UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION II
101 MARIETTA STREET, N.W.
ATLANTA, GEORGIA 30323

Report Nos.: 50-325/88-17 and 50-324/88-17

Licensee: Carolina Power and Light Company
P. O. Box 1551
Raleigh, NC 27602

Docket Nos.: 50-325 and 50-324 License Nos.: DPR-71 and DPR-62

Facility Name: Brunswick 1 and 2

Inspection Conducted: April 8, 1988

Inspectors: B. R. Crowley 4/25/88
B. R. Crowley Date Signed

W. J. Ross 4/27/88
W. J. Ross Date Signed

Approved by: E. H. Girard for J. Blake 4/28/88
J. J. Blake, Section Chief Date Signed
Engineering Branch
Division of Reactor Safety

John B. Kahle 4/27/88
J. B. Kahle, Section Chief Date Signed
Emergency Preparedness and Radiological/
Protection Branch
Division of Radiation Safety and Safeguards

SUMMARY

Scope: This routine, announced inspection at the licensee's laboratory in New Hill, North Carolina, concerned the evalution of cracks in the Insert and Withdraw lines of Unit 2 Control Rod Drives.

Results: No violations or deviations were identified.

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REPORT DETAILS

1. Persons Contacted

Licensee Employees

*W. Biggs, Principal Engineer, Site Engineering Support
*R. Block, Corporate Project Engineer, Metallurgy
*R. Hanford, Principal Engineer, Metallurgy
*C. Osman, Principal NDE Specialist - Level III
*D. Sullivan, Supervisor, Corporate Metallurgy Unit
*J. Wood, Senior Engineer, Corporate Metallurgy Unit

Other Organizations

T. Giannuzzi, Structural Engineering Integrity Associates

*Attended Exit Interview

2. Exit Interview

The inspection scope and findings were summarized on April 8, 1988, with those persons listed in paragraph 1 above. The licensee did not identify as proprietary any of the material provided to or reviewed by the inspectors during this inspection.

3. Licensee Action on Previous Enforcement Matters

This subject was not addressed in the inspection.

4. Unresolved Items

Unresolved items were not identified during this inspection.

5. Cracking in Control Rod Drive Mechanism (CRDM) Insert and Withdrawal Piping (Unit 2)

a. Background

On March 19, 1988, while performing refueling/maintenance outage Reactor Pressure Vessels (RPV) hydrostatic test, small leaks (less than one drop per minute were found in two CRDM withdrawal lines. While preparing to repair these two lines, leaks in three additional lines (two insert and one withdrawal) were identified. The CRDM insert and withdrawal lines enter the drywell in four separate bundles at 65°, 115°, 245° and 295° azimuths. All of the above leaks were in the 245° bundle, associated with brown/black rust type deposits, and located near bends inside the drywell within six feet of the drywell wall. The defective sections of the five lines were removed and replacement piping installed. Three of the removed sections were forwarded to the licensee's lab in New Hill, North Carolina for analysis. The licensee's investigation revealed that the pinhole leaks were caused by Transgranular Stress Corrosion Cracking (TGSCC). In all cases, the cracking was associated with the brown/black deposits. The licensee expanded its inspection program to locate all discolored areas and investigate these areas for cracks.

b. On April 8, 1988, the inspectors met with licensee and contractor personnel identified in paragraph 1 at the licensee's Shearon Harris Energy and Environmental Center laboratory in New Hill to:

- observe metallurgical samples and review metallurgical analyses;
- review both the work in progress to identify the contaminant(s) (brown/black rust), and the equipment being used;
- discuss with the licensee their results to date; and
- discuss with the licensee their planned additional actions.

In addition to information obtained through previous telephone conferences and from the licensee's summary for the inspection, the following summarizes information obtained through discussions with the licensee and from examinations of the CRDM pipe segments:

(1) Status of Licensee's Investigations

At the start of the meeting, the inspectors were informed that: all CRDM piping in Unit 2 had been visually inspected for indications of corrosion; all pipe that exhibited discolorations had been visually tested with a fluorescent liquid penetrant; all pipe that exhibited cracking had been cut out and replaced; other flawed pipe had been analyzed per procedures stated in Section XI of the ASME Boiler and Pressure Vessel Code and had been determined to be acceptable for continued operation; all corrective actions had been completed; and plans were being made to restart Unit 2 on April 14, 1988. The inspectors were also given an unofficial summary of the CRDM pipe cracking investigation as of April 7, 1988. With the licensee's permission, this summary is incorporated into this Inspection Report as Attachment 1.

(2) Visual Inspection

The inspectors visually examined the three flawed pipe being tested by the licensee's materials laboratory. Discolored splotches, with and without accompanying brownish-black residues, were scattered around the pipes but usually within a foot of a bend. Most of the discolored regions on the single remaining uncut pipe appeared to be on an eight-inch span between two bends and predominantly on one side. Small (_ 1/8 inch) splotches of white paint were also scattered on the same side of the uncut pipe. The inside surface of the pipes were discolored where through-wall cracking had occurred. Small pits occurred in most of the discolored regions; however, visible longitudinal cracks were observed in both discolored and non-discolored regions.

(3) Chemical Analysis

The inspectors discussed with the licensee the chemical analysis being performed, the equipment used to perform the analyses, and plans for additional analyses. Spectra obtained by analyzing the residues from the discolored areas of the flawed pipe with a scanning electron microscope had yielded a semi-quantitative analysis of the residue. The following elements had been identified:

Major - iron, chloride, chromium, silica

Lesser - aluminum, calcium, nickel, titanium, sulfur

Attempts to establish the chemical structure of the residue by x-ray diffraction had not been successful because of insufficient amounts of solid samples.

The licensee was considering using Auger Electron Spectroscopy to analyze, in situ, the discoloring material that could not be physically separated from the base metal.

(4) Metallurgical Analysis

The inspectors reviewed the metallurgical work performed by the licensee. A number of cross sections had been taken through cracks in two of the three pipes which had been removed from the plant and furnished to the laboratory. The inspectors reviewed photomicrographs of the cracks as well as observed other cracks under a microscope. Cracks were typical TGSCC indicative of chloride stress corrosion cracking. In addition, the inspectors visually and microscopically examined corrosion indications, deposits, paint spots, and cracks on the surface of the pipes. In the vicinity of the deposits the surface was generally corroded and pitted and linear cracks were distributed randomly. The cracks were predominantly longitudinal, but in some cases, diagonal on the pipe. The longest crack identified by the licensee was approximately 2". The paint spots were small, generally less than 1/8" in diameter, and appeared to have been present before corrosion had begun, because corrosion appeared to have occurred around the paint.

(5) Inspection Activities

After the original leaks were found, the licensee implemented a special fluorescent liquid penetrant (PT) procedure to detect leaks and cracks. The penetrant turned red when reacting with a liquid thus signifying the presence of leaks or through-wall defects. If no leaks were detected, a normal PT test was completed for the presence of non-through-wall defects. Indications appeared orange under a black light. The licensee's PT procedure was revised to include this special technique, and Level II qualified PT examiners were trained on the special technique by the use of cracked CRDM piping that had been removed from the plant. After removal of the first five tubes (see Paragraph 5.a above), PT inspection was performed on a six foot section of all remaining tubes (insert and withdrawal) extending from the coupling at the drywell wall inward toward the RPV. In addition, the full length of all tubes was visually inspected for rust deposits. As a result of the inspections, short sections of 15 tubes (including the original five tubes) were cut out and replaced. Twelve were at azimuth 245° and three at azimuth 115°. In addition, five tubes were accepted with PT indications based on ASME Section XI criteria. IWB-3600 flaw stability calculations were used. Two tubes had longitudinal linear (1/2" and 3/4") indications. One had a 3/8" diagonal indication, which was treated as a circumferential indication for calculation purposes. The other two tubes had rounded indications.

(6) Additional Planned Actions

(a) Unit 2

The licensee plans to continue analyzing the deposits on the tubes to try to identify the exact compounds. In addition, oil used in plant snubbers and the insulation used near the affected tubes will be analyzed for leachable chlorides.

(b) Unit 1

The licensee plans to perform an inspection on Unit 1 piping at the next refueling outage during planned hydrostatic testing. In addition, the piping will be inspected for presence of the brownish deposits the next time the unit is in cold shutdown and an outage of sufficient length is available. The licensee's decision not to inspect Unit 1 at this time was based on the following factors:

- Expected slower crack growth rate (or possibly no crack occurrence at all) based on lower drywell temperature than in Unit 2

- Shorter time since startup than for Unit 2

The licensee also pointed out that consequences of the failures of CRDM lines had been analyzed in the FSAR (Paragraph 4.6.2).

(7) Possible Cause of Degradation

Based on discussions with the licensee and review of Attachment 1, the following points can be made relative to the cause of the pipe degradation:

- No other General Electric plant has identified degradation of CRDM pipes

- The CRDM pipe had been pickled in nitric-hydrofluoric acids prior to installation.

- The CRDM pipe were not metal clean, i.e., they were coated with a slightly oily/dusty film.

- CRDM lines are located under a grating; however, only the sections of the grating above the two pipe clusters with flaws provided ready access for personnel traffic and possible contamination due to such traffic.

- The CRDM pipes were installed with varying slopes and, thereby, different configurations for deposition of contaminants.

- Rust streaks were observed on structural beams in the area of the CRDM pipe indicating the presence of moisture in the area.

- Oil from snubbers had dripped in the area of the CRD pipe.

- This region of the plant was painted in 1975, during construction, and in 1977, during the first refueling outage. (Some paint splotches overlay corroded portions of the pipe).

- The drywell is normally inerted with nitrogen, with an allowable upper limit of four percent of oxygen.

- No apparent mechanism for concentrating chloride or sulfur species on the outer surfaces of the CRD pipe has been identified or postulated.

(8) Findings

- The licensee had visually inspected the integrity of the CRDM pipe to the degree permitted by the confines of the CRDM penetration area.

- All runs of pipe that had been determined, by visual and penetrant testing, to contain indications that could become leaks had been cut out and replaced.

- The flawed pipes had been degraded from pitting and transgranular stress corrosion cracking. These failures were probably induced by the presence of chloride ions. The source of chloride contaminants and the initiating corrosion mechanism had not been established; however, the degradation may have begun before Unit 2 became operational.

- The licensee employed state-of-the-art metallurgical and chemical technology to investigate the pipe cracking.

- The licensee's investigation and corrective actions are considered sufficient to allow the Unit to restart.

Attachment:
Licensee Investigation Summary

Unit 2 CRD Pipe Cracking Investigation (updated 4-7-88)

I. Chronology

A chronology of inspections and repairs is attached.

II. Scope of the Problem

The corrosion problem has been identified as transgranular stress corrosion cracking by the CP&L materials lab. The indication of the problem observed in Unit 2 is a brownish deposit. (See attached photos of affected tubes at 245 degrees azimuth.) Chloride has been identified in the brownish deposits and is considered to be the initiator of the problem.

The corrosion was identified in the vicinity of bends near the drywell wall at azimuths 245 and 115 degrees. The locations of all deposits were within approximately six feet of the socket weld which connects each pipe to its drywell penetration. A complete walkdown of all CRD piping (all azimuths: 65, 115, 245, and 295 degrees) from the drywell penetration to the CRDs (by looking in thru the biological shield window) has confirmed that the brownish deposits do not exist in any other locations.

III. Cause

The CRD piping is 1 inch and 3/4 inch ~~O.D.~~ I.D. schedule 80, type 304 stainless steel. The requirements for transgranular stress corrosion cracking in non-sensitized austenitic stainless steel include oxygenated atmosphere, temperature above 104-122 degrees, chloride containment, and material stress. (See attached "Assessment of Crack Growth Due to Chloride Stress Corrosion Cracking", by SIA.)

The chloride contamination has been measured in the brownish deposits. Residual stresses exist in the material as a result of fabrication. The other requirements exist in Unit 2 drywell during operation. The source of the chloride contamination is not known. However, based on examination of portions of the piping studied by the CP&L materials lab, it is considered that the cracks have developed slowly and may predate initial start-up. (Reference discussions with CP&L metallurgist Jim Woods and SIA metallurgist Tony Giannuzzi.) Two possible sources which are being investigated are: tools used to form the piping; and debris which may have fallen through the 38 foot grating onto the piping.

Attached are sketches showing the locations of all defects located by PT exam (after cleaning of the brownish deposits). Note that all defects are within twelve inches of a bend, which probably would have been in the area worked by the bending tools. This scenario does not explain why some bends do not have defects (all bends closer to the reactor vessel were found to be free of the brownish deposits). However, per discussion with Pete Foscolo (Brown and Root Construction manager at the time), most bends were made in the Reactor Controls Inc. shop; those that needed field change were bent in the field. It is possible that field fit-up was performed by making limited fields rework on the drywell wall end, when required. If this scenario is correct, then it is possible that a contaminated tool or bending lubricant could have affected a limited number of bends at the location observed. The scenario of debris falling on the affected piping is supported by a common feature of the 115 and 245 degrees azimuth locations but not seen at 65 or 295 degrees azimuth. (See attached copies of photos.) The 115 and 245 azimuth locations have clear grating above the affected areas. (The 65 and 295 degree azimuths are covered by SRVs, main steam piping, and feedwater piping.) Thus, the 115 and 245 degree azimuth areas are more likely candidates for debris to have been spilled, or simply carried in by foot traffic (especially during construction, before dress-out was required). Although an elemental analysis of the contaminants on the surfaces of the tubes, as well as the brownish deposits, has been performed, the materials lab has not yet been able to identify a specific compound with the chloride contamination.

Corrective Action for Unit 2

All affected areas have been cleaned. Fluorescent PT exam has been performed of all affected areas (i.e., within approximately six feet of the drywell wall at the 115 and 245 degree azimuths). All defects have been evaluated, and defects not accepted per guidance of ASME section XI have been removed by replacement of the affected section of piping. See attached cross-section views of piping arrays at 115 and 245 degree azimuths for extent of corrective action.

Plans/Implications for Unit 1

Although no detailed walkdown of Unit 1 CRD piping has previously been performed, we can state that no leakage from CRD piping has been observed. (Note that Brunswick recently received an NRC violation for not inspecting CRD piping during plant hydrostatic testing and has written an EER to justify continued operation based on no indication of significant leakage during last hydro. This inspection of Unit 2 CRD tubes during the vessel hydro was the first performed at Brunswick.)

Although we cannot say that the same contamination has not occured in Unit 1, we can say that transgranular stress corrosion cracking would be progressing at a much slower rate, if at all. In addition, because start-up of Unit 1 followed Unit 2 start-up by approximately 1.5 years, the consequences would be lagging still further behind.

The expected slower crack growth rate (or possible no crack occurence at all) is based on the differences in drywell temperature. The attached graphs from Patel Engineers Report PEI-TR-83-4-32 show that point number seven (located at the approximate elevation of the piping defects) has averaged approximately 120 degrees in Unit 2 but only 95 degrees in Unit 1. (These averages were calculated for all days since start-up of each unit through February 1984.) Per discussion with Tony Giannuzzi of SIA, this difference in temperature could cause a reduction in TGSCC crack growth rate by a factor of 2-to-3. (Since the local temperatures may vary slightly, and the graphs indicate average temperatures, we cannot conclude that TGSCC would not occur although it has not been reported below 95 degrees in non-sensitized austenitic stainless steel.)

Because of the shorter time since start-up and the expected slower crack growth rate (if cracking occurs at all at the temperatures seen in Unit 1 drywell), we see no need to inspect Unit 1 at this time.Instead, we plan to perform inspections at the next refueling outage during planned hydrostatic testing. In addition, the Unit 1 CRD piping will be inspected for evidence of the brownish deposits the next time the unit is ~~cooled down and the drywell is available for access.~~ in cold shutdown and an outage of sufficient length is available.

CRD TUBE REPAIR CHRONOLOGY

3-19-88

- 2 CRD TUBES DISCOVERED TO BE LEAKING DURING VESSEL HYDROTEST BY VT-2 EXAMINER.

3-20-88

- PREPARED & ISSUED FR #30 (PM 87-128) TO ALLOW PRELIM. WORK TO PROCEED (SCAFFOLD, FREEZE SEAL PREP, ETC.) FOR REPAIR OF THE IDENTIFIED LEAKERS.
- DURING AS-BUILDING FOR DEFECTIVE LINES, THREE (3) ADDTL. LEAKERS WERE IDENTIFIED IN SAME AREA OF BUNDLE. (ALL THROUGH-WALL INDICATIONS ARE CHARACTERIZED BY "RUST" COLORED DEPOSITS.)

DEFECTIVE LINES

1. WITHDRAWAL LINE (3/4") FOR HCU 22-07.	INITIAL LEAKS DISCOVERED DURING RPV HYDRO
2. WITHDRAWAL LINE (3/4") FOR HCU 18-07	
3. INSERT LINE (1") FOR HCU 26-07	LEAKS FOUND SUBSEQUENT TO RPV HYDRO
4. WITHDRAWAL LINE (3/4") FOR HCU 26-07	
5. WITHDRAWAL LINE (3/4") FOR HCU 22-03.	

