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October 22, 1982

Director
Office of Nuclear Reactor Regulation
U S Nuclear Regulatory Commission
Washington, DC 20555

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Docket Nos. 50-282 License Nos. DPR-42
50-306 DPR-60

Clarification of Information Provided in Support of Request for Exemption from the Requirements of 10 CFR Part 50, Appendix R, Section III.G

Ref: Fire Protection Safe Shutdown Analysis in Compliance with 10 CFR Part 50, Appendix R, Section III.G and Substantive Basis for Exemption Requests, June 30, 1982

On October 1, 1982 a meeting was held with the NRC Staff to discuss the content of the referenced report. At the conclusion of the meeting, Northern States Power Company and their consulting engineers, EPM Incorporated, agreed to supply clarifying information in the following areas:

a. Photographs with explanatory notes of fire areas 31, 32, 58, 59, 73, 74, 37, 60, and 75

b. Description of additional modifications in fire areas 31, 32, 58, 59, 73, and 74

c. Details of methodology for assessing the hazard presented by exposure fires to electrical cables. Specifically, information related to the criteria for failure of cable, concerns associated with excess pyrolyzate, modeling of corner and wall effects, locations of fire hazards, and details of the model (including a sample calculation) was requested.

The clarifying information is provided as Attachments (1) through (3). One set of the original color photographs included in Attachment (1) was provided directly to the Prairie Island Project Manager in the Division of Licensing earlier this week.

A006
1/40 Encls Rec'd

NORTHERN STATES POWER COMPANY

Please contact us if you have any questions concerning the information we have provided.

David Musolf
Manager - Nuclear Support Services

DMM/bd

cc: Regional Administrator-III, NRC
NRC Resident Inspector
NRR Project Manager, NRC
G Charnoff

Attachments

Director of NRR
Attachment (1)
October 22, 1982

NOTES ON PHOTOGRAPHS OF

PRAIRIE ISLAND NUCLEAR POWER PLANT

Taken in Support of

Appendix R Supplemental Information

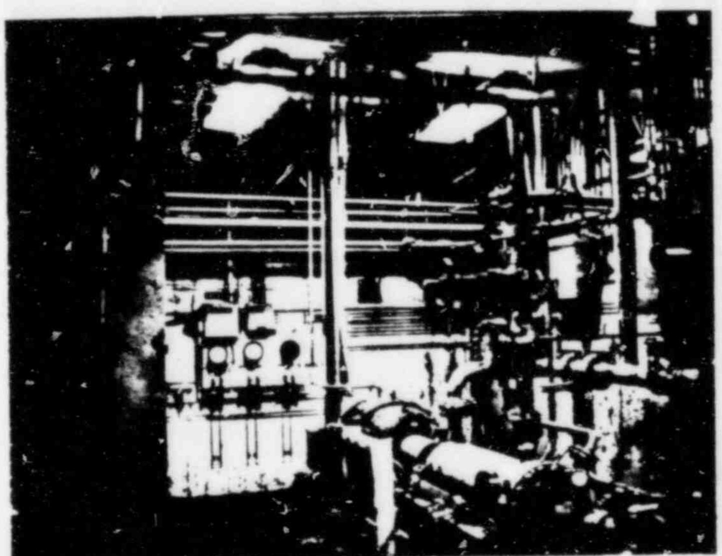
Information will be provided on

Fire Areas 31, 32, 58, 59, 73, 74, 37, 60 and 75

FIRE AREA 31: AUXILIARY FEEDWATER PUMP ROOM, UNIT 2

Location: Turbine Building, Ground Level

Photograph 1 depicts the motor-driven auxiliary feedwater pump for Unit 1 in the area opposite the hot shutdown panel and Motor Control Center Area. This photograph indicates no vertical cable trays and no fixed combustibles up to an elevation of approximately 12 feet. Conduit necessary for safe shutdown in this section of Fire Area 31 will be covered with a suitable protective covering to prevent cable damage.

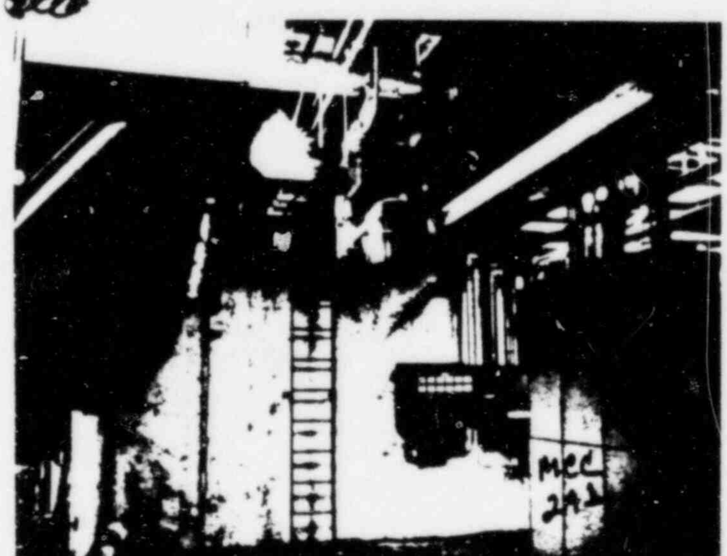


Motor Drive AFW Pump Unit 1 31-1

Photograph 2 depicts the A Train hot shutdown panel and Motor Control Center 2-A-1. In the background on the right side is the single air compressor located in Area 31. All fixed combustibles in the form of cables in this area are again at a minimum of approximately 12 feet from the floor.

31-2

Photograph 3 shows the north wall of Fire Area 31. The ladder goes up to a mezzanine level below which is located the Battery Rooms. The objects seen in the upper left-hand corner of the photograph are an air handling unit and part of the HVAC System. The cabinet on the right-hand side of the photograph is Motor Control Center 1-A-2. The air compressor in this area is on the side facing the Motor Control Center. This picture was taken from the passageway that separates the Auxiliary Feedwater Pump Area from the Air Compressor and Motor Control Center Area. By referring to the general arrangement drawings provided, one can see a physical layout of Fire Area 31 noting the position of the Motor Control Center and the air compressor on the north side of the area.

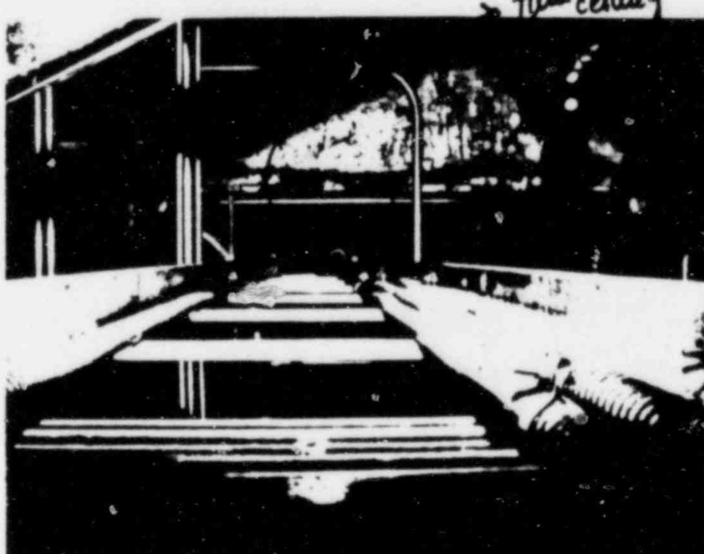


31-3

Photograph 4 depicts the physical crossover of 2SG-TA14 above 2SG-LB17. The vertical separation between the orange division and the green division is approximately 2-1/2 feet.

31-4

Photograph 5 is actually looking down the green division Tray 2SG-LB17. The cable contained in this tray is all of the armor-shielded type, and there are only 4 cables located in this tray. This tray is located below the orange division crossover 2SG-TA14, and as depicted is entering this area from the ceiling of the Battery Room and running the length of the green tray and exits through the ceiling to the level above. The only cable tray in Area 31 that would provide a path of combustible material from Division A to Division B is, in fact, an orange division tray 2SG-TA14, which has already been considered in the analysis. The modifications proposed in this area would be to protect the green division from direct plume impingement with a suitable barrier being placed underneath and on top of the green division.



→ thru ceiling

→ from ceiling of battery room

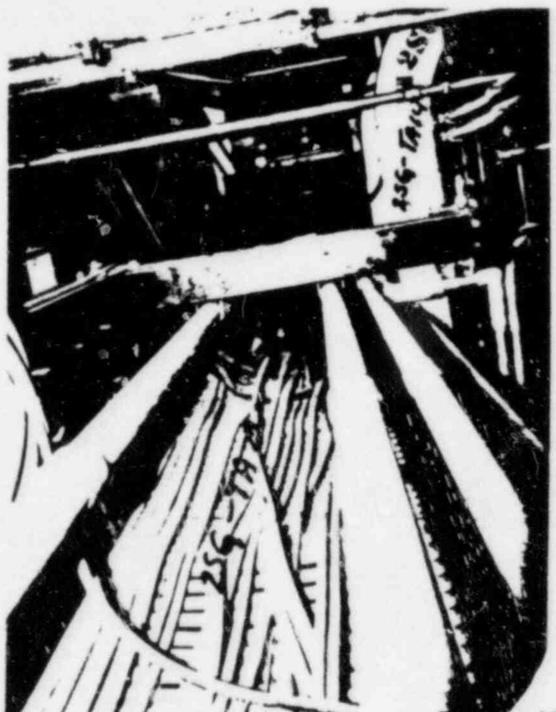
2SG-LB17

31-5

Photograph 6 depicts the non-safe shutdown trays (2SG-L12 and 2SG-T9) adjacent to 2SG-LB17. The bottom tray is relatively lightly loaded and neither tray provides a direct path of combustibles between orange and green divisions.

Trays adjacent to 2SG-LB17   31-6

Photograph 7 is looking south down 2SG-TA21 to the intersection of 2SG-TA14.



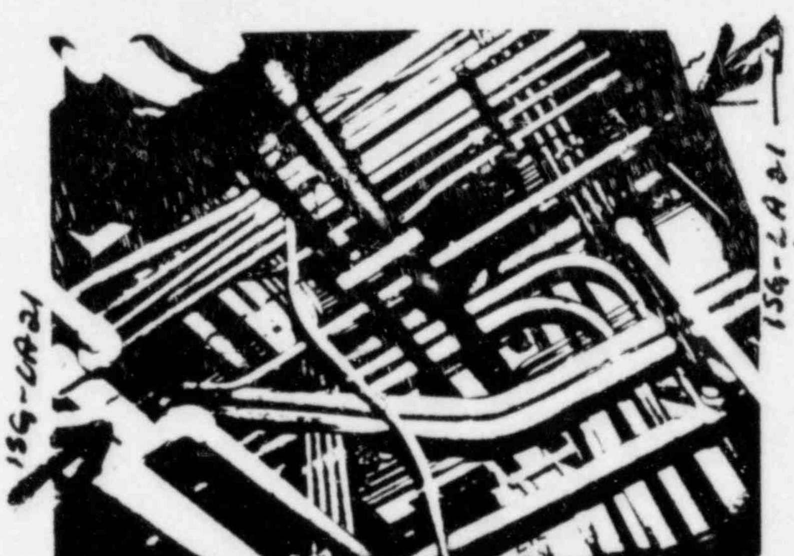
31-7

Fire Area 31 has no vertical trays below a nominal 12 foot elevation and is essentially free of intervening combustibles. The instrument and control cable trays are constructed such that approximately 75% of the tray bottoms are covered as indicated in the photographs. This construction provides inherent protection from convective heat transfer and will act to substantially inhibit the potential for initiating secondary fires. These trays are used throughout the plant for all instrument and control cables.

FIRE AREA 32: AUXILIARY FEEDWATER PUMP ROOM, UNIT 1

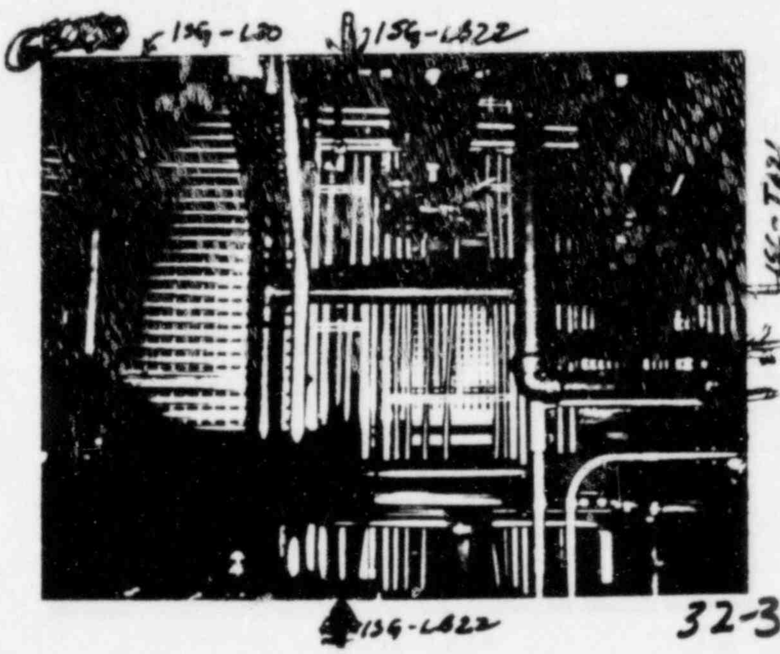
Fire Area 32 contains Motor Control Center 1-A-2 and two air compressors located in the north section of the area. This area is essentially a mirror image of Fire Area 31.

Photograph 1 is taken looking up at 1SG-LA21, the orange tray intersecting the green division. The arrows written on the photograph indicate the location of this cable tray. Again, the cable in the tray is armor-shielded and located approximately 2-1/2 feet above the green division tray 1SG-LB22.

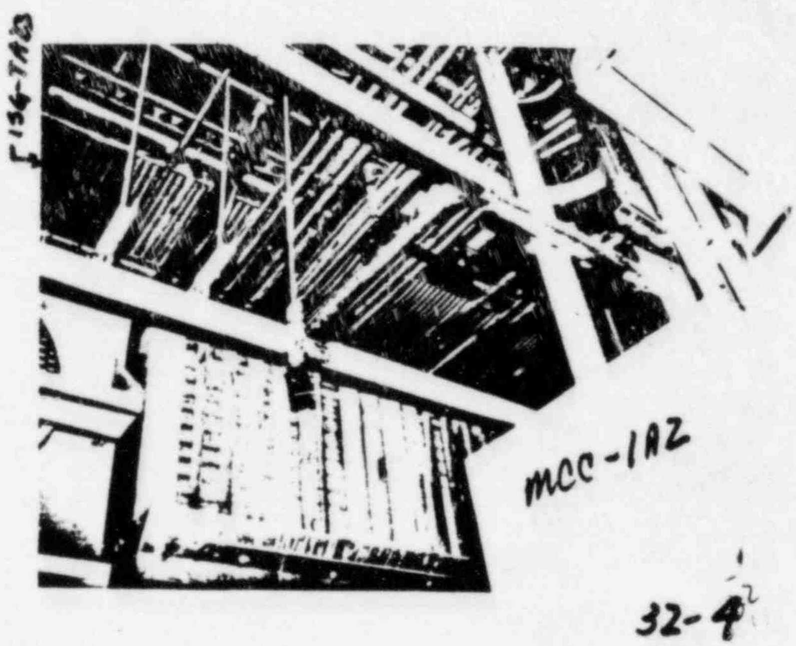


Looking up at 1SG-LA21 32-1

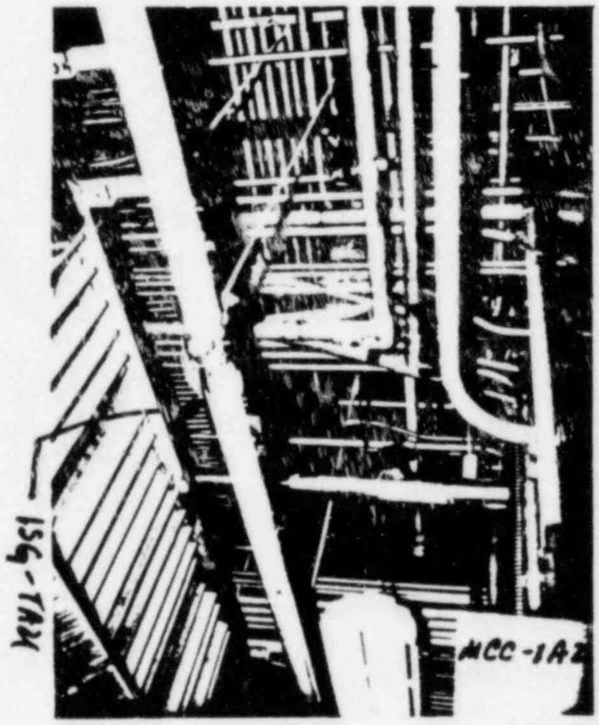
Photograph 3 shows the crossover of 1SG-LB22 and 1SG-TA21 (the top tray). The vertical separation is approximately 2-1/2 feet. As can be seen the four cables in the green tray (1SG-LB22) are armor-shielded. The tray on the left is 1SG-L20.



Photograph 4 is looking up from the south corner of MCC-1-A-2 to 1SG-TA23. Most of this tray is situated above the visible air handling unit.

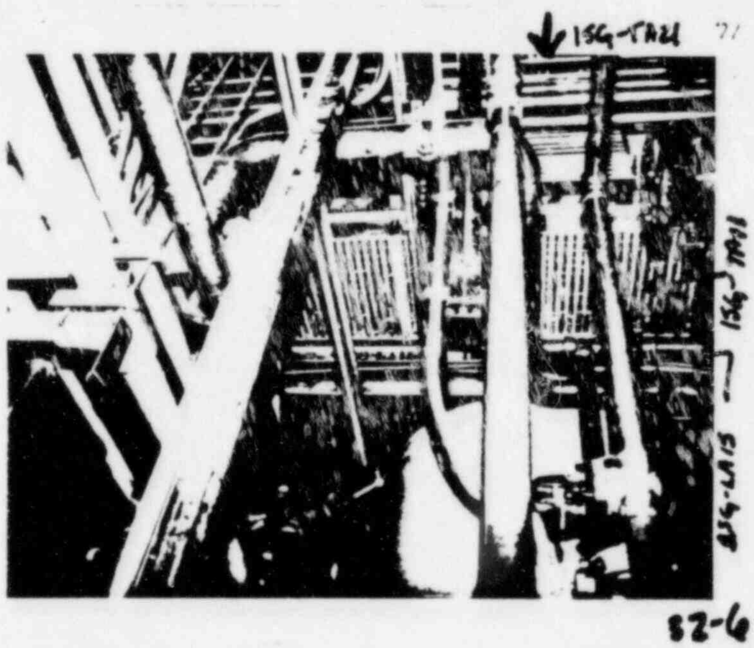


Photograph 5 is looking north behind MCC-1-A-2. On the left is orange division tray 1SG-TA23. The lower right shows MCC-1-A-2. Note the absence of any exposed cables to cause secondary fires.

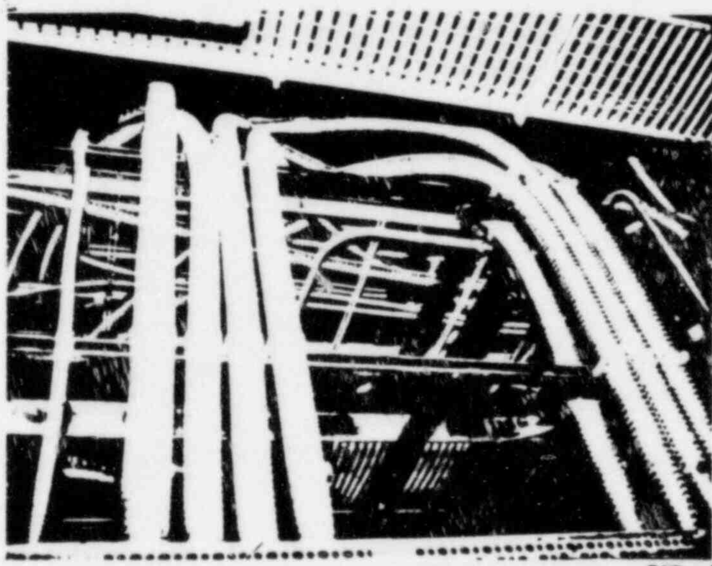


32-5

Photograph 6 was taken in the northwest corner of Area 32 showing 1SG-TA11 and 1SG-LA15. The arrow is indicating 1SG-TA21, which is the orange tray intersecting the green tray 1SG-LB22, which is not shown in this photograph.



