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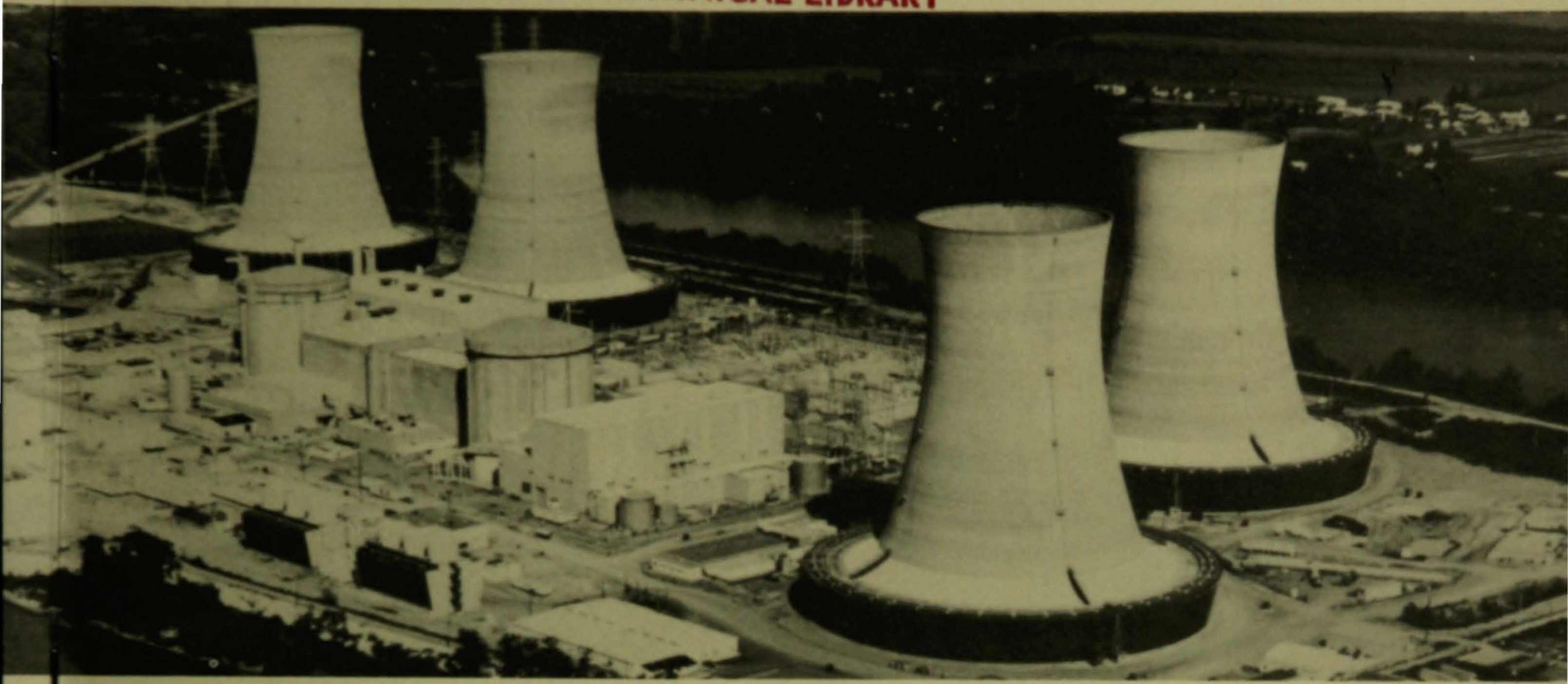

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TMI-2 CORE CAVITY SIDES AND FLOOR EXAMINATIONS

DECEMBER 1985 AND JANUARY 1986

M. L. Russell

Prepared for the
U.S. Department of Energy
Three Mile Island Operations Office
Under Contract No. DE-AC07-76ID01570

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EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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ABSTRACT

The purpose of this report is to provide a still-image photograph album of the Three Mile Island Unit 2 (TMI-2) core cavity sides and floor. The photographs were made from tape recordings of December 1985 and January 1986 video camera surveys or monitorings using a special electronic image enhancement and production system. The photographs show evidence of the following:

- Accurate determination of core cavity topography by the ultrasonic scanner, which indicated the core cavity walls were formed by the remnants of the outside ring of fuel assemblies and the core former wall

- Increased upper end fitting damage of fuel assemblies with burnable poison (Al_2O_3-B_4C) rods

- Interaction of zircaloy with steam (embrittlement), uranium dioxide (liquefaction), stainless steel, and Inconel

- No regions of flow channel blockage from fuel rod swelling.

- Peripheral fuel assembly damage appears to increase significantly below the core cavity floor level and especially near the observed height of the hard crust that has been encountered below the core cavity floor loose debris.

CONTENTS

ACRONYMS

AEP	Accident Evaluation Program
APSR	Axial power shaping rod
BPR	Burnable poison rod
CCTV	Closed-circuit television
CR	Control rod
CRDM	Control rod drive mechanism
DOE	U.S. Department of Energy
EG&G	EG&G Idaho, Inc.
GEND	Group made up from the following organizations: GPU Nuclear Corporation, Electric Power Research Institute, Nuclear Regulatory Commission, and Department of Energy
IDCOR	Industry Degraded Core Rulemaking (Program)
INEL	Idaho National Engineering Laboratory
GPR	Gadolinium poison rod
LWR	Light water reactor
NRC	U.S. Nuclear Regulatory Commission
PORV	Pilot-operated relief valve
RCS	Reactor cooling system
SA&E	Sample Acquisition and Examination
SCD	Severe core damage
TMI-2	Three Mile Island Unit 2

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TMI-2 CORE CAVITY SIDES AND FLOOR EXAMINATIONS DECEMBER 1985 AND JANUARY 1986

1. INTRODUCTION

The purpose of this report is to provide a still-image photograph album of the December 6, 7, 21, 22, 1985, and January 21, 1986, closed-circuit television (CCTV) surveys of the Three Mile Island Unit 2 (TMI-2) core cavity sides and floor. The CCTV surveys were made to: (a) determine the location and condition of the core components in the upper core region to assist the subsequent removal of loose debris and fuel rod segment sample acquisition (December 6 and 21, 1985 and January 21, 1986), and (b) monitor and record the acquisition of the six fuel rod segment samples (December 22, 1985).

Background

The examination of the TMI-2 core cavity sides and floor with the CCTV system is a small part of a large and complex TMI-2 Accident Evaluation Program Sample Acquisition and Examination Plan.[1]

Although the March 28, 1979, accident at TMI-2 involved severe damage to the core of the reactor, it had no observable effects on the health and safety of the public in the area (Reference 1). That such a severe core-disruption accident would have no consequent health or safety effects has resulted in the questioning of earlier light water reactor (LWR) safety studies and estimates. In an effort to resolve these questions, several major research programs have been initiated by a variety of organizations concerned with nuclear power plant safety. The U.S. Nuclear Regulatory Commission (NRC) has embarked on a thorough review of reactor safety issues, particularly the causes and effects of core-damage accidents. Industrial organizations have conducted the Industry Degraded Core Rulemaking (IDCOR) Program. The U.S. Department of Energy (DOE) has established the TMI-2 Program to develop technology for recovery from a serious reactor accident and to conduct relevant research and development that will substantially enhance nuclear power plant safety.

Immediately after the TMI-2 accident, four organizations with interests in both plant recovery and accident data acquisition formally agreed to cooperate in these areas. These organizations, commonly referred to as the GEND Group--GPU Nuclear Corporation, Electric Power Research Institute, Nuclear Regulatory Commission, and Department of Energy--are actively involved in reactor recovery and accident research. At present, DOE is providing a portion of the funds for reactor recovery (in those areas where accident recovery knowledge will be of generic benefit to the U.S. LWR industry) as well as the preponderance of funds for severe accident technical data acquisition (such as the examination of the damaged core).

The EG&G involvement with the TMI-2 accident has been continuous, initially providing technical support and consultation from the Idaho National Engineering Laboratory (INEL). In 1979, EG&G received an assignment from DOE to collect, analyze, distribute, and preserve significant technical information available from TMI-2. This assignment was expanded (in 1981 and 1984) to include: (a) conducting research and development activities intended to effectively exploit the generic research and development challenges at TMI-2, ano (b) developing an understanding of the accident sequence of events in the area of core damage and behavior of core radionuclides (fission products) and materials.

The TMI-2 Accident Evaluation Program report[2] defines the program required to implement the DOE assignments and contains the guidelines and requirements for TMI-2 sample acquisition and examinations.

The already-completed portion of the Sample Acquisition and Evaluation (SA&E) Plan includes in situ measurements and sample acquisition and examinations involving private organizations and state and federal agencies. It has provided the postaccident core and fission product end-state data that indicate the following:

- Large regions of the core exceeded cladding melting (~2200 K), and significant fuel liquefaction by molten zircaloy and some fuel melting occurred with temperatures up to at least 3100 K.

- Core materials relocated into the reactor vessel lower plenum region from the core, leaving a void in the upper core region equivalent to approximately 26% of the original core volume. Between 2 and 20 metric tons of core and structural materials now reside in the space between the reactor vessel bottom head and the elliptical flow distributor.

- Fission-product retention in core materials is significant. The retention of fission products outside the core was primarily in reactor cooling system (RCS) water, water in the basement, and in basement concrete.

Significant consequences resulting from these findings include: (a) increased technical interest in the TMI-2 accident because it represents a full-scale severe-core-damage (SCD) event and provides evidence of a large difference between actual and predicted SCD event offsite radiation release, (b) a reconsideration of the plans and equipment for defueling the TMI-2 reactor, and (c) an expansion in the TMI-2 accident examination plan to determine the consequences of high temperature interactions between core components and to determine the release from the fuel of the lower volatility fission products.

The CCTV examinations are part of the Reactor Vessel Internals Documentation portion of the TMI-2 Accident Evaluation Program SA&E Plan. This part of the SA&E Plan also includes ultrasonic scanner surveys for precise topographical mapping of the various regions that may be encountered during the exploration of the core and subcore regions. The SA&E Plan (Reference 1) requirements and/or objectives for the CCTV and ultrasonic scanner examinations are as follows:

> "Continued use of these in situ, nonintrusive data-recording techniques at well-planned intervals during the defueling program will provide data from which: (a) core debris volume measurements can be inferred, (b) visual indications of the extent of liquefaction and core material relocation to the lower plenum can be obtained, (c) confirmation of the degree of damage to peripheral core support structures, including the reactor vessel lower head and instrument guide tube penetrations, can be made, and (d) decisionmaking for further incore sampling plans and bulk defueling can be carried out."

Core/Core Cavity History

The history intervals of interest for the TMI-2 core cavity CCTV examinations are: (a) the core loading and operation before the accident, (b) the accident sequence that damaged the core components and created the cavity in the upper core region, and (c) the postaccident reactor vessel internals disassembly activities that caused further relocation and separation of core components at the ceiling, walls, and floor of the core cavity before the December 1985 CCTV examinations.

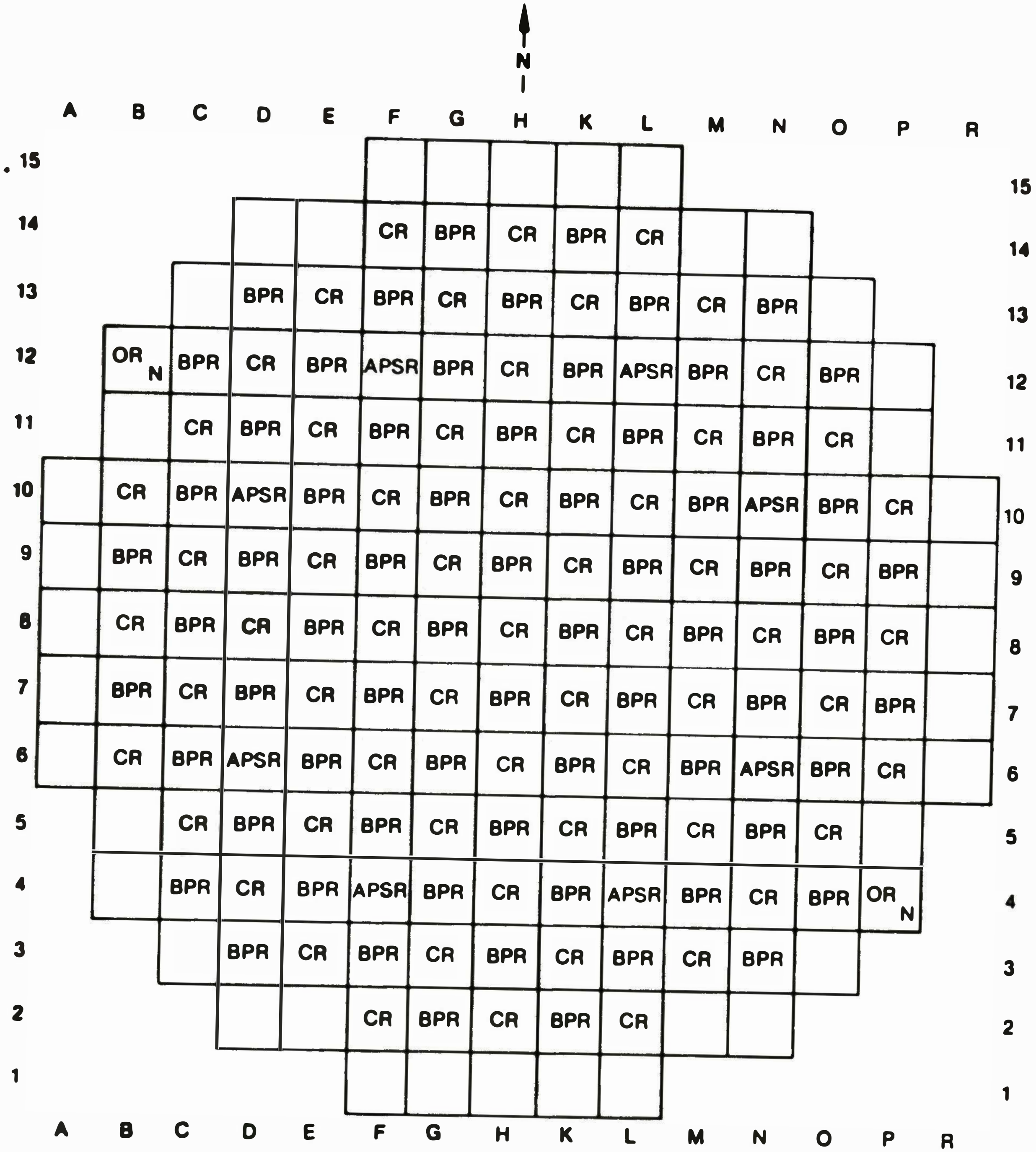
Preaccident Operations

At accident initiation, the TMI-2 core was in the initial fuel cycle at 97% of full power with 3175 MWD/MTU average core burnup. The core loading consisted of 177 fuel assemblies and 139 rod assemblies arranged in the core positions as shown in Figure 1.

Each of the fuel assemblies (see Figure 2) is a 15 x 15 array of 208 fuel rods, 16 zircaloy guide tubes and 1 center-position zircaloy instrument tube connected to and supported by 8 Inconel spacer grids and 304L stainless steel upper and lower end fittings. An Inconel, coil-type holddown spring is located in the upper end fitting.

All interior and 2 of 40 peripheral core positions also have rod assemblies consisting of 16 rods connected together at the top by arms extending from a central hub. The rods fit into the fuel assembly guide tubes. The two peripheral fuel assemblies (core positions B12 and P4, next to the core former wall) contain a stationary orifice rod assembly (see Figure 3) with 12-in.-long stainless steel rods extending into the guide tubes to restrict coolant flow, of which one in each assembly is assumed to be modified to include a neutron source rod. Interior fuel assemblies contain one of three types of rod assemblies as follows:

- o Burnable Poison Rod (BPR) Assembly (see Figure 4)--The stationary burnable poison rod assemblies are located in 72 core positions



OR Orifice Rod Assembly

CR Control Rod Assembly

BPR Burnable Poison Rod Assembly

APSR Axial-Power-Shaping Rod Assembly

N Primary Neutron Source

6 4690

Figure 1. TMI-2 core loading diagram.

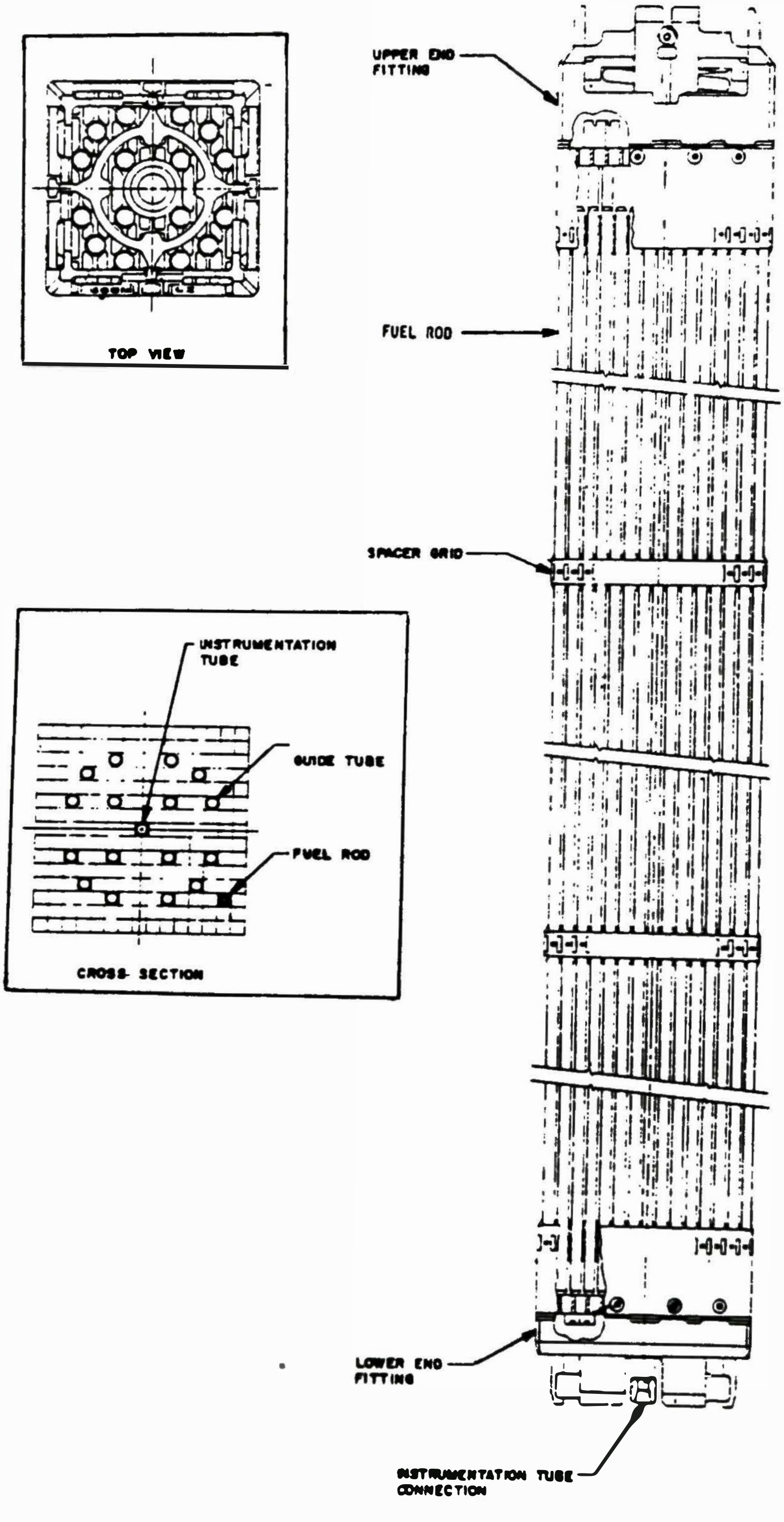


Figure 2. Side, top, and cross-sectional views of TMI-2 fuel assembly (from Reference 3).

