FirstEnergy

Davis-Besse Nuclear Power Station
5501 North State Route 2
Oak Harbor, Ohio 43449-9760

September 28, 2000

United States Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: Component Cooling Water Pump Power Supply Cable Failure
Root Cause Analysis Report

Ladies and Gentlemen:

The Davis-Besse Nuclear Power Station is providing for your information a copy of the Root Cause Analysis Report for the Component Cooling Water Pump power supply cable failure which occurred on October 2, 1999. This information-only copy is provided at your request.

Should you have any questions or require additional information, please contact Mr. David H. Lockwood, Manager – Regulatory Affairs, at (419) 321-8450.

Very truly yours,

Steven P. Moffitt
Director – Technical Services
Davis-Besse Nuclear Power Station

AWB/s

Attachment

cc: J. E. Dyer, Regional Administrator, NRC Region III (w/o)
S. P. Sands, DB-1 NRC/NRR Project Manager (two copies)
K. S. Zellers, DB-1 Senior Resident Inspector (w/o)

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FirstEnergy, DAVIS-BESSE NUCLEAR GENERATING STATION

Root Cause Analysis Report

#2 CCW Pump Trip - Revision 1

CR 1999-1648, Dated 10-02-1999

REPORT DATE :06-30-2000

Problem Statement

Description of reason for investigation

On 10/2/99 at 0155 hours the #2 Component Cooling Water Pump tripped due to an electrical fault and instantaneous overcurrent and instantaneous ground relay targets were observed.

Consequences of event/condition investigated

There was a loss of Component Cooling Water Train 2 cooling which caused the standby CRD Booster Pump #2 and CCW Pump #1 to auto start, and Letdown to isolate. Additionally, it forced the plant to enter Technical Specification (TS) 3.8.1.1 for #2 EDG inoperable, 3.7.3.1 for loss of a Component Cooling Water loop, and 3.5.2 for loss of an ECCS train due to and inoperable #2 Decay Heat Cooler.

Immediate actions taken

Operations entered the CCW Abnormal Procedure (DB-OP-02523), for "Operating Component Cooling Water Pump Failure". There are no further immediate actions in DB-OP-02523 for such an event.

Remedial actions taken

The motor circuit was meggered and a hard ground was found from the switchgear to the motor. The cable was disconnected at the motor terminal box. The ground was located on Phase A conductor of cable 2PAD113A. (WO's 99-005989-000 and 99-005989-002)

The failed cable was removed, a replacement cable was installed and the pump was returned to service.

Event Narrative

Event sequence based on information obtained

09/30/99

13:20 – In order to support performance testing per DB-PF-04705, Component Cooling Water Heat Exchanger 2, CCW Pump 3 as 2 was started and CCW Pump 2 was stopped.

14:31 – 4160V circuit breaker AD113 CCW Pump 2 was racked out and control power fuses were removed.

21:43 – Started CCW Pump 2 and then stopped CCW Pump 3 as 2.

10/1/99

The CCW Pumps were swapped as part of scheduled operation and maintenance. During the afternoon zone walkdown it was noticed that a relay target was dropped on #2 CCW Pump Motor Breaker AD113, Phase A Instantaneous and Time-Overcurrent Relay. The breaker was not tripped and the motor was operating.

Discussions with the Electricians who checked the relay stated the target was in on the lower left hand unit of the relay. As the motor was running and no abnormal condition existed the target was reset. Mechanical agitation was considered to be the cause of the dropped target.

10/2/99

01:55, The #2 CCW Pump tripped.

Immediate actions were:

- #1 CCW Pump Auto started.
- Operations entered DB-OP-02523, CCW Malfunctions.

Supplementary actions by Operations included the following:

- Operations discovered letdown had isolated on high temperature, and restored letdown to normal.
- Operations isolated EDG #2 air starts due to no cooling available.
- Operations placed #3 CCW Pump and Heat Exchanger in service as #2 CCW and exited Technical Specifications 3.8.1.1, 3.7.3.1 and 3.5.2.
- Operations directed the continuous service Electricians to megger the #2 CCW Pump Motor from Bus D1 Switchgear breaker cubicle AD113. The megger indicated a hard ground. (WO 99-005989-000)

Observations:

- The relay targets present were Cubicle AD113: Phase A, Instantaneous and Time-Overcurrent Relay, Lower Right Hand Unit ICS-T and Upper Left Hand Unit SSC-T; and the Ground Sensing Relay.
- Operations noted the white overload indication for #2 CCW Pump was on in the control room for almost a day after the pump tripped.
- Computer Point Q116 indicated TRIP when breaker tripped 99-OCT-2 01:56 and DADS information shows it remained in TRIP until 99-OCT-3 03:27.

These observations indicate that a cable on the protected circuit faulted to ground on phase A. Sufficient fault current flowed to pick up the ITH unit in the 50GS device. The SSC-T unit in the 50/51-A also saw sufficient current to energize but did not provide a trip signal to the breaker

The breaker tripped as expected. The target received on 50GS was the true trip indicator. The targets ICS/T and ICS/L on 50/51-A were dropped due to an unintended DC circuit path that contributed to a sealed in white overload light indication.

Work Orders 99-005989-000 was initiated and the motor circuit was broken at the motor terminal box to isolate the ground. The ground was located on Phase A conductor of cable 2PAD113A. The motor winding checked fine and the starting capacitor responded correctly to a test meter.

The Electricians then determinated the cable at the switchgear end and viewed the conductors with the ECAD test set. It appeared the failure location was toward the motor end of the cable in the conduit run.

Preparations were made to remove the cable.

There was no Class 1E cable or stress cone termination kits available. Material had to be ordered.

<u>10/3/99</u>

The failed cable was removed. (WO 99-005989-002) The cable was coiled and moved outside.

<u>10/4/99</u>

Replacement 15KV cable was located and brought indoors for warm-up period to prevent damage to a cold cable during the cable pull..

<u>10/5/99</u>

New 15KV cable installed.

Due to the higher capacity rating of the cable, there was a delay while waiting for termination information from Raychem.

<u>10/6/99</u>

New Cable terminated

Received permission from DEEC to use cable by 3:30 PM

Design Electrical (DEEC) discussed the cable condition with the cable vendor, Okonite, and noted that some sections of the cable appear to be degraded due to a chronic effect/mechanism. DEEC was interested in testing the pull rags for possible contaminates that may degrade the cable covering. None were available. The Electricians that removed the cable indicated that the conduit had what appeared to be ground water in it. The water was not radiologially contaminated. The water was not irritating to bare skin and was not of sufficient volume as to do anything more than make the rags wet. Unfortunately the rags were disposed of before the Root Cause team could have them analyzed for contaminates. No 'wave' of water rushed from the conduit as the rags were pulled through and no water samples were obtained. Electricians reported later that while the cable was in the switchgear room some clear water leaked out or off of it because of a small puddle was found on the floor under the cable.

2242 CCW pump #2 is started from the spare status.

10/7/99

0215 CCW pump #2 is declared operable and motor returned to service.

Failed cable sent to BETA labs for analysis.

Root Cause Determination

Two issues are being addressed by this Root Cause investigation. The first issue concerns the circuit breaker relay target that was "in" on the evening of 10/1/99. It was investigated, subsequently reset. The concern is whether or not this was a precursor to cable failure that was not adequately pursued. The second issue concerns the cable failure itself.

ISSUE 1 – RESETTING THE RELAY TARGET ON AD113 ON 10/1/99.

Data Analysis

The NOMS log entry reads as follows, "10/01/1999 19:14:5 Had the 51A target on AD113 (#2 CCW Pump Breaker) SS informed and it was investigated by an electrician. No cause was evident so the target was reset." When initially reviewed by the Root Cause team, this entry seemed to be an opportunity lost. The 51A relay is a longtime overcurrent relay, which actuates at 3.5 amps on the current transformer secondary winding which equates to 70 amps to the CCW pump motor. The 51A relay by itself would provide an alarm only function.

Interviews with Operations and Electrical Maintenance personnel, identified that the lower left target was dropped on the night of 10/01/99 while the motor was running. The lower left target is for the IIT unit. The IIT unit is an instantaneous overcurrent device set to pick up at 680 amps. The IIT relay target that fell is for the 50A relay. There is one label for the three relays (LT, ITH, IIT) which reads "50/51A". There are only two explanations shown below that would allow the target to be present and not have tripped the CCW Pump Breaker. The False Target is by far the most plausible explanation.

I – False Target

The IIT target dropped due to mechanical shock during breaker operations that occurred earlier in the day. Breaker AD108 was racked out and removed from its cubicle and secured to the wall early in morning on that Friday.

II – Momentary Fault

A momentary fault occurred but the circuit breaker did not trip because the motor continued to operate. The fault caused the IIT unit to operate. The circuit breaker would have had to fail to trip for some unknown reason. Additionally, if the fault were a ground fault, the 50GS relay would also have had to fail to operate for an unknown reason.

The electrician and operators involved with the investigation determined that a false target did indeed occur.

To evaluate this decision, Operations personnel (3 Shift Supervisors and 1 Assistant Shift Supervisor) were contacted to determine the actions taken if a breaker target is received. If an unexpected target occurs, then OPS personnel would notify an electrician, refer to Conduct of Operations, and make a unit entry. None of the Operators could remember a target that was the result of an actual condition. The result of most target investigations in the past has found the component still running. The target received in this situation indicated the component should have tripped. In these cases, the cause is normally attributed to mechanical agitation or no case is identified. The discussions with the Operators indicated that targets get a proper amount of attention.

Root Cause

It is the conclusion of this Root Cause that for Issue 1, no further actions are necessary and the actions taken by both the Operators and the electrician were appropriate and met management's expectations.

ISSUE 2 – CCW PUMP 2 CABLE FAILURE

Data Analysis

History: Okonite manufactured the failed cable in the early 1970's. The cable is approximately 270 feet long and follows a path as follows:

- The cable exits the D1 switchgear out the bottom of the breaker cubicle for AD113 (elev. 585')
- The cable is encased in PVC conduit which bends and traverses horizontally beneath the high voltage switchgear room and turbine building heater bay foundation. (elev. 581')
- The cable conduit run then slopes up as it passes into that portion of the turbine building heater bay which forms the ceiling to the Auxiliary Feedwater Rooms. (elev. 583'9")
- The cable conduit run continues at the 583'9" elevation until it reaches the CCW Pump Room where the conduit curves up and runs vertically into the CCW Pump Motor terminal box.

The cable is from a lot of cable that procurement documents indicate was received in 1972. The cable was installed in the mid-1970's. The cable package consisted of three 5kV 2/0 single conductor cables supplied by Okonite in a parallel configuration with a bare #4 copper ground conductor as the fourth part of the parallel package. The individual 2/0 copper cables consisted of a multi-strand tinned copper wire conductor, covered by 115 mils of black extruded EPR insulation. The insulation was wrapped semi-conductor tape, followed by a tinned copper tape shield and then finally covered with 80 mils of black neoprene which was "painted" to identify the three phases as black, red, and white.

Okonite used the black EPR insulation into the 1970's. Okonite has changed their formula for their EPR and uses an improved "red" EPR insulation. Carbon black was used to color the black EPR insulation and Okonite's change eliminated carbon black from the formula. The new "red" EPR has two benefits according the vendor. It has a higher dielectric strength and because of its color, it is easier for users in the field to check for cable jacket damage and/or cleanliness. An additional change Okonite has made to the cables is the use of an extruded semi-conductor versus a taped semi-conductor. This change was made possible because of improvements in their manufacturing processes. Okonite has stated that with a taped semi-conducting layer, there would be an air gap at the tape overlap, which would result in a higher stress level, and that a voltage across the insulation, in the presence of high temperature or moisture, could result in cable breakdown. Okonite also went on to state that the EPR insulation was the designed moisture barrier, not the jacket or shield layers. In summary, the new generation cable is more water resistant, and has more consistent electric field properties.

Failure Analysis: The Failed cable was sent to Beta Labs to perform a failure analysis. Although the complete failure analysis will not be completed until mid-November, enough information has been accumulated to formulate a probable root cause.

The test program established by Beta Labs was structured in three basic phases. The first phase was a complete visual exam. Initial visual inspections of the cable showed extensive cracking and the appearance of charring of the neoprene jacket along with extensive corrosion of the bare #4 copper ground wire. The severity of damage of the neoprene jacket appeared to be worst where the ground wire corroded the most. There was no failure site immediately visible. Initial theories for the extensive

damage of the jacket in the vicinity of the corroded ground cable looked at heat damage as a result of current flow through the ground cable. The theory was that as the ground corroded and its cross-section got smaller, then its resistance at that point would increase and hence additional resistive heating would take place. DEEC evaluated and rejected this theory. The current carrying capacity of a single strand of #4 copper conductor (Class B stranding is 77.2 mils thick) would be at least 35-40 amps. This is based upon #12 solid copper wire (0.08081" diameter) with 90 degrees Celsius insulation having a capacity of 40 amps in free air (NEC table 310-17). 90 degrees Celsius would not have provided enough heat to cause any burning of the Neoprene jacket. Our measurements of ground currents on the system indicate the existence of only 1.5 amps (WO 99-006135-000). The lab also reported that the cable appeared to be "swollen" at various places along the cable length, possibly from moisture intrusion or chemical attack. Subsequent testing has ruled out chemical attack, which would have altered the chemical make-up of the cable components or as a minimum have left some residue. The jacket damage was most prevalent in the first 150 feet as measured from the circuit breaker. This region corresponds to the where the conduit would be at the lowest elevation. The cause for the jacket degradation has not been identified. From a cable operability standpoint, the jacket is considered sacrificial and is intended to protect the cable during installation. Its degradation, although very noticeable, is only a concern if it can be linked to the subsequent degradation of the insulator. This connection has not been established.