Photograph 7 is taken looking directly above Motor Control Center 1-A-2. The tray immediately above it is 1SG-T13, a non-safe shutdown tray. The tray with the armored cable in it is 1SG-LB22, the green division tray in the area. None of the conduit from the Motor Control Center is contained in the green tray.



32-7

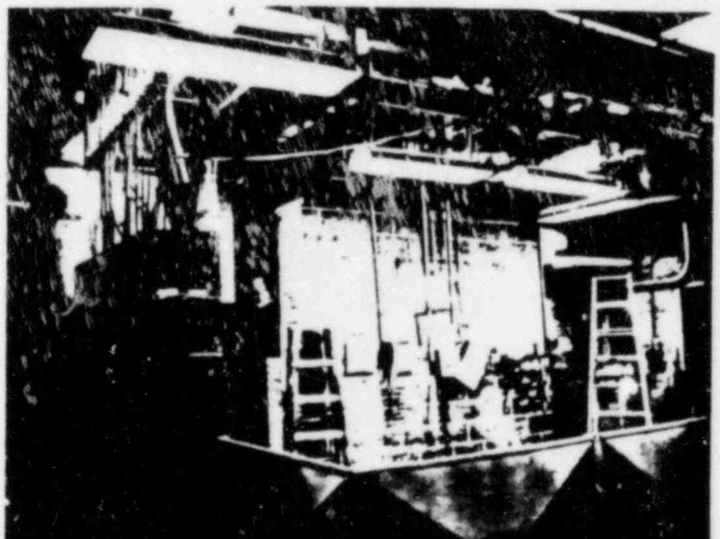
Fire Area 32 has no vertical trays below a nominal 12 foot elevation and is essentially free of intervening combustibles.

FIRE AREA 58

Location: Ground Floor Auxiliary Building, Unit 1

Referring to the general arrangement drawing, this area contains Motor Control Centers 1-K-1, 1-KA-2, and 1-K-2. It also contains the Charging Pump and the RHR Pump Rooms.

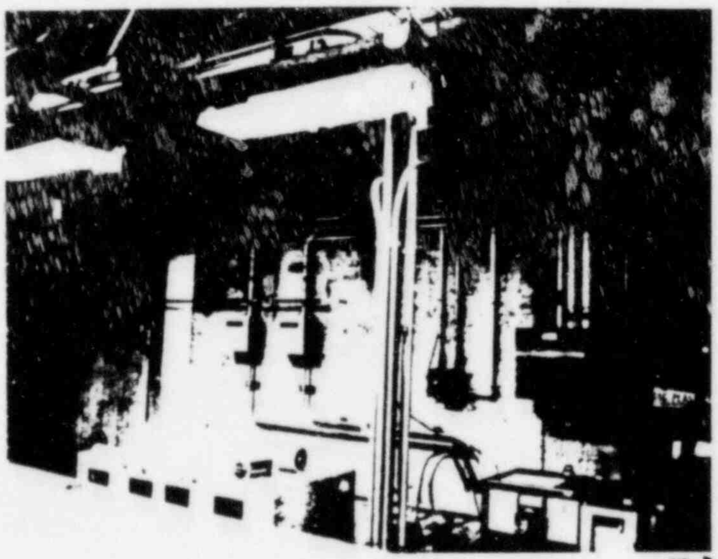
Photograph 1 shows the controlled access radiation area into the Charging Pump Rooms. The Motor Control Center to the left of the photograph is MCC 1-K-2, which is a B Division Motor Control Center.



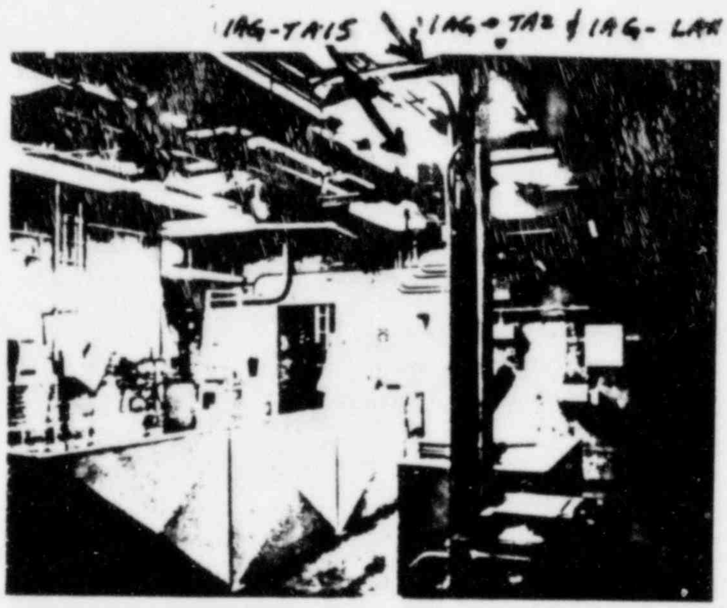
MCC1K-2 (Green Division) 58-1

<u>Photograph 2</u> was intentionally left out.

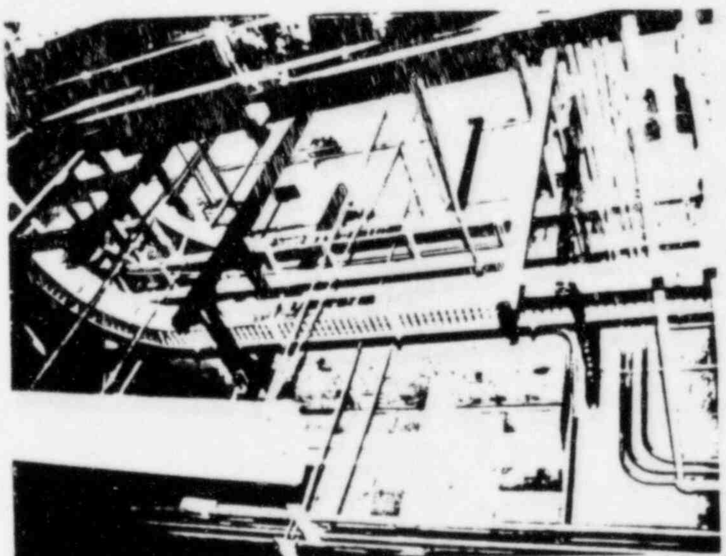
<u>Photograph 3</u> was taken from MCC 1-K-2 looking northwest. Looking across the controlled area you see the radiation monitor and the north wall. Above the radiation monitor is located the safe shutdown cable trays 1AG-LB7, 1AG-TB5 of the green division and the orange division as shown in the June 30 submittal sketch.



Photograph 4 shows the radiation monitor in the foreground and looking west the controlled access area into the Charging Pump Rooms. The arrow at the top border of the photograph is indicating the orange division trays of 1AG-LA11 and 1AG-TA2. The long arrow on the photograph is pointing to 1AG-TA15. None of the green division trays are visible in this photograph.



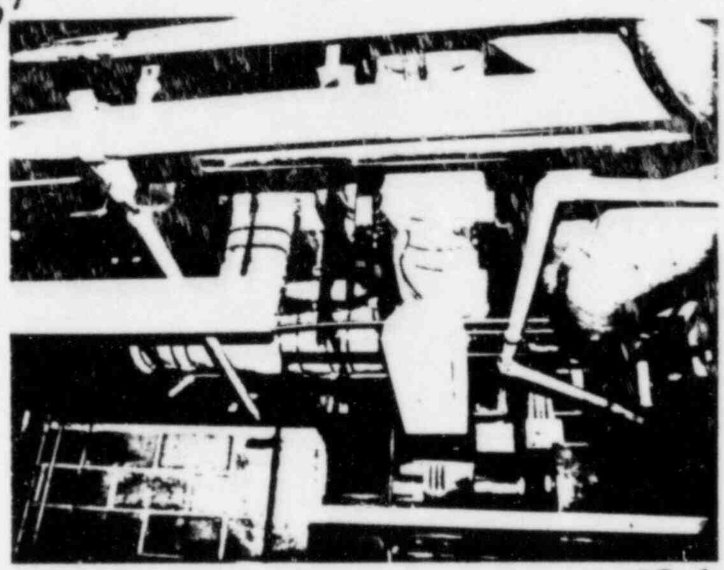
Photograph 5 shows 2 green division trays which end in a riser going through the ceiling above the RHR Pump Room.



58-5

Photograph 6 is the existing wrapping in the northwest corner of the room. The wrapped trays are part of the orange division and were not included in the Appendix R review, as they already met Appendix R. These wrapped trays would be seen on the physical layout drawings going beneath 1AG-LB7 and 1AG-TB5 to connect to the orange division trays.

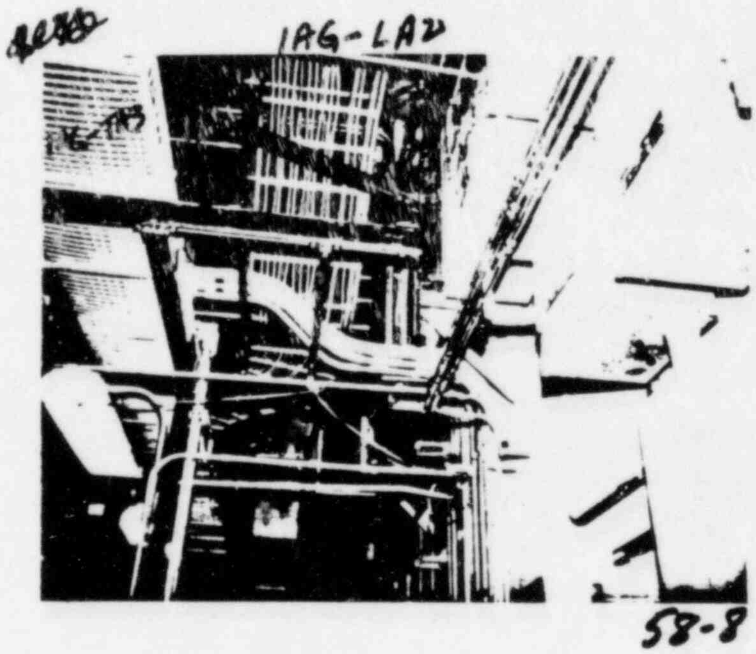
7-85



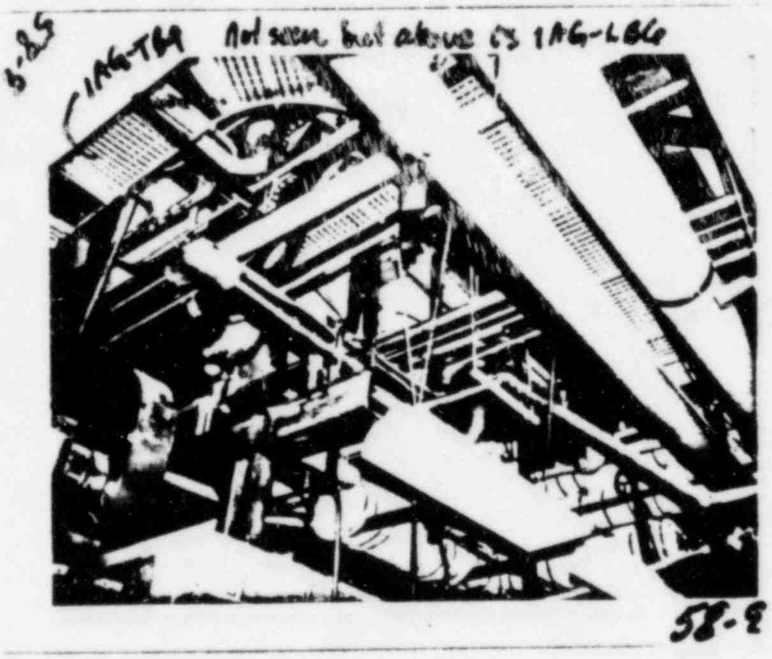
58-6

Photograph 7 is in the northeast corner of the area, depicting 1AG-TA3 with 1AG-LA12 located above it. The armor-shielded cables seen in the photograph, with the arrow indicating the tray, is 1AG-LA12. The 1-foot-wide tray seen in the upper right-hand corner of the photograph is 1AG-TA15.

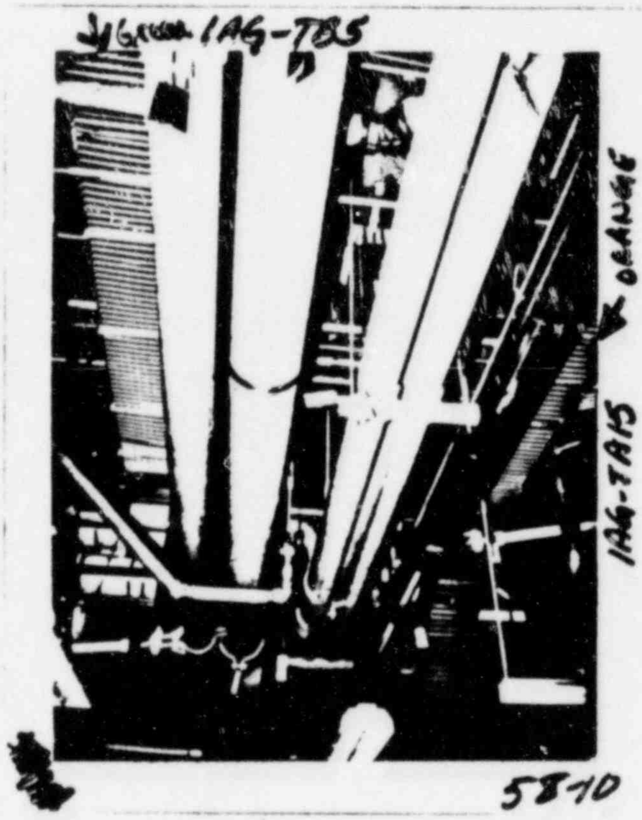
Photograph 8 is taken looking west along the north wall at the orange division at the split of 1AG-LA12 from 1AG-TA3. As can be seen from this photograph, 1AG-LA12 is armor-coated cable and very lightly loaded. The photograph indicates no vertical riser trays. All cable rising along this wall is contained in conduit.



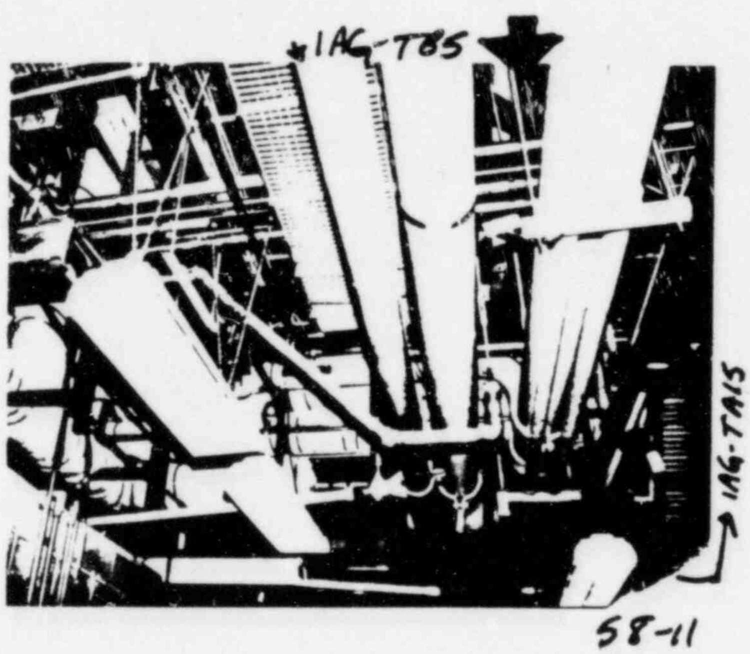
Photograph 9 is from the north wall looking west and a little south. The wrapped cables that you see are the same ones referenced earlier in Photograph 6. In the upper left-hand corner of this photograph you can see the green division trays above the Motor Control Center which are 1AG-TB4, and above that 1AG-LB6.



Photograph 10 indicates the divisional separation between the green and the orange division at the closest point of horizontal separation. As can be seen from the photograph with the green division on the left and the orange division on the right there are no trays traversing between the two divisions, and in fact four rather large pipes can be seen in the intervening area between the two divisions. The tray that you can see on the left is 1AG-TB5, and the tray on the right is 1AG-TA15. As the green tray 1AG-TB5 goes west and rises, the wrapped trays can be seen below it.



Photograph 11 is essentially the same scene. Looking between the piping to the west wall there are no intervening combustibles. The area between the two divisions is indicated by an arrow.

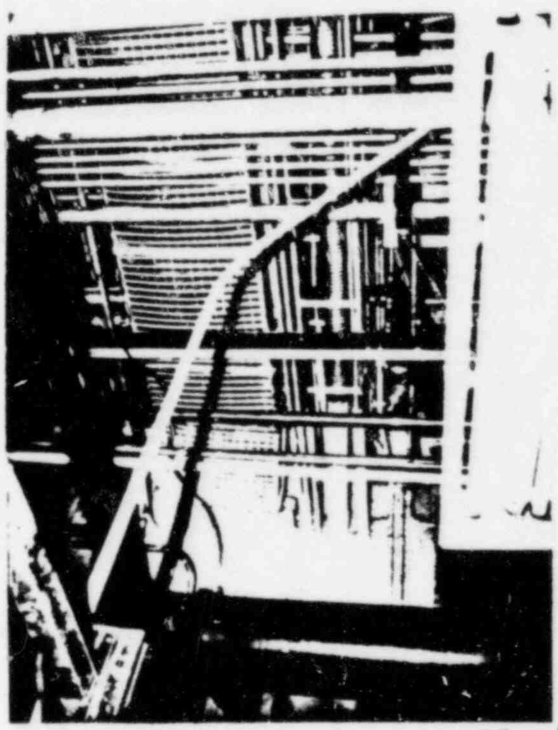


Photograph 12 is another shot of the orange division looking over the corner of the elevator enclosure. The 1-foot-wide tray again in the upper right-hand corner is 1AG-TA15.

Photograph 13 shows the only riser in any of the Prairie Island areas that have been addressed in the Appendix R report, and it should be noted that there are covers on the vertical riser coming up from the floor for approximately 6 feet. However, this particular cable tray is in excess of 20 feet from its counterpart redundant division. It does give an indication of how Prairie Island did treat vertical rising trays coming from the floor.

58-13

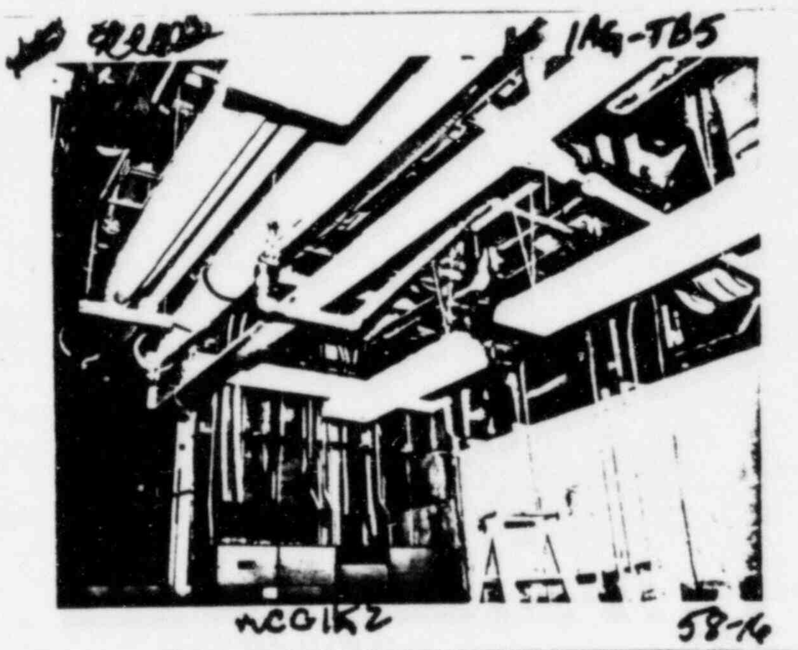
Photograph 14 is a section of orange division cable tray exiting the north wall just to indicate the method by which the penetration was made. The Flammastic coating has been put on approximately 2 feet extending from the wall.