- STARTED PREPARATION OF FR #31 FOR REPLACEMENT OF THE ABOVE LISTED FIVE CRD LINES.

3-21-88

- COMPLETED PREP. OF FR #31 AND PRESENTED REPAIR PLAN TO PNSC @ APPROX 1600. OBTAINED PNSC APPROVAL, OBTAINED NECESSARY APPROVALS FOR FR #31 & ISSUED TO FIELD @ 17:30.

3-22-88

- BCU WORKING REPLACEMENT OF CRD LINES ALL DAY.
- STARTED PREP. OF FR #32 TO ADD AT'S FOR CRD REPL.

3-23-88

- BCU COMPLETED REPLACEMENT OF FIVE (5) CRD LINES @ APPROX 0600
- COMPLETED PREPARATION OF FR #32 (AT'S) AND ISSUED @ 15:45.
- ANALYSIS OF 3 CRD LINES REMOVED BEING PERFORMED @ HARRIS

CRD TUBE REPAIR CHRONO. (CONT'D)

3-24-88

- RAY HANFORD IN TODAY TO INSPECT CRD TUBE BUNDLES. HE SUGGESTED THE FOLLOWING BE PERFORMED
  - CLEAN BUNDLE OF ALL DIRT, OIL, ETC. USING DEMIN WATER/ MEK SOLVENT.
  - BUFF/FLAP TO REMOVE CORROSION
  - RECLEAN USING DEMIN WATER.
- ANALYSIS OF REMOVED CRD TUBES INDICATED THAT THE SOURCE OF THE CRACKING WAS A CHLORIDE ASSISTED TRANSGRANULAR STRESS CORROSION CRACKING.
- STARTED ASS'Y OF FR #35 FOR CLEANING OF TUBE BUNDLES @ 245° & 115° AZ PER INSTRUCTIONS FROM R. HANFORD. 245° & 115° PICKED BECAUSE THESE WERE ONLY BUNDLES THAT HAD "BROWN DEPOSITS"

3-25-88

- CONT'D ASS'Y OF FR #35
- NO DW ACCESS DUE TO ILRT

3-26-88
3-27-88 } NO DRYWELL ACCESS DUE TO ILRT.

3-28-88

- ISSUED FR #35 FOR CLEANING OF 245° & 115° TUBE BUNDLES FROM PENETRATION COUPLING TO APPROX 7' OUT.
- CARL OSMAN IN TODAY TO DISCUSS BEST METHOD OF INSPECTING FOR POTENTIAL THRU-WALL DEFECTS ON OTHER TUBES. HE SUGGESTED USE OF FLUORESCENT PENETRANT & BLACKLIGHTS BECAUSE THEY'RE MUCH MORE SENSITIVE THAN STD. VISIBLE LIGHT LP MAT'LS.
- ORDERS PLACED FOR BY-LUX PENETRANT.
- NO DW ACCESS DUE TO ILRT.

3-29-88

- ORDER PLACED FOR BLACKLIGHTS & METER.
- BCU STARTED CLEANING OF BUNDLES NIGHTSHIFT LAST NIGHT.

3-30-88

- BCU CONT'D CLEANING OF BUNDLES
- BLACKLIGHTS / METER & FLUOR. PENETRANT RECEIVED & ISSUED FOR USE BY 1900.

3-31-88

- HELD MTG. @ 08:00 WITH QC & EXU TO DISCUSS PLAN OF ATTACK.
- QC STARTED LP EXAM OF TUBES (1/2 OF BUNDLE (25 TUBES)) @ THE 245° AZ, AT APPROX. 10:30. COMPLETED EXAM @ 04:00 ON 4-1-88.

4-1-88

- THE LP EXAM RESULTS WERE AS FOLLOWS;
  - FIVE (5) ADDITIONAL THROUGH-WALL LEAKS IDENTIFIED
    1. WITH. LINE (3/4") FOR HCU 26-15.
    2. WITH. LINE (3/4") FOR HCU 22-11.
    3. WITH. LINE (3/4") FOR HCU 14-07.
    4. WITH. LINE (3/4") FOR HCU 10-07.
    5. INSERT LINE (1") FOR HCU 18-03.
  - SIX (6) LINES WITH REJECTABLE DEFECTS WERE IDENTIFIED
    1. INSERT LINE (1") FOR HCU 22-07.
    2. INSERT LINE (1") FOR HCU 18-07.
    3. INSERT LINE (1") FOR HCU 10-07.
    4. INSERT LINE (1") FOR HCU 22-03.
    5. INSERT LINE (1") FOR HCU 10-11.
    6. WITH. LINE (3/4") FOR HCU 10-11.

> 115° BUNDLE
> TWO TUBES EXAMINED
> 1 - CLEAN
> 1 - THRU-WALL WITH. LINE FOR HCU 46-14
> 1 - ADDITIONAL TUBE WITH. LINE FOR HCU 4215 HAD DEPOSIT & APPEARED TO BE LEAKING

- DECISION MADE TO CLEAN REMAINDER OF 245° AZ & ALL OF 115° AZ BUNDLES, FOR LP EXAM. PREPARED & ISSUED FR #38 FOR THIS PURPOSE.
- STARTED PREP OF FR #39 FOR REPLACEMENT OF ALL KNOWN LEAKERS IN 245° BUNDLE, PLUS #'S 3 & 4 BECAUSE OF ACCESS PROBLEMS. SIA REP. TONY GIANNUZZI ON SITE AND SUGGESTED THAT OF THE SIX LINES WITH REJECTABLE INDICATIONS ABOVE, #'S 1, 2 & 6 COULD BE ACCEPTED AS-IS BY THEIR ANALYSIS. HOWEVER, #5 HAD A 5" LINEAR INDICATION, AND WE SHOULD DO WHATEVER POSSIBLE TO REDUCE OR REMOVE THE INDICATION.
- DECISION MADE TO LP EXAMINE ALL TUBES IN 115° AZ BUNDLE.

4-2-88

- PREP COMPLETED & ISSUED FR #39
- ADDITIONAL INSPECTION COMPLETED BY BESU TO VERIFY ABSENSE OF "BROWN DEPOSITS" @ THE 295° & 65° BUNDLES. NO DEPOSITS IDENTIFIED ON THESE BUNDLES.
- QC COMPLETED LP EXAM OF 245° BUNDLE, AND DISCOVERED NO ADDITIONAL THROUGH-WALLS. ONE REJECTABLE INDICATION ON INSERT LINE (1") FOR HCU 14-15*.

*DEFECT ACCEPTABLE BY ANALYSIS

CRD TUBE REPAIRS CHRONO (CONT'D)

4-3-88

- QC STARTED LP EXAM OF 115° BUNDLE @ 0800.
  - PRESENTLY 3 CONFIRMED LEAKERS OUT OF 14 INSPECTIONS.
- COMPLETED BASEMETAL REPAIR OF 5" LINEAR INDICATION ON INSERT LINE FOR HCU 1041. POST REPAIR LP ACCEPTABLE.
- STARTED PREPARATION OF FR #40, WHICH WILL INCLUDE ALL REPLACEMENTS OF TUBES ON THE 115° TUBE BUNDLE & THE REVISION OF ACCEPTANCE TESTS IN ACCORDANCE WITH THE "NEW" REPLACEMENTS @ 245° & 115° AZ BUNDLES.
- QC COMPLETED THREE ROWS OF FIVE @ THE 115° BUNDLE.
- STARTED REPLACEMENT OF SEVEN TUBES @ 245° PER FR #39

4-4-88

- QC COMPLETED LP EXAM OF ALL TUBES @ 115° - ONLY 3 CONFIRMED THRU-WALL INDICATIONS - THE WITHDRAWAL LINES FOR HCU'S 46-19, 42-15 & 46-15. ONLY ONE ADDITIONAL REJECTABLE INDICATION WAS DISCOVERED ON THE INSERT LINE FOR HCU 30-11 *
- ISSUED FR#40 TO ALLOW WORK IN 115° AZ TO PROCEED WHEN READY.
- COMPLETED REPLACEMENT OF TUBES @ 245° (LATE NIGHTSHIFT)

* DEFECT ACCEPTABLE BY ANALYSIS

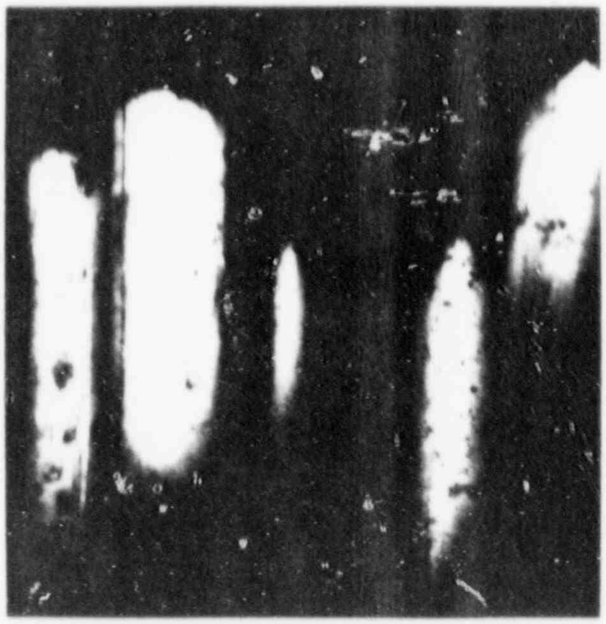
4-5-88

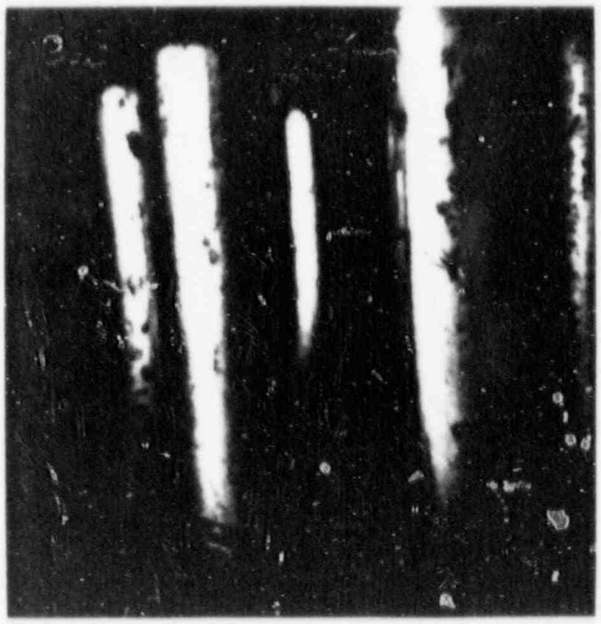
- STARTED PREPARATION WORK @ 115° FOR TUBE (3) REPLACEMENT.
- NIGHTSHIFT STARTED FREEZES FOR 3 TUBES @ 0100 (4/6)

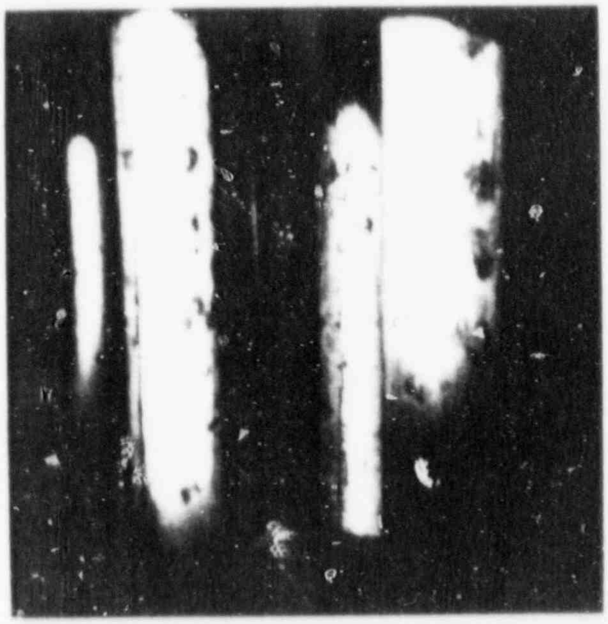
4-6-88

- COMPLETED REPLACEMENT OF TUBES @ THE 115° AZ @ 1500.
- STARTED REMOVAL OF SCAFFOLDING, EQUIP, ETC.

BROWNISH DEPOSITS ON TUBES AT 245° AZIMUTH







ATTACHMENT A

Assessment of Crack Growth Due to Chloride Stress Corrosion Cracking

Assessment of Crack Growth Due to Chloride Stress Corrosion Cracking

Several of the Type 304 stainless steel control rod drive insert and withdrawal tubes which were observed to be leaking following the March 20, 1988, ASME Section XI system hydrostatic test at Brunswick Unit 2 were examined following removal from the drywell. Three 3/4-inch Schedule 80 withdrawal tubes were sent to the Sharon Harris Energy and Environmental Center where nondestructive and destructive metallurgical examinations were performed on the tubes to ascertain the cause of cracking. Metallurgical samples were prepared from two of the tubes and energy dispersive x-ray examination was performed on the surface deposits present on the tubes. The semi-quantitative x-ray analysis confirmed the presence of significant levels of chloride on the tube surface in the deposits. The metallography revealed substantial numbers of short branched transgranular cracks typical of chloride stress corrosion cracking. Longitudinal, diagonal and transverse cracks were detected visually and confirmed by metallurgical examination. The longest longitudinal crack observed was approximately 2 inches in length, with the longest transverse crack 7/8" in length. Several cracks had penetrated through the wall in the samples examined. However, the majority of the cracks were observed to be part-wall, with OD surface length less than one inch.

The presence of short transgranular stress corrosion cracking (TGSCC) in aqueous environments containing chlorides has been observed often in austenitic stainless steel components. It is generally accepted that oxygen is a necessary contributor to chloride stress corrosion cracking and that temperature and stress are significant accelerants. The threshold temperature for TGSCC in chlorides for nonsensitized austenitic stainless steels is of the order of 40 to 50°C (104 to 122°F) at high chloride concentrations (50 ppm to 1800 ppm) [1, 2]. Sensitized austenitic stainless steel has been observed to suffer from intergranular stress corrosion cracking (IGSCC) in the presence of chlorides at or below room temperature.

The mean cracking time for TGSCC of Type 304 stainless steel in chloride environments is a strong function of temperature for a fixed chloride level. For example, in tests conducted in a 100 ppm chloride environment at 60, 80 and 100°C (140, 176, and 212°F), the mean cracking times were 3800, 600 and 160 hours, respectively [1]. Figure 1, taken from Reference 1, illustrates the effect of temperature and concentration on the stress corrosion cracking susceptibility of Type 304 stainless steel in chlorides. One notes that although cracking is observed at 40°C, the concentration of chloride required for cracking is extremely high (1800 ppm). Other investigators, examining the TGSCC susceptibility of mill annealed Type 304 stainless steel in 110°F water containing 100 ppm chloride, saw no TGSCC during the test period [3]. These investigators did observe stress corrosion cracking of this material in 100 ppm chlorides when tested at 200°F.

Surface finish also plays a role on TGSCC in chloride environments particularly at lower temperatures (of the order of 200°F) [4]. Surface abrasion and surface pickling tend to accelerate stress corrosion cracking in chloride environments. Cracking appears to occur more rapidly in pickled or abraded samples than in electropolished samples [4]. The abrading appears to provide the tensile residual stress and cold work which can accelerate crack initiation whereas the pickling produces intergranular attack which can act as a crevice concentrating the chloride bearing solution.

At Brunswick Unit 2, the design temperature for the control rod drive insert and withdrawal tubes is 150°F, and the normal drywell temperature averages 120°F. This temperature is near the threshold for TGSCC in aqueous chloride environments. Whereas TGSCC has been observed in the laboratory at temperatures as low as 40°C, (104°F), the concentration of chlorides necessary for cracking has been observed to be extremely high (1800 ppm).

At 50°C (122°F), cracking has been reported in the literature at 50 ppm chlorides and at 60°C (140°F), chloride stress corrosion cracking has been reported at chloride levels of 100 ppm. Based upon these data, high levels of chloride must have existed on the OD surface of the insert and withdrawal tubes for chloride stress corrosion to have occurred. High chloride bearing deposits were observed on the tubes in the vicinity of the TGSCC and stains (which appeared to be etched into the surface) were also present in the vicinity of the cracks. No TGSCC was observed when the deposits and stains were absent. This result is consistent with the laboratory data and suggests that some contamination of the tubes had occurred either prior to or during service. Since no apparent concentration mechanism (such as alternate wetting or drying due to boiling) is present at this location, a contamination mechanism is the most likely cause of the chloride cracking.

Investigation of drywell temperature records at Brunswick Units 1 and 2 revealed that from plant startup through February, 1984, the average temperature at the location of the CRD tube bundles was 95°F in Unit 1 and 120°F in Unit 2. Based upon the laboratory and field data described above regarding TGSCC cracking in chlorides, the tubes in Unit 2 were near or slightly above the threshold temperature for chloride stress corrosion cracking (~100°F), while the CRD tubes in Unit 1 may be at or slightly below the TGSCC threshold for annealed type 304 stainless steel. This difference in drywell temperature translates to a difference in failure time of a factor of two or more, based upon an activation energy extrapolation of the 60°C, 80°C and 100°C temperature data described above [1].