The second phase was to do a complete non-destructive exam of the cable. This cable testing consisted of a meggar and DC test while monitoring leakage currents. For the meggar test, at 2500V, the resistance was 2500 Meg ohm (a new cable would have shown infinity). The DC test started at 1000VDC, and increased by 500V every minute, after currents stabilized. Although the black phase (the A phase) held up to 5000VDC, it should have been able to hold 2.5 to 3 times its AC voltage rating. At 5500VDC, it tripped off. Beta Labs tried two more times, but the voltage was lower, around 5000VDC. The lab decided the fault location must be a tiny pinhole, and that they couldn't identify the location. Testing indicated the red phase broke down at around 5000VDC to 5500VDC. The white phase tested good, with leakage currents of less than 0.1 microamp at 7500VDC after a 15-minute test.

Next the lab called in a cable crew with a Biddle 30KV Impulse Generator Test Set, which does a capacitor discharge test, and is used for locating faults in installed cables. Using this equipment, the testing located the fault on the black phase (the A phase) at about 5KV about 54 feet in from the breaker end. Although there may have been other faults in this phase, this was the weakest point in the insulation of this phase. It is not possible to locate additional faults without removing this section of cable. At the fault location, the outside jacket looked good, and the ground wire was not corroded away, although there was some corrosion. The testing located the fault on the red phase at 7KV about 71 feet in from the breaker end. At the fault location, the jacket looked deteriorated with some cracking, but not bad. It was noted that there were sections of the cable and ground wire that looked far worse than the areas of cable where the faults were located. Although not initially intended as a destructive test, the Biddle test did prove to be destructive to the red phase when the red phase was later dissected.

The third and final phase of testing was destructive testing. We had authorized Beta to remove a section of the #4 ground cable for examination. It has at least seven strands and in some places was corroded to the point that only one or two strands remained. The section was examined with an electron microscope to see if this conductor was overheated, which would be indicated by changes in the structure of the copper. There were no indications that the damage to the ground wire was anything more than corrosion. There were no signs of melting or high temperatures. The ground cable provides the function of grounding the motor ground to the switchgear ground. The absence of the ground cable would mean that the motor frame would be grounded to the switchgear now only indirectly via the station ground. However, the corrosion of the #4 ground cable is of concern in that there appears to be a correlation

between the jacket degradation and the ground cable corrosion, and there may be a correlation between jacket breakdown and the insulation failure, although this correlation has not been found yet.

Beta Labs removed the jacket to inspect the copper tape and insulation.

Beta Las reported that testing had confirmed that the insulation and jacket materials were EPR and neoprene, respectively. This testing included testing of the mechanical properties of the materials and confirmed that it matches the properties of the specified material, which ruled out a "bad run" during the manufacturing phase. The lab noted that there was a fungus growth on the neoprene jacket in the areas where the jacket was cracked. It appeared that the cable had been in a wet environment for a long time. The jacket was highly carbonized where the cracking occurred and the fungus was not likely a contributor to the cracking.

Approximately 18" of cable was removed from the red and black phases in the respective fault areas. These sections were then dissected. When the section of the red phase was cut, droplets of water came out of the cable. The cloth binding tape was saturated although the neoprene jacket was intact in this area. The tin/copper shielding tapes were discolored from the moisture and there was a puncture in the shielding tape, indicating the location of the fault. There was also a tiny pinhole in the EPR insulation but no evidence of burning. There was also no evidence of 'treeing' on the EPR material but this is not unusual since 'treeing' is more common with cross-linked polyethylene (XLPE) insulation. 'Treeing' is a surface cracking of the insulation along the axis of the cable due to moisture damage. The cracking forms random spidery finger like cracks that resemble branches off a tree, hence the term 'treeing'. The insulation was removed to exam the conductor. All strands of the conductor were discolored indicating that there had been moisture in the cable for some period of time.

The black phase section also had moisture under its jacket. However, unlike the red phase, the fault location was very visible due to an 8" black burn mark on the cloth binder tape. Beneath the tape was a very evident puncture, which penetrated all layers down to the conductor. There was less moisture present in this cable compared to the red phase. This was attributed to the drying out action that the fault current would have cause. The conclusion of the lab was that the black cable fault was the fault that caused the CCW pump to trip on ground current. The Biddle testing caused the puncture on the red phase. The lab concluded that the lack of burning at the puncture site was indicative of a test-induced failure. The test equipment was capable of causing a puncture of the insulation but then would trip off before passing enough fault current to char the material surrounding the puncture site.

Chemical analysis of the water found in the cable indicated that the water was void of chemicals that would have chemically reacted with the cable and degrade it. Based upon the deposits on the jacket, it appeared that the cable had gone through several wet and dry cycles. The deposits were analyzed and in addition to the elements common to ground water, there were significant amounts of copper sulfates on the jacket that most likely were from the corrosion of the #4 copper ground cable.

On Thursday, October 21,1999, the results of testing were discussed in a group session at the Beta facility. The following individuals were in attendance:

Mark Bridavsky	Beta Lab.	Paul Shemanski	NRC Washington
Jim Hirsch	Beta Lab.	Jit Vora	NRC Washington
Bruce Warner	Beta Lab.	Kevin Zellers	NRC Senior Resident
Dave Geisen	Davis-Besse	Tom Kopchick	Engineering Services.
Gerry Wolf	Davis-Besse	George Dobrowolski	Okonite Co.

After an extensive discussion, a probable failure scenario was theorized. This failure scenario can not be completely proven based on one cable exam but the scenario represents what sound engineering judgement and past industry experience would indicate is the most credible scenario.

To understand the scenario, a few basic electrical cable principles first have to be reviewed.

Current passing through the conductor will create a magnetic field around the conductor. The shield, which is this case was a wrapped tin-coated copper tape, cuts through the field. The insulator acts as a dielectric between the shield and conductor. The semi-conductor tape also affects the field strength. Experience with sub-marine cables has shown that as the cable passes from one medium to another such as from water to soil and back, a field disturbance is created. This field disturbance creates a localized imbalance in the field strength across the dielectric (insulator) and allows for polarization in the region of highest electric field strength. Over time, the repeated polarization of a localized site will cause a breakdown of the local material. Essentially what happens is a slow 'boring' of a puncture hole in the immediate area of highest electric field strength. To prevent this the cable components (conductor, insulator, shield, semi-conductor, and binding tape) are arranged to maintain the electric field strength as constant as possible across the length of the cable so as to not have localized polarization.

EPR insulation is the moisture barrier but it is not entirely impervious. Over time, moisture does penetrate through the insulation in a process that can be best described as osmosis. The result is pure water on the inside of the insulation, which by itself does not impact the cable because pure water is a good insulator since it has no ionic impurities.

In January and February of this year Doble Power Factor Testing and Partial Discharge Testing was performed on the other two CCW pumps. Subsequent visual inspection upon removal of the cables revealed no defects and good overall cable physical condition. Based upon the results of CCW pump #1 and #3 cable testing and replacement, the inspection plan was revised to only perform Doble Power Factor testing on Make-Up Pumps 1 & 2. The basis for this decision was that the results of the Doble Power Factor testing were as accurate and conclusive as the Partial Discharge testing, and the Doble testing can be performed using on-site resources. No additional cable change-outs were planned unless Doble testing indicated that it was warranted.

During 12RFO (April), both Make-Up Pumps' cables were Doble Tested satisfactorily.

Root Cause

This Root Cause theorizes that water in the cable conduit over time penetrated the outer jacket and wicked throughout most of the cable via the cloth binder tape, which is just inside the neoprene jacket. The moisture would seep between the various layers of the cable construction to reach the EPR insulation. The osmosis of the water molecules through the EPR insulation would occur. All of this would be benign to the cable by itself. However, the water seeping into the cable layers would likely bring with it some impurities which would plate out in the outer layers of the EPR as the osmosis process filtered them out. These impurities would disturb the electric field strength if they were deposited non-uniformly or the conductor was off-centered in the insulation, which it was. The breakdown of the neoprene as evidenced by the cracking and apparent carbonizing of the jacket material would release even more impurities into the water seeping into the cable. As a side note, the cause of the breakdown of the neoprene jacket has not been identified. It is unknown what caused the carbonization of the neoprene.

Over time, the electric field created by the current passing through the conductor bored a hole in the area of highest field strength. It is unknown weather or not a pre-existing flaw was present at the fault site because the area was highly carbonized and pre fault conditions would be pure supposition. However, the successful testing of the other two CCW pump cables, and the Make-Up pump cables further increases the probability that the failure of CCW Pump 2 cable "B" Phase was an isolated fault.

Generic Implications

This cable failure could have generic implications if it can be shown to be a generic cable aging failure. That conclusion can not be reached . The CATPR associated with the original Root Cause gathered additional data. Without a clear, concise failure mechanism, a postulated failure mechanism was assumed and then through additional testing and field observations of other in-service 4160V cables, we disproved the presence of a generic postulated failure mechanism. The secondary goal of the CATPR was to ratify a means of testing existing cables that would confirm the functional integrity of the cables. This secondary goal was achieved and the site has chosen on-site Doble Power Factor testing as its primary means of testing cable insulation integrity.

Previous Occurrence Evaluation

Davis-Besse experience with medium voltage cable failures are:

- 4160V Cable bus failure in early 80s may have been due to installation or maintenance splice failed.
- 13.8 KV Stress cone powdering in late 80's due to poor routing of cable ground shields.
- 13.8 KV several cable failures in the directly buried cable to the Beach Station Substation. One this year.
- 12.38 KV Underground distribution, Owner Controlled Area cable termination flashovers in junction boxes due to surface contamination, and several cable failures.

The experience review for PCAQR 1999-1648 found the following:

- There were no Previous Quality Audit Findings pertained to this subject.
- The PCAQRs /CRs were searched for the events applicable to medium voltage cable failures. No failures beyond those described above were identified. There were no similarities that could be derived from the above cable failures and this event.
- The INPO Website was searched for the events applicable to cable failure. Eighteen cable failures were reviewed. One LER from Diablo Canyon documented three 4kV and two 12kV underground cable failures. The cable was the same cable type, age, and manufacturer as our CCW cable. PG&E had concluded that the 12kV cable failures were due to long -term chemical degradation of the neoprene jacket, probably due to chloride and/or fatty acids, followed by corrosion of the copper shield. When the shield deteriorates, uneven electrical stresses occur, ultimately resulting in a cable ground. Their 4kV cable failures could not be tied to chemical attack and therefore the failure was attributed to localized point defects or other anomalies that occurred randomly in time. It was this LER that prompted our testing from chemical attack. Our testing did not identify any presence of foreign chemicals.

Conclusion:

Although there have been other failures of this type cable in the industry, attempts to identify the cause have not been successful. Because of the infrequency of such failures, these failures have been historically accepted as isolated incidents with no broad common mode failure identified or evaluated.

Recommended Corrective Action Plan

Because of the failure mode of the cable is speculative, addition data must be obtained. Without a clear, concise failure mechanism, the only alternative is to postulate a failure mechanism and then through additional testing and field observations of other in-service 4160k cables, either confirm or disprove the postulated failure mechanism. The goal of the Recommended Corrective Actions will be to do just that and in the absence of proving the mechanism, the secondary goal of the Recommended Corrective Actions will be to ratify a means of testing existing cables that would confirm the functional integrity of the cables. Although any cable that is embedded and runs underground could degrade and fail, only the Class 1E cables would pose an immediate safety concern. The intent of these Corrective Actions is to first identify the steps necessary to ensure our Class 1E cables are not degraded and then eventually apply those same steps to the remainder of the plant.

Based upon our postulated failure mechanism, our Recommended Corrective Actions will focus on Class 1E medium voltage (4160V) cables that are both energized (presence of and electric field) and are wetted (disturbances in electric field). The total population of 4160V Class 1E cables is 28. Narrowing the population to those cables that are normally energized reduces this number to 16 cables. Adding the requirement of energized and wetted, reduced the population down to 8 cables, Make-up Pumps 1 & 2, Component Cooling Water Pumps 1, 2, & 3, and Service Water Pumps 1, 2, & 3. Based upon a review of cable conduit elevation schematics, CCW Pumps are believed to be the worst case cables because their conduit path results in the largest 'loop seal'. The 'loop seal ' is a low spot that occurs the conduit run where both ends of the conduit where the run enters the ground and exits the ground are at a higher elevation than the horizontal portion in the ground. For the CCW Pumps, this elevation change is greater than the other pumps. CCW Pump 2 cable has already been replaced and CCW Pumps 1 & 3 will be pulled following testing to be subjected to a complete visual inspection. The Service Water pumps virtually have no 'loop seal' in that their cable run low points are in manholes that are pumped dry by permanent sump pumps.