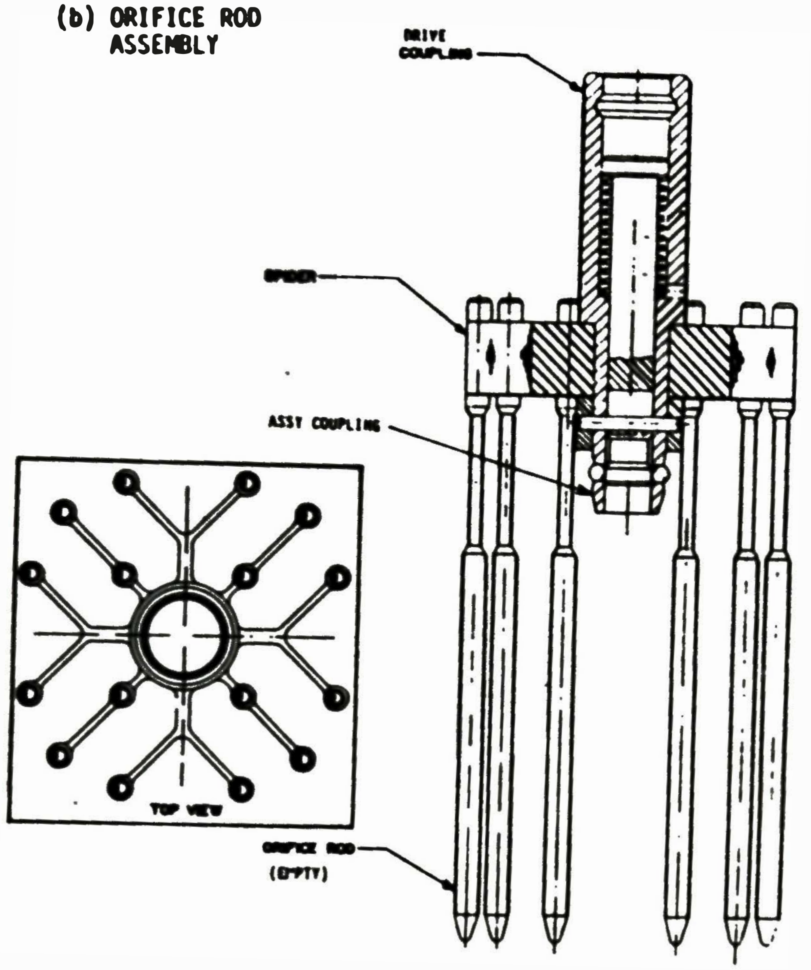


Figure 3. Orifice rod assembly (from Reference 3).

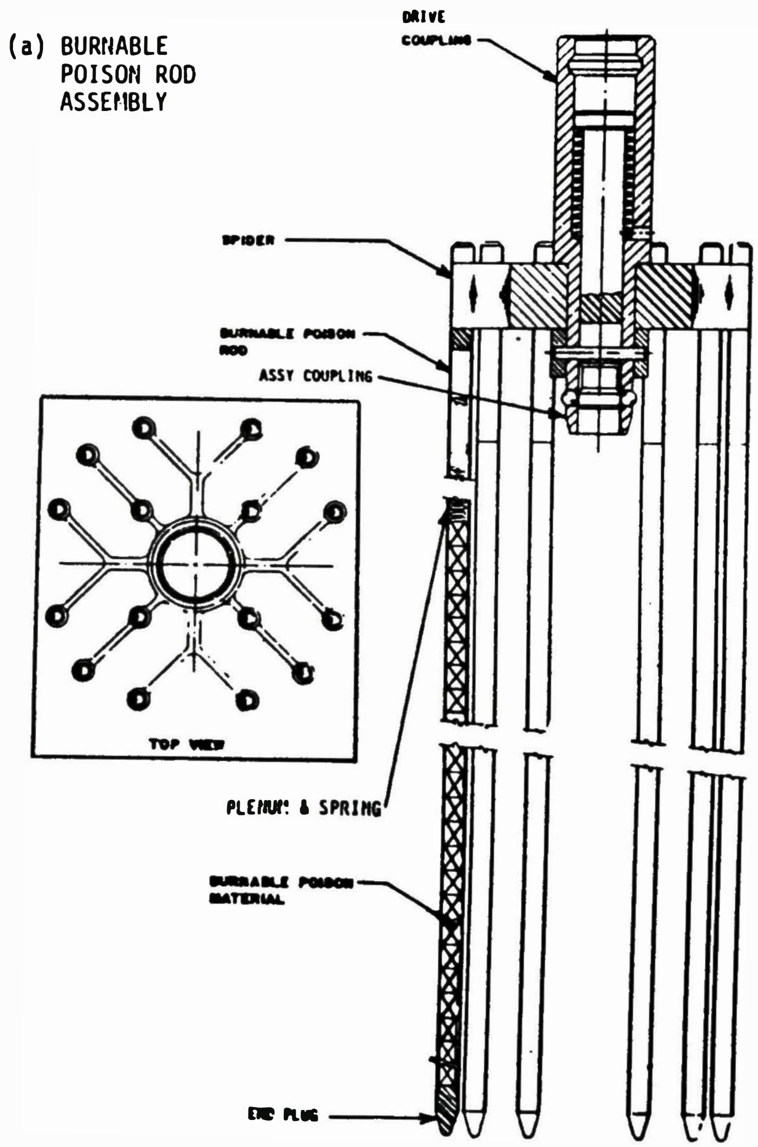


Figure 4. Burnable poison rod assembly (from Reference 3).

as shown in Figure 1. Each BPR rod contains a 126-in.-long stack of Al_2O_3 (0.95)-B_4C (0.01)-impurities (0.04) ceramic pellets clad in zircaloy, except for core position N13, which is assumed to contain 8 rods with borated graphite instead of Al_2O_3-B_4C.

- Control Rod (CR) Assembly (Figure 5)--The CR assemblies are located in the 61 core positions shown in Figure 1. The rods contain 134 in. lengths of Ag-In-Cd clad in Type 304L stainless steel. The CR assemblies were fully inserted during the accident sequence.

- Axial Power Shaping Rod (APSR) Assembly (Figure 6)--The APSR assemblies are located in the eight symmetrical core positions shown on Figure 1. Each rod contains a 36 in. length of Ag-In-Cd material clad in stainless steel. The APSR assemblies remained withdrawn at 37 in. during the accident sequence.

TMI-2 Accident Sequence

Reference 2 includes the current theory of the core-component damage and relocation and the formation of the core cavity. A summary of this theory is as follows:

The critical time period of the accident sequence contributing to core-damage progression and fission-product release is believed to be between 102 and 210 minutes after the reactor tripped. The 102 minutes corresponds to the beginning of core uncovery following phase separation of the primary coolant, when the last of the reactor coolant pumps was turned off in the A-loop at 101 minutes. The 210 minutes corresponds to the approximate time of core refill following the resumption of sustained high-pressure injection, which occurred at about 200 minutes and resulted for the most part in termination of core heatup. At 135 minutes, the reactor building air sample particulate monitor went off scale, indicating some core damage. At 142 minutes, the operators closed the pilot-operated relief valve (PORV) block valve. Following additional radiation detector

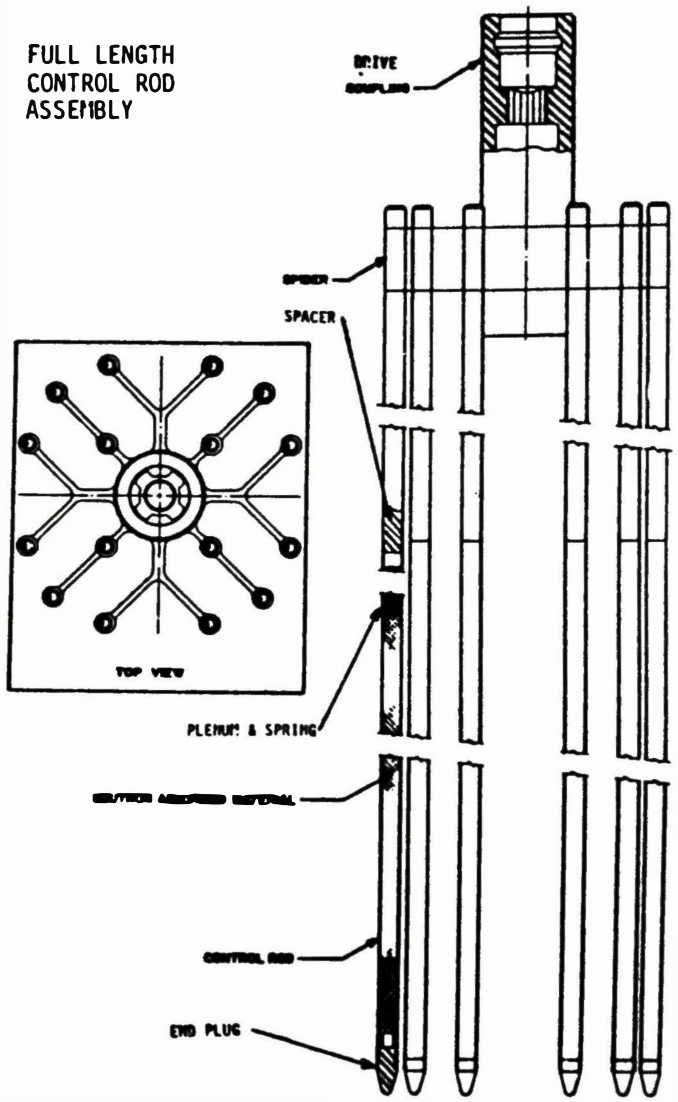


Figure 5. Control rod assembly (from Reference 3).

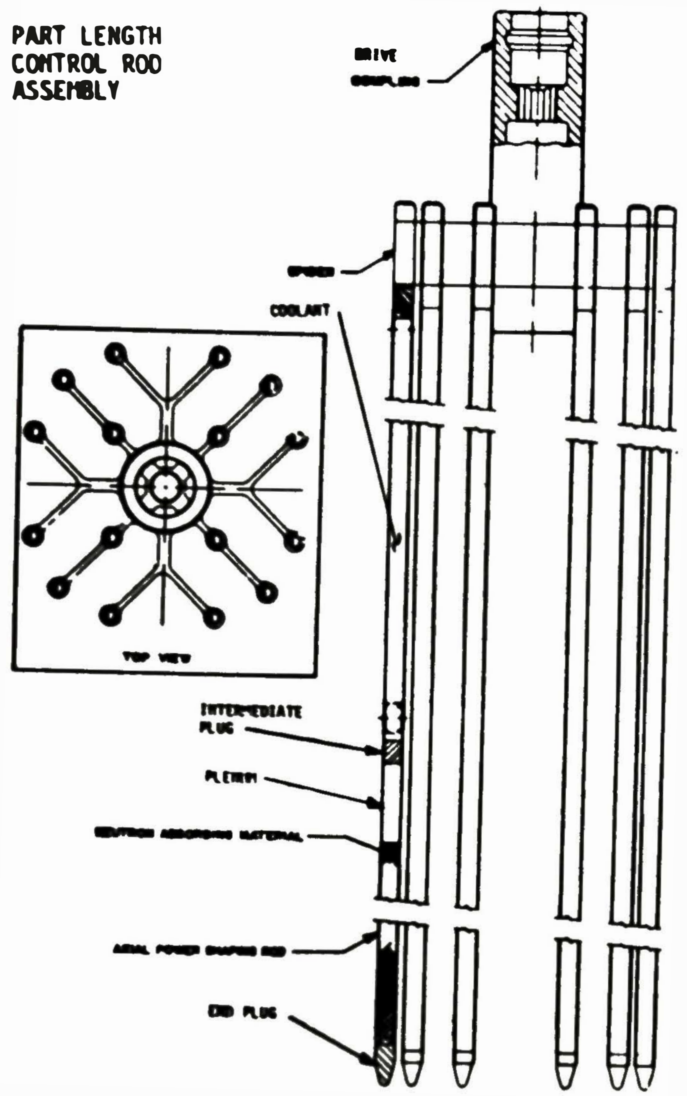


Figure 6. Axial-power-shaping-rod (APSR) assembly (from Reference 3).

responses that indicated significant core damage, reactor coolant pump 2B was started and run for a short period, forcing water through the core and causing significant fuel rod fracturing. The PORV block valve was reopened for approximately 5 minutes at the 192-minute period. This sequence of events defines the accident time period when damage may have occurred to the fuel assemblies.

Between the accident and December 22, 1985, the core components remained submerged in an ambient temperature and pressure, treated, water solution with the following target specifications:

- o ph: 7.5 to 7.7
- o boron: >4350 ppm
- o buffer: Na OH.

Postaccident Reactor Vessel Internals Disassembly Activities

A series of disassembly activities including precursor examinations were accomplished between the accident-sequence termination and December 22, 1985, which affected or determined the condition of the core cavity walls and floor. No activities or examinations were attempted until personnel access inside the reactor building was reestablished in 1981. A summary of significant examination and disassembly events that have occurred is as follows:

Quick-Look Video Surveys. In 1982, control rod leadscrews from core positions H8, E9, and B8 were removed for possible CCTV access to the core area. The CR spider was still in place at B8, but was missing at core positions H8 and E9. The CCTV survey discovered a large, empty region (core cavity) in the upper core region.

APSR Assembly--Insertion.[4] In the first quarter of CY 1983, an attempt was made to insert all eight APSR assemblies which, if successful, would relocate the APSRs 37 in. downward (see Figure 1 for APSR core positions). Insertion into the core cavity depths were as follows:

Core Position	Insertion Depth (In.)
D6	0
D10	4
F4	30
F12	35
L4	8
L12	31
N6	0
N10	37

Ultrasonic Scanner Survey.[5] On August 31, 1983, an ultrasonic scanner survey was made to determine the shape and dimensions of the core cavity. Figures 7 through 10 are the topographical maps of the core cavity. The core topographical features included the following:

- The cavity extended from the upper grid-plate bottom downward to approximately 7.5 ft above the core bottom and radially to the core former wall in some places

- The core cavity volume was equivalent to approximately 26% of the original core region

- Fuel assembly remnants appeared to encircle the core cavity completely toward the upper grid plate; the maximum fuel assembly damage appeared to be on the core East side, and the least fuel assembly damage on the core West side

- The APSRs that had been inserted projected from the cavity ceiling and interfered with ultrasonic-scanner measurement of topography in the cavity upper regions.

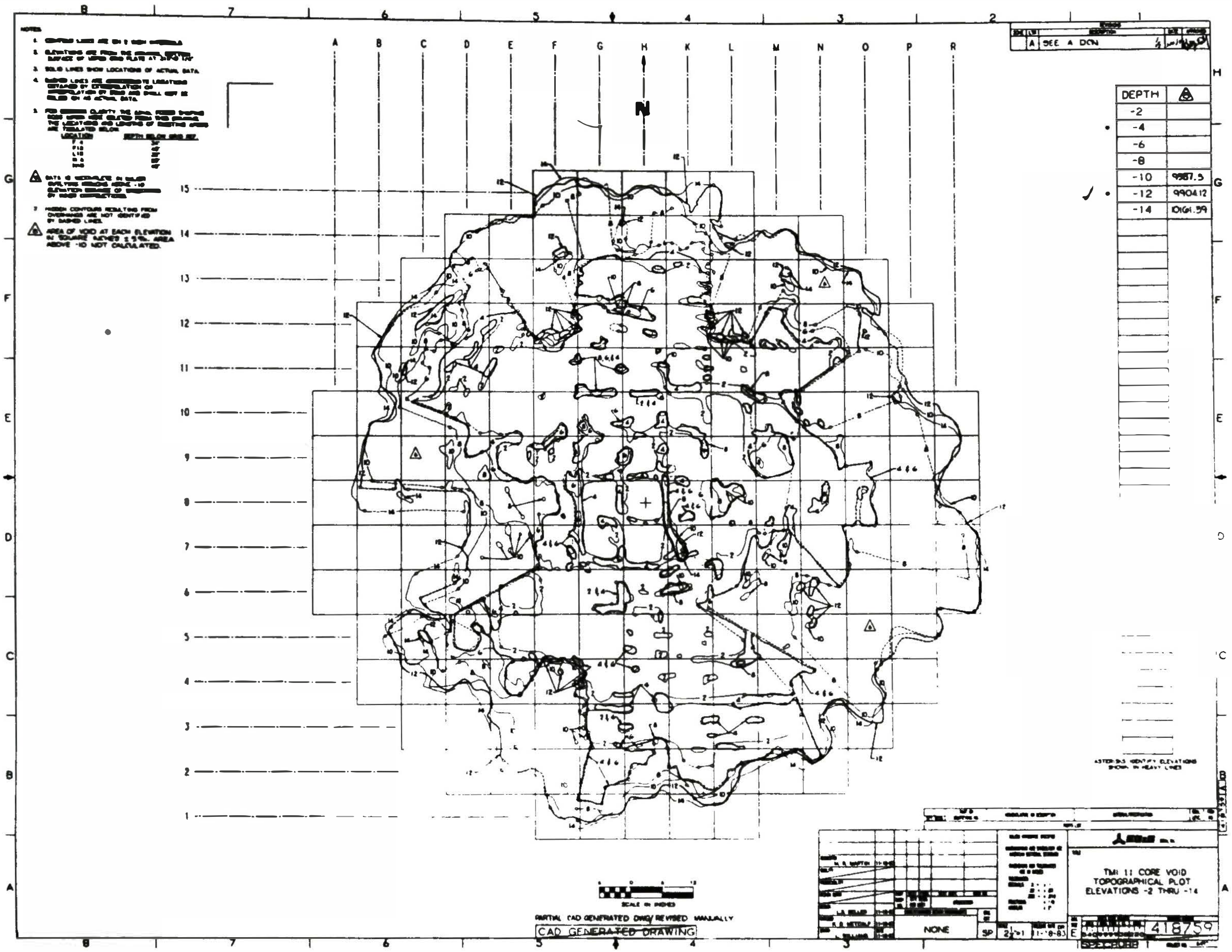


Figure 7. TMI-2 core void topographical plot elevations -2 through -14.

