, and could not be used to judge the accuracy of the neutron flux, but does provide additional evidence that the flux level is reasonable. Additionally, the experimental and analytical predictions were compared to help judge the conservatisms of trace element assumptions used in the activation analysis. The trace composition of cobalt in carbon steels in the activation analysis was assumed to be approximately 200 ppm. This is almost twice the average level found in the rebar and vessel steel samples surveyed in NUREG/CR-3474 (Reference 4). The average Co-60 specific activity measured in the Charpy specimens was 2.48E-02 microCi/gram and the analytical predictions resulted in a value of 5.59E-02 microCi/gram, which, as expected, is almost twice as high as the measured. Although the sample could not be used to judge the accuracy of the thermal neutron flux, the results do provide evidence that the flux predictions are reasonable and the the assumptions of the cobalt levels are conservative.

C. PCRV Tendon Wire Samples

The activation analysis (Reference 5) predicts that at five years after shutdown, approximately 24" of concrete would require removal from the PCRV sidewalls to achieve a dose rate of 3.4 microR/hr. The 24" depth is based on the assumption that the dose rate in the PCRV would be due to contributions from the top head, core support floor and sidewalls. The top head and core support floor will be removed during decommissioning, leaving only the PCRV sidewalls contributing the dose rate inside the PCRV. In this case, a dose rate of 5 microR/hr is predicted to be achieved when approximately 23" of concrete is removed (Note: Calculated dose rates are at a distance within 2" from the concrete surface). In order to assess the accuracy of this dose rate prediction, the accuracy of the neutron flux solution was determined through comparison of predicted versus actual specific activities of the tendon wires.

The closest set of vertical tendons to the inside of the PCRV lie at a distance of 32" from the inside of the PCRV liner (31.25" concrete depth) (See Figure 3). Wires were selected from a tendon which was located radially next to region 22, a high powered region during Cycle 4 (See Figure 2).

Due to the hexagonal geometry of the fuel elements, the radius of the active core varies from approximately 275 cm to 305 cm. Therefore, actual activities levels may vary somewhat in the azimuthal direction. The location of the selected tendon corresponds to a maximum active fuel radius, i.e., where the tendon wires are closest to the active fuel. The activity in the selected tendon wires is considered to be a maximum activity in the azimuthal direction.

The selected tendon is contained in a 4.28" I.D. carbon steel tube and contains 169, 1/4" diameter, carbon steel wires (Figure 4). The tendon diameter is approximately 3 1/2 inches. Six wires have been

pulled at equidistant positions around the circumference of the tendon. The tendon wires spiral down through the tendon tube. Therefore, selecting six circumferential wires provided confidence that at least one wire would be located closest to the core (having the highest activity).

Four test sample segments, each 12" in length, were selected from each wire. Each test segment was divided into four 3" segments for use in independent verification. The sample locations correspond to elevations of: 1) the top fuel block, 2) slightly above core midplane (location of highest axial peaking factor during operation), 3) bottom fuel block and 4) at the bottom of the core support floor (CSF) (See Figure 1). The sample segments at different axial locations provide axial profile activation information. The sample segment below the CSF was intended to provide verification for the assumption that there is negligible activation of the concrete below the core support floor.

In addition to the test samples, an unirradiated control sample was taken from the bottom of each wire. The control samples will be analyzed for the exact composition of the wires. The exact isotopic composition of the wire must be known to make an accurate assessment of the flux level solutions at the tendon location.

Each test/control sample and remaining wire segment has been properly labeled to preserve its axial location and orientation. Remaining segments have been archived. The test samples have been examined in the FSV radiochemistry lab using gamma spectroscopy to determine the activity (if it was detectable) in the samples.

The predicted specific activity of the tendon wires from the activation analysis is extremely low, in the picoCi/g range for both Co-60 and Mn-54 (the only isotopes that were anticipated to be detectable). The fact that the neutron population in the area of the tendons was low (very low flux) makes the analytical prediction of the neutron flux in that location difficult.

Preliminary results from the FSV radiochemistry lab for the gamma spectroscopy exam of the tendon wire samples are available. Duplicate samples are in the process of being examined for independent verification. The details of the specific activities of the wire samples will be provided after the independent verification has been performed. This process should take approximately 2 - 3 months since an outside lab will be contracted to perform the verification work.

The preliminary results of the relative activity of the samples vary, as expected, with core axial location. The variation follows the axial profile of the reactor core during operation, also an expected result. The highest activity occurred at sample location 2, slightly above midplane. Wires at sample locations 1 and 3

showed less activity. No activity was detected at sample location 4, which was expected since activation of the concrete below the core support floor is not anticipated.

One 3" segment of the highest activity wire at locations 1 - 3 was quantitatively examined. The results of the quantitative analysis indicate that the thermal flux at the tendon location was under predicted by the activation analysis by a factor of 2.5 to 3. This agreement is considered to be good in light of the distance from the core, and the number of mean free paths (about 12) traveled by the neutrons through the concrete before reaching the tendon wire.

The under prediction of the thermal flux may also be, in part, due to the azimuthal location of the tendon wires. The location of the wires, as previously discussed, corresponds to a maximum active fuel radius of approximately 305 cm. The activation analysis assumed an average active core radius of 297 cm. Therefore, the tendon wires would be closer to the active core than predicted and would have seen a slightly higher thermal flux.