Several investigators have examined the chloride induced TGSCC crack growth rates or pit growth rates of Type 304 stainless steel in aqueous solutions at temperatures ranging from 90°F to 212°F [5-10]. Although significant scatter exists in the data, the growth rates range from 20 to 120 mils per year, with the higher rates observed at higher temperatures. These data provide confirmation that the stable cracks observed in the five defected tubes accepted by analysis for an additional cycle will remain stable through the next operating cycle at Brunswick Unit 2.

References

1. D. Warren, Proceedings of the Fifteenth Annual Industrial Waste Conference, Purdue University, May, 1960.

2. J. A. Collins, Corrosion, 11, November, 1955.

3. W. L. Clarke, "Summary of BWR Plant Materials Tested During 1968", February, 1969.

4. R. P. Jackson, "Effects of Surface Grinding on Stress Corrosion Cracking of Austenitic Mn-Cr and Mn Steels in Seawater", Proc. of Conference, Fundamental Aspects of Stress Corrosion Cracking, NACE, Houston TX, 1969.

5. Perry's Chemical Engineer's Handbook.

6. Metals Handbook, Volume 3 - Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, ASM Ninth Edition.

7. D. D. MacDonald, et al., "Corrosion and Corrosion Cracking of Materials for Water Cooled Reactors, EPRI Progress Report for the Period July-December, 1980, Report Number FCC-7806.

8. L. R. Scharfstein and W. F. Brindley, "Chloride Stress Corrosion Cracking of Austenitic Stainless Steel - Effect of Temperature and pH", Corrosion, 14 (112), December, 1958.

9. S. P. Rideout, "Effects of pH on Stress Corrosion Cracking of 18-8 Stainless Steel in Low Chloride Water", CONF-492-2, April 24, 1964.

10. B. D. Hayner, D. H. Pope, B. E. Crane, "Microbiologically Influenced Corrosion in Condenser Water Boxes at Crystal River-3", presented at the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, Traverse City, August/September, 1987, Traverse City, Michigan.

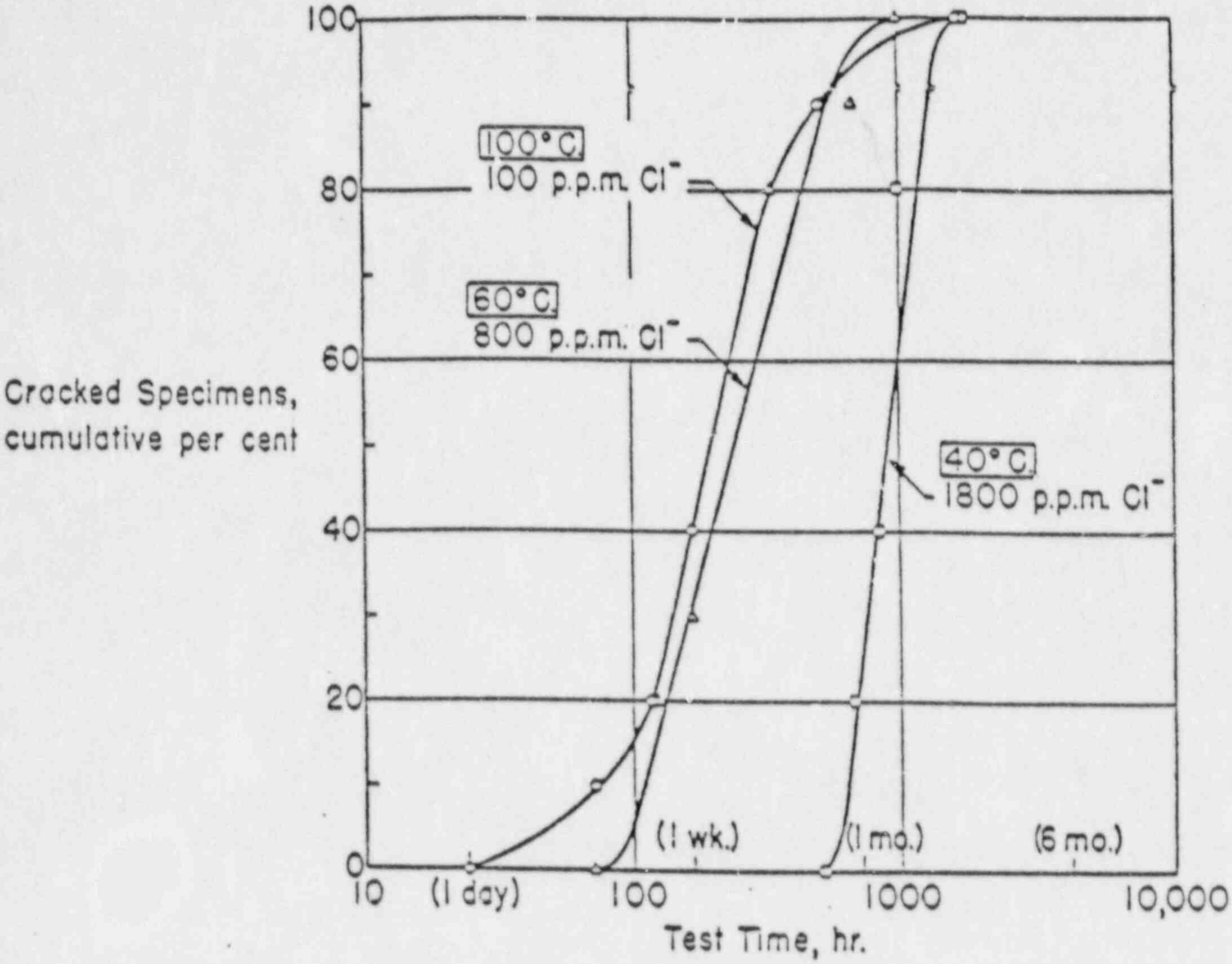
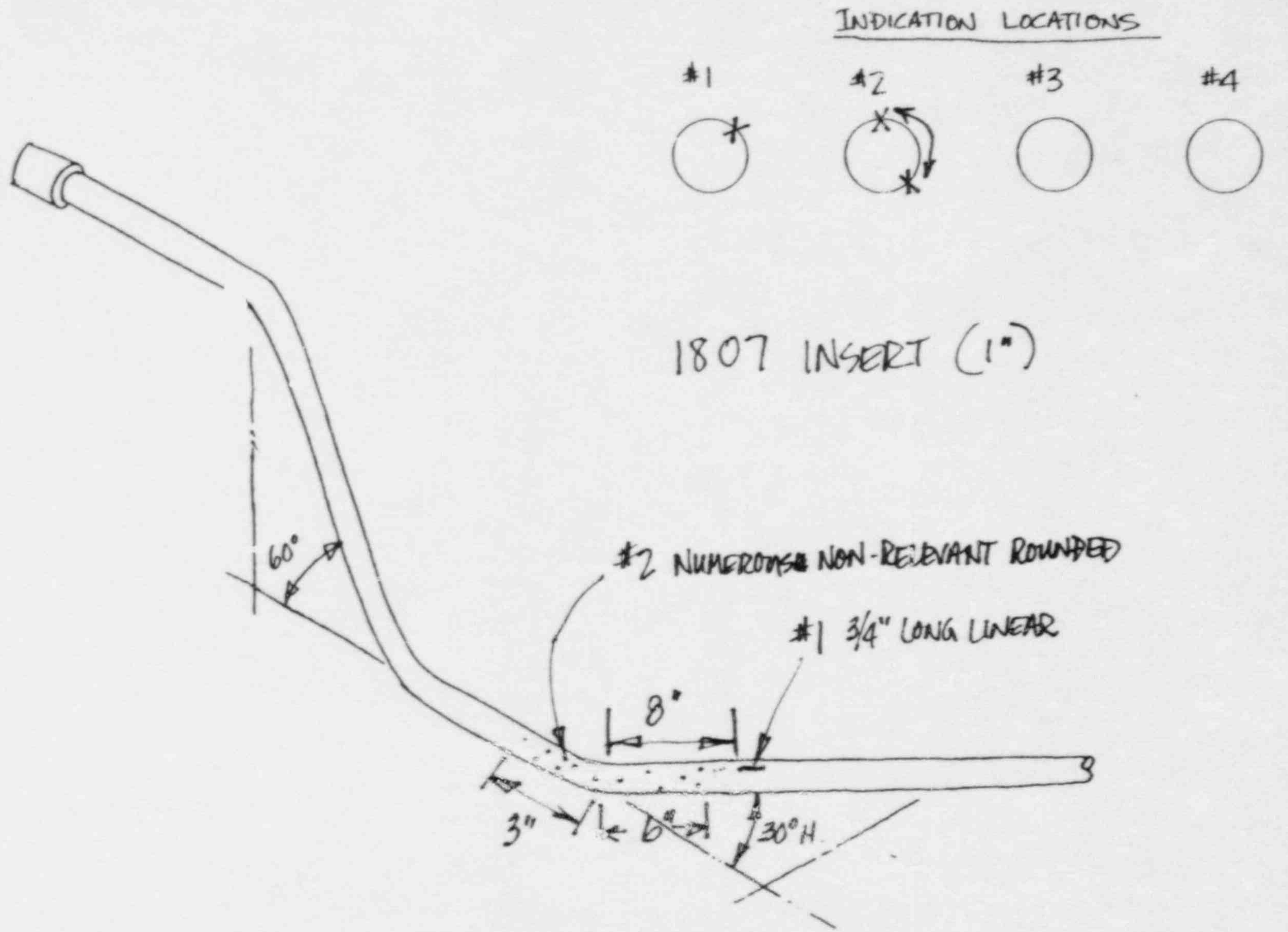
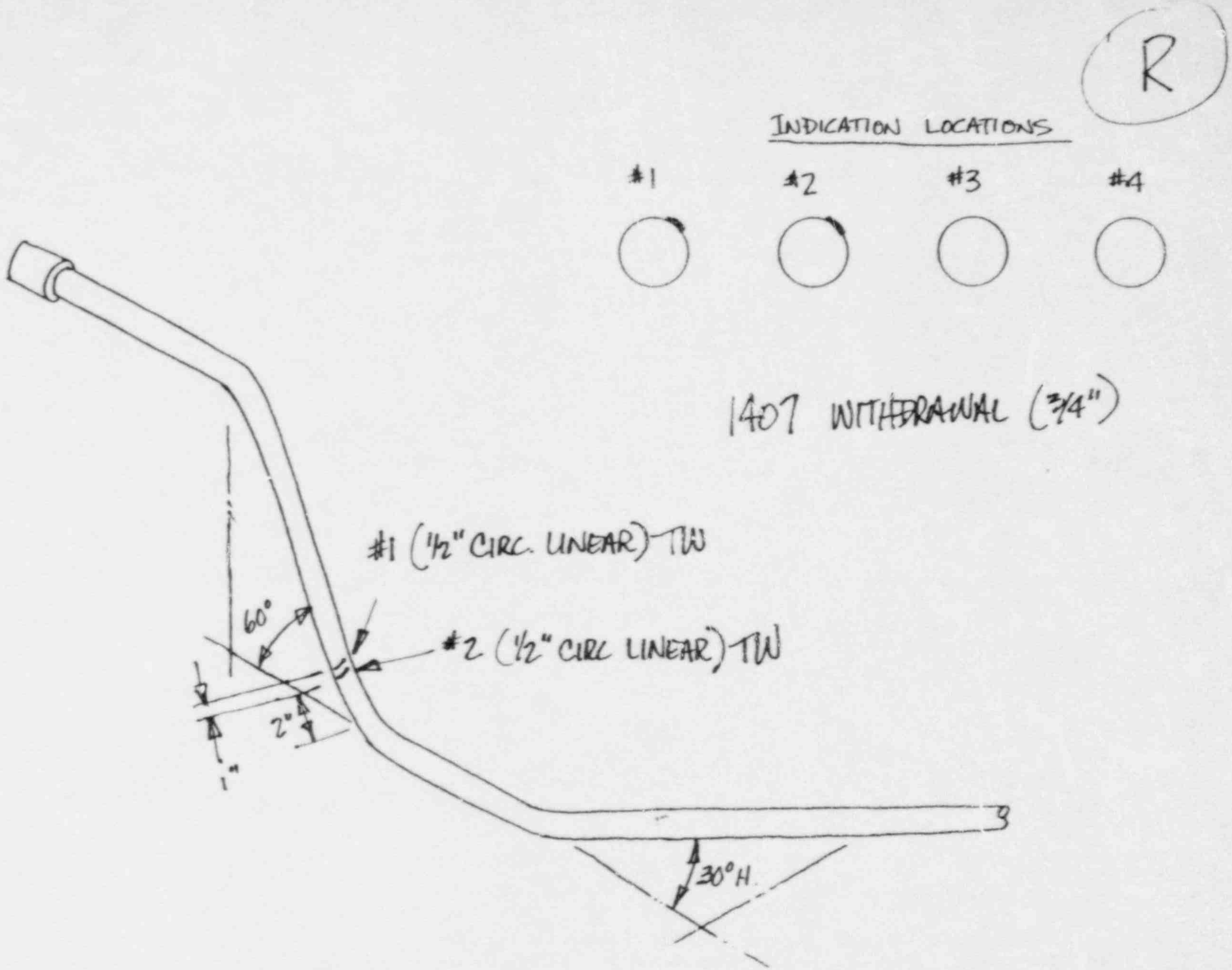
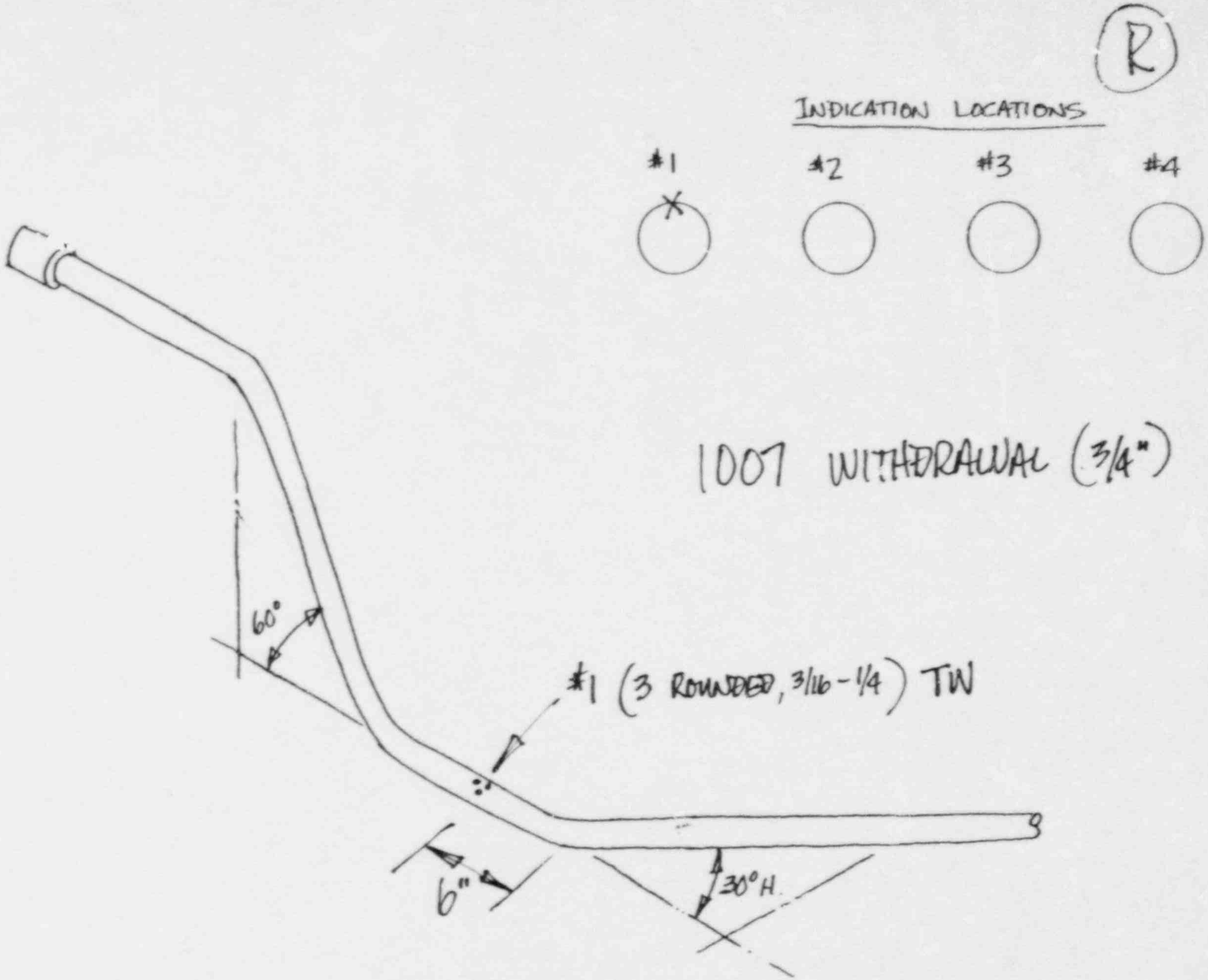
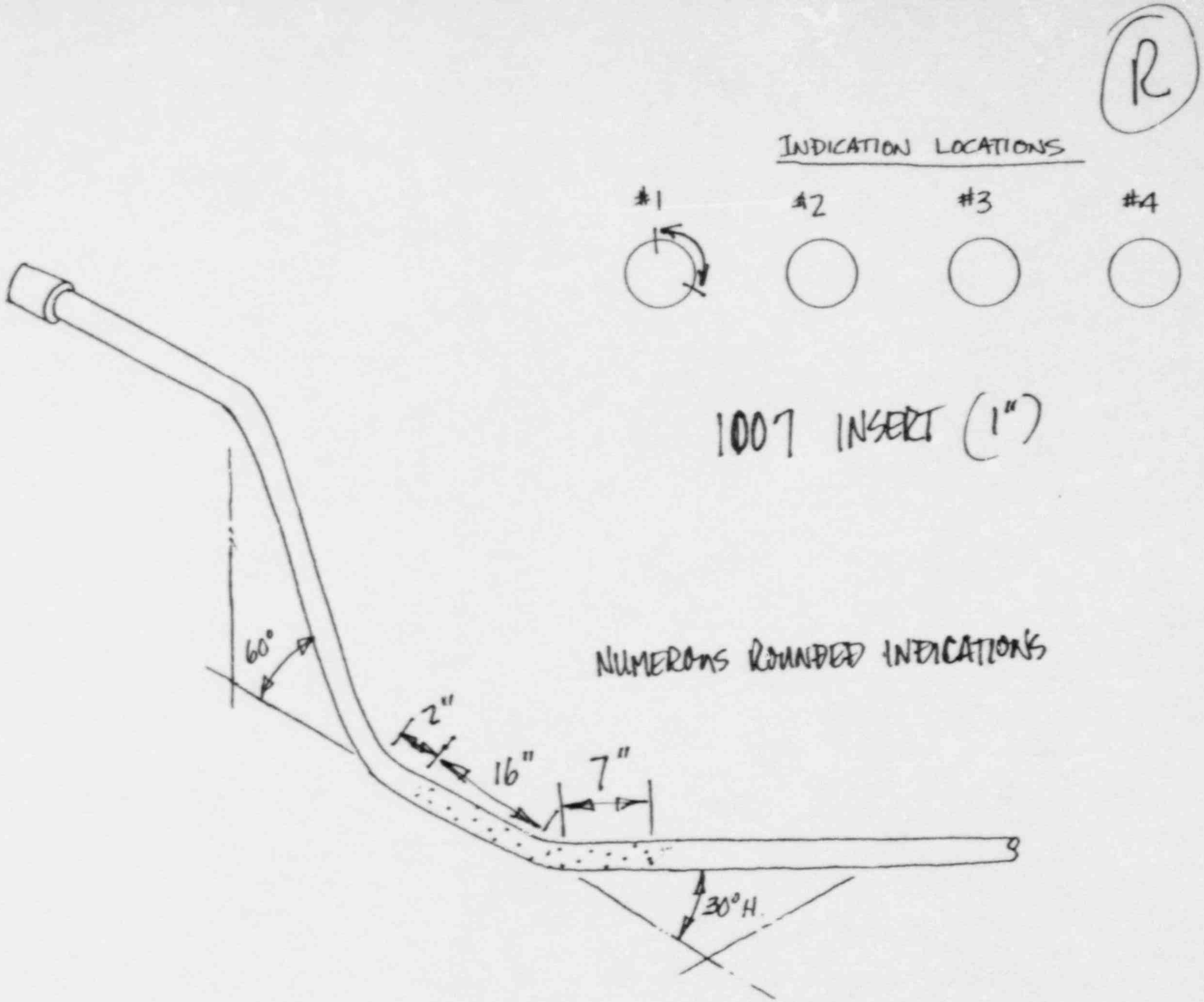