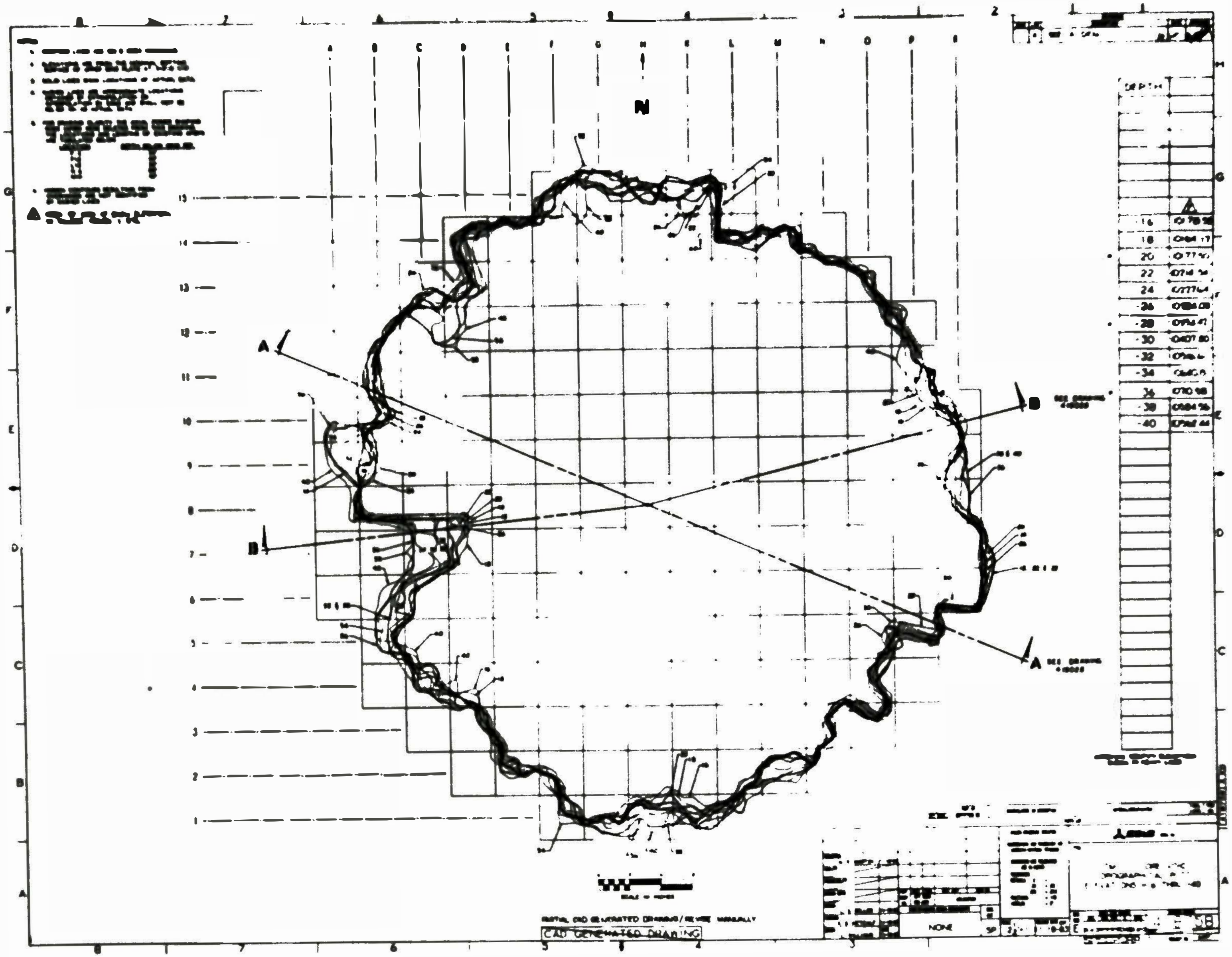


Figure 8. TMI-2 core void topographical plot elevations -16 through -40.

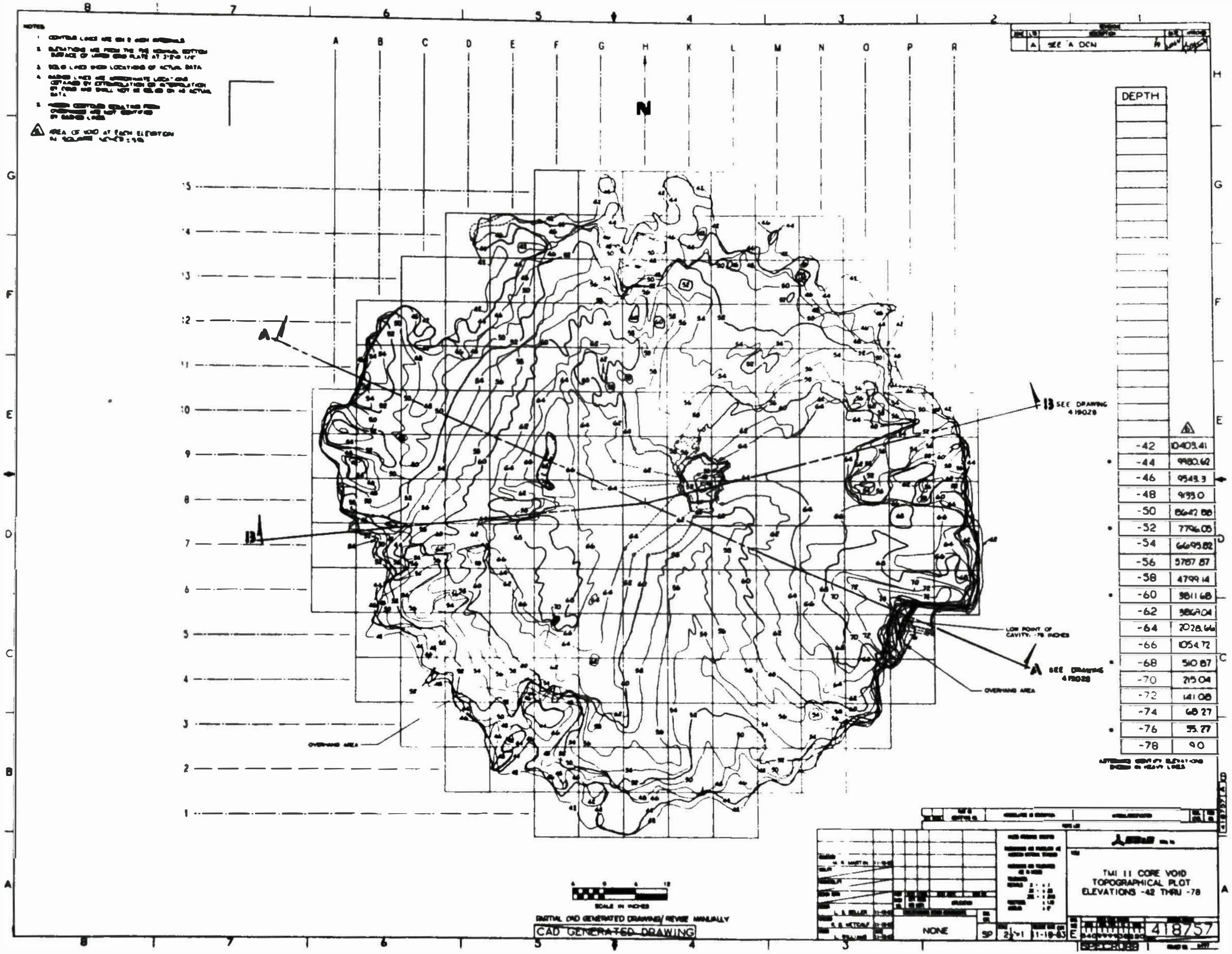


Figure 9. TMI-2 core void topographical plot elevations -42 through -78.

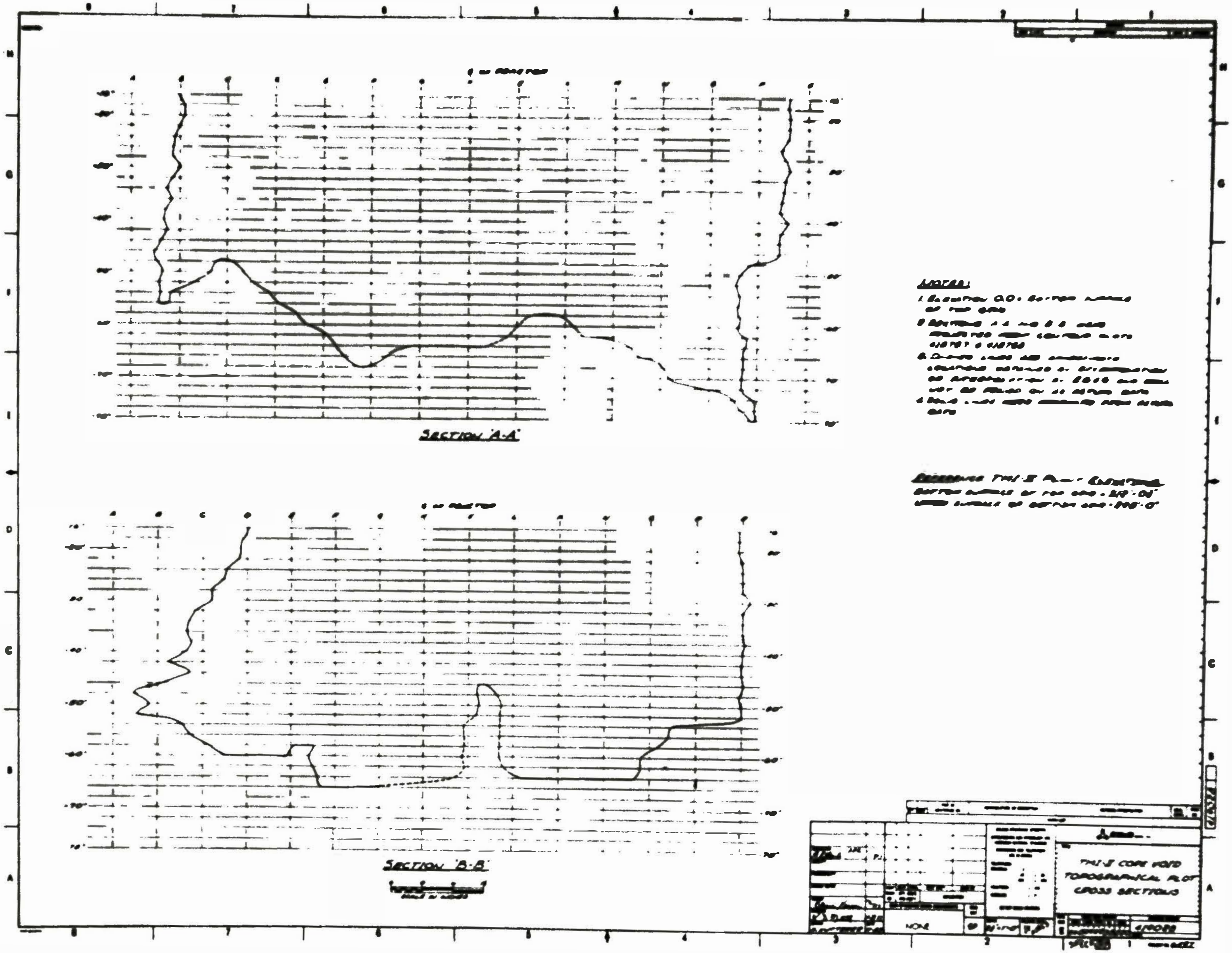


Figure 10. TMI-2 core void topographical plot cross sections.

Reactor Vessel Head Removal.[6] In July 1984, the reactor vessel head removal, which included prerequisite uncoupling of the leadscrews from the CR assemblies and raising the leadscrew into the control rod drive mechanism (CRDM), was accomplished. The leadscrew uncoupling indicated the following:

- Thirty CR spiders were supported by the fuel assembly upper end fitting
- Twenty-Three CR spiders appeared to be unsupported by the fuel assembly upper end fitting, or were missing
- Four CR spiders became supported by the fuel assembly upper end fitting when lowered a small distance (less than 2 in.).

Plenum Assembly Removal.[7,8] In May 1985, the plenum assembly removal, which included prerequisite dislodging of fuel assembly upper end fittings (Reference 7) and water jet flushing loose debris from horizontal (upward facing) surfaces (Reference 8), was accomplished. The dislodging of fuel assembly upper end fittings indicated the following:

- Four upper end fittings (core positions D5, F3, F13, and K14) could not be dislodged
- Ten upper end fittings (core positions E4, G14, K6, L2, L13, O3, O8, O11, P8, and R6) could only be partially dislodged
- All other end fittings were missing, dislodged, or attached to their respective fuel bundles.

The water jet flushing removed loose debris "ranging in size from very fine particles to nearly fuel pellet size" from the plenum assembly, upward-facing, horizontal surfaces. Post-flushing CCTV inspection indicated "some of the debris actually adhered to the plenum and could not be removed."

Early Fuel Removal. Early fuel removal commenced on November 12, 1985, and continued to December 22, 1985. By December 22, 1985, three fuel canisters (D-136, D-141, and D-139) had been loaded with upper end fittings (42) from fuel, CR, and BPR assemblies, and four partial-fuel assemblies. The early fuel removal included some successful and unsuccessful attempts to topple standing peripheral fuel assemblies onto the core cavity floor to provide clearance for the fuel canisters, occasional unaided toppling of unstable standing peripheral fuel assemblies onto the core cavity floor, and shear-tool sectioning of some partial fuel assemblies lying on the floor of the core cavity.

2. EXAMINATION METHOD

The examination method was to obtain a tape recording of the signal from the video camera surveys at TMI-2 and generate still-image photographs at INEL from the tape recordings using a special electronic image enhancement and production system.

TMI-2 CCTV System

The CCTV system used at TMI-2 to examine the core cavity sides and floor in December 1985 consisted of the following:

- An underwater video camera
- A camera manipulator system to provide camera support and articulation
- A 6 MHz bandwidth AMPEX VPR-80 video recorder, Synair video distribution system, and Quantex video quantitizer.
- The TMI-2 defueling platform for support and azimuthal positioning of the camera manipulator system.

Figure 11 shows the reactor vessel conditions in December 1985 when the video surveys were conducted.

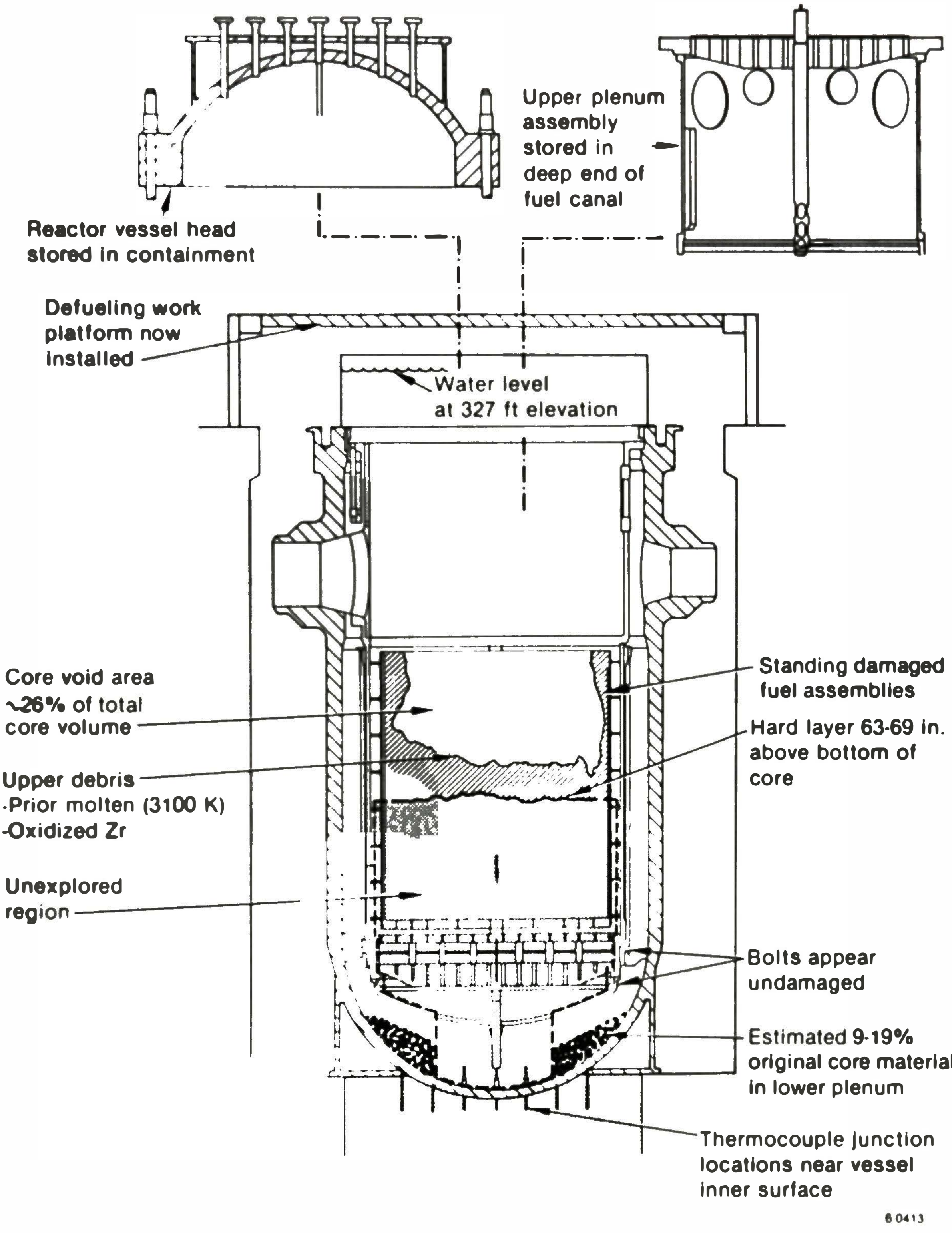


Figure 11. Reactor vessel conditions--December 1985.

