50-267

Public Service Company of Colorado

16805 WCR 19 1/2, Platteville, Colorado 80651

RECEIVED APR 12 1984

April 6, 1984
Fort St. Vrain
Unit #1
P-84104

Mr. John T. Collins
Regional Administrator, Region IV
U. S. Nuclear Regulatory Commission
611 Ryan Plaza Dr., Suite 1000
Arlington TX 76011

SUBJECT: Fort St. Vrain Unit No. 1
Fuel Element Meeting

Dear Mr. Collins:

On April 4, 1984, a meeting was held in Bethesda with members of the NRR staff to discuss the two cracked fuel elements that were discovered in 1982 and the present inspection program for segment 3 fuel. We are transmitting herewith the information presented at that meeting.

As a general summary we presented the following information:

1. HISTORICAL REVIEW, FUEL ELEMENT INSPECTION PROGRAMS

An historical review of the spent fuel element inspection program at Fort St. Vrain was presented. This included a general overview of the PIE Programs for segments 1 and 2. A typical fuel inspection video tape was shown of element 1-2693 to indicate inspection capabilities and to depict typical fuel element conditions. The video tape also contained a portion of the hot cell inspection at Fort St. Vrain of one of the cracked fuel elements (1-2415). Typical inspection results were presented. The history of the two cracked elements was presented along with the results of investigations that have been conducted to date.

The conclusions from this portion of the presentation were as follows:

A. All fuel elements with the exception of the two cracked elements (1-2415 and 1-0172) have been found to be in excellent condition.

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B. The equipment utilized to inspect fuel elements in the FSV hot cell provides excellent inspection results and certainly provides more than adequate resolution to detect any significant fuel damage.

C. The program for investigating the two cracked elements has progressed to the point where probable cause for the cracking has been defined. No detrimental effects on fuel element integrity or fuel performance has been identified that could result in cause for concern for public health and safety.

D. Some portions of the cracked fuel element program are on-going. The results of any continuing efforts will be reported to the NRC in a timely fashion.

E. All correspondence and reports were summarized and are listed in the attached viewgraphs.

2. CURRENT SEGMENT 3 INSPECTION PROGRAM

The current segment 3 fuel inspection program was discussed. The discussion included a description of the fuel element inspection program in the fuel handling machine and changes that were made in the program as a result of experiencing problems with underexposed photographs.

High quality photographs were obtained of all six (6) faces of all elements from Regions 18 and 33. In addition a detailed video camera inspection was made for Region 18 fuel elements utilizing the Fuel Handling Machine Cask Camera, and 7.5 power 35 mm photographs were taken of the center of all faces of all Region 18 fuel elements. Typical photographs were presented at the meeting.

Tentative plans for the Segment 3 PIE Program were set forth. Present plans include inspection of about 60 fuel and reflector elements in the Fort Saint Vrain Hot Cell. We intend to examine all of the Region 18 fuel elements plus some precharacterized elements from Regions 3, 13, 22 and 29. Present plans are to begin the PIE program in late May 1984 with anticipated completion by late July 1984.

Conclusions from this portion of the presentation were as follows:

A. No significant fuel damage was found for those elements inspected. The elements had stains, scratches, abrasions, minor gouges, all of which were typical of previous segment inspection results. No fuel element cracking was identified.

B. The quality of the 35 mm photographs is excellent and resolution is certainly adequate to detect any significant fuel damage. A complete file of all 8 X 10 photographs, including inspection evaluation sheets, is available at the site for NRC review. In addition the video tapes of the inspection efforts are available on site for review.

C. Based on power history, control rod patterns, and the fact that Region 18 is a ring 3 region similar to Region 8 in which the Segment 2 cracked elements were found, we have decided to examine all Region 18 elements in the hot cell for the PIE program. The PIE program will be done in the same manner as previous PIE programs, the results of which have been reported to the NRC.

3. ANALYSES/TESTS FUEL ELEMENT PROGRAM

A detailed description of the probable causes for two cracked elements from Segment 2 was presented. The probable cause was defined as a high tensile stress experienced on the "B" face of the elements induced by high thermal gradients and shrinkage induced by neutron flux.

The fuel element stress analysis program that was developed by GA for the large HTGR was described and the application of that program to Fort Saint Vrain fuel elements was presented.

This detailed stress analysis was also utilized to investigate the probability of crack progression in Fort Saint Vrain fuel elements. The results of this analysis were presented.

Loading tests of typical H-327 unirradiated fuel elements were conducted with fuel element web cracks being simulated by physically cutting the webs with a hack saw. The results of various loading combinations along with combinations of fuel element web failures (from 0 to 3) were presented.

The conclusions from this portion of the program were as follows:

A. High thermal stresses induced by gap flows in combination with irradiation induced stresses resulted in high tensile stresses on the inter-regional faces of the two cracked elements. The detailed stress analysis predicted the highest stress at the location of cracks. Given these causes and the possibility that these same conditions may exist in other areas of the core there is some possibility that other cracked elements might be observed in future refuelings.

B. There was a discussion of H-451 graphite properties, and it was pointed out that H-451 graphite properties are better than H-327, but it would still be possible to exceed strength/strain ratios for H-451 graphite given the right conditions. This situation has been reported to the NRC in response to questions on the use of H-451 graphite in Segment 9.

C. Detailed stress analysis of the Fort Saint Vrain elements indicates that crack progression in the element is limited. As coolant hole/fuel hole webs are progressively cracked the tensile stress is reduced. The result of progressive cracking of five (5) webs from the fuel element face inward indicates that tensile stresses are reduced to acceptable values within the strength of the graphite. Cracking in one area also significantly reduces tensile stress of the other inter-regional faces of the fuel element resulting in a low probability that cracking would occur in any more than one area of a fuel element.

D. Given the possibility of fuel element cracking actual load testing was performed on elements with various combinations of cracked webs. The end result of the testing indicates that with various combinations of cracked coolant hole/fuel hole webs from 0 to 3, the strength of the fuel element is essentially unaffected. Even with cracked webs it would take in excess of 100,000 lbs. of compressive load to fail a fuel element.

4. SAFETY SIGNIFICANCE, FUEL ELEMENT CRACKS

The safety significance of fuel element cracking was discussed in terms of maintaining core cooling capabilities and maintaining the capability of control material insertion.

Various bounding conditions which have already been analyzed in the FSAR and other bounding conditions analyzed during the fluctuation test program were presented. It was pointed out that it would take several, non mechanistic failures of fuel elements to approach the bounding conditions.

On a more realistic basis the scope of a seismic loading on individual fuel elements at Fort Saint Vrain based conservatively on large HTGR analysis would have no affect on cracked fuel elements. Any loss of core cooling geometry would be very localized with minimal overall effects and certainly no effects on the health and safety of the public. There is no mechanistic failure of fuel elements of the type seen in 1-2415 or 1-0172 that could lead to failure to insert either control rods or reserve shutdown material.

The conclusions from this portion of the program were as follows:

A. Fuel element cracking as identified to date has had no significant effect on fuel element integrity or fuel performance.

B. Fuel element cracking does not represent any increased risks to the health and safety of the public.

5. OVERALL SUMMARY

The overall summary of the meeting was presented as follows:

A. There have been two (2) fuel elements (1-2415 and 1-0172) that have hairline cracks vertically along the "B" face.

B. A program to investigate these two (2) elements to determine probable cause as well as any detrimental effects has been setforth.

C. The program has progressed to the point of identifying the probable cause, and has not identified any detrimental effects on fuel performance or fuel element integrity that could be related to the health and safety of the public.

D. Some facets of the cracked fuel element program are still in progress and/or are scheduled in the future. Results of these on-going programs will be made available in a timely fashion.

E. There are adequate inspection programs in place to inspect Fort St. Vrain spent fuel as it is removed from the core.

F. The programs to date have resulted in the inspection and examination of a very high percentage of spent fuel elements, both in the fuel handling machine and in the PIE programs.

G. A very high percentage (approximately 30%) of Segment 3 spent fuel elements have been inspected to date with no apparent problems identified. The upcoming PIE program will provide inspection of approximately 60 fuel elements in the hot cell. Photographs of all Segment 3 spent fuel elements will be obtained in conjunction with fuel shipping.

H. Inspections to date confirm the capability of detecting any significant fuel element damage.

I. In terms of Fort St. Vrain operation:

Fuel element cracking is not progressive in nature and has not resulted in degrading overall fuel block strength or fuel particle integrity. Fuel performance to date has been excellent as directly evidenced by circulating activity as well as the PIE program results.

Fuel element cracking as seen to date has no implications involving the health and safety of the public.

PSC plans to continue inspection of spent fuel elements in the fuel handling machine during all future refueling operations.

The circulating activity of Fort St. Vrain is continuously monitored. Any significant fuel damage can be readily detected.

6. CONCLUSION

The NRC indicated that they were satisfied with analyses and inspections done to date in terms of allowing Fort St. Vrain to return to power operation. The NRC expects to be kept informed of the results of the PIE program inspection and would expect timely notification of any significant fuel element damage that might be discovered.

The NRC asked that consideration be given to establishing an on-going fuel surveillance program, perhaps as a part of the Technical Specifications.

PSC indicated that they fully intended to maintain the fuel handling machine inspection efforts for all future refuelings, i.e. PSC plans to obtain 35 mm photographs of all six (6) faces of each spent fuel element in the fuel handling machine. In addition PSC has already committed to a surveillance program (see P-83348) with reference to inspection of H-451 graphite elements which has been accepted by Amendment 40 to the Operating License.

7. OTHER

An informal update was provided on the Fort Saint Vrain PCRV tendon prestressing system.

Sincerely,

Don W. Warembourg

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

DWW/djc

cc: Jim Miller, NRR
Phillip Wagner, Region IV
Debbie Bennett, LANL

FORT ST. VRAIN
FUEL ELEMENT INFORMATIONAL MEETING
APRIL 4, 1984

AGENDA

DESIGN FEATURES

- OVERALL REACTOR DESIGN FEATURES
- FUEL PARTICLE/ELEMENT DESIGN
- OVERALL CORE CONFIGURATION

HISTORICAL FUEL ELEMENT INSPECTION PROGRAMS

- GENERAL OVERVIEW PAST PIE PROGRAMS
- TYPICAL FUEL INSPECTION VIDEO TAPE
- TYPICAL INSPECTION RESULTS
- HISTORY OF CRACKED ELEMENTS
- INSPECTION RESULTS OF CRACKED ELEMENTS

FORT ST. VRAIN
FUEL ELEMENT INFORMATIONAL MEETING
APRIL 4, 1984

AGENDA

CURRENT INSPECTION PROGRAMS, SEGMENT 3

- INSPECTION PROGRAM CRITERIA
- TYPICAL INSPECTION RESULTS
- PLANS FOR SEGMENT 3 PIE PROGRAM

ANALYSES/TESTS FUEL ELEMENT PROGRAM

- CAUSES, EXISTING CRACKED ELEMENTS
- CRACK PROGRESSION
- FUEL ELEMENT STRENGTH WITH CRACKING

SAFETY SIGNIFICANCE, FUEL ELEMENT CRACKS

- CORE COOLING
- CONTROL MATERIAL INSERTION

FORT ST. VRAIN
FUEL ELEMENT INFORMATIONAL MEETING
APRIL 4, 1984

SUMMARY

- THERE HAVE BEEN TWO (2) FUEL ELEMENTS (1-2415 AND 1-0172) THAT HAVE HAIRLINE CRACKS VERTICALLY ALONG THE "B" FACE.

- A PROGRAM TO INVESTIGATE THESE TWO (2) ELEMENTS TO DETERMINE PROBABLE CAUSE AS WELL AS ANY DETRIMENTAL EFFECTS HAS BEEN SETFORTH.

- THE PROGRAM HAS PROGRESSED TO THE POINT OF IDENTIFYING THE PROBABLE CAUSE, AND HAS NOT IDENTIFIED ANY DETRIMENTAL EFFECTS ON FUEL PERFORMANCE OR FUEL ELEMENT INTEGRITY THAT COULD BE RELATED TO THE HEALTH AND SAFETY OF THE PUBLIC.

- SOME FACETS OF THE CRACKED FUEL ELEMENT PROGRAM ARE STILL IN PROGRESS AND/OR ARE SCHEDULED IN THE FUTURE. RESULTS OF THESE ON-GOING PROGRAMS WILL BE MADE AVAILABLE IN A TIMELY FASHION.

FORT ST. VRAIN
FUEL ELEMENT INFORMATIONAL MEETING
APRIL 4, 1984

SUMMARY

- THERE ARE ADEQUATE INSPECTION PROGRAMS IN PLACE TO INSPECT FORT ST. VRAIN SPENT FUEL AS IT IS REMOVED FROM THE CORE.
- THE PROGRAMS TO DATE HAVE RESULTED IN THE INSPECTION AND EXAMINATION OF A VERY HIGH PERCENTAGE OF SPENT FUEL ELEMENTS, BOTH IN THE FUEL HANDLING MACHINE AND IN THE PIE PROGRAMS.
- A VERY HIGH PERCENTAGE (APPROXIMATELY 30%) OF SEGMENT 3 SPENT FUEL ELEMENTS HAVE BEEN INSPECTED TO DATE WITH NO APPARENT PROBLEMS IDENTIFIED. THE UPCOMING PIE PROGRAM WILL PROVIDE INSPECTION OF APPROXIMATLEY 60 FUEL ELEMENTS IN THE HOT CELL. PHOTOGRAPHS OF ALL SEGMENT 3 SPENT FUEL ELEMENTS WILL BE OBTAINED IN CONJUNCTION WITH FUEL SHIPPING.
- INSPECTIONS TO DATE CONFIRM THE CAPABILITY OF DETECTING ANY SIGNIFICANT FUEL ELEMENT DAMAGE.

FORT ST. VRAIN
FUEL ELEMENT INFORMATIONAL MEETING
APRIL 4, 1984

SUMMARY

- IN TERMS OF FORT ST. VRAIN OPERATION:

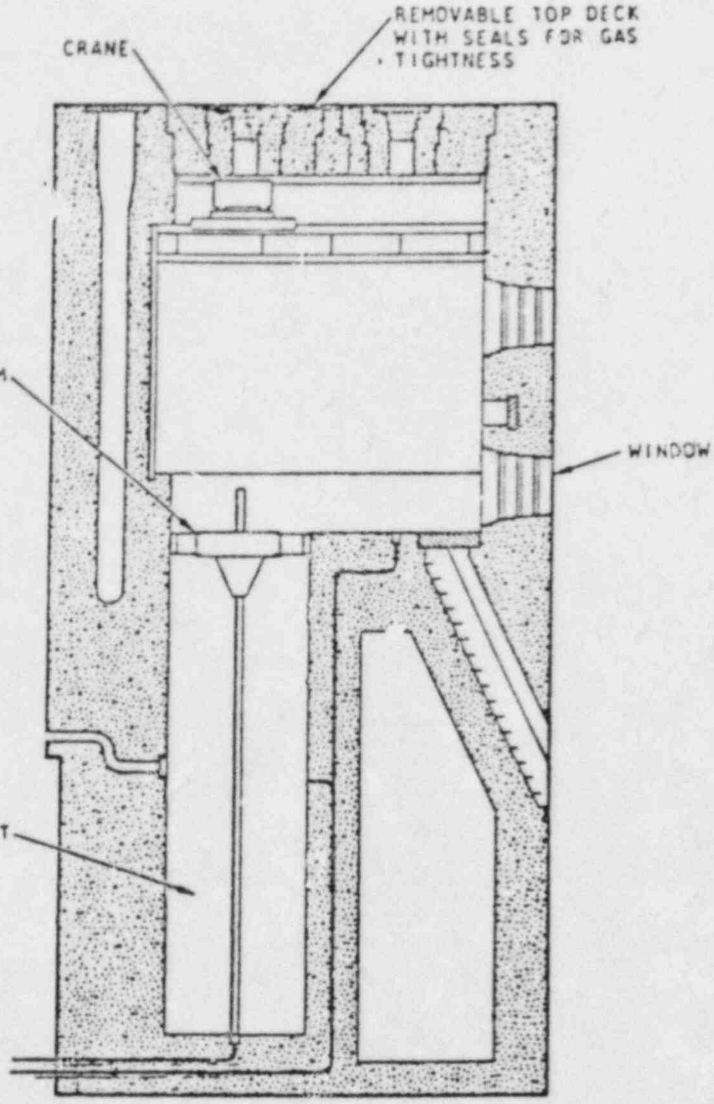
    - FUEL ELEMENT CRACKING IS NOT PROGRESSIVE IN NATURE AND HAS NOT RESULTED IN DEGRADING OVERALL FUEL BLOCK STRENGTH OR FUEL PARTICLE INTEGRITY. FUEL PERFORMANCE TO DATE HAS BEEN EXCELLENT AS DIRECTLY EVIDENCED BY CIRCULATING ACTIVITY AS WELL AS THE PIE PROGRAM RESULTS.

    - FUEL ELEMENT CRACKING AS SEEN TO DATE HAS NO IMPLICATIONS INVOLVING THE HEALTH AND SAFETY OF THE PUBLIC.

    - PSC PLANS TO CONTINUE INSPECTION OF SPENT FUEL ELEMENTS IN THE FUEL HANDLING MACHINE DURING ALL FUTURE REFUELING OPERATIONS.

    - THE CIRCULATING ACTIVITY OF FORT ST. VRAIN IS CONTINUOUSLY MONITORED. ANY SIGNIFICANT FUEL DAMAGE CAN BE READILY DETECTED.

PREVIOUS FORT ST. VRAIN NON-DESTRUCTIVE POST IRRADIATION EXAMINATION PROGRAMS



Hot Service Facility

SCOPE OF NON-DESTRUCTIVE

POST-IRRADIATION EXAMINATIONS

PERFORMED IN THE FORT ST. VRAIN HOT SERVICE FACILITY

DIMENSIONAL MEASUREMENTS

- Across Flats Dimensions
- Length
- Coolant Hole Diameters
- Distances Between Coolant Holes
- Bow
- Distances Between Surveillance Element Fiducial Holes

VISUAL INSPECTIONS

- Cracks
- Graphite Oxidation
- Evidence of Mechanical Interaction Between Elements
- Scratches
- Stains
- Flow Marks
- Other Features of Interest

RADIOACTIVITY MEASUREMENTS

- Gamma
- Neutron

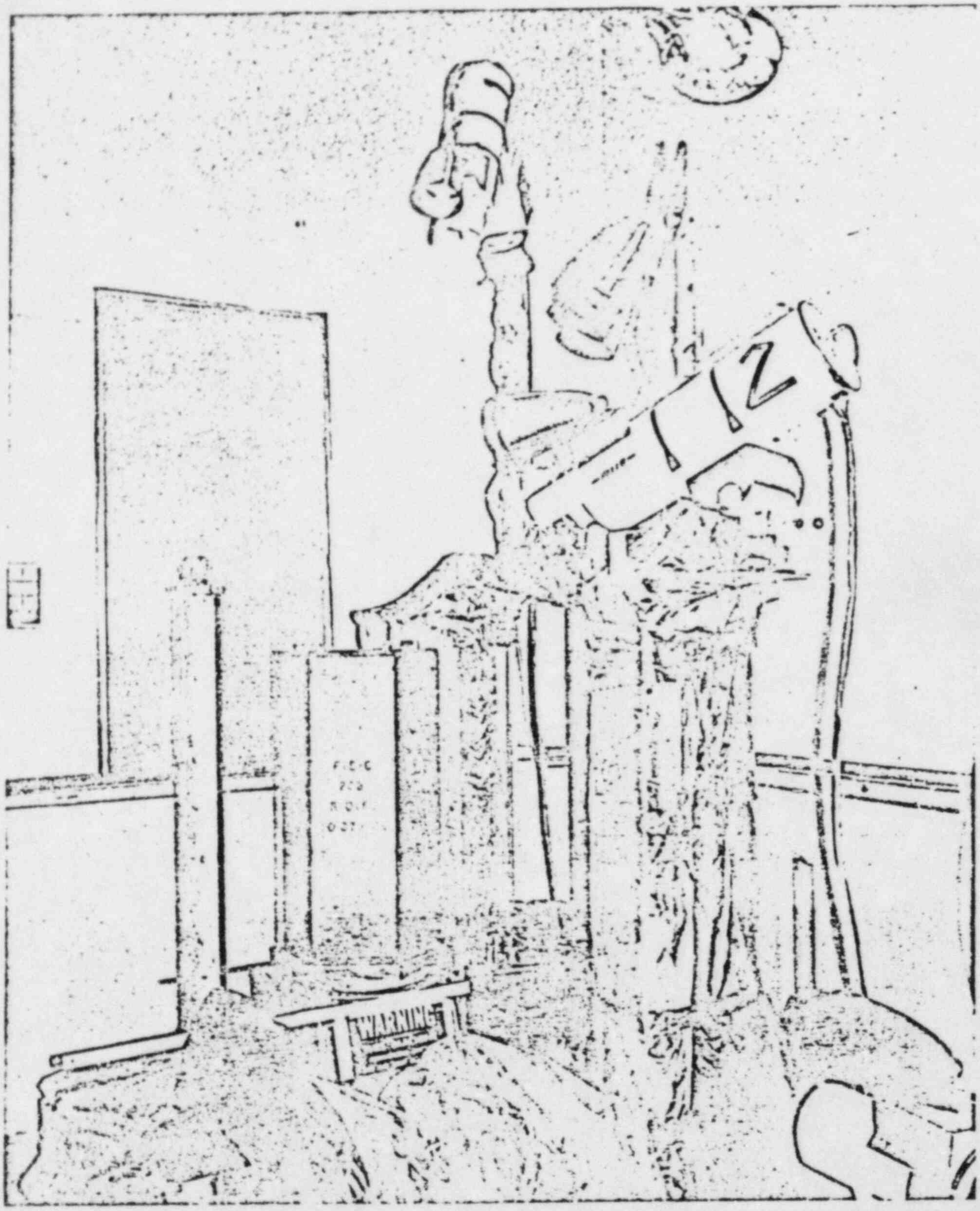


Fig. 4-1. Metrology robot in HSF at FSV

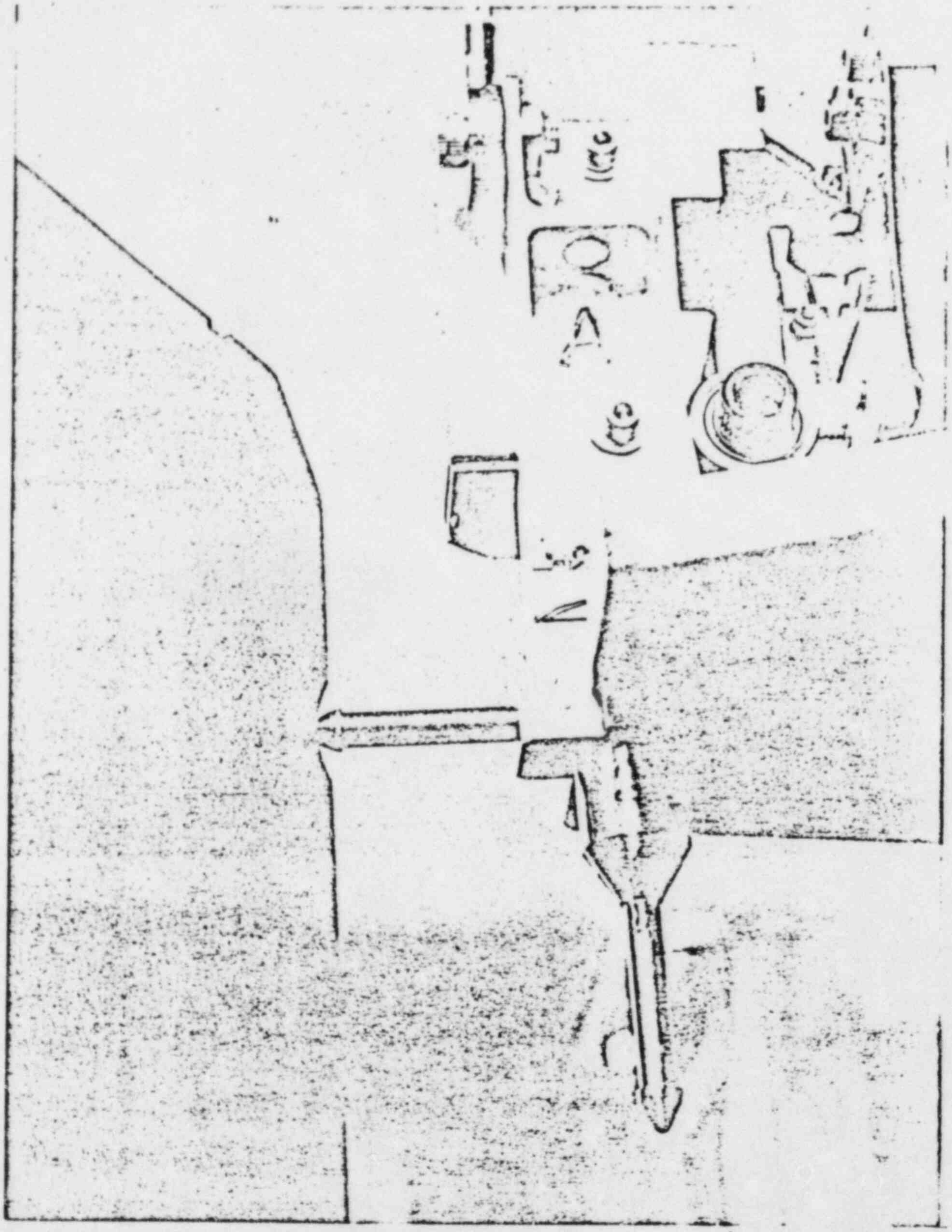


Fig. 4-2. Side view of the metrology robot probe; the probe leg is inserted into a fiducial hole in the corner of a surveillance fuel element.