Action 1: Perform as-found Doble Power Factor testing and Partial Discharge testing of CCW Pump 1 (AC113) and CCW Pump 3 (ACD1) power cables. This testing was chosen based upon industry research into VLF testing (see references). It is expected that this testing by itself may not be conclusive but when compared to subsequent visual inspections, expected values to the testing may be developed to preclude further cable replacements. MDT Z0621 & Z0622 initiated. Requires purchase/rental of test equipment. (ELEC) 01/31/00
COMPLETED

Action 2: Replace CCW Pump 1 (AC113) and CCW Pump 3 (ACD1) power cables. Save cables for full visual examination. As part of the replacement effort, the presence of water in the conduit will be monitored and if present the water shall be tested. The conduit run will be visually inspected to the greatest extent possible using remote cameras prior to pulling in the replacement cable. The replacement cable will utilize an insulated ground cable to

eliminate or at least minimize future corrosion of the ground cable. By insulating the ground cable we may eliminate a degradation mechanism of the neoprene jacket. WO's 99-006419-000 for CCW pump 1 and 99-006520 for CCW Pump 3. Requires cable which has ~8 week lead time. (ELEC) 01/31/00
COMPLETED

Action 3: Issue results of cable inspection and testing to industry through Operating Experience Report. (SYSC) 02/15/00
COMPLETED

Action 4: Evaluate data from cable testing and replacement. Adjust action plan accordingly. (SYSC) 02/15/00
Doble Power Factor testing was chosen for program, with cable replacement based on a review of all gathered data.
COMPLETED

Action 5: As-found Doble Power Factor testing of Make-up Pumps was completed. No replacement of cables needed.
Service Water Pump cable testing scheduled in Cycle 13 during normal maintenance evolutions.
(SYSC & ELEC) 06/01/00.
COMPLETED

Action 6: Systems Engineering is to develop a comprehensive cable testing program to incorporate lessons learned from this event and the above testing. The cable testing program will include non-class 1E cables and will factor in the importance of the cables to power production and plant reliability when establishing the scope and frequency of testing.
(SYSC) 06/01/00
COMPLETED

References

Documents reviewed:

DB-OP-02523, Component Cooling Water System Malfunctions Abnormal Procedure.

E-300 Series Drawings, Conduit & Cable raceway drawings for Elevations 585 & 565.

Perry Nuclear Plant PIF 97-0919, 110-PY-B Tripping of June 5, 1997.

IEEE Electrical Insulation Magazine Article "Insulating and Semi-conductive Jackets for Medium and High Voltage Underground Power Cable Applications", By Gordon Graham and Steve Szaniszlo, Sept/Oct 1995 – Vol. 11, No. 5.

IEEE Electrical Insulation Magazine Article "Field Testing of HV Power Cables: Understanding VLF Testing", By Hans R. Gnerlich, Sept/Oct 1995 – Vol. 11, No. 5

Calculation C-EE-004.01-006 Rev. 1 – Component Cooling Water Pump 1-2 Breaker AD113 Time-Current Characteristics Curves.

Personnel contacted:

Mark S. Bridavsky, Beta Labs.

Thomas M. Kopchick, Beta Labs.

Bruce V. Warner, Beta Labs.

Jim Hirsch, Beta Labs.

Gene Willman, Contractor, Perry Technical Services

George Dobrowolski, The Okonite Co.

John Cancelosi, The Okonite Co.

James J. Jiamachello, DB Plant Engineering

Linda L. Makatura, DB Design Engineering

Andrew G. Migas, DB Design Engineering

James H. Whitright, DB Plant Operations

Methodologies employed:

Situational Data

Document Review

Interviews

Lab Testing

Events and Causal Factor Charting for Equipment Performance.

Attachments

I. Photos of as-found cable condition (20 pages)

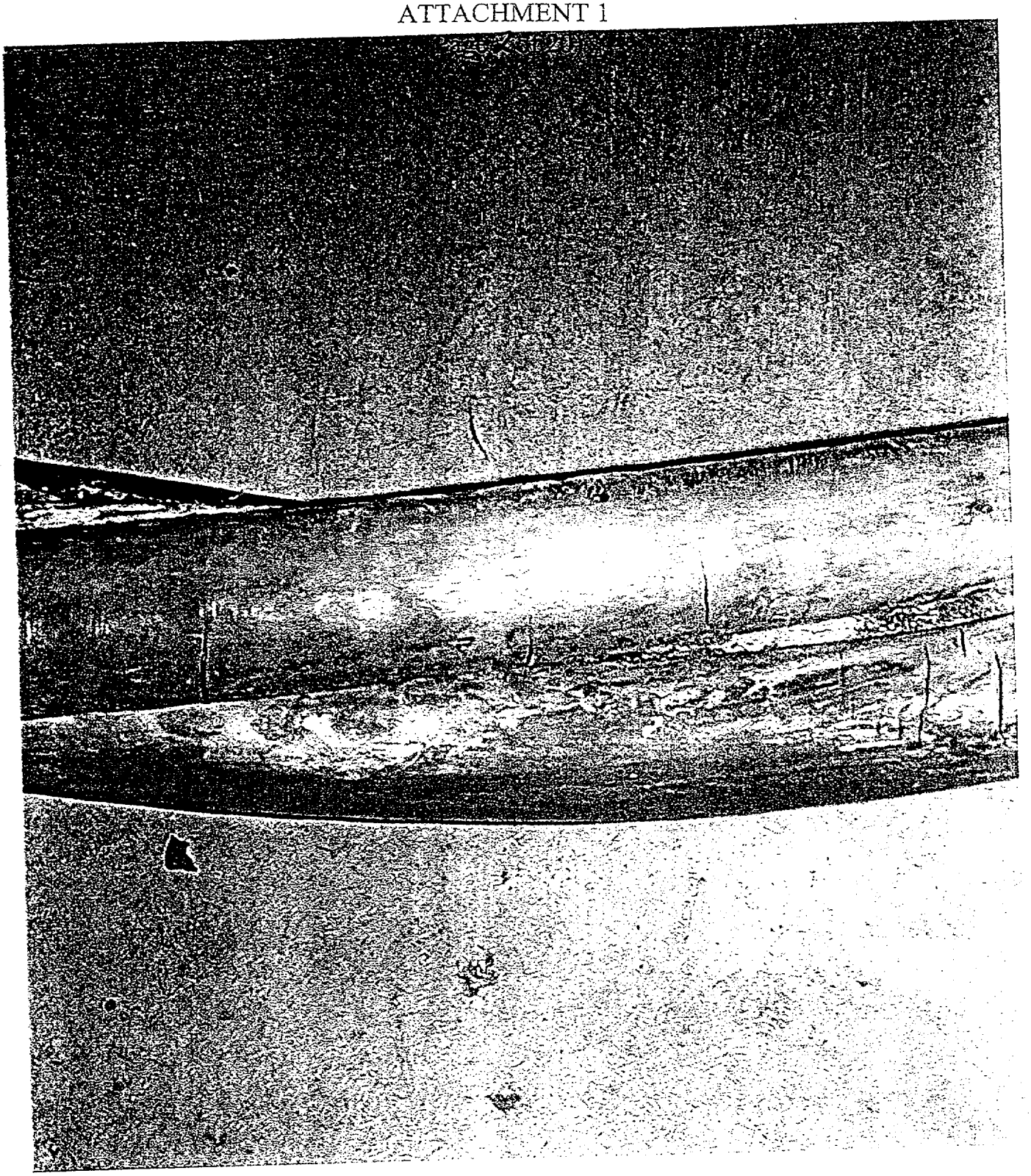
II. Magnified photos of Neoprene Cable jacket (4 pages)

III. Beta Lab Test Program for failed cable.

IV. Cable Electrical Testing Results.

V. Events and Causal Factor Chart for Equipment Performance

ATTACHMENT 1



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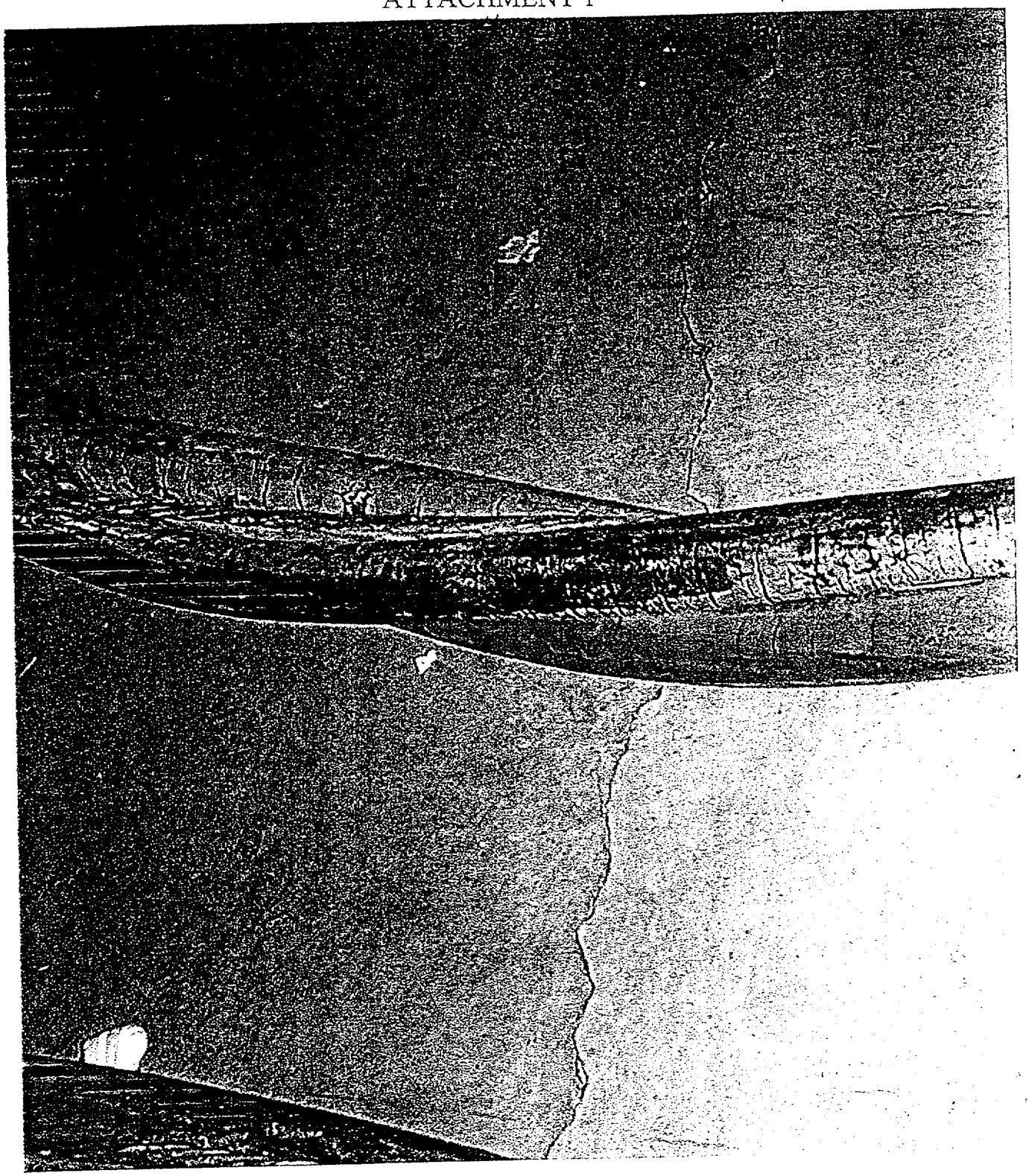