3. EXAMINATION RESULTS

The examination results are presented in the form of 10 plates of still-image photographs, a narrative identifying points of interest, and the TMI-2 AEP observations in terms of new TMI-2 accident information produced by the December 1985 and January 1986 core-cavity CCTV examination.

The small-size photographs represent an optimum still-image size for the reader. Enlargements appear blurred because the video lines become visible. Additional image deterioration is caused by video-system distortion, water turbidity, underwater lighting, and dark low-contrast objects. Also, shadows can generate misleading mirages.

The plates are arranged to show: (a) the core cavity walls as eight sides (five fuel assemblies/wall) starting from the North (Plate 1) and proceeding clockwise, (b) some points of interest observed in objects lying on the floor and deposited in the fuel assembly upper end regions (Plate 9), and (c) a more detailed image of the core position L1 fuel assembly (Plate 10).

Appendix A is an index to the EG&G Photography/Micrographics Unit's file number for each still-image photograph used in the 10 plates.

Plates of Still-Image Photographs

Plate 1--TMI-2 Core Cavity North Side

The damaged fuel assembly at core position L15 is the only fuel assembly still standing on the North Side. The upper end fitting and fuel bundle damage is consistent with the damage patterns observed on symmetrically located fuel assemblies.

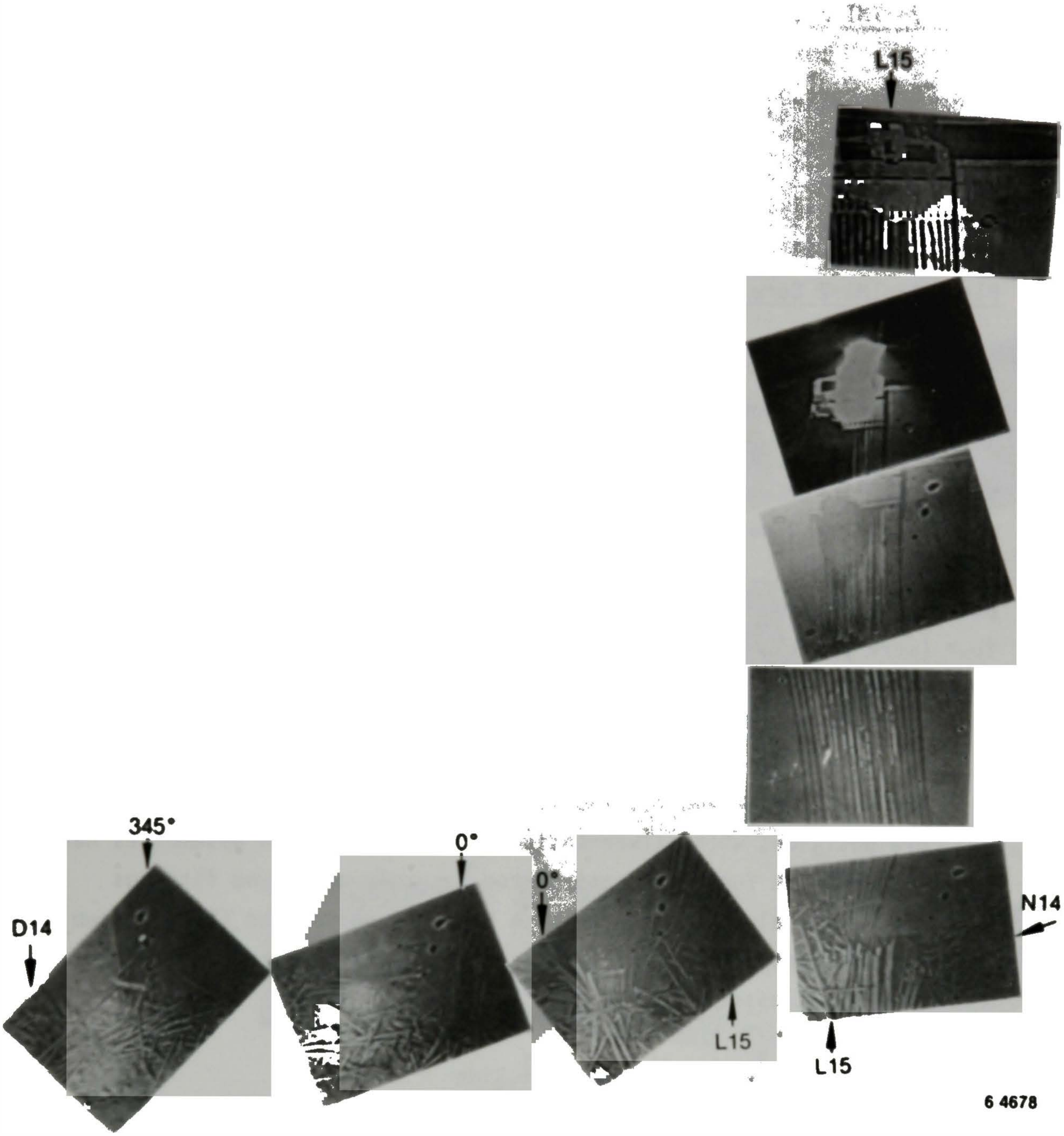


Plate 1. TMI-2 core cavity north side--December 6 through 21, 1985 core position L15 fuel assembly.

Plate 2--TMI-2 Core Cavity Northeast Side

Three core positions (N14, O13, and P12) damaged fuel assemblies were still standing on the Northeast side. The upper end fitting and fuel bundle damage is consistent with the damage patterns observed on symmetrically located fuel assemblies.

Plate 3--TMI-2 Core Cavity East Side

Portions of 9 to 10 fuel assemblies are visible. In the foreground, one can see the upper end fittings of the core position P4 fuel assembly, which is leaning into the field of view from the southeast side. An APSR upper end fitting is visible in the early (December 6) survey near core position R7, and was probably relocated before the December 21 and 22 surveys were made. The fuel assembly upper end fittings at peripheral core positions R10, R9, R8, and R7 are visible in the background and portions of four (core positions P10, P9, P8, and P7) or five Row P upper end fittings can be seen. The only rod bundles that are visible are at core positions R10 and R9, and P10, which is only a suspended remnant

The Row P upper end fittings are of special interest. Both (P10 and P8) core positions with silver-indium-cadmium poison rod assemblies have relatively intact fuel- and control-rod assembly upper end fittings compared to the alumina-boron-carbide burnable poison rod (BPR) assemblies at core positions P9 and P7, which have completely missing BPR assemblies and gutted fuel assembly upper end fittings.

Plate 4--TMI-2 Core Cavity Southeast Side

Four damaged fuel assemblies were still standing at core positions P4, O3, N2, and M2 on December 6, 1985, although the P4 core position fuel assembly was leaning into the East side field of view. The M2 core position fuel assembly toppled over before the December 21, 1985, video survey leaving three fuel rods still standing, but leaning inwards. The upper end fitting and fuel bundle damage are consistent with the damage patterns observed on symmetrically located fuel assemblies.

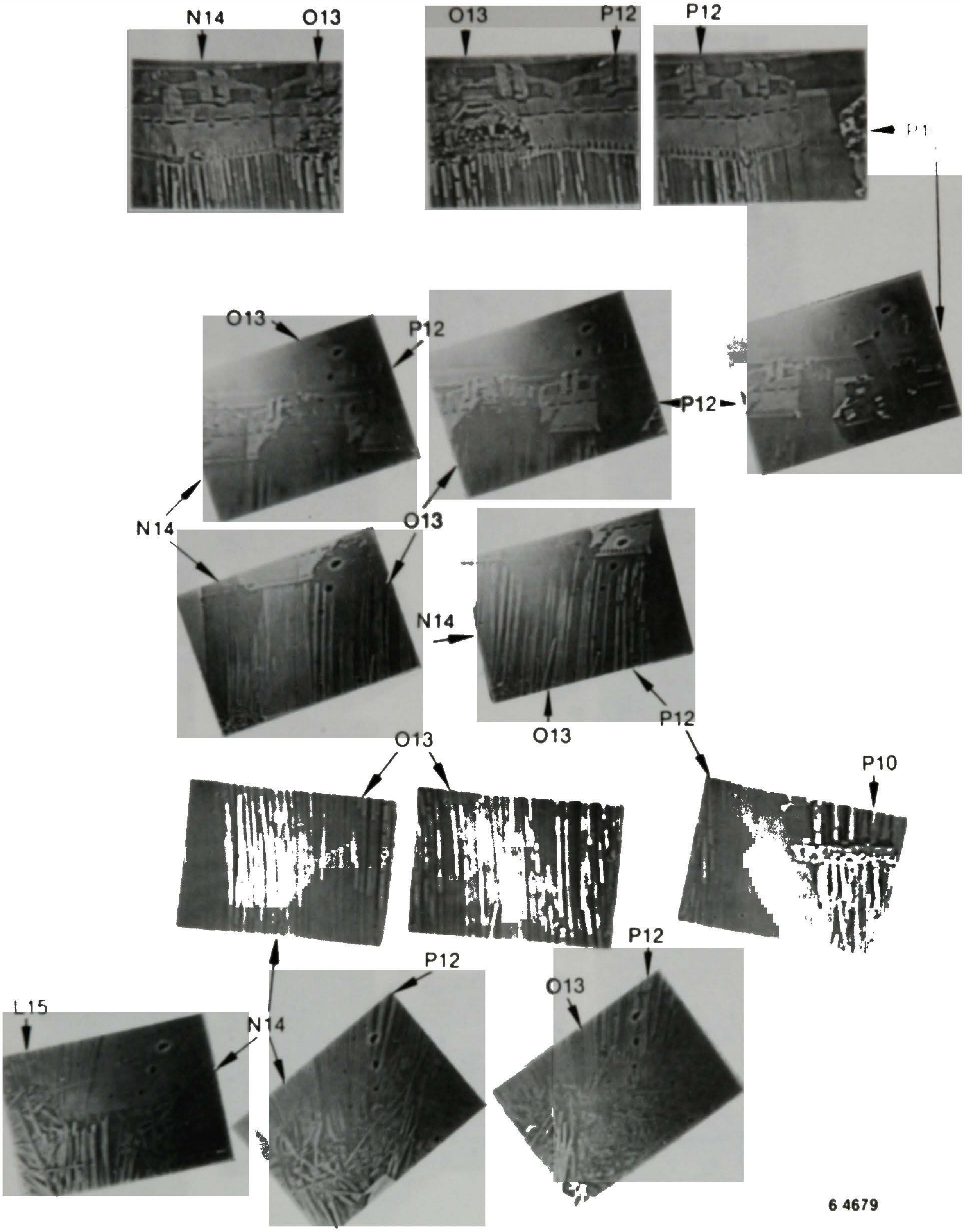


Plate 2. TMI-2 core cavity northeast side--December 6 through 21, 1985 core position N14, O13, and P12 fuel assemblies.

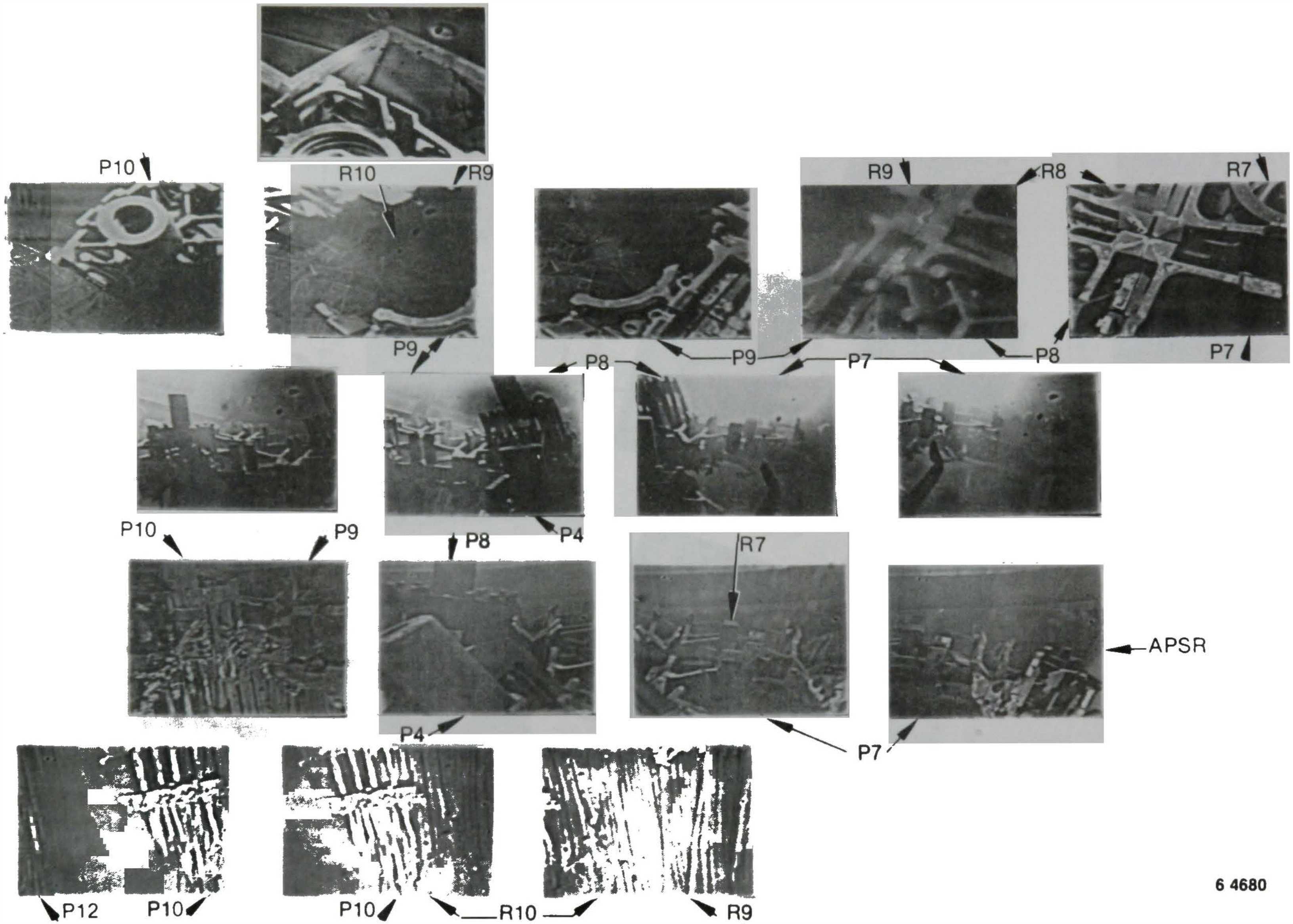


Plate 3. TMI-2 core cavity east side--December 6 through 21, 1985 core position P10, P9, P8, P7, R10, R9, R8, and R7 fuel assemblies.

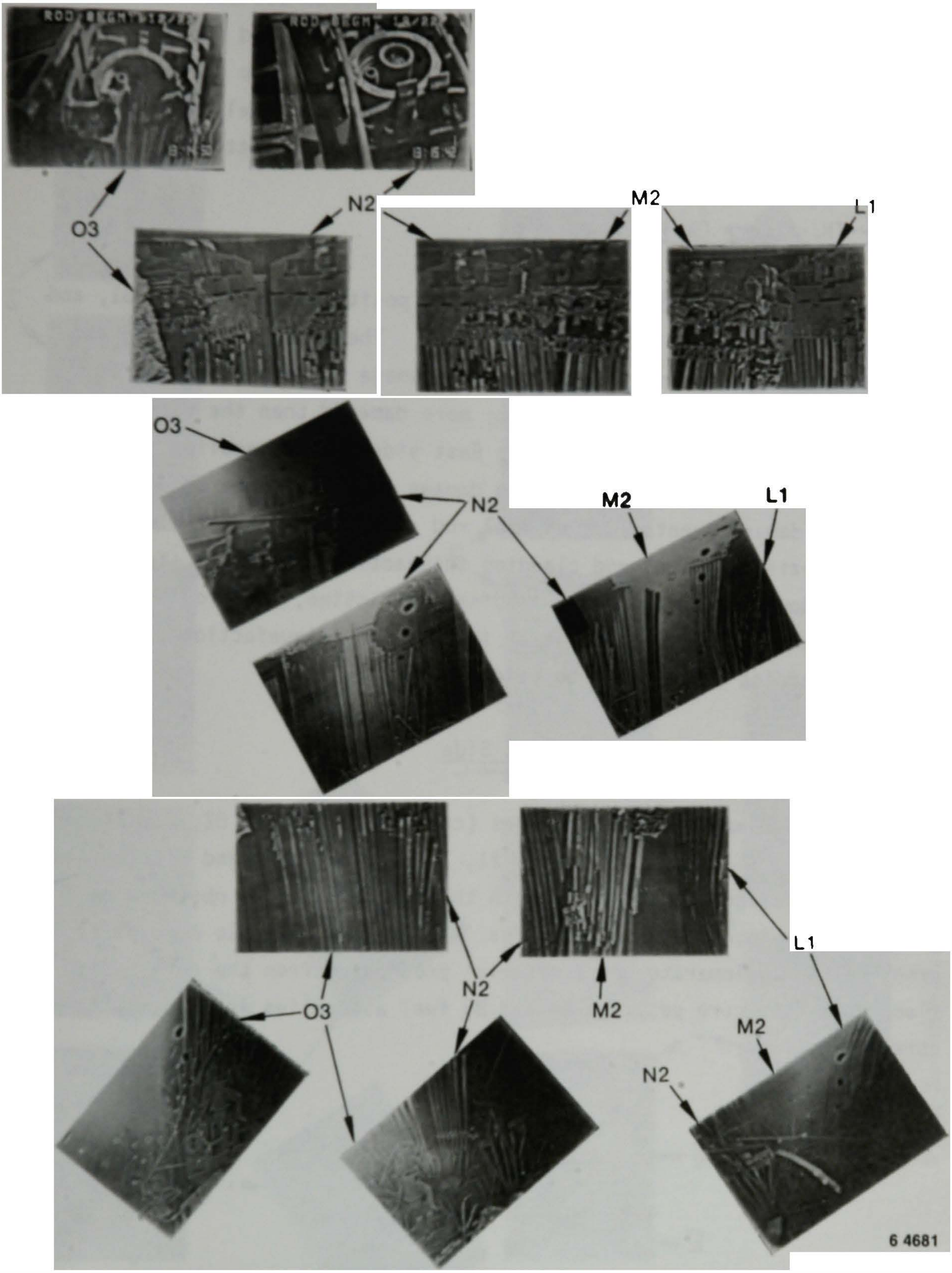


Plate 4. TMI-2 core cavity southeast side--December 6 through 22, 1985 core position O3, N2, and M2 fuel assemblies.