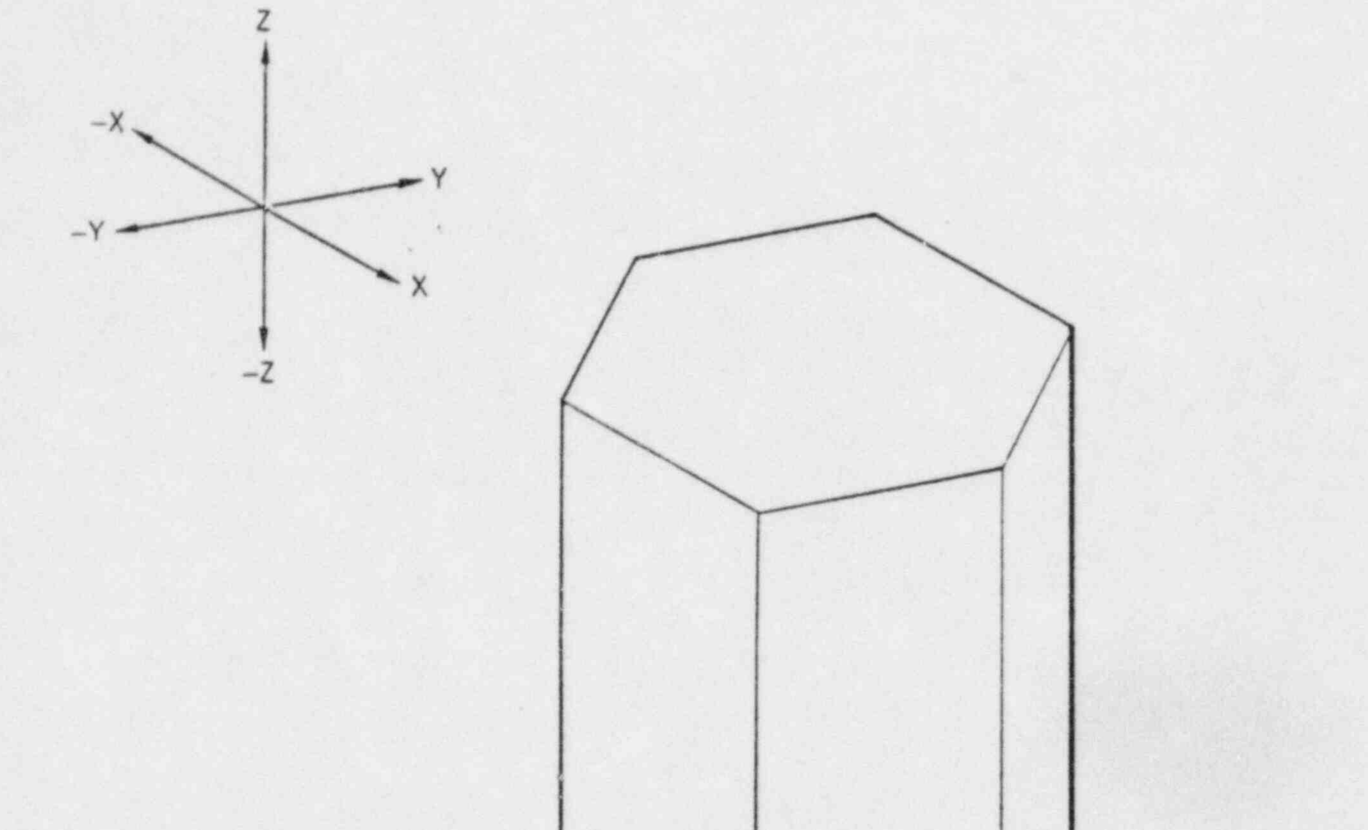
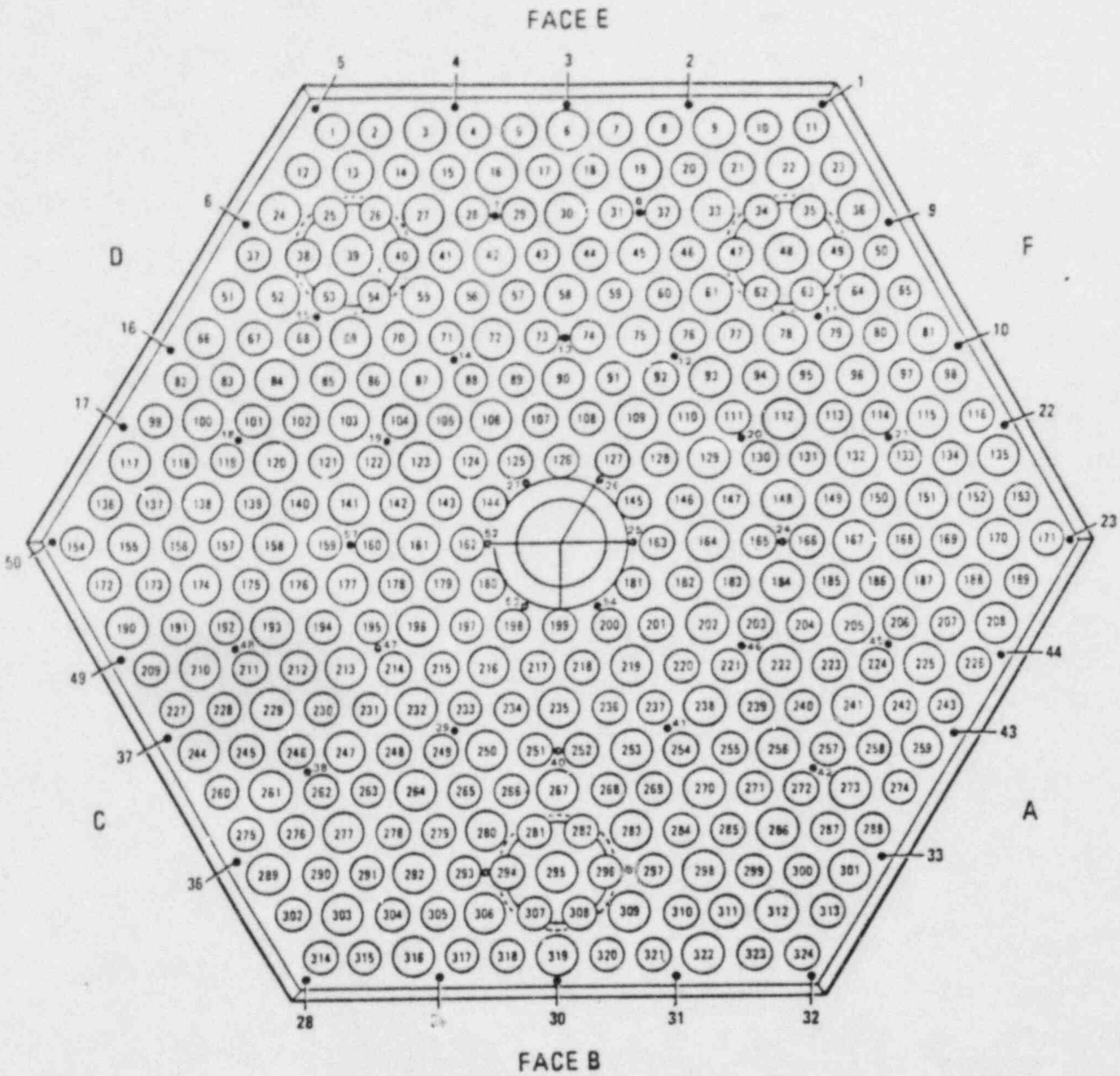


Fig. 4-3. Metrology robot coordinate system



(a) REGULAR FUEL ELEMENT; FULL LENGTH AND ABBREVIATED INSPECTIONS

Fig. 4-6. Top surface measurements of FSV core components (sheet 1 of 2)

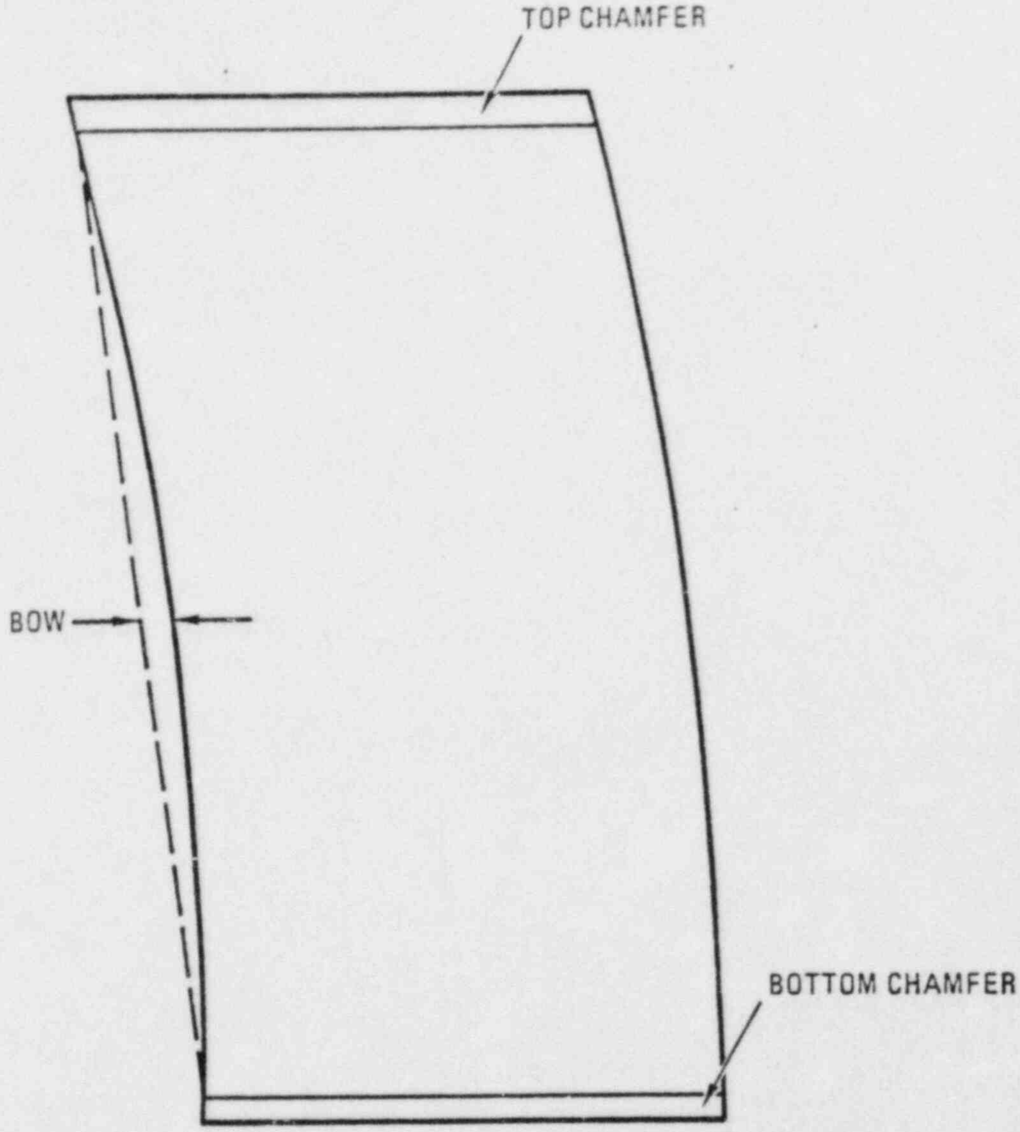


Fig. 4-9. Bow of FSV core components. Bow is defined as the displacement of the side face relative to a straight line connecting the top and bottom (below and above the chamfers) of the side face

SEGMENT 1 AND SEGMENT 2

NON-DESTRUCTIVE

POST IRRADIATION EXAMINATIONS

COMPONENTS EXAMINED

•	Segment 1	49 Fuel Elements 2 Reflector Elements
•	Segment 2	48 Fuel Elements 6 Reflector Elements

METROLOGY RESULTS

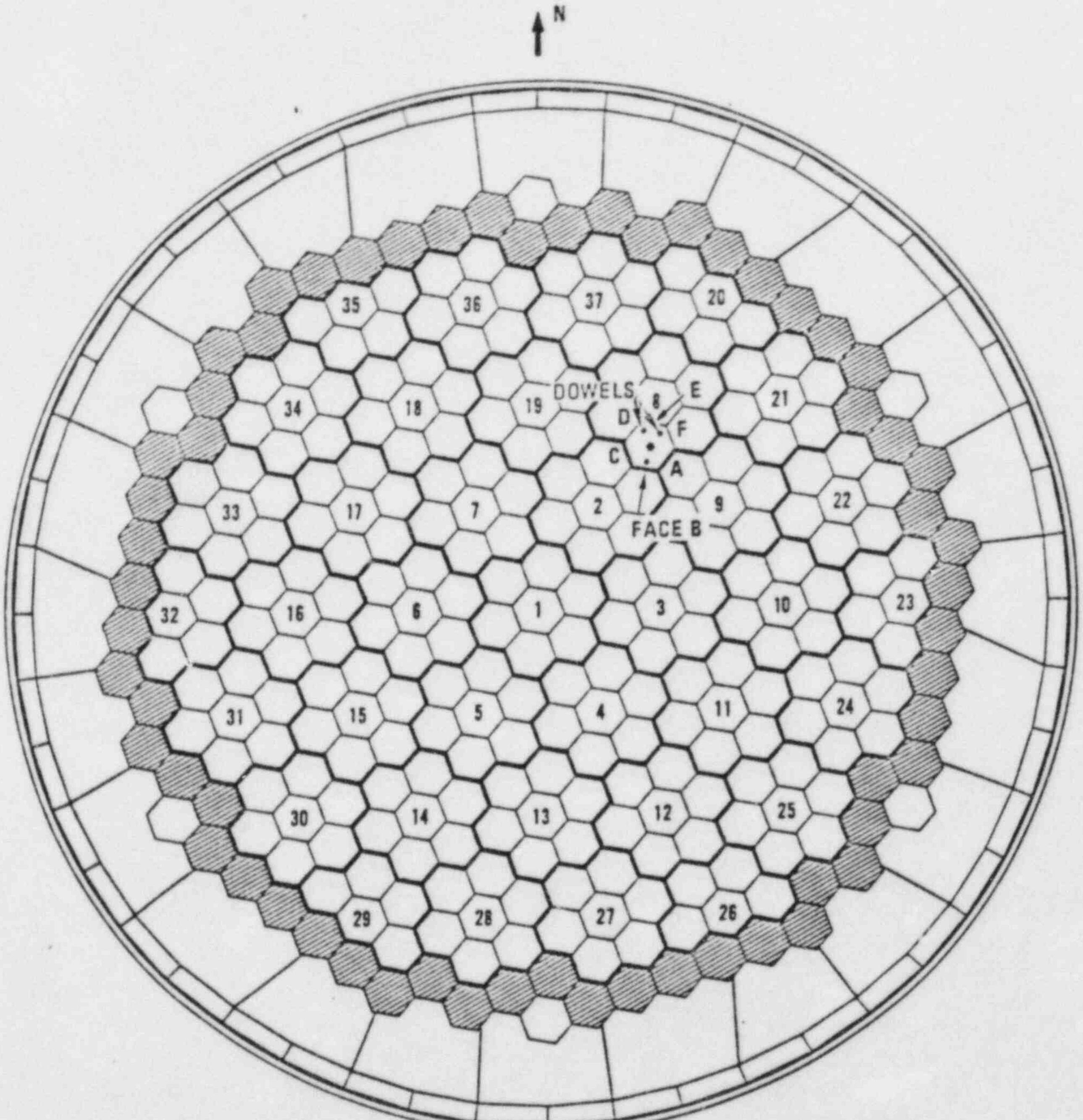
•	Segment 1	Axial and Radial Fuel Element Shrinkage Little Dimensional Change in Reflector Elements
•	Segment 2	Same

VISUAL INSPECTION RESULTS

•	Segment 1	All Elements in Excellent Condition
•	Segment 2	All Elements in Excellent Condition Except for Two with Single Localized Cracks on Face B

REFERENCES

•	Segment 1	PSC Letter, Lee to Novak Dated 11/16/81 (P-81254)
•	Segment 2	PSC Letter, Brey to Collins, Dated 6/2/83 (P-83196)



*FUEL ELEMENT 1-2415
REGION 8, COLUMN 5, CORE LAYER 6 (ACTIVE CORE LAYER 3)

Fig. 3-3. Core location of fuel element 1-2415

CHRONOLOGICAL HISTORY

DECEMBER, 1981

REQUEST TO DELETE DESTRUCTIVE EXAMINATION OF A SEGMENT 2 FUEL ELEMENT (P-81322, 12/11/81)

APRIL, 1982

FIRST INDICATION OF A CRACK IN 1-2415 (04/26/82)

CONFIRMATION AND TELECON NOTIFICATION (04/30/82)

WRITTEN NOTIFICATION (P-82130, 05/04/82)

MAY, 1982

SELECTION OF CANDIDATE ELEMENTS FOR GA HOT CELL

REVIEW OF PIE VIDEOTAPES

CHRONOLOGICAL HISTORY

JUNE AND JULY, 1982

SHIPMENT OF FIVE FUEL ELEMENTS TO GA TECHNOLOGIES (YVB-ZGQ-005, RECEIVED 06/30/82)

INSPECTION PROGRAM BEGINS (07/07/82)

CONFIRMATION OF CRACKS IN 1-2415, 1-0172 (07/07/82)

TELECON NOTIFICATION (07/08/82)

DISCUSSION IN BETHESDA (07/14/82)

AUGUST THROUGH OCTOBER, 1982

CONTINUED FIVE-ELEMENT INSPECTION PROGRAM, REPORT GENERATION

UPDATED STATUS (P-82394, 09/15/82)

JANUARY, 1983

NRC GRANTED REQUEST TO DELETE SEGMENT 2 ELEMENT DESTRUCTIVE EXAM (G-83042, 01/24/83)

SUPPLEMENTAL EXAM OF ROD FROM 1-2415

SUPPLEMENTAL EXAM OF ROD FROM FTE-2

CHRONOLOGICAL HISTORY

FEBRUARY, 1983

PSC COMMITMENT TO G-83042

LANL TO PSC REQUEST FOR INFORMATION (G-83075, 02/16/83)

MARCH, 1983

LANL TO PSC REQUEST FOR MEETING (G-83130, 03/22/83)

APRIL, 1983

LANL/GA/PSC MEETING 04/07-08/83

MAY, 1983

PSC TO LANL CORRESPONDENCE (P-83176, 05/13/83)

JUNE, 1983

COMPILED SUBMITTAL OF REPORTS (P-83196, 06/02/83)

JULY, 1983

PSC TO LANL CORRESPONDENCE (P-83247, 07/14/83)

CHRONOLOGICAL HISTORY

AUGUST, 1983

GRAPHITE SECTIONS TO LANL FROM GA

TRANSMITTAL OF DATA TAPE FOR REGION 8 TO LANL FROM GA

OCTOBER, 1983

UPDATE OF CRACKING MECHANISM (P-83348, 10/27/83)

NOVEMBER, 1983

COMPLETED METALLOGRAPHIC EXAM OF 1-2415 FUEL ROD (11/08/83)

DECEMBER, 1983

REVIEWS AND APPROVALS OF METALLOGRAPHIC REPORT

JANUARY, 1984

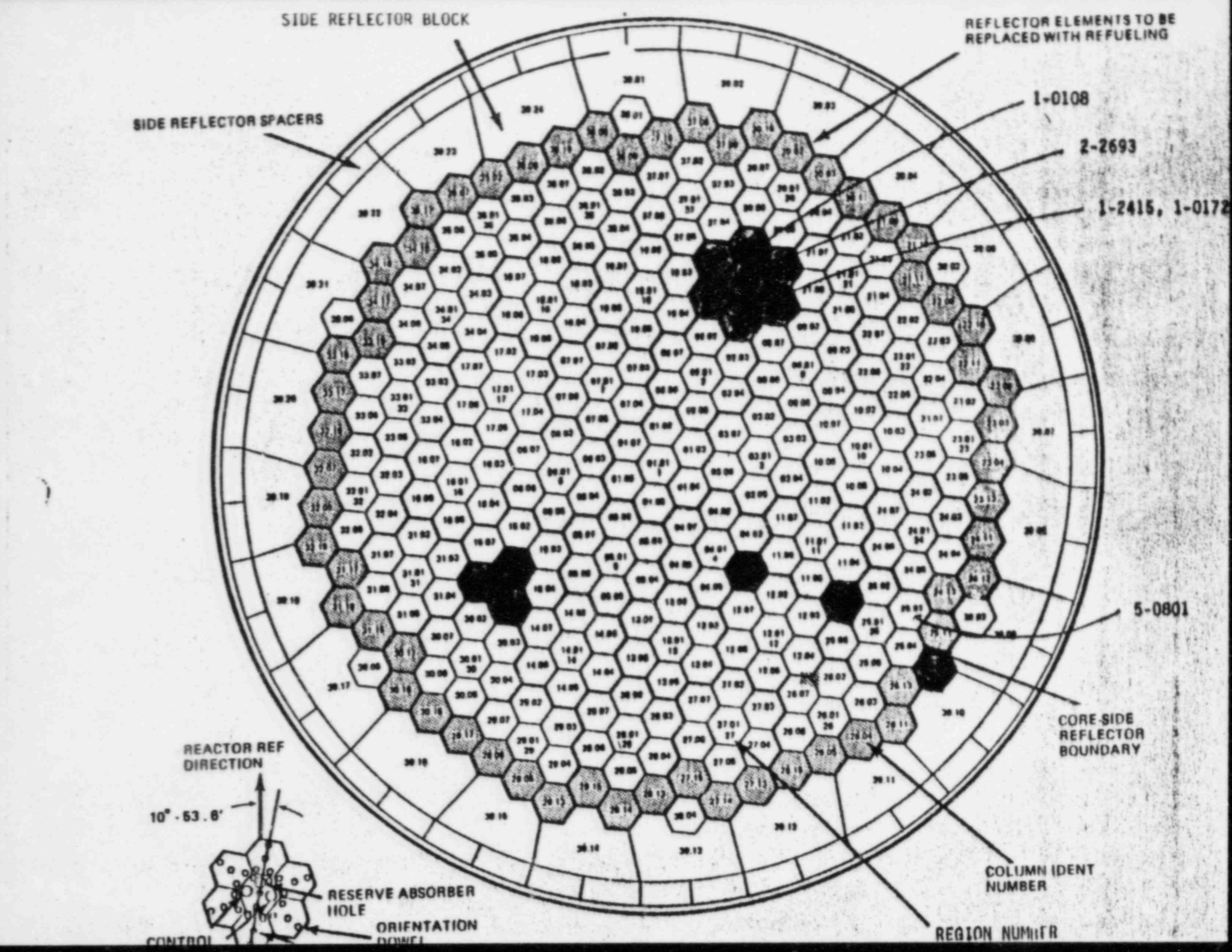
SUBMITTAL OF METALLOGRAPHIC REPORT (P-84001, 01/03/84)

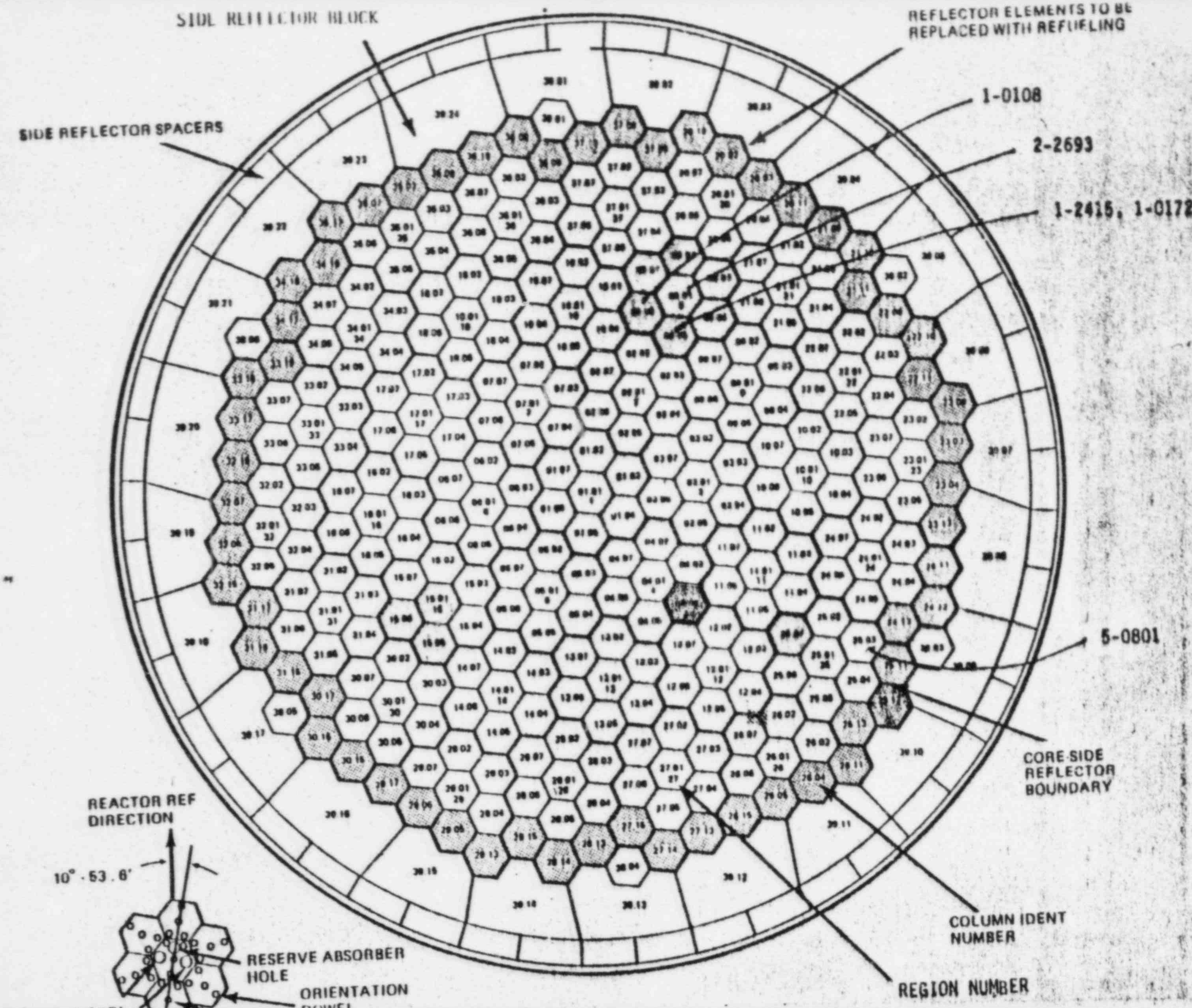
CHRONOLOGICAL HISTORY

FEBRUARY, 1984

NRC CONCERNS OVER SEGMENT 3 INSPECTION PROGRAM (TELECON, 02/10/84)