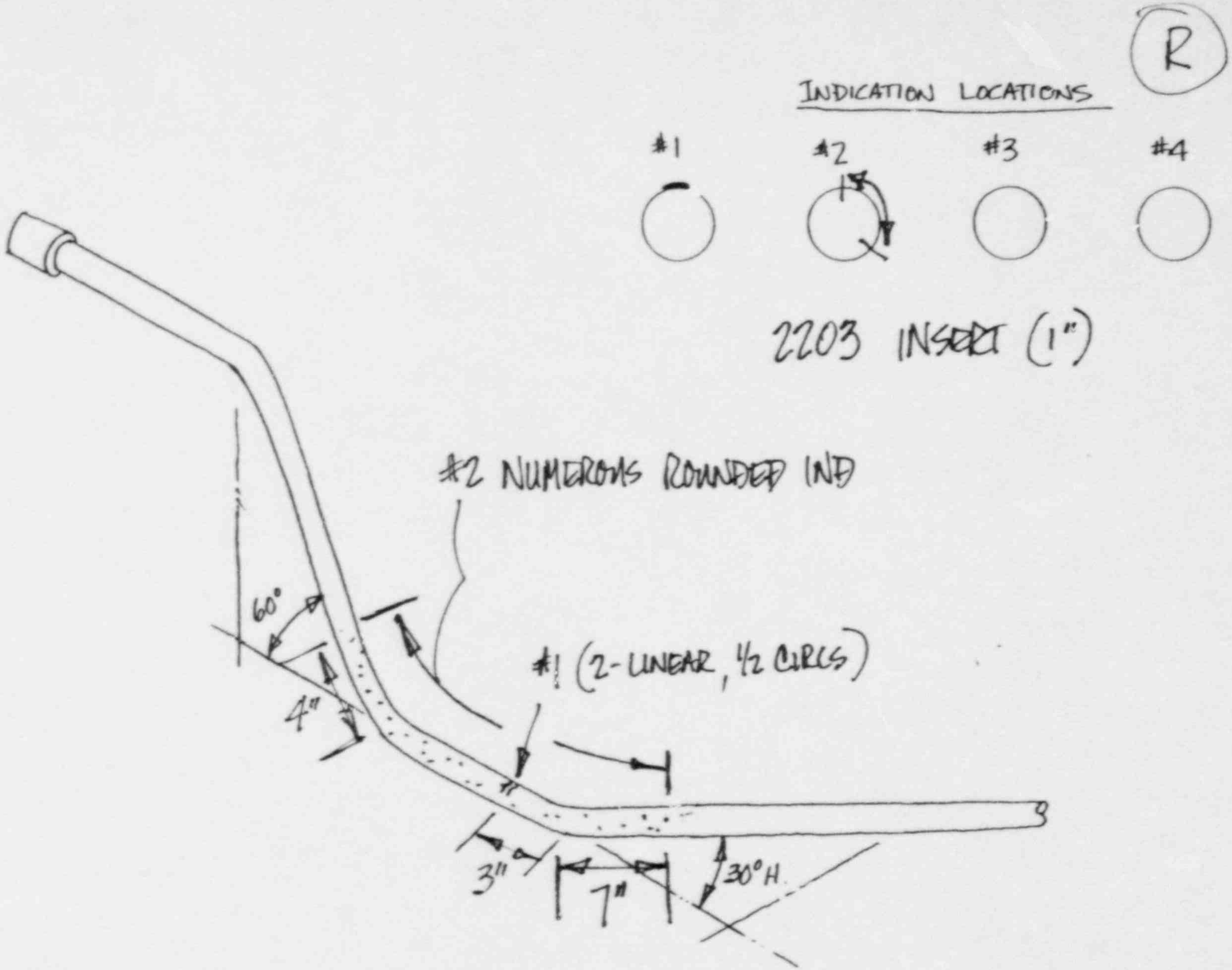
Figure 1. Effect of temperature on the time to cracking of Type 304 stainless steel exposed to water with chloride adjusted to provide the same rate of chloride concentration at three temperatures. U-bends from 16-gauge stock. (Warren 1)

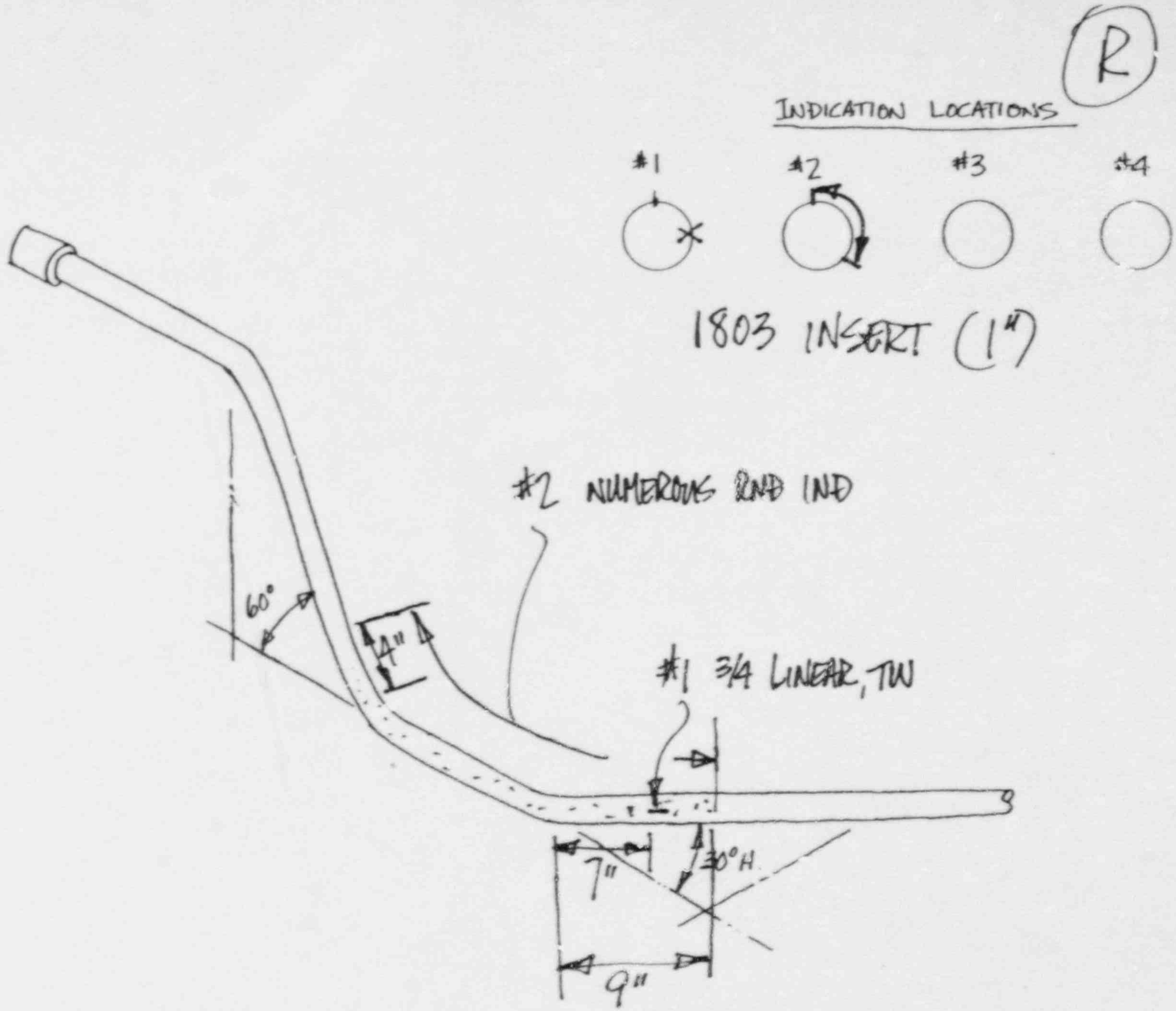

INDICATION LOCATIONS
#1
#2
#3
#4
1807 INSERT (1")
#2 NUMEROUS NON-RELEVANT ROUNDED
#1 3/4" LONG LINEAR
8"
60°
3"
6"
30°H


R
INDICATION LOCATIONS
#1
#2
#3
#4
1407 WITHDRAWAL (3/4")
#1 (1/2" CIRC. LINEAR) TW
#2 (1/2" CIRC LINEAR) TW
60°
2"
1"
30°H


R
INDICATION LOCATIONS
#1
#2
#3
#4
1007 WITHDRAWAL (3/4")
#1 (3 ROUNDED, 3/16 - 1/4) TW
60°
6"
30° H

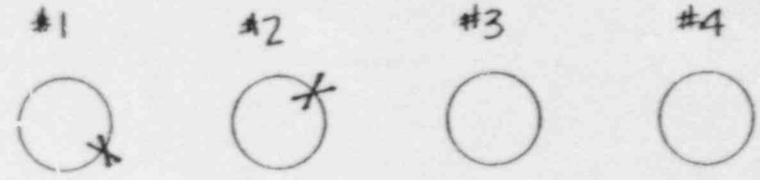

R
INDICATION LOCATIONS
#1
#2
#3
#4
1007 INSERT (1")
NUMEROUS ROUNDED INDICATIONS
60°
2"
16"
7"
30°H.