In comparison with similar activation data in NUREG/CR-5343 (Reference 6), the accuracy of the thermal flux prediction is reasonable. A comparison of the predicted and actual measured activities found in NUREG/CR-5343 resulted in agreement between 10% and a factor of 2. However, the predictions and actual data measurements were made for areas near the reactor core, where the activation flux levels were much higher (and much better characterized) than in the area of the PCRV tendon wires which are relatively far away from the active core. The Charpy/wire specimens taken from the PCRV provide the same degree of accuracy for those areas closer to the core.

In one case in NUREG/CR-5343, the predictions were made for in-core fuel assemblies and the agreement was quite good (except for end fittings where the geometry was complex). The activity of the samples was in the Ci/g range, 12 orders of magnitude higher than the specific activity predicted for the tendon wires. In a second case, for the Gundremigen reactor, samples of the vessel steel were analyzed. The actual and predicted specific activities compared within a factor of 2, which was considered good by NUREG/CR-5343 since the neutron flux varied by over two orders of magnitude from the reactor pressure vessel wall. In comparison, the neutron flux in the FSV PCRV drops three orders of magnitude from the PCRV liner to the tendon wire location, and ten orders of magnitude from the reactor core/reflector interface to the tendon.

It was concluded in NUREG/CR-5343 that very good agreement can be obtained near fueled regions, as evidenced by the samples provided from the fuel assemblies and the pressure vessel steel. PSC's Charpy/wire specimen data also confirm this conclusion. Predictions further away from the core become more difficult. No data from NUREG/CR-5343 was available at large distances from the reactor

core, but the preliminary results from the tendon wire analysis appear to be reasonable, based on the accuracy of near core predictions in NUREG/CR-5343.

As indicated above, the predictions nearer the core should be more accurate. The neutron flux at the 24" concrete removal depth is predicted to be higher by about an order of magnitude than the flux at the tendon wire location. It is anticipated that the agreement between the actual and predicted flux at the location where 24" of concrete would be removed should be more accurate.

If the flux (at a depth of 23" of concrete removed) were under predicted by a factor of 2.5 to 3, the resulting dose rate (5 years after shutdown) would be approximately 12 microR/hr, compared to 5 microR/hr. This increased dose rate would require approximately 4" of additional concrete to be removed to obtain a dose rate in the 5 microR/hr range.

The activation analysis modeled the PCRV concrete and rebar as a homogeneous mixture. In the actual rebar configuration, two sets of rebar lay just outside the PCRV liner and the remainder of the rebar lays at least 1.5′ beyond the inside ring of tendons (See Figures 3 and 5). The two inner sets of rebar will be removed during decommissioning and the outer sets of rebar will not be activated. Therefore, the assumption of a homogeneous mixture at a depth of 23" of concrete is conservative.

A sensitivity study of the contribution of the rebar to the overall dose rate was performed to assess this conservatism. The rebar number densities were removed from the homogeneous mixture and the activation analysis was rerun. The resulting predicted dose rates at 5 years after shutdown, with 20" and 22" of concrete removed, are 6.15 microR/hr and 3.14 microR/hr, respectively. Therefore, the actual predicted removal depth would be closer to 21" rather that 23" to achieve a dose rate in the 5 microR/hr range.

III. MATERIAL COMPOSITION VERIFICATION

Analytical sensitivity studies have been performed for the homogeneous rebar/concrete mixture to assess the effect of trace element abundances on the amount of concrete required for removal in the radial direction. Surface concrete samples will be taken to help determine the actual trace element abundances in the PCRV concrete.

A. Sensitivity Studies

The sensitivity of the trace element concentrations to the amount of concrete required for removal in the radial direction was investigated using the available trace element data in NUREG/CR-3474. The activation analysis assumed that the trace element constituents in concrete were at the average trace element

impurity level found in samples from the bioshield concrete of twelve different nuclear plants.

In order to assess the effect of varying the trace element concentrations on the amount of concrete requiring removal, a worst case scenario was considered. The elements whose activation products are most important to dose rate were assumed to be at the maximum values given in NUREG/CR-3474 for both the rebar and the concrete. The exception to this was the cobalt level in the rebar, which was conservatively set at 200 ppm, a value higher than the maximum value given in NUREG/CR-3474. The elements considered to be most important, in the short and/or long term, were cobalt (Co-60), niobium (Nb-94), silver (Ag-108) and europium (Eu-152), where the isotope in parenthesis indicates the isotope of concern. The increase in number densities of the above elements varied from a factor of 1.5 to 2.2. The results of the study are as follows:

Dose rate 5 years after shutdown (microR/hr):

	Max Trace Elements	Previous Calculation Trace Elements
24" Concrete Removed	6.0	3.4
26" Concrete Removed	3.2	n/a

Dose rate 60 years after shutdown (microR/hr):

	Max Trace Elements	Previous Calculation Trace Elements
8" Concrete Removed	7.4	3.5
10" Concrete Removed	3.7	1.7

The above results indicate that the effect of using the maximum value for all trace elements is an increase in the required depth of concrete to be removed of approximately 2" in both the long and short term. In the short term, the dominant gamma emitting isotope is Co-60 from both the rebar and concrete. The increase in the cobalt number density was approximately 1.66 and the corresponding increase in dose rate at 5 years after shutdown was 1.76. In the long term Eu-152 is the dominant isotope. The increase in the europium number density was 2.2 and the corresponding increase in dose rate at 60 years after shutdown is 2.1.