The core position P4 fuel assembly upper section was subsequently examined by video survey on January 21, 1986, after it had toppled onto the core cavity floor. The upper section appears to extend to the elevation of the fourth spacer grid (approximately 63 in. above the fuel region bottom) and the damage becomes progressively worse towards the bottom of the section.

Plate 5--TMI-2 Core Cavity South Side

The five damaged fuel assemblies (core positions L1, K1, H1, G1, and F1) were still standing on December 6, 1985. The upper end fitting and fuel bundle damage is consistent with the damage patterns observed on symmetrically located fuel assemblies; more damaged than the West side fuel assemblies, and less damaged than the East side fuel assemblies. The core position L1 fuel assembly fuel bundle damage shows evidence of a variety of severe fuel damage events such as fuel rod swelling and burst, Inconel spacer grid-zircaloy fuel rod cladding interaction, stainless steel fuel pellet holddown spring-fuel rod cladding interaction, fuel rod cladding-uranium dioxide fuel pellet interaction (liquefaction), and zircaloy cladding and guide tube oxidation.

Plate 6--TMI-2 Core Cavity Southwest Side

The five damaged fuel assemblies (core positions E2, D2, C3, B4, and B5) were still standing on December 21, 1985. The upper end fitting and fuel bundle damage is consistent with the damage patterns observed on symmetrically located fuel assemblies. There is a possible deposit of prior-molten agglomerated core material protruding from the core cavity floor where the core position B4 and B5 fuel assemblies intersect with the core cavity floor.

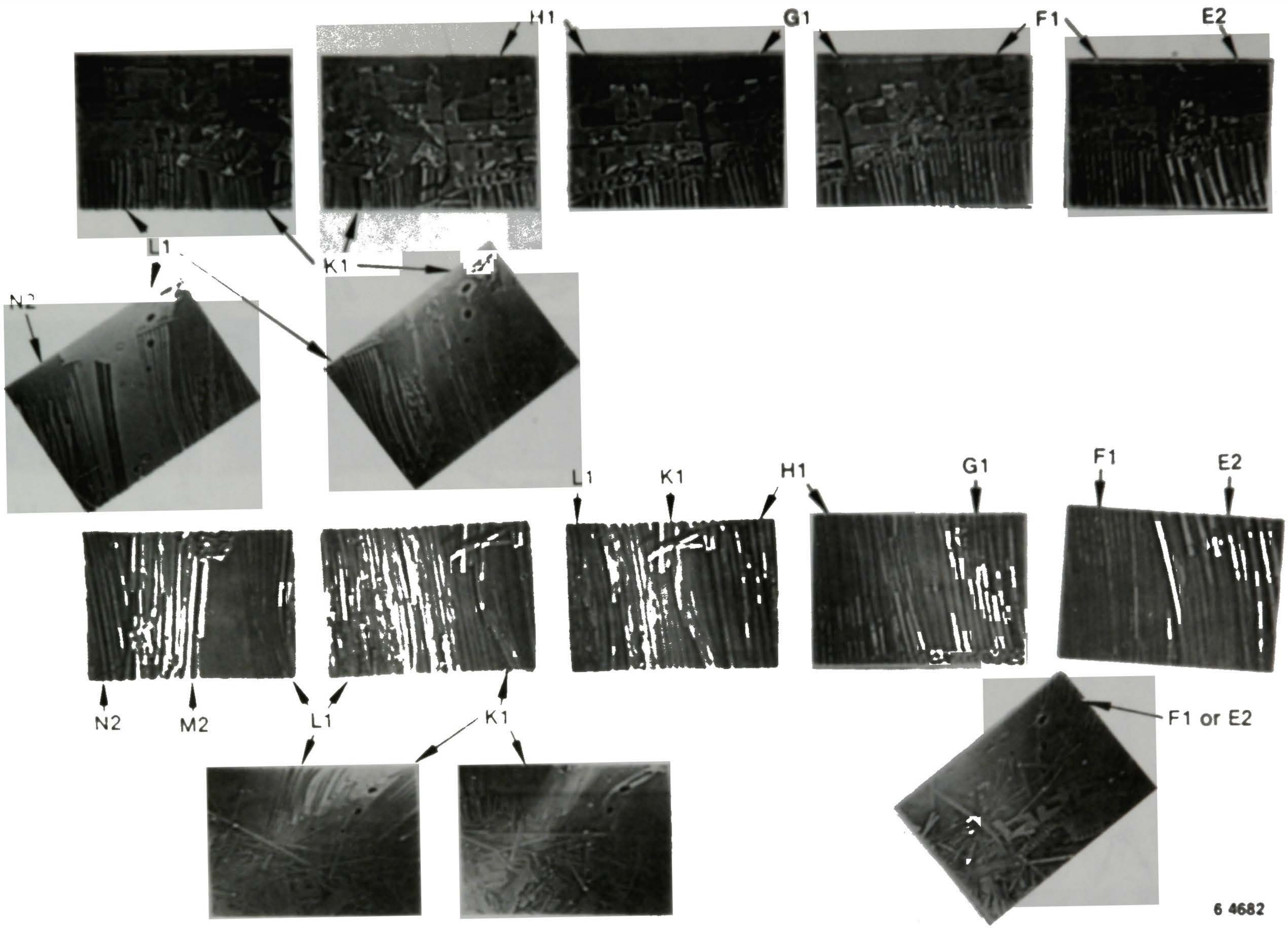


Plate 5. TMI-2 core cavity south side--December 6 through 21, 1985 core position L1, K1, H1, G1, and F1 fuel assemblies.

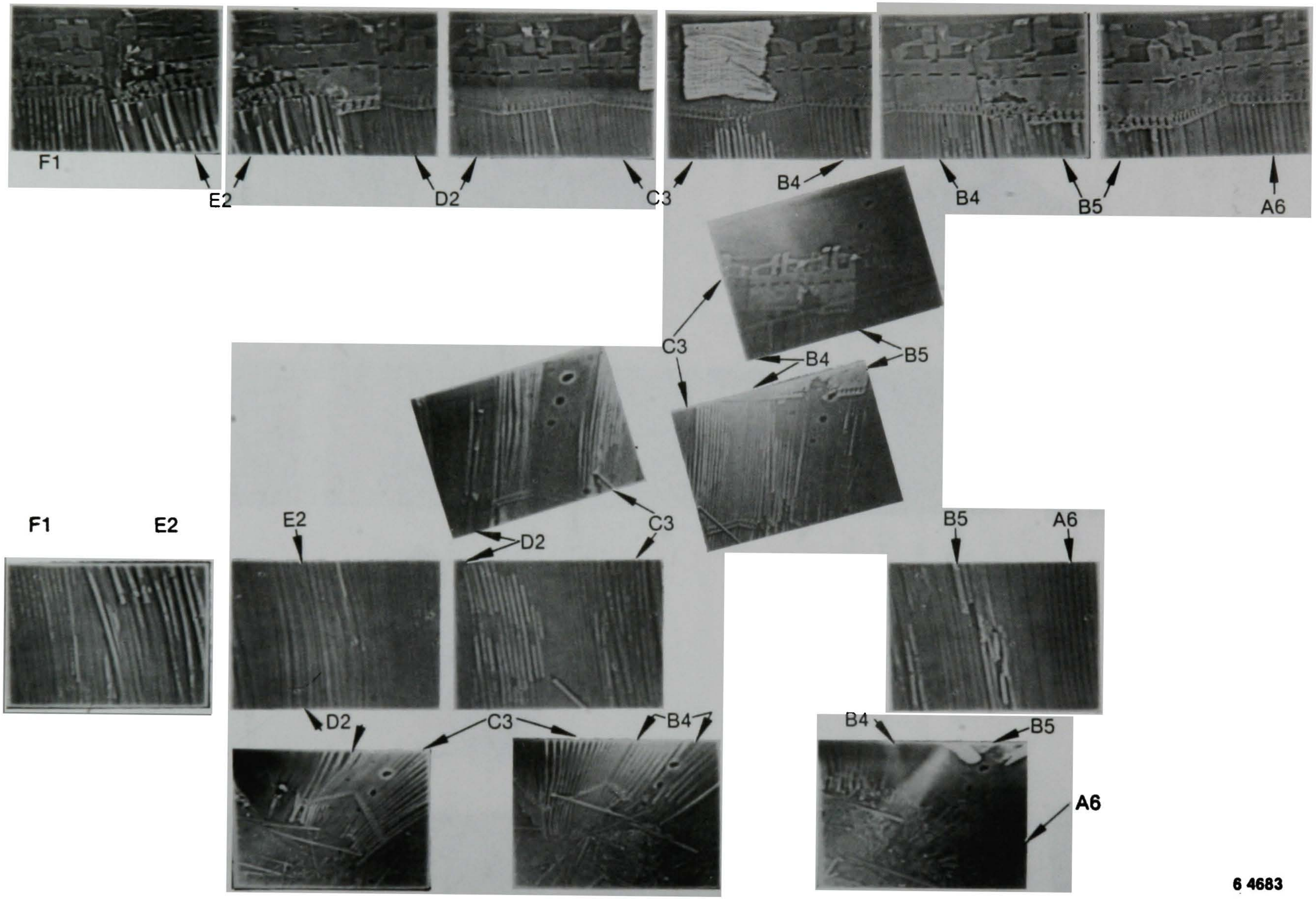


Plate 6. TMI-2 core cavity southwest side--December 6 through 21, 1985 core position E2, D2, C3, B4, and B5 fuel assemblies.

Plate 7--TMI-2 Core Cavity West Side

The five damaged fuel assemblies (core positions A6, A7, A8, A9, and A10) were still standing on December 21, 1985. The upper end fitting and fuel bundle damage represents the least damage of any of the eight sides and ranges from the core position A6 fuel assembly, which appears to have some fuel rod damage (slightly bent) toward the core cavity floor, to the other four fuel assemblies, which have examples of damage (ablated upper end fittings and missing fuel rod regions) similar to other peripheral fuel assemblies.

Plate 8--TMI-2 Core Cavity Northwest Side

Three damaged fuel assemblies (core positions B12, C13, and D14) were still standing on December 6, 1985. The upper end fitting and fuel bundle damage is consistent with the damage patterns observed on symmetrically located fuel assemblies. The upper end fitting at core position B12 appears to have been separated from the fuel bundle by laterally pulling at the end fitting, which fractured the brittle fuel rods and guide tubes and left the more elastic fuel rods toward the core former intact. There is a possible deposit of prior-molten agglomerated core material protruding from the core cavity floor where the core position D14 fuel assembly intersects with the core-cavity floor.

Plate 9--TMI-2 Core Cavity and Floor and Sides Miscellaneous Distinct Component Details

This plate shows some potentially useful information from the video surveys as follows:

o Agglomerated Core Material--Possible deposits of agglomerated core material were observed resting on or protruding through the core cavity floor. The rock-size piece resting on the top of fuel rod pieces appears to be decomposed fuel rods cemented together.

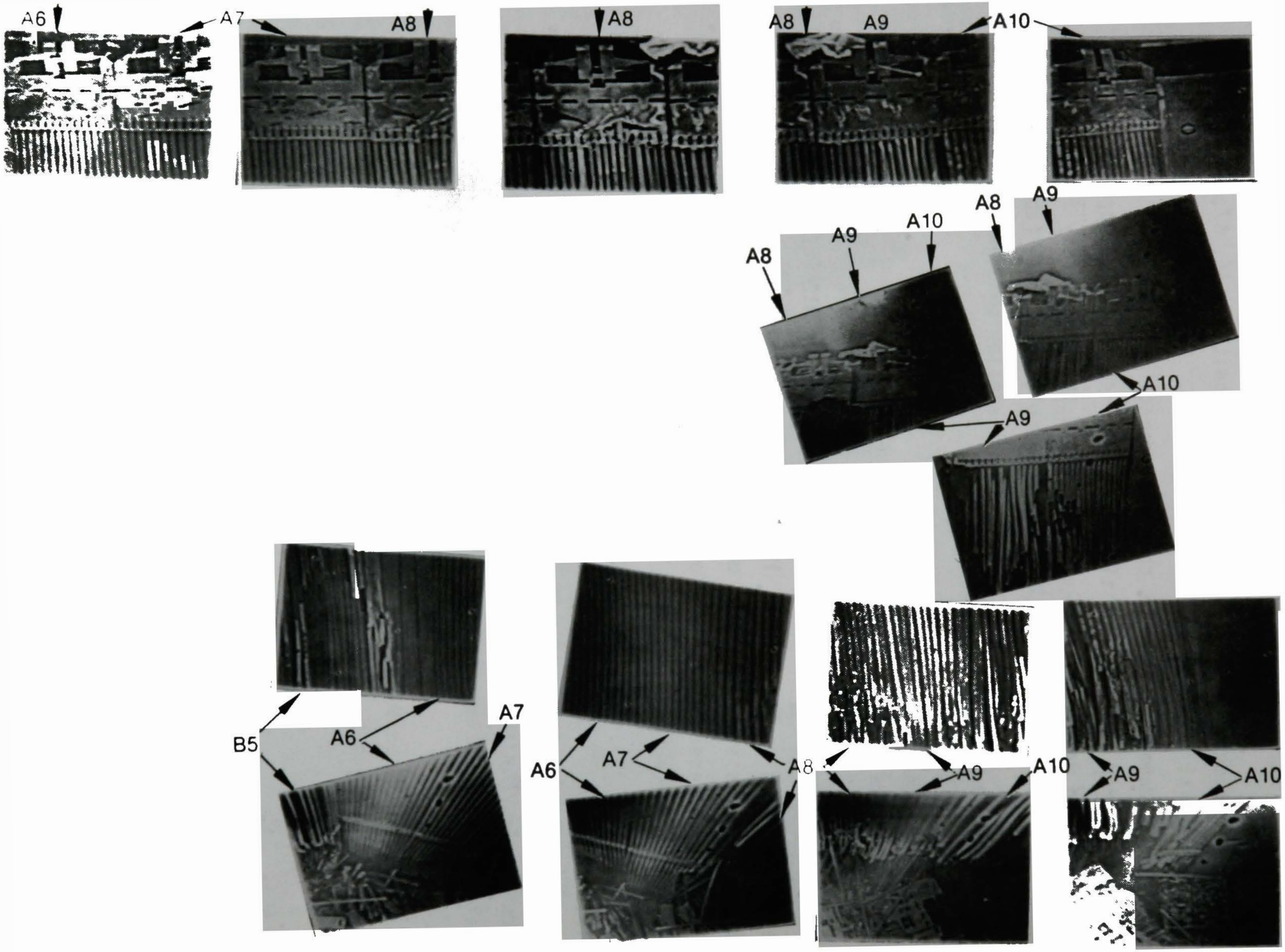


Plate 7. TMI-2 core cavity west side--December 6 through 21, 1985 core position A6, A7, A8, A9, and A10 fuel assemblies.