R
INDICATION LOCATIONS
#1
#2
#3
#4
2203 INSERT (1")
#2 NUMEROUS ROUNDED IND
#1 (2-LINEAR, 1/2 CIRCS)
60°
4"
3"
7"
30° H

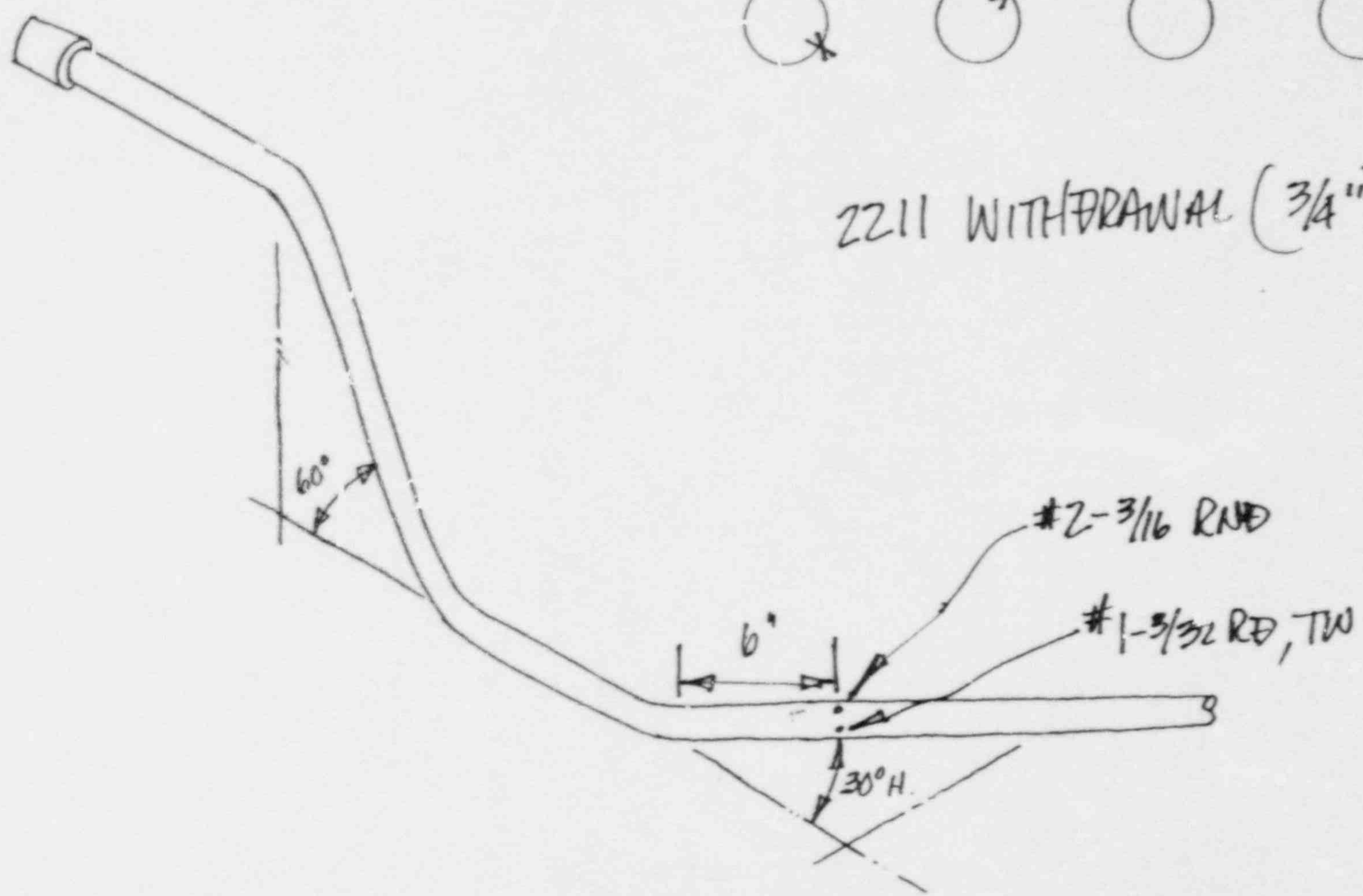


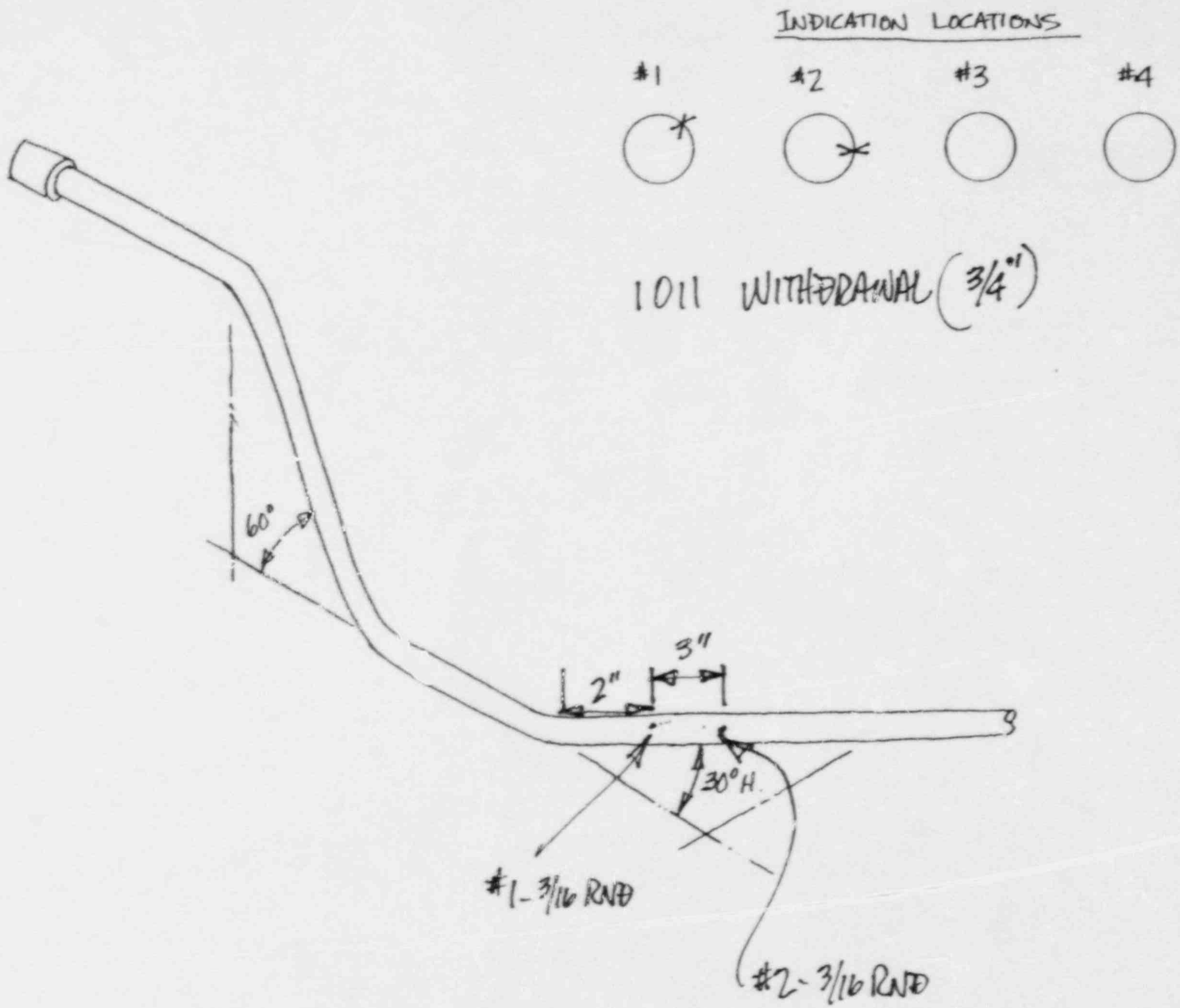
R
INDICATION LOCATIONS
#1
#2
#3
#4
1803 INSERT (1")
#2 NUMEROUS RND IND
#1 3/4 LINEAR, TW
60°
4"
7"
30°H
9"

(R)



2211 WITHDRAWAL (3/4")



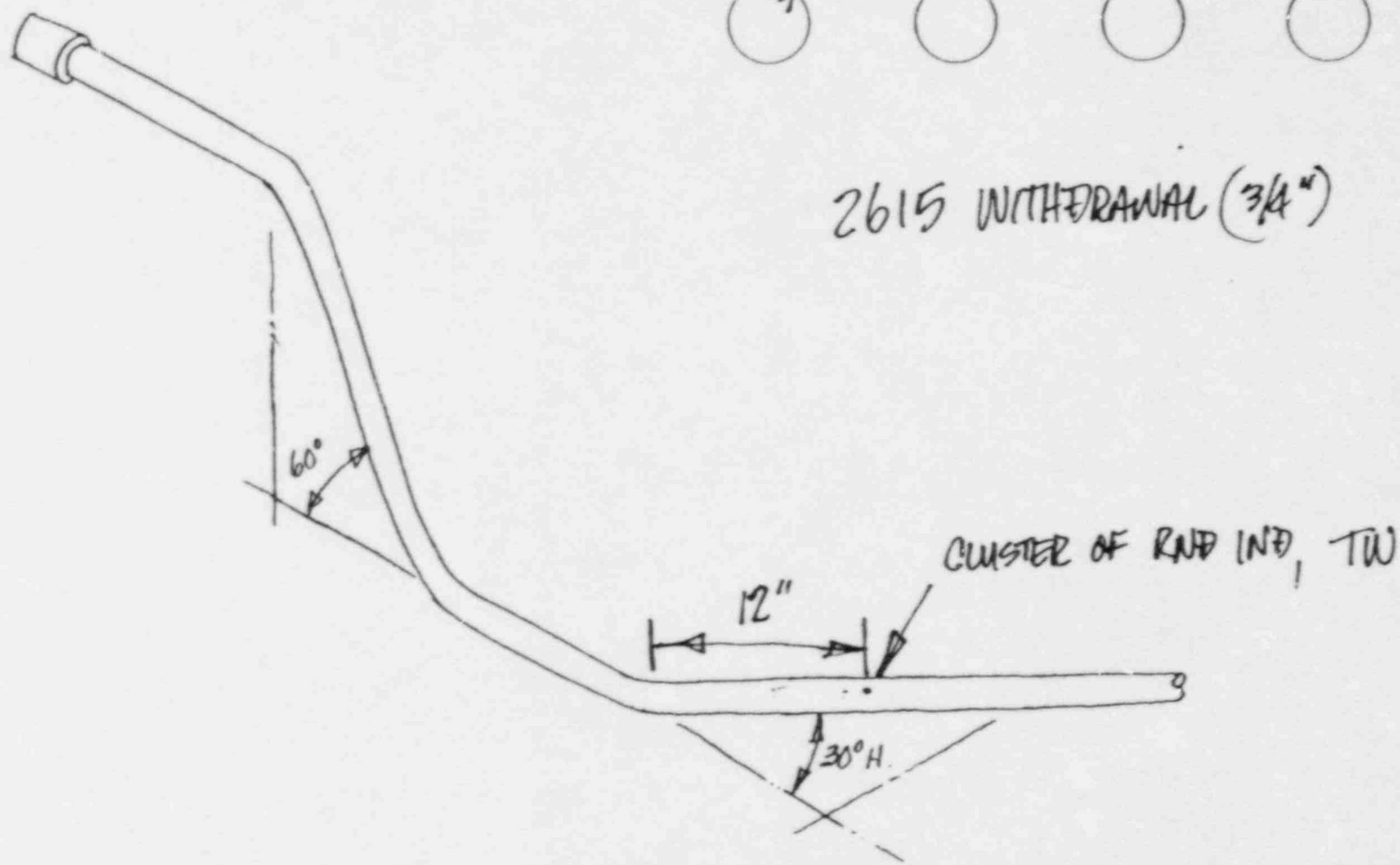

INDICATION LOCATIONS
#1
#2
#3
#4
1011 WITHDRAWAL (3/4")
60°
2"
3"
30° H.
#1 - 3/16 RND
#2 - 3/16 RND

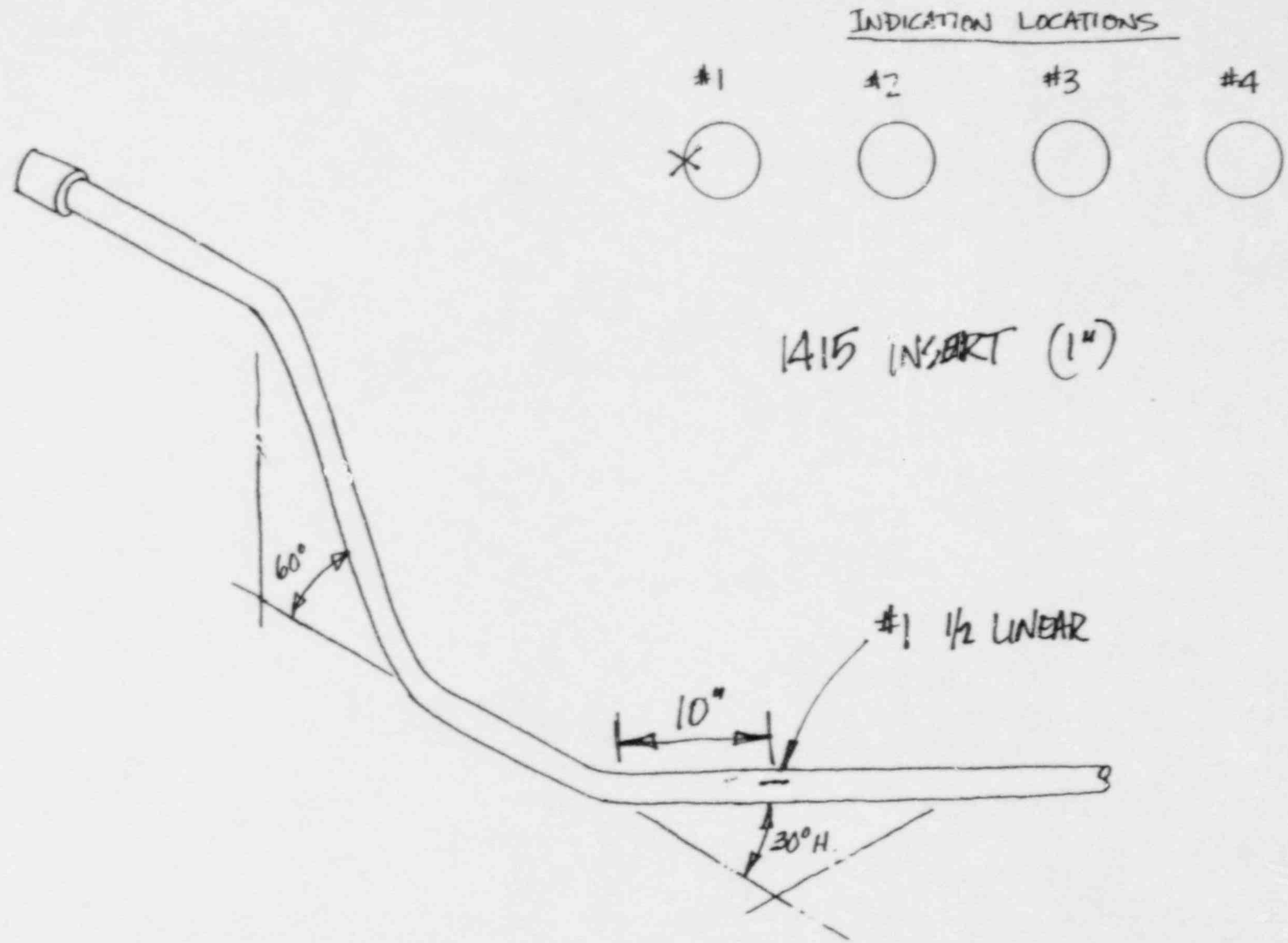
(R)

INDICATION LOCATIONS

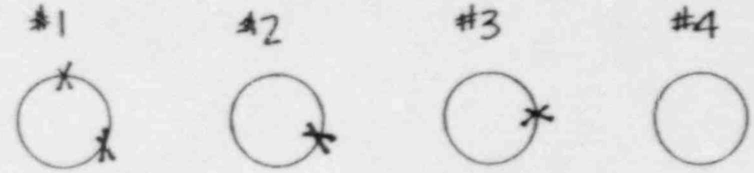
#1 (X) #2 #3 #4

2615 WITHDRAWAL (3/4")




INDICATION LOCATIONS
#1
#2
#3
#4
1415 INSERT (1")
#1 1/2 LINEAR
10"
60°
30°H

INDICATION LOCATIONS

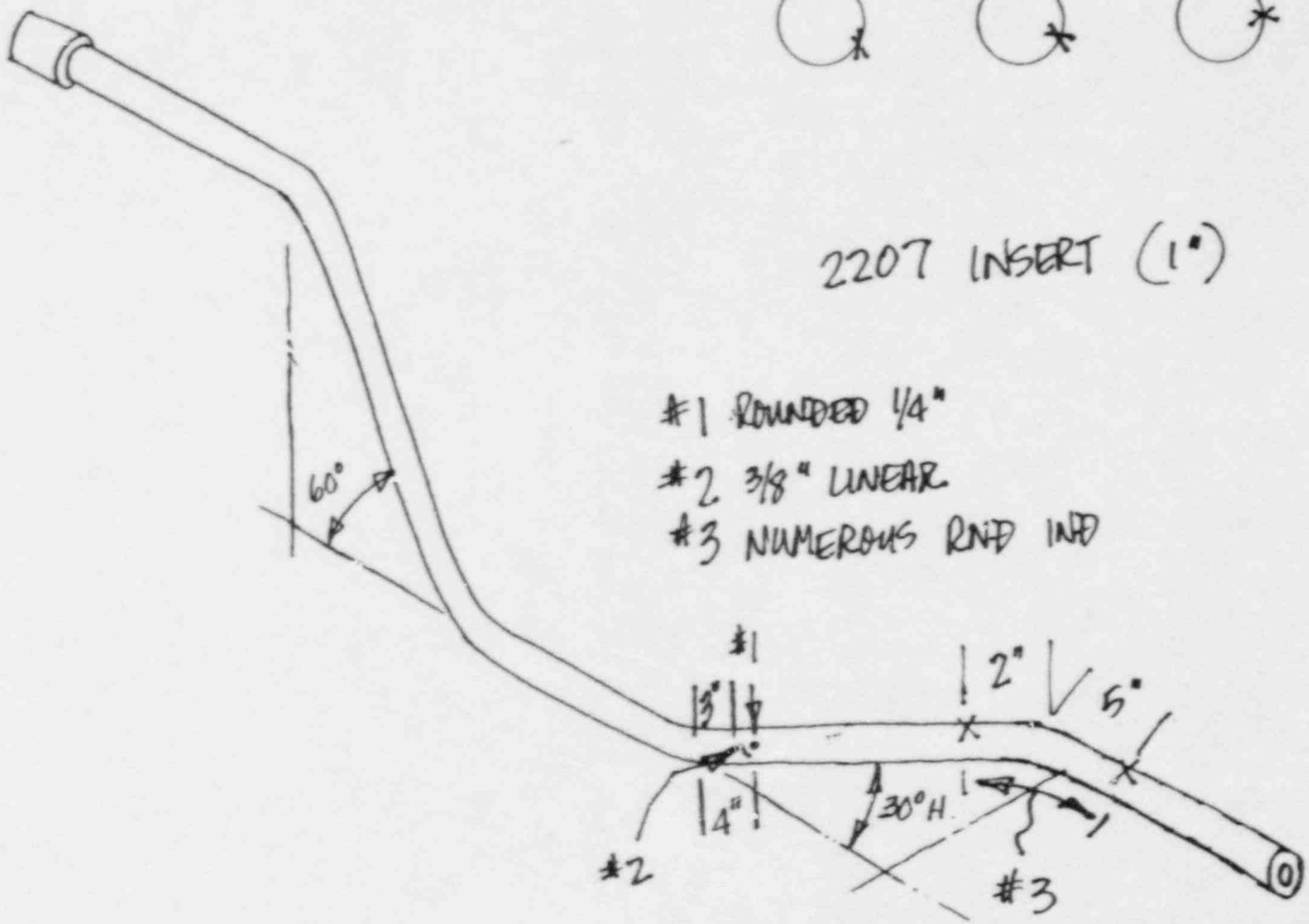


2207 INSERT (1")

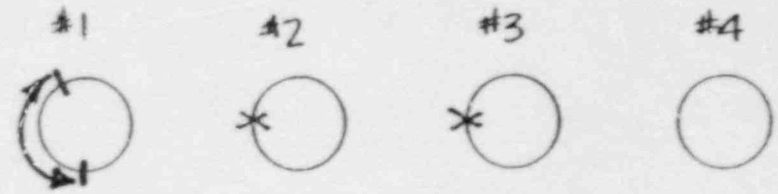
#1 ROUNDED 1/4"