PSC COMMITMENTS TO SEGMENT 3 INSPECTION PROGRAM (P-84053, 02/15/84)


SIDE REFLECTOR BLOCK
REFLECTOR ELEMENTS TO BE REPLACED WITH REFUELING
SIDE REFLECTOR SPACERS
1-0108
2-2693
1-2415, 1-0172
5-0801
CORE-SIDE REFLECTOR BOUNDARY
COLUMN IDENT NUMBER
REGION NUMBER
REACTOR REF DIRECTION
10° - 53.6'
RESERVE ABSORBER HOLE
ORIENTATION DOWEL
CONTROL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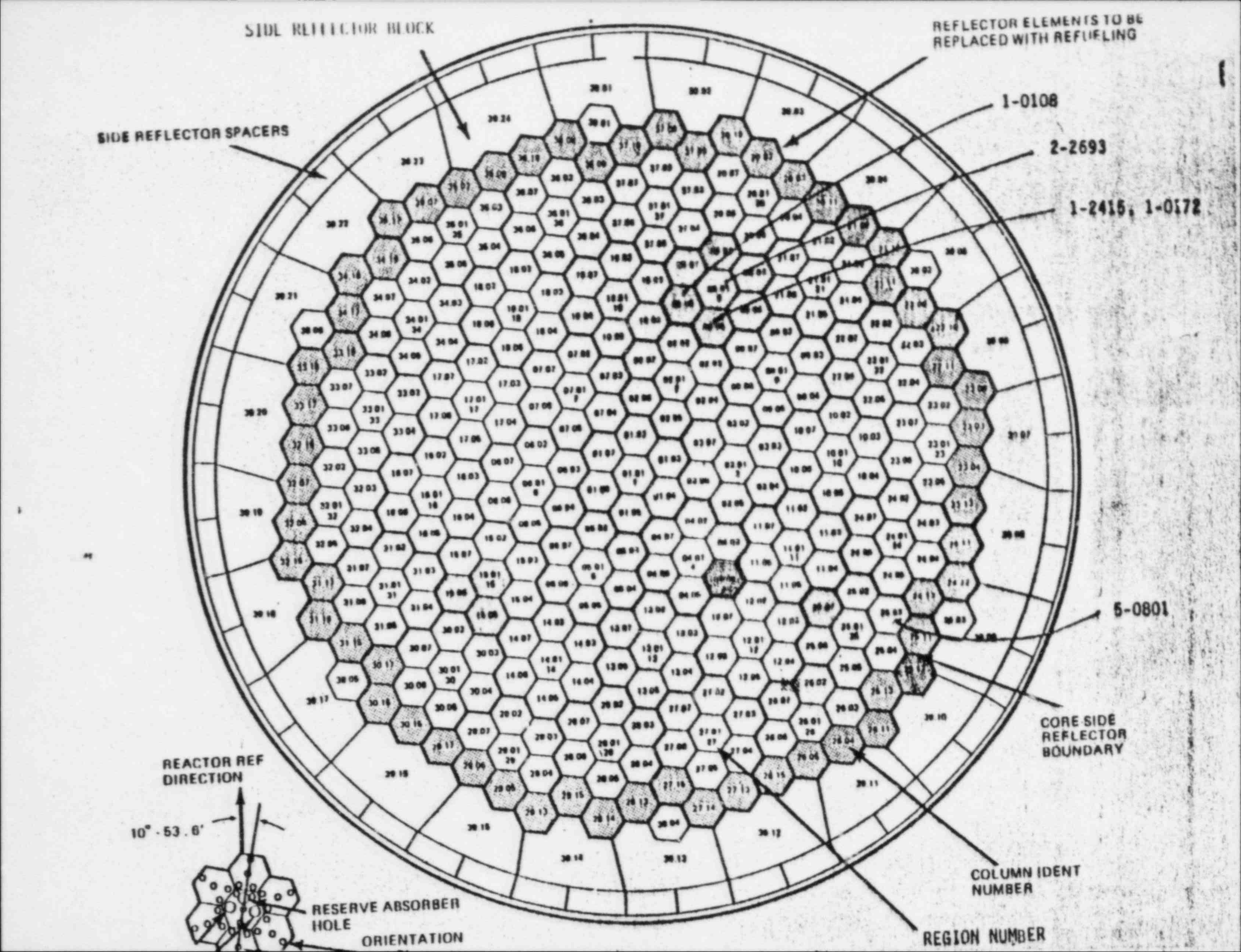
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CORE SIDE REFLECTOR BOUNDARY
COLUMN IDENT NUMBER
REGION NUMBER
REACTOR REF DIRECTION
10° - 53.6'
RESERVE ABSORBER HOLE
ORIENTATION

PROGRAM RESULTS

VISUAL EXAMINATION OF 54 ELEMENTS AT FSV

ELEMENT SELECTION

PERTINENT RESULTS

ALL SURFACES WERE VISUALLY EXAMINED, PHOTOGRAPHED, AND VIDEOTAPED.

INSPECTED ELEMENTS WERE IN GOOD CONDITION.

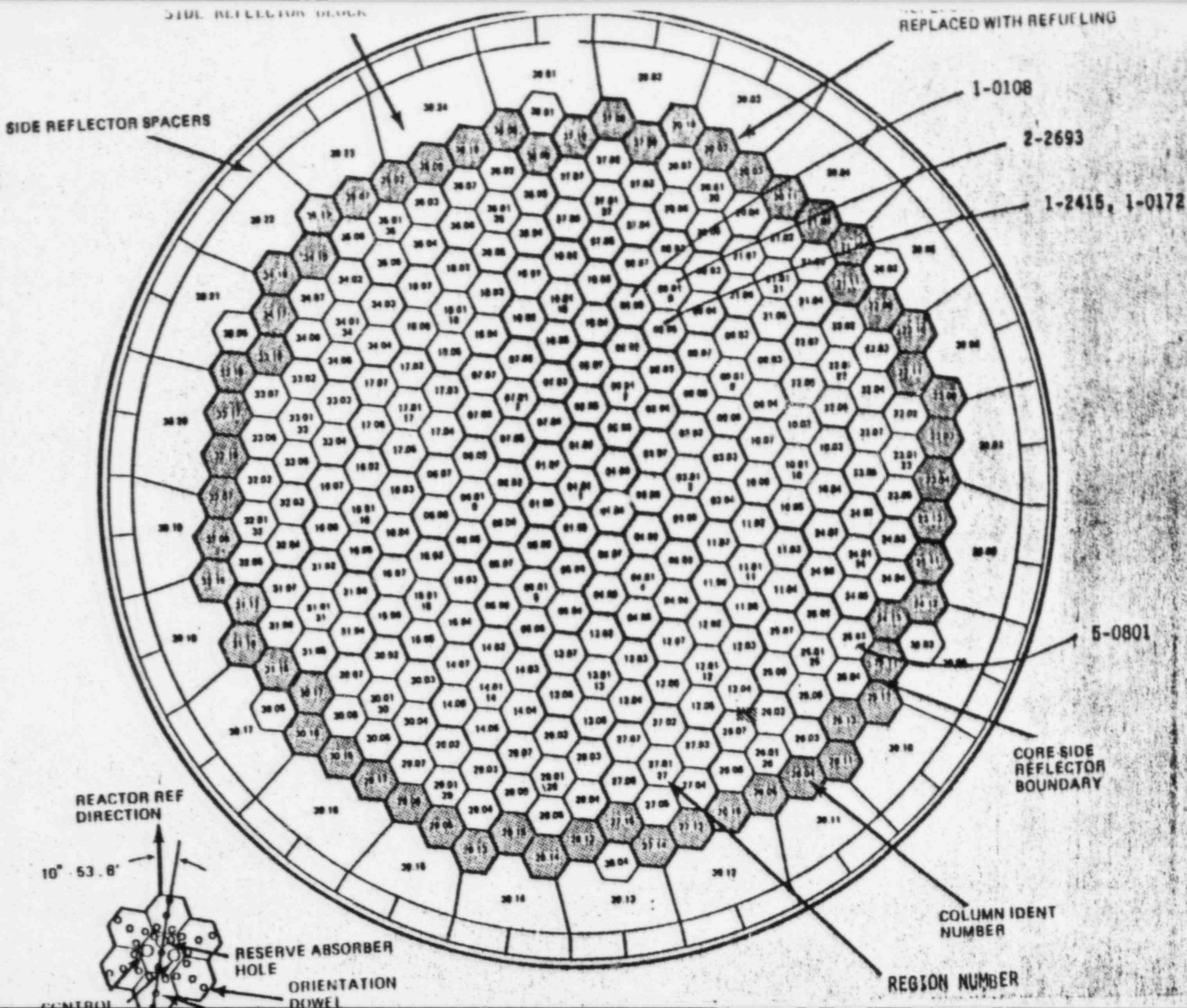
SINGLE CRACKS IN EACH OF TWO ELEMENTS WERE OBSERVED. THESE CRACKS DID NOT AFFECT ELEMENT GEOMETRY, COOLANT CHANNEL ALIGNMENT, OR HANDLING.

OBSERVED BLEMISHES WERE SIMILAR TO THOSE SEEN IN PREVIOUS EXAMINATIONS.

PROGRAM RESULTS

NON-DESTRUCTIVE EXAMINATION OF 1-2415 AT FSV

- DESCRIPTION OF CRACK
- ALCOHOL TEST WAS INCONCLUSIVE

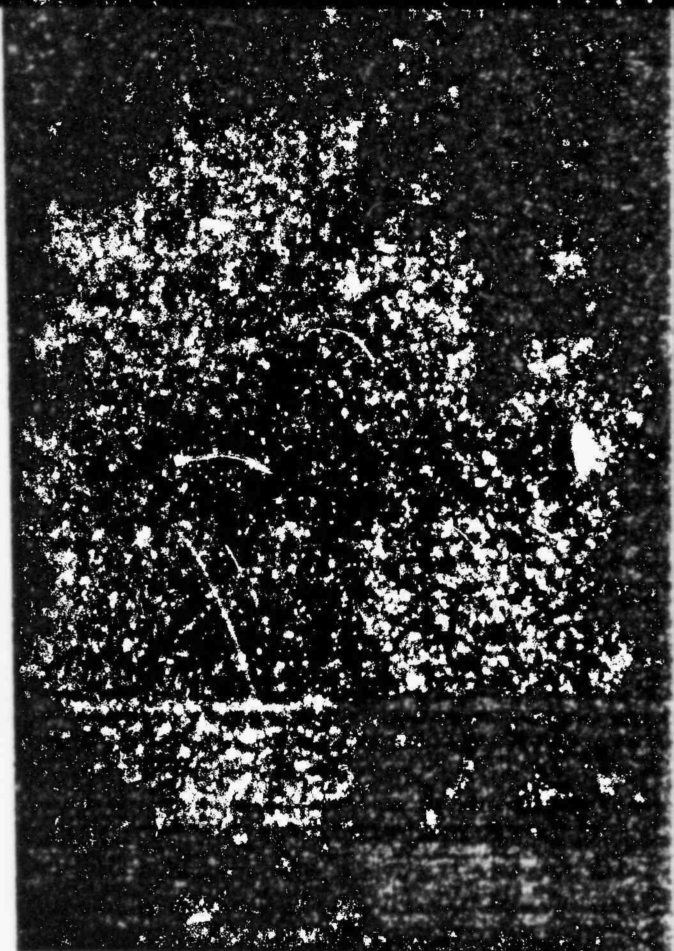

SIDE REFLECTOR BLOCK
REPLACED WITH REFUELING
SIDE REFLECTOR SPACERS
1-0108
2-2693
1-2415, 1-0172
5-0801
CORE SIDE REFLECTOR BOUNDARY
COLUMN IDENT NUMBER
REGION NUMBER
REACTOR REF DIRECTION
10° 53.6'
RESERVE ABSORBER HOLE
ORIENTATION DOWEL

PROGRAM RESULTS

VISUAL EXAMINATION OF FIVE FUEL ELEMENTS TO GA HOT CELL

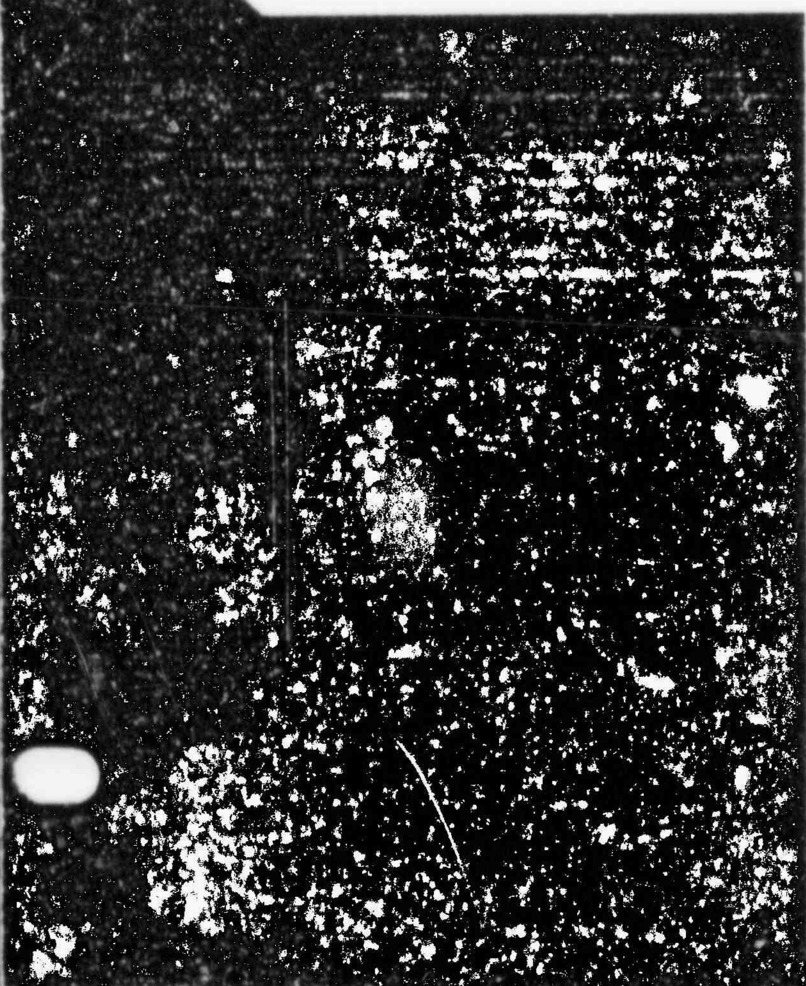
- ELEMENT SELECTION PROCESS
- CRACK CHARACTERISTICS
  - 1-2415
    - 0.008" TO 0.010" AT TOP
    - 0.011" TO 0.012" AT BOTTOM
  - 1-0172
    - 0.005" TO 0.006" AT TOP
    - 0.002" TO 0.003" AT BOTTOM
  - NO OTHER CRACKS OBSERVED
- STACKING DEMONSTRATION
  - CLEARANCE WAS ABOUT 0.040" to 0.050"

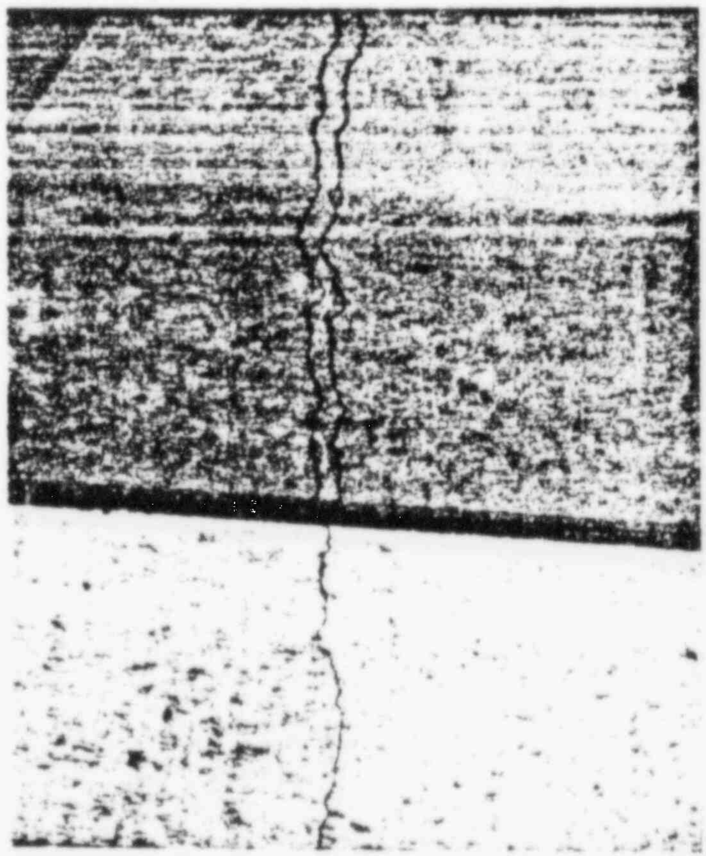
(2)

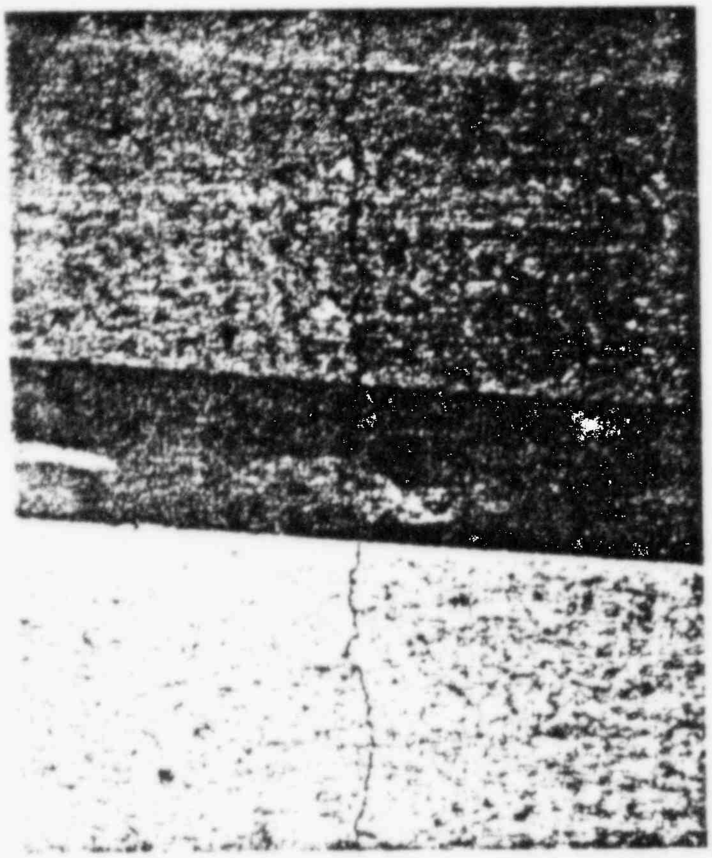


Crack Appearance Enhanced

Crack Appearance Enhanced







Crack Appearance Enhanced

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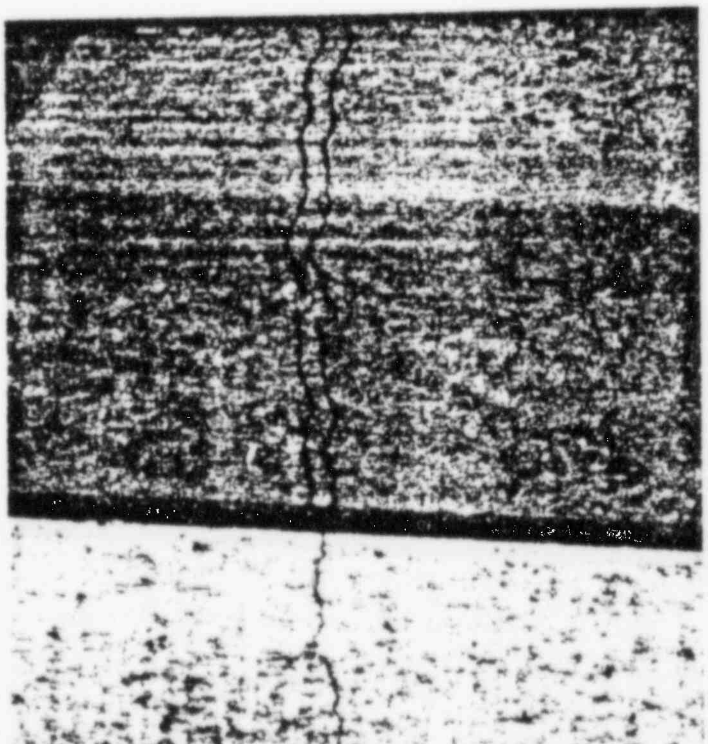


PROGRAM RESULTS

PROBABLE CAUSE OF CRACK

- INTER REGION GAP FLOWS → RELATIVELY COOL SURFACE
- SKEWED POWER/FLUX DISTRIBUTION → INCREASED THERMAL GRADIENT
- RESULT - GREATER IRRADIATION INDUCED CONTRACTION →

  TENSILE STRESSES

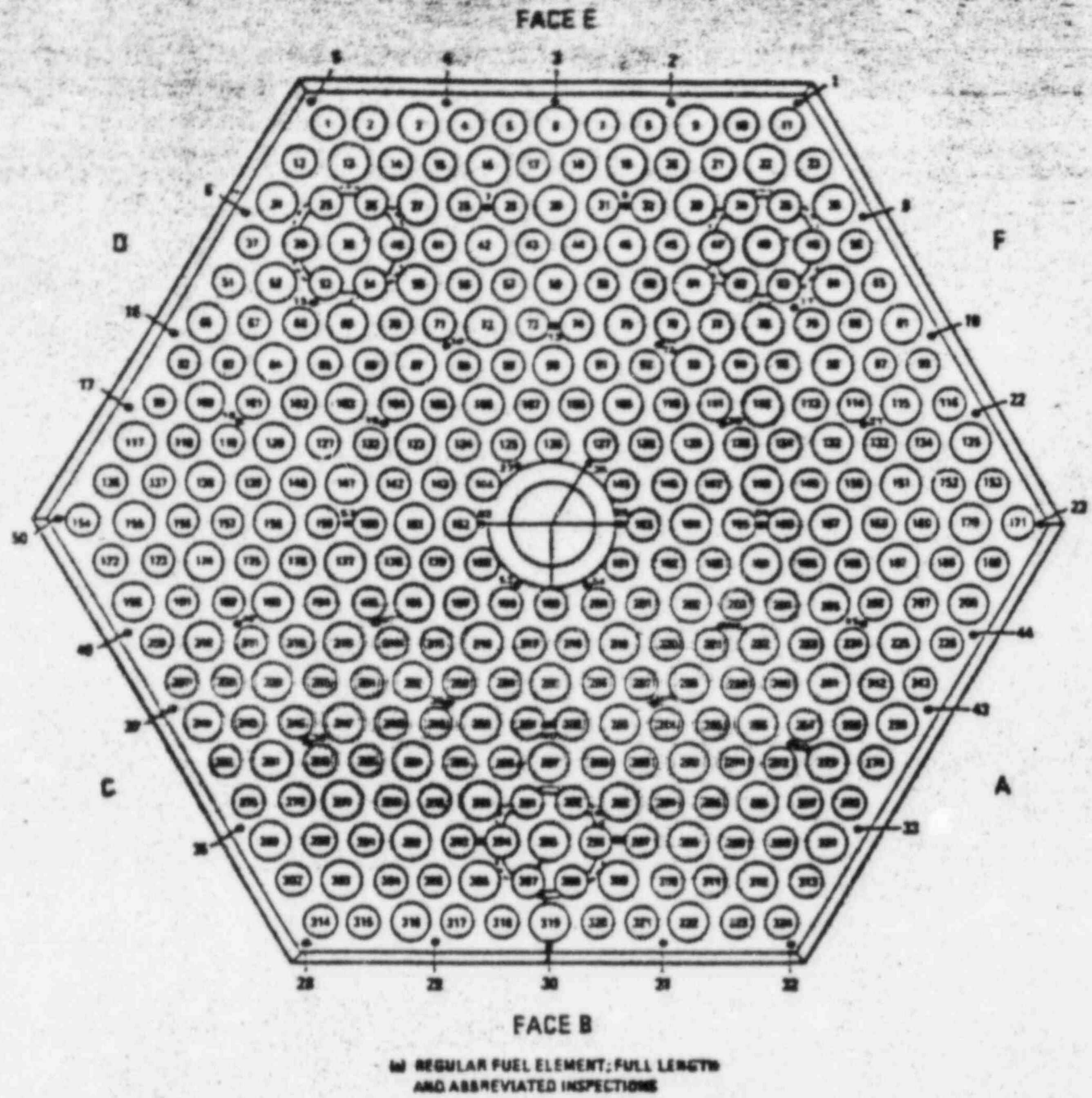
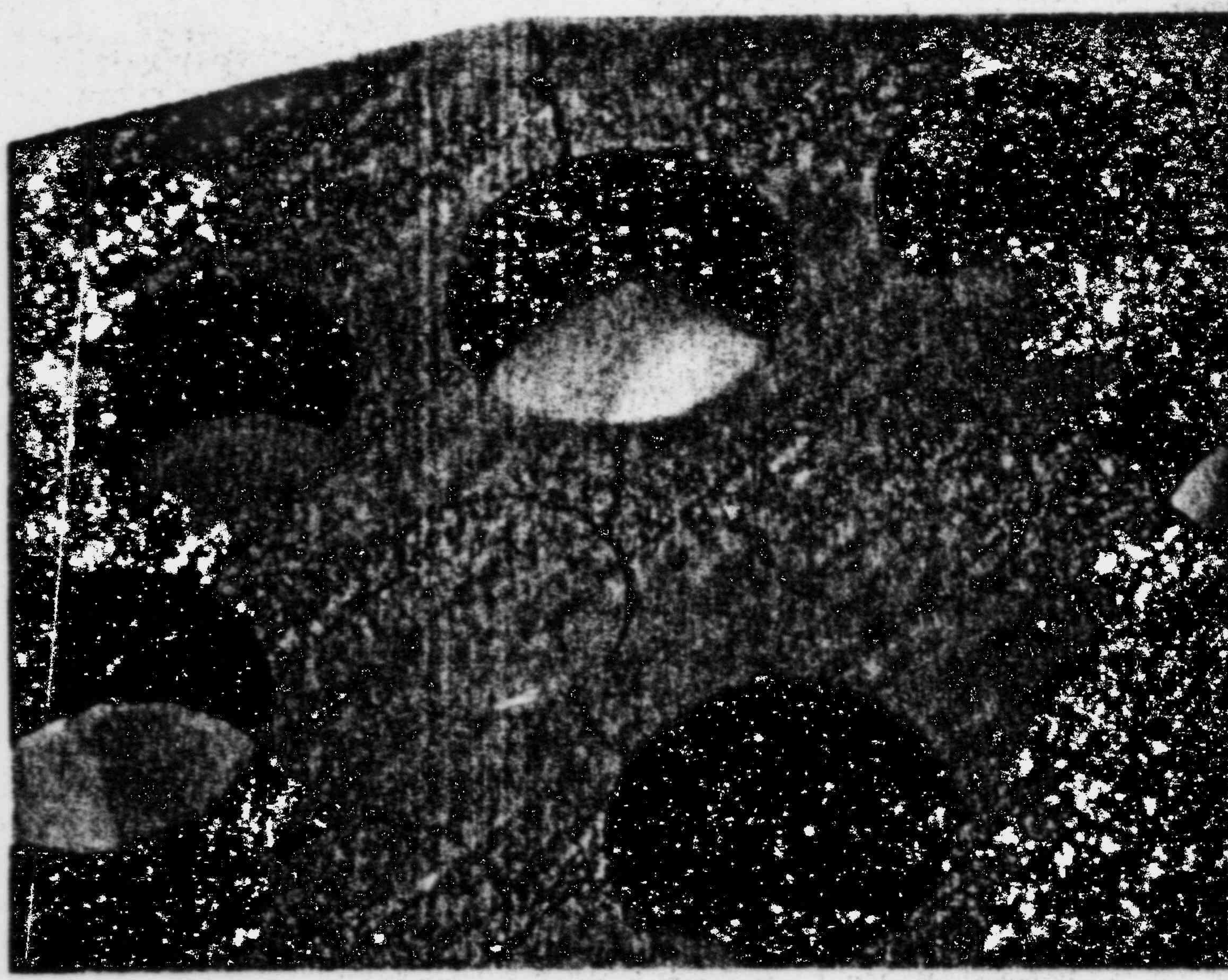