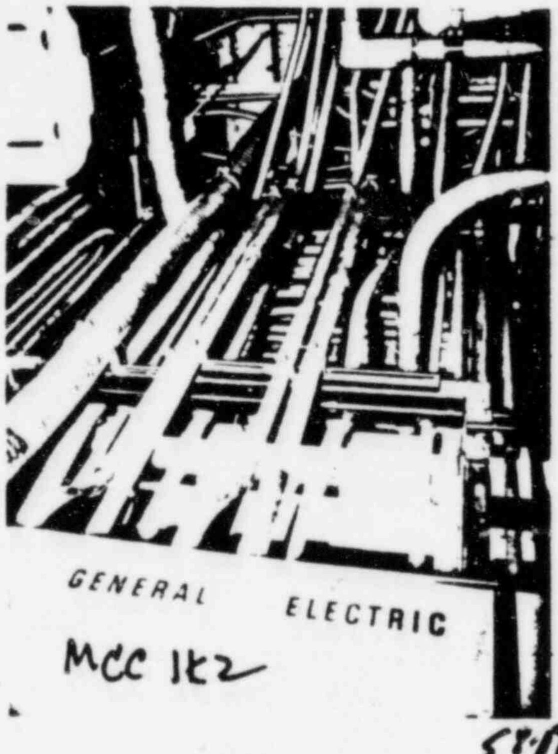
58-14

Photograph 15 is looking east from the northwest section of the area looking at MCC 1-K-2, a green Motor Control Center. To the right of it are the Charging Pump Rooms. The tray that can be seen in the upper left corner of the photograph is 1AG-TA15. No green division trays can be seen. They are hidden behind the pipes and the light in the photograph.

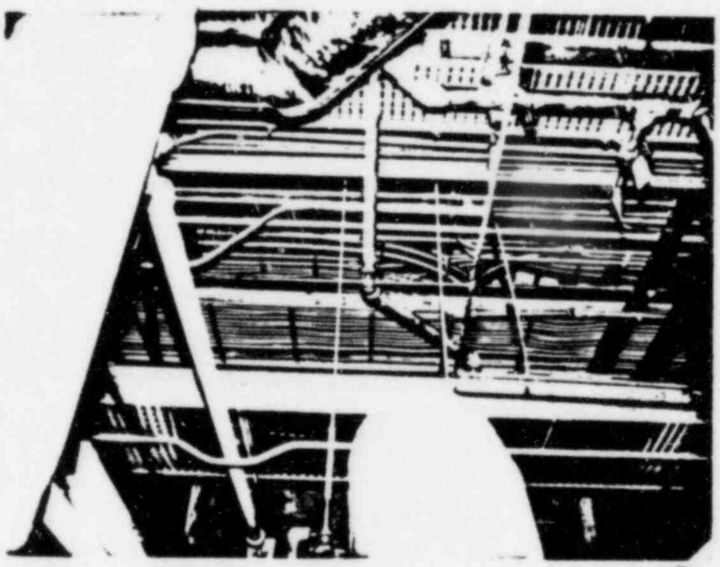
Photograph 16: You can just catch the green division tray indicated by an arrow which would be 1AG-TB5.



Photograph 17 is looking straight up from MCC 1-K-2 and indicates that all cable leaving the Motor Control Center is either in conduit or armor-shielding. This is generally true throughout the plant. Most cable exiting motor control centers is either in conduit or armor-shielded cable.



Photograph 18 is again of the orange division but provides a representative example of how cable trays are dealt with at Prairie Island. All of the power cable is in armor-shielding and provides little chance of being a fixed combustible source or a source of intervening combustibles.



58-18

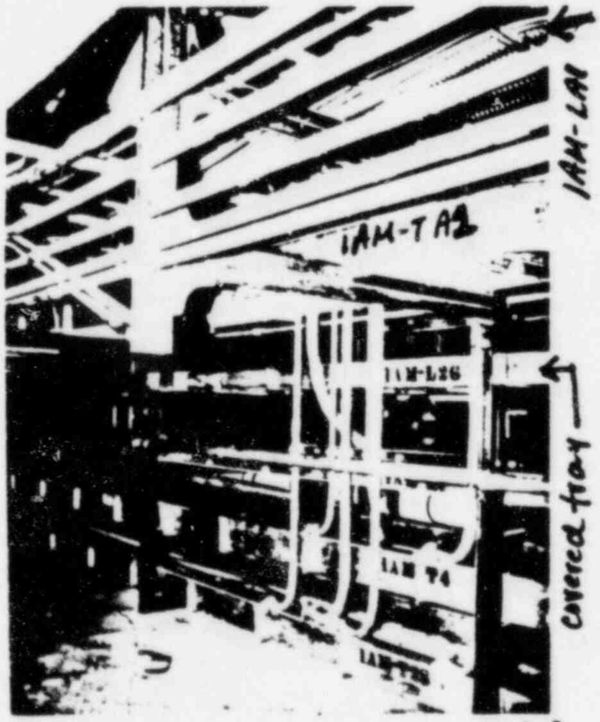
Fire Area 58 is essentially free of any intervening combustibles. Nearly all the trays which are susceptible to a transient fire are required for safe shutdown and thus there are very few trays in the area which are not represented on the sketch in the submittal report. Those that are non-safe shutdown trays do not intersect both divisions and are very lightly loaded.

FIRE AREA 59

Location: Mezzanine Level, Auxiliary Building, Unit 1

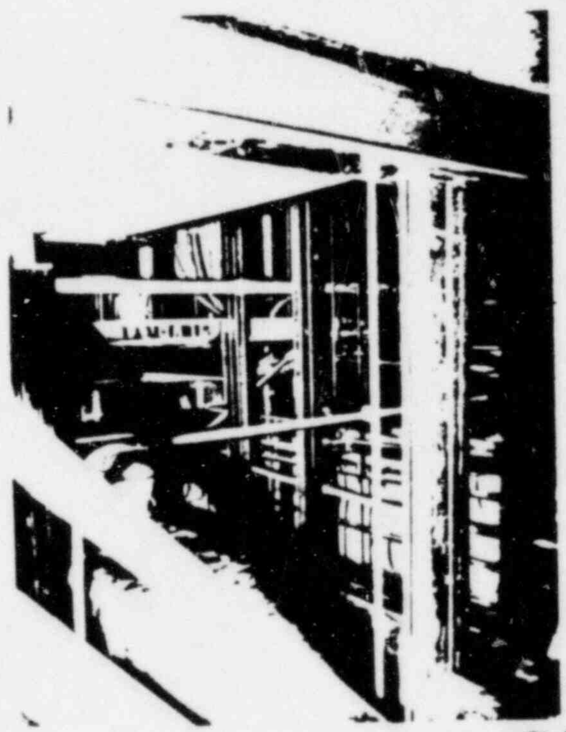
Looking at the general arrangement drawing, this area contains Motor Control Center 1-L-2, 1-L-1, and the Unit 1 Refueling Water Storage Tank. As indicated in the general arrangement drawings and the physical layout drawings, the sections of 1AM-LB5, 1AM-LB15 going north, and the orange division of 1AM-LA2 going north are located in an approximately 5-foot-high mezzanine level which is actually the ceiling of the Access Control Area.

Photograph 1 taken on the Access Control Area ceiling indicates four stacked non-safe shutdown trays 1AM-T25, 1AM-T4, 1AM-L7 and 1AM-L26. At the top of the photograph indicated by an arrow is 1AM-LA1, which can be seen with the armor-shielded cable.



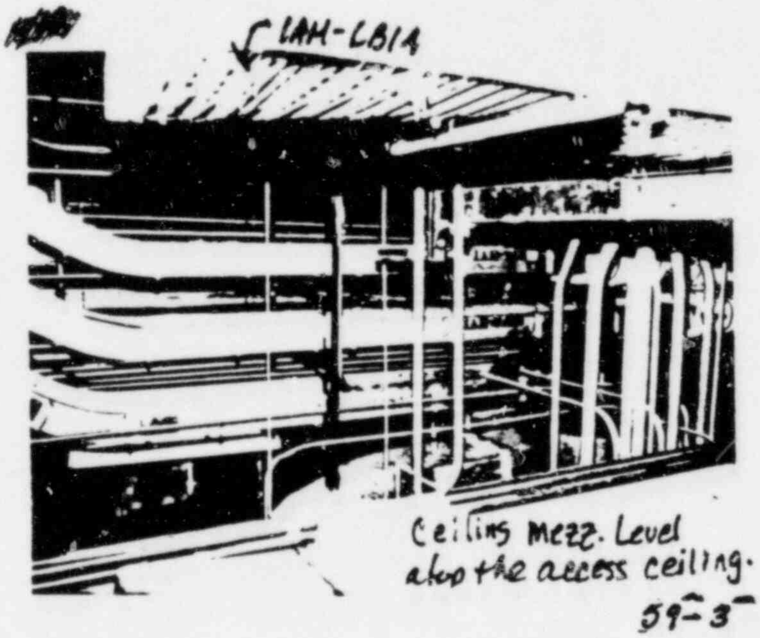
59-1

Photograph 2 shows green division tray 1AM-LB15 intersecting an orange division of trays which is wrapped in 1-hour Kaowool. That can be seen on the electrical physical layout drawings.

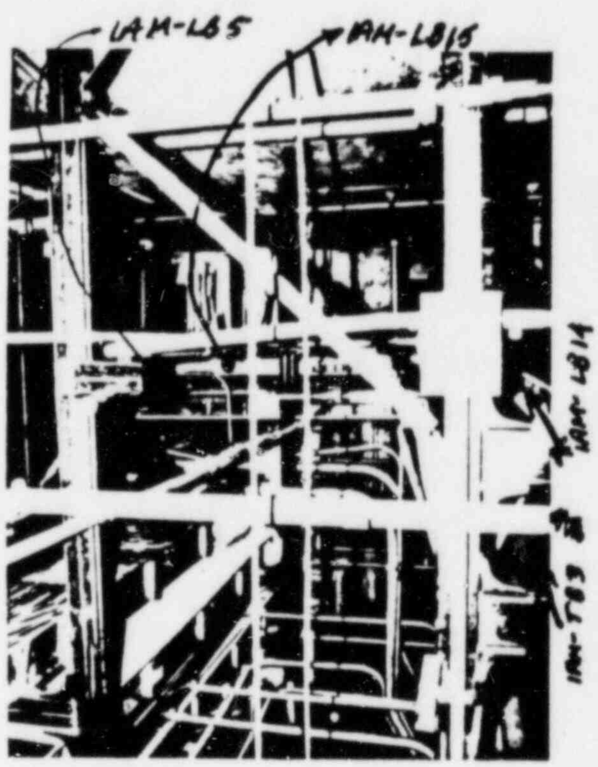


57-2

Photograph 3 depicts the three orange trays that are wrapped on the right-hand side of the photograph which were the same orange orange trays wrapped in the previous photograph. At the top of this photograph is the green division tray 1AM-LB14, located over the Access Control Area ceiling.



Photograph 4 shows again the three orange trays wrapped on the left heading west and intersecting the green division 1AM-LB15 (seen at the top). On the right-hand side of the photograph are the two green trays 1AM-LB14 and 1AM-TB3.



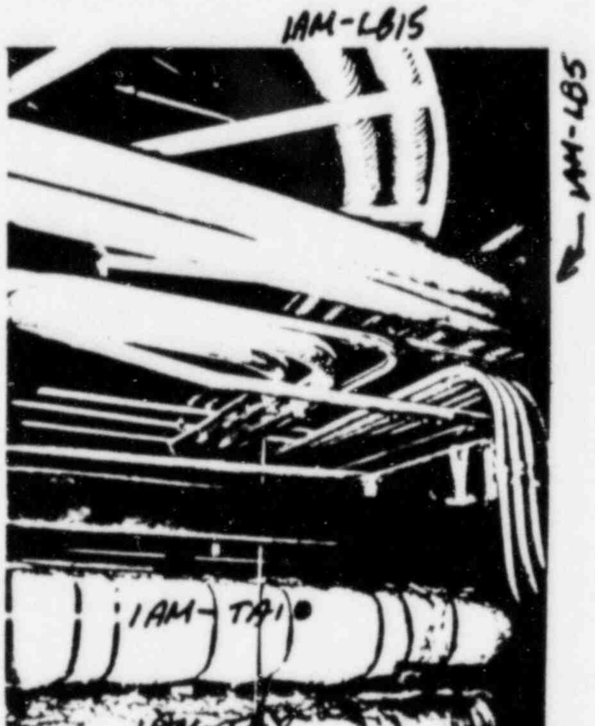
65-4

Photograph 5 in this area indicates two green division trays, the top one 1AM-LB14, the bottom one 1AM-TB3. Note that 1AM-LB14 does exit through the ceiling as indicated in the photograph.

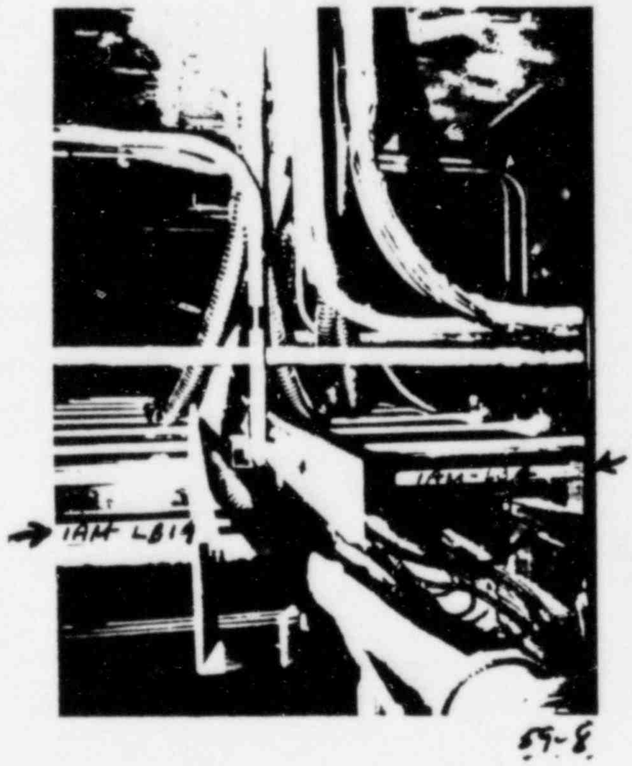
Photograph 6 depicts green division trays 1AM-LB5 and 1AM-TB4. 1AM-LB5 is of the armor cable type, and as seen here is coming to the west and going south. The tray in the upper left-hand corner of the photograph is 1AM-LB15.

59-6

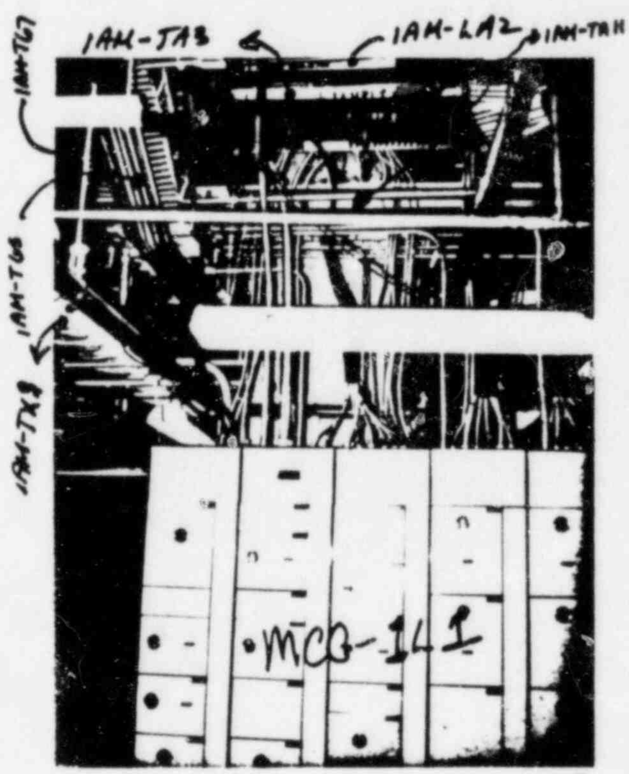
Photograph 7 is a continuation of the previous photograph indicating 1AM-LB15 and 1AM-LB5 intersecting the orange tray 1AM-TA10. Again, the photograph points out all power cables in armor-shielding.



Photograph 8 shows the termination point of the two green divisions above the Access Control Area ceiling 1AM-LB14 and 1AM-LB4. All the cable in both trays exit through the ceiling to the operating floor.

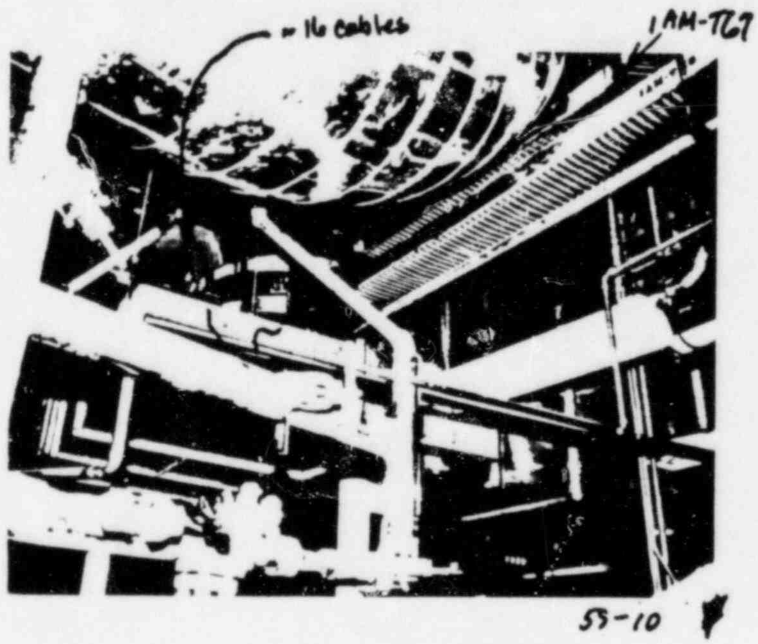


Photograph 9 shows a face-on view looking east to MCC 1-L-[illegible]. In the left-hand corner there is a wrapped tray 1AM-TX3. Above that tray is 1AM-T67, and to the right of that tray is 1AM-T65. 1AM-T65 and 1AM-T67 are very lightly loaded control cable trays that do connect the orange and green divisions running east and west. 1AM-T65 is a covered tray, and 1AM-T67 contains approximately 16 cables.

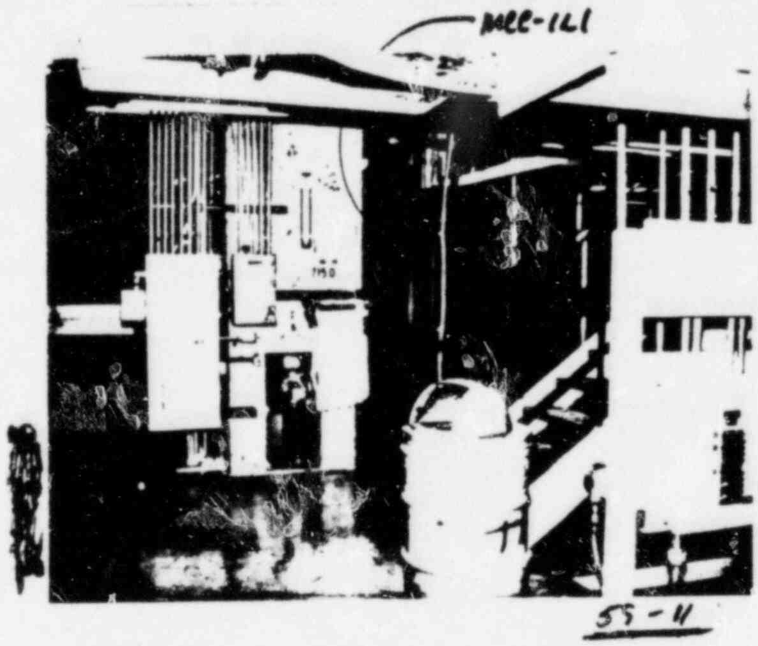


-55-9

Photograph 10, again a continuation of 9, indicates the 1AM-TX3 tray on the bottom after it was wrapped beyond the green tray, and 1AM-T67 indicating further down the cable tray the yellow bundled control cables.