6 4684

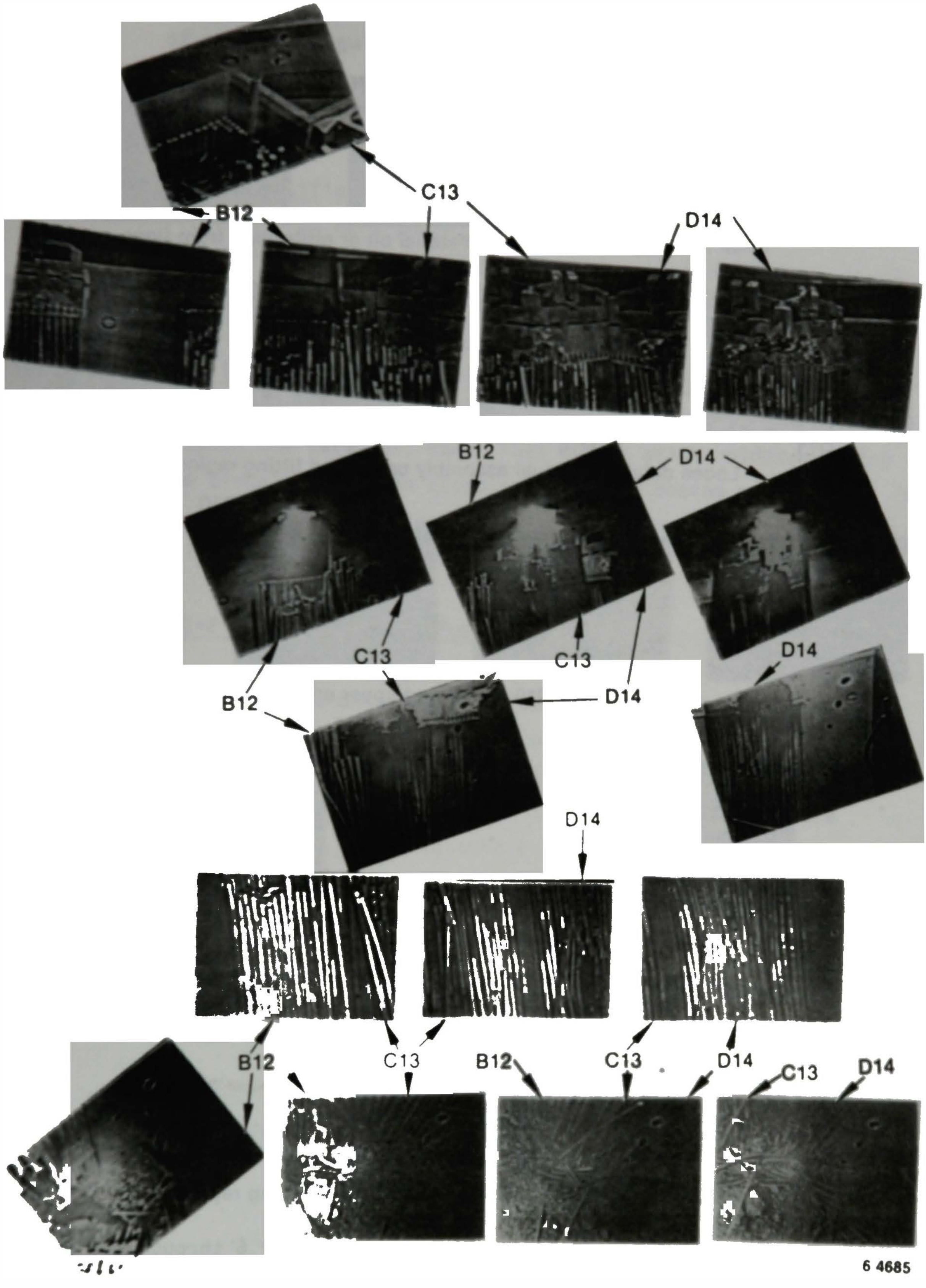
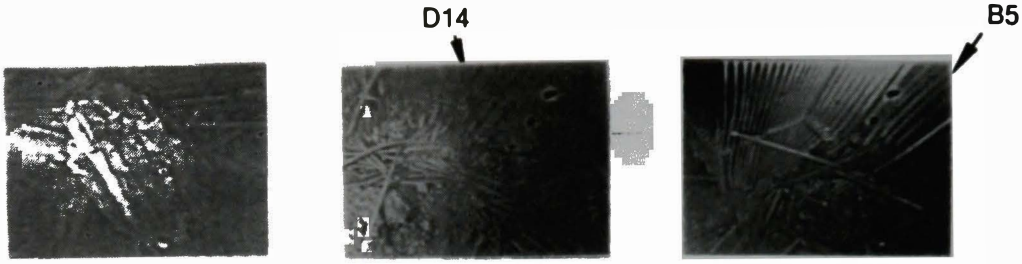
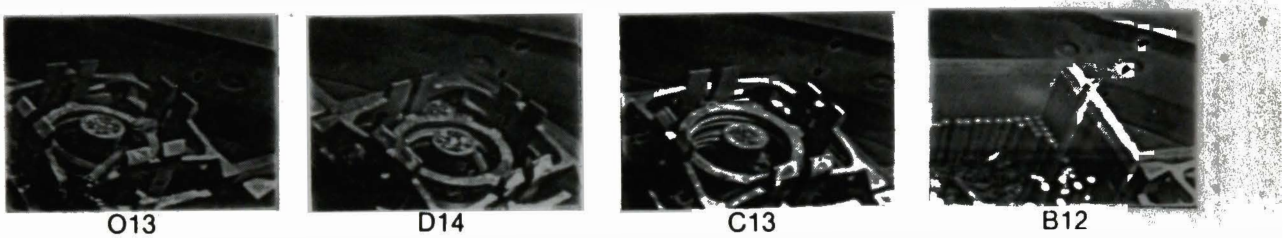


Plate 8. TMI-2 core cavity northwest side--December 6 through 21, 1985 core position B12, C13, and D14 fuel assemblies.



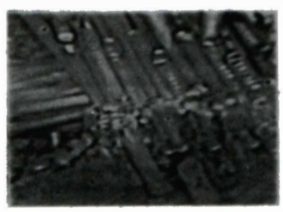
Rock size agglomerated core material on or protruding from floor



Loose debris on/in fuel assembly upper end fitting region

Core position B10 spider and upper end fitting

Core position C4, C5, D4 and D5 upper end fitting damage



Fuel rod damage in pellet stack holddown spring region

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Plate 9. TMI-2 core cavity floor and sides--December 6 through 21, 1985 miscellaneous distinct component details.

- Loose Debris In Fuel Assembly Upper End Fitting Region--Deposits of small, irregular-shaped particles have collected on upward facing surfaces and cup-like areas of the fuel assembly upper rod fittings.

- Other Identifiable Upper End Fittings--The damaged upper end fittings from core positions B10, C4, C5, D4, and D5 were identified during the video surveys in the loose debris on the core cavity floor.

- Fuel Rod Damage in Pellet Stack Holddown Spring Region--A still-image photograph of fuel rod damage from interaction between the stainless steel fuel pellet stack holddown spring and the zircaloy fuel rod cladding is at the bottom of Plate 9. The fuel rod bundle section was lying on the core cavity floor; its original core location is unknown.

Plate 10--TMI-2 Core Position L1 Fuel Assembly

Plate 10 shows more detailed still-image ph.tographs of the core position L1 fuel assembly, most of which were obtained from the December 22, 1985, video monitoring of the fuel rod segment acquisition. The fuel rod bundle damage is of special interest because there are possible examples of the following severe fuel damage accident events:

- Fuel rod burst

- Zircaloy interaction (eutectics) with Inconel (spacer grids) and stainless steel (fuel pellet stack holddown springs)

- Zircaloy fuel rod cladding interaction (liquefaction) with uranium dioxide fuel pellets.

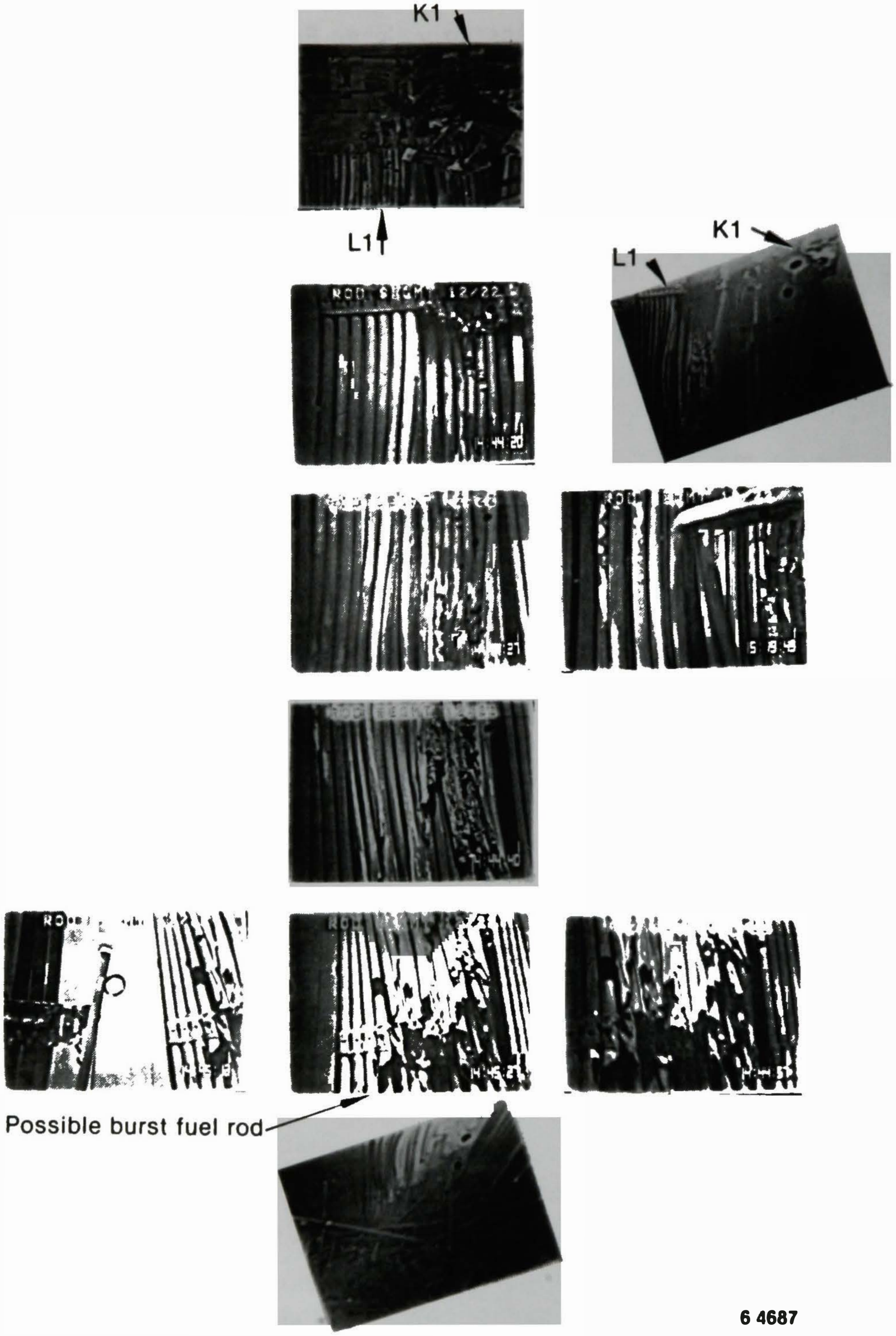

Plate 10. TMI-2 core cavity south side--December 6 through 22, 1985 core position L1 fuel assembly.

Plate 11--TMI-2 Core Position P4 Fuel Assembly

Plate 11 shows some detailed still-image photographs of the core position P4 fuel assembly south and east sides and a sketch of the fuel assembly's south face. The quality of the still images is poor due to distortion of the tape recording video signal and water turbidity. The video survey was conducted on January 21, 1986, after the peripheral fuel assembly had toppled completely to the core cavity floor. In the December 1985 surveys, the fuel assembly was leaning from its core southeast side position and obstructing the survey of the core eastside core positions (see Plate 3).

This examination is of special interest because approximately an additional 40 in. of fuel assembly is exposed compared to the December 1985 surveys. The fuel assembly damage appears to increase significantly at the fourth spacer grid, which is approximately 70 in. above the core bottom and close to the height of the hard crust that has been encountered below the core cavity floor loose debris.

The fuel assembly upper region damage is consistent with other peripheral fuel assemblies including the bow on the rod bundle that exists above spacer grid 5. The rod bundle bowing appears to have occurred also at core south (Plates 5 and 10), southeast (Plate 6), east (Plate 7), and northeast (Plate 8) locations. Because the bow appears to occur between only one set of spacer grids, it may be an artifact of fuel assembly buckling from differential thermal expansion between the fuel assembly and the core support structures during the core heatup.

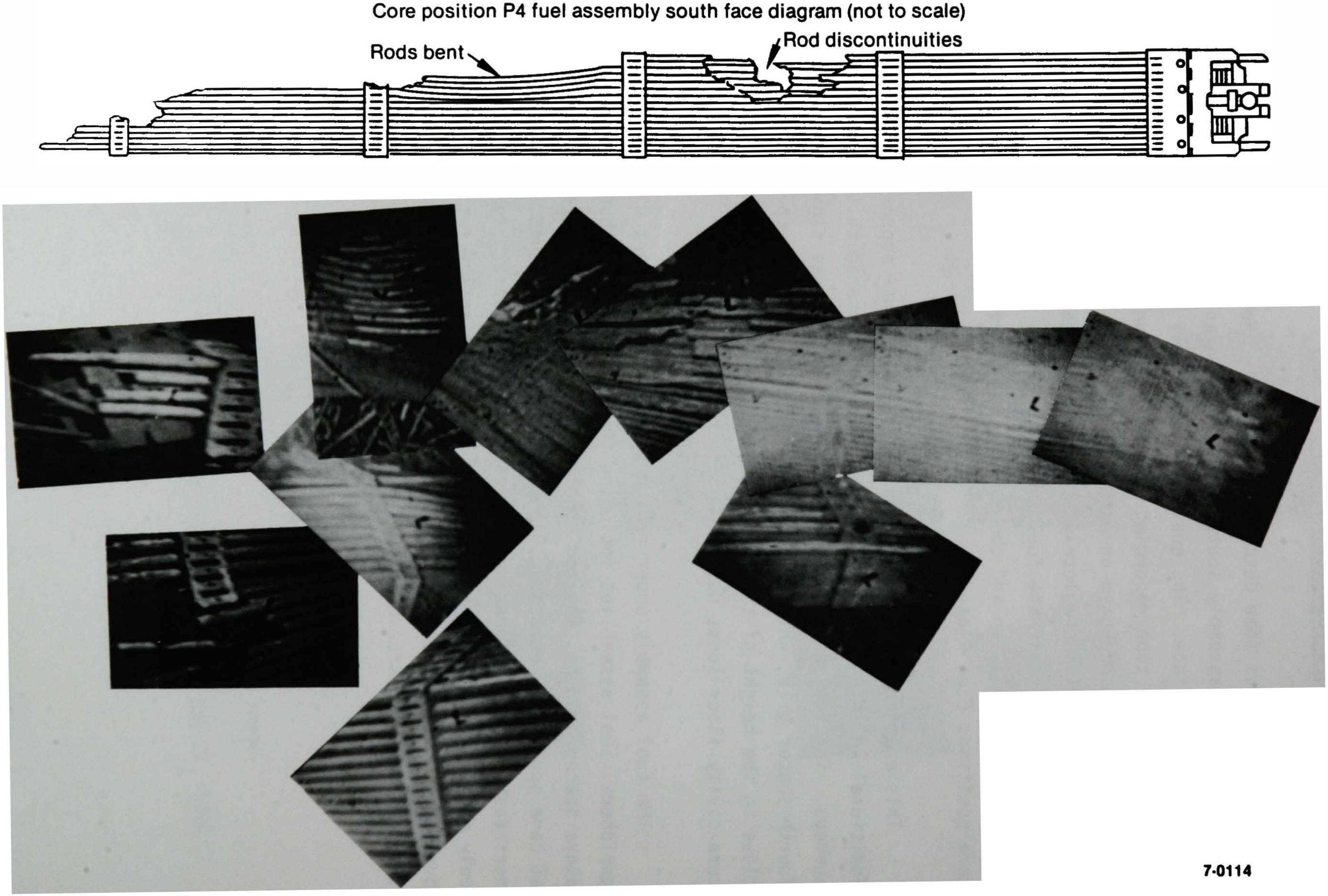

Plate 11. TMI-2 core position P4 fuel assembly.

Observations

The observations presented are intended to summarize what was learned about the TMI-2 accident and severe-core-damage events by the December 1985 January 1986 core cavity video surveys and still-image productions as follows:

Core Cavity Side Topography

The portions of fuel assembly upper end fittings and rod bundles that are missing are consistent with the topography measured by the ultrasonic scanner. The video survey corroborates the ultrasonic-scanner indications that the core cavity walls were formed by the remnants of the outside ring of fuel assemblies and the core former walls.

Burnable Poison Rod Fuel Assembly Increased Damage

The upper end fitting region of the burnable poison fuel assemblies appears to have incurred more damage than the adjacent control rod fuel assembly upper end fitting region. The cause of the increased damage may be the effect of chemical reactions with the zircaloy used for burnable poison rod cladding and end fittings or the alumina used in the burnable poison rod material. The end-fitting damage indicates increased gaseous currents and probable aerosol generation occurred during some stages of the TMI-2 core damage sequence. The effect on fission-product transport from the suspected chemical reactions is unknown.

Fuel Rod Swelling and Burst

No regions of fuel rods were discovered that appeared to have uniform fuel rod swelling or coolant channel blockage regions. Plate 10 shows a possible fuel-rod-burst region near an upper spacer grid at core position L1.

Zircaloy Interaction with Stainless Steel and Inconel

The expected early damage from eutectics between zircaloy and Inconel or stainless steel are evident. Fuel-rod-damage regions penetrate further at Inconel spacer grid locations and stainless steel fuel pellet holddown springs are exposed in the fuel rod upper regions.

Zircaloy Interaction with Uranium Dioxide

The expected liquefaction of the uranium dioxide by molten zircaloy and the downward flow of the liquefied material is also evident. The L1 fuel assembly fuel rod bundle (Plates 5 and 10) and the possible agglomerated core material deposits (Plates 6, 8, and 9) are the examples.

Fuel Assembly Damage Below the Core Cavity Floor

The core peripheral fuel assembly damage appears to increase significantly below the core cavity floor level and especially near the observed height of the hard crust that has been encountered below the core cavity floor loose debris. The observation was derived from the examination of the toppled core position P4 fuel assembly (Plate 11), which has typical peripheral fuel assembly damage in the upper regions.

4. REFERENCES

1. M. L. Russell et. al., TMI-2 Accident Evaluation Program Sample Acquisition and Examination Plan, EGG-TMI-7132, January 1986.

2. E. L. Tolman et. al., TMI-2 Accident Evaluation Program, EGG-TMI-7048, February 1986.

3. TMI-2 Accident Core Heat-Up Analysis, NSAC-25, Nuclear Associates International and Energy Incorporated, June 1981.

4. R. W. Garner et. al., An Assessment of the TMI-2 Axial Power Shaping Rod Dynamic Test Results, EG&G Idaho Inc., GEND-INF-038, April 1983.

5. L. S. Beller and H. L. Brown, Design and Operation of the Core Topography Data Acquisition System for TMI-2, GEND-INF-012, EG&G Idaho Inc., May 1984.

6. P. R. Bengel, TMI-2 Reactor Vessel Head Removal, GEND-044, GPU Nuclear Corp., September 1985.

7. V. R. Fricke, Results of End Fitting Separation in Preparation for Plenum Jacking, TPB-84-2, GPU Nuclear Corp, November 1984.