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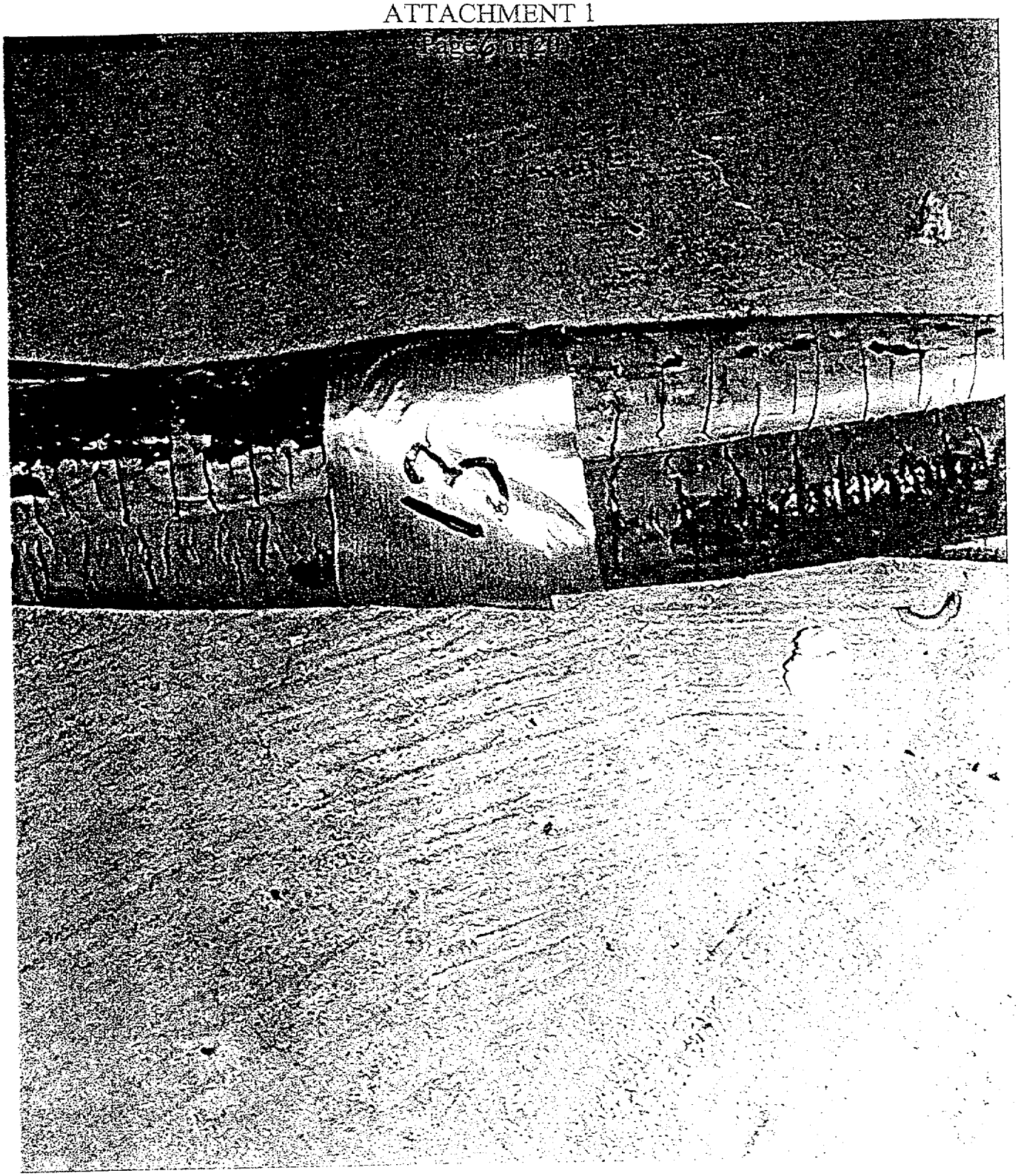

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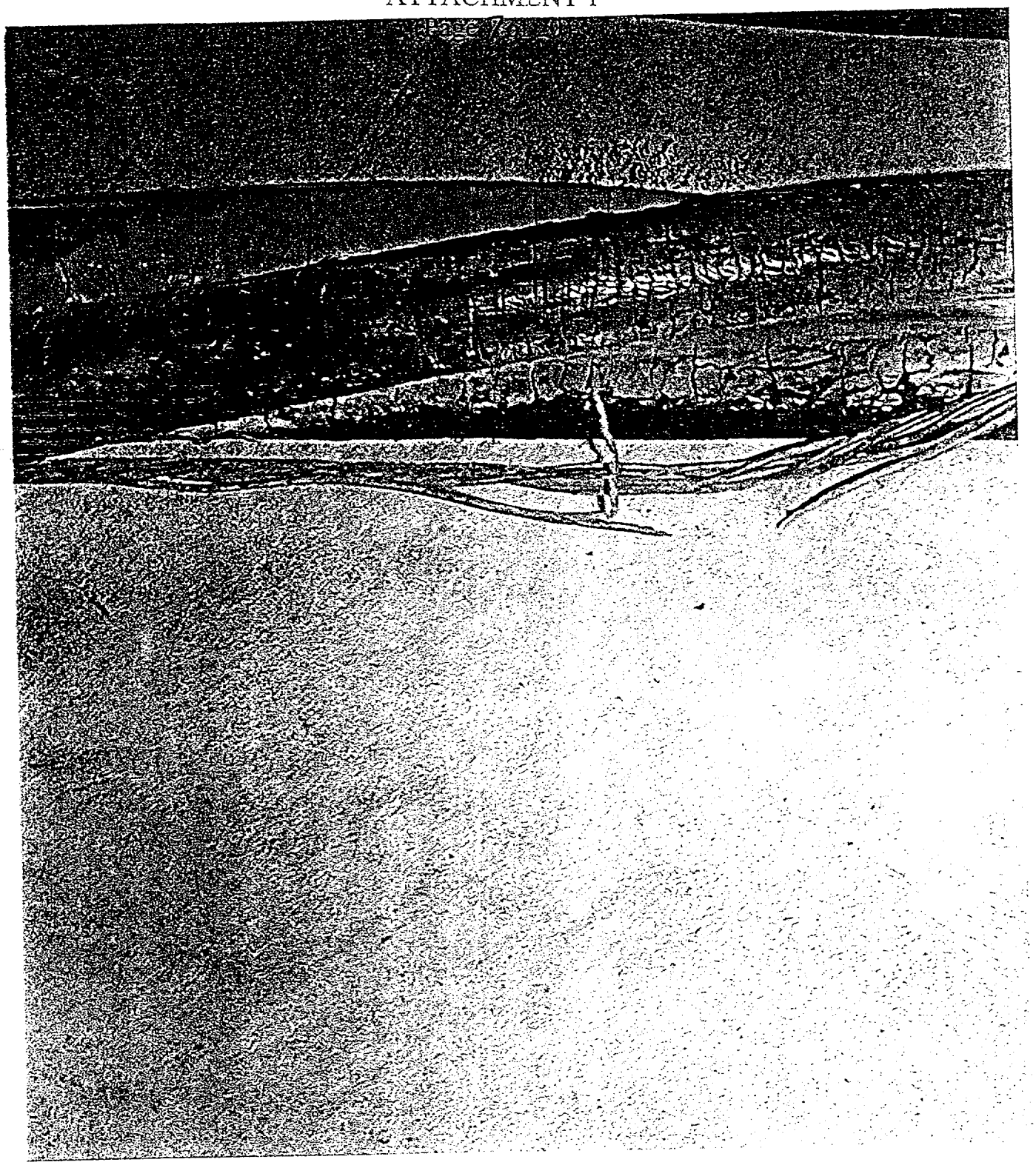

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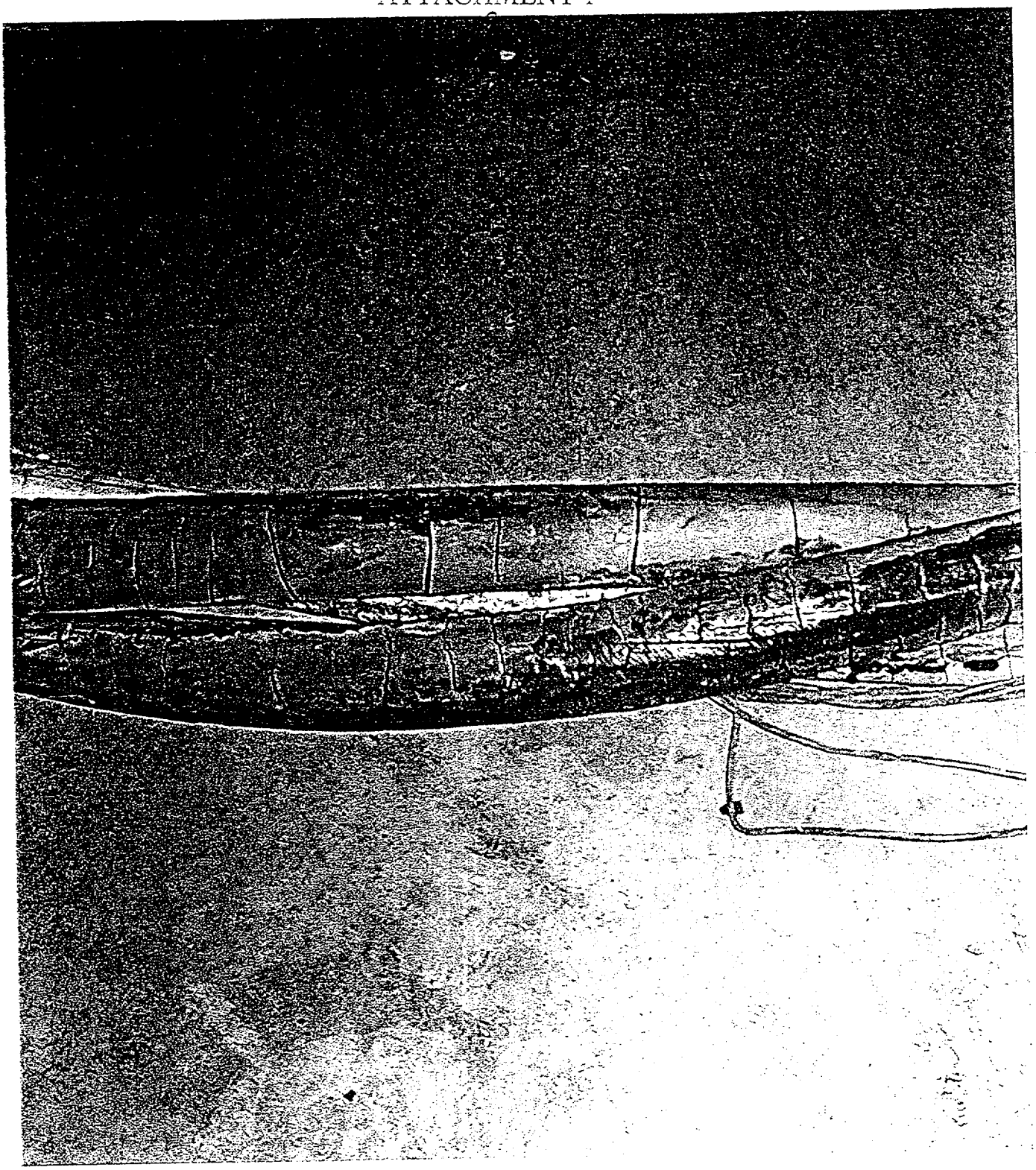

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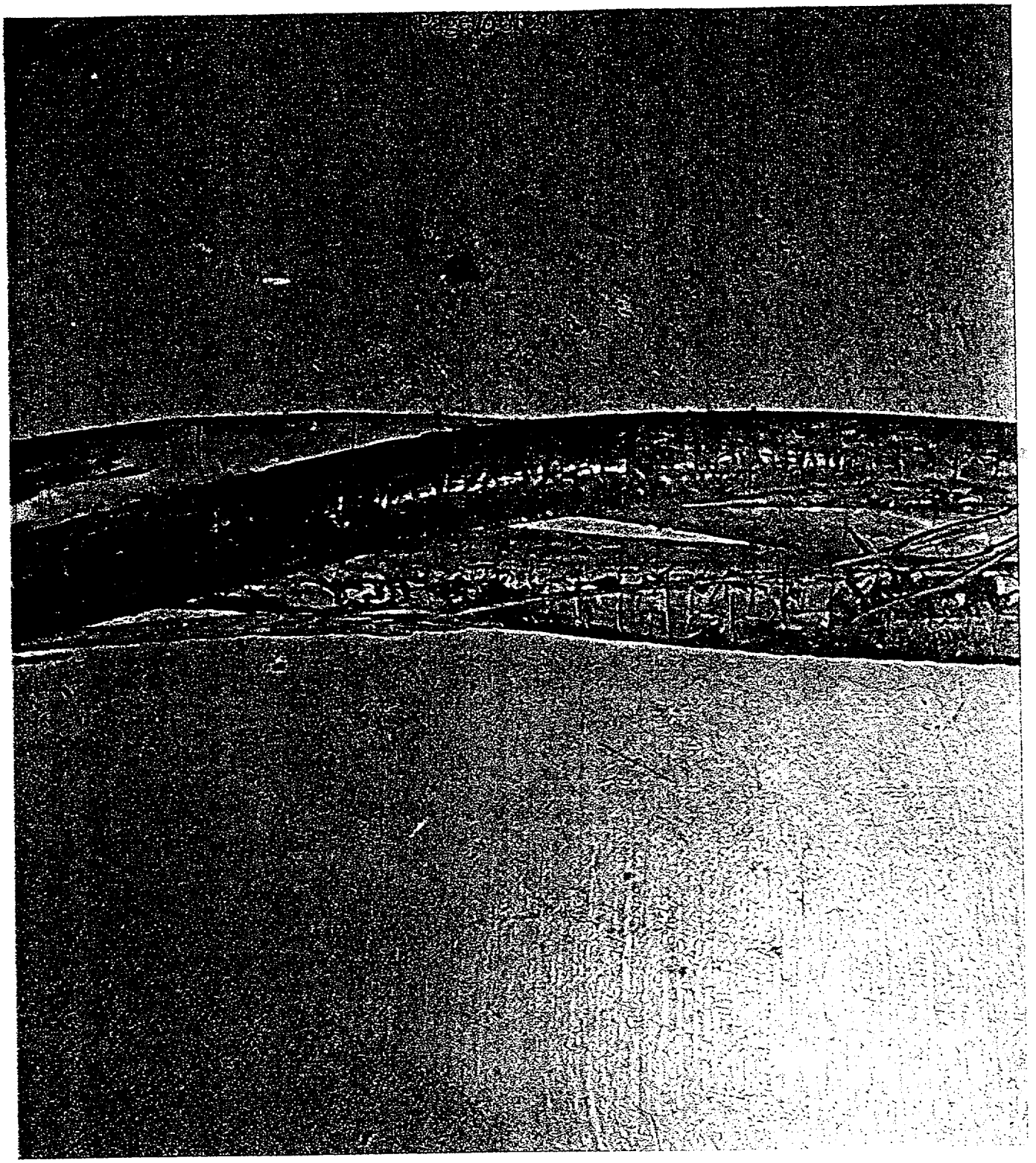

