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**GEND-INF-023**

Volume I

June 1982



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**GEND**

General Public Utilities • Electric Power Research Institute • U.S. Nuclear Regulatory Commission • U.S. Department of Energy

Investigation of  
Hydrogen-Burn Damage  
In the Three Mile Island  
Unit 2 Reactor Building

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

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GEND-INF--023 Vol. 1

DE82 018639

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INVESTIGATION OF HYDROGEN-BURN DAMAGE IN  
THE THREE MILE ISLAND UNIT 2 REACTOR BUILDING

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Published June 1982

Prepared by Lawrence Livermore National Laboratory  
for the Nuclear Regulatory Commission  
Under Fin A0406  
and by EG&G Idaho, Inc. for the U.S. Department of Energy  
Under Contract No. DE-AC07-76ID01570

Technically edited and published  
on behalf of the GEND group by:  
EG&G Idaho, Inc.  
U.S. Department of Energy  
Idaho Operations Office  
Under DOE Contract No. DE-AC07-76ID01570

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## ABSTRACT

About 10 hours after the March 28, 1979 Loss-of-Coolant Accident began at Three Mile Island Unit 2, a hydrogen deflagration of undetermined extent occurred inside the reactor building. Examinations of photographic evidence, available from the first fifteen entries into the reactor building, yielded preliminary data on the possible extent and range of hydrogen burn damage. These data, although sparse, contributed to development of a possible damage path and to an estimate of the extent of damage to susceptible reactor building items. Further information gathered from analysis of additional photographs and samples can provide the means for estimating hydrogen source and production rate data crucial to developing a complete understanding of the TMI-2 hydrogen deflagration.

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INVESTIGATION OF HYDROGEN BURN DAMAGE IN  
THE THREE MILE ISLAND UNIT 2 REACTOR BUILDING

BACKGROUND

About 10 hours after the March 28, 1979 Loss-of-Coolant Accident began at Three Mile Island Unit 2 (TMI-2), a pressure spike of nearly 30 psi and associated high temperature indications, along with some pertinent gas readings, indicated that a sudden, brief hydrogen burn (or "deflagration") of undetermined extent occurred in the reactor building. Photographs taken during preliminary entries into the TMI-2 reactor building showed some thermal damage to polymeric materials at apparently random locations throughout the reactor building. Indications of overpressure were also noted. In subsequent entries, photographers attempted to record as much thermal damage as they could conveniently observe while performing other assigned duties.

Fifteen entries into the TMI-2 reactor building were made in the period between the accident and October 1981. Photographs and video recordings from these entries were displayed at a variety of conferences and meetings; however, lack of personnel and a necessary commitment to radiation surveys and decontamination studies did not allow for ordering of photographic data to best display patterns of thermal damage. Such patterns, if any, may reveal spatially distributed thermal exposure information and thermal exposure intensity, ascertained from the degree of damage to the exposed item.

The Fire Science Group of the Hazards Control Department at Lawrence Livermore National Laboratory (LLNL) contracted with the Nuclear Regulatory Commission (NRC) to conduct a preliminary analysis of existing photographs of thermally damaged materials in the TMI-2 reactor building. From this survey, we attempted to define spatial distribution and extent of thermal damage to susceptible reactor-building items. We also were asked to recommend further work that could increase the accuracy of estimates of hydrogen deflagration intensity for the purpose of estimating hydrogen concentration range in the reactor building just prior to the deflagration.

Hydrogen concentration and distribution are not defined in this report. Because actual accident pressure and temperature data are uncertain, interpretations of hydrogen distribution in the building just prior to the burn vary widely. To reduce the variance in interpretations of hydrogen distribution, more photographs and actual samples need to be analyzed. Such information may provide means to estimate hydrogen source and production rate data. This report examines photographic evidence from the first 15 reactor building entries and suggests a preliminary pattern of burn and overpressure damage throughout the TMI-2 reactor building.

## APPROACH

Our approach was to segregate and organize existing photographs into categories where the pictures showed: (a) items that definitely exhibit effects of thermal exposure (charred, sooted, melted, thermally relaxed, blistered, discolored, and embrittled items); (b) items susceptible to--but not exhibiting--thermal damage; (c) items not susceptible to thermal damage at temperature levels found in fires and explosions (we deleted these photographs from our analysis); and (d) items that exhibit "blast" or overpressure damage.

Preliminary photographs received at LLNL from the NRC contained only a portion of those available at TMI. To expedite progress, two members of the Fire Science Group staff traveled to the Department of Energy (DOE) Technical Integration Office (TIO) at TMI to survey their file of photographs and schematics, and to construct preliminary thermal damage distribution maps.

As we sorted and organized photographs, we plotted positions of thermal damage on plan view schematics of the reactor building levels. Before we left TMI, we developed a list of items to be either photographed in detail or removed for critical inspection. This list appears in Appendix A. We also developed a list of data which pertain to formation of explosive or flammable mixtures of hydrogen and air. This list appears in Appendix B. Upon returning to LLNL, we constructed an approximate scale model of the reactor building interior using polystyrene foam. Thermal and blast damage locations were transcribed from schematics to the model to better illustrate spatial location of damage. The model was transported to DOE Headquarters on November 9, 1981 to help illustrate the thermal damage spectrum for a meeting pertaining to analysis of the TMI-2 hydrogen reaction. After the meeting the model was taken to TMI-2 so that damage data from subsequent reactor building entries could be added to existing patterns.

## INVESTIGATION OF DAMAGE PHOTOGRAPHS

Figures 1 through 30 picture overpressure and thermal damage to components and items at various locations in the TMI-2 reactor building.

### Overpressure Damage

Figures 1 through 5 show overpressure damage in the reactor building. Most overpressure damage was in the vicinity of the elevator and enclosed stairwell complex on the 305- and 347-foot elevations. Since no other photographed region of the reactor building showed any overpressure damage (e.g., crushing of switch boxes, collapse of hermetic enclosures, light bulb or fluorescent light breakage, translation or knocking over of untethered items) we conclude that forceful overpressure was localized to interior elevator and stairwell locations and nearby regions.

Figure 1 shows apparently crushed barrels (content unknown) found on both sides of the elevator and enclosed stairwell complex on the 347-foot elevation. Such damage could result from a pressure pulse, or possibly from heating followed by rapid cooling. Other items in proximity did not appear displaced (except for fallen circumferential bus bars from the reactor building polar crane). Pending closer examination, the cause for barrel distortion will remain undefined.

A floor plate in front of the air coolers on the 305-foot elevation was displaced from its normal position, thus indicating a slight overpressurization pulse in the basement region below the 305-foot elevation. The elevator and enclosed stairwell complex is open to the basement level so that the overpressurization pulse that caused elevator and stairwell door distortion may be related to displacement of this floor plate.

### Thermal Damage in the Polar Crane Region

Figures 6 through 13 show thermal damage to the polar crane: charred and melted bus bar insulation; charred and embrittled labels and hosing; burned seat cushions; and blistered, peeled, and charred ceiling paint.

Bus bar insulation uniformly melted and charred along the polar crane bus complex. Control cab upholstery sustained substantial and uniform burn damage. Paint flaking off walls was concentrated at each end of the crane. Edges of separated paint charred in some areas.

The polar crane festoon and control pendant sustained charring along its entire length. According to one of the authors of this report, control pendant charring existed as far down the pendant line as he could see. However, thermal damage was not noted at the pendant control end at the top level of the D-ring personnel shield.

Dislocation of conductors from the circumferential bus bar ring was most evident at the polar crane ends, and may have been caused by thermal relaxation of insulation "stand-offs." Charring of bus insulation was obvious on the bus bars which fell to the 347-foot elevation floor from circumferential attachments across the south end of the reactor building. Char patterns on the fallen bus bars appear the same as those on the bus insulation retained on the overhead circumferential bus bar ring. Thus, we assume that thermal damage was sustained before the bus bars fell to the 347-foot elevation.

Thermal damage to polar crane components appears relatively uniform. Reviewed photographs showed no apparent shadowing or shielding effects, as though all burned and melted materials were engulfed in flame or hot gas for a short period. No evidence of a pressure pulse was found on polar crane components; the crane is designed to sustain overpressure conditions.

#### Possible Hydrogen Dispersal Mechanisms in the Polar Crane Region

Reaction of a hydrogen and air mixture in the polar crane region was apparently uniform, and possibly was constrained to circulation patterns created by cooling fan flow directions. Two loss-of-coolant accident (LOCA) vents<sup>a</sup> convey a major portion of cooling system air to overhead

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a. LOCA vents provide a discharge path for the air coolers. LOCA dampers, which control flow to the LOCA vents, open in the presence of a high containment-pressure signal (3.58 psig).

regions of the reactor building on the south wall. (Both vents were to the right side of the polar crane position during the accident.) Circulation patterns during normal cooling operations draw air from the 305-, 347-, and 282-foot elevations and exhaust through the D-rings (personnel shields). During the accident the LOCA vent dampers were automatically opened following reactor building isolation. Since no record exists of operators manually closing the LOCA vent dampers, efflux from the air coolers was directed through the LOCA dampers and discharged to the upper containment regions during much of the accident sequence. Cooling fan flow directions may account for burn patterns on the crane, and also on the 347-foot elevation of the reactor building.

#### Thermal Damage on the 347-foot Elevation

Burn patterns on materials located on the south half of 347-foot elevation and the top of D-ring do not define whether thermal radiation or direct flame contact was responsible for observed thermal damage. Figures 14 through 28 show examples of burning and melting that could be caused by either flame contact, convection from high temperature gas, or thermal radiation from burning hydrogen and air remote from the damage.

Intensity of thermal damage appears to be uniform toward the south half of the reactor building and between the D-rings. Char patterns on the scaffolding on the head alignment tool, and charring of the exposed surface of the plywood backing of the telephone stand attached to the south wall, along with softening of telephone plastic and the apparent burn pattern on telephone lines, indicate heat exposure sufficient to raise material temperature several hundred degrees Celsius. Fire consumed maintenance manuals and plastic light covers.

Uniform thermal damage to a plywood box next to the northeast arc of the east D-ring and melted polymers on the east side of the reactor building contrast sharply with lack of thermal damage to the extension of the open stairwell "chicken wire" support, a wood 2 x 4 inch frame which restricts access to the top of the west D-ring. Similarly, the partially burned manual on the north containment wall (Figure 17) appears to be the



most westerly extension of thermal damage along the north containment regions, since undamaged fabric items were observed next to the northeast limit of west D-ring.

Figures 25 through 28 show thermal damage and burning of auxiliary fuel handling bridge control buttons, and burning of manuals on the deck next to the north side of the control panel. Thermal intensity appears to be similar to that of the south reactor building area. The control and power cable festoon exhibit thermal damage to insulation on the side away from the wall (Figure 27), indicating a relatively uniform exposure in the region between the D-rings.

#### Total Surface Heat Exposure at a 347-foot Elevation Location

Our preliminary estimates lead us to believe that in at least one area of the reactor building, the total surface heat exposure or heat flux during the accident was greater than  $3 \text{ W/cm}^2$  ( $9500 \text{ BTU/hr-ft}^2$ ). In estimating possible total surface heat exposures we studied the charred scaffolding shown in Figures 14 and 15. The minimum charring temperature for such wood is around  $300^\circ\text{C}$ , and the minimum total surface heat exposure, or heat flux, required to produce the charring is  $3 \text{ W/cm}^2$ . We assumed that the scaffolding was probably covered with polyethylene film (an assumption based on the patterns of the variations in the char and the presence of adhesive tape), so the polyethylene had to melt before the wood could char. At a minimum heat flux of  $3 \text{ W/cm}^2$ , this polyethylene-covered board would take hundreds of seconds to char. However, since accident records indicate the hydrogen burn did not last for hundreds of seconds, but rather for tens of seconds, total heat flux near the charred scaffolding had to be greater than  $3 \text{ W/cm}^2$  in order to produce the observed damage.

#### Thermal Damage on the 305-foot Elevation

Figure 29 shows one of the only indications of possible thermal damage on the 305-foot elevation level. Here the telephone cord relaxed and may exhibit some charring on the front surface. The control buttons for the

elevator were also thermally deformed. However, a wooden stepladder to the left of this telephone had no thermal damage. Figure 30 shows undamaged shoring wood located in the northwest area of the 305-foot elevation.

## PRELIMINARY DAMAGE PATTERN ESTIMATES

Figures 31 through 33 are photographs of the styrofoam model on which damage patterns were plotted according to photographs from the first 15 reactor building entries. This model currently resides at the EG&G Idaho site office at TMI. New information about thermal and overpressure damage recorded during subsequent reactor building entries is being added to the model to increase the accuracy of the damage pattern.

Very tentative patterns can be proposed with the limited information available to this analysis. While much more information is required before credence can be given to interpretations of thermal or overpressure damage, we do offer the following preliminary estimates based on our data.

1. Blast or overpressure damage appears to be localized in regions around the elevator and enclosed stairwell complex. More indications of blast damage may exist in basement regions which, because of radiological hazards, have not yet been surveyed.
2. Thermal damage to polar crane components appears uniform. Discharge of the air coolers through the LOCA ducts may have been a primary dispersal mechanism of hydrogen and air to the polar crane region. No evidence of overpressure damage was found on polar crane components.
3. Thermal damage on the 347-foot elevation exists in north, east, and south quadrants, while none is found in the west quadrant behind the D-ring. These patterns may follow flow paths developed by discharge of the air coolers through the LOCA ducts.
4. Photographs of the 305-foot elevation indicate no thermal damage in that area. Thermal damage to the telephone cord and elevator buttons could have resulted from hot gas emission from the distorted elevator and stairwell doors.