#2 3/8" LINEAR

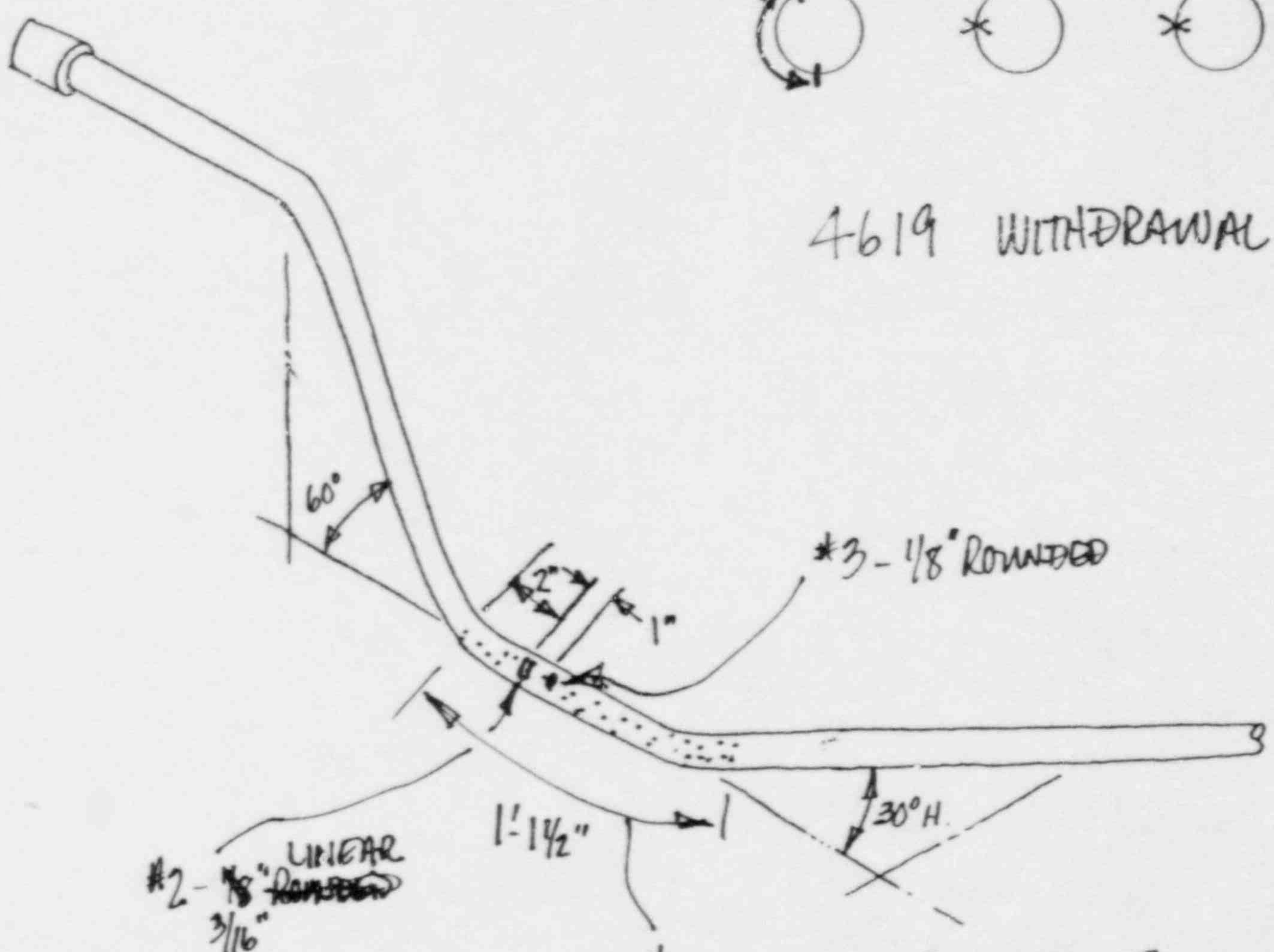
#3 NUMEROUS RND IND

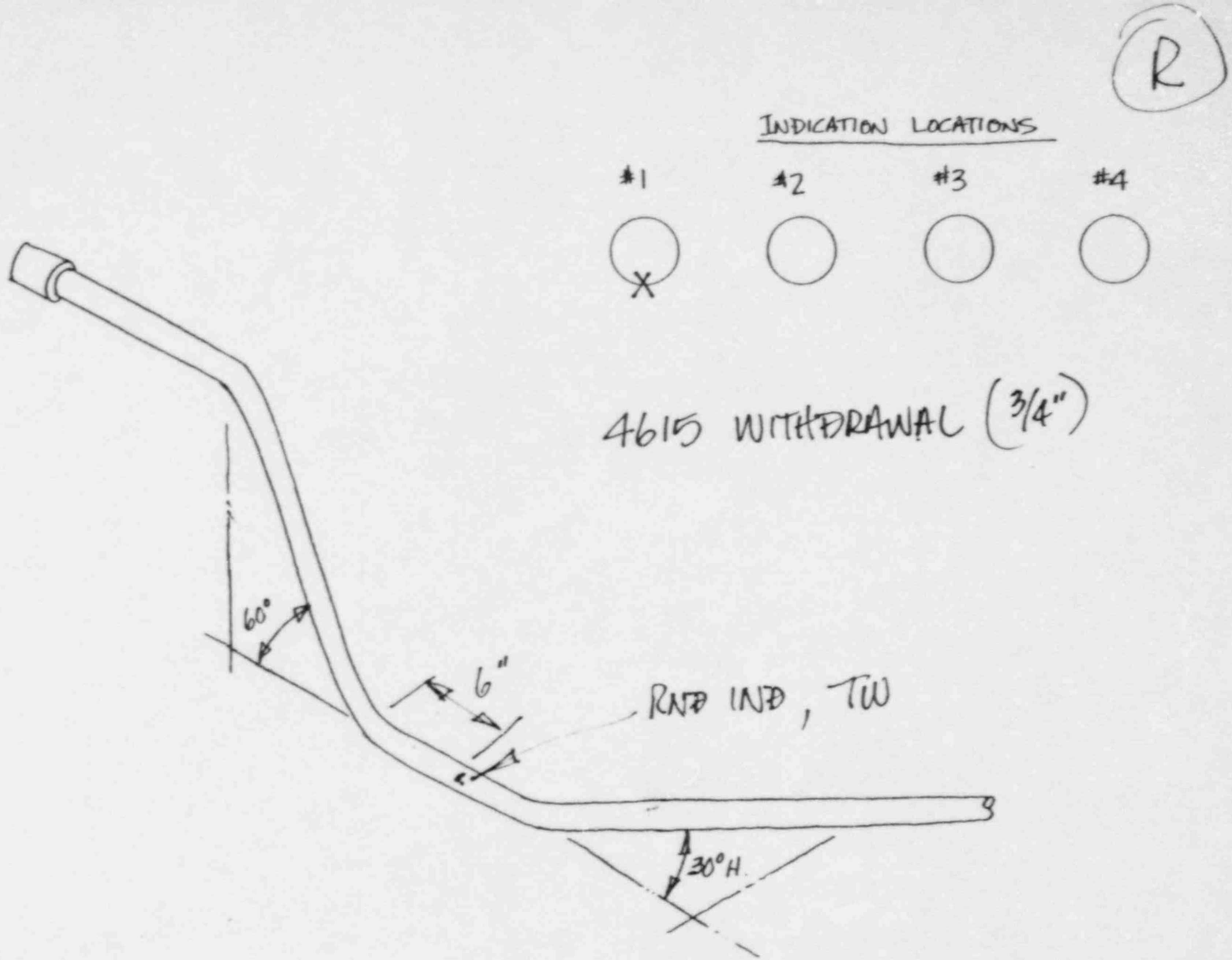


(R)

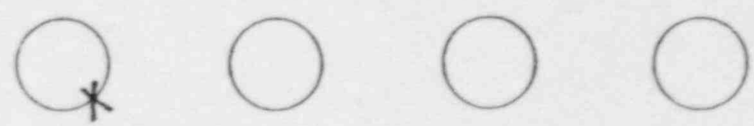


4619 WITHDRAWAL (3/4")

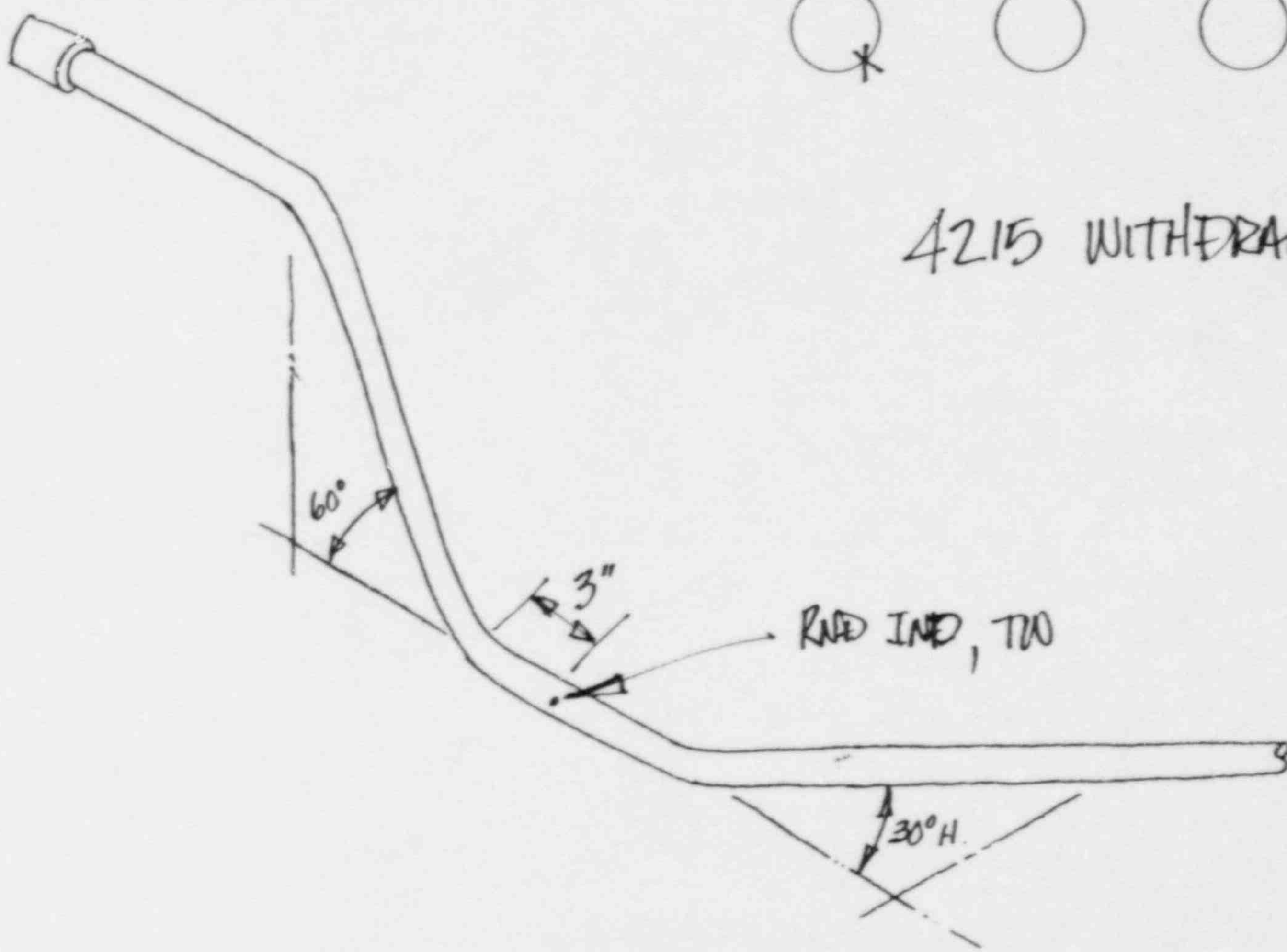


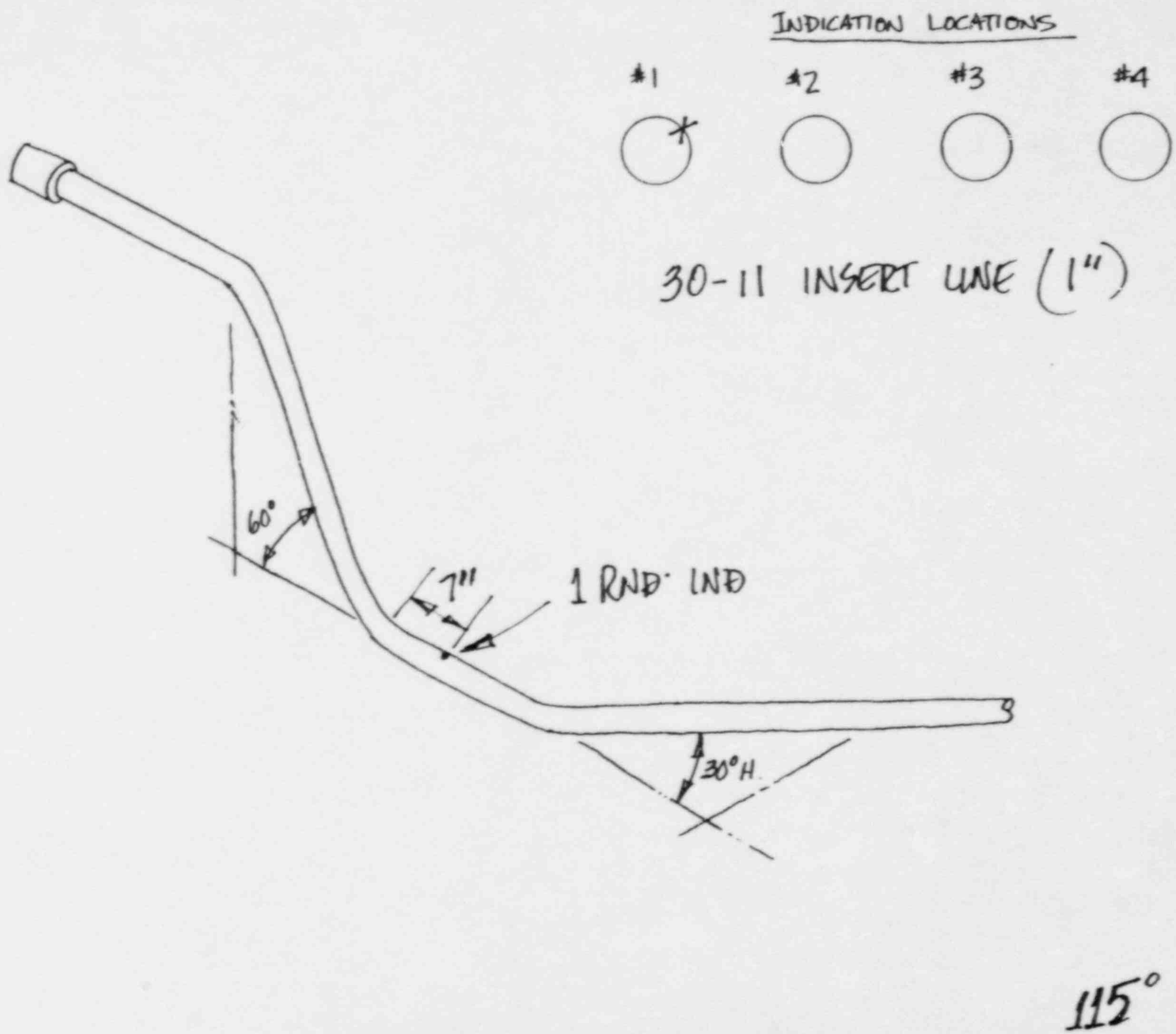

R
INDICATION LOCATIONS
#1
#2
#3
#4
4615 WITHDRAWAL (3/4")
60°
6"
RND IND, TW
30°H

(R)