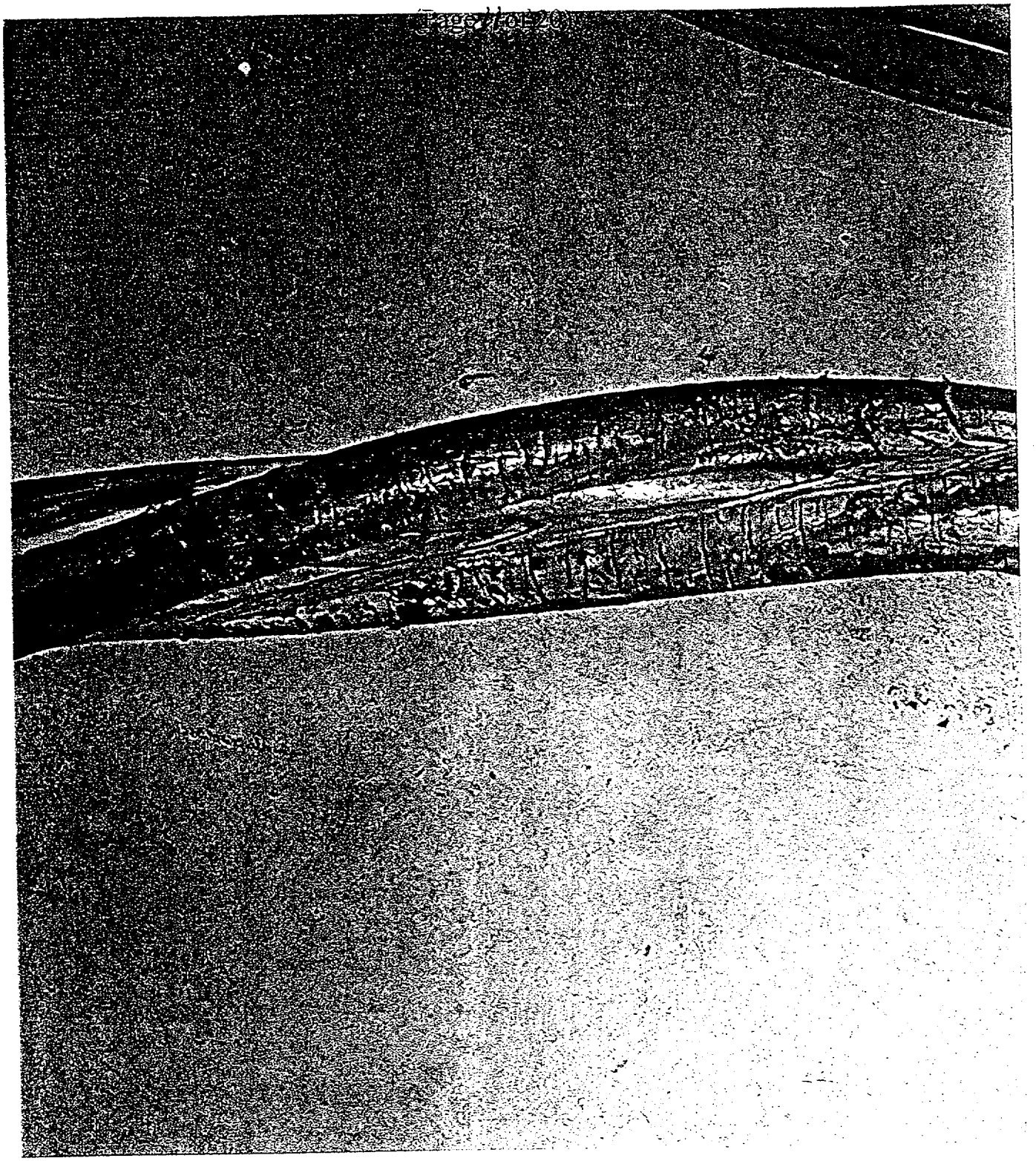

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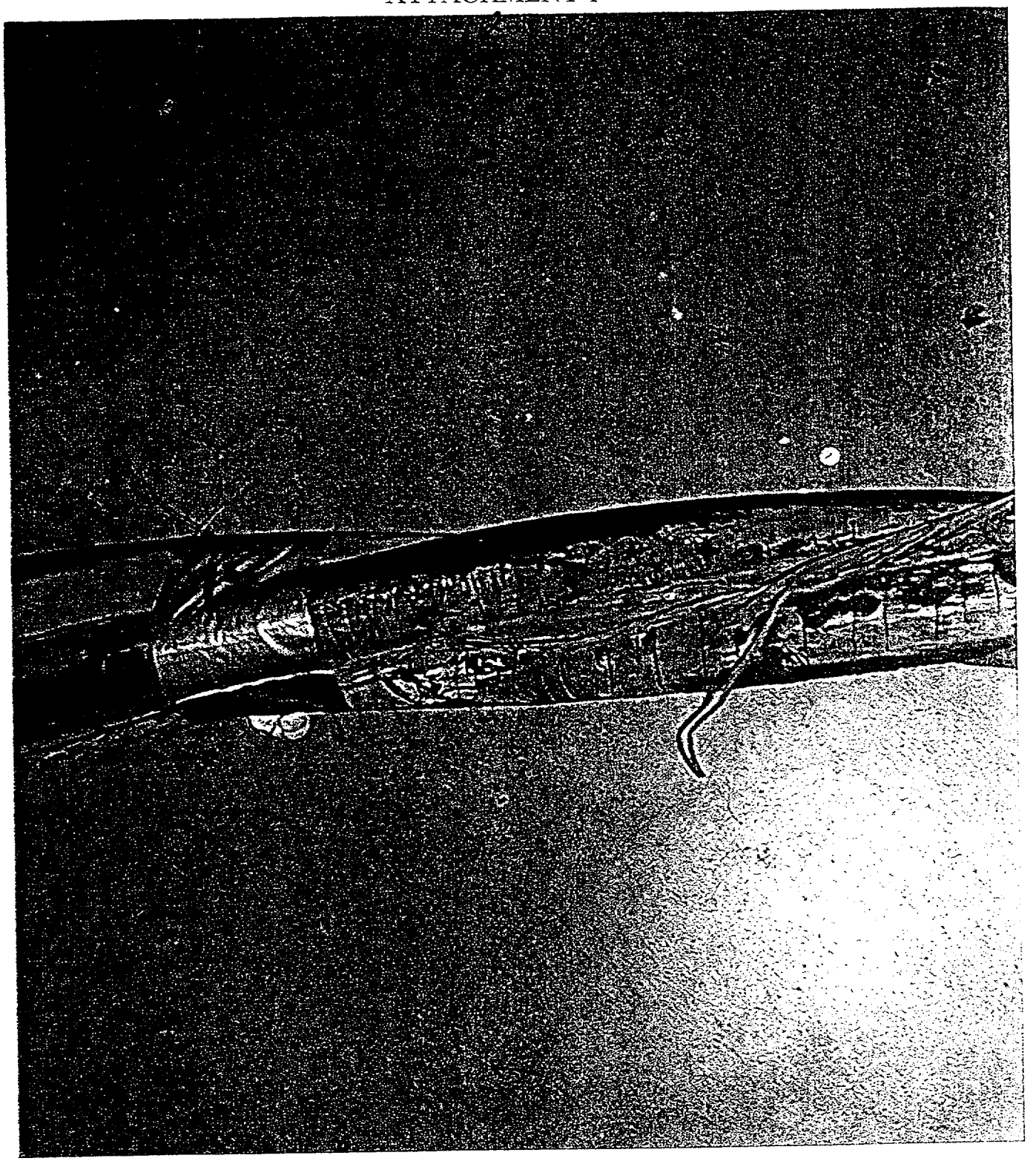

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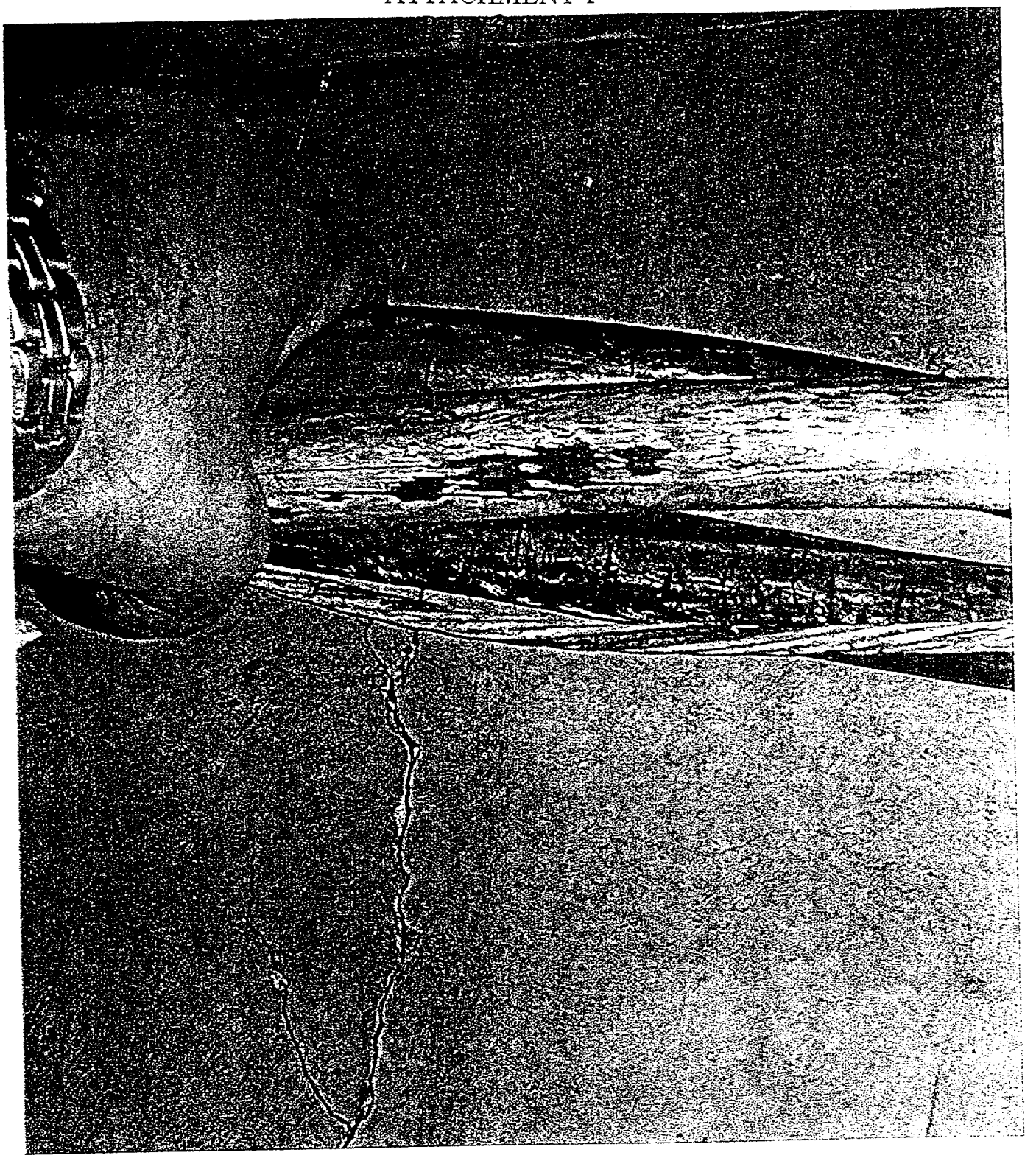