Much more information will be required before the full extent and range of the hydrogen burn during the accident is understood. Further close examination of various thermally-damaged items located in southern areas of the 347-foot elevation might allow a better estimate of exposure intensity than is now available. Appendix A lists specific recommendations for further data acquisition required to support a more complete hydrogen burn damage assessment.

Studying such fine fuels as thin films, paper, cloth, and thin insulated wire which respond to constant energy exposure in predictable ways relative to their composition and geometry could yield more precise data on the burn. Another strategy to further define exposure conditions is to attempt to duplicate the thermal damage in a laboratory with a reasonable set of experimental sources. As more information of this nature is gathered, investigators can compile a more complete set of facts with which to understand the full nature and extent of hydrogen burn damage at TMI-2.

APPENDIX A

RECOMMENDATIONS FOR DATA COLLECTION FROM  
TMI-2 TO SUPPORT HYDROGEN BURN DAMAGE ASSESSMENT





## APPENDIX A

### RECOMMENDATIONS FOR DATA COLLECTION FROM TMI-2 TO SUPPORT HYDROGEN BURN DAMAGE ASSESSMENT

#### 305-foot Elevation

1. Close-up of red telephone cord: especially look for char or melt on exposure surface
2. Door opening material; polyethylene foam
3. Any char or soot pattern on wooden stepladder
4. View of front of side stairwell door
5. Condition of plastic buttons around corner from red phone
6. Thickness and construction of elevator doors (both levels)
7. Construction description and natural ventilation of enclosed stairwell complex, i.e., major openings not including doors.

#### 347-foot Elevation

1. Plywood panel: Back surface appearance, edge appearance. Ascertain if black surface coat can be scraped off to clean wood; if so, estimate char depth.
2. Hemp rope near reactor coolant pump stand (east side vent duct). Status of burn evidence--function of height.

3. Condition of electrical conductors on polar crane, especially burn pattern on pendant.
4. Close-up of telephone cord from melted telephone behind indexing fixture. Appearance of wire insulation above metal bracket welded to reactor building containment wall east side of telephone stand.
5. 12 x 12 inch wood blocks supporting indexing fixture. Any evidence of polyethylene melt and possible wood char inside and outside of the ring.
6. Wood blocks near telephone stand south wall. Extent of polyethylene melt on sides; also, evidence of wood char.
7. Burn pattern of plastic-covered pipe or electrical conductor inside of head storage stand. Any char, melt, or burn of cotton wraps. Unburned regions as important as burned regions.
8. Description of 12 x 12 inch girder along southeast D-ring wall across from elevator. Char extent and polyethylene melt, if any.
9. Survey items hanging on reactor building wall that have good exposure to the seismic gap area. Divide the reactor building floor surface into 45° segments: note any common patterns at the seismic gap. Also photograph bus insulation fallen from polar crane to 347-foot elevation.
10. Survey D-ring wall hangings; look for same distribution as on reactor building wall. Here we need char or scot locations relative to positions on the reactor building surface.
11. Survey top of D-ring (cords, fire hose, rope, tags); look for melt evidence, char pattern, cord exposure, paint blistering. Look for same pattern as D-ring hangings.
12. Top of open stair cage: look for char, displace the 2 x 12 inch board, determine any polymer melting.

Polar Crane, by Telescope if Necessary

1. Detail of bus insulation and conductors along crane travel; detail all bus levels.
2. Survey of paint blister or other thermal damage along catwalk; include top and bottom orientation.
3. Directional (if any) blistering, melting, and charring on fire extinguisher.
4. Pattern of insulation on circumferential bus bars as far as can be observed from crane (top, bottom, inside, outside).
5. Paint flake on dome, especially parts that might have charred edges.
6. Investigation of cab--e.g., extent of seat and seat back burning. Any pattern to indicate rapid quench, e.g., "frozen melting" flow of plastic.
7. If feasible, check paint condition on vertical surfaces of box Girders A and B i.e., between the girders and on outboard girder surfaces.
8. Polar crane end carriages; to the wall and to the center surfaces. Look for paint bubbles and polymer degradation.



APPENDIX B

INFORMATION PERTAINING TO FORMATION OF  
COMBUSTIBLE MIXTURES OF HYDROGEN AND AIR





## APPENDIX B

### INFORMATION PERTAINING TO FORMATION OF COMBUSTIBLE MIXTURES OF HYDROGEN AND AIR

1. Relief valve operation history
2. Rupture disk operation history
3. Time of cooling fan start
4. Time of LOCA damper opening
5. Temperature rise on:
  - The 282-foot elevation
  - The 305-foot elevation
  - The 347-foot elevation
  - The polar crane
6. Specific humidity and ambient temperature on the 347-foot elevation prior to accident
7. Specific humidity at  $T_0 + 9$  hours on the 347-foot elevation
8. National Electric Code rating requirement in electric meters, etc.



Figures 1 through 5. Overpressure damage.



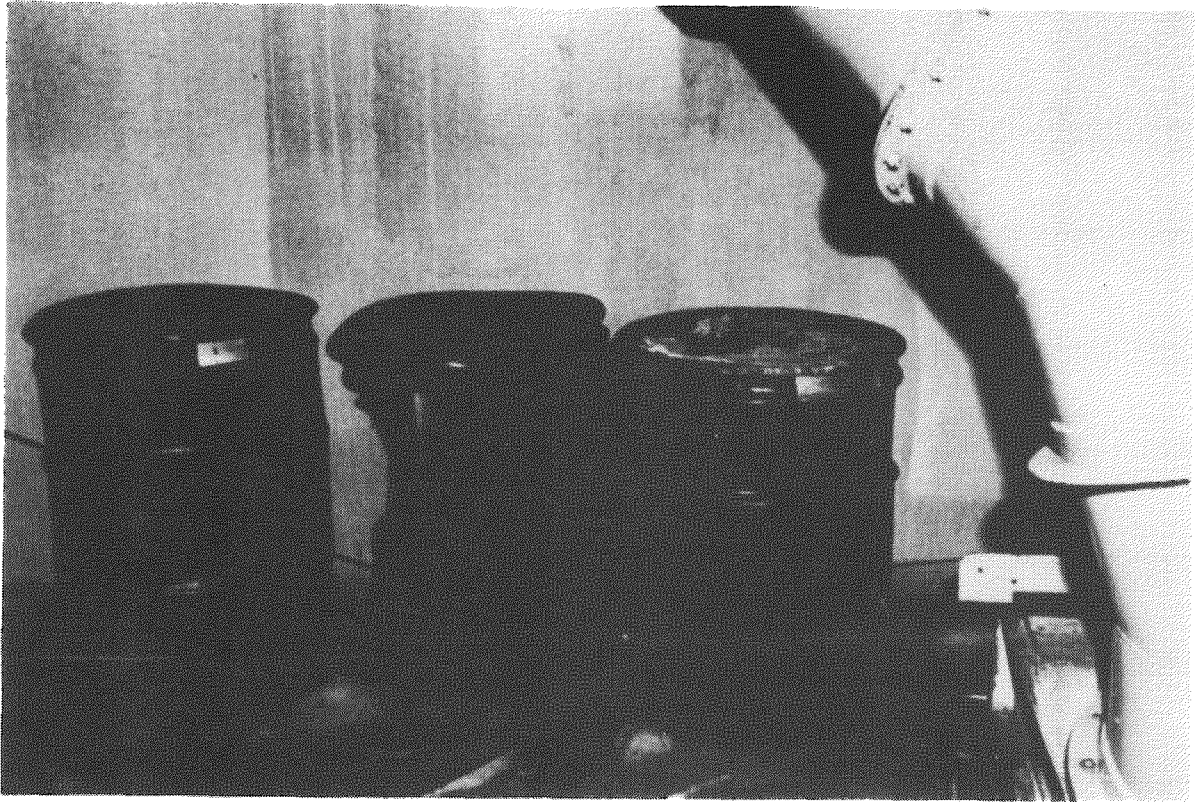


Figure 1. Crushed barrels near the elevator door and enclosed stairwell on the 347-foot elevation.

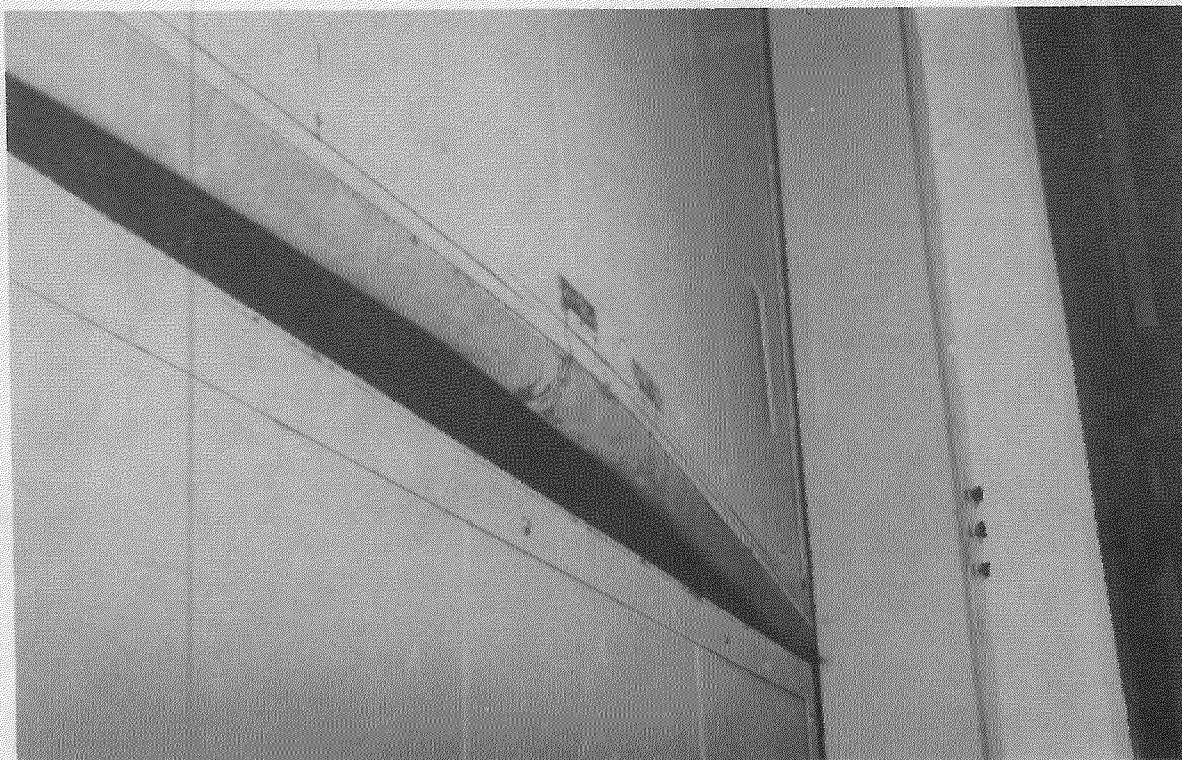


Figure 2. Elevator door on the 347-foot elevation indicating overpressure damage.





Figure 3. Enclosed stairwell door on the 305-foot elevation indicating overpressure damage.

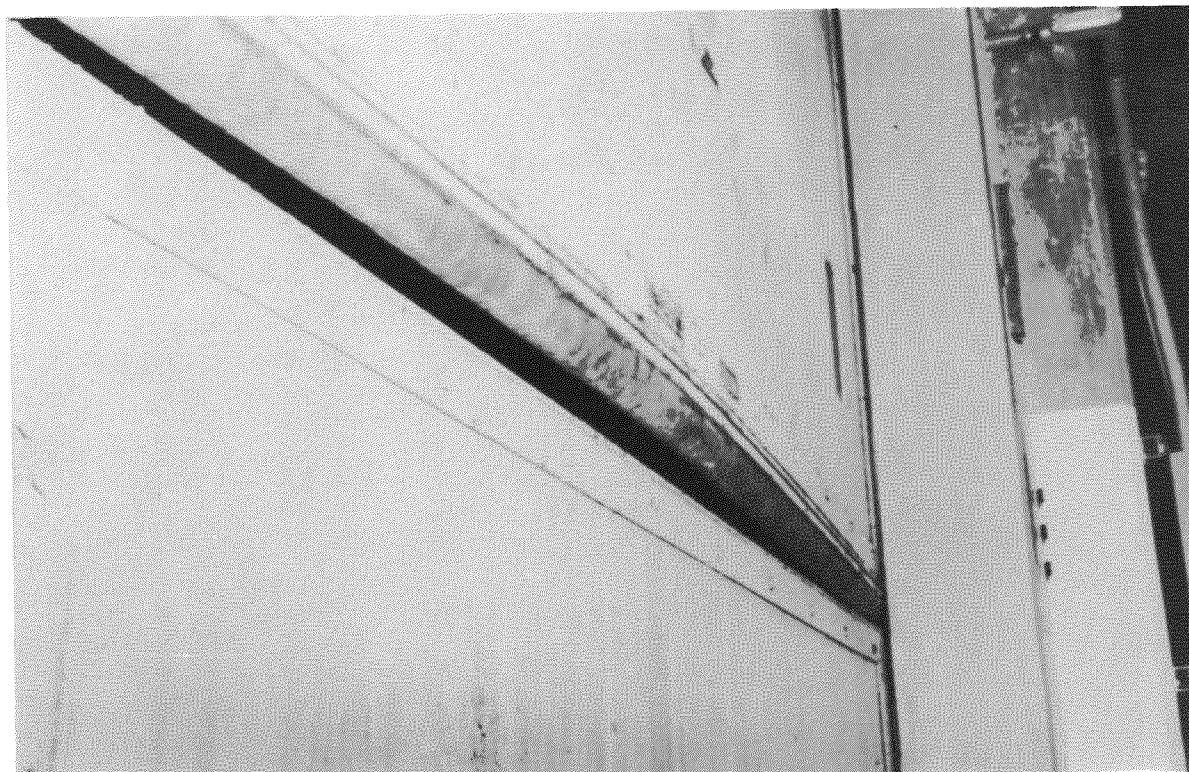


Figure 4. Elevator door on the 305-foot elevation indicating overpressure damage.