Fig. 4-6. Top surface measurements of FSV core components (sheet 1 of 2)

CRACK PATTERN IN FORT ST. VRAIN FUEL ELEMENT NO. 1–2415



PROGRAM RESULTS

METALLOGRAPHIC EXAMINATION

FUEL ROD 13 FROM STACK 308

RESULTS

NO KERNAL MIGRATION

NO FUEL ROD/FUEL BLOCK INTERACTION

MACROPOROSITY WITHIN DESIGN

SOME SiC/FISSION PRODUCT INTERACTION

NO TOTAL COATING FAILURES

CONCLUSION

ACCEPTABLE PERFORMANCE

<u>FORT ST. VRAIN SEGMENT 3</u>

<u>FUEL AND REFLECTOR ELEMENT</u>

<u>INSPECTION PROGRAM</u>

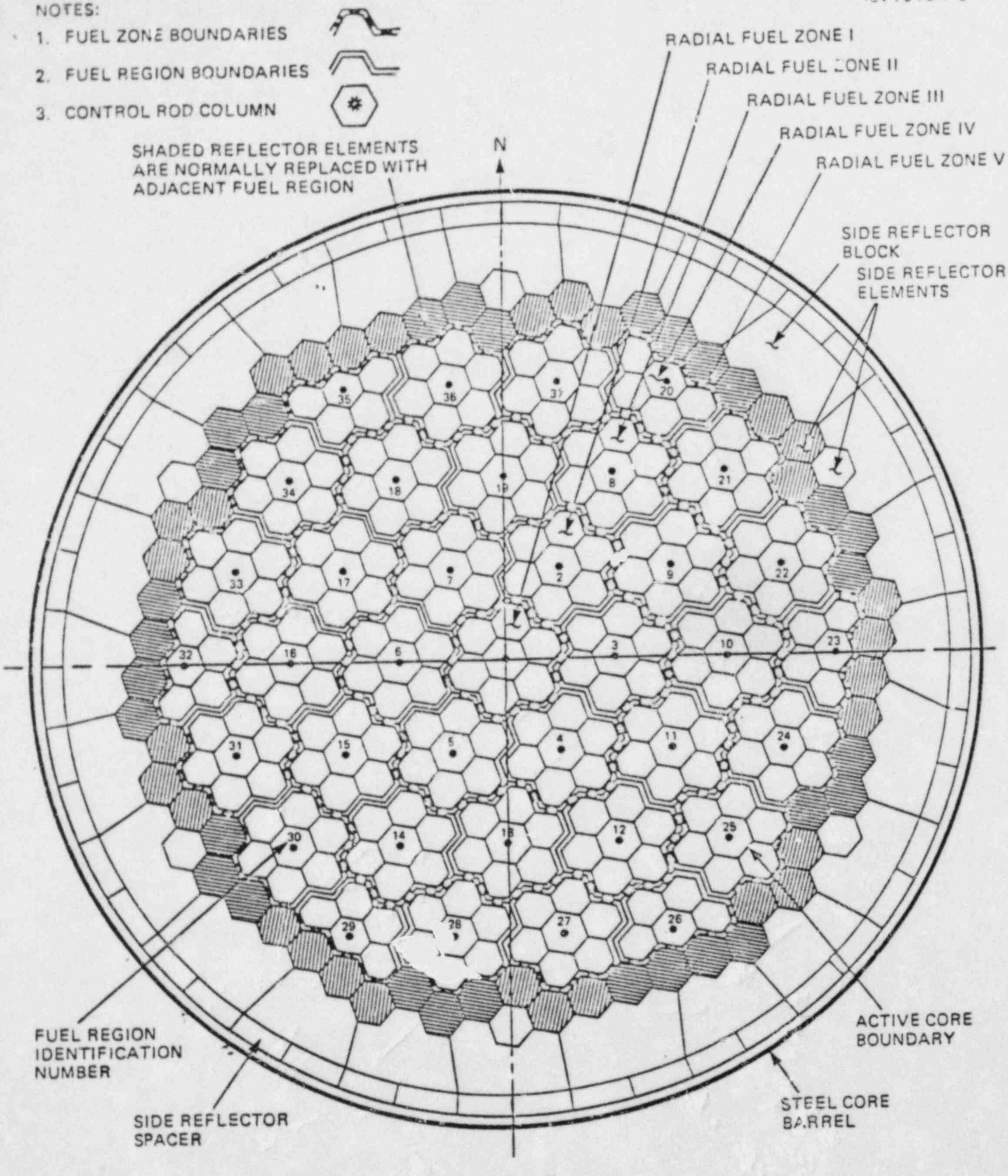


Figure 3.1–2 Core Plan View

SEGMENT 3 FUEL ELEMENT

INSPECTION PROGRAM

PRIOR TO FEBRUARY 10, 1984

SCOPE

- Photograph Two Faces of One in Every Ten Fuel Elements Using the Fuel Handling Machine 35mm Camera
- Visually Examine Each Fuel Element Not Photographed Using the Fuel Handling Machine Cask Video Monitor
- Perform a Non-Destructive Post Irradiation Examination on 50 to 60 Segment 3 Fuel and Reflector Elements Similar to That Performed on Segment 1 and Segment 2 Elements

BASES

- Ensures Early Detection of Significant Structural Abnormalities
- Provides Additional Information with which to study the Fuel Element Cracking Mechanism

SEGMENT 3 FUEL ELEMENT

INSPECTION PROGRAM

AFTER FEBRUARY 10, 1984

MINIMUM SCOPE

- Photograph All Faces of the Remaining Segment 3 Fuel Elements (~ 175) Using the Fuel Handling Machine 35mm Camera

- Evaluate All Photographs for Indications of Significant Structural Abnormalities Prior to Returning to Power Operation

- Using the Fuel Handling Machine Cask Video Monitor, Carefully Examine the Two Segment 3 Fuel Elements With Operational Histories Believed To Be Most Similar to Those of the Cracked Segment 2 Fuel Elements

- Perform a Non-Destructive Post Irradiation Examination on 50 to 60 Segment 3 Fuel and Reflector Elements Similar to That Performed on Segment 1 and Segment 2 Elements

- Keep the NRC Abreast of Findings

BASES

- Ensures Early Detection of Significant Structural Abnormalities

- Provides Additional Information with which to Study the Fuel Element Cracking Mechanism

Reference: PSC Letter, Warembourg to Collins, Dated March 6, 1984 (P-84076)

RESULTS OF SEGMENT 3 FUEL

ELEMENT INSPECTIONS TO DATE

- First Set of Photos Developed Were Discovered To Be Underexposed. NRC Region IV Was Notified.
- Exposure Time Settings Were Corrected for the Last Region Refueled (Region 33)
- PSC Subsequently Committed to Retrieve and Re-Inspect Region 18 Fuel Elements Aleady in Spent Fuel Storage As Follows:

  Photographs All Faces of Each Element at x 1 Power
  Photograph the "B" Face of Each Element at x 7.5 Power

- Actual Region 18 Fuel Element Inspection Consisted of:

  Photographing All Faces of Each Element at x 1 Power
  Photographing the Center of Each Face at x 7.5 Power
  Videotaping Examinations of Each Face

- No Significant Surface Abnormalities Have Been Detected
- All Photographs, Videotapes, and Evaluations Are Available On-Site for NRC Review

Reference: PSC Letter, Warembourg to Collins, Dated March 6, 1984 (P-84076)

REMAINING SEGMENT 3 FUEL

ELEMENT INSPECTIONS

SEGMENT 3 POST IRRADIATION EXAMINATIONS

- Components To Be Examined

  All Fuel Elements from Region 18
  Additional Selected Fuel and Reflector Elements from Regions 3, 13, and 22
  Total of 50 Fuel Elements and 10 Reflector Elements

- Scope

  Dimensional Measurements
  Visual Inspections
  Gamma Activity Measurements

- Anticipated Date of Completion - July 31, 1984

SPENT FUEL SHIPPING EXAMINATIONS

- Components To Be Examined

  All Fuel Elements Not Previously Examined Under the Current Inspection Program

- Scope

  Photograph All Faces of Each Element

- Anticipated Date of Completion - November 30, 1984

POST-IRRADIATION FUEL ELEMENT INSPECTION SHEET

SERIAL NO. 1-2939

CORE LOCATION 18. C4. 07
(REG.COL.LAY.)

CHEMICAL TYPE 11C

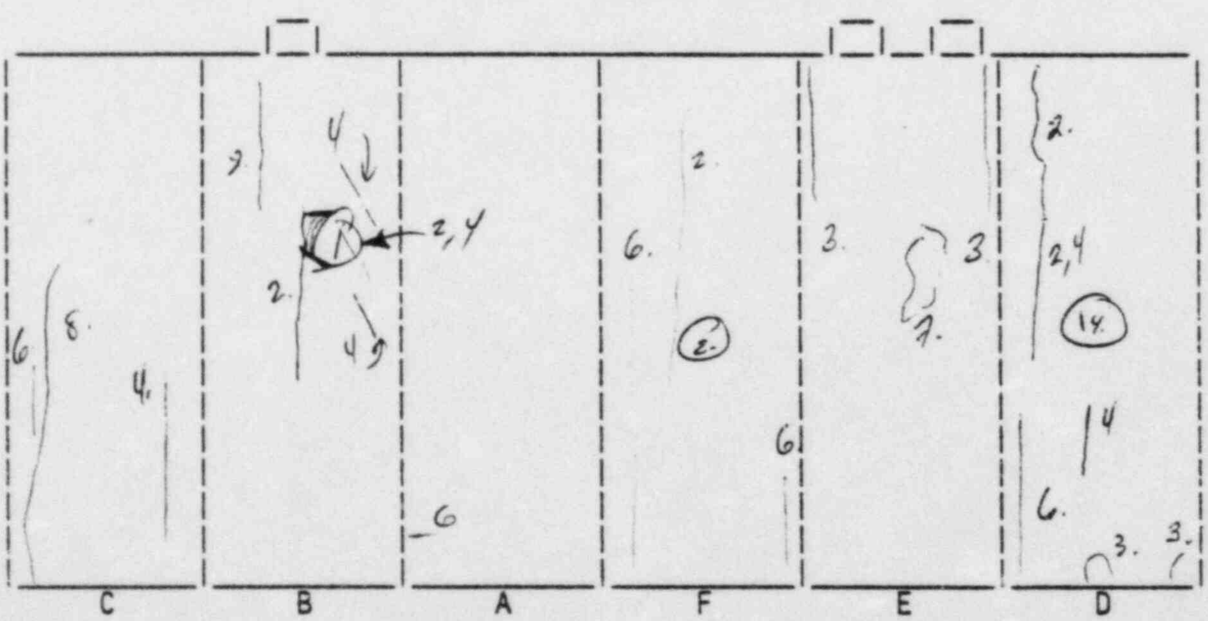
PHOTO LISTING

	FACE					
	A	B	C	D	E	F
X 1 POWER (oven)	6072	~~6064~~ JE 6077	6069 6076	6075	6074	6073
X 7.5 POWER	6211	6216	6215 6066 6067 6068 6070	6214	6213	6212

SURFACE FLAW TYPES

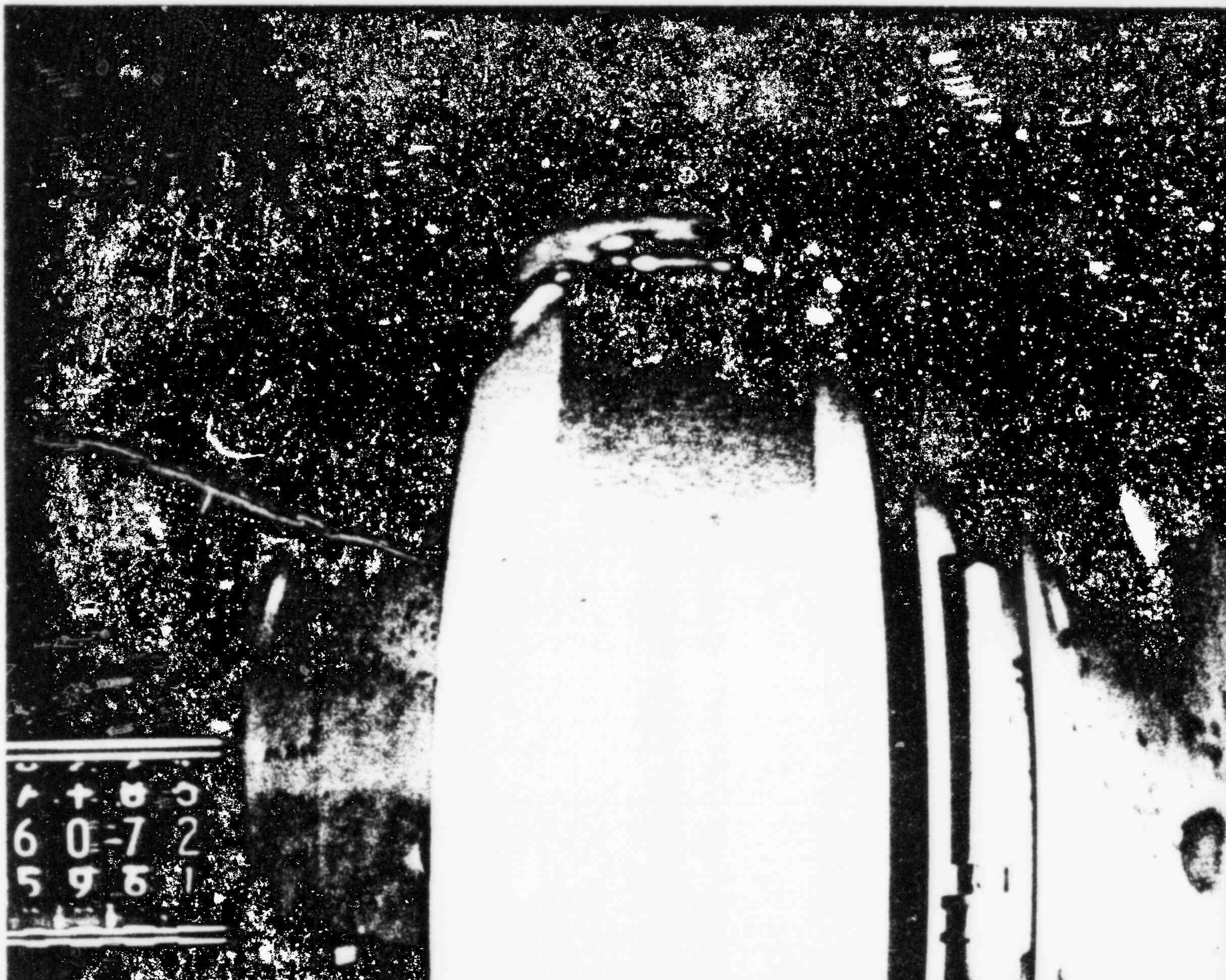
1. Crack
2. Stain
3. Flow Mark
4. Scratch/Scribe
5. Oxidation
6. Rub Mark
7. Other Discoloration
8. Light Stain

EVALUATION SUMMARY

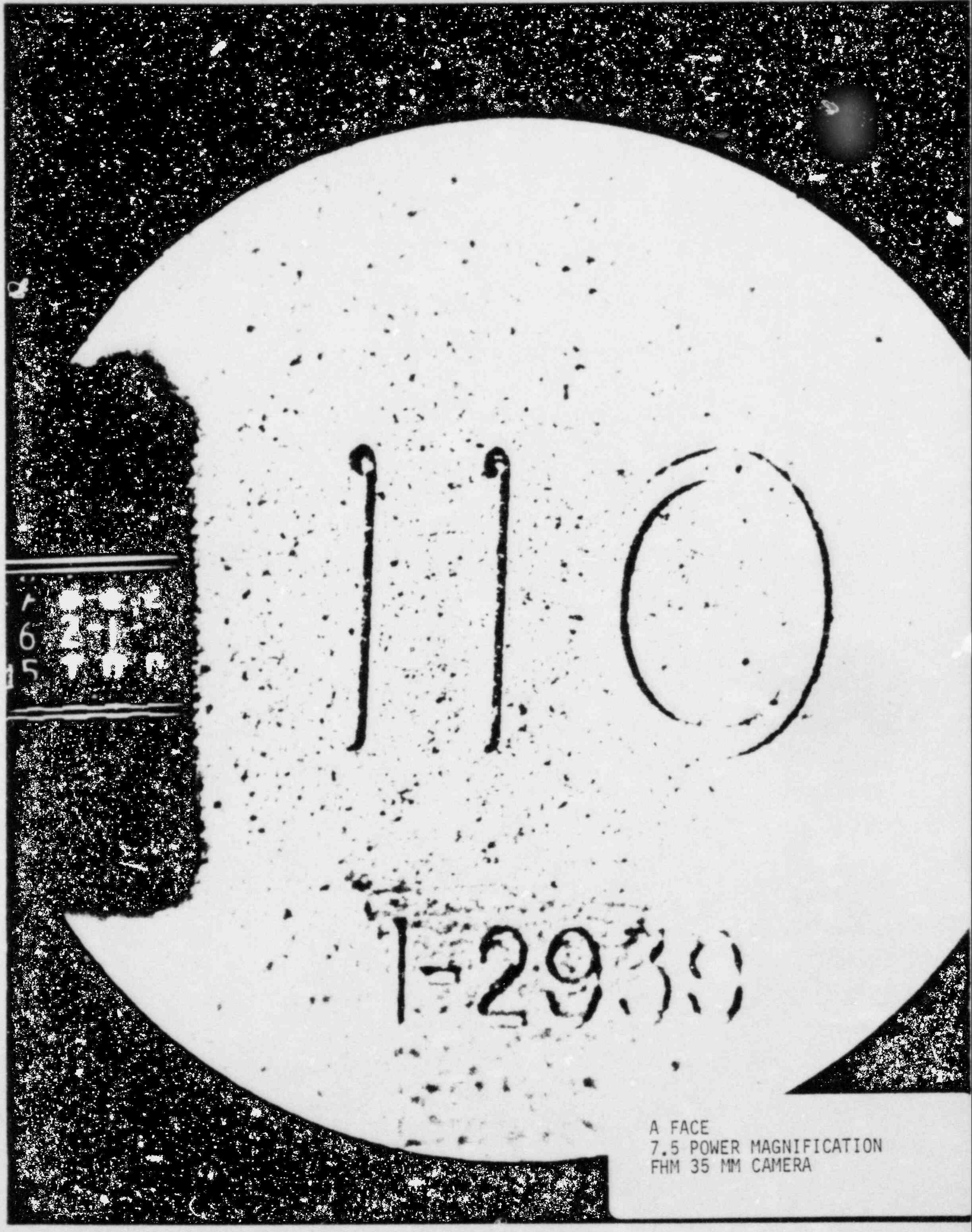


COMMENTS

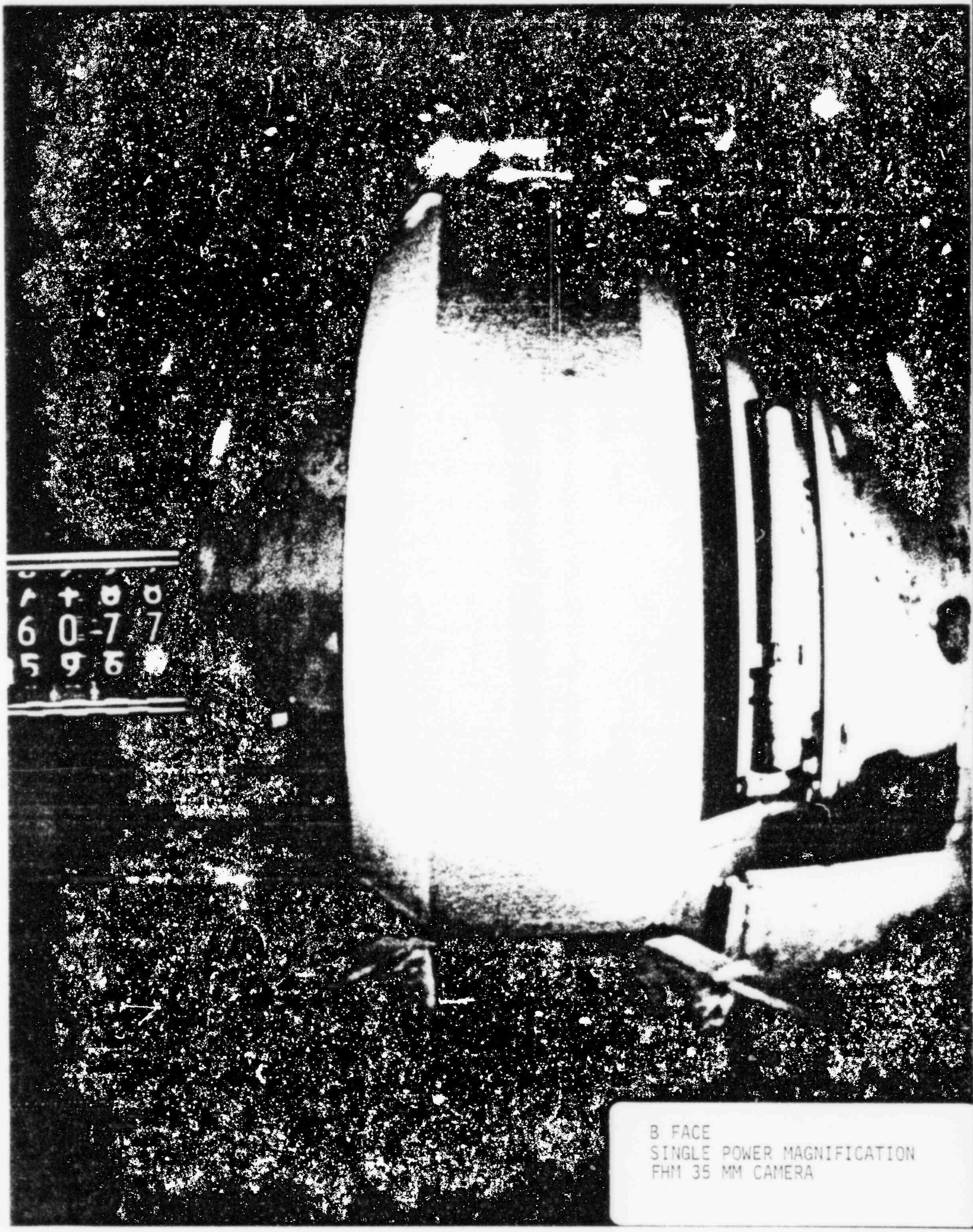
JE 4-2-84



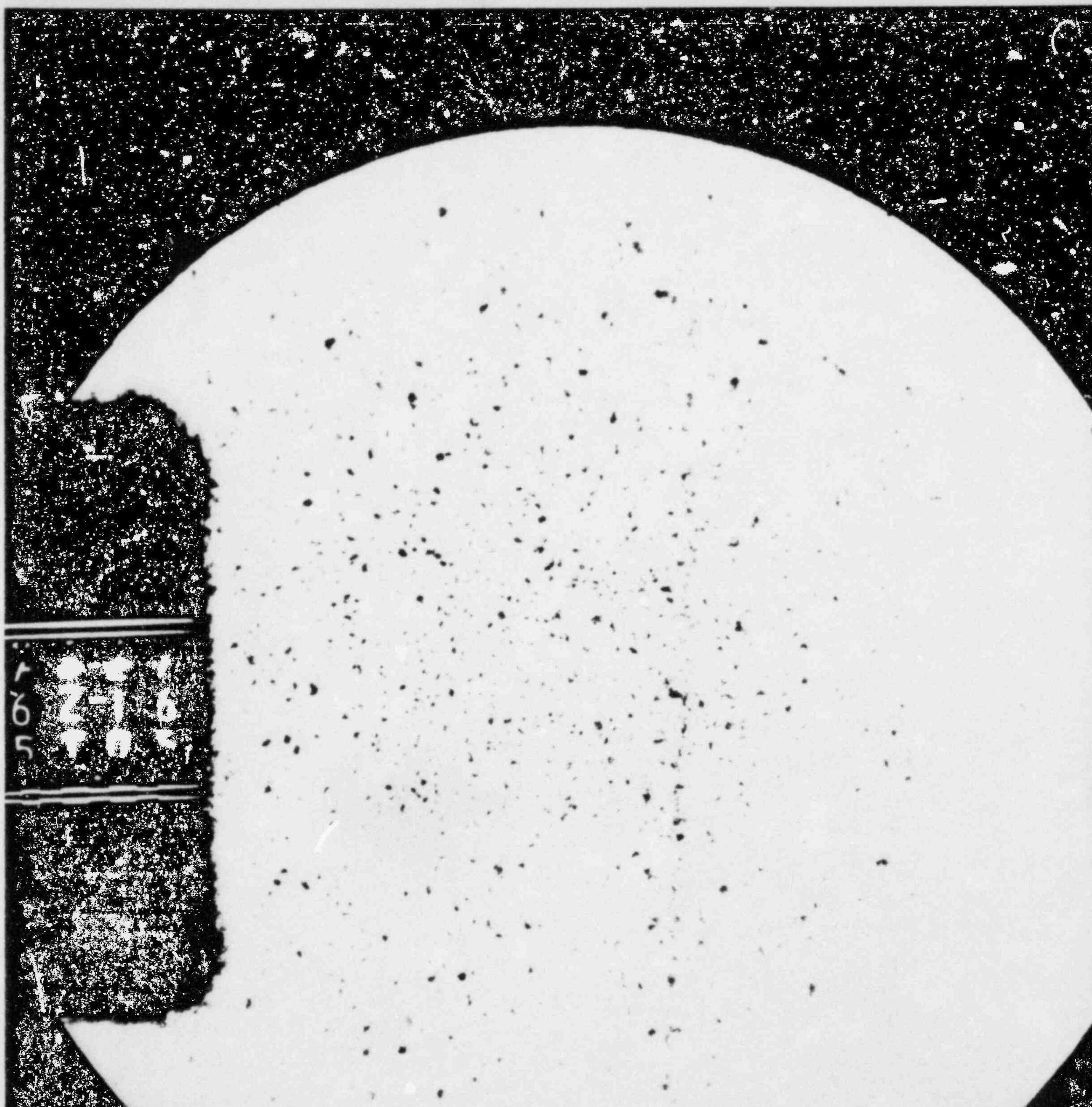
A FACE
SINGLE POWER MAGNIFICATION
FHM 35 MM CAMERA



A FACE
7.5 POWER MAGNIFICATION
FHM 35 MM CAMERA



B FACE
SINGLE POWER MAGNIFICATION
FHM 35 MM CAMERA



B FACE
7.5 POWER MAGNIFICATION
FHM 35 MM CAMERA

POST-IRRADIATION FUEL ELEMENT INSPECTION SHEET

SERIAL NO. [illegible]

CORE LOCATION [illegible]
(REG.COL.LAY.)