These results indicate that the increase in the required depth of concrete to be removed is related to the increase in the levels of

cobalt (short term) and europium (long term). It is unlikely that the cobalt and europium concentrations in PCRV concrete are widely different than those sampled in NUREG/CR-3474. In that respect, the depth of concrete requiring removal would be bounded by an increase of not more than 2" in a worst case scenario for trace element concentrations.

B. Concrete Samples

Surface samples of the PCRV radial concrete will be taken in six locations and, in combination with the sensitivity study discussed above, will aid in eliminating any concern that the trace element concentration assumptions in the activation analysis could be significantly non-conservative. The samples taken will be representative of the concrete mixes used in the PCRV sidewalls adjacent to the active core. Plans for this work are currently in progress, and it is anticipated that the process of taking samples, performing trace element analysis, and final review can be be completed within 3 to 4 months.

The sample size required for a trace element analysis is only a few grams, but large enough samples will be taken to ensure a good mix between the aggregate and other concrete constituents in the sample. It is recognized that the abundancy of trace elements in the concrete can vary and the results of a few samples may not ensure that all mixes of concrete would have the same trace element abundances as the samples. We believe, however, that it is highly unlikely that the abundances would vary significantly from the sample data. Additionally, it is unlikely that the abundances would be dramatically different from those listed in NUREG/CR-3474. To this end it is reasonable to assume that the results of the surface samples, when combined with the sensitivity analysis and NUREG/CR-3474 data, will provide a high level of confidence in the activation analysis results.

IV. CONCLUSIONS

The indications from the Charpy/wire specimens data, preliminary tendon wire data and sensitivity studies (and with future concrete samples) provide strong evidence that the predictions from the activation analysis are reasonable. In a worst case scenario, both the thermal flux predictions could be low and the trace elements abundances could be under predicted. An additional 2" of concrete would need to be removed due to the under prediction of the trace elements and approximately 4" of additional concrete would need to be removed if the thermal flux were underpredicted. The total additional amount of concrete requiring removal, in a worst case scenario, would then be approximately 6". To achieve a dose rate of 5 microR/hr the total removal depth of the concrete would increase from 21" to 27".

Based upon the information provided in this document: preliminary benchmark data, sensitivity studies and comparison with results from NUREG/CR-5343, PSC believes that the calculational methods and material composition assumptions used have provided reliable estimates of the activation products within the PCRV.

V. References

1. Engle, W.W., "ANISN-P - Multigroup One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," Radiation Shielding Information Center, Oak Ridge National Laboratory,] Oak Ridge, Tennessee.

2. PSC Internal Memo, NDS-91-0066, "Comparison of Upper PCRV Wire Specimen and Charpy Bar Activity Measurements to Analytical Predictions," February 8, 1991.

4. NUREG/CR-3474, "Long Lived Activation Products in Reactor Materials," August, 1984.

3. Ebasco Services Incorporated, "REBATE - A Computer Program for Calculation of Decay Gamma Source Strength For One or Two Dimensional Gamma Transport Analysis," Ebasco Services Incorporated, New York, New York.

5. EE-DEC-0010, "Fort St. Vrain Activation Analysis," October, 1990.

6. NUREG/CR-5343, "Radionuclide Characterization of Reactor Decommissioning Waste and Spent Fuel Assembly Hardware," January, 1991.