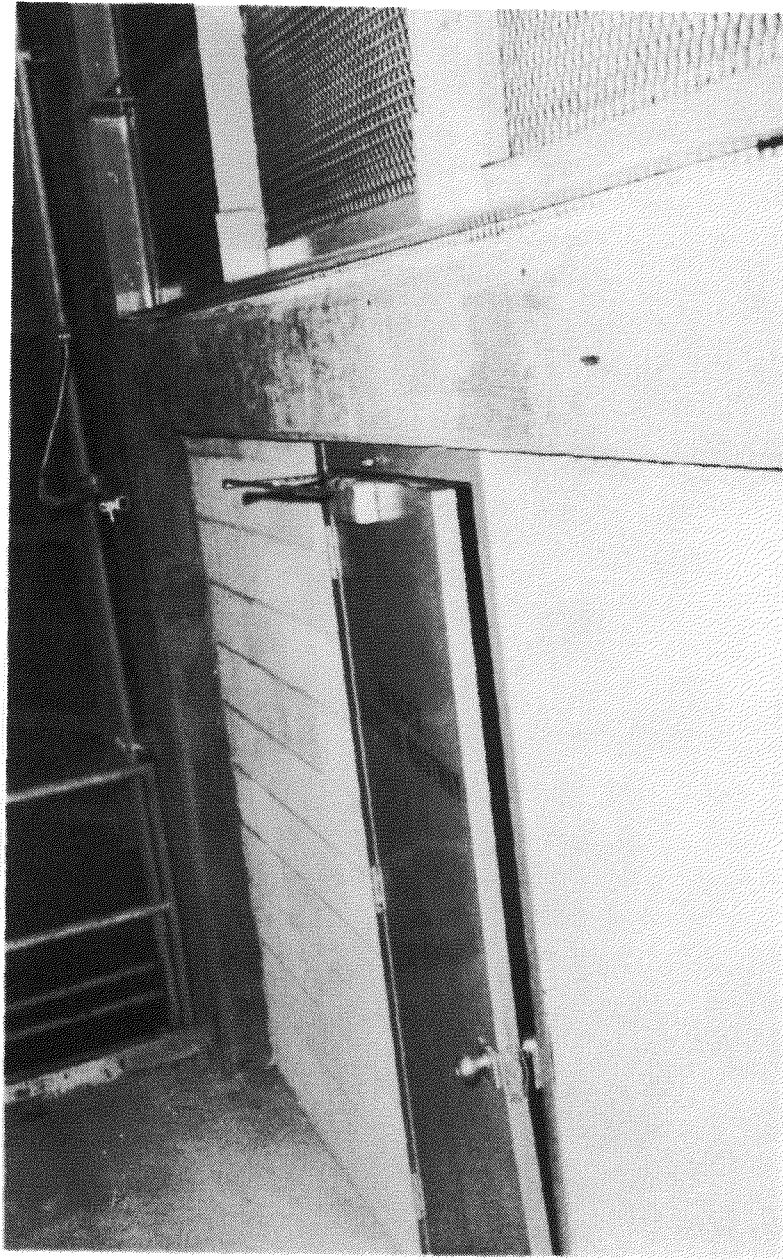


Figure 5. Door on 325-foot elevation with broken latch; door forced open by overpressure.



Figures 6 through 13. Thermal damage in the polar crane region.



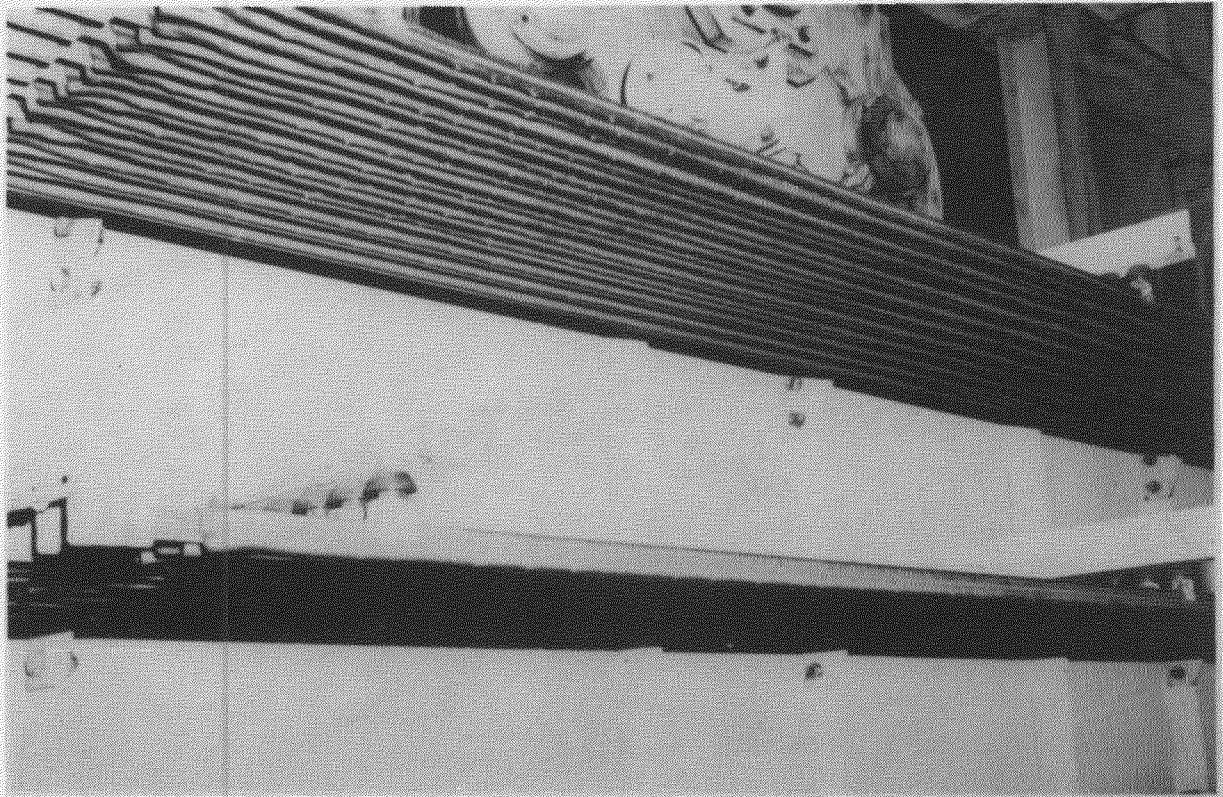


Figure 6. Burned and melted insulation on the polar crane bus bars.



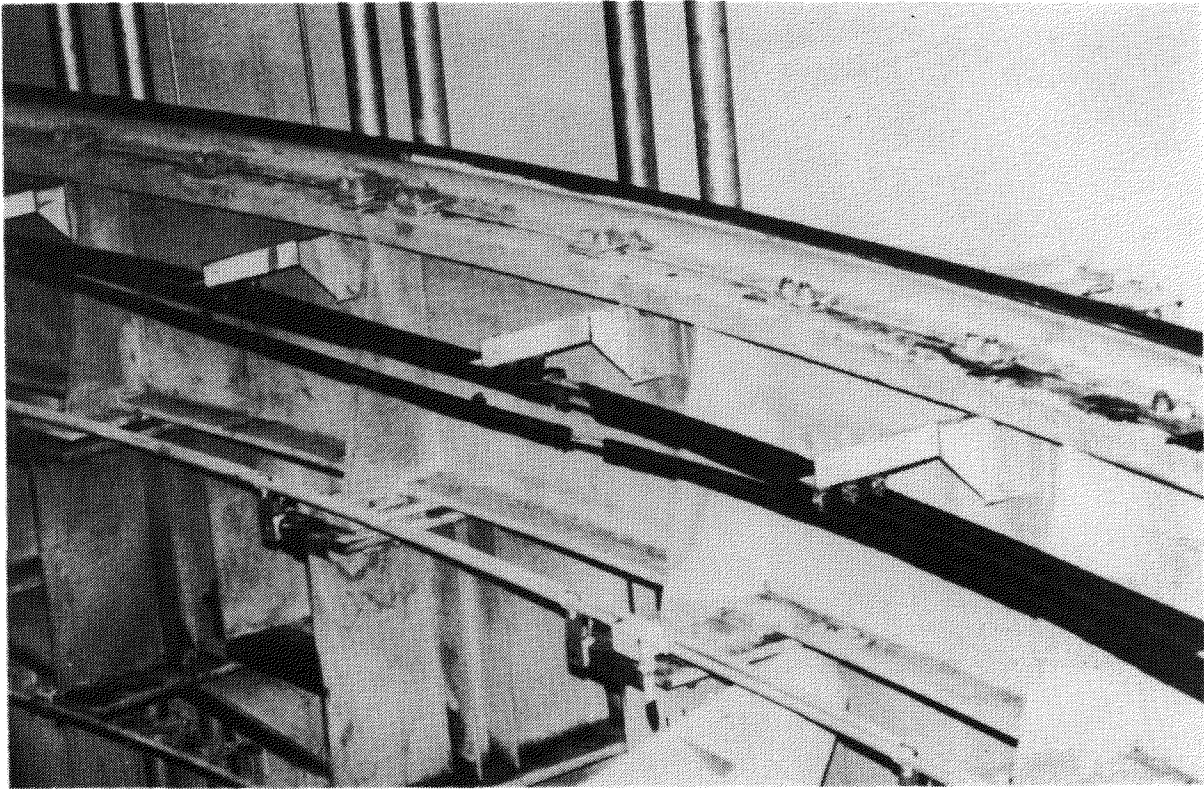


Figure 7. Charred insulation on the containment bus.

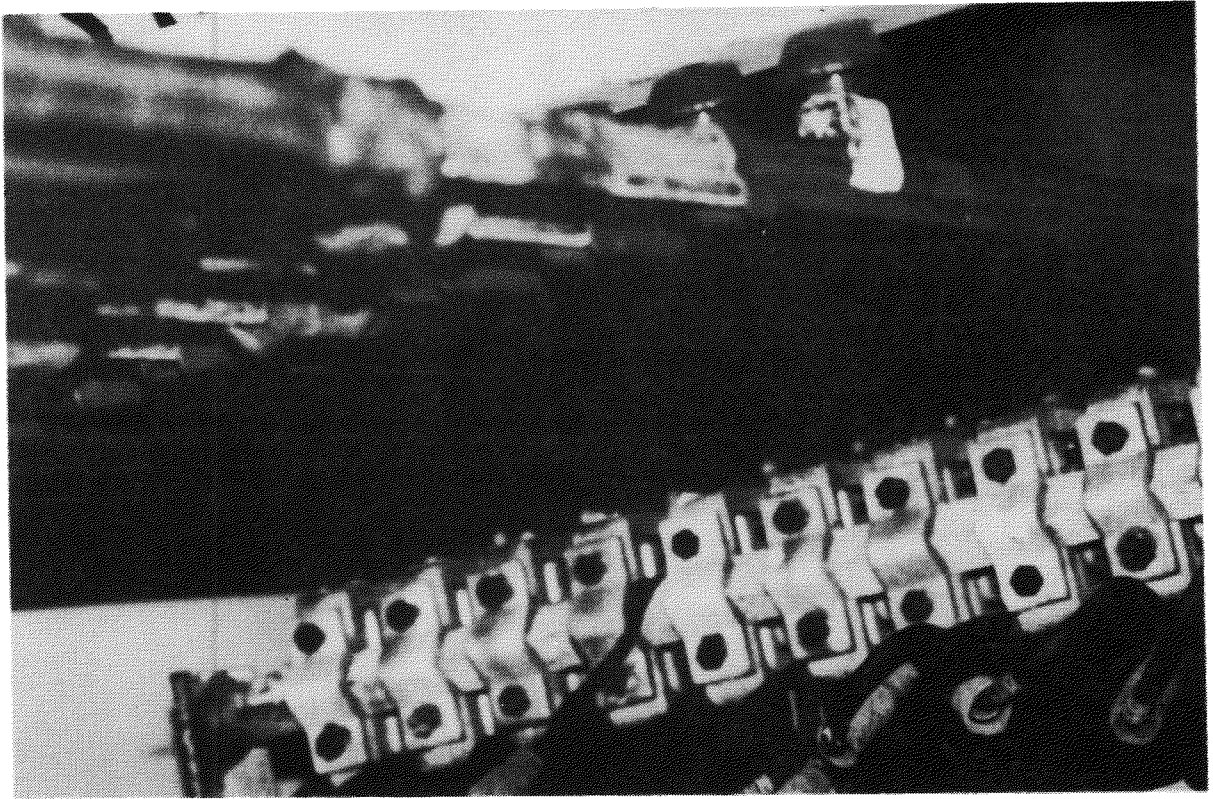


Figure 8. Damage to polar crane bus insulation.