CHEMICAL TYPE [illegible]

PHOTO LISTING

	FACE					
	A	B	C	D	E	F
X 1 POWER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X 7.5 POWER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

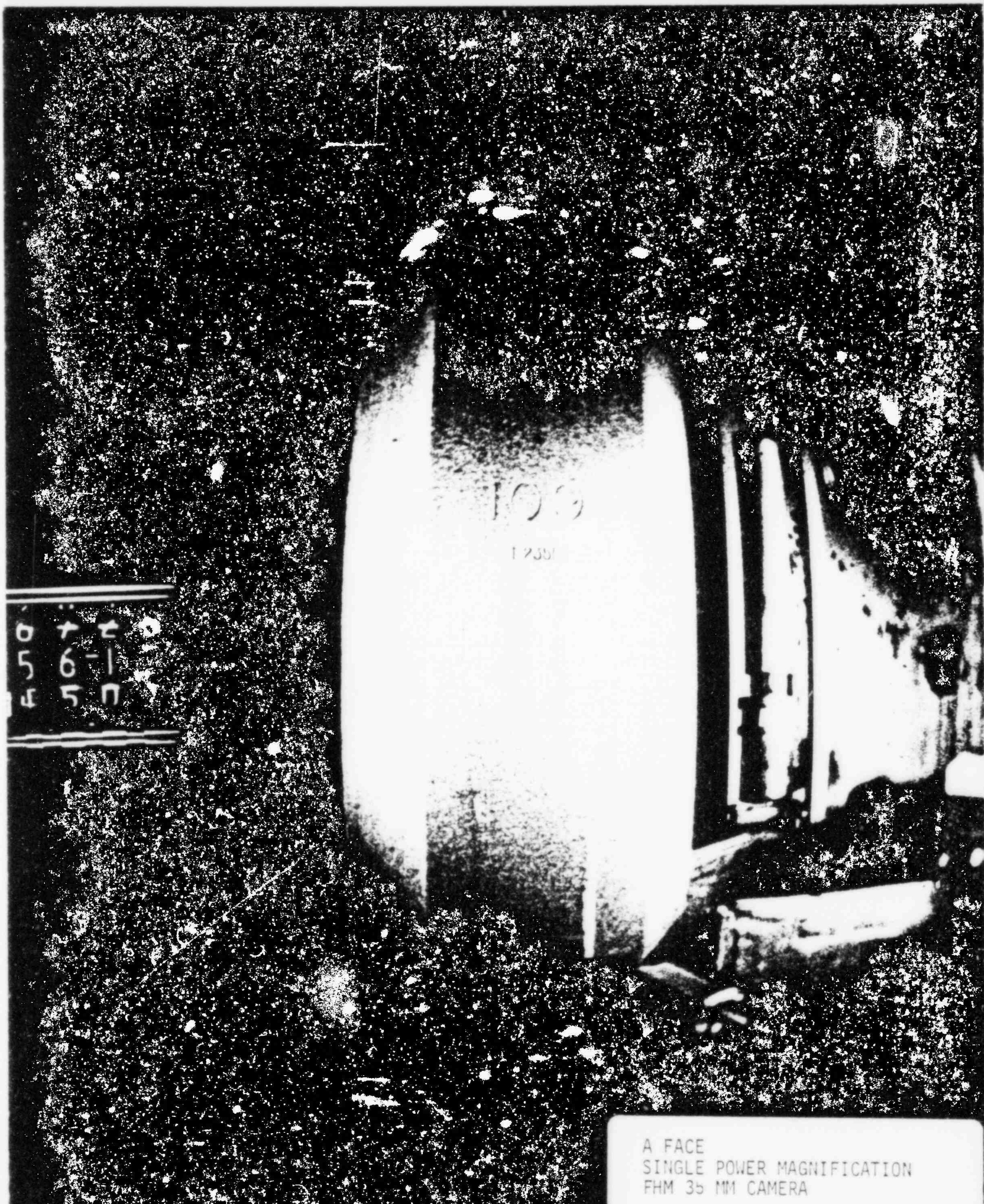
SURFACE FLAW TYPES

1. Crack
2. Stain
3. Flow Mark
4. Scratch/Scribe
5. Oxidation
6. Rub Mark
7. Other [illegible]

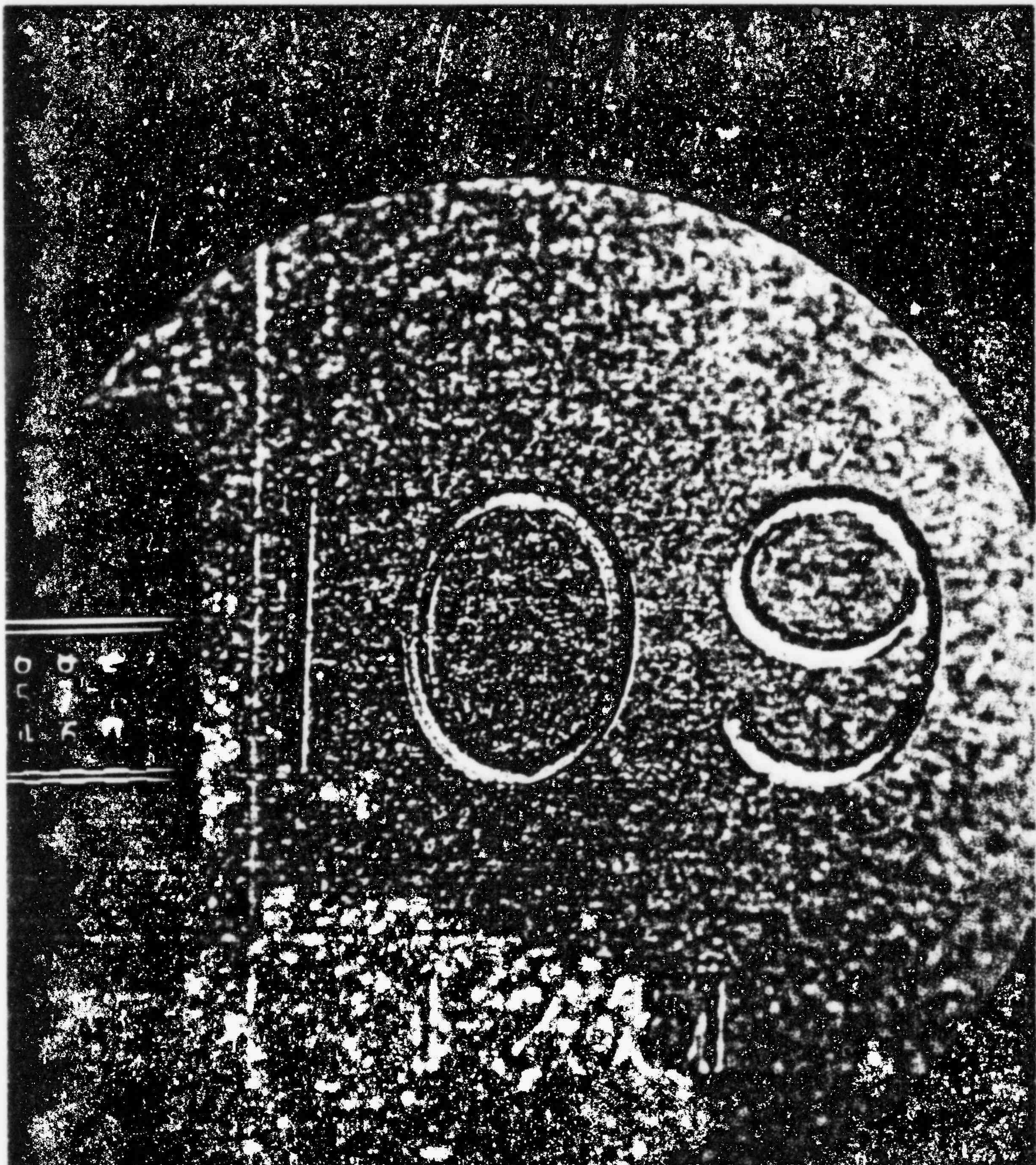
EVALUATION SUMMARY

C	B	A	F	E	D

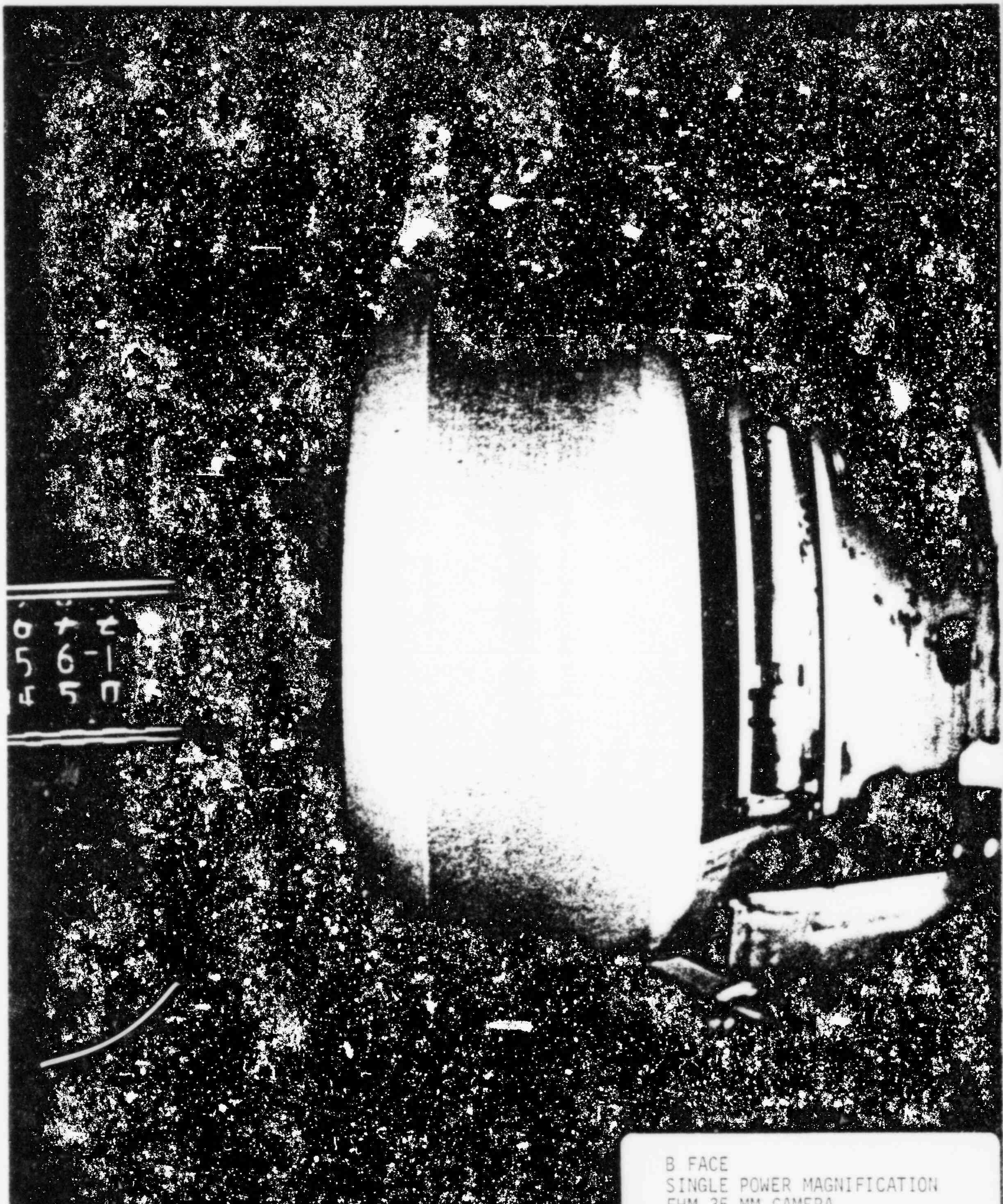
COMMENTS



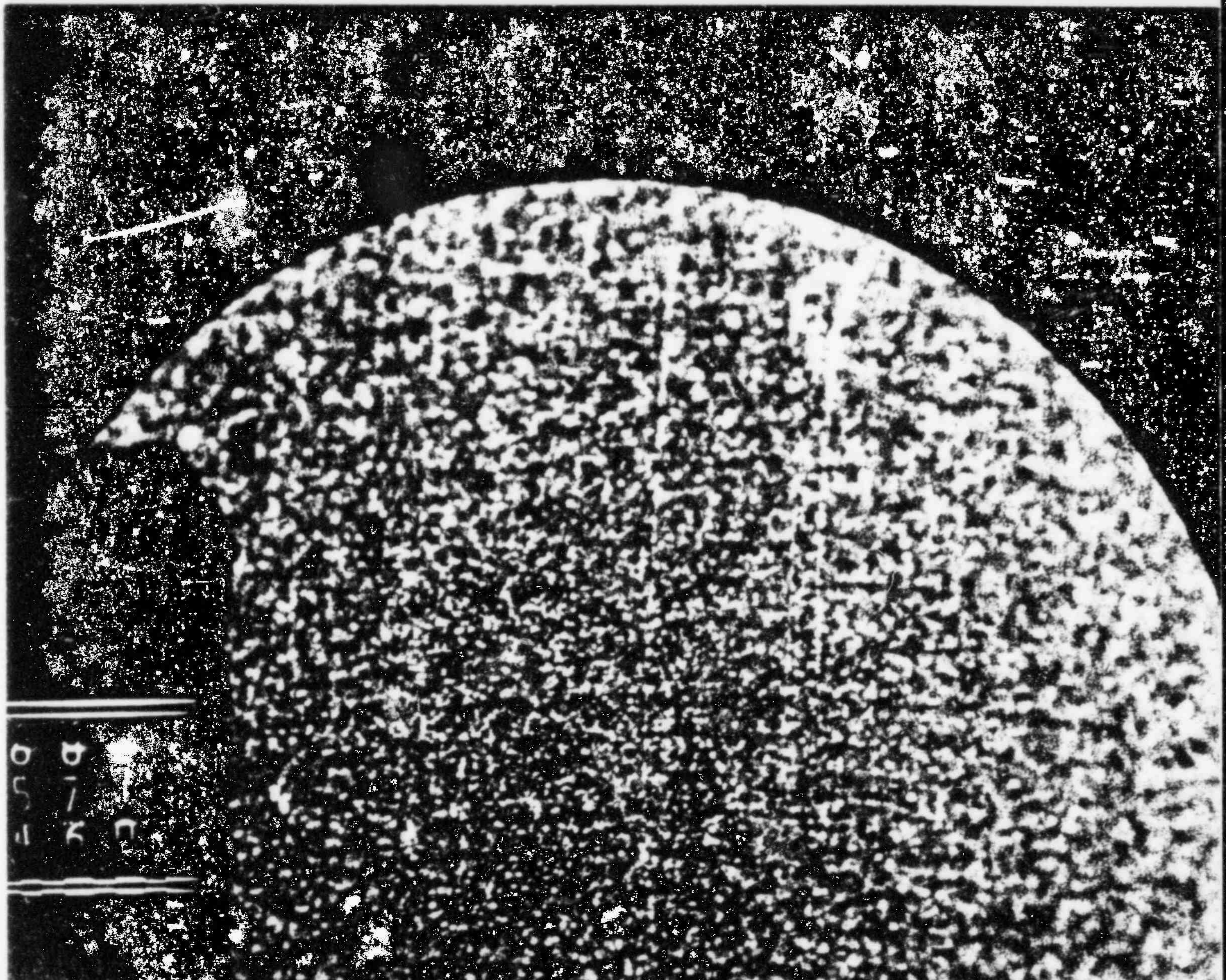
A FACE
SINGLE POWER MAGNIFICATION
FHM 35 MM CAMERA



A FACE
7.5 POWER MAGNIFICATION
FHM 35 MM CAMERA



B FACE
SINGLE POWER MAGNIFICATION
FHM 35 MM CAMERA


B FACE
7.5 POWER MAGNIFICATION
FHM 35 MM CAMERA

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LHTGR DESIGN ANALYSIS

- ONGOING LHTGR DEVELOPMENT CONTRIBUTES TO UNDERSTANDING FSV FUEL ELEMENT STRESS
- FULL CROSS-SECTION THERMAL AND STRESS ANALYSIS USING GBEAM (AXIAL) AND TWOD (RADIAL) CAN NOW BE USED
- WORK ON PROBABILITY OF CRACKS EXTENDING INTO ADDITIONAL WEBS GAVE INSIGHT INTO THE FSV CRACKED ELEMENT SITUATION

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PROBABILITY OF WEB CRACKING

- THE OVERLAPPING DISTRIBUTIONS OF THE UNCERTAINTIES IN PREDICTED STRESS AND THE KNOWN VARIATION OF GRAPHITE MATERIAL STRENGTH PROPERTIES ARE UTILIZED

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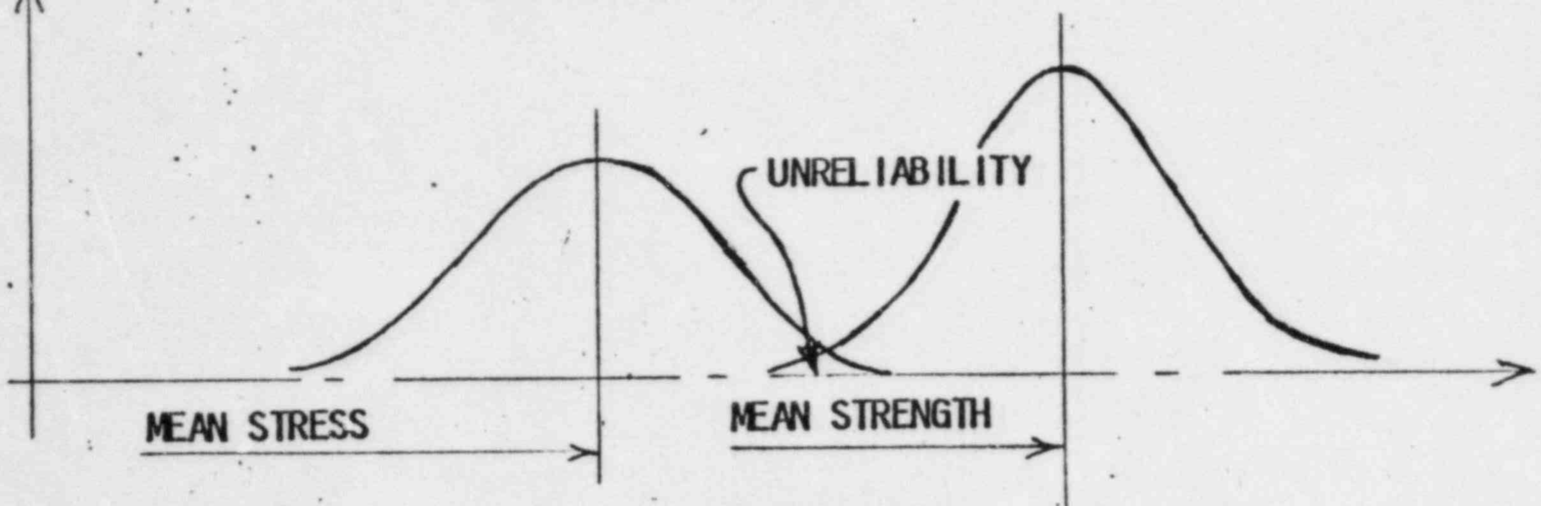
"OVERLAPPING" METHOD, CONCEPT



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ANALYSIS APPROACH

- STEP 1: CALCULATE PROBABILITY THAT HIGHEST STRESSED WEB IN ENTIRE FUEL ELEMENT CROSS SECTION WILL CRACK
- STEP 2: SIMULATE THAT THAT WEB HAS CRACKED, BY SETTING ITS STIFFNESS ESSENTIALLY TO ZERO IN THE FINITE ELEMENT MODEL
- STEP 3: REANALYZE AND OBTAIN NEW STRESS DISTRIBUTION
- STEP 4: CALCULATE PROBABILITY THAT NEW HIGHEST STRESSED ELEMENT WILL CRACK
- STEP 5: REPEAT AS MANY TIMES AS NEEDED

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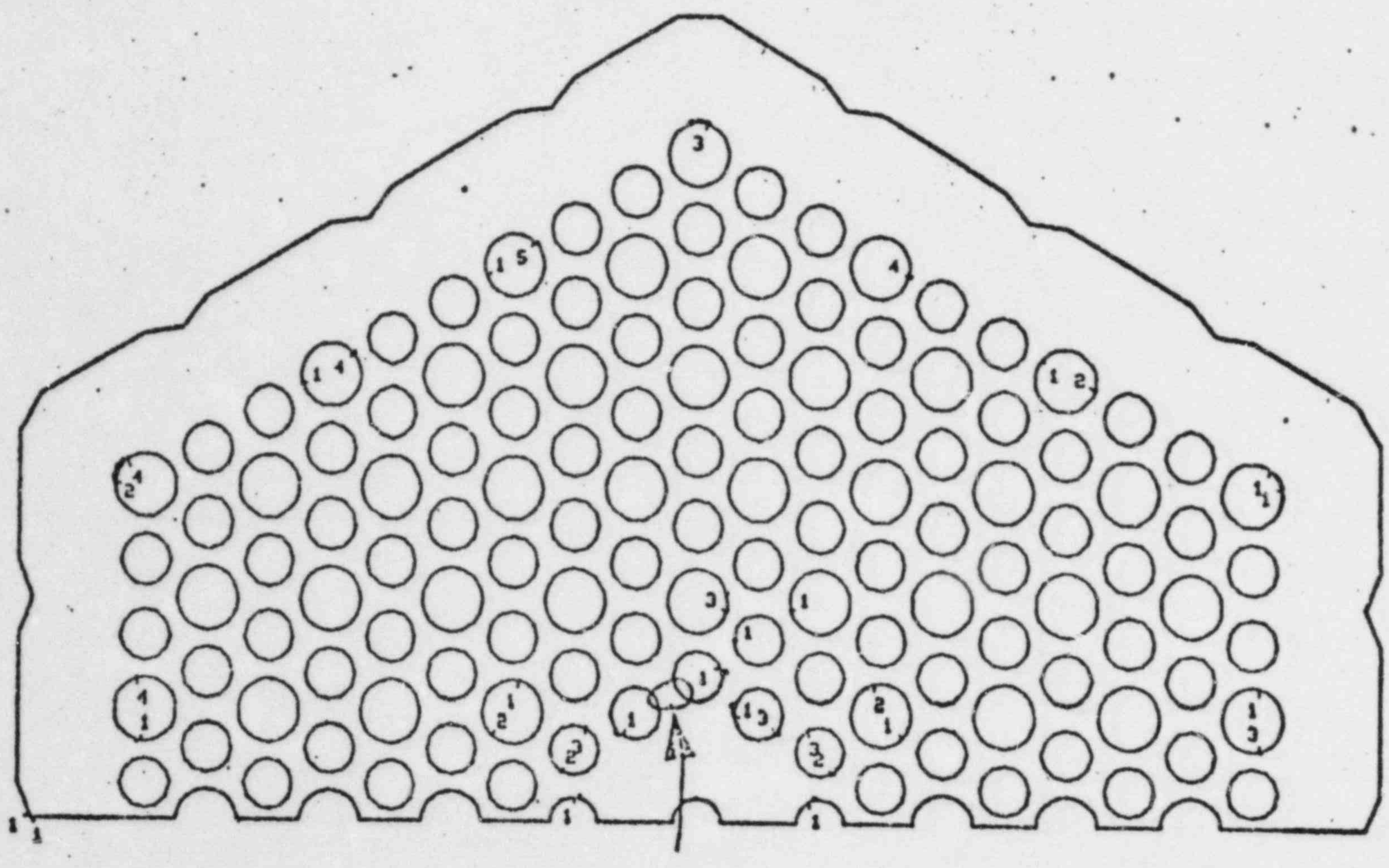
FIRST CRACK NEAR MIDDLE