Photograph 11 is a general area shot showing MCC 1-L-1.



Fire Area 59 has many existing wrapped trays which protect safe shutdown trays from the effects of intervening combustibles. Most of the trays potentially considered as intervening combustibles are very lightly loaded and horizontally intersect redundant safe shutdown trays separated by approximately 18 feet. These trays will be provided with fire stops to preclude any fire from propagating between divisions. Specifically, 1AM-T50, 1AM-T55 and 1AM-TB21 will be fire-stopped.

FIRE AREA 73

CONTAINS MOTOR CONTROL CENTERS 2K1, 2K2 AND 2KA2

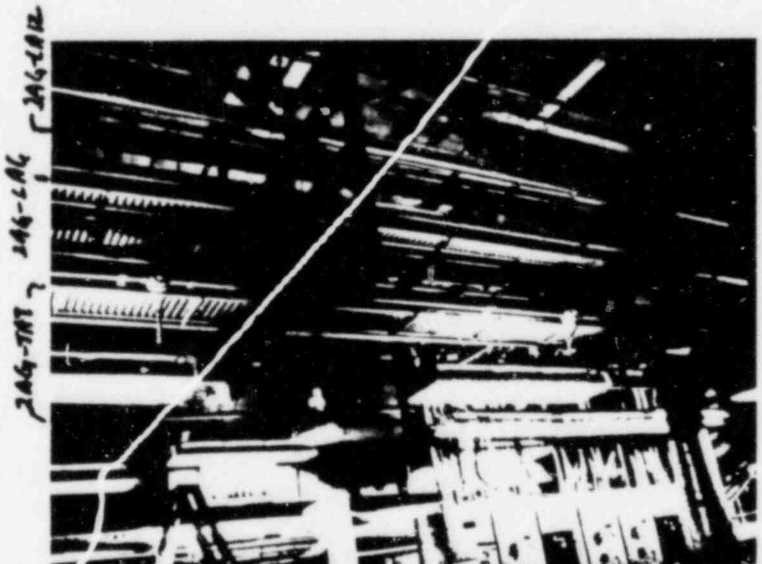
Location: Ground Floor, Auxiliary Building, Unit 2

Photograph 1 is looking north at Motor Control Center 2K1.

NORTH AT 2K1 Motor Cont. C.

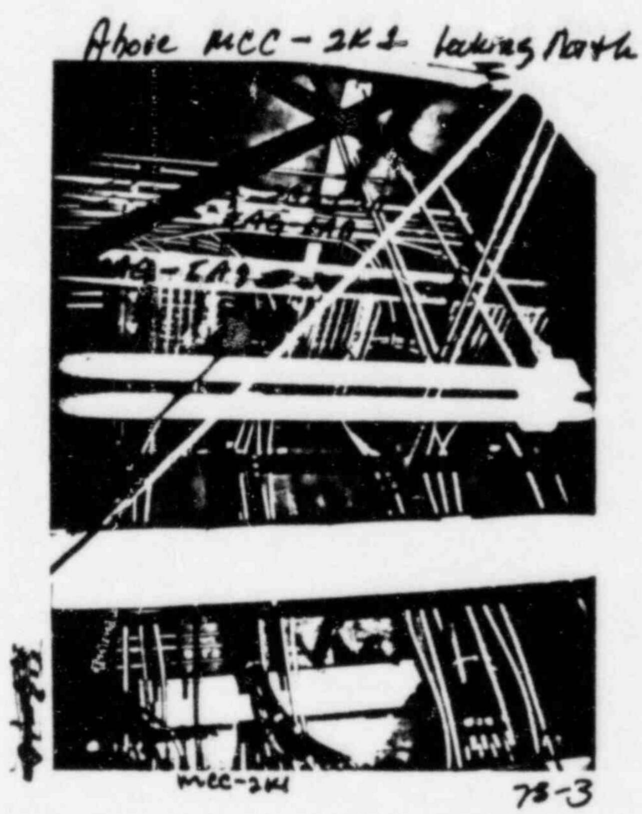
73-1

Photograph 2, looking north at MCC-2K1 as indicated on the photograph, the bottom tray is 2AG-TA7, going up is 2AG-LA6, and on top is 2AG-LA12. All of the trays in this photograph are from the orange division; and as can be seen at the top of the photograph, there are no perpendicular trays toward the direction of the green division (not seen).



Looking north at MCC-2K1 73-2

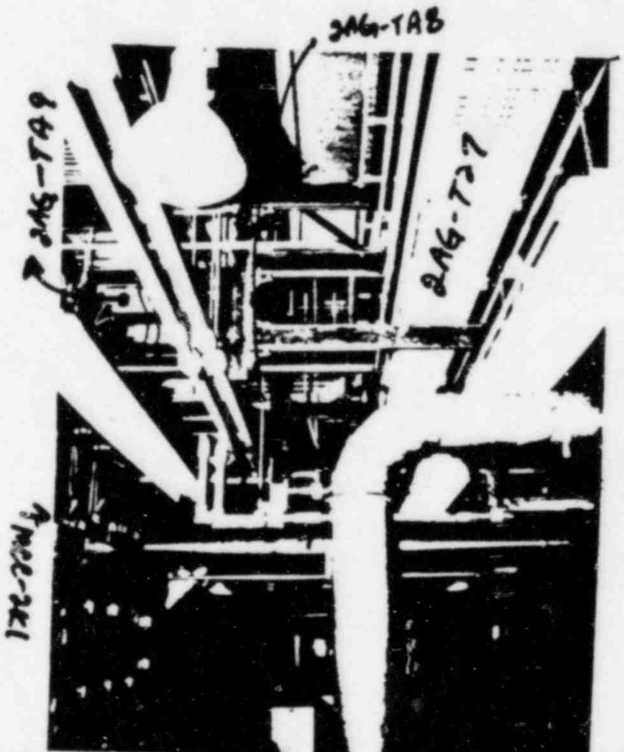
Photograph 3 is looking north above MCC-2K1. The orange division trays are, from the top: 2AG-LA11, 2AG-LA8, and 2AG-TA9.



Photograph 4 is looking East at the green division along the north side parallel to the orange trays in photograph 2. The trays indicated on the photo are, from right to left, 2AG-LB29, 2AG-TB23, FUT-D3 (Future), and 2AG-T24. To the left of where this photograph was taken would be the orange divisional trays as seen in the previous photograph.

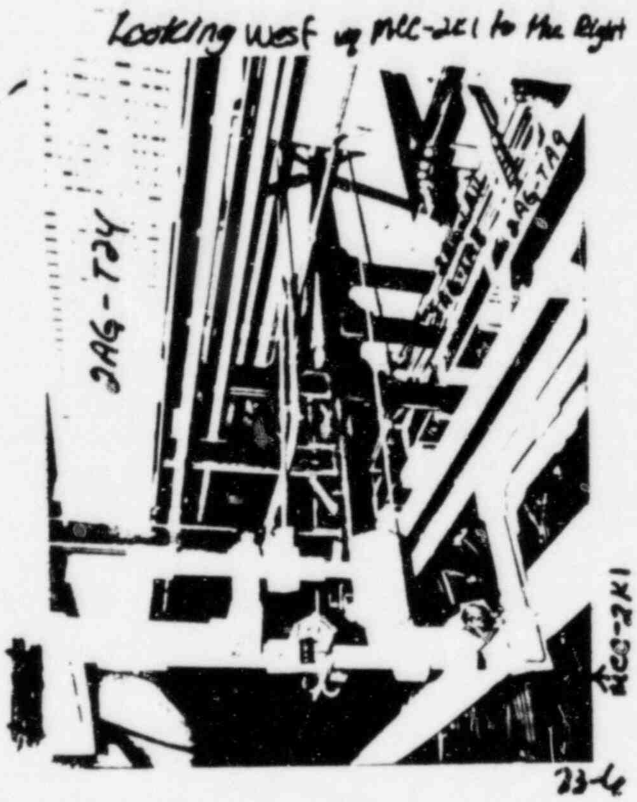
Looking east @ green div. 73-4

<u>Photograph 5</u> is looking east on the north side. The orange division Motor Control Center 2K1 can be seen in the lower left-hand corner of the photograph. The first tray above the Motor Control Center is 2AG-TA9. This photograph indicates the divisional separation of the green and orange trays in the east-west direction. The tray 2AG-T27 as seen on the right side of the photograph is the bottom tray from the previous photograph of the green division, and above it to the south is located the green divisional trays.



Looking East on North side 73-5

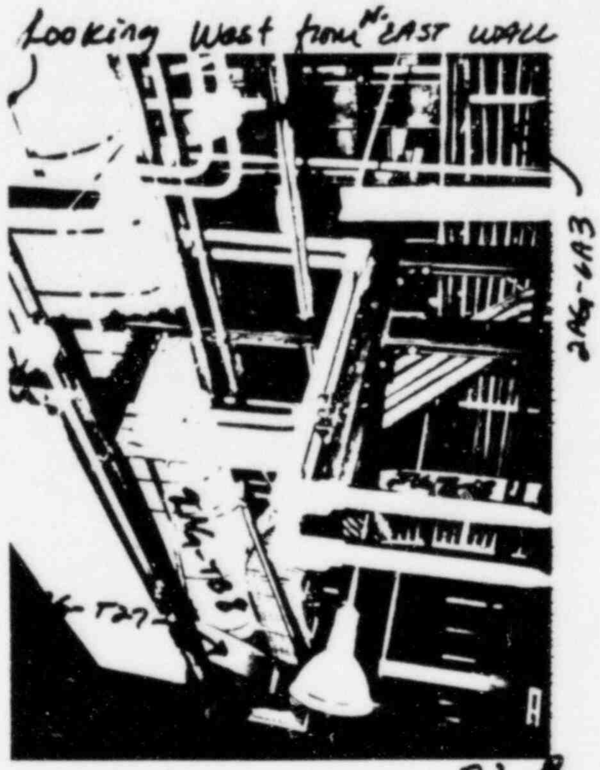
Photograph 6 shows divisional separation of orange and green. This photograph is looking west with Motor Control Center 2K1 to the lower right-hand area of the photograph. The trays from the top on the right side are 2AG-LA11, 2AG-LA8 and 2AG-TA9. The tray at the left side of the photograph is a non-safe shutdown tray 2AG-T24. Above and to the left in this photograph would be the green division trays.



Photograph 7, taken to the east of the Motor Control Center 2K1, indicates wrapped green division trays situated below the orange division. The orange division tray numbers from top to bottom are 2AG-LA13 and 2AG-TA11. It should be noted that 2AG-TA11 and 2AG-LA13 both have bottom covers on them. 2AG-TA11 likewise has a top on it. The green division 2AG-LB29 and 2AG-TB23 are seen with "Kaowool" wraps on them extending out approximately 8 to 10 feet from the the divisional crossover in both directions. In the far right-hand corner of this photograph is an orange division tray 2AG-LA14, which is a branch of 2AG-LA13 going first west, then south and terminating through a riser in the ceiling.

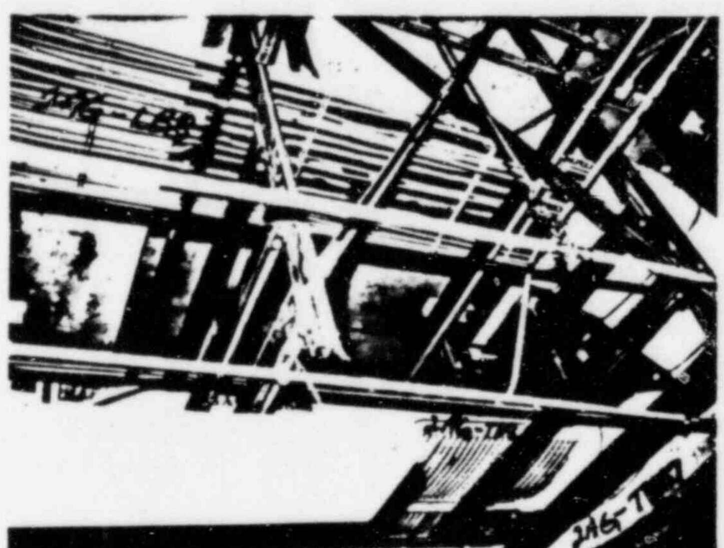
73-7 [redacted]

Photograph 8 is along the north side of the area looking east at two unprotected non-safe shutdown trays. The bottom one is labeled 2AG-T27. The next one up is FUT-D3. The wrapped cable tray indicated in this photograph is the green division. The tray number is 2AG-TB8. Above and to the right is seen 2AG-LA3, an orange division tray. This photograph indicates a potential intervening combustible tray between the orange and green divisions. At the point of connection the green division is wrapped and the orange division is exposed. However, it is contained in armor-shielding. The FUT-D3 tray, in fact, is an empty tray; and the 2AG-T27 tray has approximately six control cables located within it.



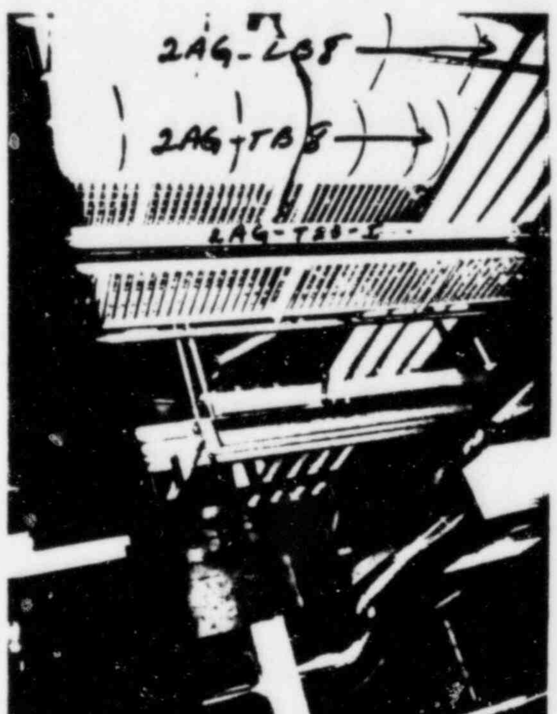
73-B

Photograph 9 indicates the continuation of the green wrapped division from the previous photograph. The top tray 2AG-LB8 contains armor-shielded power cables. The bottom tray shown right behind the fluorescent light is 2AG-TB8. Below that in the lower right-hand corner is 2AG-T27.

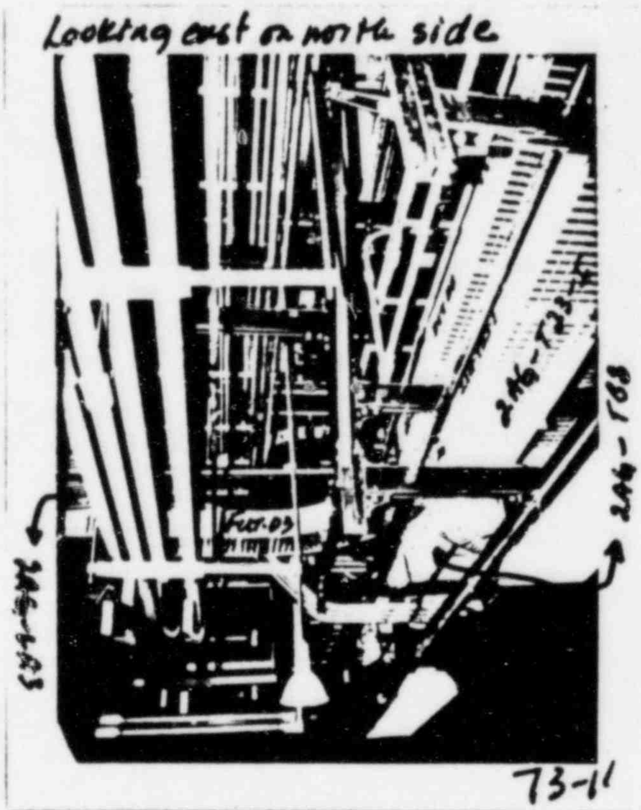


73-9

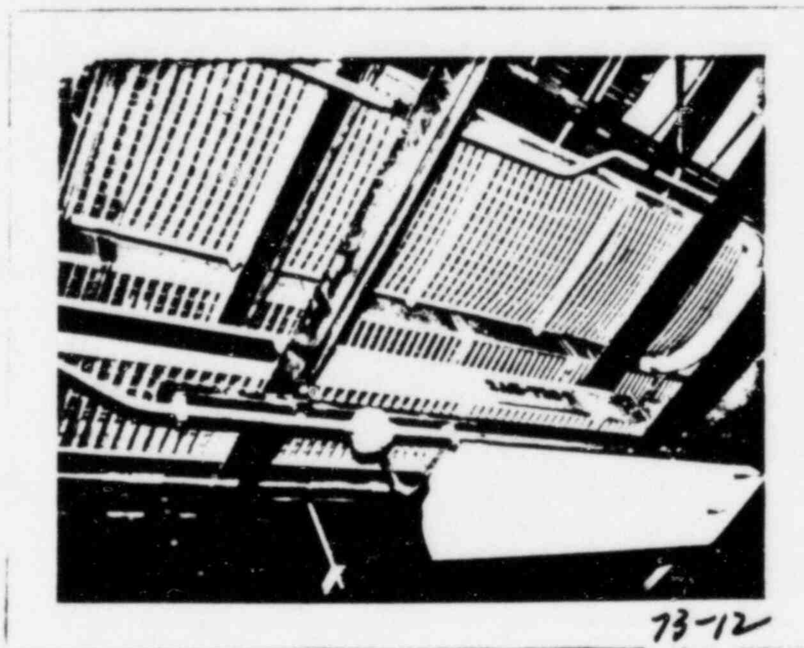
Photograph 10 is a continuation of the wrapped green division trays showing the top tray, 2AG-LB8. The next tray down is 2AG-TB8, and the bottom tray is 2AG-T23-I. As can be seen in the photograph, there are hardly any visible cables in the bottom cable tray. From this bottom cable tray is the section in the previous photograph where 2AG-T27 originates.



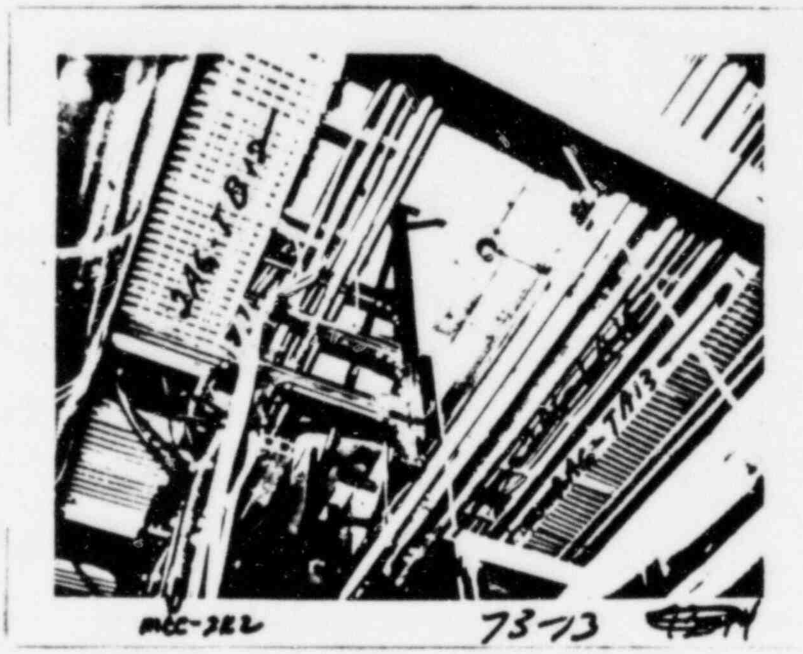
Photograph 11 looks east on the north side. The cable tray on the very bottom is again 2AG-T23-I, which goes to the south. Running to the north directly above it is FUT-D3, the empty tray, and above that would be the green division of safe shutdown cables. On the far left just visible is 2AG-LA3 going directly above FUT-D3.



Photograph 12 shows a partial view of tray FUT-D3, which is empty, and the tray below it, 2AG-T23-I, which is very lightly loaded with about 1/2 dozen instrument cables in it.