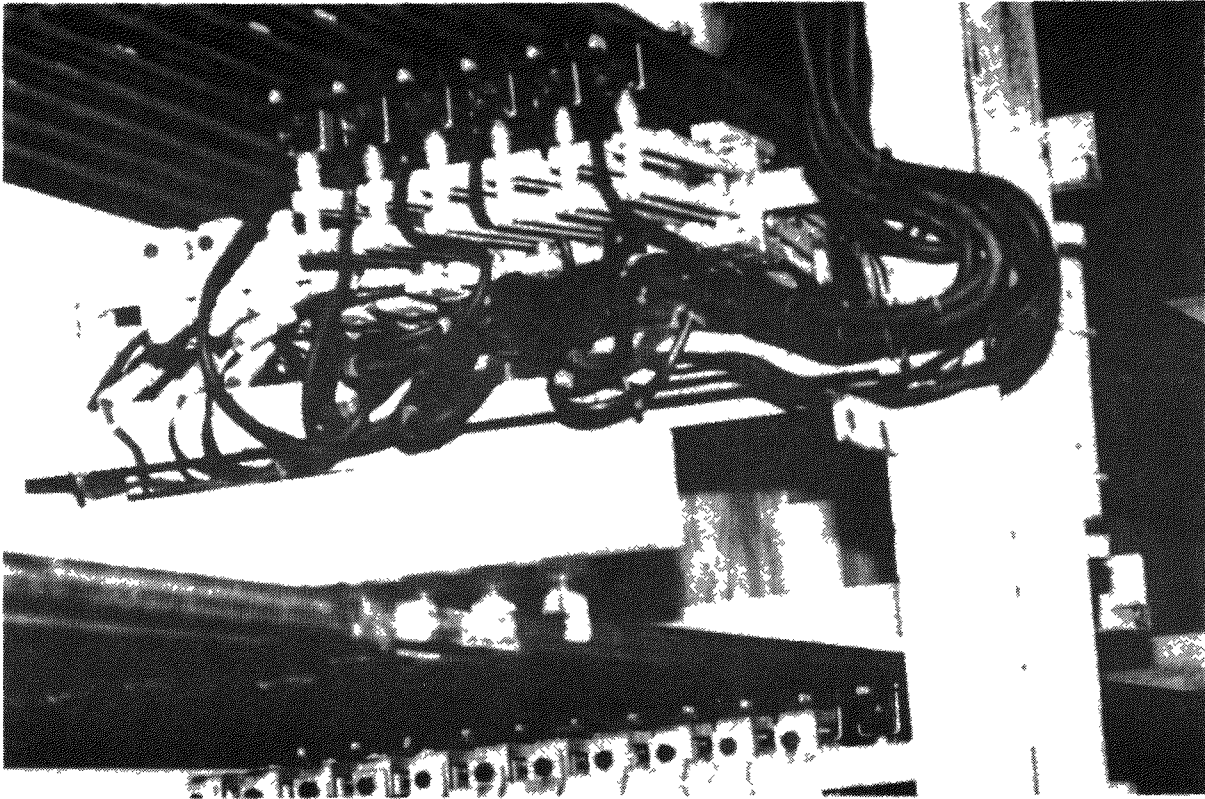


Figure 9. "Scalloped" damage to polar crane bus insulation; appears to decrease close to crane.



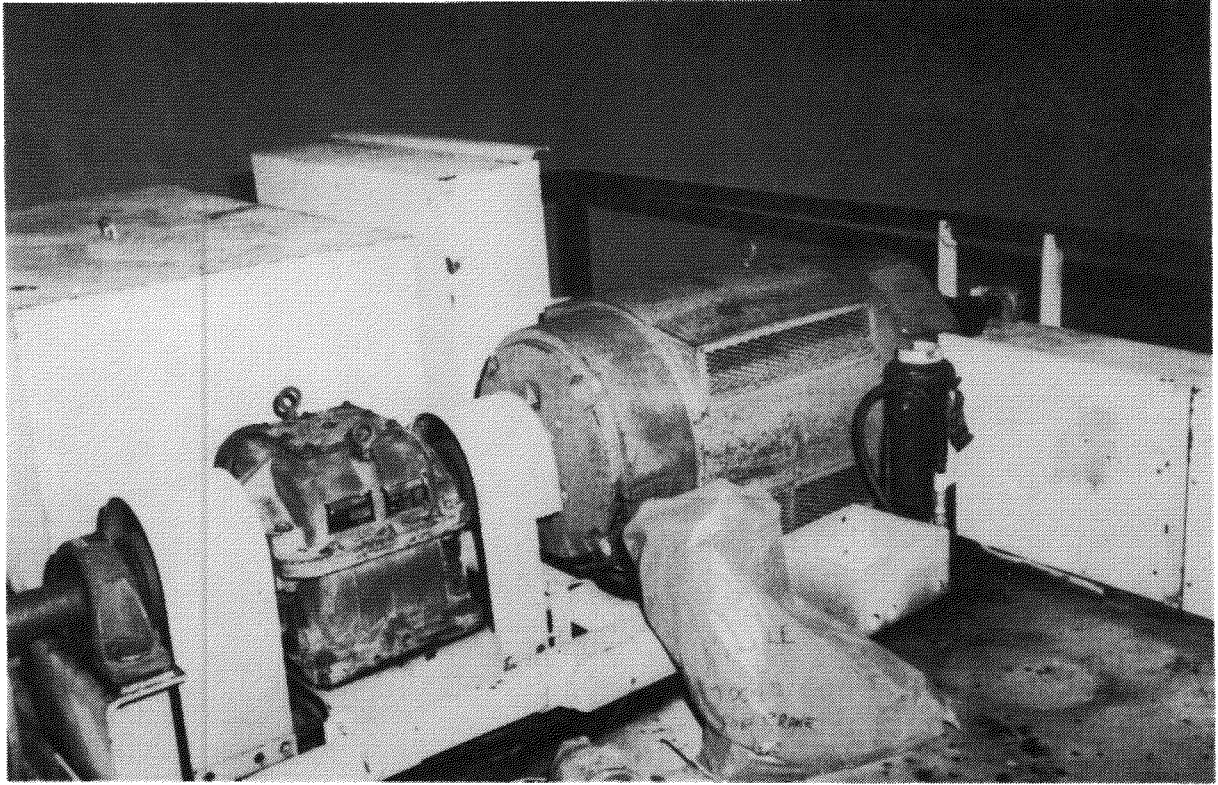


Figure 10. Charred hose and charred label on fire extinguisher.

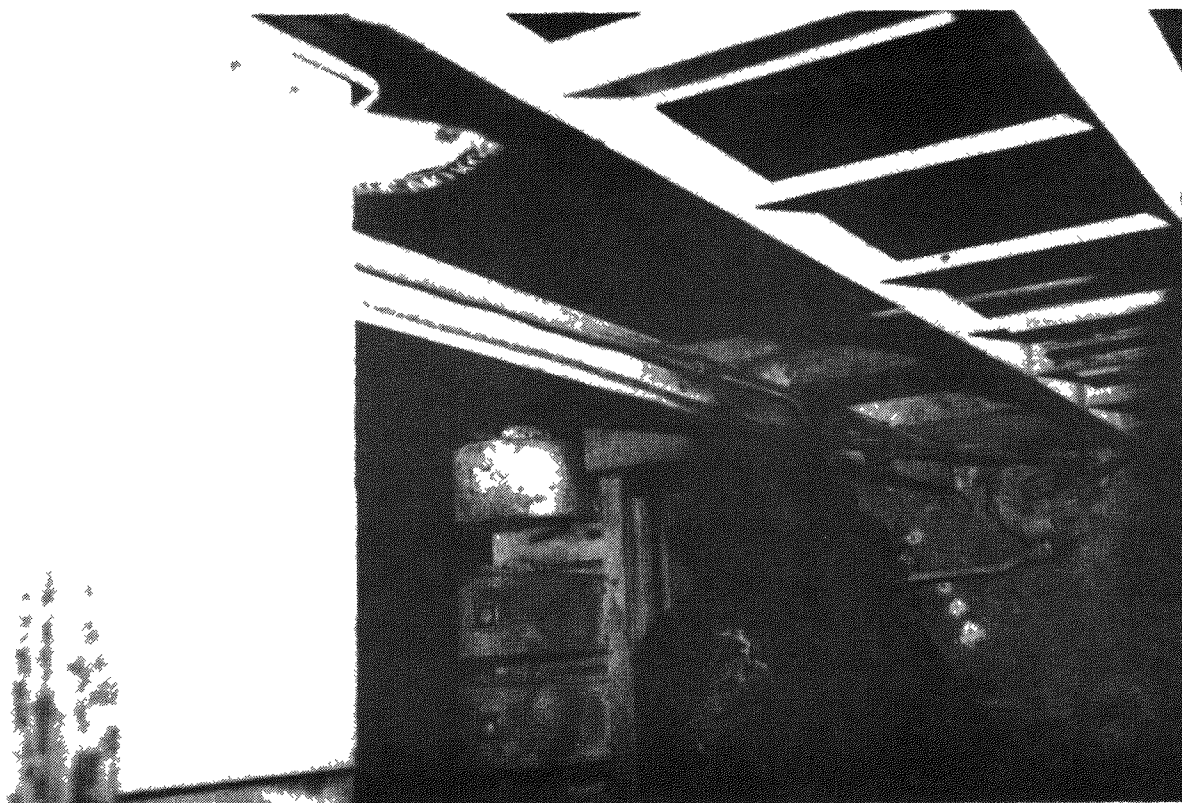


Figure 11. Burned operator's chair in crane control cab, looking down into cab.

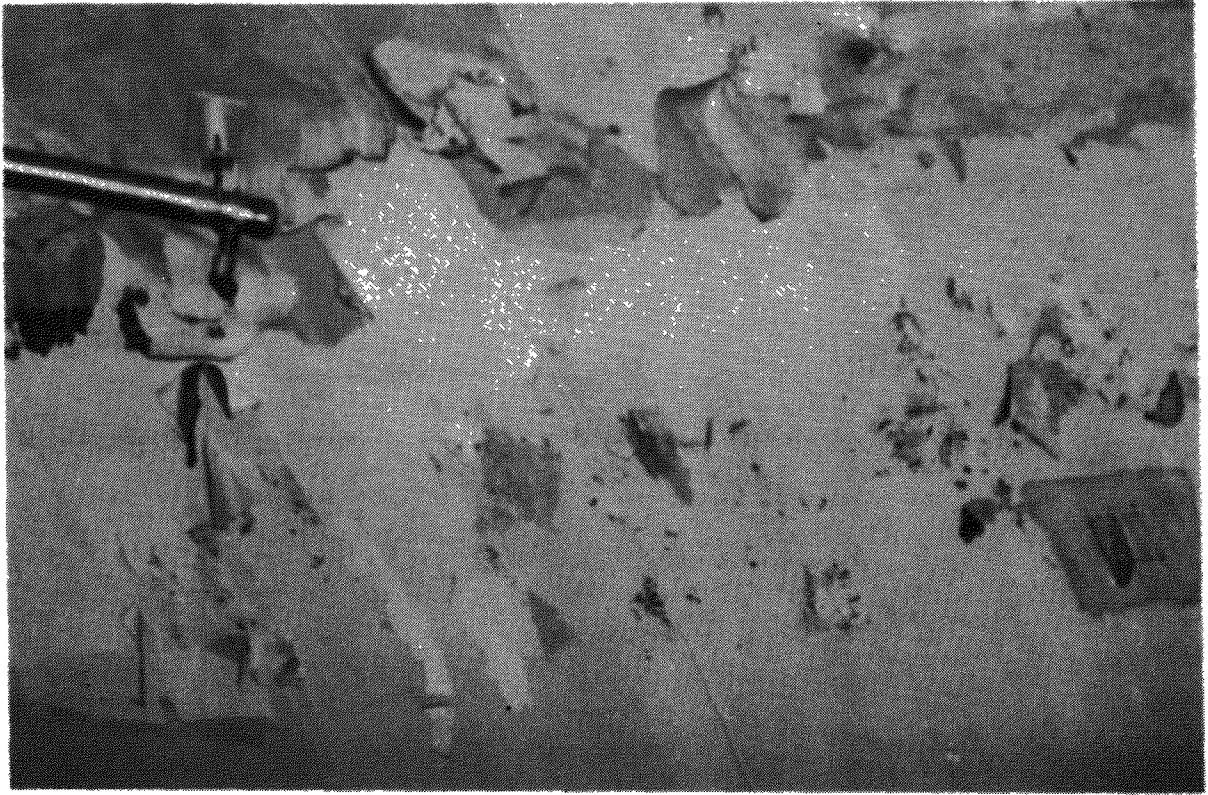


Figure 12. Stripped, charred, and blistered paint in the polar crane region.

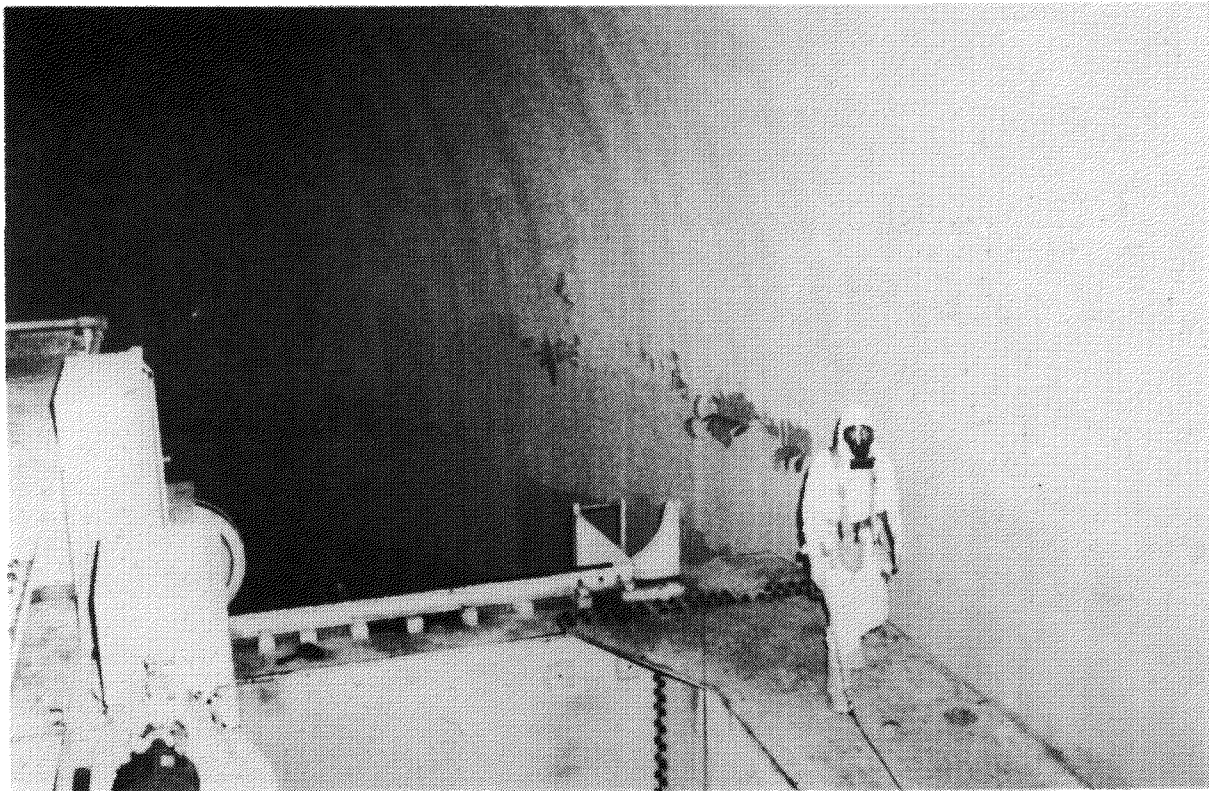


Figure 13. Peeling paint on containment wall (behind man) in polar crane region.