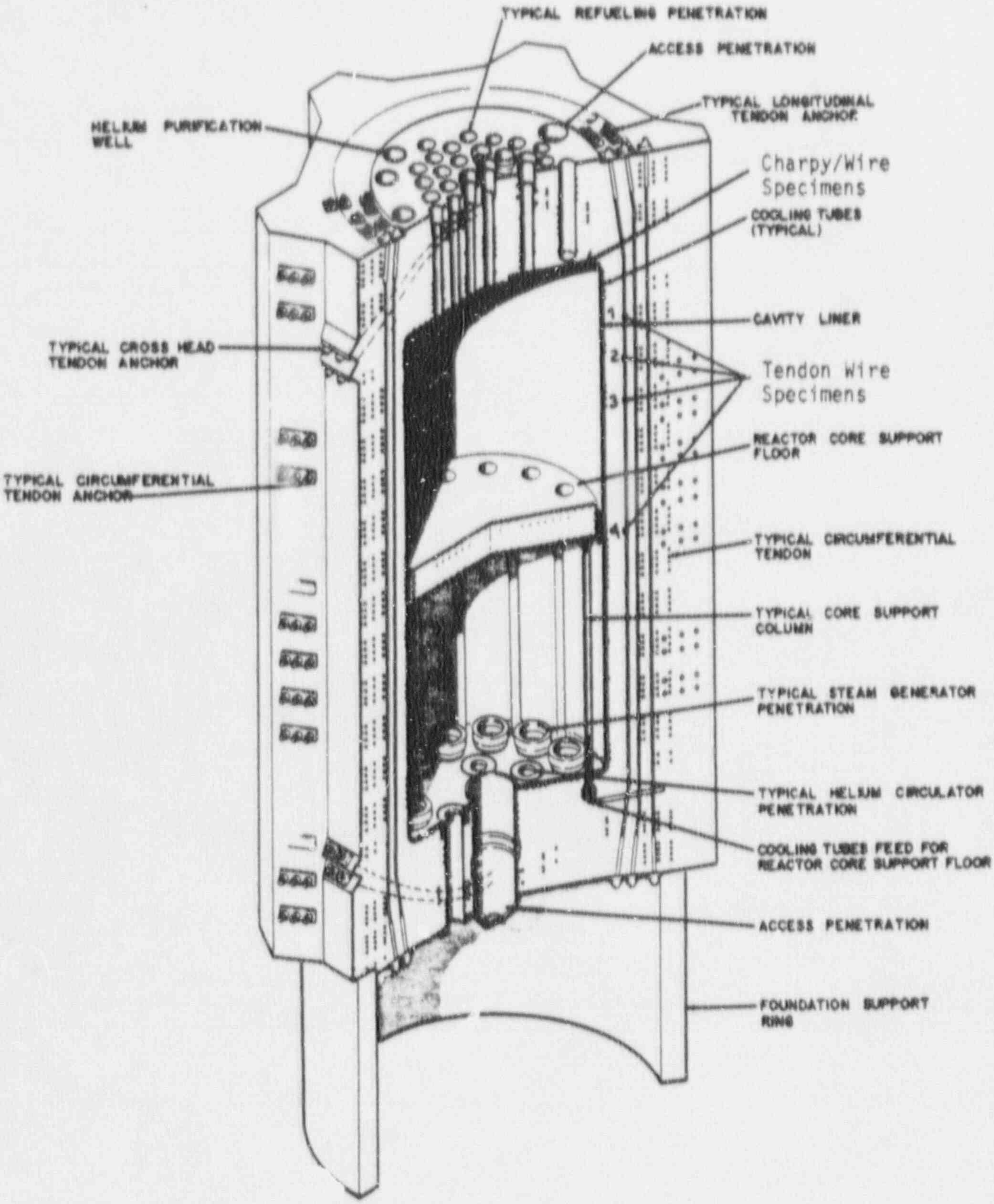


Figure 1

Test Specimen Locations