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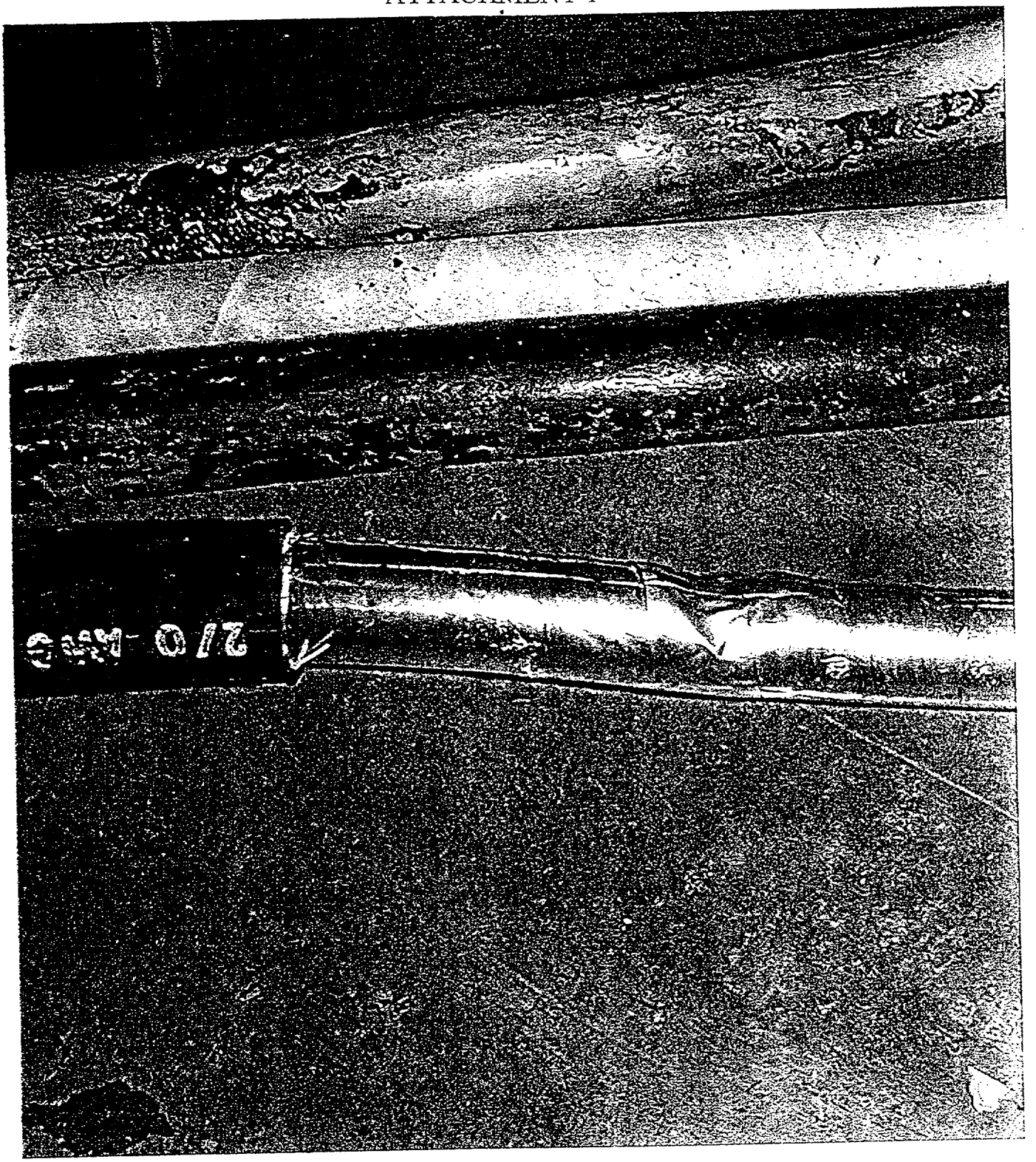

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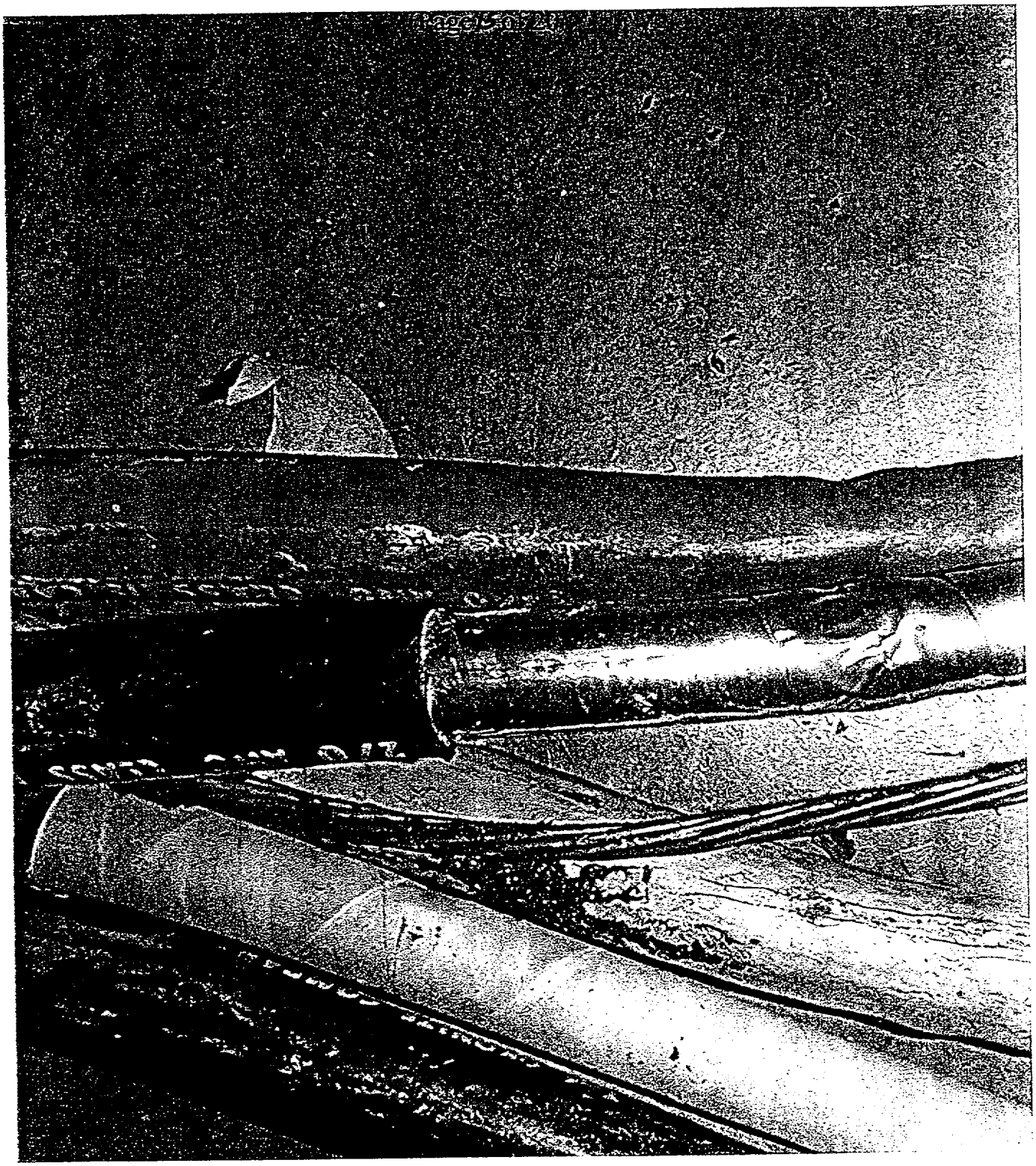

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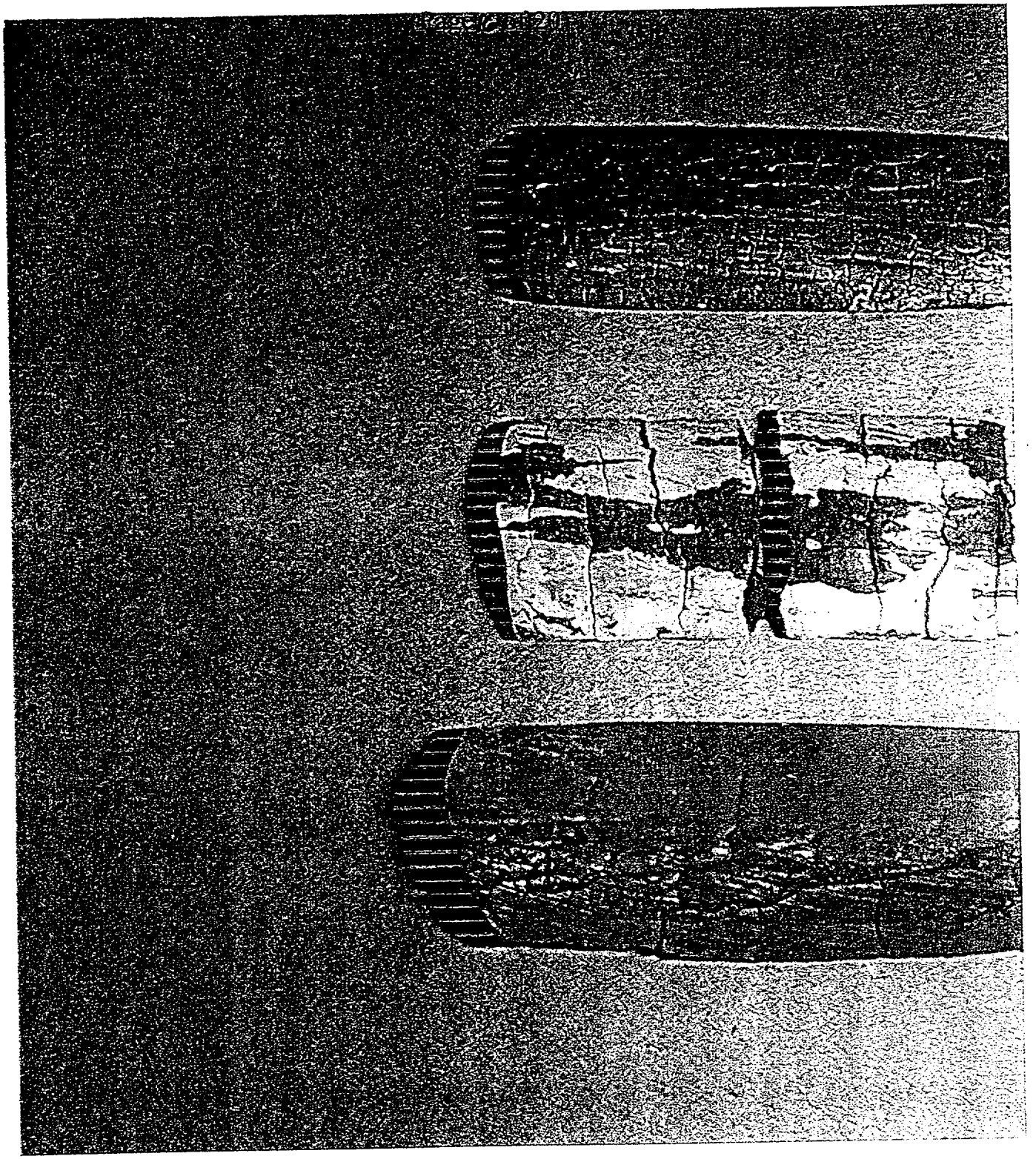

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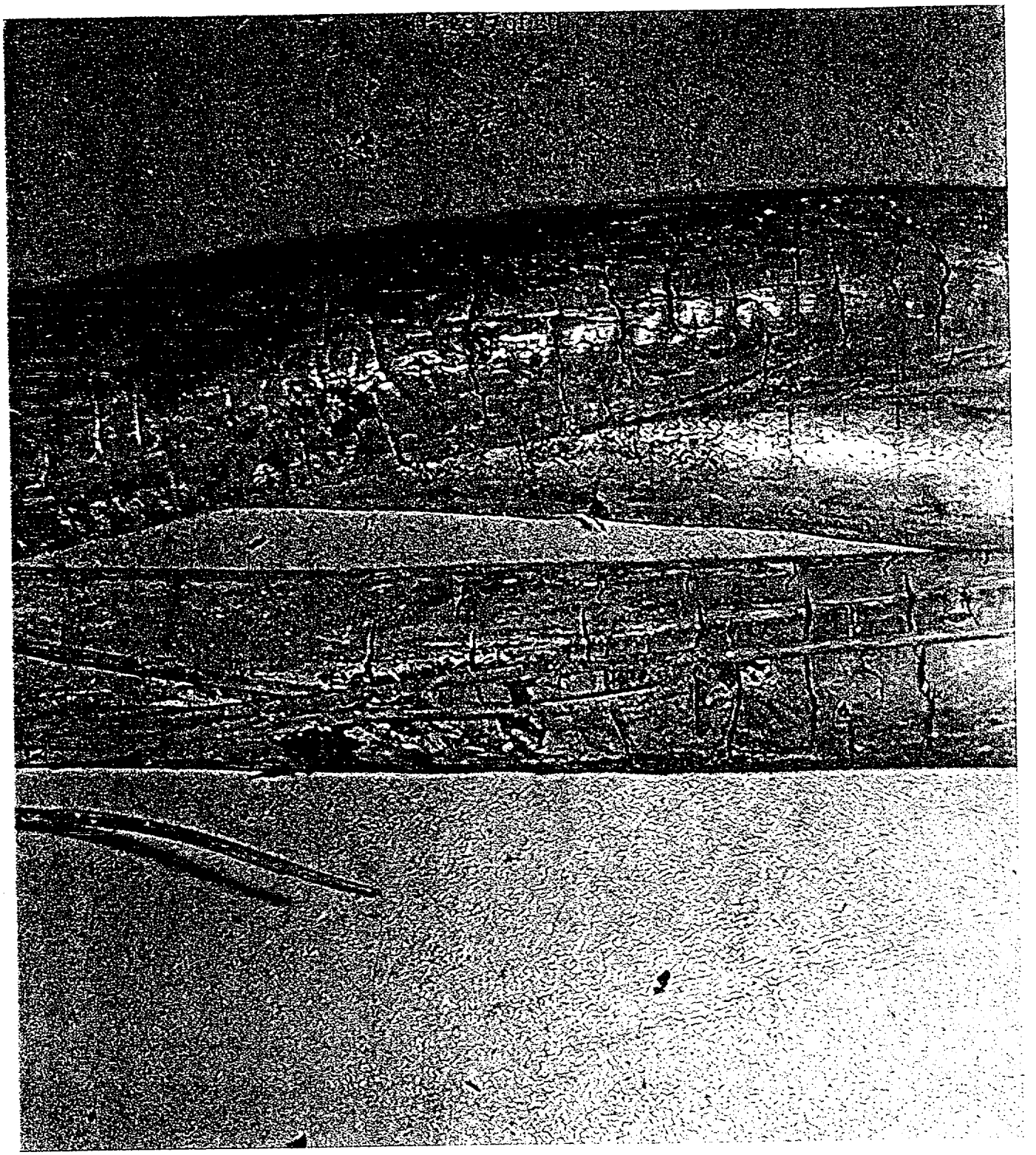