Figures 14 through 28. Thermal damage on the 347-foot elevation.





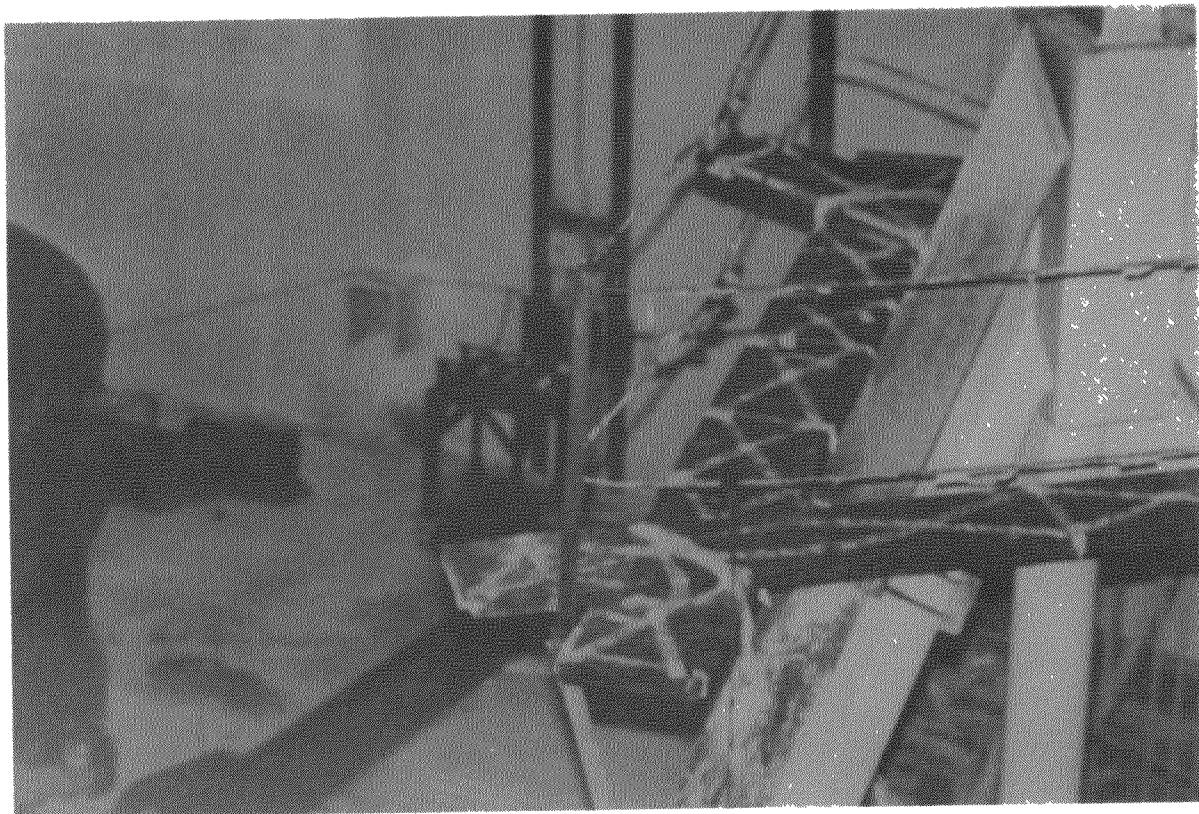


Figure 14. Top view of charred scaffolding with tape shields showing and polyethylene cover melted off. Note phone table in background: front surface of plywood backing against south wall is charred.

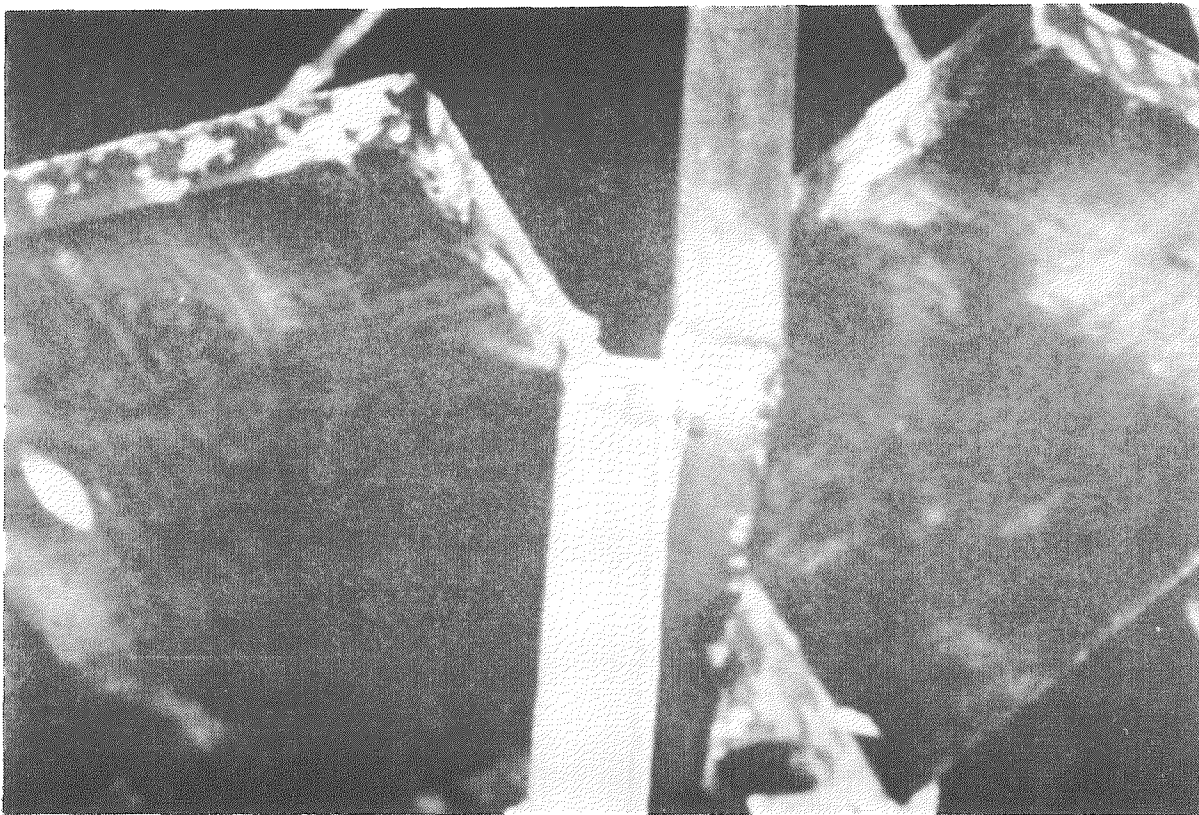


Figure 15. Bottom view of charred scaffolding showing tape shields, and with polyethylene cover melted off.



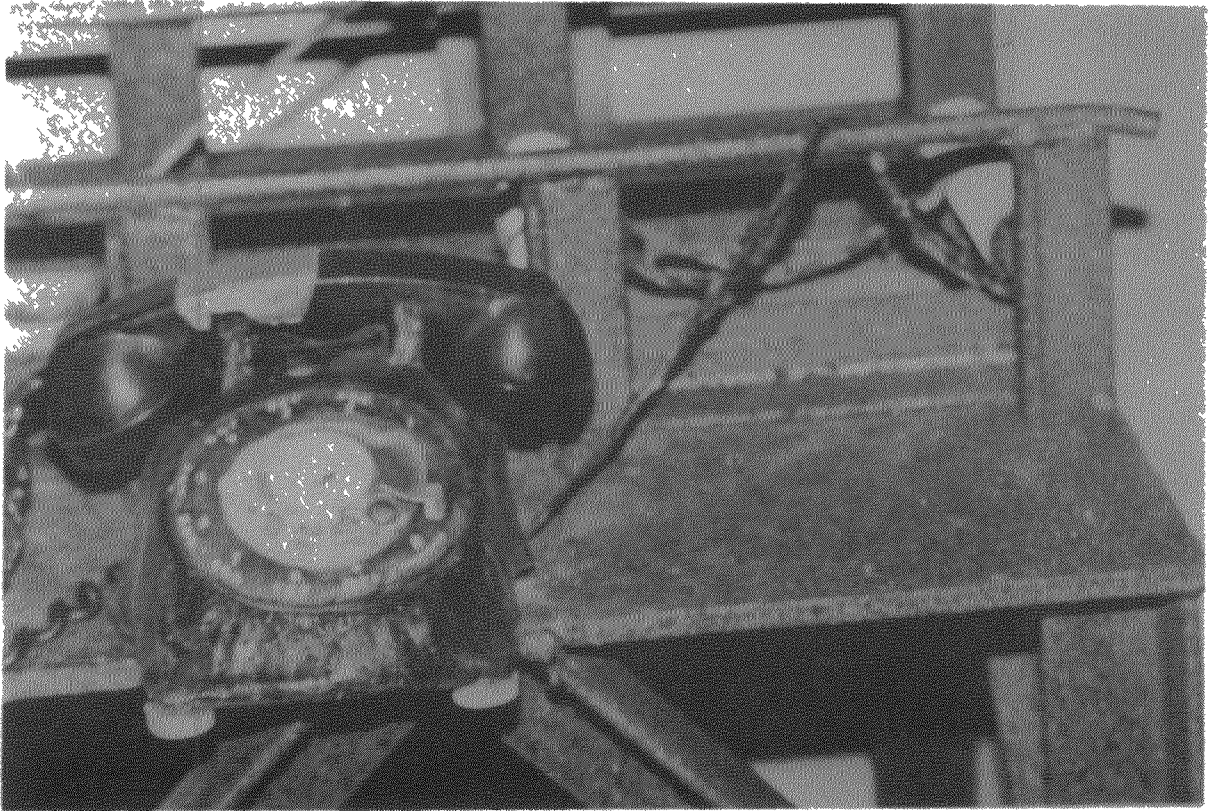


Figure 16. Melted telephone with charred cord along the south wall of the 347-foot elevation.

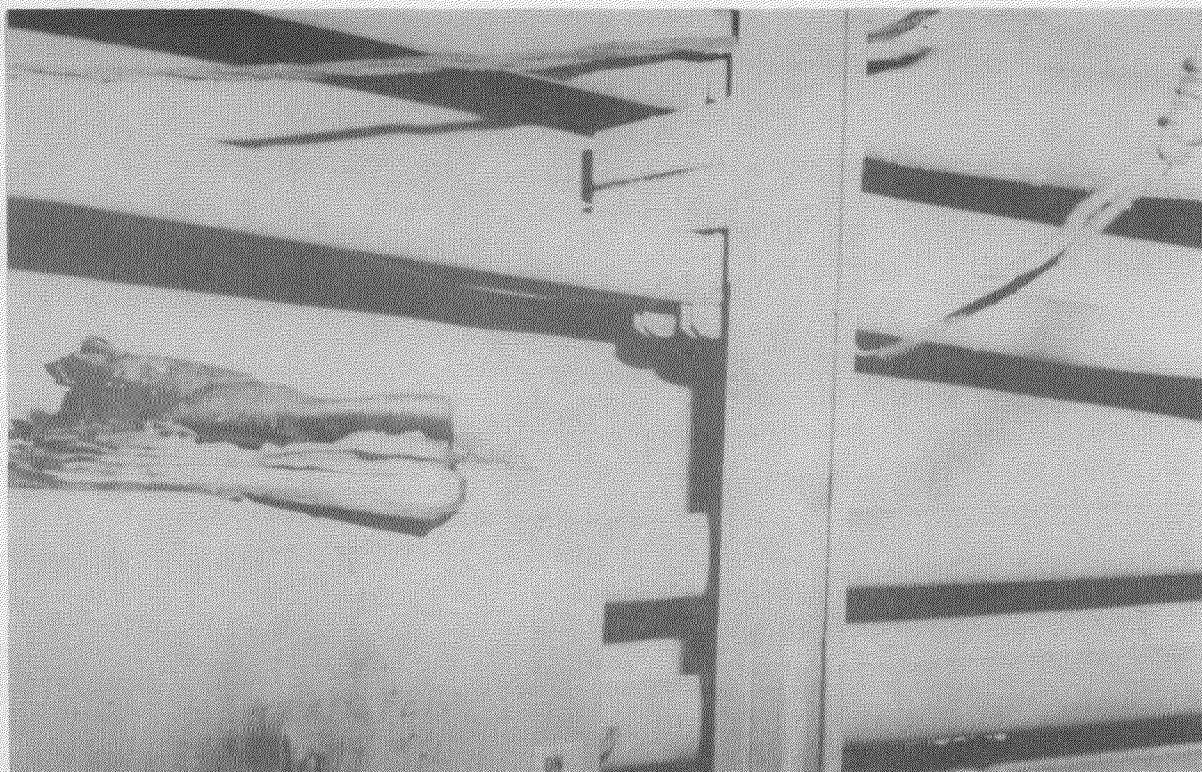


Figure 17. Charred material along north containment wall on 347-foot elevation.