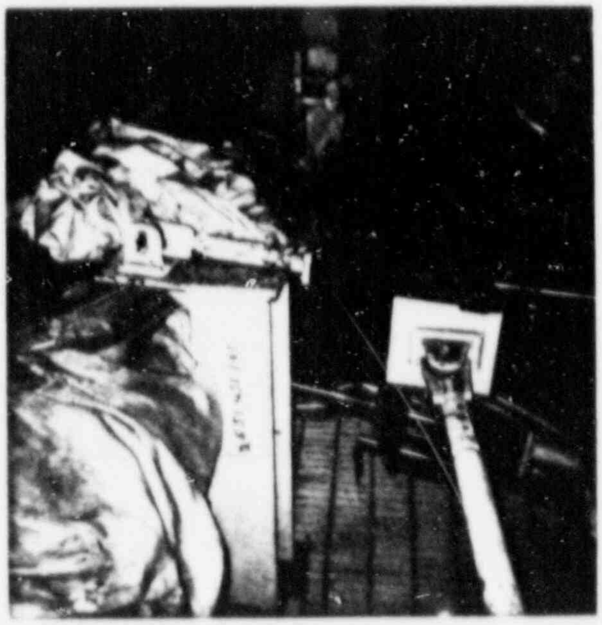


4215 WITHDRAWAL (3/4")

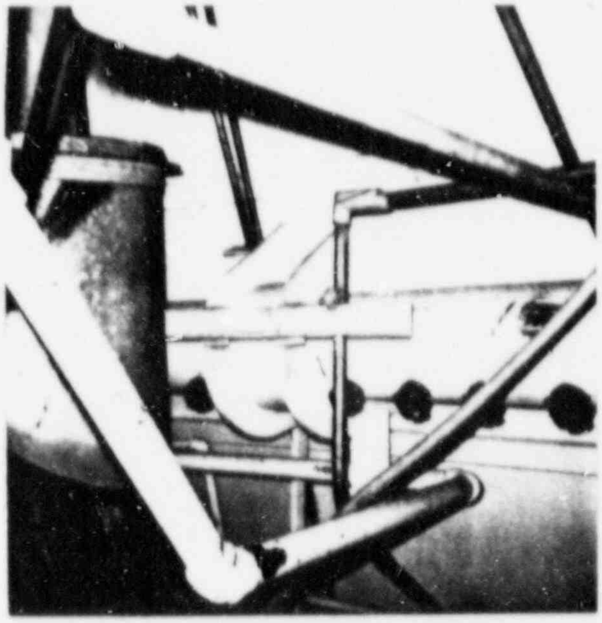



INDICATION LOCATIONS
#1
#2
#3
#4
30-11 INSERT LINE (1")
60°
7"
1 RND· IND
30°H.
115°

245° AZIMUTH

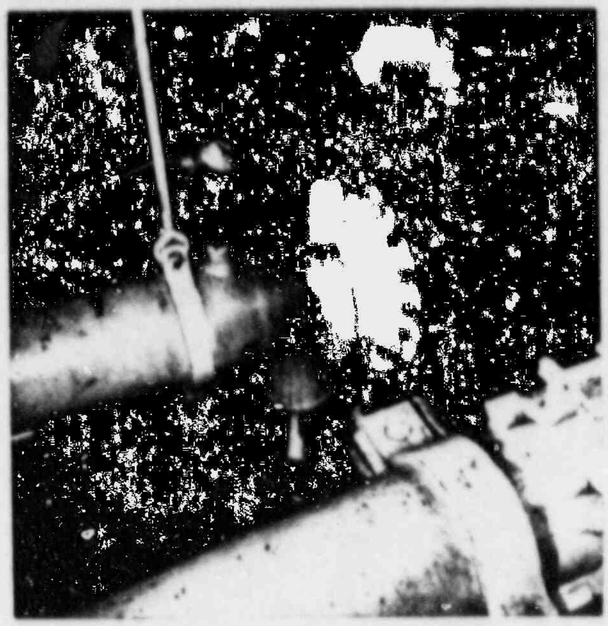


(1)



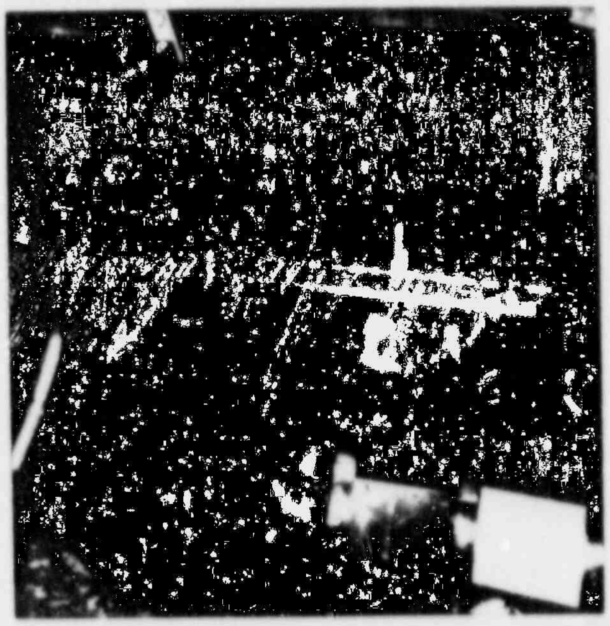
(2)

295° AZIMUTH



(3)

(4)



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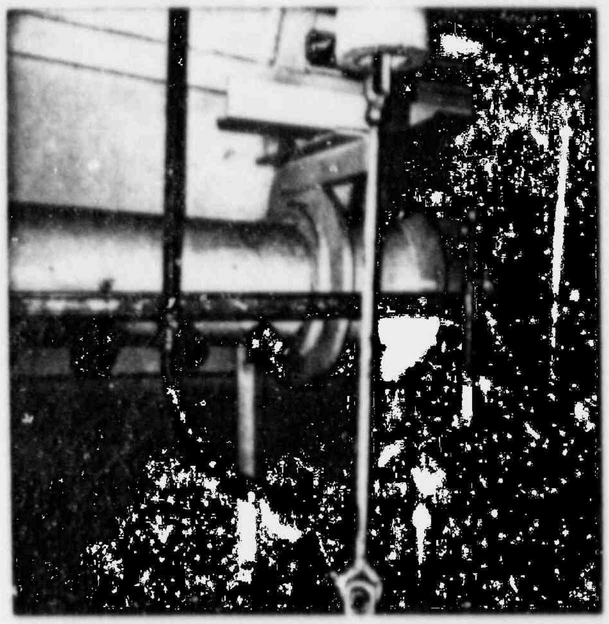
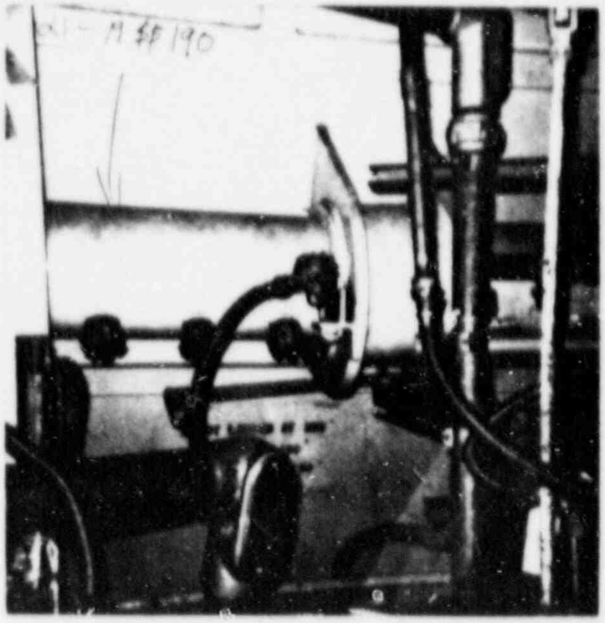


(6)

65° AZIMUTH

(7)



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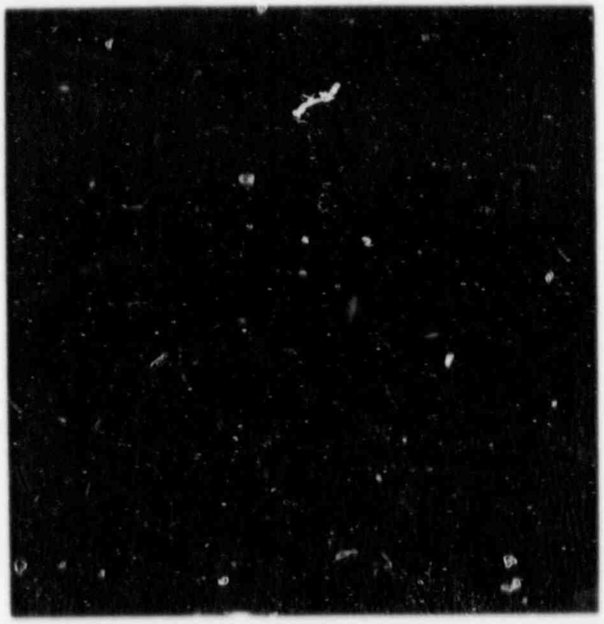
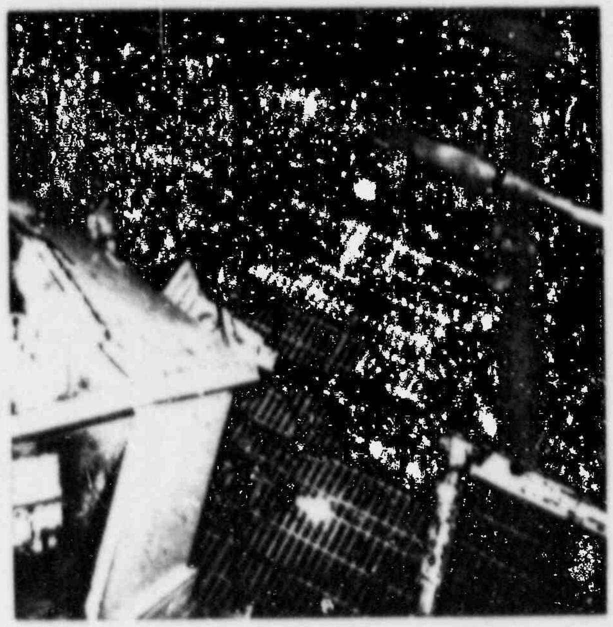


(9)

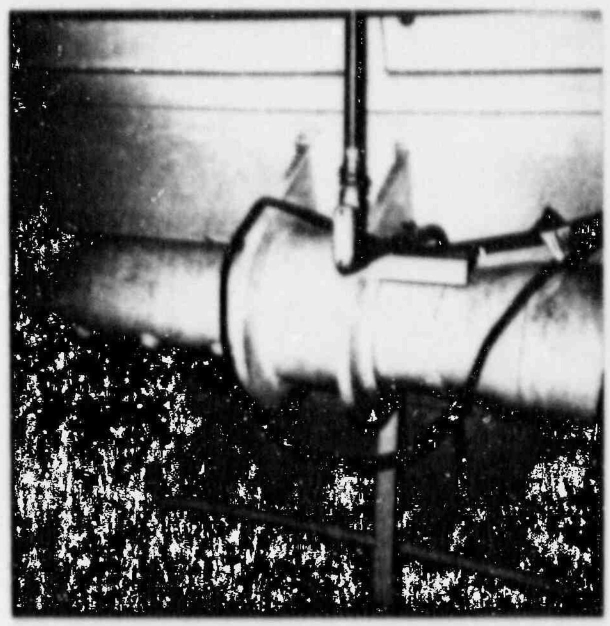
115° AZIMUTH

(10)

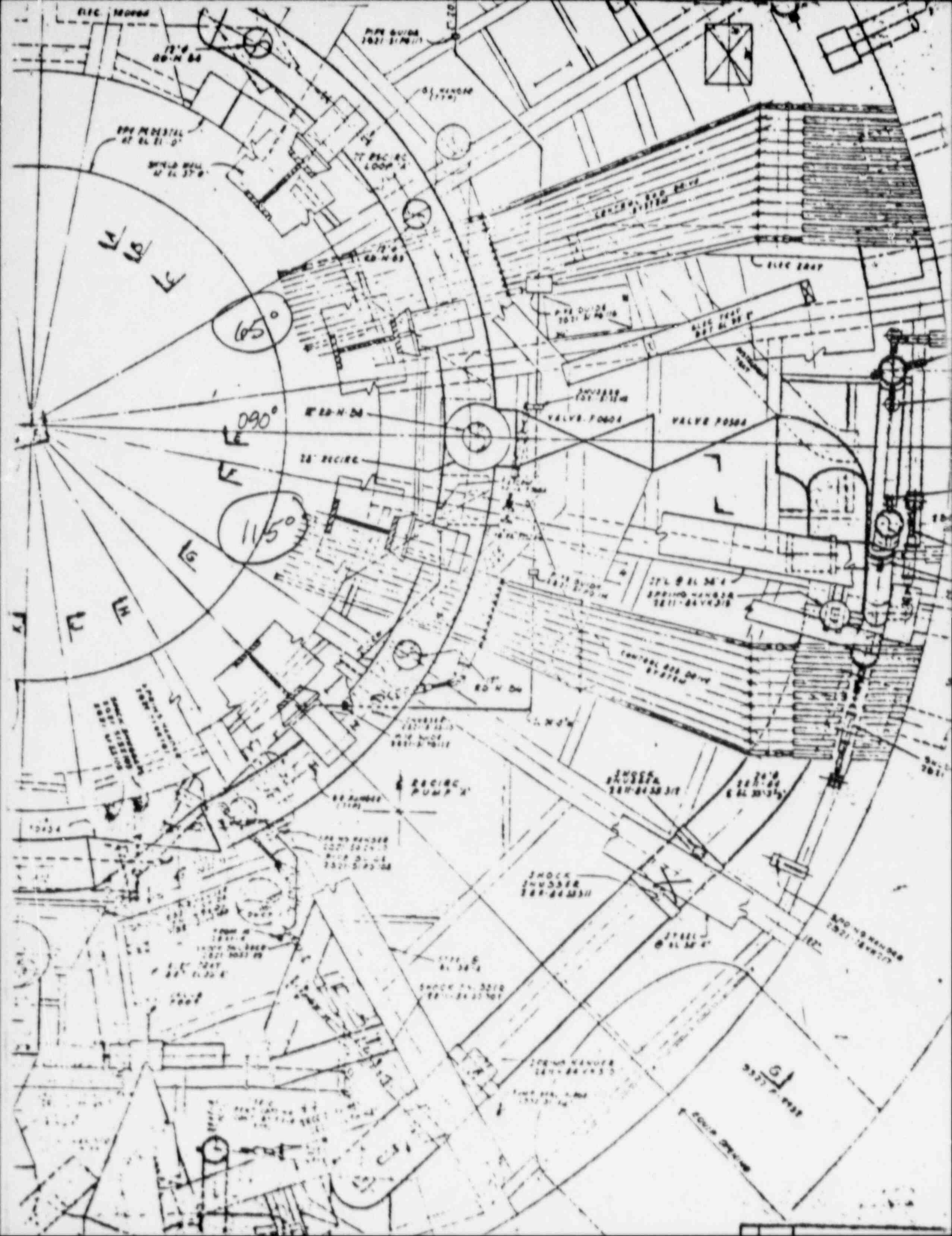


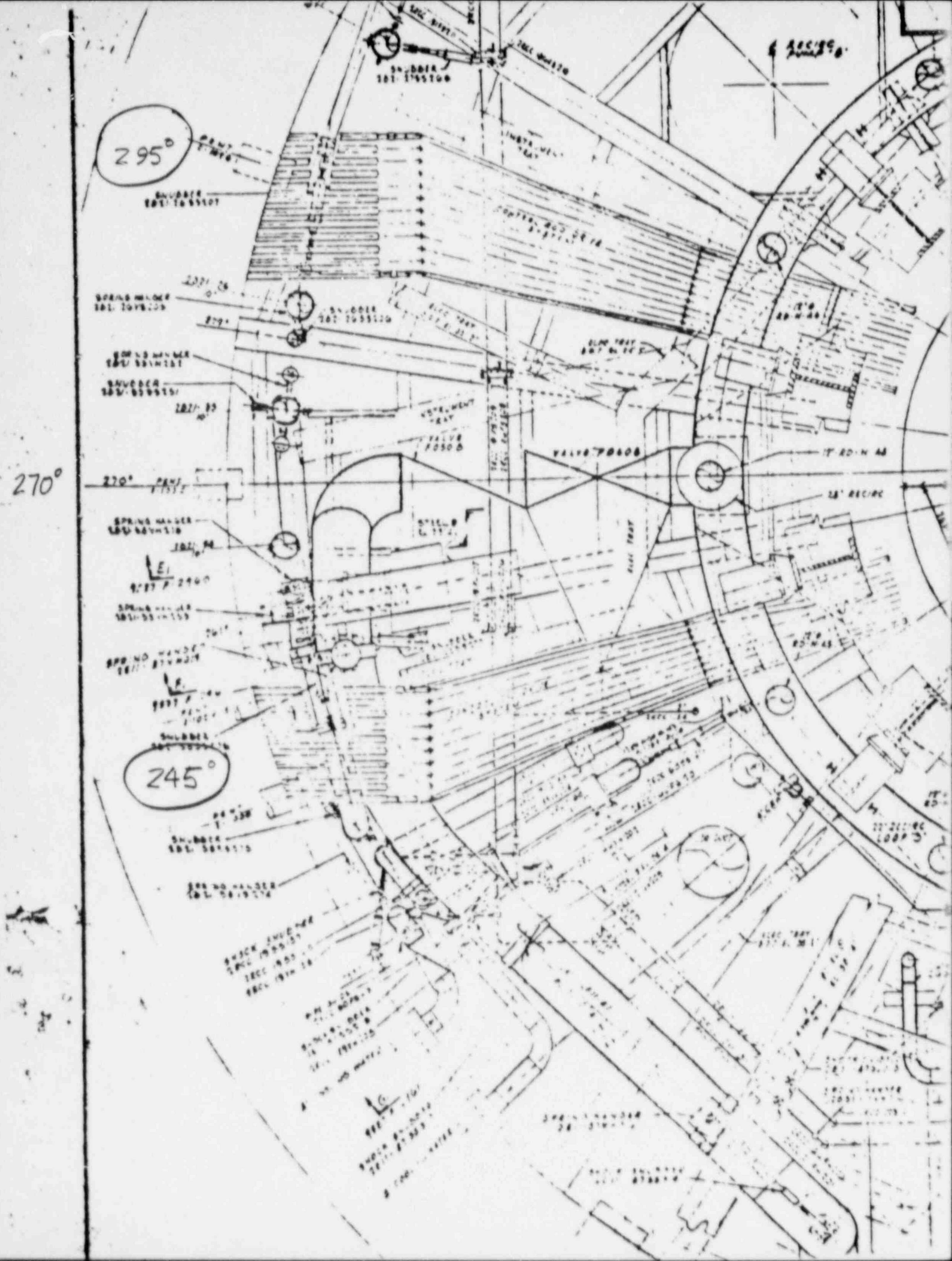
(11)