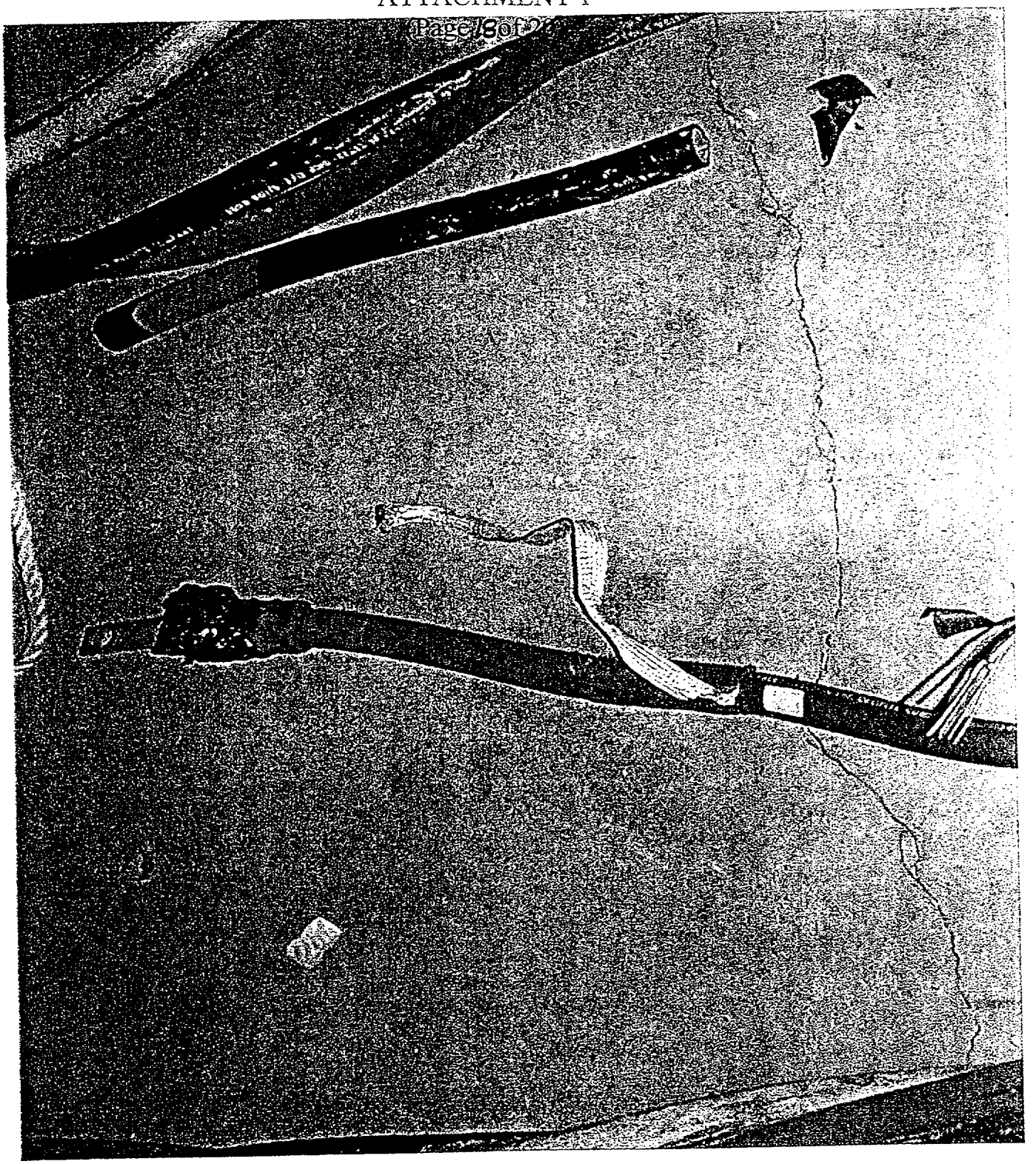

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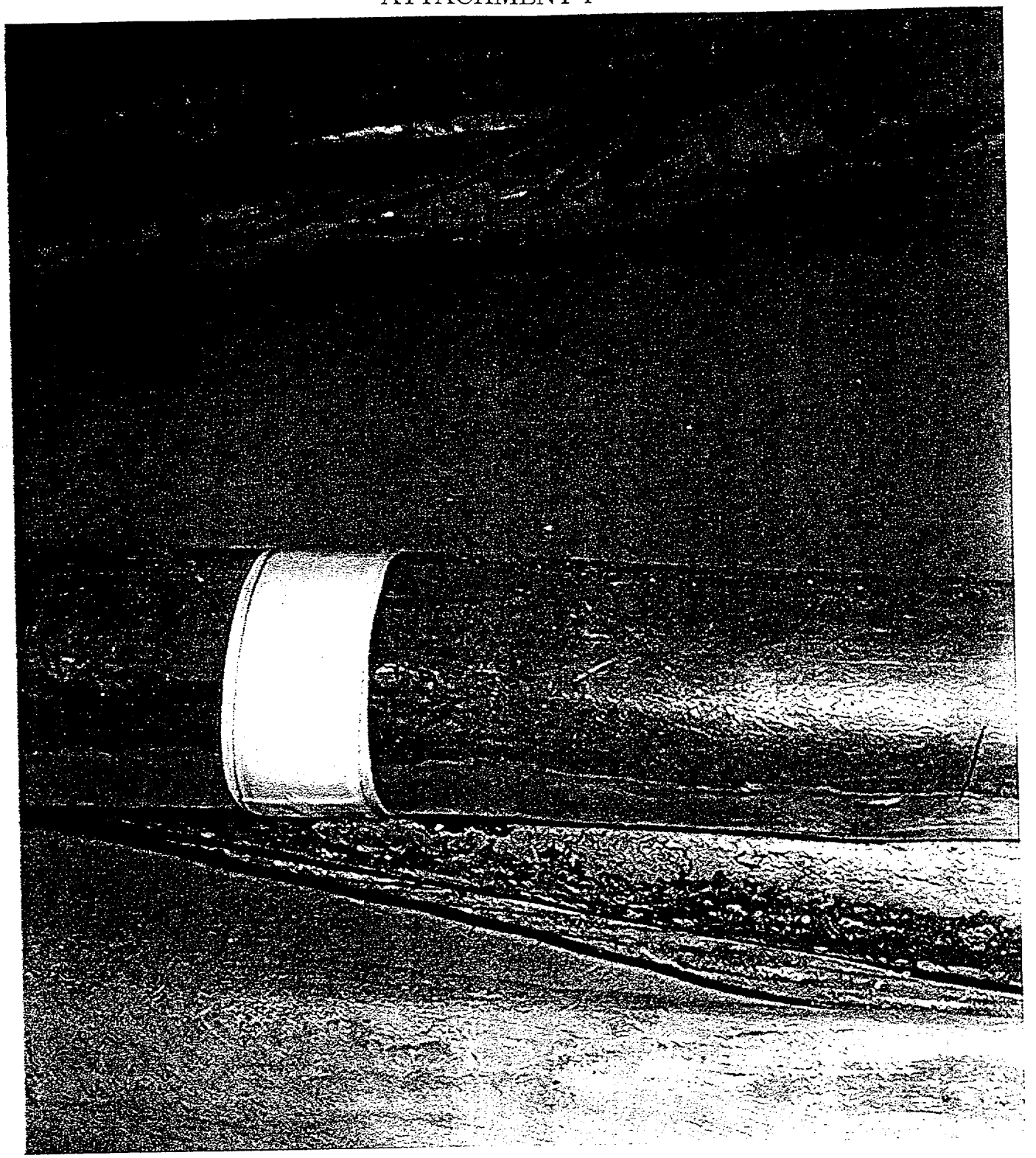
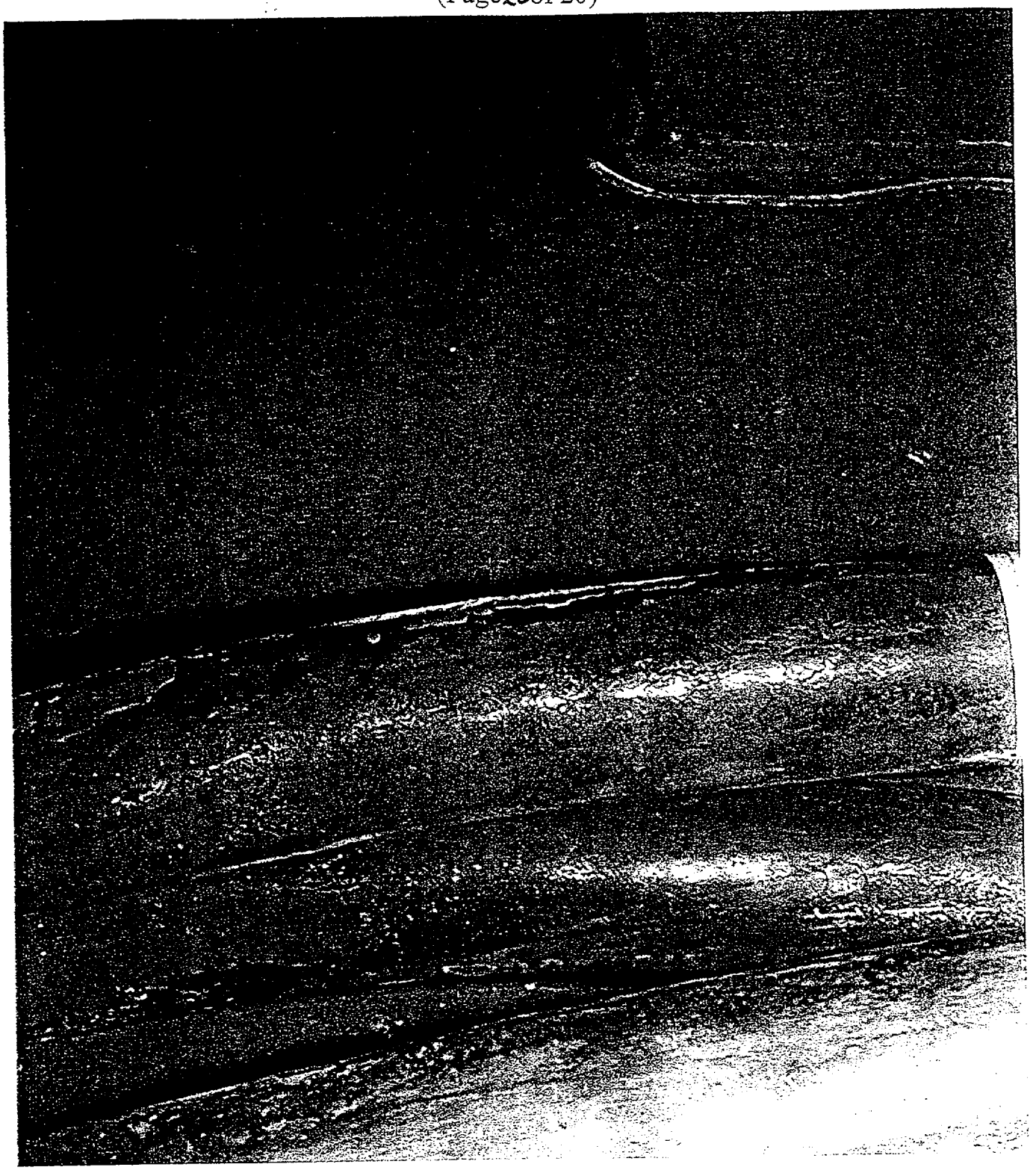
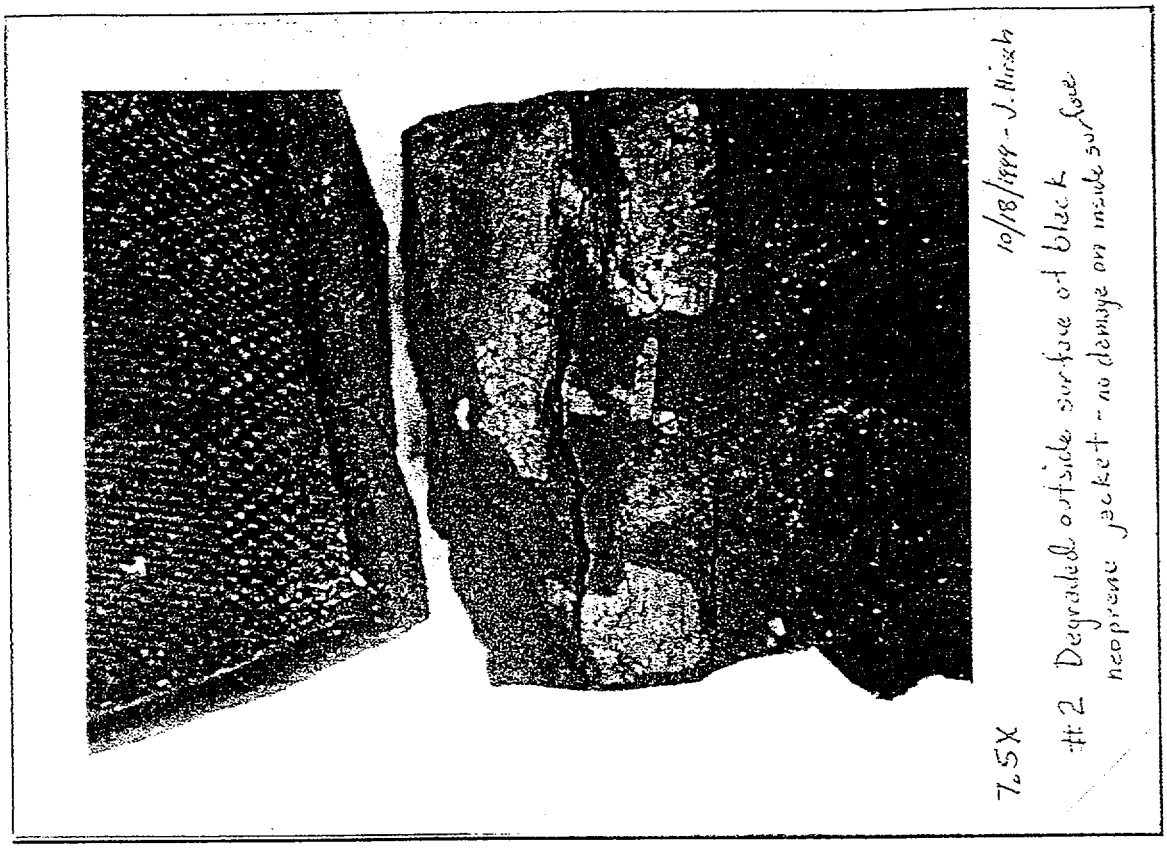
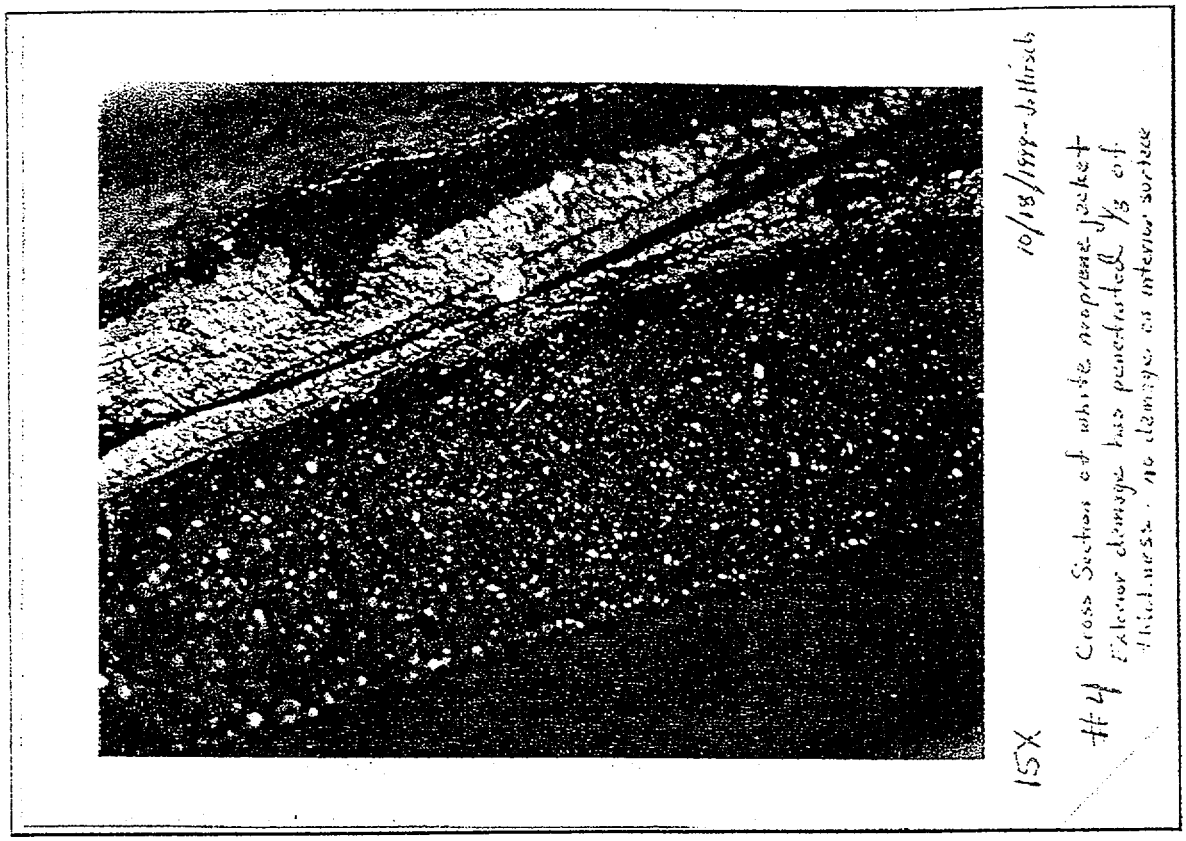