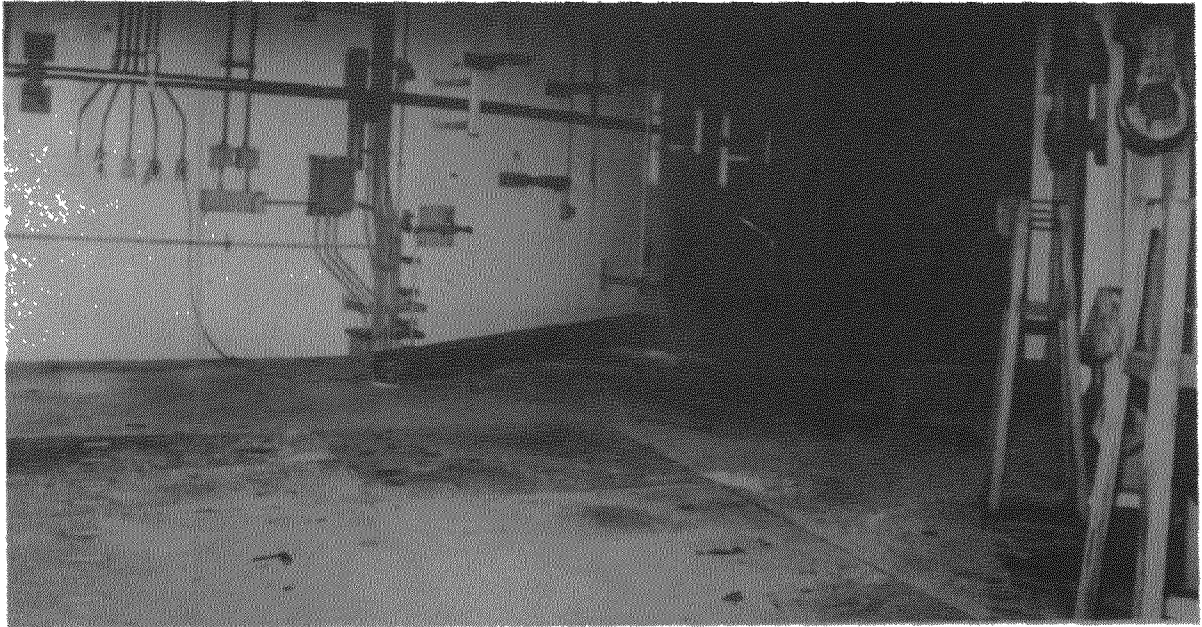


Figure 18. Uniformly charred plywood box against D-ring wall in the southeast area of the 347-foot elevation.



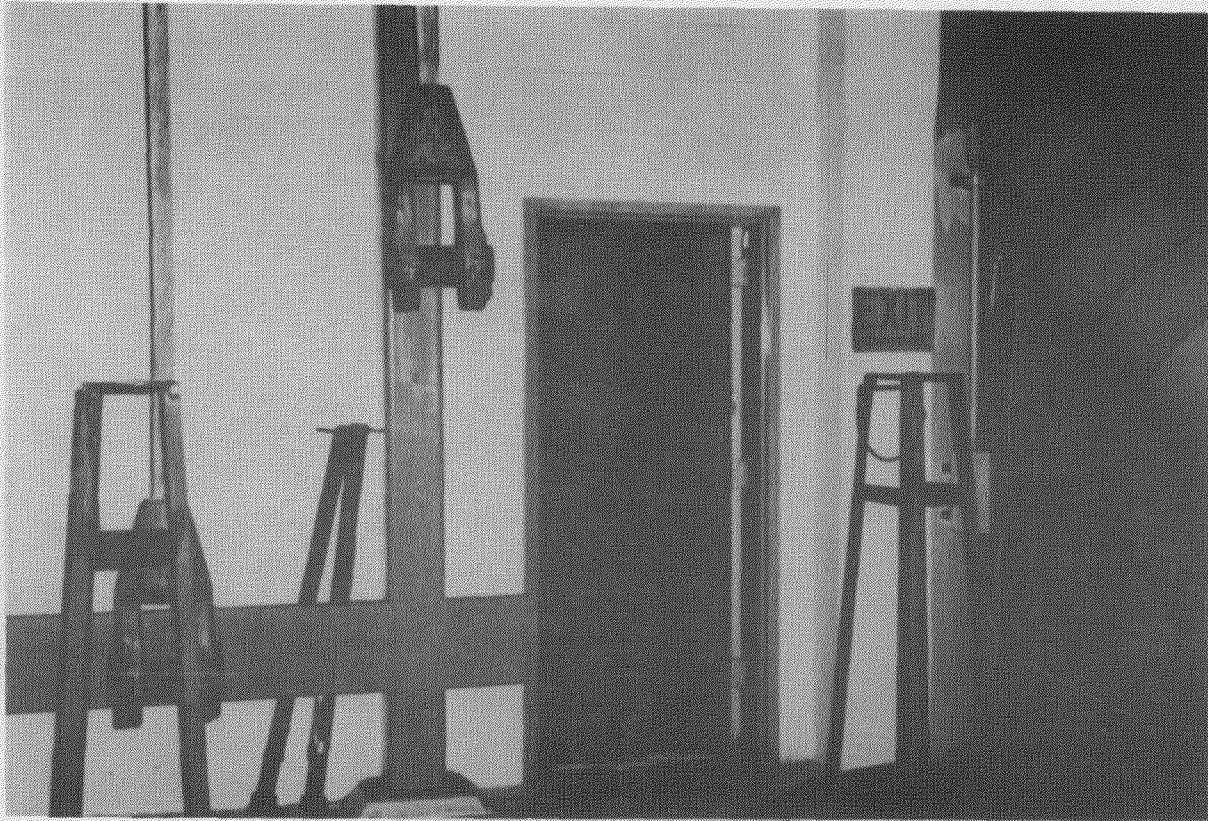


Figure 19. Discolored exit sign, burned in right top corner; located in the southeast area of the 347-foot elevation.



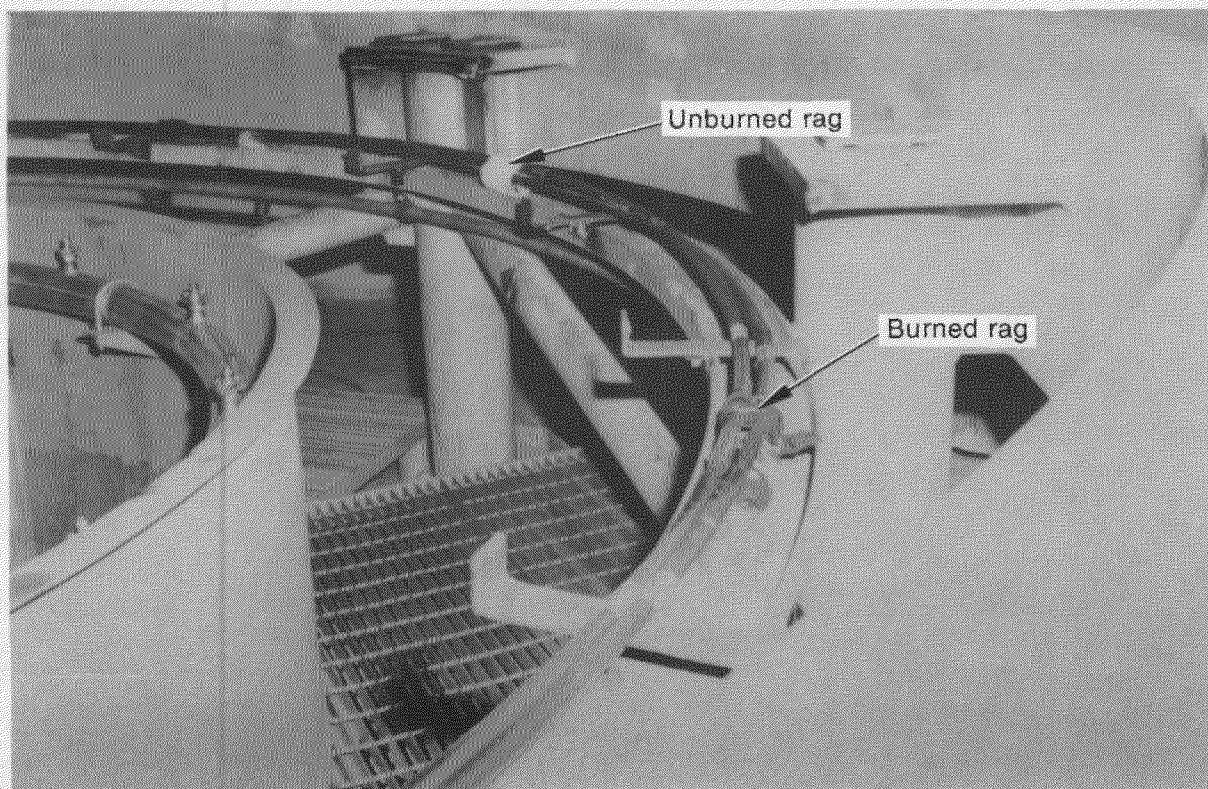


Figure 20. Random fabric char inside the head storage stand on the 347-foot elevation.



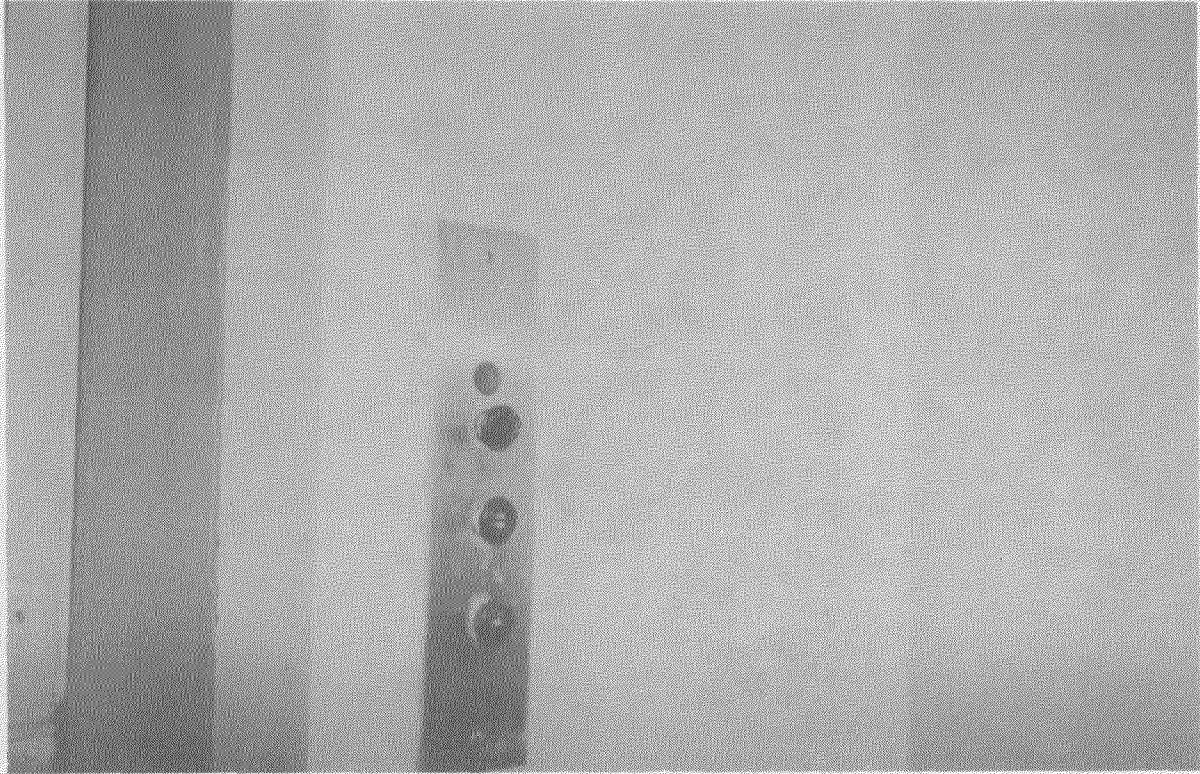


Figure 21. Melted buttons in the southeast area of the 347-foot elevation.



Figure 22. Charring and melted door seal material on electrical panel in southeast area of the 347-foot elevation.