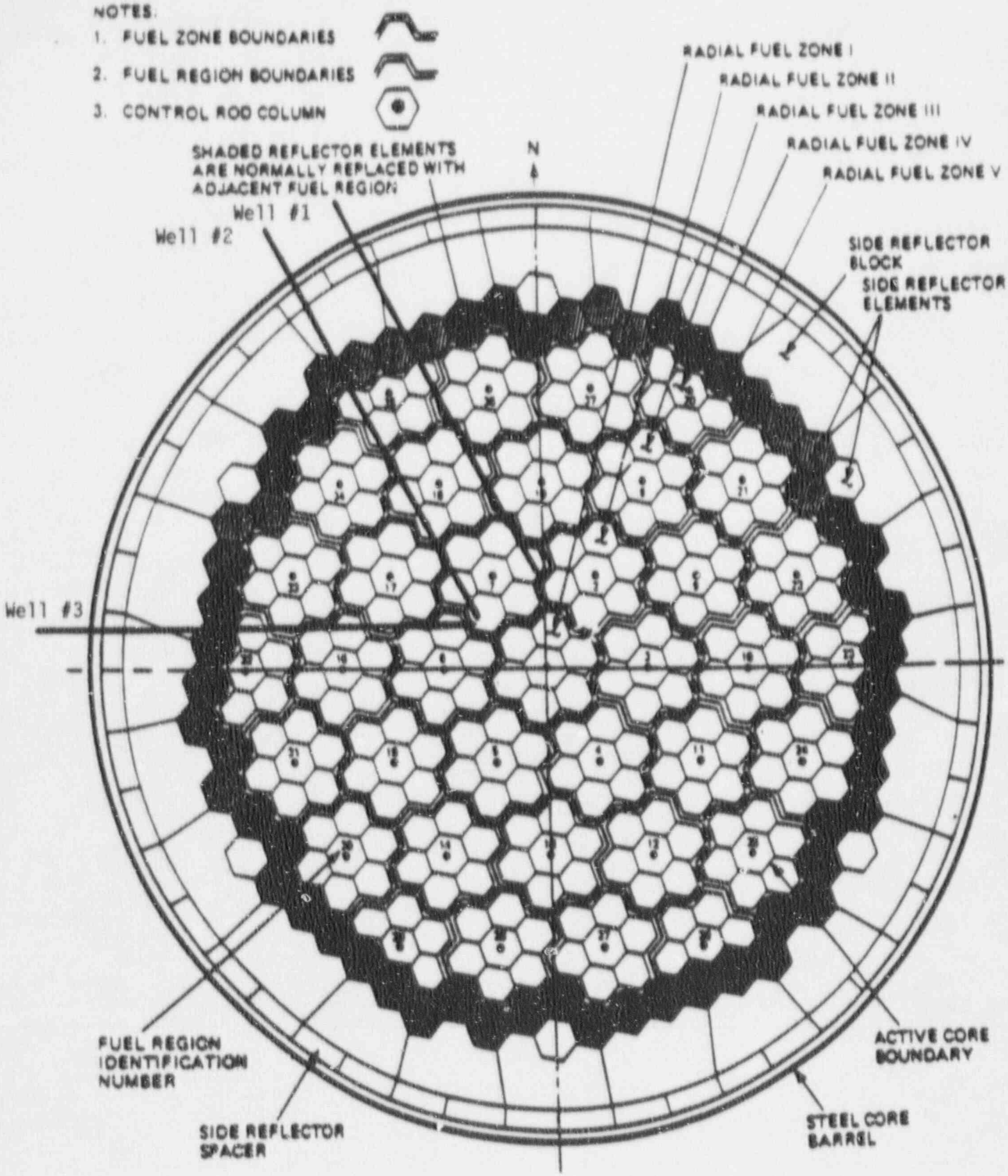


Figure 2

Core Map With
Charpy/Wire Well Locations