8. D. C. Wilson, TMI-2 Reactor Vessel Plenum Final Lift, GEND-054, GPU Nuclear Corporation, January 1986.

APPENDIX A
PHOTO NUMBER INDEX

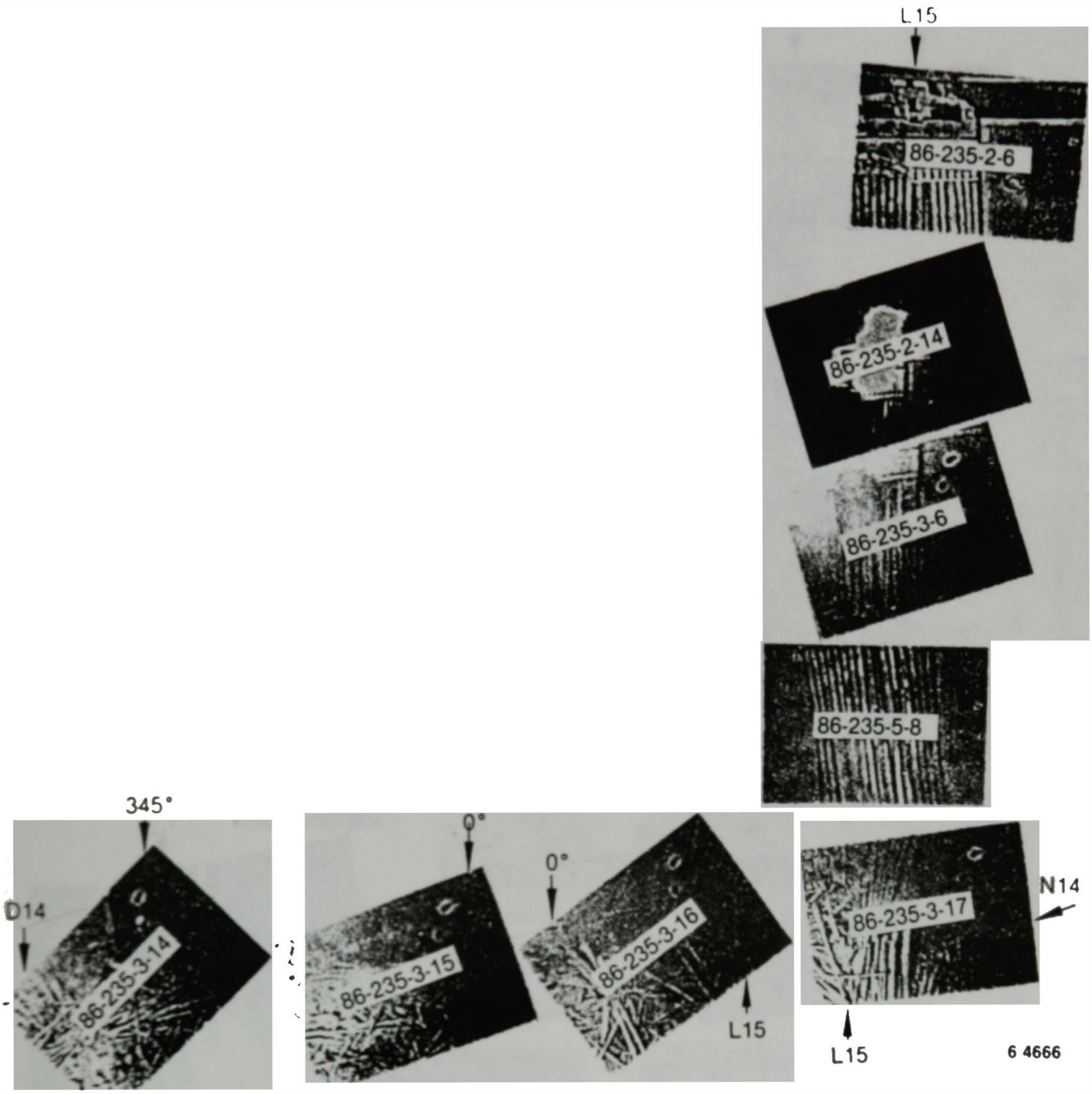

Plate 1. TMI-2 core cavity north side--December 6 through 21, 1985 core position L15 fuel assembly.

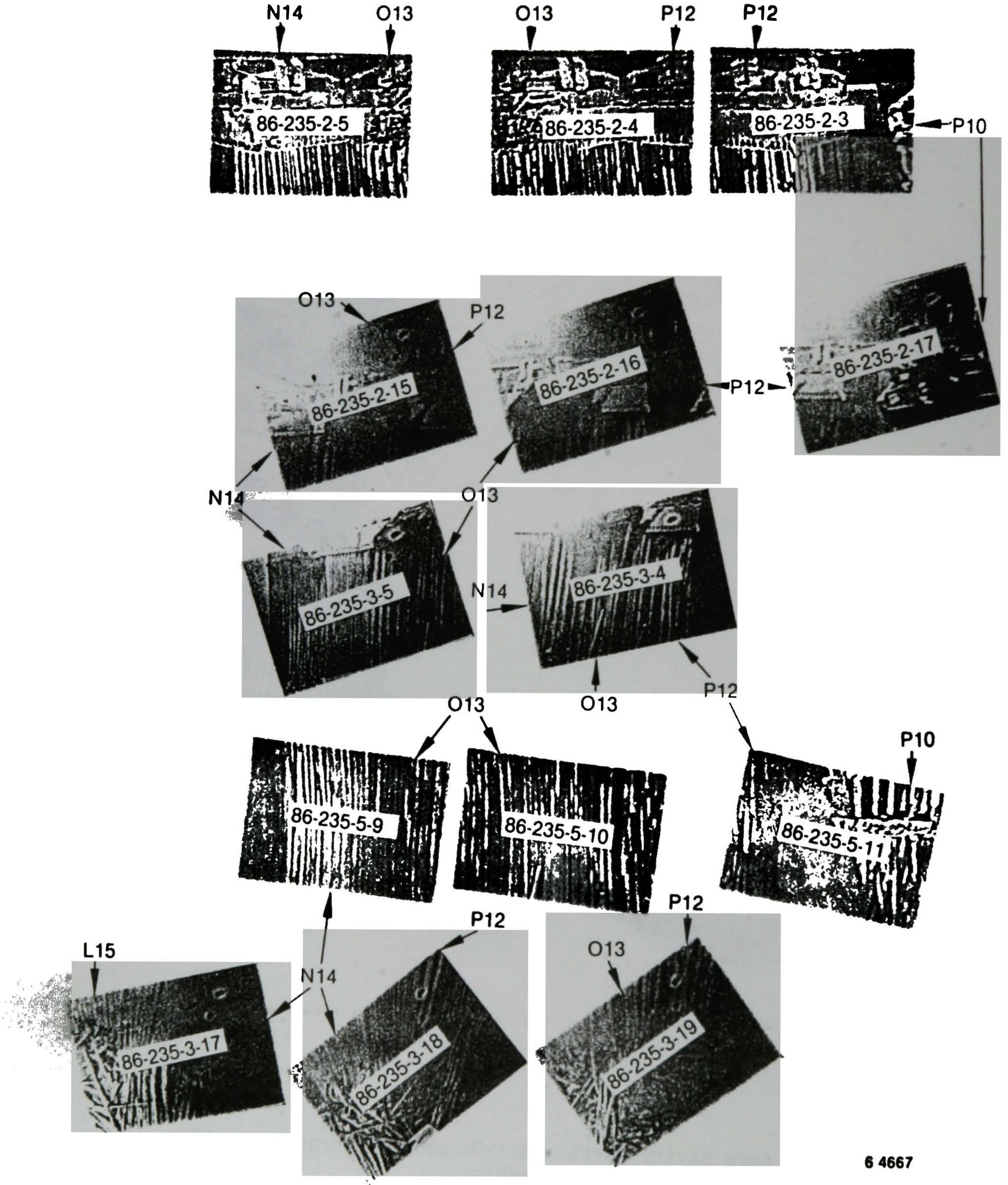

Plate 2. TMI-2 core cavity northeast side--December 6 through 21, 1985 core position N14, O13, and P12 fuel assemblies.

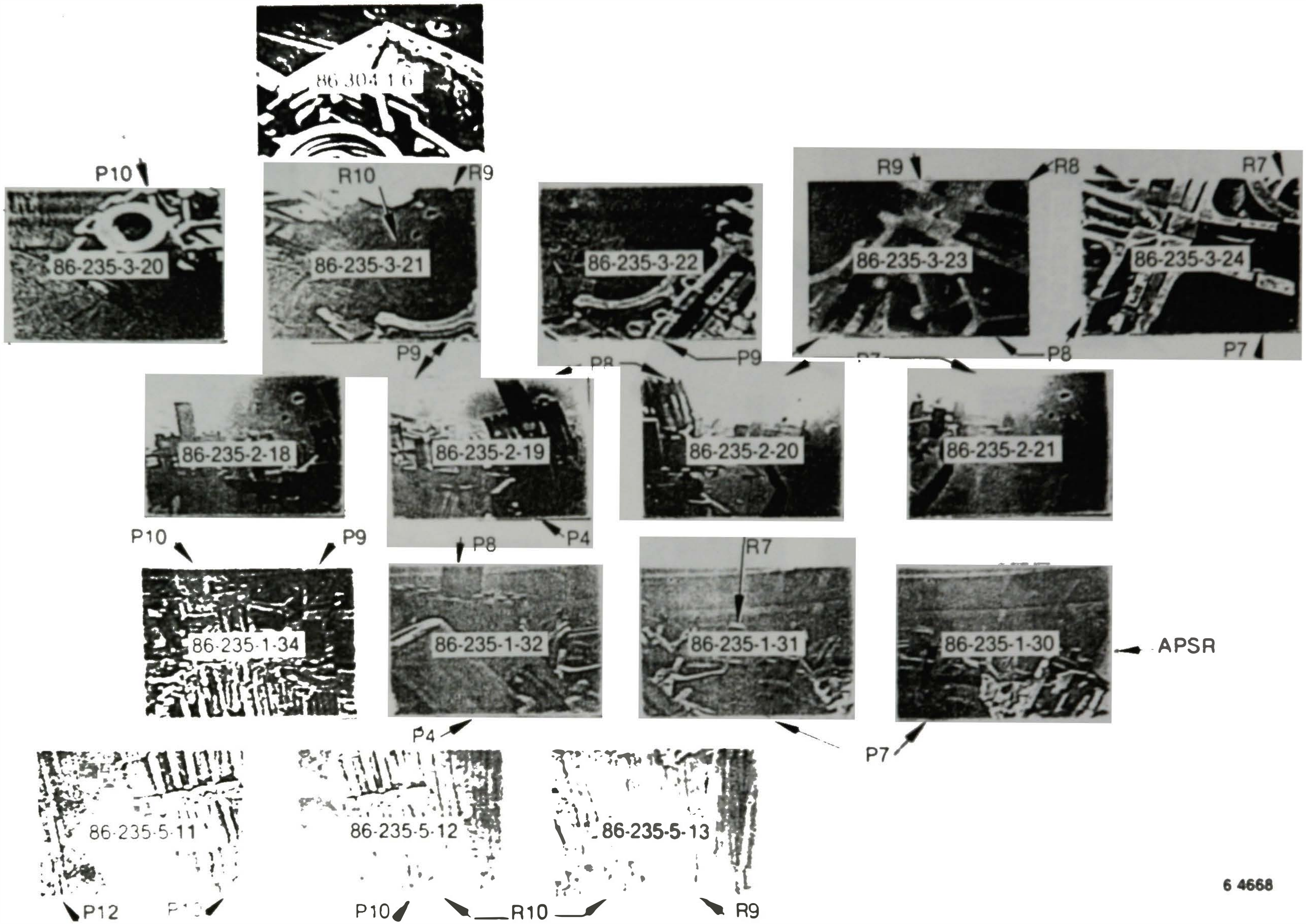

Plate 3. TMI-2 core cavity east side--December 6 through 21, 1985 core position P10, P9, P8, P7, R10, R9, R8, and R7 fuel assemblies.

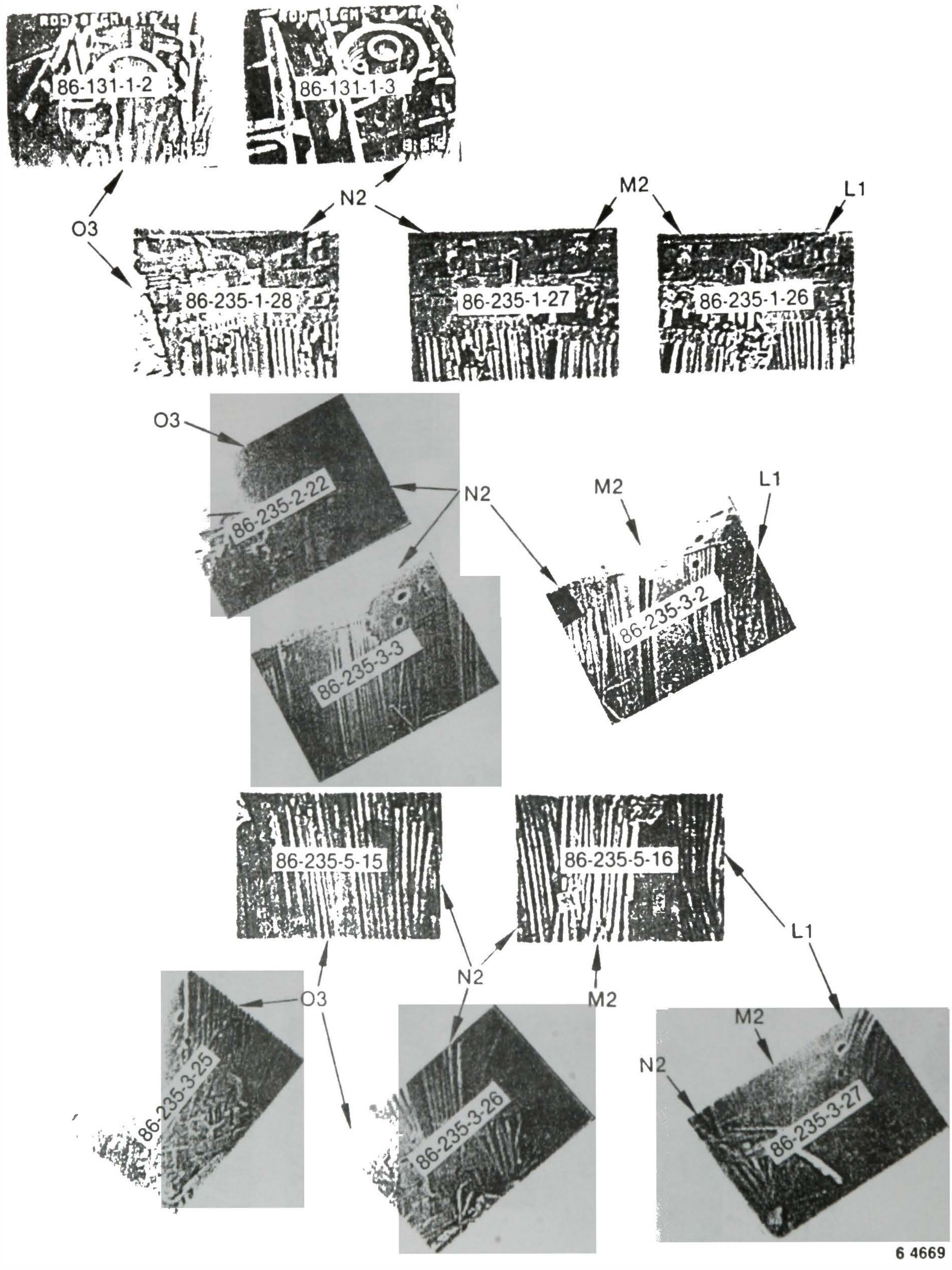

Plate 4. TMI-2 core cavity southeast side--December 6 through 22, 1985 core position O3, N2, and M2 fuel assemblies.

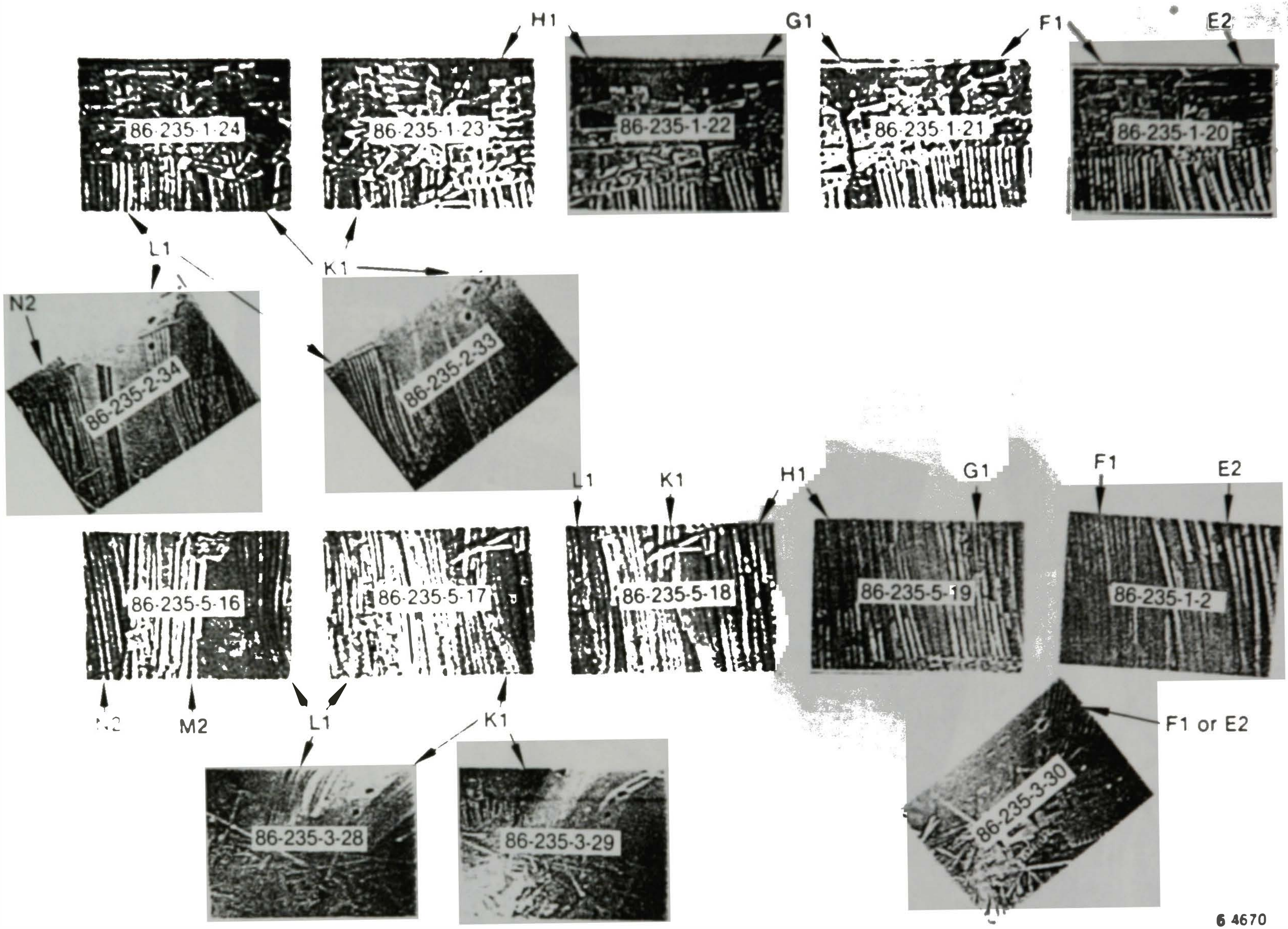

Plate 5. TMI-2 core cavity south side--December 6 through 21, 1985 core position L1, K1, H1, G1, and F1 fuel assemblies.