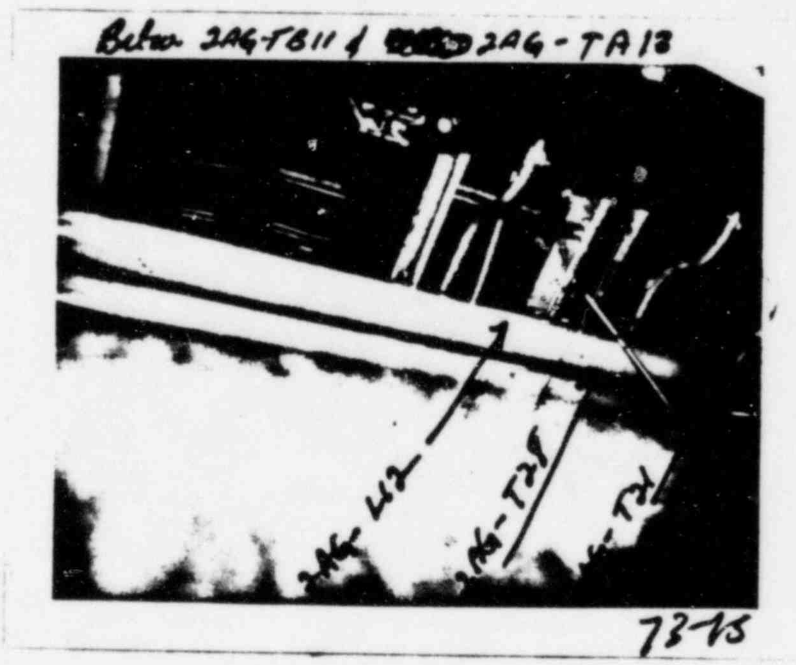


Photograph 13 is looking south between orange and green divisions at MCC-2K2. The green division is on the left; orange is on the right. Motor Control Center 2K2 cables can be seen in the lower left-hand portion of the photograph. Directly above it is 2AG-TB12. Above that is 2AG-LB11. On the right side of the photograph is the orange division. The top tray is 2AG-LA15, and below that is 2AG-TA13. This photograph also indicates no direct line of intervening combustibles connecting the two divisions at this point.



Photograph 14 indicates a shot that is taken looking up at 2AG-TA13 from the south end of Motor Control Center 2K2. The orange division trays are labeled. The top tray is 2AG-LA15, and the tray below it is 2AG-TA13.

<u>Photograph 15</u> indicates potential intervening combustibles between redundant safe shutdown divisions. There are three trays that are located on the physical layout drawing at co-ordinates 12 and between H and J. These three trays are very lightly loaded as the photograph will indicate. 2AG-L12 is on the left, 2AG-T28 is in the middle, and 2AG-T21 is on the right. All of these trays have covers on them, as indicated on the layout drawing. However, each of them contains approximately 12 cables.



The separation between red and orange divisions in Area 73 is sufficient with the modifications proposed. However, there are three trays which were considered as intervening combustibles. The light loading of the trays and the covers on them preclude them from being considered intervening combustibles. The two trays that were discussed earlier in the photographs, FUT-D3 and 2AG-T27, are of no significant importance. The FUT-D3 tray is empty, and the 2AG-T27 tray has only six cables in it.

FIRE AREA 74

Location: Mezzanine Level, Auxililary Building, Unit 1

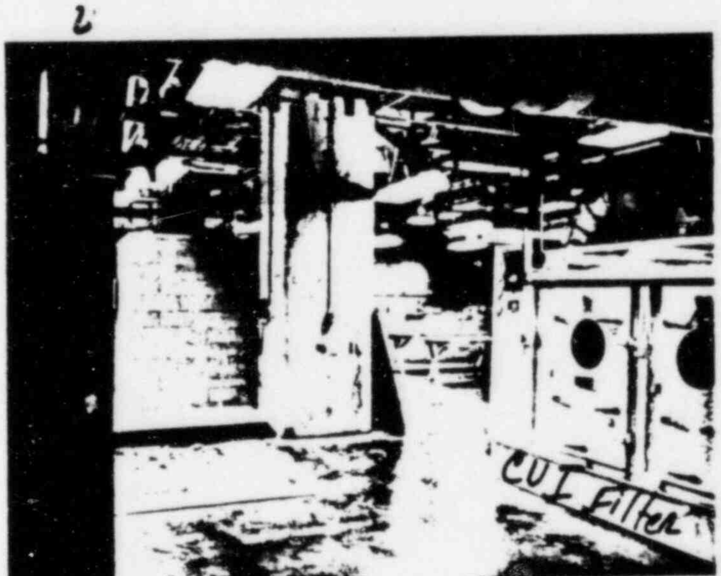
From looking at the general arrangement drawings, this area contains Motor Control Centers 2L2 and 2L1.

<u>Photograph 1</u> This shot is just to provide a sense of the general arrangement of the area. It does show the two motor control centers and also indicates, in all but one area, the absence of vertical trays.

Looking West at MCC-2L1 74-1

Photograph 2 is a picture looking to the northwest corner. In the lower right-hand corner the CVI filter is seen.

2

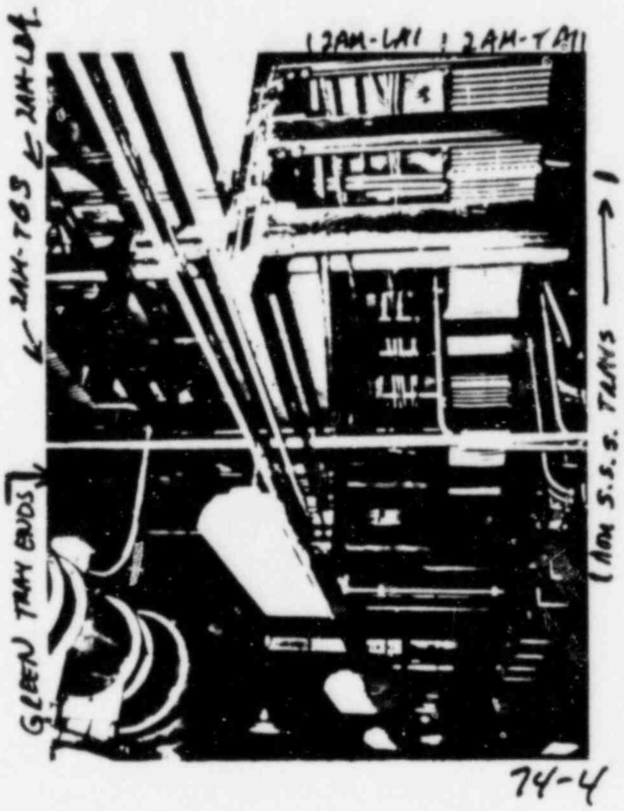


74-2

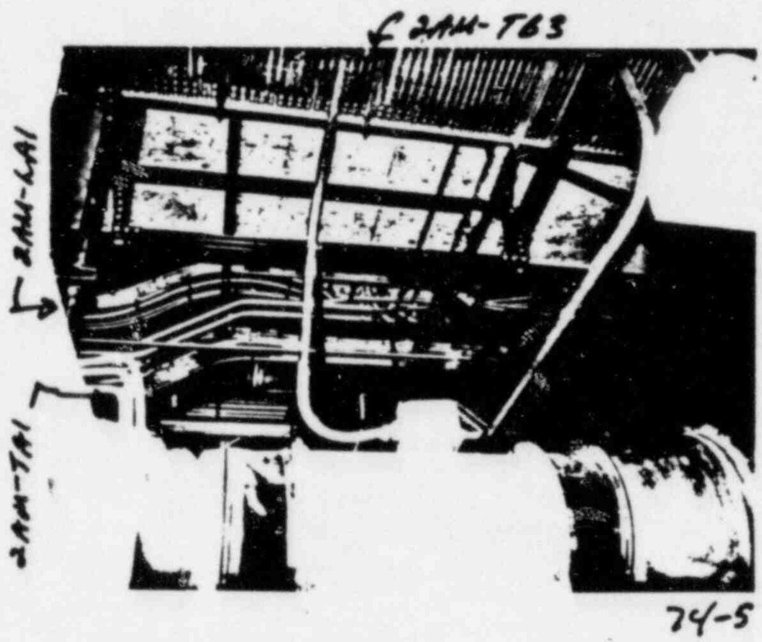
Photograph 3 was taken against the north wall looking east. The right-hand side again indicates the filter. Above the filter and above the center of this photograph are the cable trays of concern in this area.

LOOKING EAST

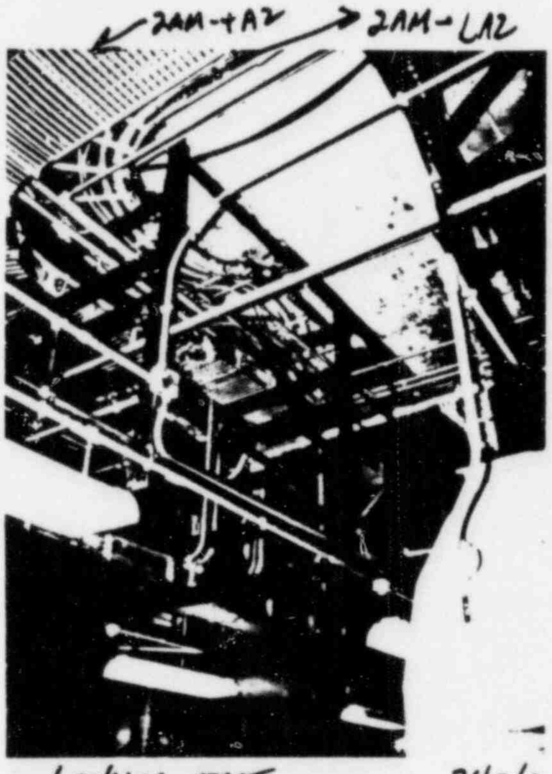
Photograph 4 is a picture that was taken looking west. The CVI filter is in the lower left-hand portion of the photograph. The right-hand trays are orange division and the left-hand trays are green division. The orange divisional trays are 1AM-LA1 in the center of the photograph and 1AM-TA11 on the far right side. On the left-hand side the beginning of 2AM-LB4 and 2AM-TB3 can be seen. In the lower right-hand corner there are approximately three trays seen that are non-safe shutdown cable trays.



Photograph 5, taken looking north over the top of the CVI filter. At the very top of the photograph the green division tray 2AM-TB3 can be seen which is also seen ending in this photograph with the cable exiting the ceiling. In the background on the top is 2AM-LA1 and 2AM-TA1, both orange division safe shutdown trays. The photograph also indicates that in this section there are no intervening combustibles located between the two divisions.



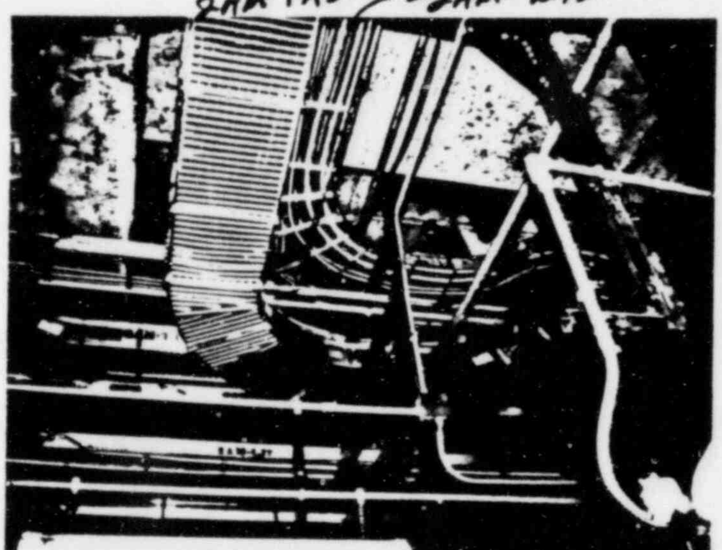
Photograph 6 is taken looking northeast. It indicates the orange division trays at the very top being 2AM-TA2 and, to the right of that, above it is 2AM-LA2. The lower right-hand corner is a segment of the CVI filter. In the background can be seen the continuation of the two previously mentioned trays.



Photograph 7 was taken looking directly above the CVI filters. The green division tray 2AM-TB3 can be seen where it splits and runs north and south with a major segment in the photograph seen to the left going west.

Green Trays above CVI Filter 7 4-7

Photograph 8, at the west end of the CVI filter, depicts the orange division trays 2AM-TA2 to the left and above. To the right is the tray 2AM-LA2. In the background are the previously mentioned non-safe shutdown trays that run east and west against the north wall.



above Filter 74-8

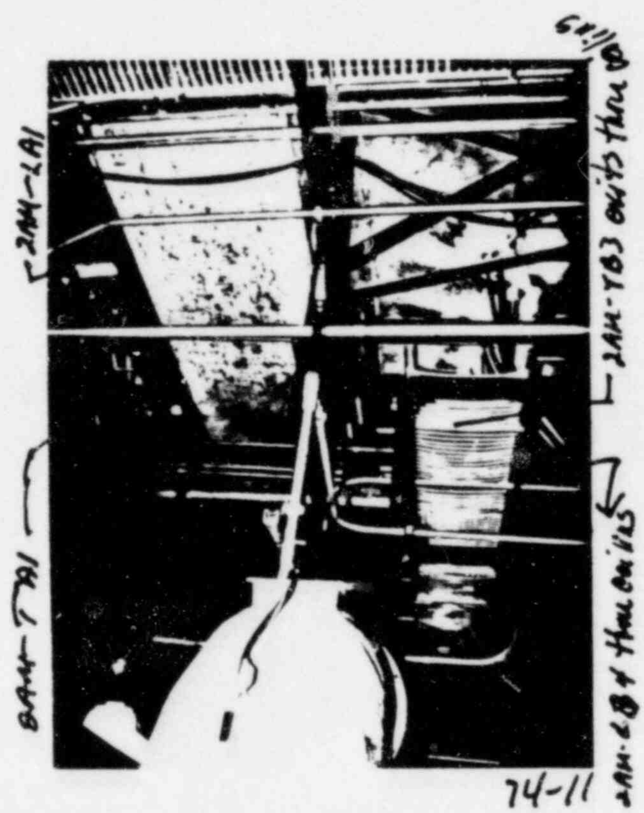
Photograph 9 was taken above the CVI filter. The two trays seen are green division trays. The bottom tray is 2AM-TB3, and the top tray is 2AM-LB4. As can be seen in this photograph, both trays are lightly loaded. The top tray is armor-shielded cable.

Green Div. above Filter 74-E

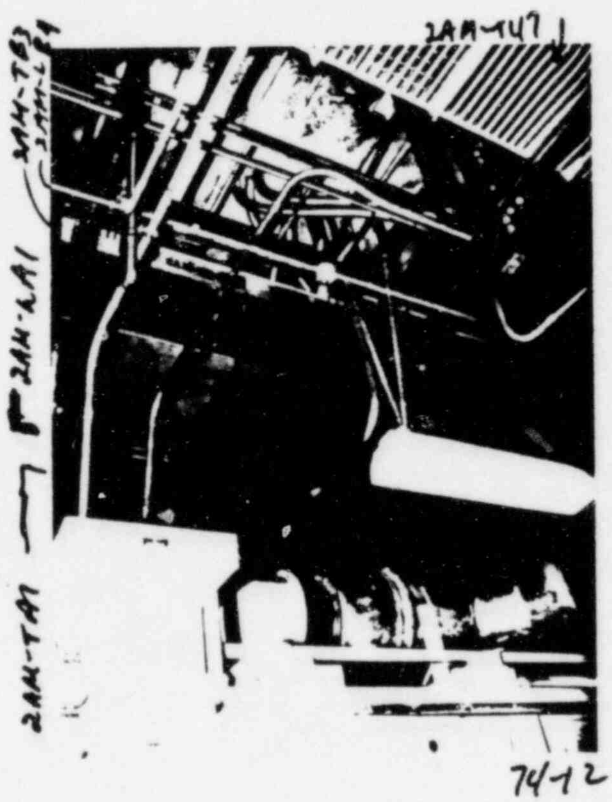
Photograph 10 The top 2AM-LB4 again can be seen, and 2AM-TB3 is below it. In the upper right-hand corner of the photograph is a non-safe shutdown tray 2AM-T47.

above Filter 74-10

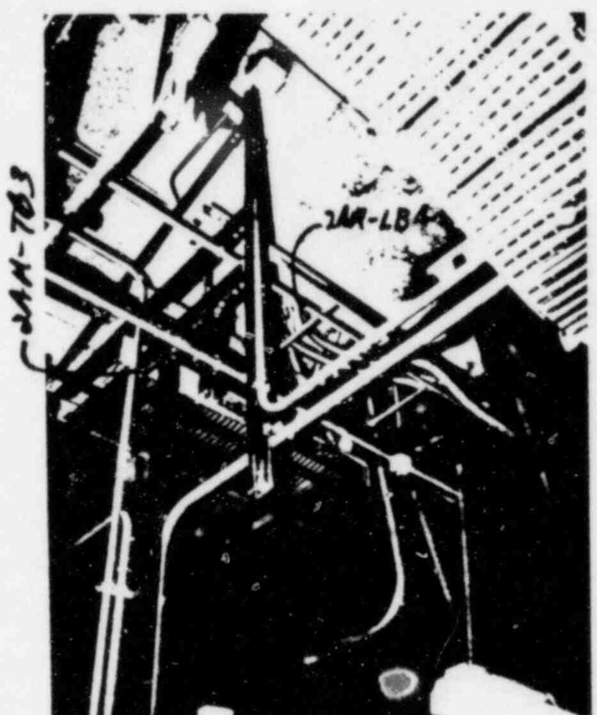
Photograph 11 was taken looking directly east over the top of the CVI filter. To the right center portion of the photograph is the termination of the green trays. The lower one is 2AM-TB3 and the upper one is 2AM-LB4. Both exit through the ceiling. To the left are the orange division trays. The top is 2AM-LA1, and directly beneath it is 2AM-TA1.



<u>Photograph 12</u> was taken looking north over the top of the filters. To the upper right-hand corner is again the non-safe shutdown tray 2AM-T47. The green division trays can be seen. The top is 2AM-LB4 and 2AM-TB3 is directly beneath it. Again the two orange division trays are in the background, 2AM-LA1 and 2AM-TA11.

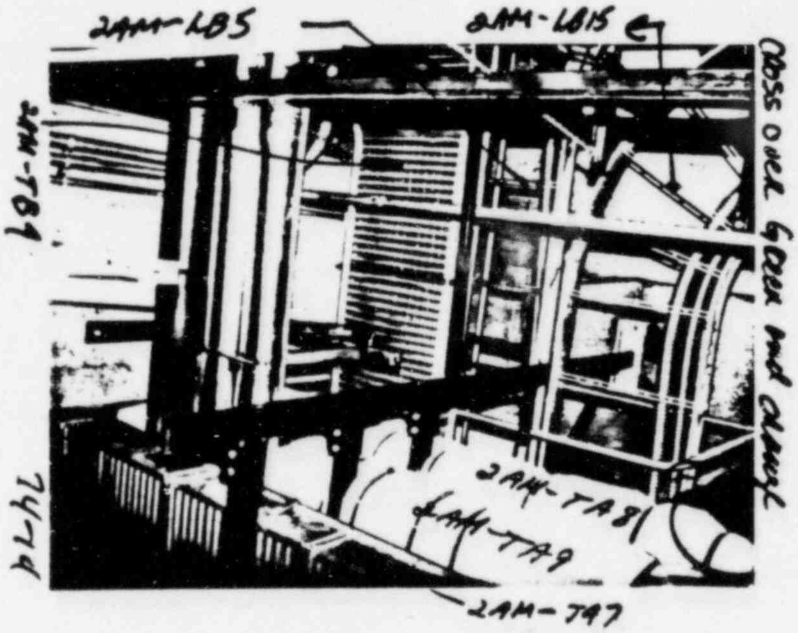


Photograph 13 was taken from the south looking north at the termination point of the green division trays 2AM-TB3 and 2AM-LB4, both seen exiting through the ceiling.