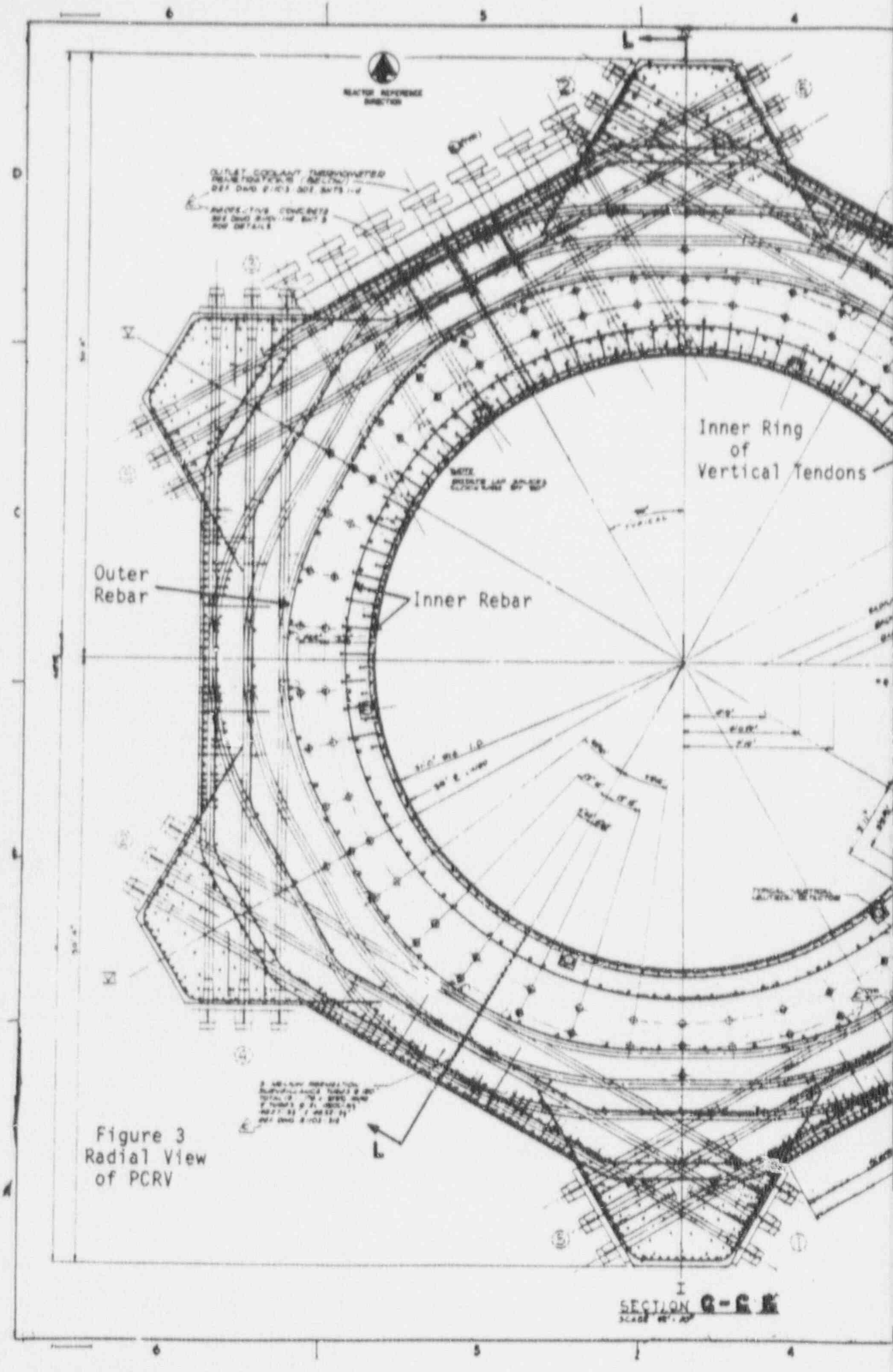
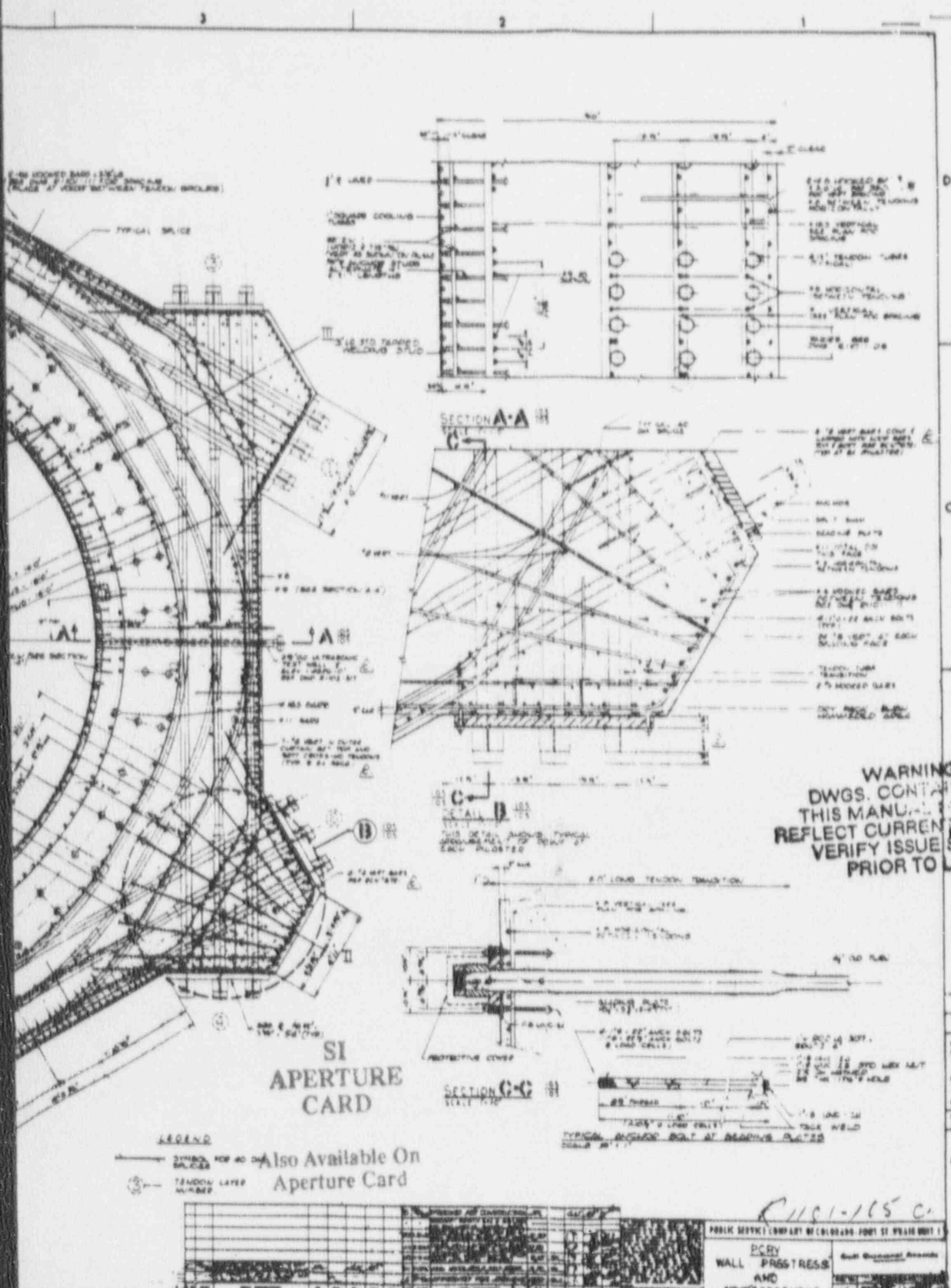