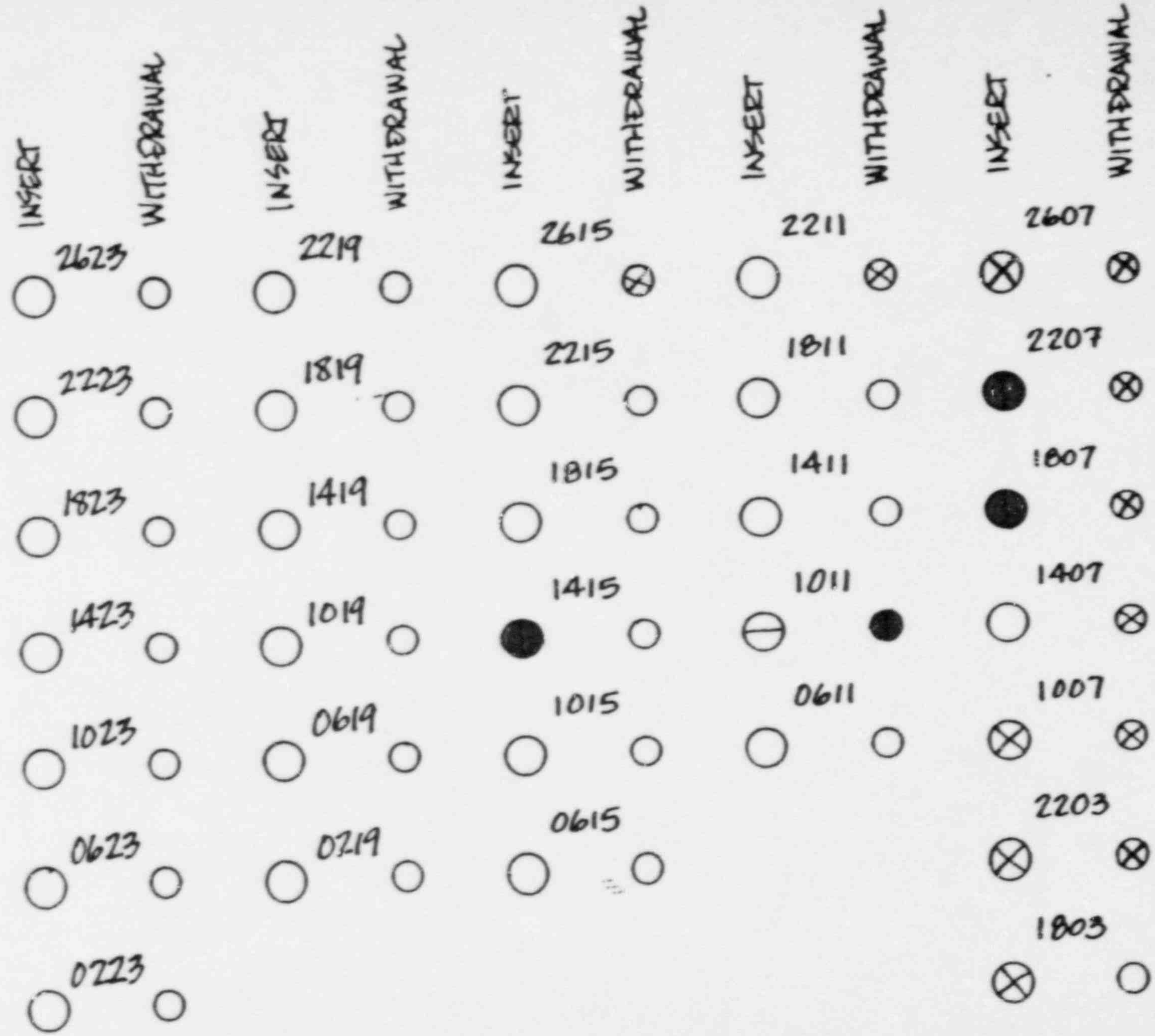
(12)



(13)

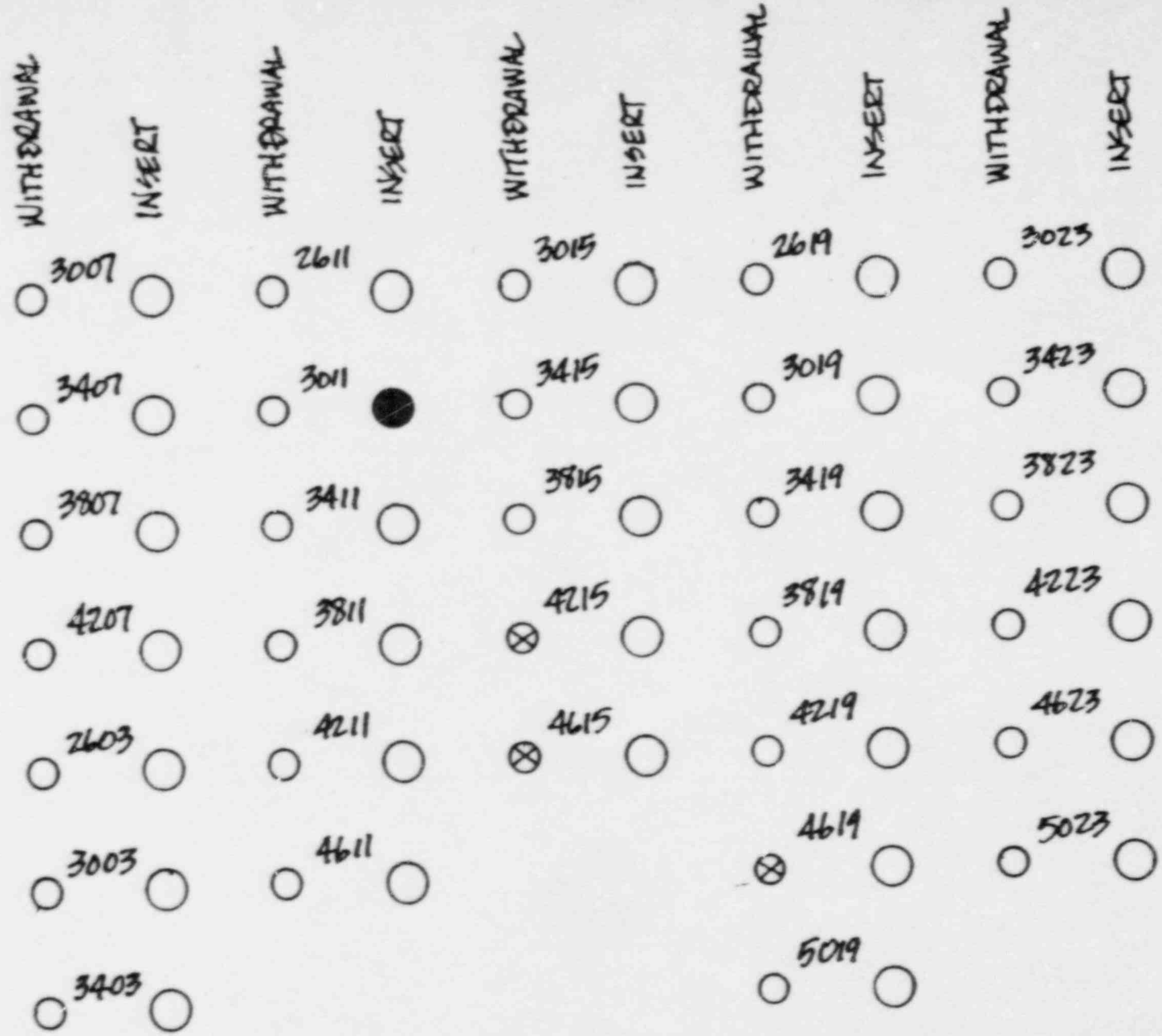

65°
090°
115°
CONTROL ROD DRIVE SYSTEM


295°
270°
245°



TO BE REPLACED (OR REPL. COMPLETE)
ACCEPT BY EVALUATION
BASEMETAL REPAIR REQ'D.

CRD BUNDLE @ 245° AZ
(LOOKING TOWARD RPV)



TO BE REPLACED (X = REPL. COMPLETE)

ACCEPT BY EVALUATION

CRD BUNDLE @ 115° AZ
(LOOKING TOWARD RPV)

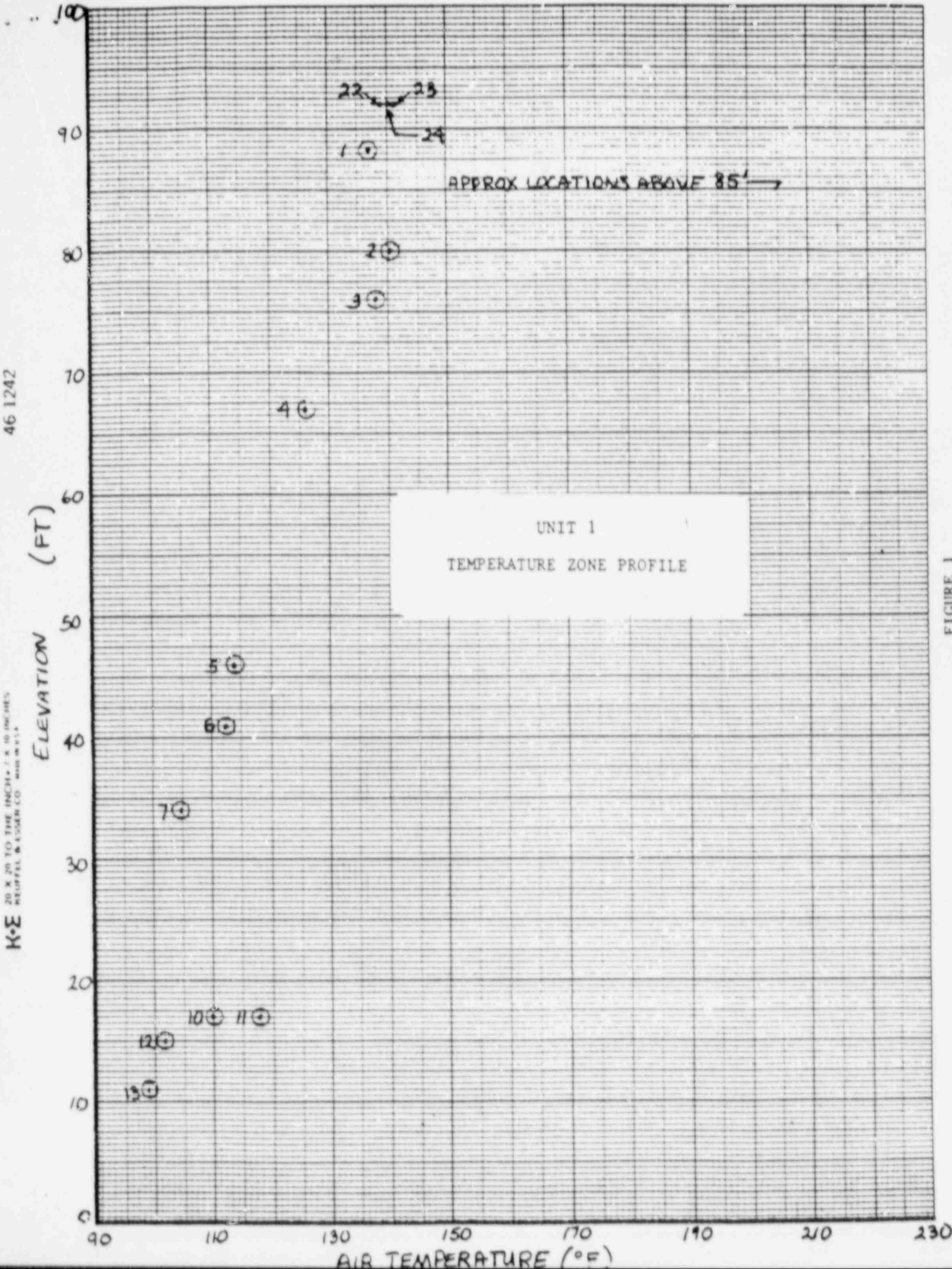

UNIT 1
TEMPERATURE ZONE PROFILE
APPROX LOCATIONS ABOVE 85'
ELEVATION (FT)
AIR TEMPERATURE (°F)
0
10
20
30
40
50
60
70
80
90
100
90
110
130
150
170
190
210
230
1
2
3
4
5
6
7
10
11
12
13
22
23
24
K·E
46 1242

FIGURE 1

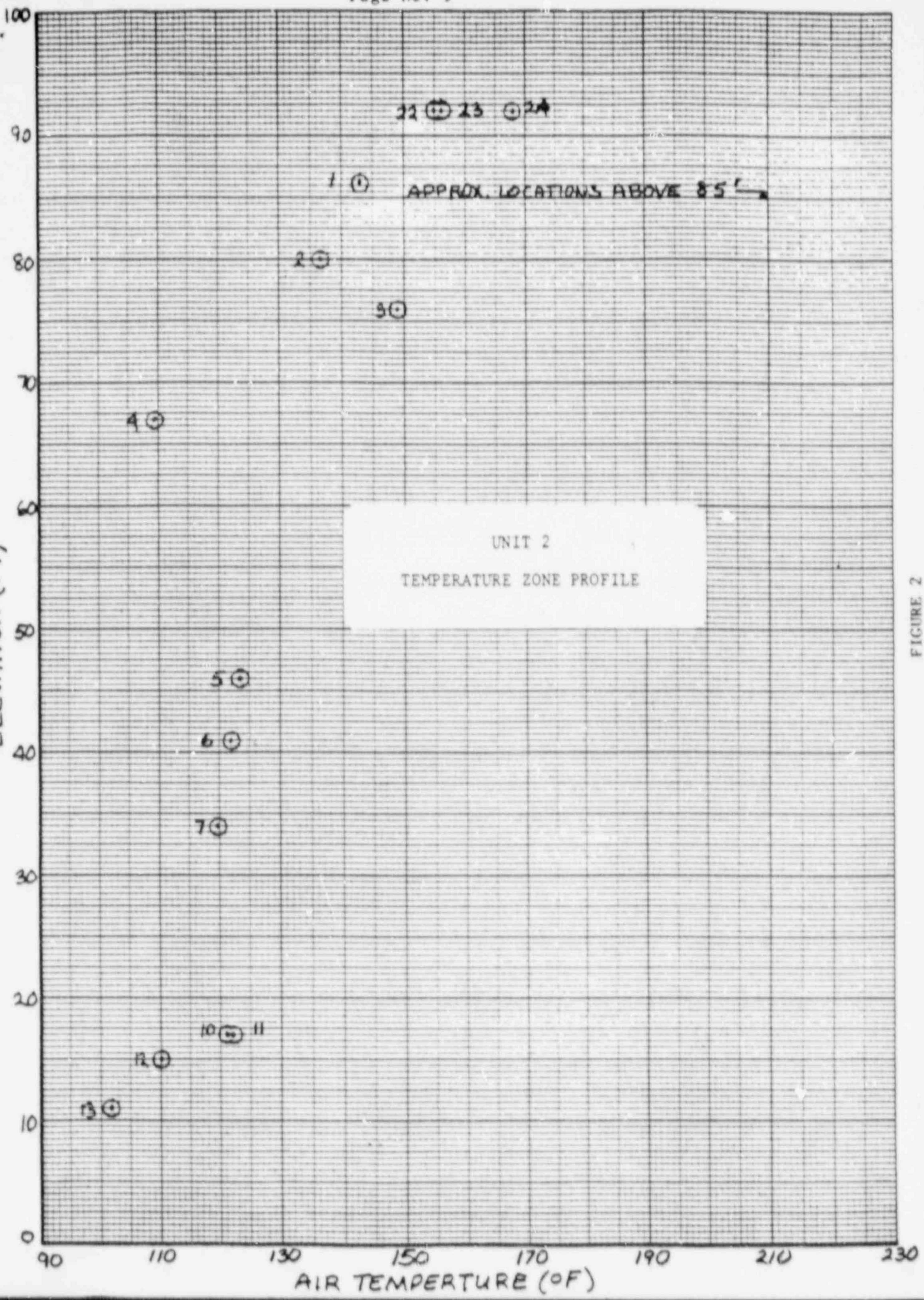

UNIT 2
TEMPERATURE ZONE PROFILE
APPROX. LOCATIONS ABOVE 85'
ELEVATION (FT)
AIR TEMPERTURE (°F)
100
90
80
70
60
50
40
30
20
10
0
90
110
130
150
170
190
210
230
1
2
3
4
5
6
7
10
11
12
13
22
23
24

FIGURE 2