Above Filter 74-13

Photograph 14 was taken on the southeast corner of the CVI filter indicating an orange/green crossover. The orange trays are wrapped in this photograph. The top one is 2AM-TA8; below it is 2AM-TA9; and the non-safe shutdown tray 2AM-T47 is below that. There are three trays in this photograph perpendicular to the wrapped orange division trays. At the very top of the photograph is 2AM-LB15. Directly below that and in the background is 2AM-LB5, and 2AM-TB4 is located below both of them. As this photograph indicates, the latter trays are both very lightly loaded, one with two armored cables in it and one with one armored cable in it.



Photograph 15 is looking west. The trays seen are the orange trays previously shown in Photograph 14. The top tray is 2AM-TA8. Below that is 2AM-TA10, and the non-safe shutdown tray 2AM-T47 is on the bottom. At the very far left of the photograph can be seen 2AM-TB4 going perpendicularly to the orange division trays. Above that is 2AM-LB5. It should be noted in this area that all cable trays necessary for safe shutdown are armor-shielded power cables. The photographs provided indicated no potential intervening combustibles. However, there are trays intersecting both divisions which run east and west that will be fire-stopped to prevent the possible propagation of fires from one division to another, specifically, trays 2AM-T50, 2AM-T55 and 2AM-TB21.

FIRE AREA 37

Location: Ground Floor, Turbine Building
North of the Unit 1-Unit 2 Battery Rooms

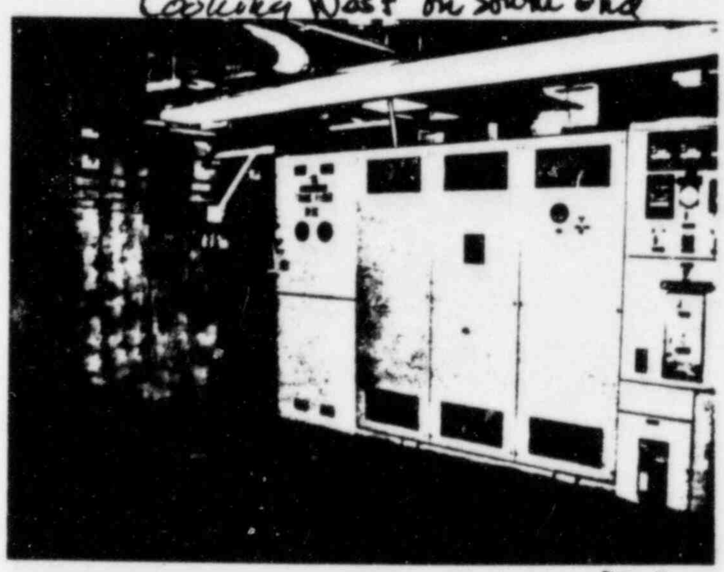
Photograph 1 is looking at the east wall. There are no vertical cable trays in this area anywhere and the area is very lightly loaded with fixed combustibles.

EAST WALL

Green conduit is on [redacted] east wall 37-1

Photograph 2 is looking southwest at the normal switchgear panel. Note the tops of the panel and that very few cables exit it.

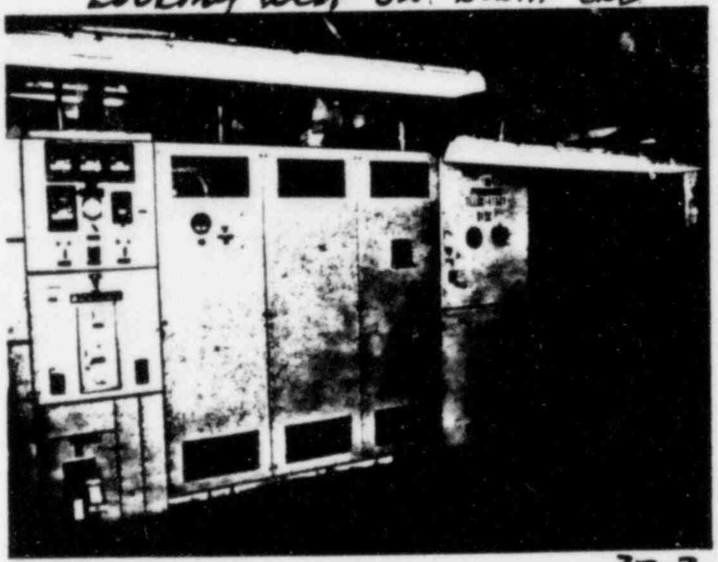
Looking West on South end



37-2

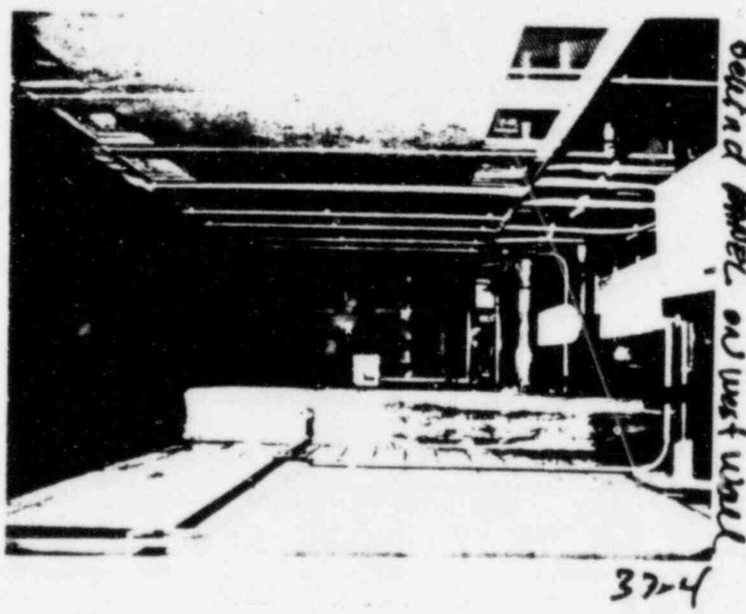
Photograph 3 is looking west at the switchgear panel on the north end.

Looking west on NORTH END



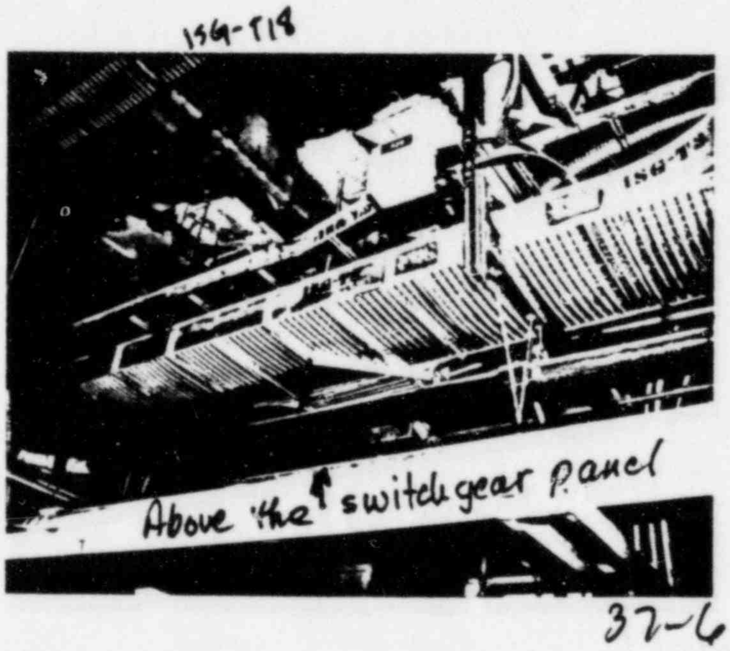
37-3

Photograph 4 is taken behind the panel on the west wall looking south. There are no cable trays that exit the west wall in this area. No cable trays are within approximately five feet of the west wall.

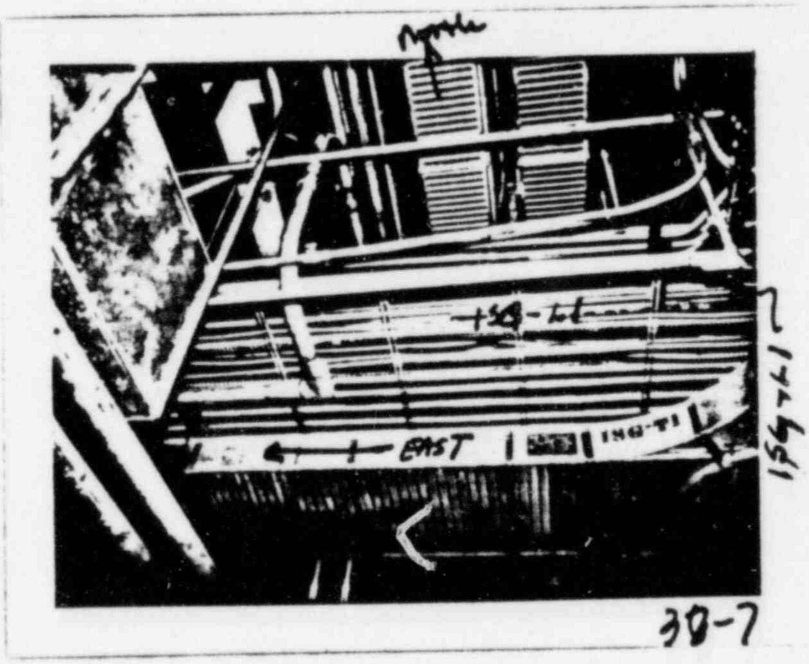


Photograph 5 is looking above the switchgear panel in the northwest direction. The tray 1SG-T3 which tees into 1SG-T1 runs north and south. 1SG-T1 runs from the tee going directly to the east wall. The two trays seen running north and south in this photograph are, on the left, 1SG-T18, and on the right 1SG-TA7. The small tray located above 1SG-T3 is 1SG-L27, which tees into 1SG-L1 above 1SG-T1. The armor-shielded cable in 1SG-L1 comes from the tray into the top of the switchgear panel, or parallels 1SG-T3 above and exists either the north or south wall.

<u>Photograph 6</u> is looking west above the switchgear panel. The armor-shielded cable can be seen coming from the cable trays above and dropping into the panel. In the upper left-hand portion of the photograph is tray 1SG-T18.

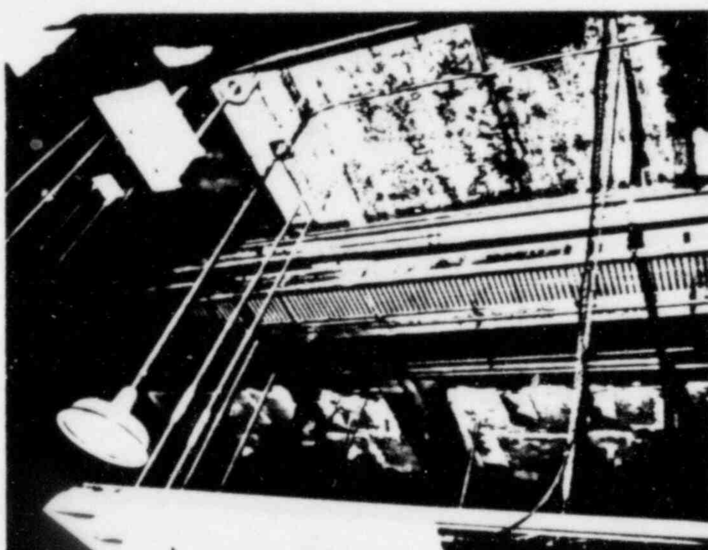


Photograph 7 is looking north at 1SG-T1. Above it is the 1SG-L1 tray. The two small parallel trays running north and south are again seen in this photograph. This photograph indicates the extensive use of armor-shielded cable in this area. Most of the cable tray runs in this area are of this nature.



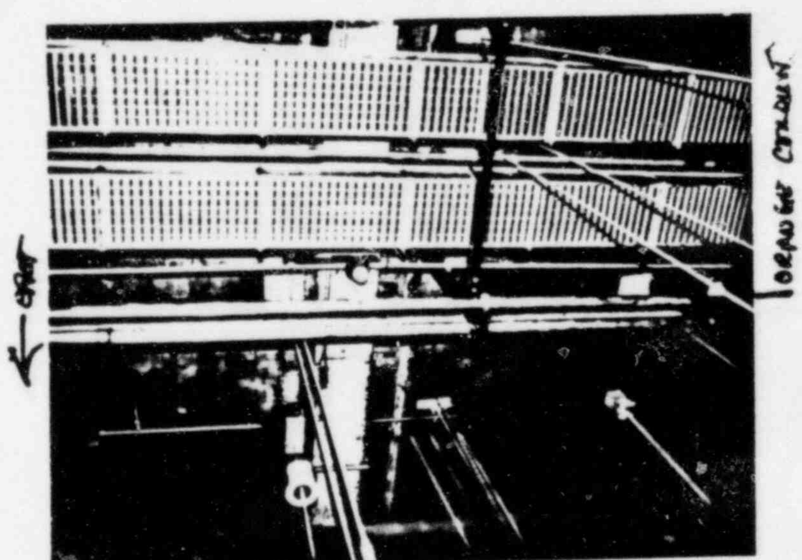
3B-7

Photograph 8 is looking west from the east wall. 1SG-TA7 is visible. The conduit that is located on the top of the cable tray, indicated in the photograph with an arrow, is the orange division conduit that is depicted in the sketch of the Appendix R analysis. This conduit runs north and south, paralleling cable tray 1SG-TA7 on the east side of the tray.



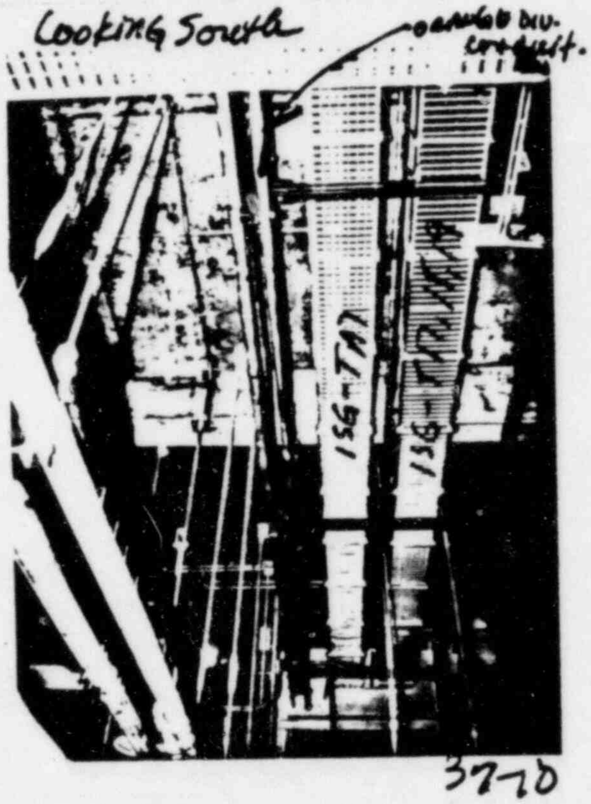
Looking west 37-8

Photograph 9 is looking east from the west side, again indicating the conduit from the orange division at almost ceiling height running north and south, paralleling tray 1SG-T17. As indicated in this photograph, there are no cable trays traversing the area at this elevation from the east-west direction.



37-9

Photograph 10 is looking south. The conduit with the orange label is the orange division conduit as depicted in the sketch. That would be on the west side.

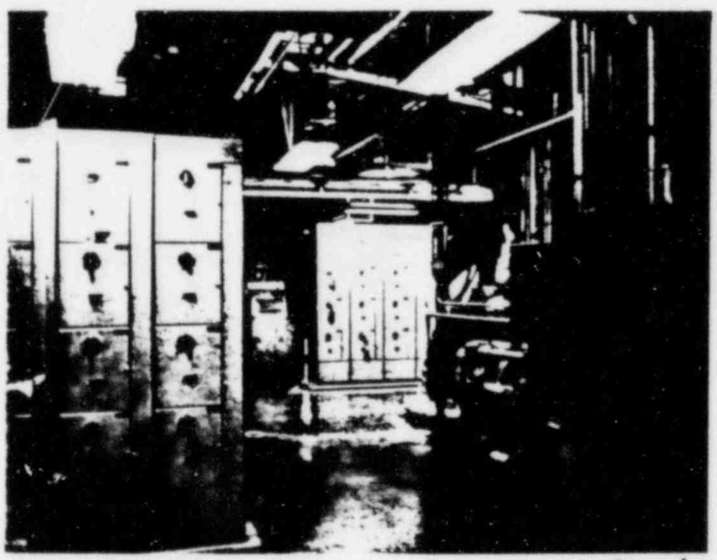


Fire Area 37 has two conduits located in it that are required for safe shutdown. The orange division runs along the east wall, the green division along the west wall. There are no cable trays that extend from the east wall to the west wall. The combustible loading in this area of exposed cables is extremely light. Photograph 5 depicts the most heavily loaded tray in the area, that is 1SG-T3 to 1SG-T1, with the remainder of the trays in the area predominantly being armor-shielded cable.

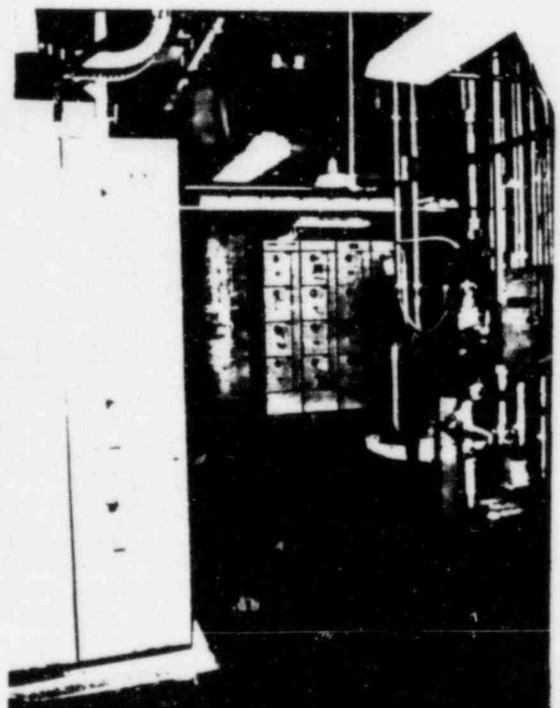
FIRE AREA 60

Location: Operating Level, Auxiliary Building, Unit 1

This area contains two Motor Control Centers, MCC-1LA and MCC-1LA2. Both motor control centers are fed from the floor beneath. No cables exit either motor control center from the top. As can be seen from both photographs provided of Area 60, there are no trays that are running transversely between the two motor control centers. The area is extremely lightly loaded with fixed combustible materials, and both motor control centers are in excess of 20 feet apart.



60-1



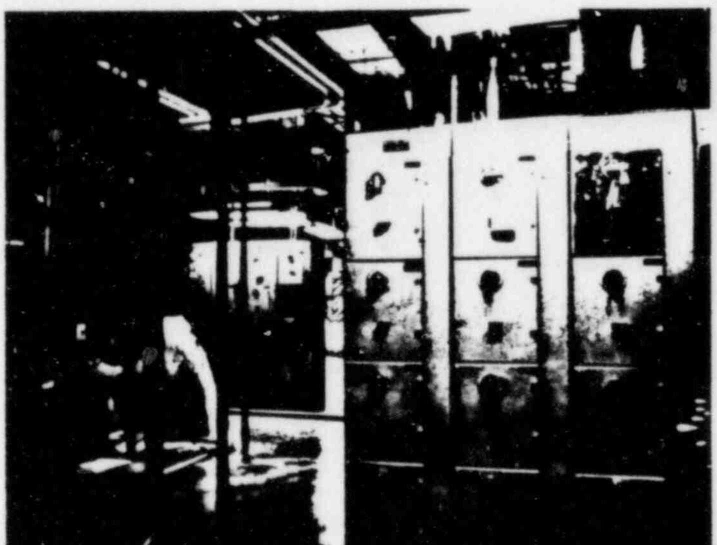
60-2

FIRE AREA 75

Location: Operating Level, Auxiliary Building, Unit 2

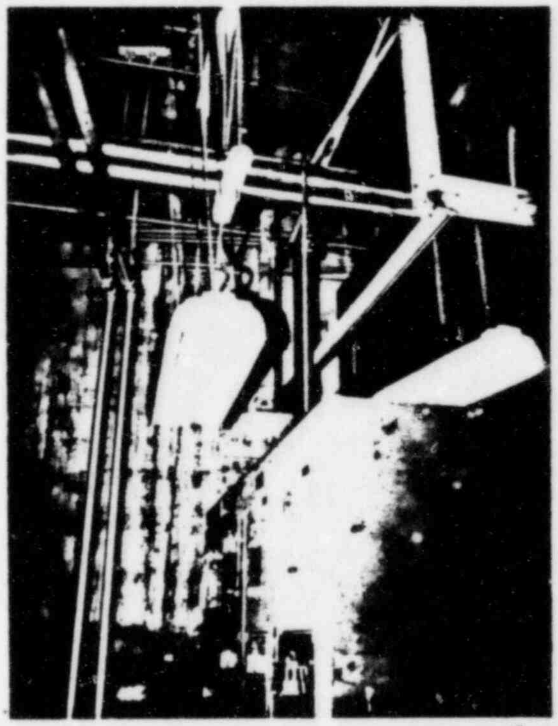
This area contains two Motor Control Centers, MCC-2LA2 and MCC-2LA1. They are an exact mirror image of Fire Area 60.