Figure 3
Radial View
of PCRV



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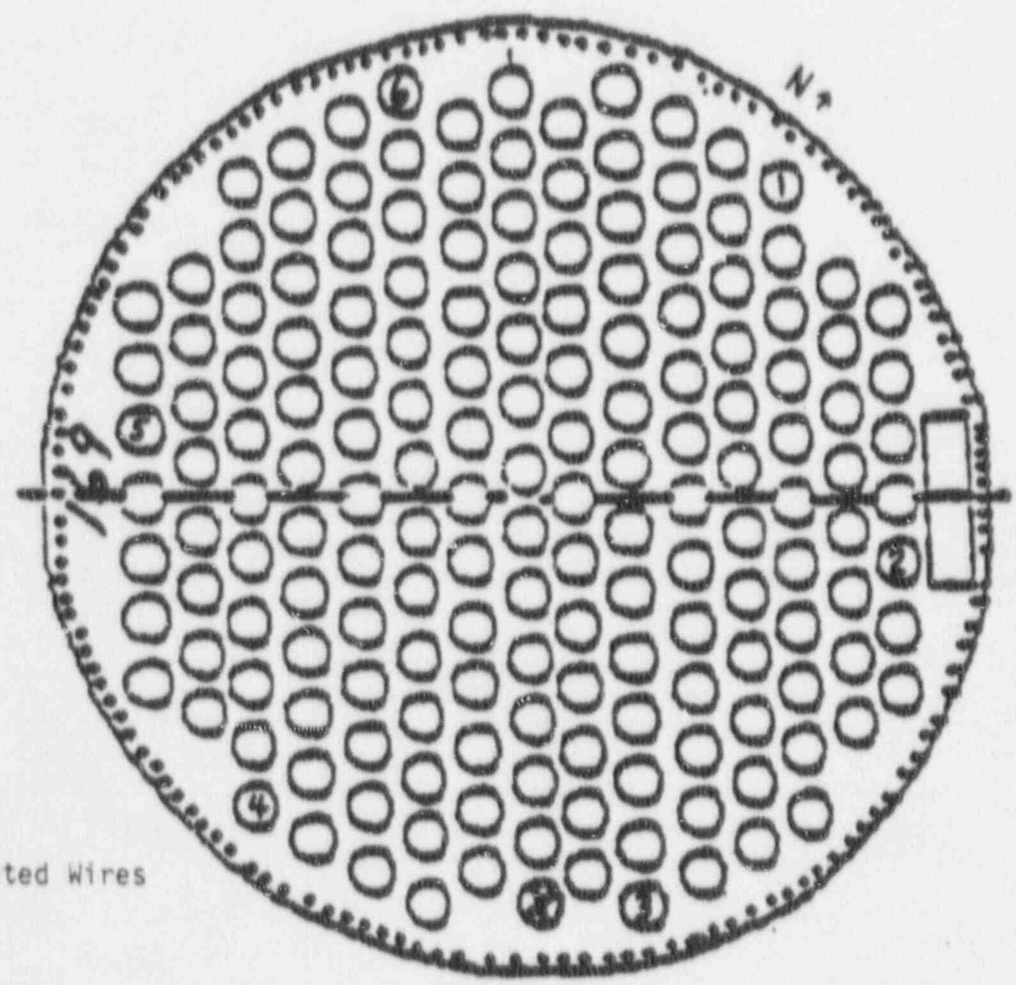
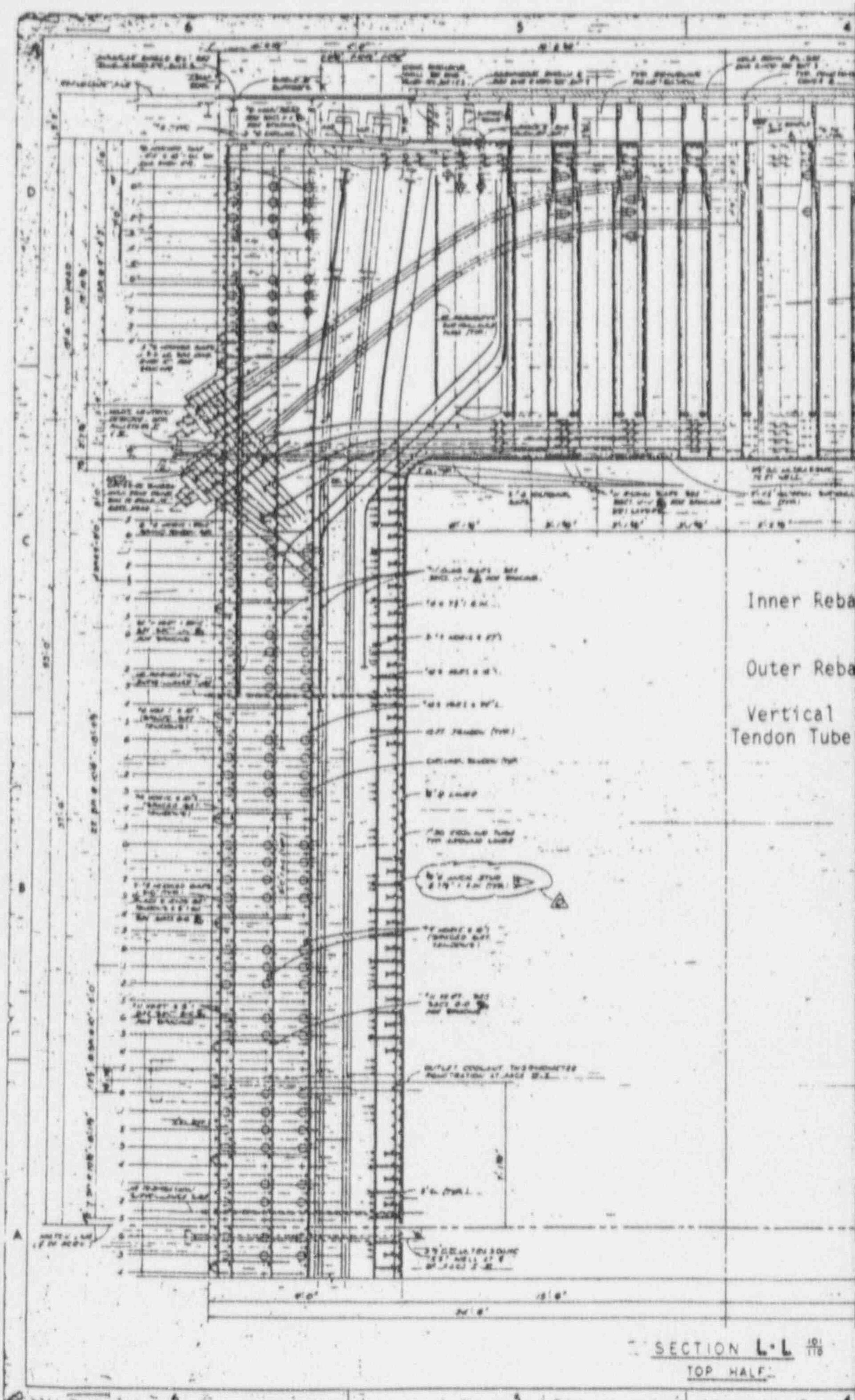


(6) Selected Wires

(X) Empty Hole

Figure 4
Selected Tendon
Wire Locations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Outer Reba
Vertical
Tendon Tube
SECTION L-L
TOP HALF