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RESULTS OF WEB CRACKING ANALYSIS

NUMBER CRACKED WEBS	STRESS/STRENGTH RATIO	PROBABILITY OF ANOTHER CRACK
0	0.16	1.0×10^{-3}
1	0.17	1.0×10^{-3}
2	0.14	0.4×10^{-3}
4	0.13	0.2×10^{-3}
8	0.11	0.2×10^{-5}
16	0.10	0.5×10^{-6}

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CONCLUSIONS

- THESE RESULTS ARE NOT DIRECTLY RELEVANT TO THE FSV SITUATION BECAUSE OF MAJOR DIFFERENCES IN THE STRESS DISTRIBUTIONS AND MAGNITUDES
- THEY DO HOWEVER SHOW THAT A CRACK MAY RELIEVE STRESS IN A FUEL ELEMENT WHEN THE DISTRIBUTION IS HIGHLY NON-UNIFORM
- THE METHODOLOGY HAS BEEN APPLIED TO THE SPECIFICS OF THE FSV CRACKED FUEL ELEMENT AND WILL BE PRESENTED SEPARATELY

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CRACKED FUEL ELEMENT ANALYSIS

- TWO FUEL ELEMENTS WITH HAIRLINE CRACKS FOUND DURING FSV FUEL ELEMENT SURVEILLANCE PROGRAM

- ALL INDICATIONS WERE THE CRACKS WERE CAUSED BY HIGH STRESSES IN OTHERWISE NORMAL BLOCKS

- CRACKED FUEL ELEMENT ANALYSIS UNDERTAKEN TO UNDERSTAND THE CAUSE OF THE CRACKS

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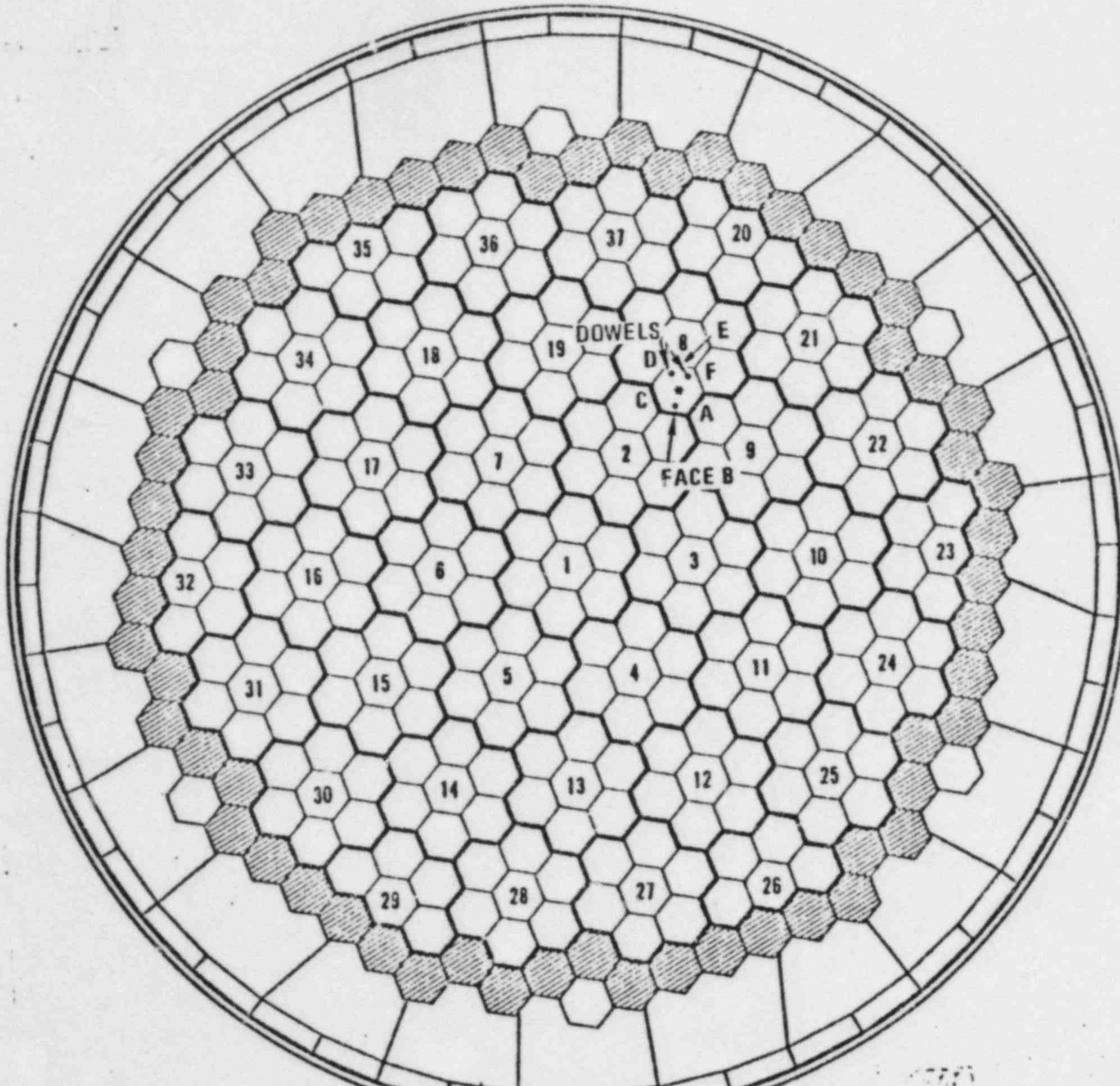

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ANALYSIS - INPUT

- o POWER AND FLUX DISTRIBUTIONS FROM FUEL ACCOUNTABILITY NUCLEAR DEPLETION CALCULATIONS
- o POWER LEVEL, FLOWS AND TEMPERATURES FROM MEASUREMENTS AT FSV
- o THESE DATA USED TO DERIVE OPERATING HISTORY

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ANALYSIS CASES

(1) TIME HISTORY ANALYSIS THROUGH CYCLES 1 AND 2

(2) ALSO EVALUATED SENSITIVITY TO GAP FLOW AND COOLANT CHANNEL FLOW:

2X EXTERNAL GAP
4X EXTERNAL GAP
80% COOLANT CHANNEL FLOW

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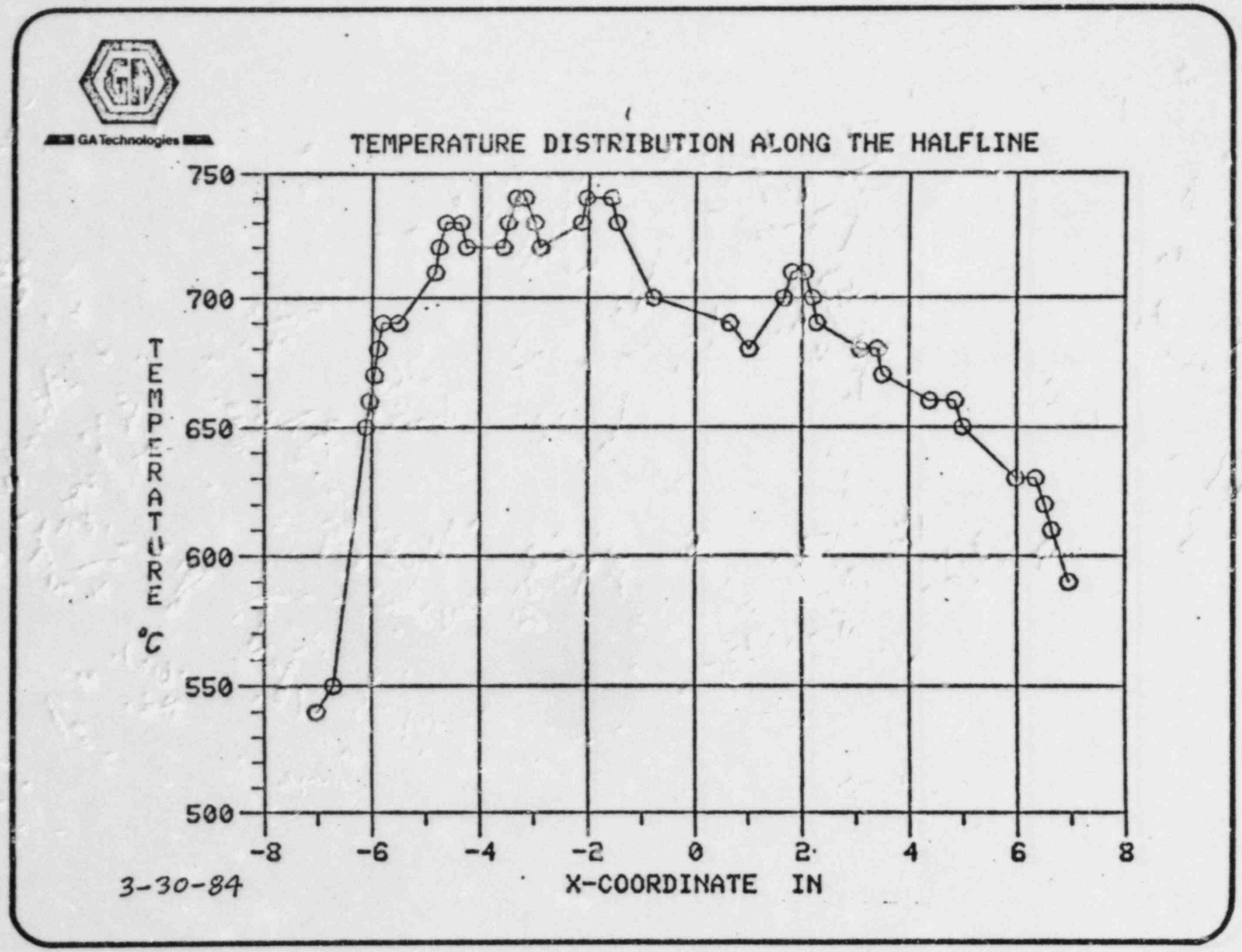
GA Technologies
TEMPERATURE DISTRIBUTION ALONG THE HALFLINE
TEMPERATURE °C
750
700
650
600
550
500
-8
-6
-4
-2
0
2
4
6
8
X-COORDINATE IN
3-30-84

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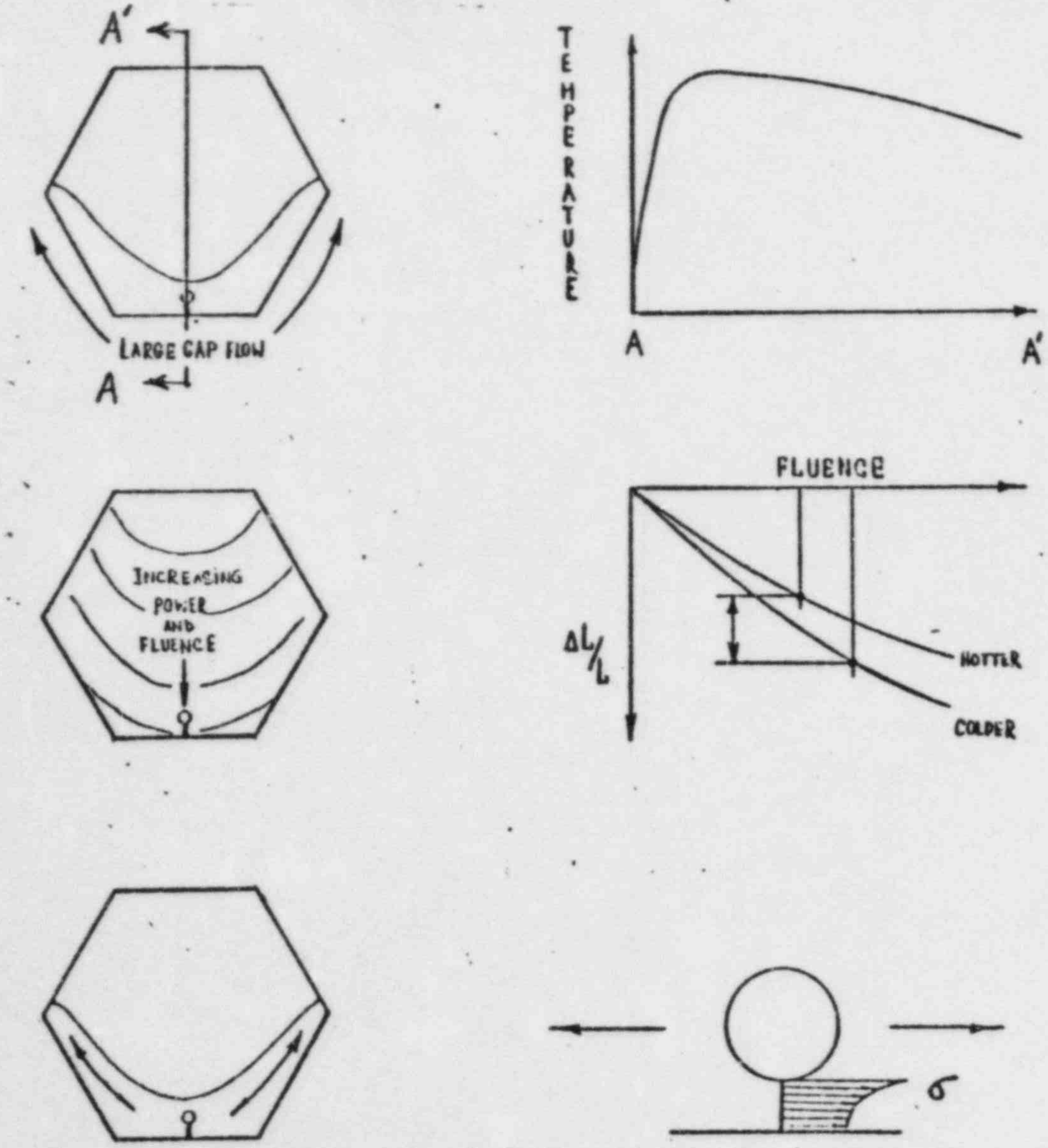
CAUSES OF STRESS



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RESULTS

TIME-HISTORY ANALYSIS

PEAK AXIAL /UTS	PEAK IN-PLANE /UTS
0.42	0.70

SENSITIVITY ANALYSIS

	INCREASE IN PEAK IN-PLANE /UTS
2X GAP WIDTH	40%-50%
4X GAP WIDTH	60%-75%
80% COOLANT CHANNEL FLOW	35%-40%

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EVALUATION OF RESULTS

(1) IN-PLANE STRESS/STRENGTH RATIO ARE HIGHER THAN AXIAL STRESS/ STRENGTH RATIOS

(2) PEAK IN-PLANE STRESS/STRENGTH RATIOS ARE CALCULATED AT THE LOCATION OF THE HAIRLINE CRACK

(3) PEAK STRESS/STRENGTH RATIOS ARE <1.Ø. ASSUMING NOMINAL, TIME-AVERAGED FLOWS. HOWEVER, THESE PEAK VALUES OCCUR DURING OPERATION AND ARE SENSITIVIE TO VARIATIONS FROM NOMINAL OPERATING CONDITIONS, WHICH ARE CAPABLE OF INCREASING RATIO >1.Ø

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STRESS ANALYSIS RESULTS ON

CRACKING BEHAVIOR

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OBJECTIVES OF THE ANALYSIS

(1) EVALUATE CRACK PROGRESS BEHAVIOR IN THE FUEL ELEMENT

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SUMMARY RESULTS FROM PREVIOUS ANALYSES

- PEAK STRESS/STRENGTH = Ø.7Ø (NORMAL FLOW CONDITIONS)
- IN-PLANE STRESS > AXIAL STRESS
- HIGH STRESSES LOCALIZED
- PEAK STRESS/STRENGTH CALCULATED AT THE OBSERVED CRACK LOCATION
- STRESSES SENSITIVE TO FLOW/THERMAL CONDITIONS

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CRACKING ANALYSIS

- PERFORMED ANALYSIS AT THE TIME POINT OF PEAK STRESS/STRENGTH
- SIMULATED CRACKS PROGRESSIVELY, EACH AT THE PEAK STRESS/STRENGTH LOCATION IN THE BLOCK
- SIMULATED UP TO 5 CRACKS

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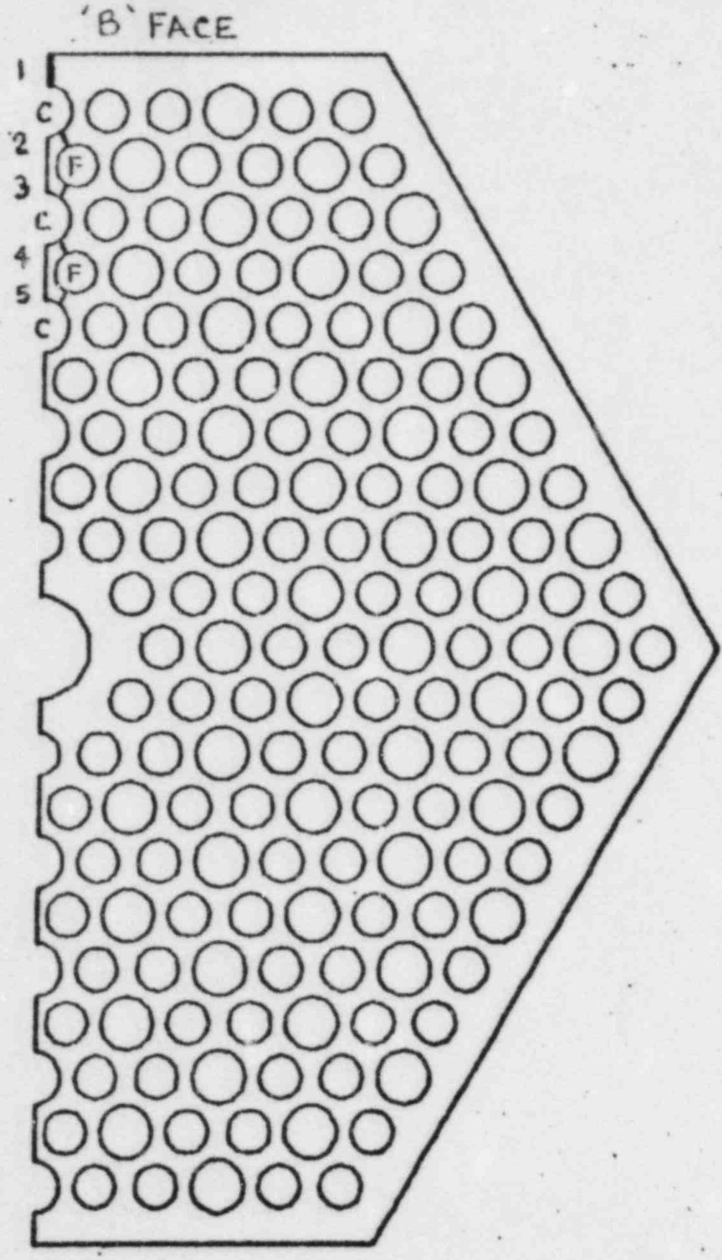
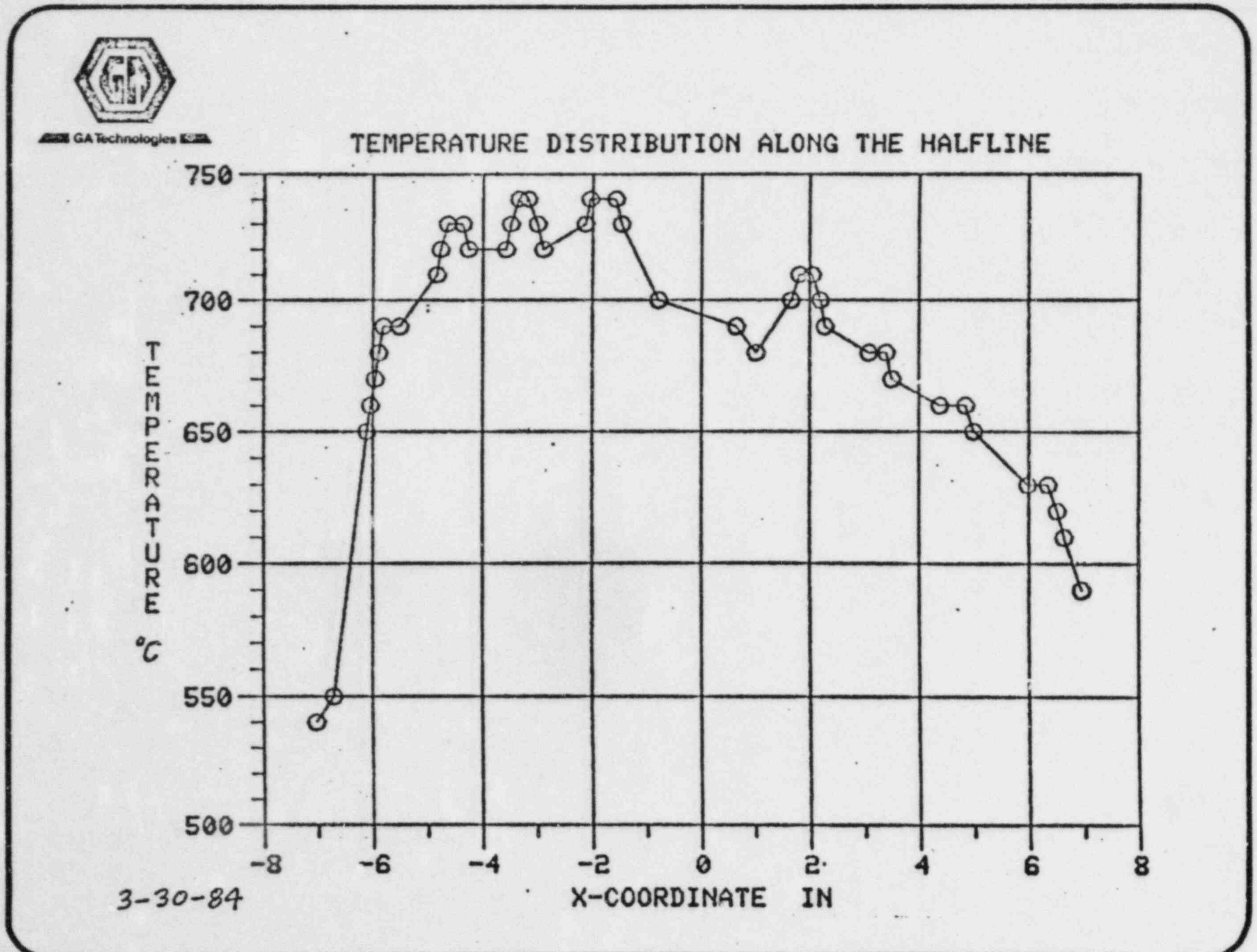
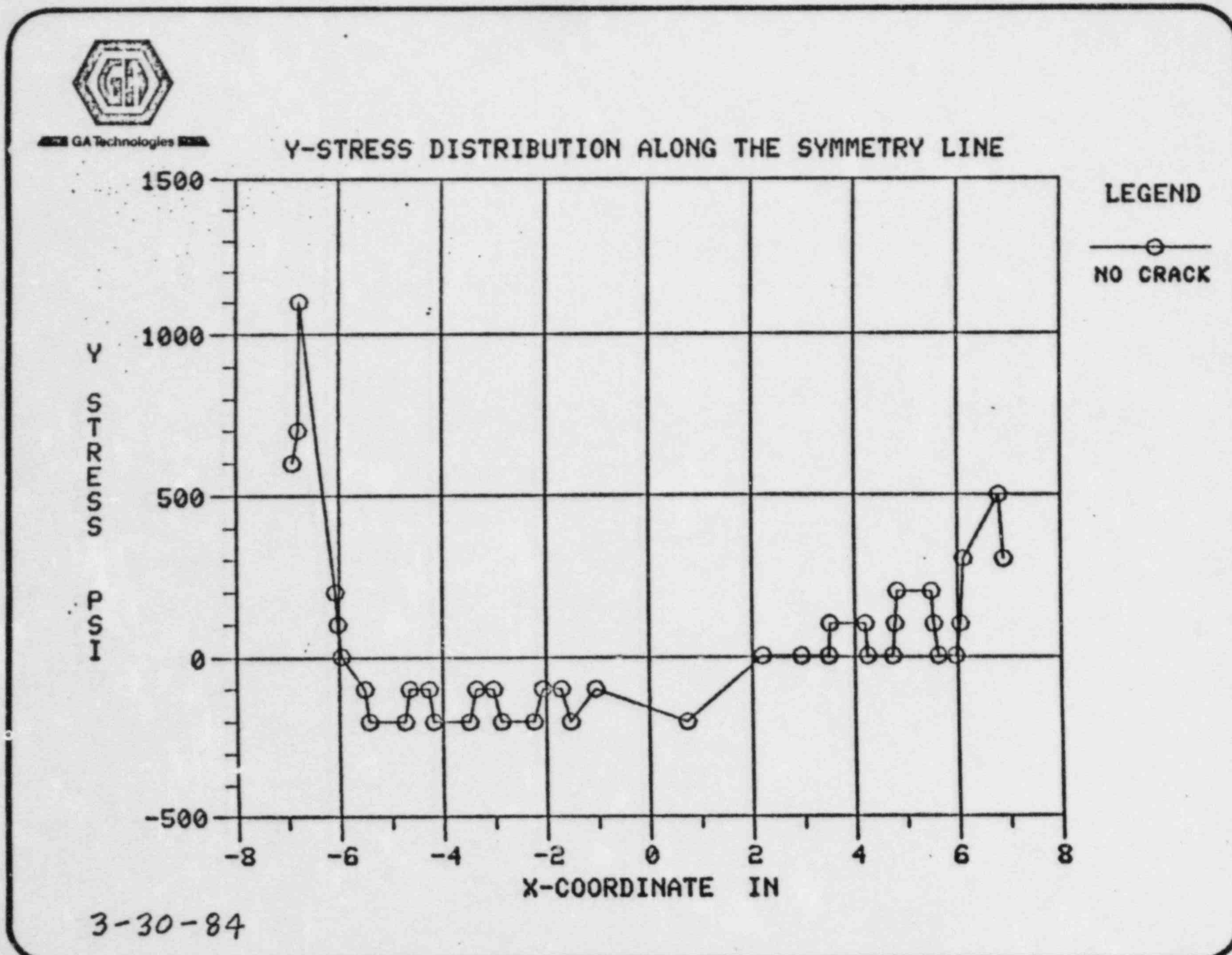
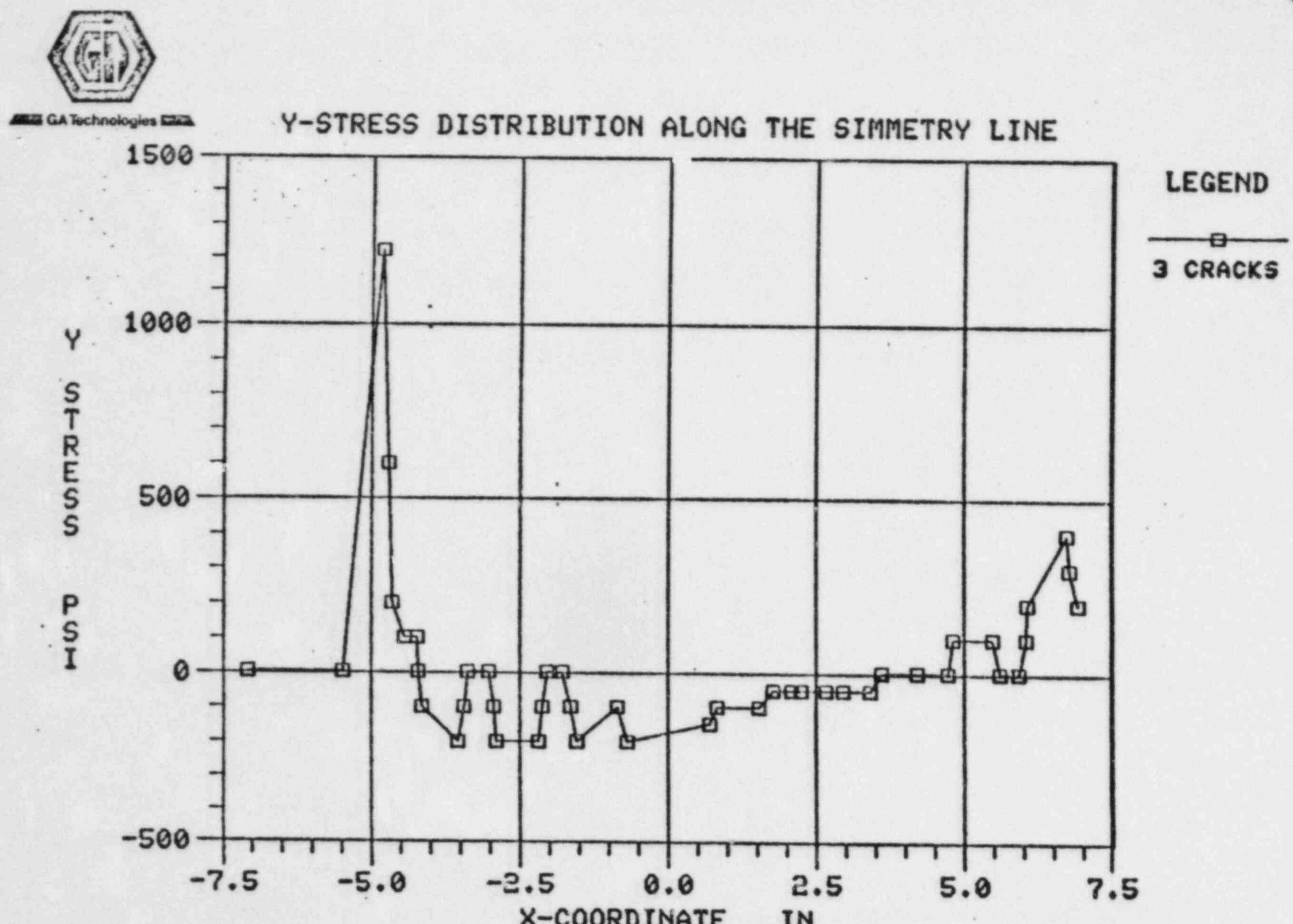
FSV FUEL ELEMENT