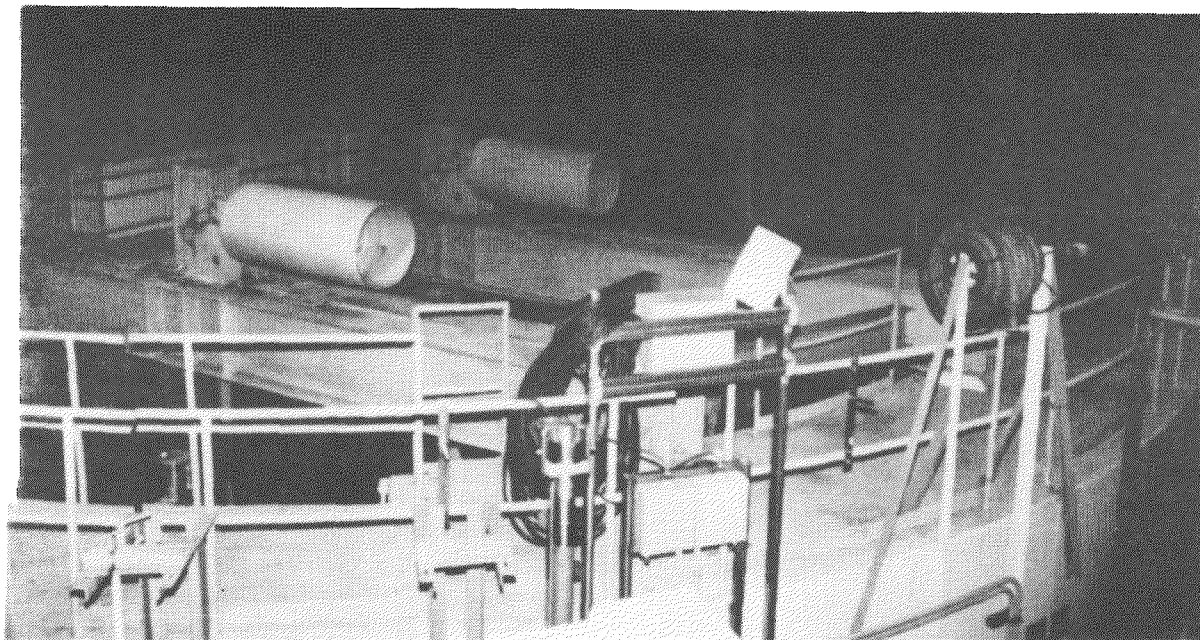


Figure 23. Charred paper in metal box in the east D-ring on the 347-foot elevation.



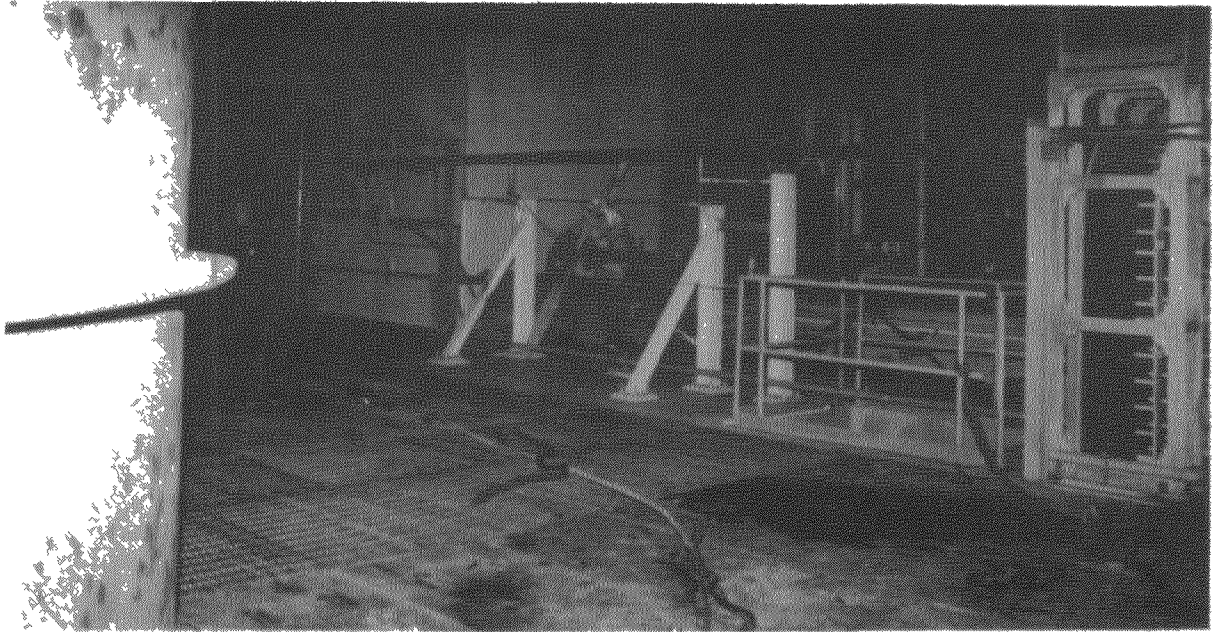


Figure 24. View towards the refueling canal on 347-foot elevation showing fallen bus bar from polar crane and charred electrical insulation.

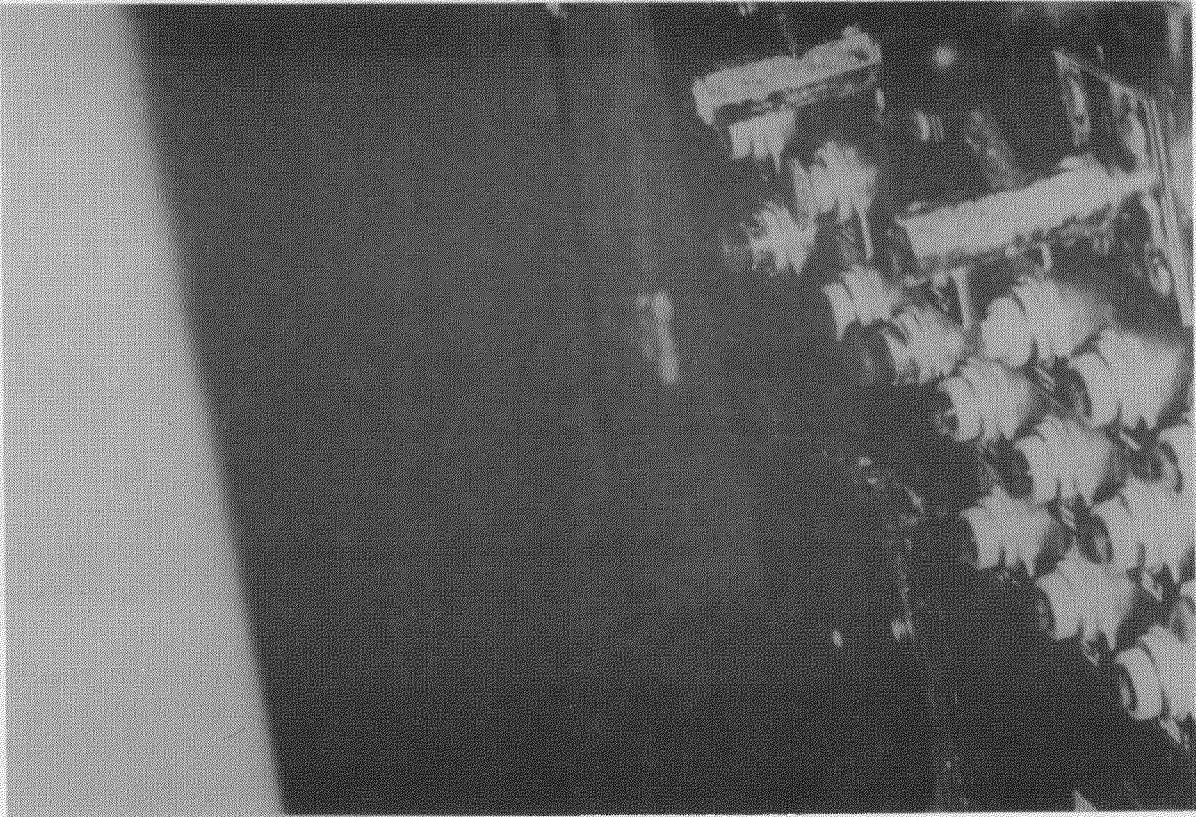


Figure 25. Burned and melted buttons on the auxiliary fuel handling bridge on the 347-foot elevation.

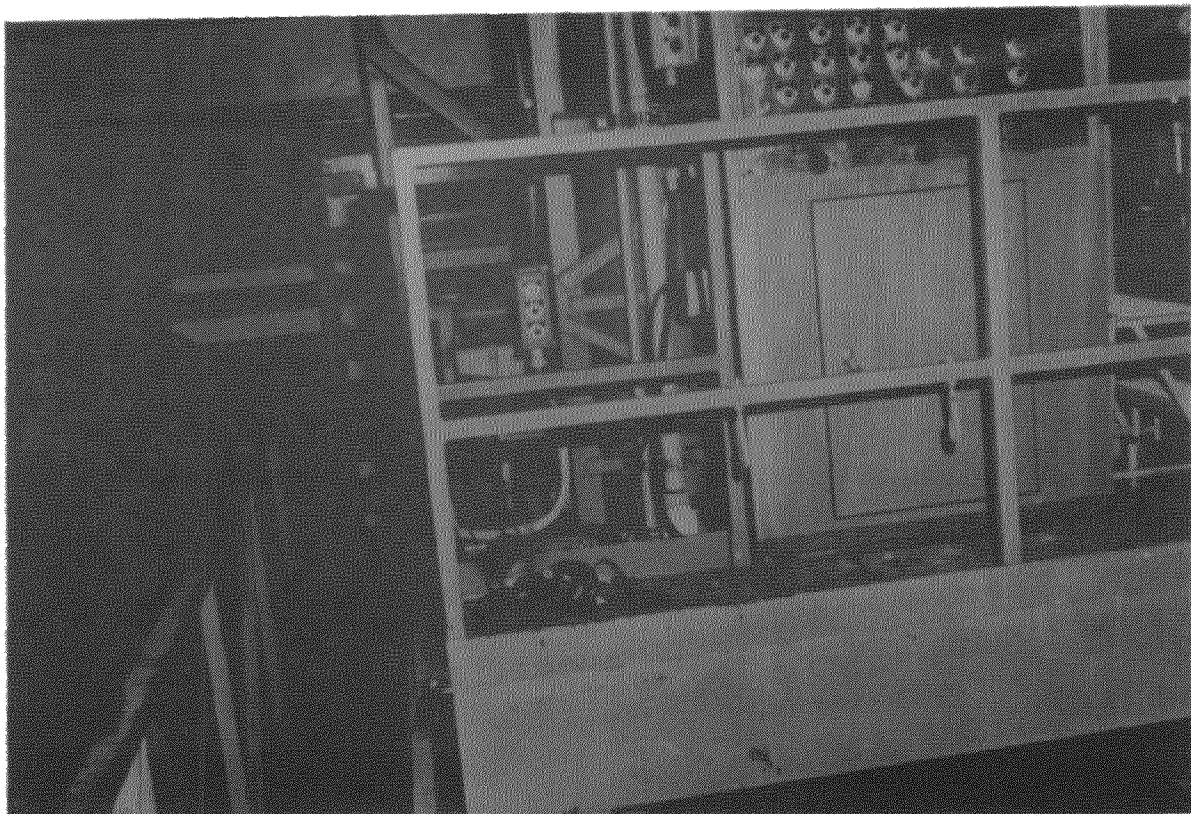


Figure 26. Burned manual and melted earphones on the auxiliary fuel handling bridge on the 347-foot elevation; just below view in Figure 25.





Figure 27. Electrical festoon for fuel handling bridge, on the 347-foot elevation; charred on the exposed surface.

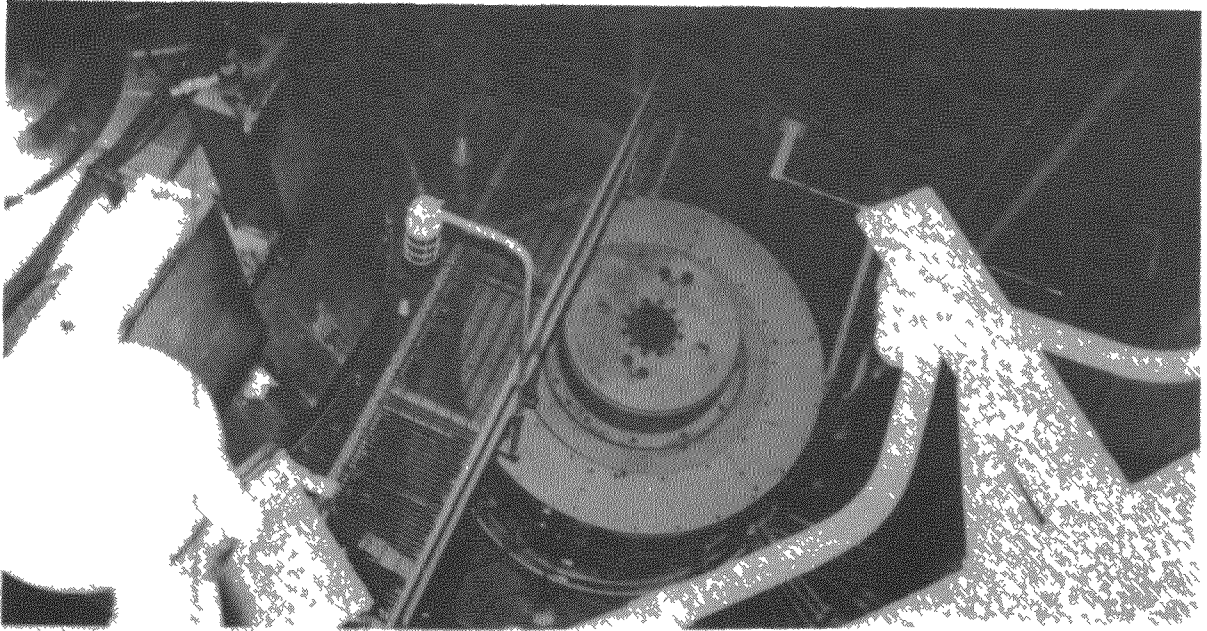


Figure 28. Darkened edge of junction box inside east side of west D-ring.



Figures 29 through 30. Limited damage on the 305-foot elevation.