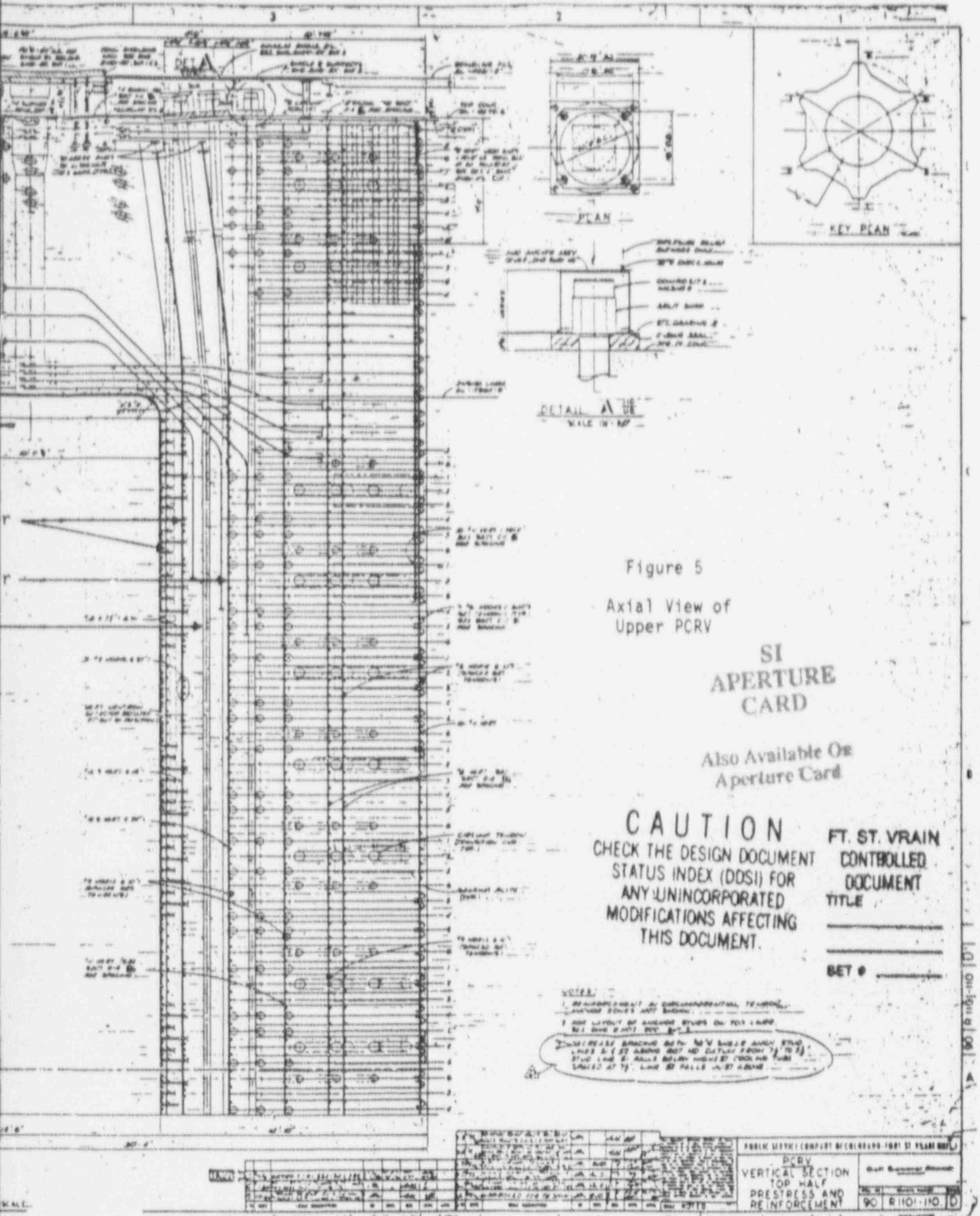

Figure 5

Axial View of Upper PCRV

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Appendix A
Tritium Migration in the PCRV Concrete

Tritium Migration in the PCRV Concrete

Tritium activity in the concrete is not a factor in determining how much concrete must be removed to achieve the release criteria of 5micro R/hr. Tritium is a beta emitter, and the 5 microR/hr criteria is based on gamma emitting isotopes. However, the total amount of tritium in the remaining concrete must be considered in pathways analyses performed for site release. The release criteria for pathways analysis is proposed to be 10 mrem/yr.

Tritium generation in the concrete is due to the thermal neutron reaction with Lithium or other impurities in the concrete. In discussions with the British (P. Woollam, Nuclear Electric), tritium does not diffuse from the primary coolant through the PCRV liner and into the concrete. The initial predicted tritium profile tends to decrease exponentially from the inside of the PCRV, following the thermal flux profile directly. This is consistent with the initial predictions made by the British. Over time, the tritium will diffuse through the concrete, flattening the profile. From British experience, it may take up to 130 years for the profile to become flat. The total amount of tritium in the concrete will remain constant during this time, except for decay and a small amount of tritium that will diffuse into the air.

Assuming no tritium migration, the specific activity in the first 6" of concrete at five years after shutdown predicted from the activation analysis is approximately 5.0E-03 microCi/gram. The actual specific activity in the first 6" would be somewhat less due to the tritium migration.

The tritium activity, regardless of its final profile, is not anticipated to be a dominant dose contributor in a pathway analysis for FSV. If a conservative specific activity of 5.0E-03 microCi/gram is assumed for the concrete, the total effective dose equivalent (TEDE) for the expected tritium activity would be less than 0.01 mrem/yr (1). This value is only a small fraction of the 10 mrem/yr proposed release criteria. Based on the low contribution of the expected tritium activity to a total effective dose, it is reasonable to assume that the removal of additional concrete will not be required to meet the proposed release criteria for a pathway analysis.

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(1) Based on the unit equivalent TEDE for tritium from Table 3.1, from NUREG/CR-5512, "Residual Radioactive Contamination From Decommissioning," January, 1990 (for comment).