WITH SIMULATED CRACKS

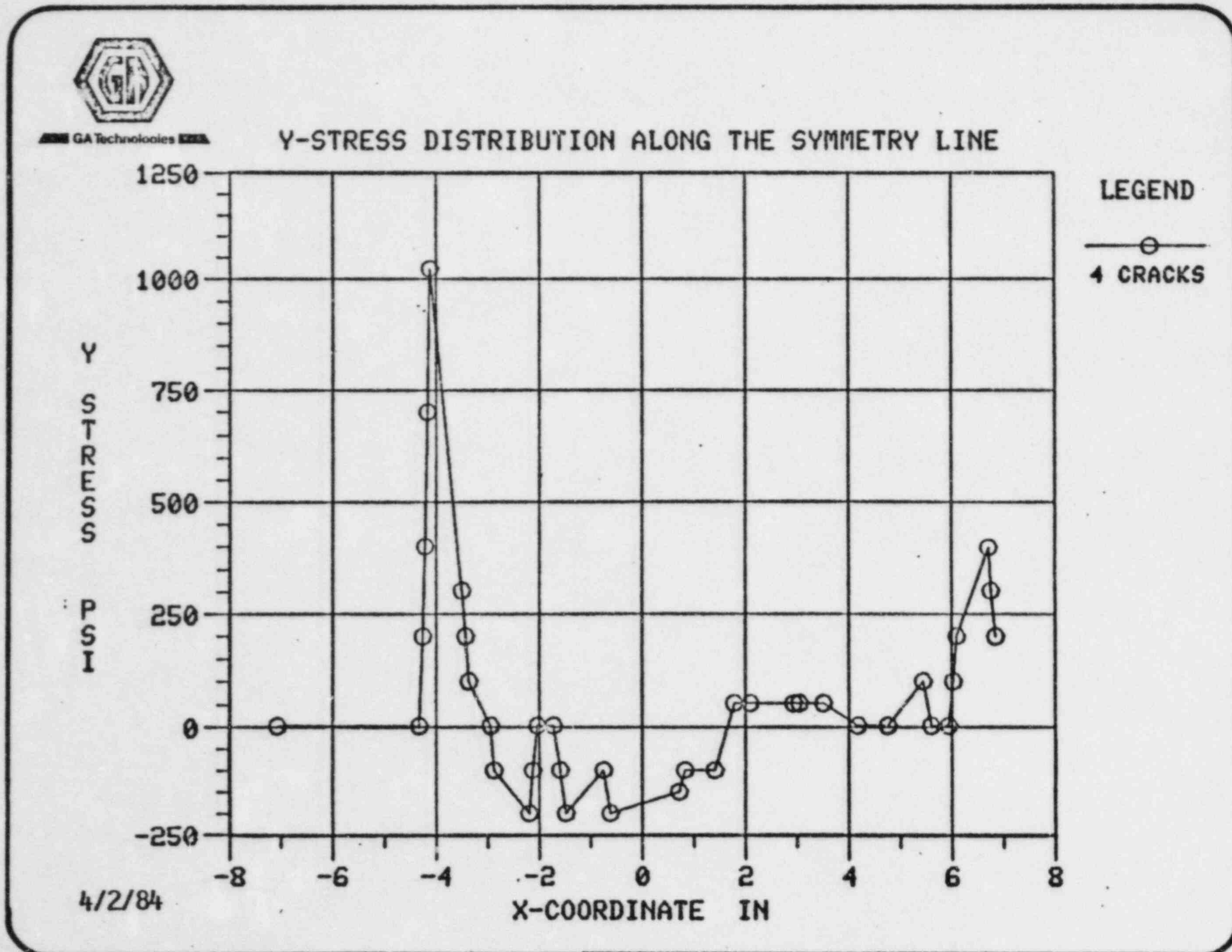



GA Technologies
TEMPERATURE DISTRIBUTION ALONG THE HALFLINE
750
700
650
600
550
500
TEMPERATURE
°C
-8
-6
-4
-2
0
2
4
6
8
X-COORDINATE IN
3-30-84

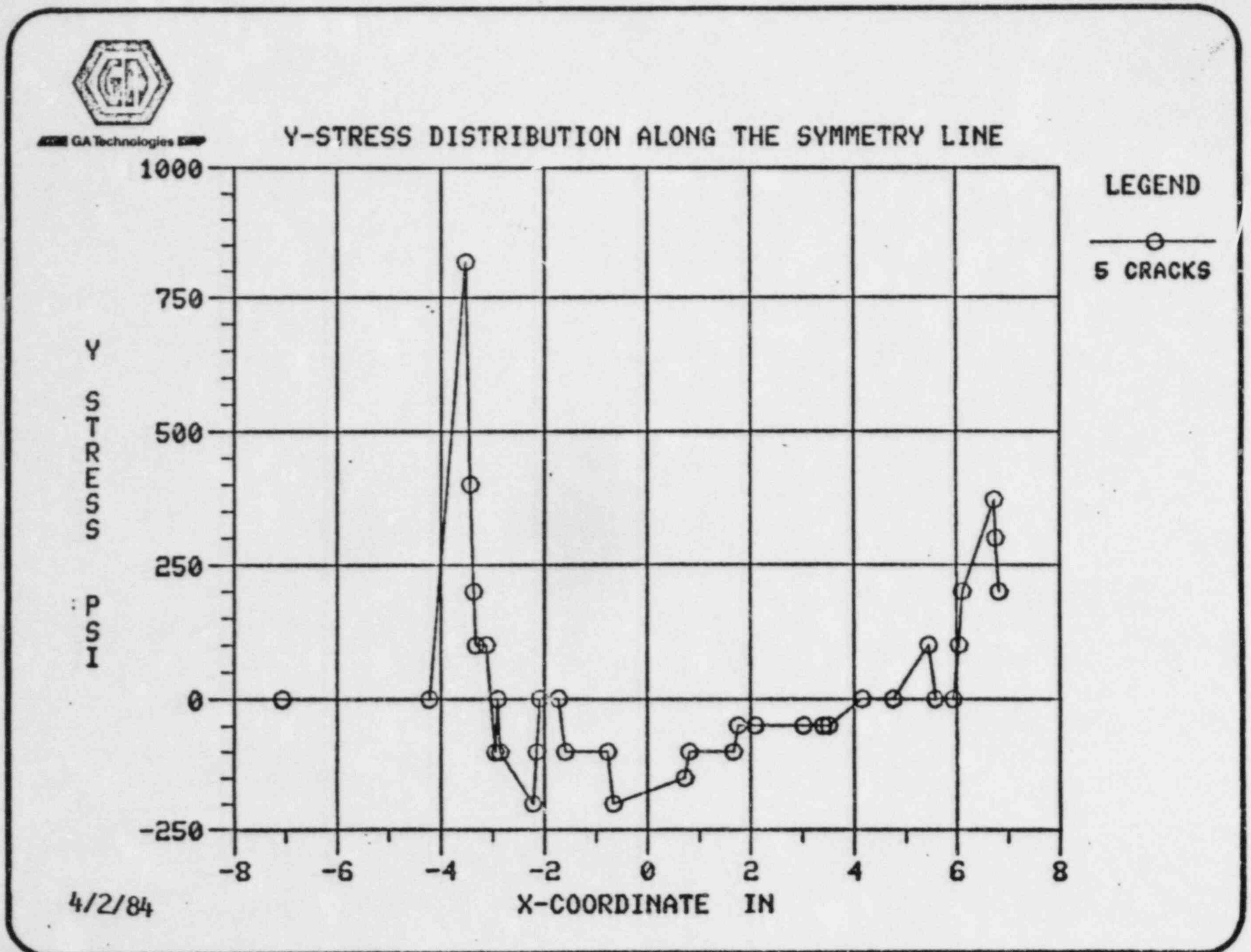

GA Technologies
Y-STRESS DISTRIBUTION ALONG THE SYMMETRY LINE
1500
1000
500
0
-500
Y STRESS PSI
-8
-6
-4
-2
0
2
4
6
8
X-COORDINATE IN
LEGEND
NO CRACK
3-30-84


GA Technologies
Y-STRESS DISTRIBUTION ALONG THE SIMMETRY LINE
1500
1000
500
0
-500
Y STRESS PSI
-7.5
-5.0
-2.5
0.0
2.5
5.0
7.5
X-COORDINATE IN
LEGEND
3 CRACKS

3-30-84



GA Technologies
Y-STRESS DISTRIBUTION ALONG THE SYMMETRY LINE
1250
1000
750
500
250
0
-250
Y STRESS PSI
LEGEND
4 CRACKS
-8
-6
-4
-2
0
2
4
6
8
X-COORDINATE IN
4/2/84



GA Technologies
Y-STRESS DISTRIBUTION ALONG THE SYMMETRY LINE
1000
750
500
250
0
-250
Y STRESS PSI
-8
-6
-4
-2
0
2
4
6
8
X-COORDINATE IN
LEGEND
5 CRACKS
4/2/84

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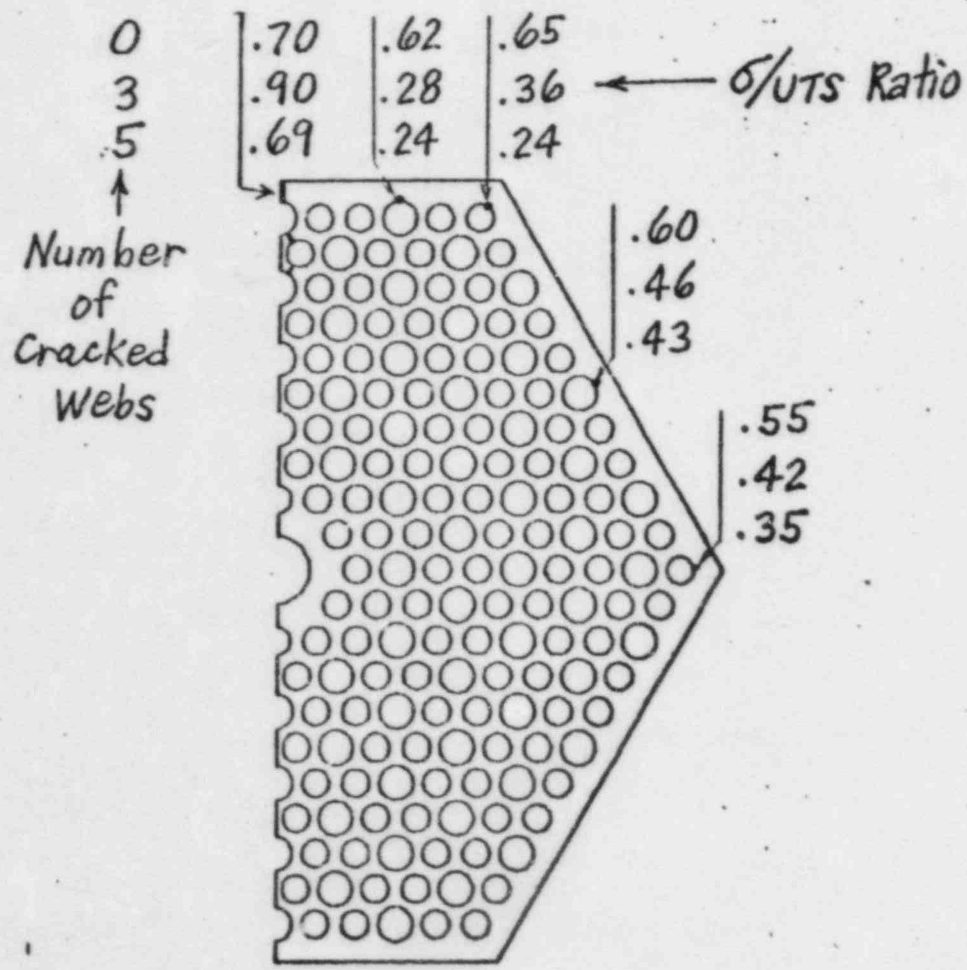
STRESS REDUCTION AFTER CRACKING



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EVALUATION OF CRACKING ANALYSIS

- CRACK PROGRESSION PATH COMPATIBLE WITH OBSERVATION
- PEAK STRESS/STRENGTH DECREASES AFTER A FEW WEBS ARE CRACKED
- AFTER ONE CRACK DEVELOPS, STRESSES IN THE REST OF THE BLOCK REDUCE DRAMATICALLY

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CONCLUSIONS:

- CRACK ARREST AFTER A FEW WEBS CRACKED

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TEST RESULTS

OF COMPRESSIVE LOADS APPLIED TO

FUEL ELEMENTS WITH SIMULATED CRACKS

(CRACKS WERE SIMULATED BY HACK-SAW CUT)

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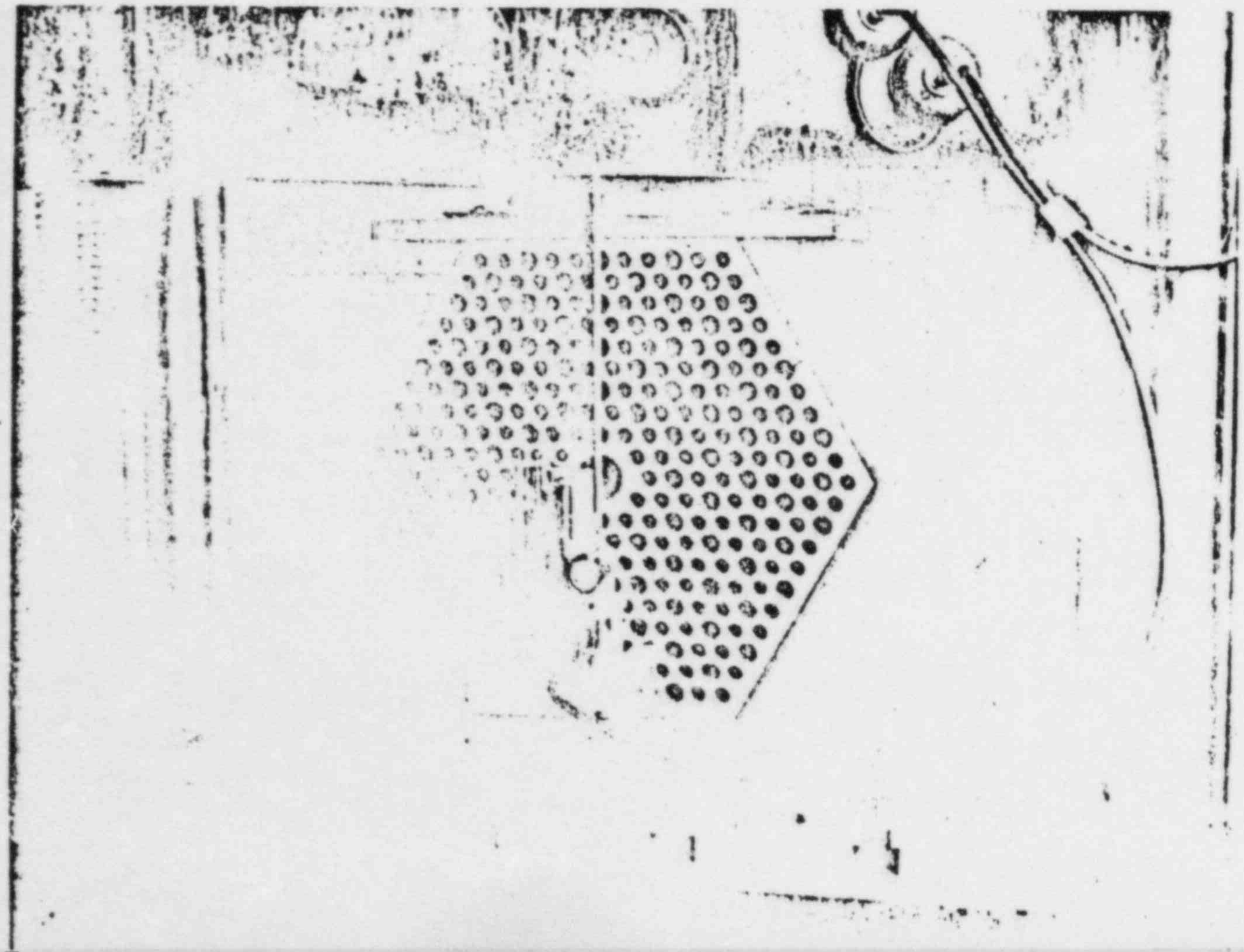
TEST SETUP OF ELEMENT 1-4568 SLAB 8 PRIOR TO TEST WITH CRACKS 60° OFF FROM LOADING AXIS



EFFECT OF CRACKS ON LATERAL STRENGTH OF FSV H327 FUEL ELEMENT SECTIONS

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ELEMENT NO.	SLAB NO.	NO. OF CRACKED WEBS	LOADING ORIENTATION	FAILURE LOAD (KIPS)
1.4545	1	3	0°	25.25
	2	0	0°	20.7
	3	0	60°	21.65
	4	3	60°	21.9
1-4568	5	1	60°	25.15
	6	0	60°	22.8
	7	2	60°	24.5
	8	3	60°	24.25

THICKNESS OF TEST SLAB = 6.5 IN.

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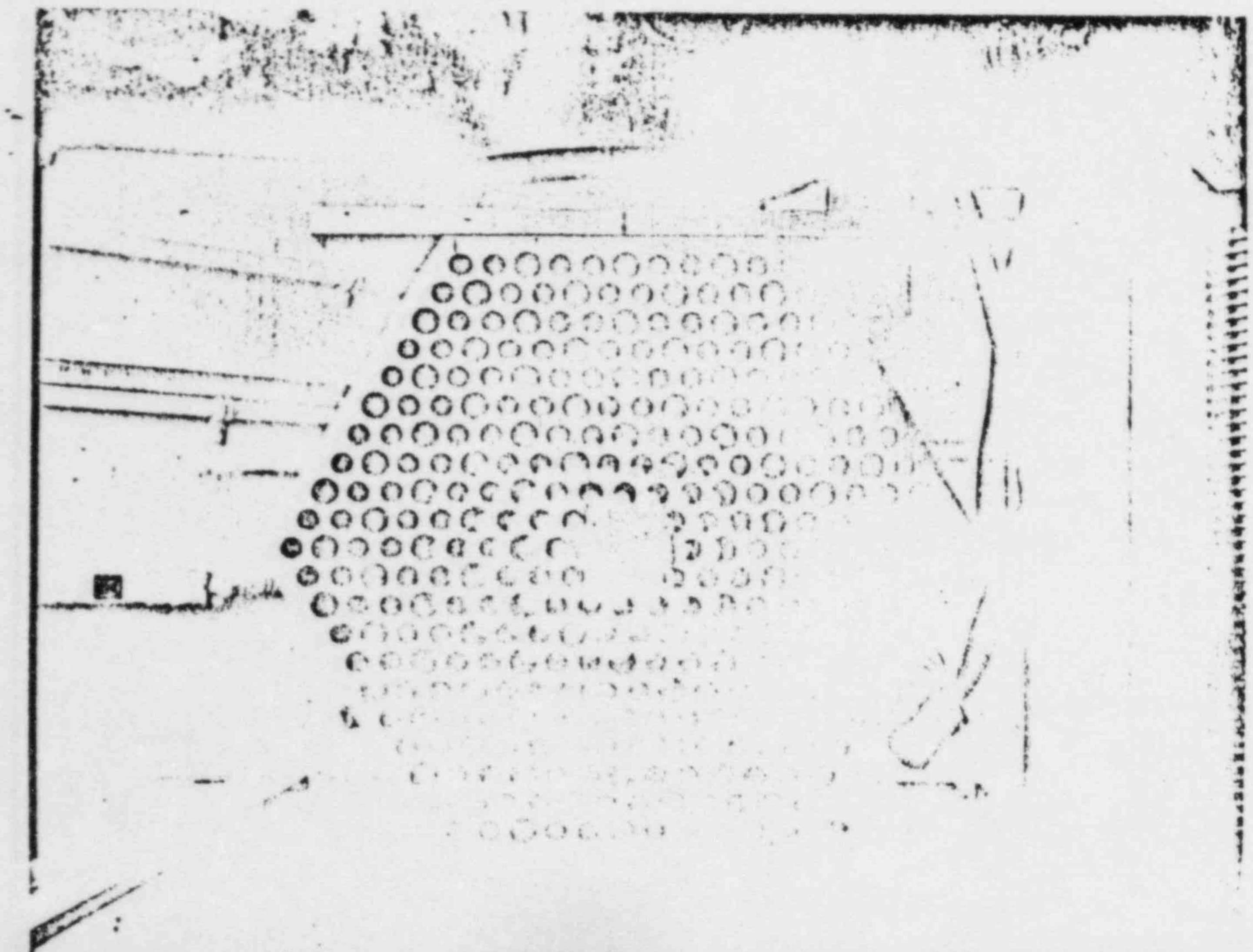
CRACK PATTERN OF ELEMENT 1-4568 SLAB 6 WITH NO SIMULATED CRACK