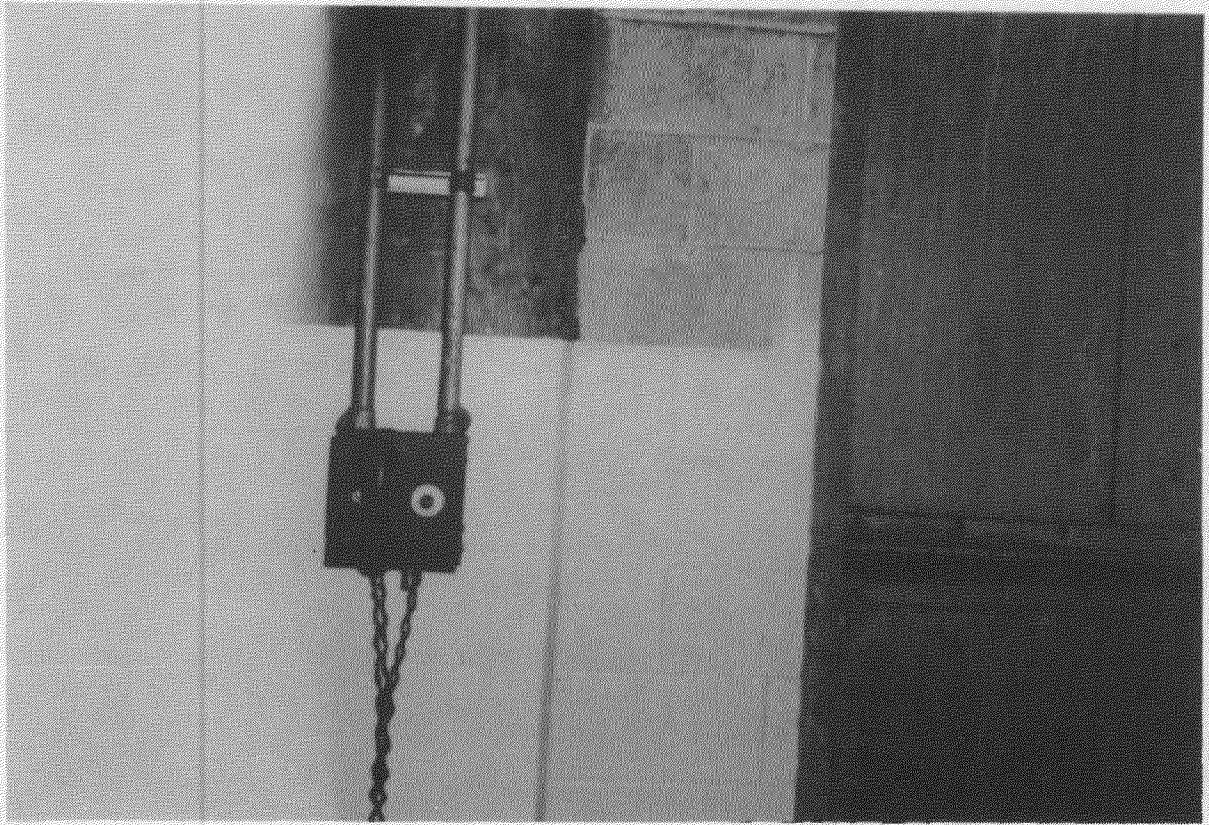


Figure 29. Thermally relaxed telephone cord on 305-foot elevation.



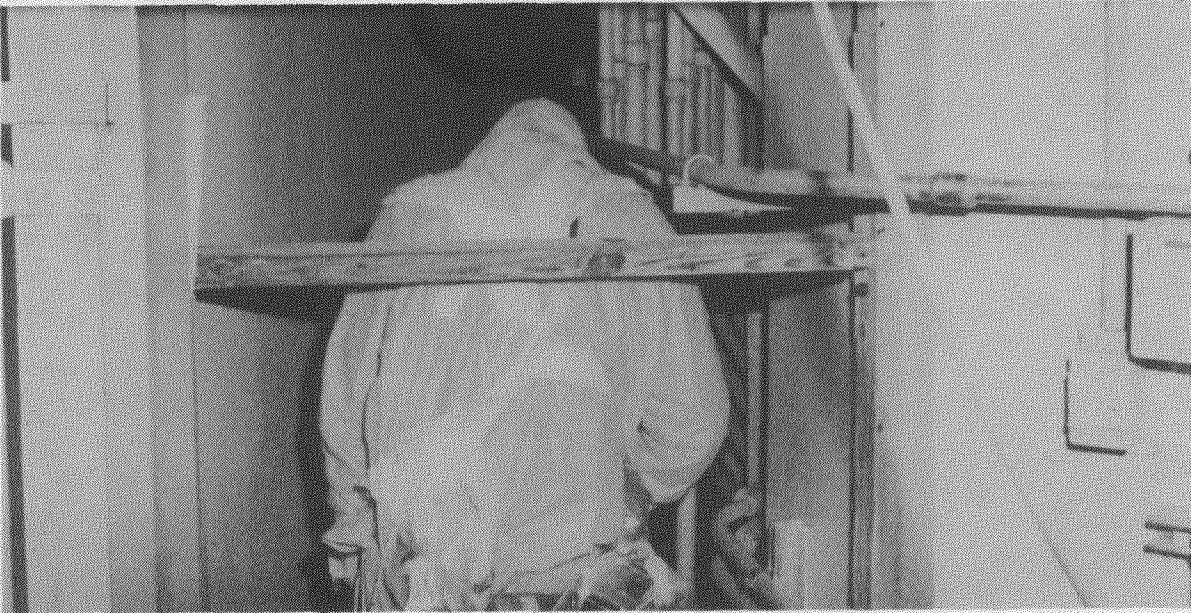


Figure 30. Undamaged wood shoring on 305-foot elevation.

Figures 31 through 34. Model of the TMI-2 reactor building showing damage locations.



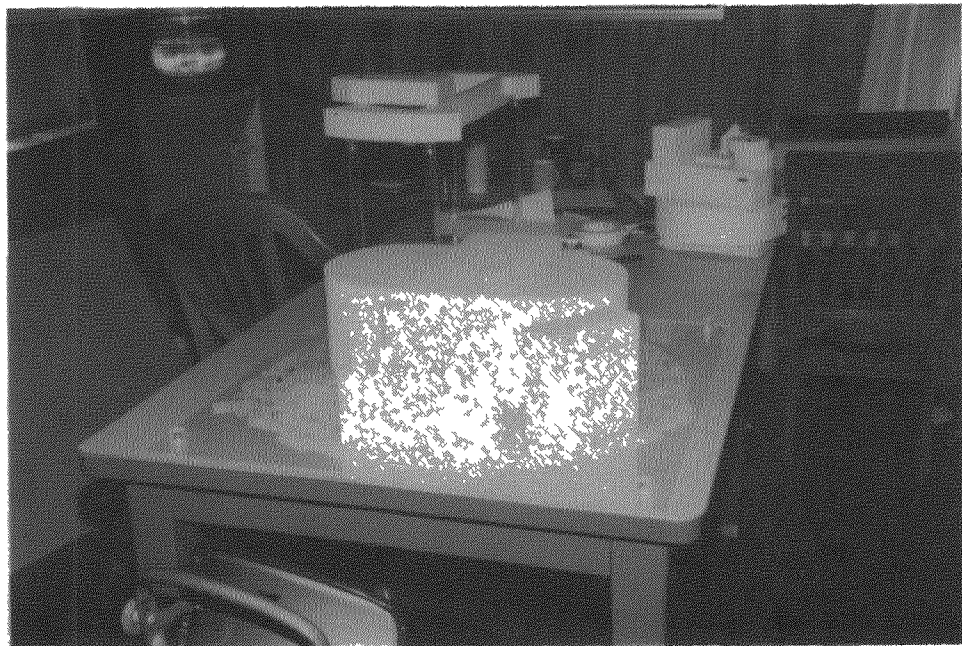


Figure 31. Building model south view--305 level.

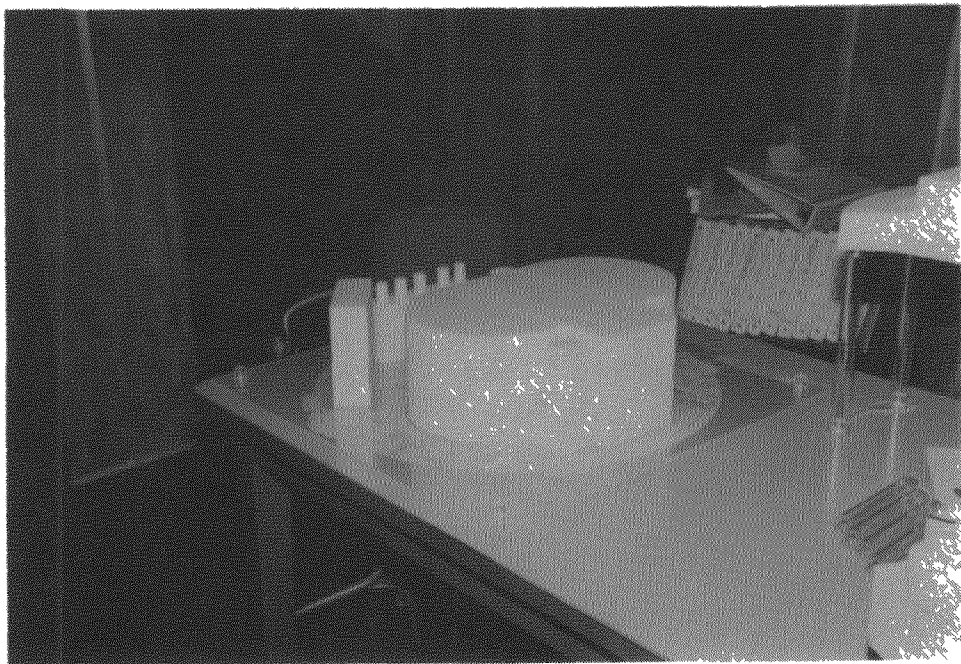


Figure 32. Building model north view--305 level.



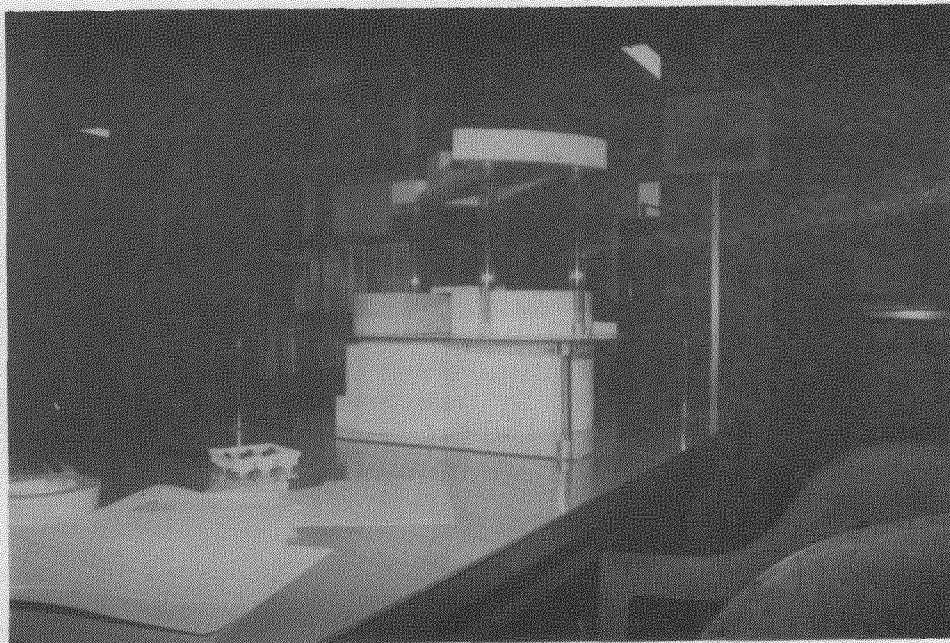


Figure 33. Building model north view--305, 347, and crane.

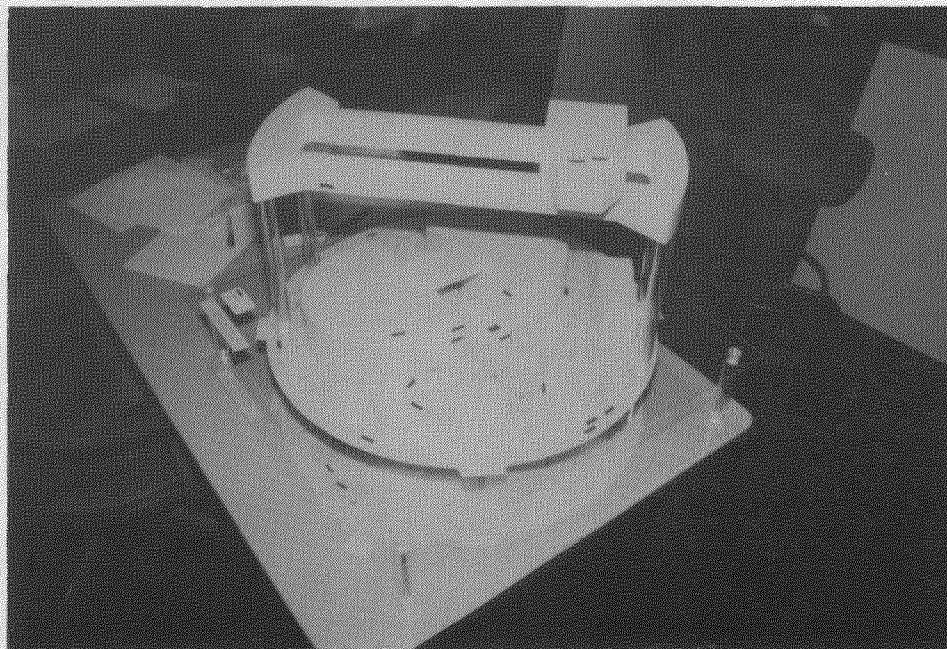


Figure 34. Building model top view--crane and 347 level.