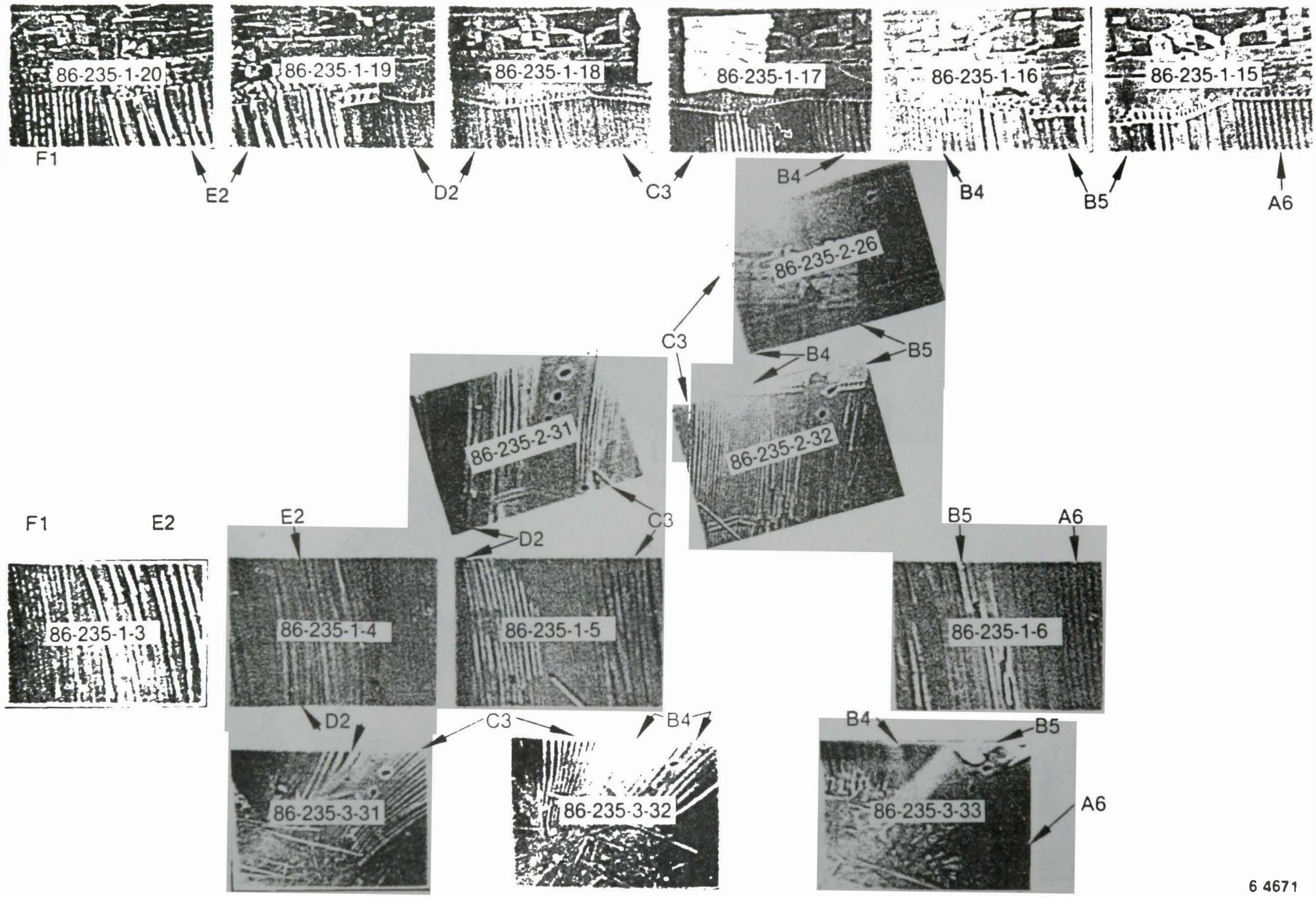

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Plate 6. TMI-2 core cavity southwest side--December 6 through 21, 1985 core position E2, D2, C3, B4, and B5 fuel assemblies.

Plate 7. TMI-2 core cavity west side--December 6 through 21, 1985 core position A6, A7, A8, A9, and A10 fuel assemblies.

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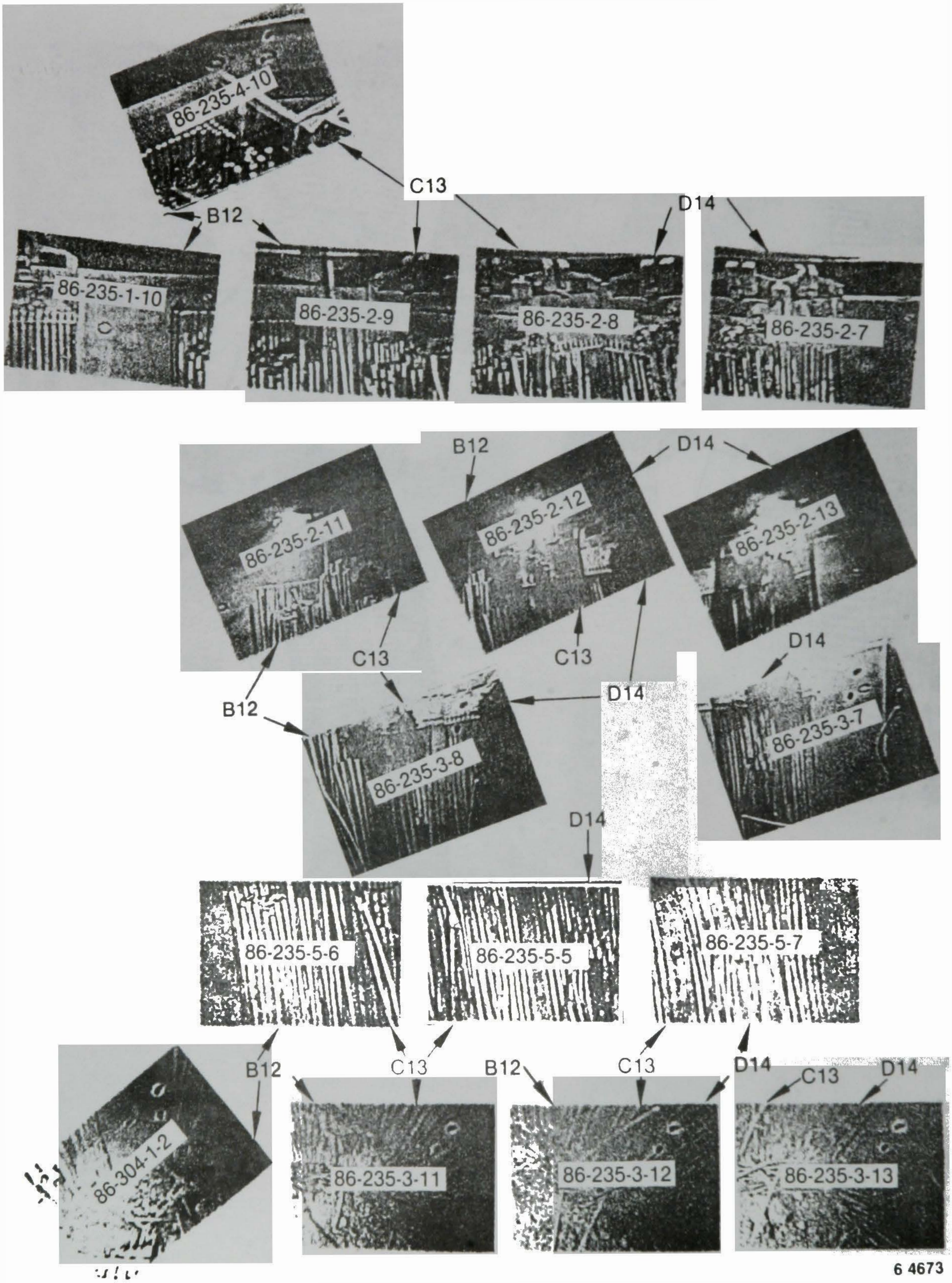
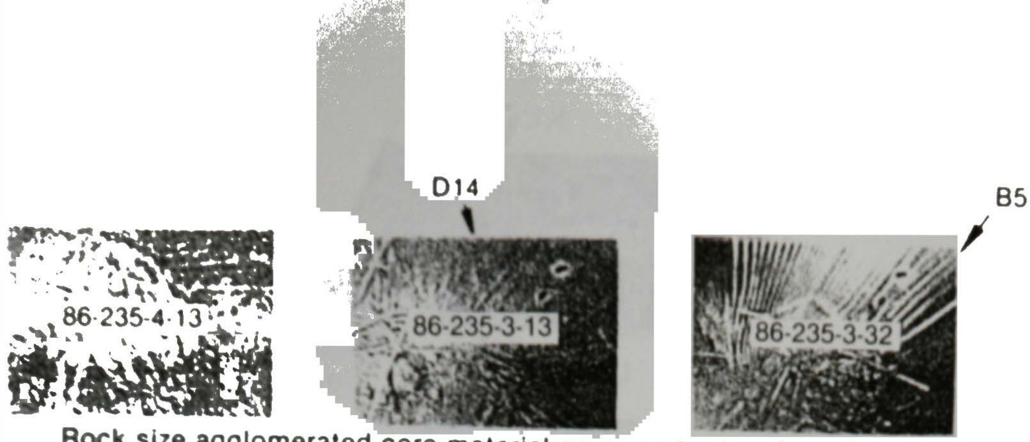
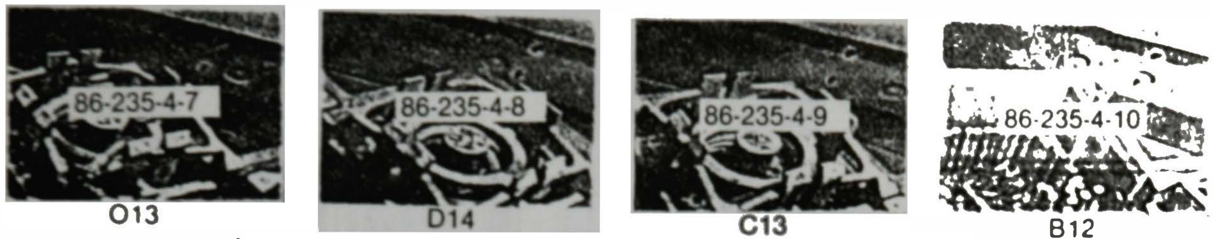


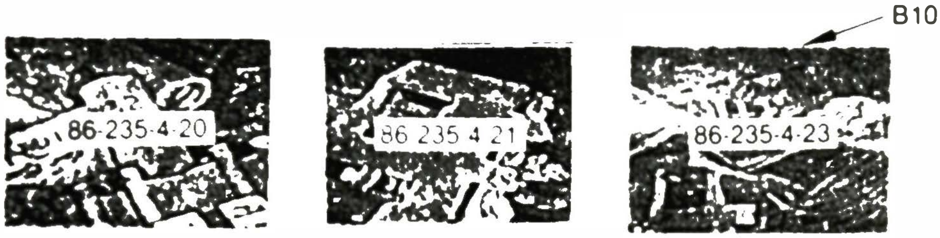
Plate 8. TMI-2 core cavity northwest side--December 6 through 21, 1985 core position B12, C13, and D14 fuel assemblies.



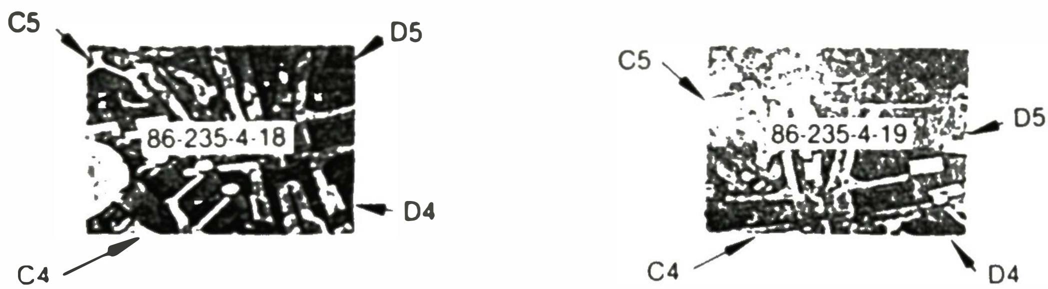
Rock size agglomerated core material on or protruding from floor



Loose debris on/in fuel assembly upper end fitting region



Core position B10 spider and upper end fitting



Core position C4, C5, D4 and D5 upper end fitting damage

Fuel rod damage in pellet stack holddown spring region

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Plate 9. TMI-2 core cavity floor and sides--December 6 through 21, 1985 miscellaneous distinct component details.

Plate 1C. TMI-2 core cavity south side--December 6 through 22, 1985 core position L1 fuel assembly.

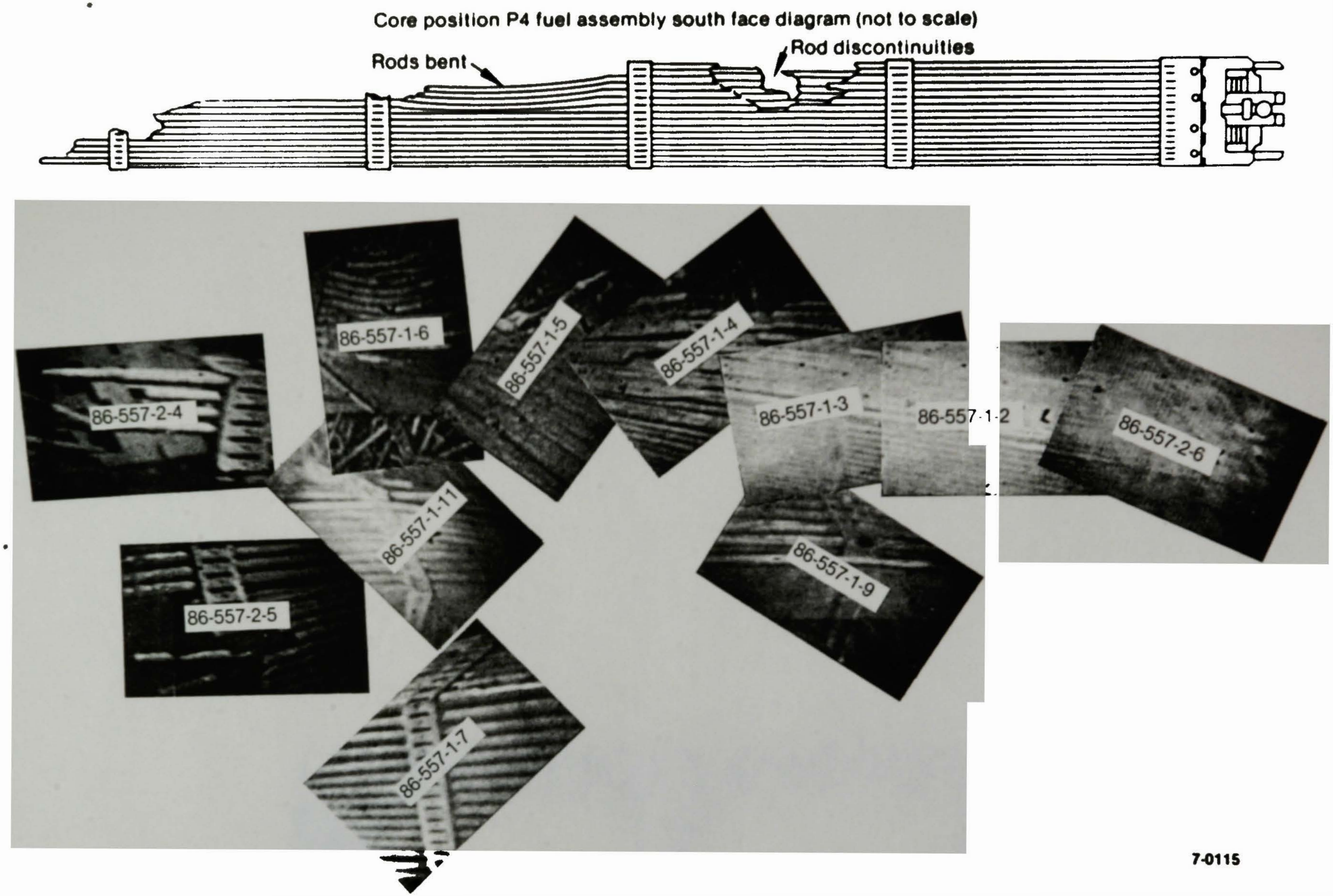

Plate 11. TMI-2 core position P4 fuel assembly.