This piece was broken in half to view both the interior and exterior surfaces. The black neoprene jacket was severely carbonized on the exterior surfaces yet the interior surface does not show any signs of damage.



This is a cross section from the white neoprene cable removed from a damaged area. The carbonization damage has effected the outer layer traveling about a third of the way through the neoprene jacket. The interior surface of the jacket was not effected.

Outer neoprene jacket is hardened with a loss of elasticity. Flexing the material results in cracking and breaking due to its brittle nature. This piece was removed in a section adjacent to a damaged area where the neoprene was carbonized.

15X

#3 Copper based salt deposits on exterior surface of black neoprene jacket

10/18/1999-J.Hirsch

This was removed from a damaged area (carbonized) on the black cable. The exterior neoprene contains a layer of copper salts. The copper ground cable in this area was severely corroded.

ATTACHMENT III

LAB. NO. M99175
DB CABLE FAILURE

TEST PROGRAM

TEST STEP		TEST DESCRIPTION	PERFORMED BY	STATUS
A		VISUAL EVALUATION OF THE CABLE.		
	1	Photograph the damaged areas	TMK, BVW	Done
	2	Electrical test to identify the damaged cables.		Done
	3	Electrical test to identify the area of fault on the cables		Done
B		SEARCH FOR THE FAULTED AREAS		
	1	Cut out: a) identified in previous step fault areas, b) areas from the ends of the cables without visible damage (areas which have not been in the PVC conduit)	TMK, BVW	Done
	2	Disassemble cut out portion of the cable registering each step of the process by photographing. The goal is to identify the faulted areas and to establish the mode of failure	TMK, BVW	Done
C		PROPERTIES OF THE CABLE PARTS		
	1	Identify the jackets' material (neoprene and EPR)	JLH	
	2	Cut out part of the ground wire – corroded and visibly intact. Evaluate: a) microstructure of the copper wire b) contaminants on the surface by means of EDX	AM, MSB	Done
	3	Evaluate mechanical properties in tension of: a) outside neoprene jacket taken from the ends of the cable b) EPR taken from damaged and visibly undamaged areas (areas which have not been in the PVC conduit)	BVW	Done
	4	Evaluate the mode on the neoprene deterioration – chemical or heat	JLH	In progress
	5	Identify the presence of the contaminants by EDX on: a) neoprene jacket b) on the surface of the conductor wire	AM	Done

ATTACHMENT IV
(Page 1 of 2)

DAVIS BESSE 5KV CABLE TEST –10 / 11 / 99

1) Megger Test of Black Cable :

Voltage	Megohms
500 v	3500
1000 v	3000
1500 v	2700
2000 v	2500
2500 v	2400

2) DC Test of Black Cable :

Test consisted of one Minute Voltage Steps

Test Set – AR 50 KV DC Test Set

Voltage	Leakage Current (microamps)
1000 v	.2
1500 v	.3
2000 v	.5
2500 v	.6
3000 v	.7
3500 v	1.0
4000 v	1.4
4500 v	1.9
5000 v	1.9
5500 v	TEST SET TRIPPED OFF -- CABLE FAULTED

Using a BIDDLE IMPULSE 30 KV TEST SET at a Discharge of 6 KV --- The Cable Fault was isolated to a 1 foot portion of the 250' length.

3) DC Test of Red Cable :

Voltage	Leakage Current (microamps)
1000 v	.1
1500 v	.1
2000 v	.1
2500 v	.1
3000 v	.1
3500 v	.1
4000 v	.2
4500 v	.3
5000 v	.5
5500 v	.8
6000 v	1.8
6500 v	8.0
7000 v	TEST SET TRIPPED OFF --- CABLE FAULTED

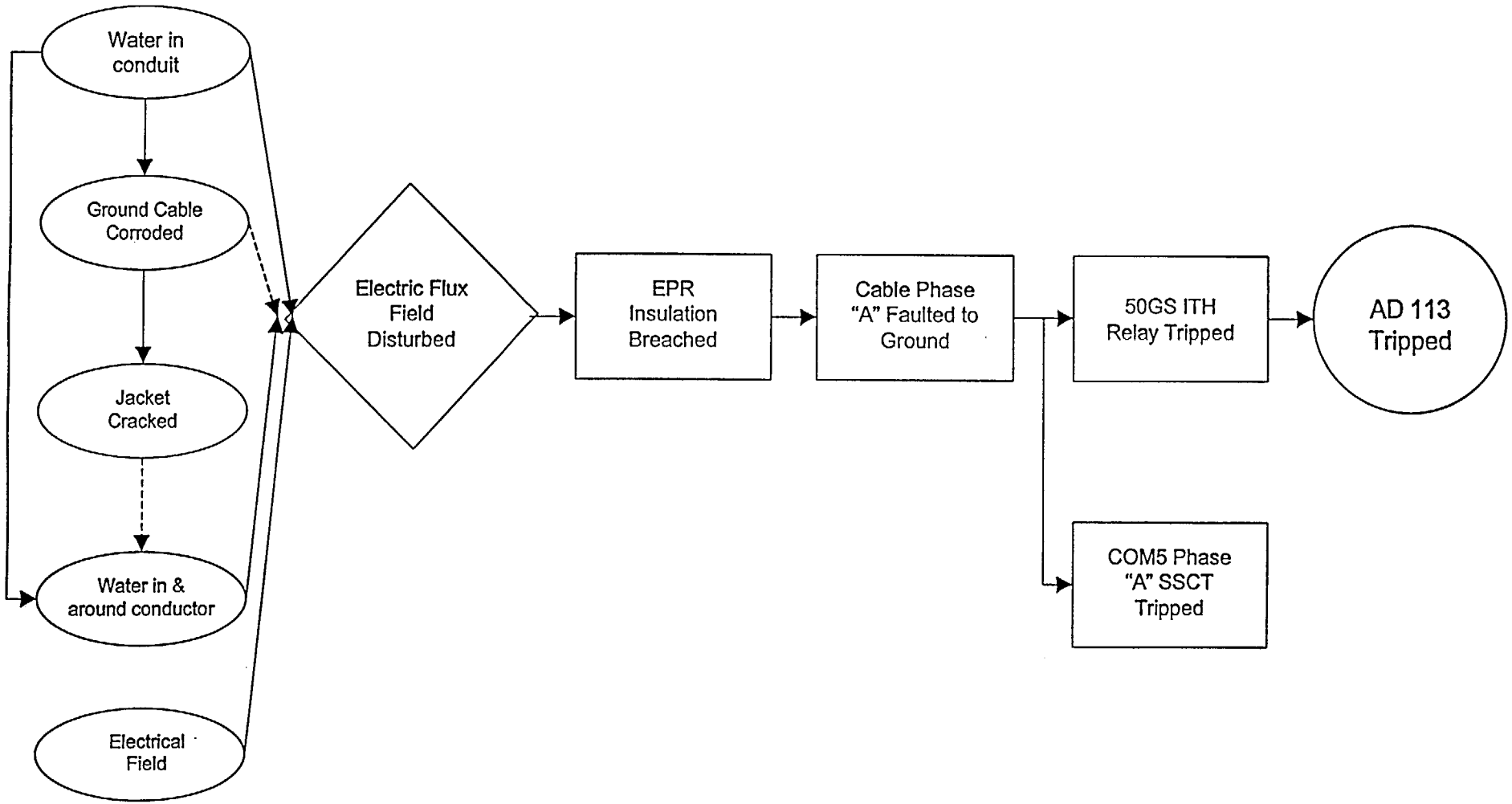
Using the BIDDLE IMPULSE SET also at a Discharge of 6 KV --- The Cable Fault was isolated to a 1 foot portion of the 250' length. The Red Cable Fault was approx 20' away from the Black Cable Fault.

4) DC Test of White Cable :

Voltage	Leakage Current (microamps)
1000 v	.1
1500 v	.1
2000 v	.1
2500 v	.1
3000 v	.1
3500 v	.1
4000 v	.1
4500 v	.1

ATTACHMENT IV
(Page 2 of 2)

5000 v	.1
5500 v	.1
6000 v	.1
6500 v	.1
7000 v	.1
7500 v	.1

TEST WAS COMPLETED ---- CABLE DID NOT BREAK DOWN UNDER THIS TEST

ATTACHMENT V. - EVENTS AND CAUSAL FACTOR CHARTING FOR EQUIPMENT PERFORMANCE