Photograph 1 shows again the arrangement of both motor control centers.



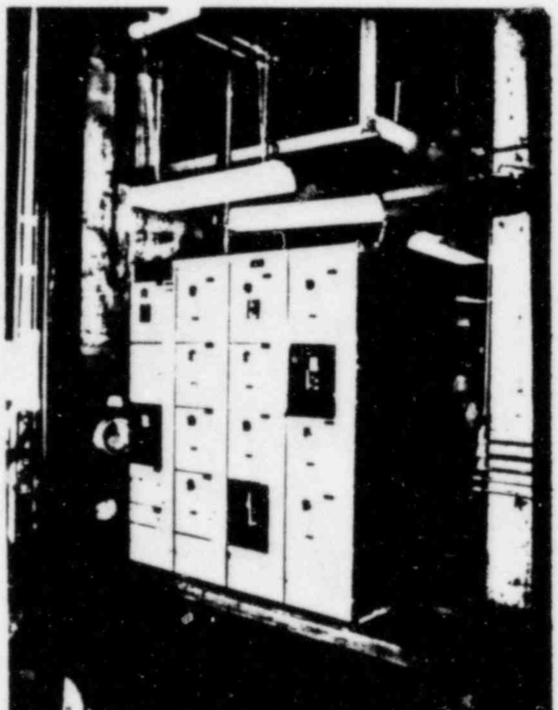
75-1

Photograph 2 indicates that no power cables exit the top of the motor control center.



75-2

Photograph 3 is a picture of the other motor control center in the area, and again no cable is exiting through the top of the MCC.



75-3

These pictures can be used for a graphic representation of the motor control centers in Area 60 as well. Fire Area 75, like Fire Area 60, has no cable trays above the motor control centers that would be potential invervening combustible trays. The line of sight between the two motor control centers at the ceiling down to the top of the motor control centers is free of any cable trays or any fixed combustible source.

SUPPLEMENTAL INFORMATION REGARDING MODIFICATIONS FOR PRAIRIE ISLAND NUCLEAR GENERATING PLANT

Northern States Power Company proposes to provide the following modifications as a result of recent NRC Staff meetings:

1. <u>Fire Areas 31 and 32, Auxiliary Feedwater Pump Areas</u>

The sprinkler system will be modified to provide coverage below cable trays. The additional sprinkler system will provide wet pipe suppression for all of the major components located in each of the fire areas. The modification proposed to the green division in each of the areas will be changed to include the use of "3M Fire Barrier" material to be fitted to the tray on the top and the bottom. This modification will provide protection of the green division from direct plume impingement due to a floor based exposure fire and prevent any possible damage of the safe shutdown cables from a local cable tray fire above the tray. The previous commitment to an "ASTM-1-hour-rated wrapping" for conduits is to be replaced with "an appropriate fire barrier wrap of 3M-type.

2. <u>Fire Area 58, Ground Floor Auxiliary Building, Unit 1</u>

The previously proposed modifications to the green division trays in this area will be replaced with "3M Fire Barrier" material to be placed on the bottom of the applicable green trays in the area. Where practical, the tops of these green trays will also be covered with the same material.

3. <u>Fire Area 59, Mezzanine Level, Auxiliary Building, Unit 1</u>

Non-safe shutdown cable trays 1AM-T50, 1AM-T55 and 1AM-TB21 will be provided with an appropriate fire stop to prevent the possibility of propagating fires between redundant divisions as a result of an intervening combustible fire. Fire Area 59 will also be supplied with a wet pipe suppression system to provide spot area coverage in the area of safe shutdown cable trays.

4. Area 73, Ground Floor, Auxiliary Building, Unit 2

The previously proposed modifications to the green division in this area will be replaced with "3M Fire Barrier" material to be placed on the bottom of the affected green trays. Where practical, this "3M Fire Barrier" material will also be placed on the top of the trays.

5. Fire Area 74, Mezzanine Level, Auxiliary Building, Unit 2

Non-safe shutdown trays 2AM-T50, 2AM-T55 and 2AM-TB21 will be provided with an appropriate fire stop to prevent the possibility of propagating fires from one division to another as a result of an intervening combustible.

1. BASIS FOR FAILURE CRITERIA

EPR/Hypalon electrical cable insulation undergoes a series of damage stages when exposed to an external heat flux. These stages include the onset of jacket degradation through offgassing, electrical failure and then ignition, with the incident heat flux and energy necessary for a cable to achieve each stage determined under controlled laboratory conditions. The most obvious reason for the selection of electrical failure as the cable damage criteria in the Prairie Island analysis was the requirement for consistency with the assumptions used in the rest of the modeling effort. Such consistency is especially important in order to accurately describe a particular zone's resistance to the combined effects of an exposure fire. This consistency in the base assumptions regarding failure criterion, fire size, ventilation effects, etc. is necessary in order to assign a meaningful relative figure of merit to the existing configuration and to properly evaluate specific proposed modifications. The relationship of the criteria to the modeling assumptions may be best described through a review of some of their principal features.

The stratification model utilizes empirically derived, spatially dependent, transient and steady state heat fluxes reported by Newman and Hill (1981) of Factory Mutual Research Corporation. Because this model does not assume steady state conditions immediately after exposure fire ignition, some amount of time is required to develop the ceiling layer of hot combus-

tion gases. This implies that the heat flux at any fixed elevation increases over time until some maximum steady state value is achieved. Therefore, any cable of interest will first exceed the lowest critical flux and start the accumulation of damage energy for that failure stage. For EPR/Hypalon this results in the accumulation of damage energy for both insulation degradation and electrical failure prior to exceeding the critical flux for ignition. Ignition of electrical cables due to the effects of ceiling combustion gas stratification is, therefore, not considered in the analysis.

In addition to these modeling considerations it is noted that experimental testing of EPR/Hypalon cable indicates that it is not susceptible to auto ignition when exposed to heat fluxes up to 70 kW/m^2. A heat flux of this magnitude cannot be realistically created by stratification effects unless an impossibly huge exposure fire is assumed. The only other ignition event which could lead to cable fires would be piloted ignition. This damage stage is determined experimentally by exposing a cable sample to an external heat flux with a pilot flame 1 cm above the surface of the cable. For cable trays 12-17 feet off the floor and removed from the direct effects of the exposure fire, exposure to a sustained pilot is likewise not credible. The extremely low horizontal propagation of EPR/Hypalon is well documented. Even if a localized tray fire were to occur, it would not approach the magnitude of the heat release rate of the postulated exposure fire. The low heat release rate of a localized cable

fire in comparison to the postulated exposure fire results in a negligible positive feedback effect. For this reason the selection of piloted ignition as a failure criteria for a cable removed from the direct effect of an exposure fire is inappropriate and would result in the addition of an unnecessary conservatism to the analysis process.

This conclusion is substantiated by recent experimental results from two different sources. Klamerus (1982) describes results for a test program specifically designed to examine the effects of combustion gas stratification. The two types of target cables used in this program were both less resistant to ignition than EPR/Hypalon. In the six tests conducted, none of the cable trays subjected to stratification effects ignited. As target cable ignition was not noted, it can be inferred that these test results support the contention that piloted ignition of cable trays exposed to stratification effects is a low probability event and will not impact the conservative nature of the analysis. Recently published test results by Sumitra (1982) of Factory Mutual Research Corporation are supportive of Sandia's results and also highlight the extreme fire resistance of EPR/Hypalon cables. These cables were subject to the direct flame impingement of 5 gallons of heptane at or below the critical height of the fire and still required long periods of time (>30 minutes) to fully ignite the target cable trays.

Because EPR/Hypalon resists auto ignition, two conditions

must be met in order to cause ignition of this cable. First there must be an ignition source present which, as previously discussed, is not a credible occurrence for cables high off the floor and removed from the direct effects of an exposure fire. Secondly the heat flux necessary to ignite EPR/Hypalon under piloted conditions is very high, typically in the range of 23-29 kw/m. To cause this magnitude of a heat flux by combustion gas stratification requires a huge exposure fire especially for a fire area with a 19 foot high ceiling. To postulate a liquid hydrocarbon exposure fire with a diameter of 10-15 feet while maintaining the base assumption of ideal ventilation for perfect combustion in all regions of the burning pool is completely unrealistic. For liquid fires with diameters greater than 6-10 feet this assumption concerning ventilation yields especially non-realistic results.

In summary, the proper cable failure criteria selection for the stratification model is electrical failure. This results in a consistent modeling approach and is justified by the room geometry and cable type being analyzed. It is consistent with the conservative nature of the exposure fire calculation efforts and results in realistic conclusions.

2. EXCESS PYROLYZATE

Excess pyrolyzates from incomplete fuel combustion within the exposure fire or resulting from evolution of combustible vapors from cable insulation material exposed to heat fluxes has not been reported to be a significant mechanism for failure of cables. Recent Sandia tests of cable tray installations, designed to examine the stratification effects of a heptane fire in a small enclosure, did not report the phenomenon of pyrolyzate accumulation contributing to damage (energy deposition) at the target cables.

Due to energy conservation considerations, if the excess pyrolyzate accumulation rate increases due to incomplete exposure fire combustion, then the heat release rate associated with the exposure fire must decrease due to reduced combustion efficiency. This implies that the heat flux exposure of the target cables must also be less. Exposure fire combustion in the Prairie Island fire hazard analyses was assumed to be unaffected by oxygen starvation and reduced combustion efficiency in order to maximize the heat flux and energy deposition at the target cable. Therefore, to be consistent, maximization of the imposed heat fluxes obviated the need to consider excess or unburned fuel pyrolyzates.

Furthermore, the objective of the use of the stratification model in establishing a general "figure-of-merit" (as measured in gallons of acetone based upon the failure of cables within the

artificially defined enclosure) would not have been enhanced by an additional cumbersome and necessarily speculative treatment of unburned fuel pyrolyzates in the stratification layer.

The concern for the hazards of pyrolyzate accumulation from fixed combustibles has its origins in observations of the progress of fires in residential and commercial rooms with high combustible loadings, a situation atypical of nuclear power plants. In residential and commercial fires there may be significant generation of pyrolyzates from objects and structures remote from the initial exposure fire that can contribute to the fire propagation. The nuclear power plant rooms examined in the Prairie Island fire hazard analyses have much lower combustible loadings composed primarily of EPR/Hypalon cable insulation, which is quite different from typical residential and commercial room furnishings in its thermal exposure response.

The analytical techniques used in the Prairie Island fire hazard analyses to assess the performance of EPR/Hypalon in rooms with exposure fires may lead one to unrealistically infer a potential problem that this high quality, flame propagation resistant cable material is subject to the phenomenon of cable pyrolyzate accumulation. This complex physio-chemical degradation process cannot be completely described by the two values of "qcrit" and "Ecrit" used to determine cable failure. Data for the mass loss rates from EPR/Hypalon cables as a function of imposed heat flux without ignition and combustion is not presently available.

In order to better address the potential hazards of this phenomenon, a functional relation for the cable insulation pyrolysis rate at heat fluxes between the onset of mass loss and cable ignition need to be developed for each cable type. The relationship could then be used to determine the accumulation of pyrolyzates in the room atmosphere and to deal with mitigating conditions such as room ventilation or atmospheric vitiation. The cable insulation pyrolysis rate data would be required before any meaningful assessment of the significance of cable pyrolyzates could be made.

The issue is reduced to insignificance at Prairie Island because of the manner in which the analytical evaluations of cable failure in each fire area was conducted. In each area, the safety related cables penetrate the ceiling or are located within the highest cable tray, and therefore were exposed to the maximum heat fluxes associated with the stratification layer. Also in each area, by original plant design, the unarmored control cables which might be postulated to be contributors of pyrolyzed combustibles are at significantly lower elevations where they would experience substantially reduced heat fluxes, being in cooler regions of the stratification layer. These cables would, therefore, also experience a reduced pyrolysis rate. As stated previously, however, the actual values for the pyrolysis rates at these heat flux values are unknown.

3. CORNER AND WALL EFFECTS

An issue that was raised by Brookhaven National Laboratories concerns the potential for an enhanced heat release rate for exposure fires located in the corners or against the walls of non-combustible enclosures. This issue is based upon an interpretation of conclusions presented by Alpert (1975) for a hydrodynamic treatment of a fire plume and ceiling jet using image symmetry arguments. Alpert's work was referenced in the Prairie Island Appendix R submittal and considered in the analysis of the effects of fire plumes on electrical cables. The interpretation made in that report reflected the view of image symmetry and discounted any impact of the walls on the source fire's heat release rate. This interpretation has recently been confirmed to be correct in a telephone conversation between R. W. Sawdye (EPM) and R. L. Alpert (Factory Mutual Research Corporation) on October 8, 1982. In that discussion, Dr. Alpert stated that it was not his intention to state that a fire located next to a wall or in a corner would have any significant enhancement of its burning or heat release rates. Rather, Alpert stated that the correct conclusion to be derived from his paper was that a fire next to a wall or in a corner would exhibit effects on flame length and plume geometry. These effects occur as a result of impaired air entrainment into the plume to support combustion of the fuel vapors, and the potential attachment of the plume to the solid surfaces. Further, these wall and corner effects are localized

and only modify the fire plume geometry without feeding back to the pool fire itself.

While it is not possible at this time to assess completely the effects of walls and corners on convection or radiation calculations, it is considered that phenomenon of plume attachment and flame extension may act to both mitigate the heat transfer to target cables in the vicinity, as well as enhance its effects. Since the analysis focuses on failure of redundant divisions, these effects may be considered to be compensatory in these regimes.

Turning to the issue of stratification, since the localized effects of non-combustible walls impact only on the fire plume dynamics without enhancing the heat release rate due to fires, the effects of an altered plume geometry due to an impaired air entrainment function on the stratified layers are considered to be negligible.

4. LOCATIONS OF EVALUATED FIRE HAZARDS

The Prairie Island analysis focuses on floor based fires in demonstrating the value of passive protective measures. This approach reflects the concern for providing fire protection against hazards where they are most likely to occur through the use of bounding analysis. With this perspective, it was recognized early in the analytical process that a small subset of possible fire scenarios may not be examined in detail through a simple set of deterministic analyses. This was not considered to be a significant deficiency since the objective of the analysis was to provide a conservative and consistent treatment of the effects of a type of fire which bounds the majority of cases. In so doing, the reviewer would be provided with a perspective of the relative merit of the existing and proposed fire protective measures. With a focus on the transient combustible fires as a potentially significant source, and the relationship of such materials to maintenance activities and normal traffic patterns, it was decided that this objective would be best served by consistently addressing floor based fires.

The physical configuration of the zones for which exemptions are requested, both in the existing and in the modified states, also confirm the appropriateness of the selection of floor based fires. As has been previously noted, the armored power cables are run in open ladder trays with rung spacing in excess of one foot. Further, in the zones for which exemptions are requested

the power cable trays are lightly loaded, often with twelve or fewer cables per tray. There is no credible mechanism by which liquid hydrocarbon accumulation can be postulated in these power cable trays. Also, the control cable trays in the areas of concern are typically lightly loaded or covered and have perforated bottoms which acts to preclude the accumulation of any postulated spilled liquid within the trays.

Maintenance activities requiring the use of flammable fluids anywhere in the plant, and particularly where safeguard equipment is located, requires written authorization. Introduction of flammable materials into any plant area requires both a completed Work Request Authorization and a Hot Work/Flammable Materials Use Permit. The latter is required prior to the introduction of either an ignition source or a source of flammable materials. This permit also requires the presence of a fire watch at the work location during the conduct of the work. It is difficult to envision the type of activities that would involve placing of personnel in proximity with the trays in the areas of interest with even small quantities of flammable liquids given the absence of congestion, equipment and/or piping at the elevations of interest. This can be seen from the photographs of the plant provided in Attachment 1. Finally the point should also be made that high levels of plant maintenance and modification activity is most likely to occur during periods when the particular unit is in cold shutdown.

5. DESCRIPTIONS OF MODELS USED IN THE PRAIRIE ISLAND FIRE HAZARDS ANALYSIS

5.1 Heat Release from Fuels

References:

(1) A. Tewarson, "Heat Release Rate in Fires", Fire and Materials, v.4, pp. 185-191, 1980.

(2) A. Tewarson, "Physico-Chemical and Combustion/Pyrolysis of Polymeric Materials", RC80-T-9, FMRC, 1980.

(3) A. Tewarson, "Fire Behavior of Transformer Dielectric Insulating Fluids", DOT-TSC-1703, FMRC, 1979.

Assumptions:

The fire heat transfer models require specification of fuel thermal performance. The fuel data of Tewarson was used to create a single set of bounding fuel parameter values for an unconfined turbulent combustion plume above a large pool for each fuel. The set of fuel performance parameters is used in all heat transfer computations to describe the heat release characteristics of that particular fuel.

Acetone Pool Fire Performance Parameters

fuel vaporization rate	=	40.0 $g/(m^2.s)$
actual total heat release	=	936.0 kW/m^2
convective heat release rate	=	480.0 kW/m^2

5.2 Cable Failure Criteria

Reference:

J. L. Lee, "A Study of Damageability of Electrical Cables in Simulated Fire Environments", NP-1767, FMRC, 1981.

Assumptions:

The assessment of fire hazards requires specification of cable damage and failure criteria. The model for cable response to imposed heat fluxes employs the test results presented by Lee. Damage energy accumulation commences when and if the imposed heat flux is greater than or equal to the specified cable critical heat flux (qcrit). The failure mode occurs when the accumulated damage energy reaches the corresponding specified cable critical energy (Ecrit). The full imposed heat flux is used for damage energy accumulation (not the difference between the imposed and critical heat fluxes as implied by Lee). The ability of armour to protect cable from degradation is ignored in the analyses. Cable armor is assumed to protect against piloted and auto-ignition of cables. Cable failure criteria are associated with cable jacket and insulation material types, such as EPR/Hypalon cables.

EPR/Hypalon Cable Failure Criteria

Failure Mode	sample no.	qcrit (kW/m^2)	Ecrit (kJ/m^2)
Initiation of Insulation Degradation	11	6.0	3390.0
	8	11.0	1792.0
	59	19.0	1420.0
Piloted Ignition of Cable	11	23.0	640.0
	59	27.0	390.0
Electrical Failure of Cable	11	9.0	19600.0
	8	14.0	16950.0
	59	17.0	23700.0

5.3 Heat Transfer from Stratification Layer

Reference:

J. S. Newman and J. P. Hill, "Assessment of Exposure Fire Hazards to Cable Trays", NP-1675, FMRC, 1981.

Assumptions:

The combined convective and radiative heat transfer to cables immersed in the stratification layer that develops in a room containing a fire is modeled by correlations of data presented by Newman and Hill. The fire enclosure is empty except for the fire and target cable. The room has dimensions of H x H x 2H, where H is the ceiling height. There is no reduction of imposed heat flux at the cable surface due to room ventilation. There is no variation of imposed heat flux with horizontal position within the enclosure. The stratification layer model utilizes a different correlation of data presented by Newman and Hill for the steady state heat flux, because their correlation behaved poorly with ventilation rate.