CLOSEUP OF CRACK PATTERN AT TOP REAR CORNER FOR ELEMENT 1-4568 SLAB 6

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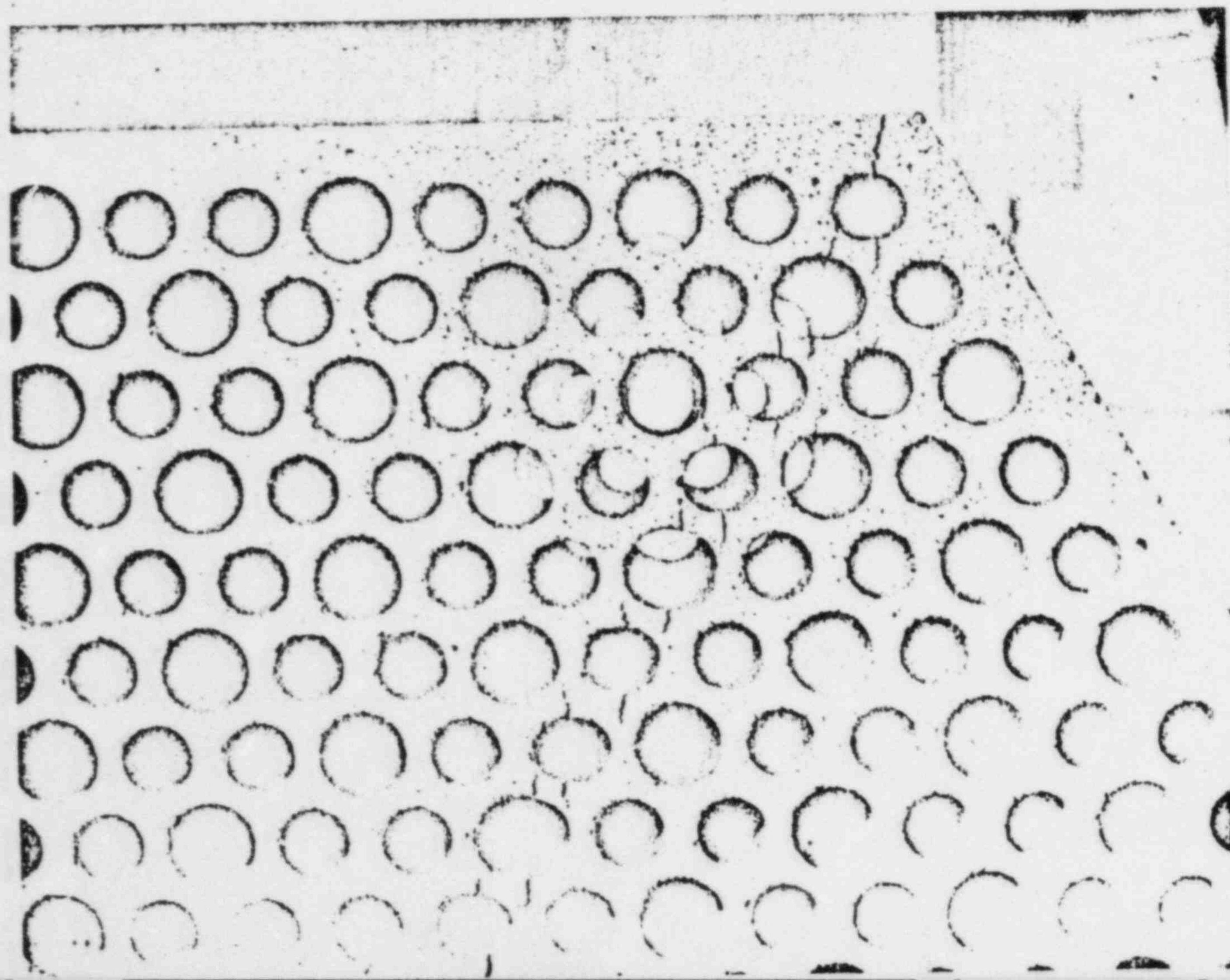

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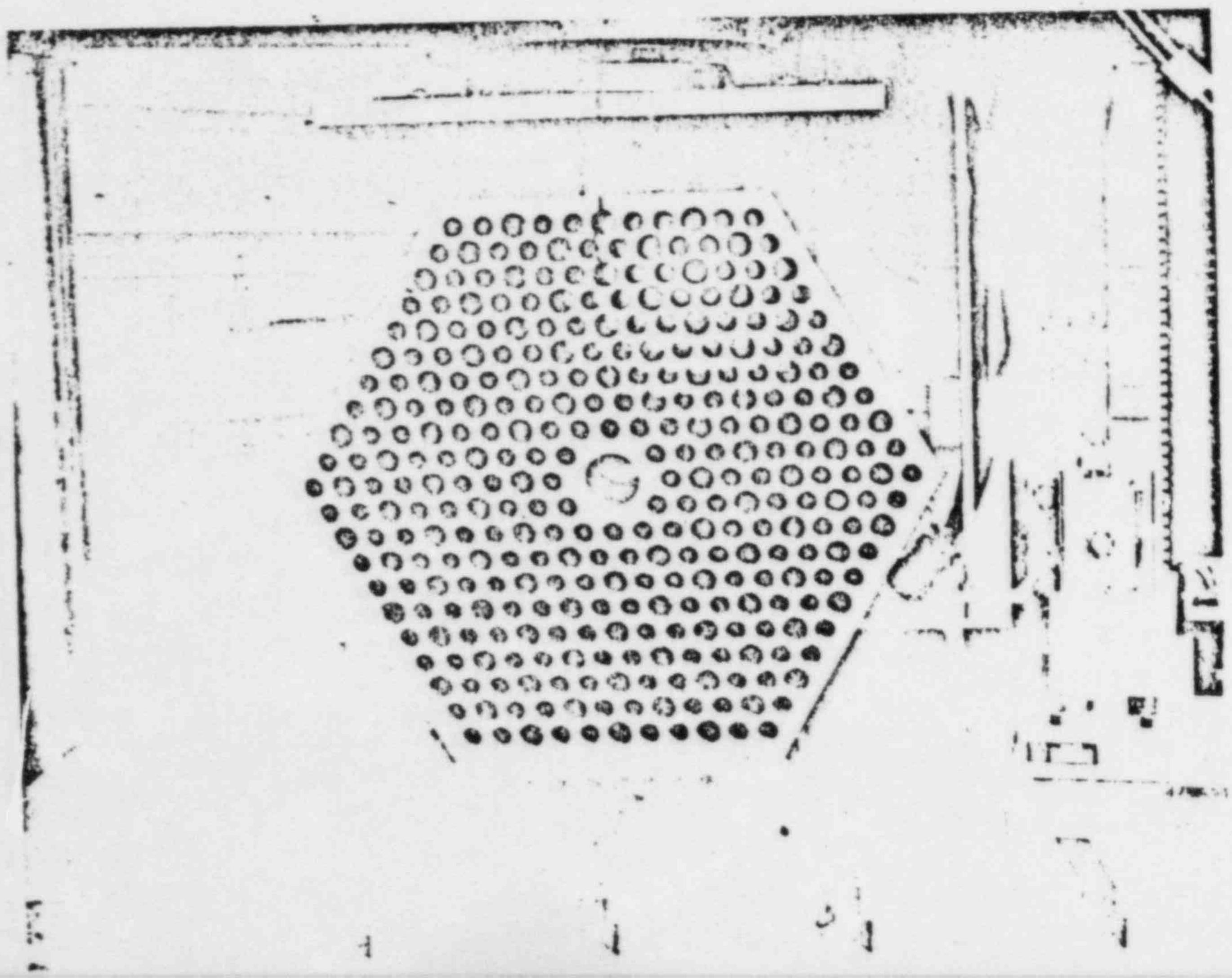
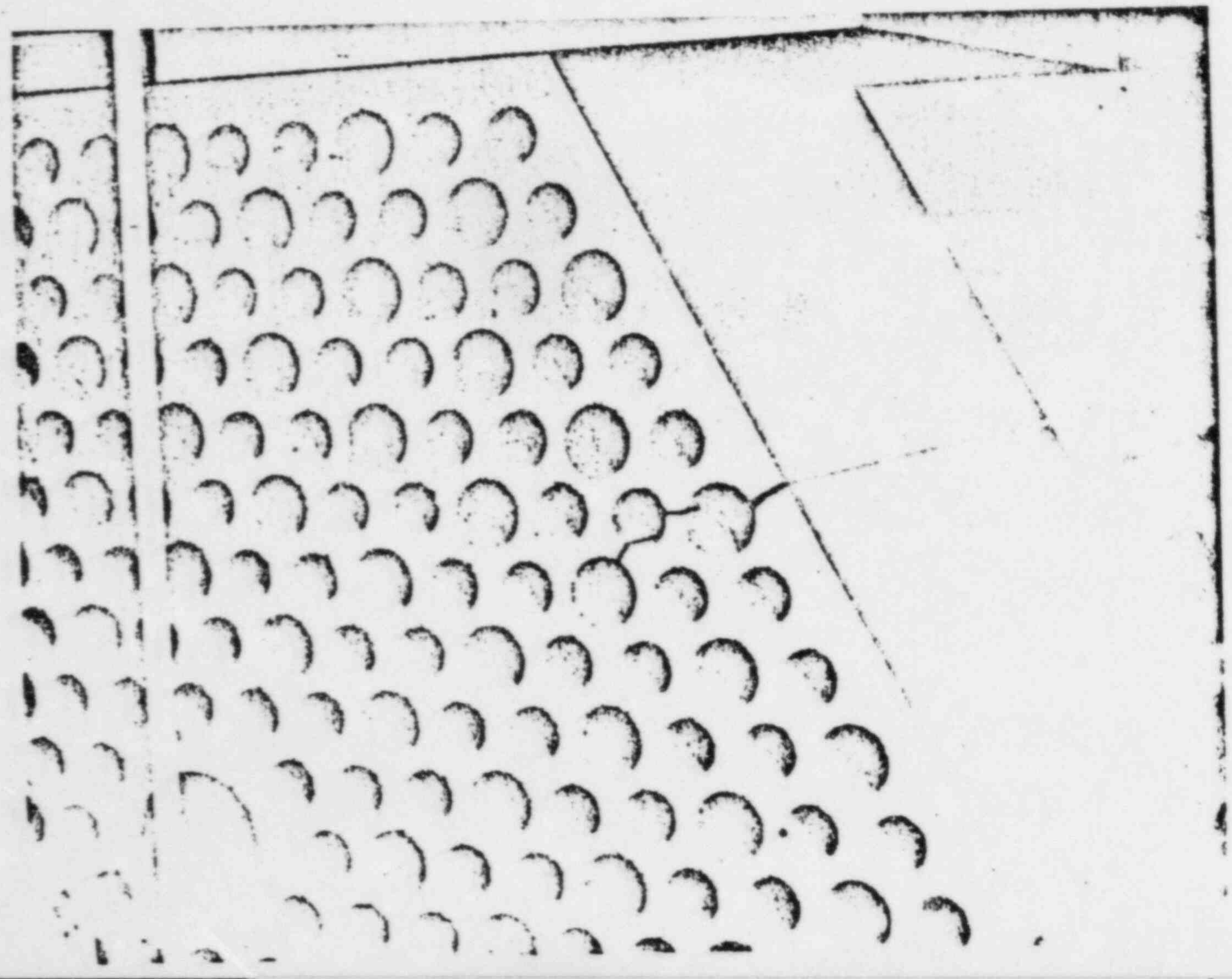
ORIENTATION OF ELEMENT 1-4545 SLAB 1 IN TEST SETUP WITH CRACKS UNDER LOADING PLATE



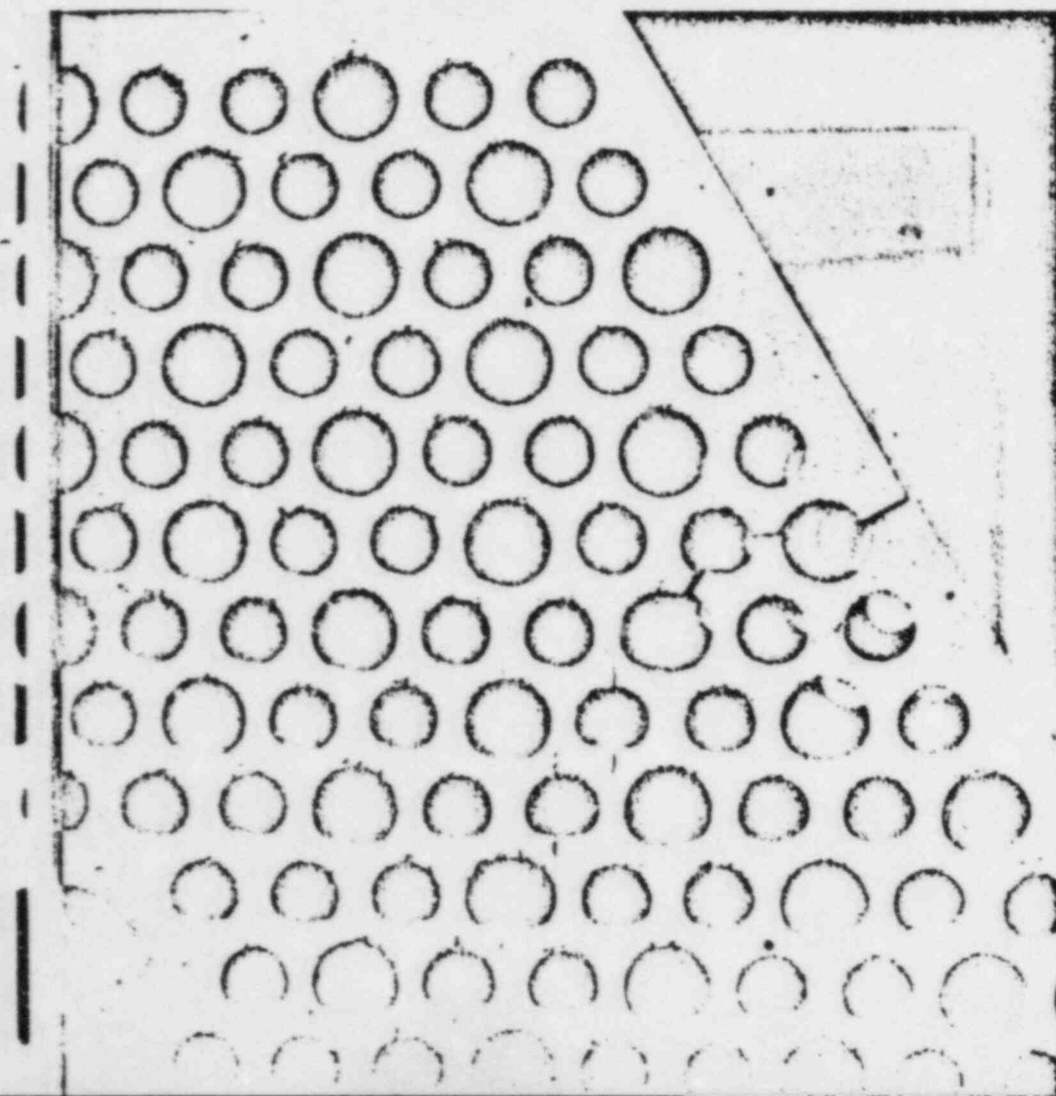
CLOSEUP OF SIMULATED CRACKS FOR ELEMENT 1-4568 SLAB 8 PRIOR TO TEST

GA Technologies



CRACK PATTERN OF ELEMENT 1-4568 SLAB 8 AFTER INITIAL FAILURE WTIH BLOCK STILL UNDER 20,750 LB LOAD

GA Technologies



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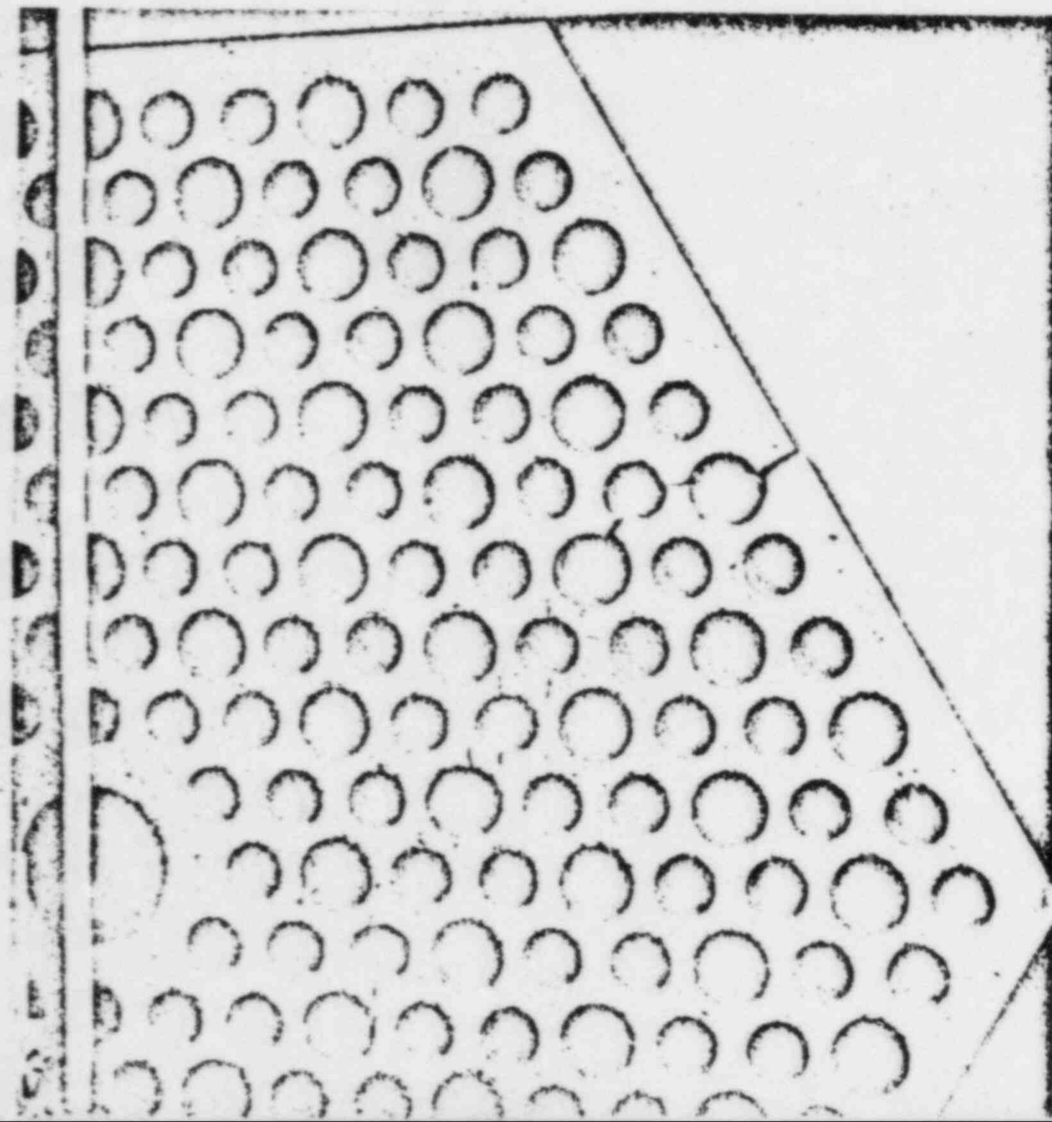
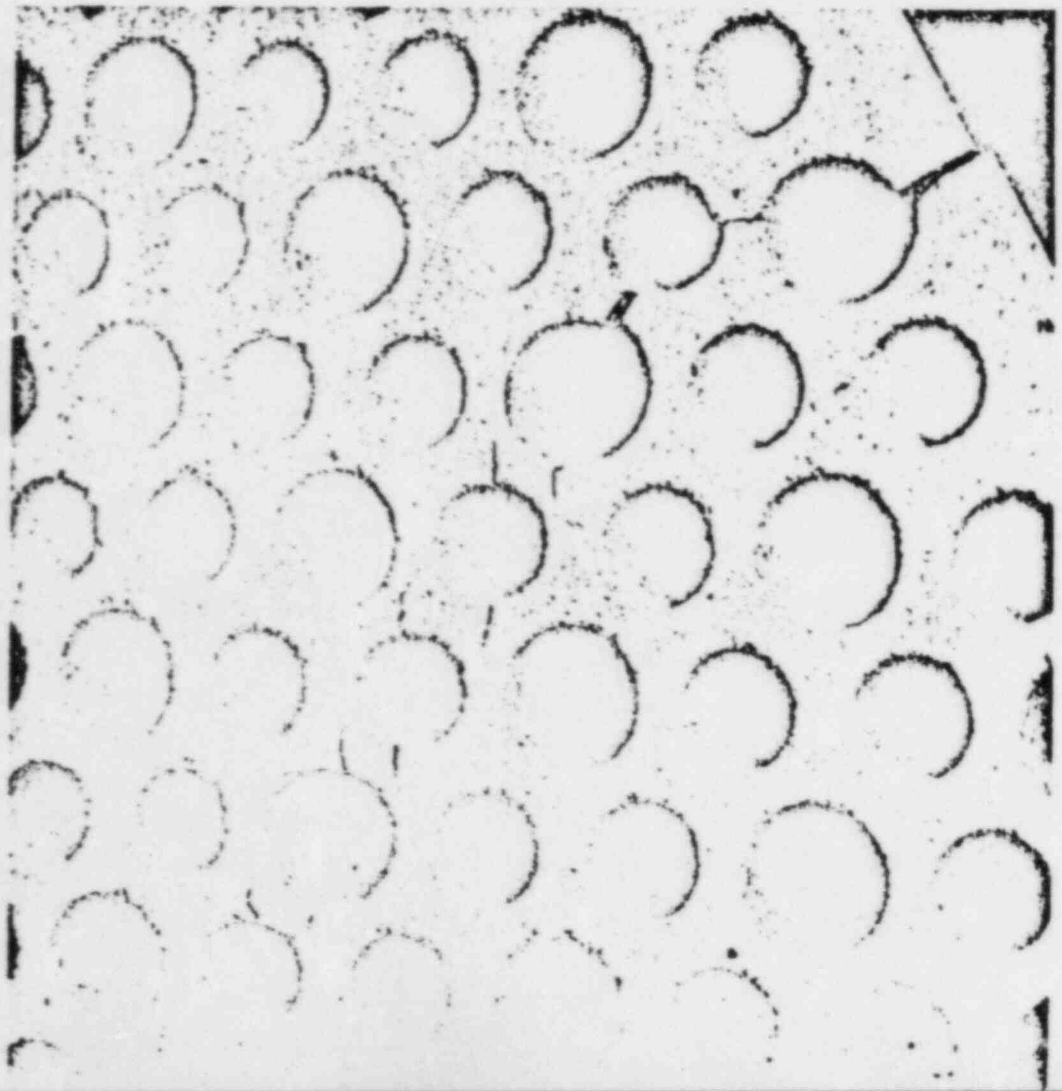
CRACK PATTERN OF ELEMENT 1-4568 SLAB 8 AFTER INITIAL FAILURE WITH BLOCK STILL UNDER 20,750 LB LOAD



CLOSEUP OF CRACK TIPS FOR ELEMENT 1-4568
SLAB 8 WITH BLOCK STILL UNDER
20,750 LB LOAD



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CONCLUSIONS

- o EFFECT OF CRACKS ON COMPRESSIVE STRENGTH
  - o NO REDUCTION
- o EFFECT OF CRACKS ON FAILURE MODE
  - o NO EFFECT WITH CRACKS UNDER THE LOAD
  - o NO EFFECT WITH ONE CRACK ON ONE OF THE LOAD FREE FACES
  - o CRACKS INITIATE AT THE TIPS OF SIMULATED CRACKS WITH TWO OR MORE CRACKS ON ONE OF THE LOAD FREE FACES

4/2/84

FORT ST. VRAIN FSAR

FUEL ELEMENT INTEGRITY

"STRUCTURAL INTEGRITY OF THE FUEL ELEMENTS WILL BE MAINTAINED THROUGHOUT THE DESIGN LIFETIME UNDER ALL OPERATING CONDITIONS." (PG 3.4-7)

"THE ELEMENTS WILL MAINTAIN SUFFICIENT INTEGRITY AT THE COMPLETION OF DESIGN BURNUP TO PERMIT SAFE REMOVAL FROM THE CORE." (PG 3.2-2)

GA Technologies

SIGNIFICANCE OF FUEL ELEMENT CRACKING

CRACKING COULD ADVERSELY AFFECT:

1. CORE COOLABILITY	SAFETY
2. CONTROL MATERIAL INSERTABILITY	
3. FUEL ELEMENT REMOVABILITY	INVESTMENT

G.A. Technologies

COLUMN FLOW BLOCKAGE
CONSERVATIVE ASSUMPTIONS

1. MAXIMUM RPF (1.83) AND COLUMN TILT (1.54)
2. INSTANTANEOUS RELEASE OF COLUMN FP INVENTORY (35,000,000 Ci)
3. TID-14844 PCRV RELEASE FRACTIONS (100% NOBLE GASES, 25% HALOGENS, 1% CONDENSIBLES)
4. HELIUM PURIFICATION SYSTEM INOPERATIVE
5. PCRV AT FULL PRESSURE (COOLDOWN NOT TAKEN INTO ACCOUNT)
6. MAXIMUM ALLOWABLE PCRV LEAK RATE (22 LBS/DAY)

GA Technologies

COLUMN FLOW BLOCKAGE CONSEQUENCES

180 DAY LPZ DOSES:

0.002	REM	WHOLE BODY
0.01	REM	THYROID
0.02	REM	BONE

DBA #1 - LOSS OF FORCED CIRCULATION

0.33	REM	WHOLE BODY
8	REM	THYROID (NRC ESTIMATES)
5	REM	BONE

REF: P-78146, SEPTEMBER 6, 1978

CONTROL MATERIAL INSERTABILITY

CONTROL RODS:

INSERTION CAN BE IMPEDED BY:

Ø.2 TO Ø.5 INCH LATERAL DISPLACEMENT

RESERVE SHUTDOWN SYSTEM (RSS):

INSERTION CAN BE IMPEDED BY:

Ø.5 INCH LATERAL DISPLACEMENT

MAXIMUM INTRA-REGION GAP ≈ Ø.1 INCH

GA Technologies

SUMMARY AND CONCLUSIONS
SAFETY SIGNIFICANCE OF CRACKING

1. CRACKING SUCH AS THAT SEEN TO DATE HAS NO IMPACT ON PUBLIC HEALTH AND SAFETY.

2. ORDERS OF MAGNITUDE MORE SEVERE CRACKING ARE REQUIRED TO IMPACT PUBLIC HEALTH AND SAFETY.

3. ANY POSSIBLE PUBLIC HEALTH AND SAFETY IMPACT IS LESS THAN THAT REVIEWED AND ACCEPTED BY NRC FOR OTHER FSV ACCIDENT SCENARIOS.