Stratification Layer Heat Transfer Model

t	=	time after start of fire (s)
z	=	elevation of target cable (m)
D	=	fire diameter (m)
H	=	ceiling height (m)
B	=	fuel transient burn parameter = 51.0 (for acetone)
	=	Time Constant (s)

Q = fire heat release rate (kW)

= D**(-0.5)*B

tss = time to steady state = B/(D**0.5*(0.52*(z/H)**0.5)**1.111) seconds

qss = steady state heat flux = (Q/H**2)*(0.05585/(1.193-z/H)**0.5)/ (0.01161-0.01031/(2.13-z/H)**0.5)**0.153 kW

qt = transient heat flux (for t<tss) = (0.52*qss*(z/H)**0.5*(t/)**0.9 kW

5.4 Thermal Radiation from Flames

References:

(1) H. C. Hottel and A. F. Sarofim, "Radiative Transfer", McGraw-Hill, N. Y., 1967.

(2) S. Hadvig, "Gas Emissivity and Absorptivity: A Thermodynamic Study", Journal of the Institute of Fuel, 1970.

(3) R. Siegel and J. R. Howell, "Thermal Radiation Heat Transfer", 2nd Edition, McGraw-Hill, N. Y., 1981.

Assumptions:

Thermal radiation from the fire is modeled by the radiative flux from a steady, luminous right circular cylinder of 1800^{o}F gases with partial pressures of both CO_2 and H_2O equal to 0.131 atm (complete combustion). The cylinder is defined by the fire diameter and the critical height of the plume, the height above which the plume flow relations apply and the plume gas temperatures are significantly less than 1800^{o}F (plume flow and gas temperatures are treated in the convection model). The total gas

emissivity is calculated using an expression developed from results of Hadvig, whose work was based on the original gas emissivity charts of Hottel. An emissivity increment of 0.1, as recommended by Hottel for furnaces, is included to account for the presence of soot. The radiation configuration factors for exposure to disk and cylindrical surfaces are developed from the standard expressions presented in Siegel. Re-radiation from target cables was not considered since the cable failure criteria are based on imposed heat flux, not net heat flux.

Thermal Radiation Model

D	=	fire diameter (m)
T	=	gas temperature = 1800°F = 1255.6°K pCO_2 = partial pressure of CO_2 = 0.131 atm
s	=	Stefan-Boltzmann constant = 5.67E-11 $kW/(m^2.K^4)$
es	=	soot emissivity increment = 0.1
CF	=	configuration factor for radiation from top disk and cylinder walls
eg	=	gas emissivity = 600.0*(0.94*pCO_2*D)** 0.412/T
	=	253.2*D**0.412/T
qr	=	radiative heat flux = CF*(eg+es)*s*T**4
	=	CF*(1.435E-08*D**0.412*T**3+5.67E-12*T**4) kW/m^2

5.5 Heat Convection from Flames and Plume

References:

(1) F. Kreith, "Principles of Heat Transfer", 3rd Edition, Intext Press, N. Y., 1973.

(2) W. M. Rohsenow and H. Choi, "Heat, Mass, and Momentum Transfer", Prentice-Hall, Englewood Cliffs, N. J.,

1961.

(3) P. Stavrianidis, "The Behavior of Plumes above Pool Fires", Master of Science Thesis in the Department of Mechanical Engineering, Northeastern University, Boston, Mass., 1980.

Assumptions:

The convective heat transfer computation uses a cylinder cross-flow model presented by Kreith to calculate an average surface heat transfer coefficient for the flow of hot air around an object, with air properties correlated with temperature. The kinematic viscosity values for air were obtained from Rohsenow and were also correlated with temperature to be used in the heat transfer calculations. The gas temperatures and velocities in a fully-developed fire plume are computed using relations developed by Stavrianidis. The cable surface temperature is maintained at 70°F and the cable is completely exposed to the plume flow to maximize computed imposed convective heat transfer, unless a flow baffle is placed below the cable to prevent its exposure to the plume gases.

<u>Heat Convection Model</u>

d = outer diameter of cable (m)

r = radial distance of target cable from fire axis (m)

z = elevation of target cable (m)

Ta = ambient temperature = 70°F = 294.4°K

Qc = convective heat release rate of fire (kW)

ac = fire efficiency parameter = 0.39 (for acetone)

zv = plume virtual source height = (0.11274/ac**0.6-0.15)*Qc**0.4 meters

zc = plume critical height = 0.13*Qc**0.4+zv meters

T = plume gas temperature = Ta + Ta*(0.092*Qc**0.667/(z-zv)**1.667) *exp(-71.0*(r/z)**2) (for plume centerline temperature, To <1255.6 K)

V = plume gas velocity = (1.2*Qc**0.333/(z-zv)**0.333) *exp(-96.0*(r/z)**2) (for plume centerline velocity, Vo <2.1*Qc**0.5 m/s)

nu = kinematic viscosity of air = 6.721E-11*T**2 + 5.765E-08*T - 7.762E-06 m^2/s

Re = Reynolds number = d*V/nu

h = heat transfer coefficient for cylinder cross-flow = (0.4*Re**0.5 + 0.06*Re**0.67) *(3.174E-08*T + 1.402E-05)/d $kW/(m^2.K)$

qc = convective heat flux = h*(T - 294.4) kW/m^2

6. SAMPLE CALCULATIONS

The sequence of the analyses followed for a fire area is a function of the configuration of the safety related cable trays within that area. Generally, the first step is a plume impingement calculation which determines the quantities of spilled liquid hydrocarbon necessary to damage the lowest cable tray of each division within the fire area. In the case of a cable tray stack containing a safety related cable tray of a division, the assumption is made that the lowest tray in the stack contains the safety related cables of interest. After the minimum plume impingement fuel quantities have been determined for each division, one division is selected for a plume impingement barrier modification. This modification results in the selected division being considered functionally protected from the effects of direct plume impingement.

The next step in the analysis is to determine the effects of stratification heat fluxes on the highest cables of the "protected division". The stratification quantity which results in failure of the highest cables of the protected division is then compared with the quantity required to effect damage on the unprotected division due to impingement. At this point the analyst may terminate the evaluation. Alternatively he may choose to wrap the protected division down to the elevation of

the protected tray. In those instances, the stratification calculation would then be run at the height of the protected division's tray.

Finally, a radiation calculation is performed to look at the radiation heat flux associated from the fire plume on the protected tray. This calculation is necessary to confirm that the tray which is assumed to be protected only by a bottom plume impingement shield will not experience functional cable failure as a result of the radiation heat transfer.

The subsequent paragraphs will describe the plume impingement calculations, the stratification calculations, and the radiation calculation indicating both the results of the computer analysis and presenting the detailed results of a hand calculation for Fire Area 31. These calculations will indicate plume impingement acetone volumes on the order of approximately 26.5 gallons as being required to cause failure of the orange and green cable trays at an approximate elevation of 16 feet. The green trays are then selected for modification because of shorter run length within the room. Stratification calculations are presented for the green cables penetrating the ceiling at 19 feet; the acetone volume required to cause electrical cable failure at that elevation is approximately 27.4 gallons. The green conduit is then wrapped down from the ceiling to an elevation of 16 feet and a second stratification calculation is presented at that elevation. The fuel volume required to cause cable failure at 16 feet due to stratification is approximately

37 gallons. The final calculational step is the radiation calculation that looks at the potential for cable failure as a result of radiation heat fluxes impinging on the green cable.

It should be noted that an equally logical and perhaps more practical evaluation of this area would have been to look at the plume impingement acetone fuel volumes required to cause failure of the orange control cable tray and the green power cable tray. These volumes, which are approximately 27 gallons, compare closely to that which is required to cause failure of the green power cable due to stratification at the ceiling. Those quantities which are required for failure take no credit for the armor on the power cable or for the increased diameter of the power cable (1.8 inch actual versus an assumed 0.6 inch diameter) nor do they credit in any way the tray bottom design of the control cable trays. In reality, due to the conservatisms of the models and the assumptions, the actual quantities of spilled liquid hydrocarbon necessary to cause failure in this area would be even larger than those reported.

6.1 <u>Choice of Fire Zone</u>

Prairie Island Fire Zone 31 was chosen for the sample calculations presented herein. This zone contains tray configurations which fully exercise the modeling processes. Refer to Figures 6-1 and 6-2 at the end of Section 6.

6.2 Cable Failure Criteria

Electrical failure has been chosen as the failure mechanism, as discussed in Section 1. The cable chosen for this analysis is Specimen #8 from Lee (1981).[1] This cable was chosen because the combination of critical heat flux and critical heat absorbed gives the most rapid failure time of the three cables reported by Lee.

6.3 Contribution of Postulated Secondary Fires

The Staff's consultant raised an issue regarding the potential contribution of secondary fires towards accelerating the achievement of electrical failure conditions.

This zone contains a low quantity of exposed, unarmored cables with relative minor concentrations in any location. Such locations generally involve at most a single tray of bare EPR/ Hypalon cable which could conceivably be involved in a postulated fire. Assuming for the moment that a tray is ignited, it would be useful to develop an assessment of the overall heat release rate from such a fire.

In work performed on behalf of the Electric Power Research Institute, Sumitra (1982) reports on results of intermediate scale fire tests involving a variety of cable types. One test (Test 12) measured the energy released by a stack of 12 cable trays 8 feet in length each containing EPR/Hypalon cables. The

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[1]References are listed at the end of Section 6.

tray stack was ignited by an external heptane source, the flames of which completely engulfed the tray stack. Measurements taken during this test indicated minimal (i.e., less than 400 kW) total heat release rate from the burning cables within early stages of the fire up to the 30-minute point. After approximately 30-40 minutes of cable burning the total heat release rate began to rise and peaked at 2600 kW. At this point of maximum burning the fire was fully developed and had engulfed the full extent of all 12 trays. The total (convective and radiative) heat release rate per linear foot of cable tray at this point in the fire was approximately 27 kW. Assuming a six-foot diameter acetone pool fire and the tray configuration of Fire Area 31, it is estimated that approximately six linear feet of control cable tray would be exposed to the fire plume. The heat flux associated with this fire at the elevations of interest is below the critical heat flux necessary to initiate ignition of a bare cable. Further, the design of the tray bottoms will substantially reduce the delivered heat flux making control cable ignition even more unlikely. In the unlikely event of cable tray ignition, no more than 6 feet of cables would be burning. This cable fire would therefore be expected to release 162 KW. This should be compared with the heat release rate for a two meter acetone pool fire of 2939 kW. Thus the secondary fire contributes approximately 5.5% of the total energy of the pool fire. Moreover, the pool fire would achieve its maximum heat release rate instantaneously while the

secondary cable tray fire would not release energy at the maximum rate until approximately 45 minutes after ignition. The potential contribution of unlikely secondary fires is therefore considered to be insignificant and would not accelerate the achievement of electrical failure.

6.4 Radiation Due to Cable Tray Fires

The analysis has considered the effects of potential adjacent cable tray fires on accelerating the time to achieve electrical failure. The results of this analysis indicate that the effects are insignificant. The bases for this conclusion are presented below.

In Subsection 6.3, it was demonstrated that EPR/Hypalon cable tray fires, if they can be sustained, require a significant time for growth. These fires, when fully developed, are much less hazardous in terms of heat release rates than liquid hydrocarbon pool fires which can more rapidly cause cable electrical failure. Sumitra (1982) presents measured radiant heat flux values of 1200 kW for the 12-tray vertical stack over one-half hour following ignition. This radiant heat release rate is equivalent to approximately 12 kW per linear foot of burning cable tray. For a flame height of aproximately 2 feet under maximum burn conditions, the heat flux delivered to a cable separated by one foot of free space is below the threshold for cable damage. The conclusion to be derived from this analysis is that the radiant effects of a single cable tray fire are relatively minor.

This analysis is further supported in a conservative treatment by Pinkel (1978) of the appropriate horizontal separation between cable trays assuming one tray consisting of PE/PVC cable is engulfed in a fire. For two-foot flame heights, horizontal distances in excess of 18 inches were determined to be sufficient to protect electrical cables from damage for critical heat fluxes of 15-19 kW/m^2 and exposure durations ranging from approximately 5 to 15 minutes.

Considering the low bare cable density, the existing horizontal and vertical separation, the view factors provided by such geometries and intervening structures, and the significant time delay necessary before postulated cable tray fires develop, it was decided that radiant energy delivered to the target cables of concern by postulated adjacent cable tray fires is minimal and need not be considered.

6.5 Stratification Analysis

This portion of the analysis examines the effects of stratification on limiting electrical cable. The fuel used in this analysis is acetone with a heat release rate of 936 kW/m^2 and a pool recession rate (burn rate) of approximately 3.0 mm/min. Other assumptions considered are:

q_r = total heat release rate per unit area = 936 kW/m^2

B = Build-up factor = 51 for acetone (Newman and Hill, 1981)

The cable is EPR/Hypalon

Z = Elevation of cable = 192 in. = 4.88 m

H = Ceiling height = 228 in. = 5.79 m

Ed = Damage energy = 16,950 kJ/m^2

q_c = Critical heat flux = 14 kW/m^2

Using these assumptions, the optimum acetone quantity and geometry required to just fail the above cable is:

D = acetone pool diameter = 74.8 in. = 1.9 m

V = acetone quantity = 36.47 gal

These results may be duplicated by hand using the following expressions:

$$t_{ss} = \frac{B}{\left[\sqrt{D}\left(0.5\left(\frac{Z}{H}\right)^{0.5}\right)\right]^{1.111}} \quad (1)$$

$$q_{ss} = (Q/H^2)\left[0.05585 \,/\left(1.193 - \frac{Z}{H}\right)^{0.5}\right] \Big/ \left[0.01161 - 0.01031 \,/\left(2.13 - \frac{Z}{H}\right)^{0.5}\right]^{0.153} \quad (2)$$

$$q_t = 0.52\, q_{ss} \left(\frac{Z}{H}\right)^{0.5} \left(\frac{t}{\tau}\right)^{0.9} \quad (3)$$

where:

t_{ss} = time to reach steady state, [s]

q_{ss} = steady state heat flux, [kW/m^2]

Q = total heat release rate of acetone, [kW]

BR = pool burn rate

q_t = instantaneous heat flux, $[kW/m^2]$

τ = heat flux time constant = $\frac{B}{\sqrt{D}} = \frac{51}{\sqrt{1.9}}$

τ = 37 sec

h = right cylinder pool depth = $\frac{V}{\frac{\pi D^2}{4}}$ = 48.68 mm

t_B = burn time = $\frac{h}{BR} = \frac{(48.68 \text{ mm})(60 \text{ sec/min})}{3 \text{ mm/min}}$ = 973.6 sec

These functions are convex suggesting the existence of an optimal solution for pool geometry since:

$q_{ss} = f_1\ (D,t)$

$q_t = f_2\ (D,t)$

and $t = f_3\ (R)$

By constraining the heat flux necessary for damage to the value of the critical heat flux, it is possible to converge on an optimal solution for pool diameter and depth. It is recognized, however, that this solution would be dependent upon the value of the ventilation term if the Newman and Hill methodology is used. This analysis conservatively takes no credit for the benefits of ventilation by assuming no ventilation for cooling.

The elevation of concern in this analysis is 16.0 feet (4.88 m) above the floor which is 3.0 feet below the ceiling. Since the conduits exiting through the ceiling are assumed to be wrapped, the objective of this analysis is to just achieve elec-

trical failure conditions, ($q'' > 14$ kW/m^2; $E'' > 16950$ kJ/m^2) for the redundant division at that elevation. It is noted that bare and armored cable of both divisions below 16.0 feet would not fail by stratification and would remain intact.

Substituting the following values in the equation from (1), the time to reach the steady state condition is:

$$t_{ss} = \frac{51}{\left[\sqrt{1.9}\left(0.5\left(\frac{4.88}{5.79}\right)^{0.5}\right)\right]^{1.111}} = 84.8 \text{ sec}$$

The heat release rate of acetone during this period is:

$$Q = \frac{\pi D^2}{4} q = (2.8353 \text{ m}^2)(936 \text{ kW/m}^2) = 2653.8 \text{ kW}$$

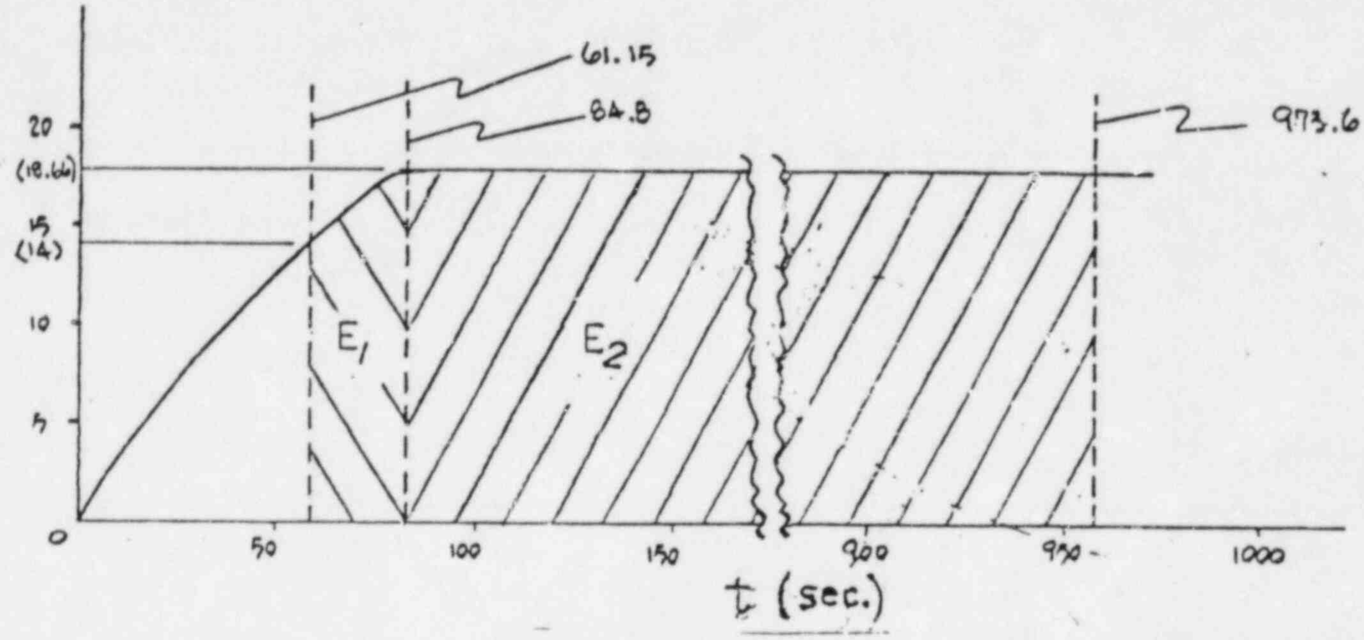
The steady state heat flux is therefore given by expression (2) as:

$$q_{ss} = \left[\frac{2653.8}{(5.79)^2}\right]\left[0.05585 / \left(1.193 - \frac{4.88}{5.79}\right)^{0.5}\right] / \left[0.01161 - 0.01031 / \left(2.13 - \frac{4.88}{5.79}\right)^{0.5}\right]^{0.153}$$

$$q_{ss} = 18.66 \text{ kW/m}^2$$

Note that the steady state heat flux is greater than the critical heat flux. The mechanism for cable failure as the fire progresses may be best illustrated on the following diagram:

Attachment 3, ELNSP82-021



The shaded area under the curve represents the total energy deposited on the cable. The damage process does not start until the heat flux reaches 14 kW/m^2 (critical heat flux of the cable of interest).

At this point, q_t = 14 kW/m^2 which implies by expression (3):

$$14 \text{ kW/m}^2 = 0.52\, q_{ss} \left(\frac{4.88 \text{ m}}{5.79 \text{ m}}\right)^{0.5} \left(\frac{t}{T}\right)^{0.9}$$

where: q_{ss} = 18.66 kW/m^2

= 37.0 sec

therefore: t = 61.15 sec

At time 84.8 seconds after the start of fire the steady state heat flux is reached. The damage energy is defined as the area under the curve.

$$E = E_1 + E_2 \quad \text{(see figure)} \qquad (4)$$

$$E_1 = g(t)$$

$$E_2 = (t_b - t_{ss})q_{ss} = (973.6-84.8)(18.66) = 16{,}585 \text{ kJ/m}^2$$

Area E_1 may be calculated as follows:

$$E_1 = \int_t^{t_b} q_t(t)\, dt$$

$$E_1 = \int_{61.15}^{84.8} q_t(t)\, dt$$

From (3), q_t is:

$$q_t = (0.52)(18.66)\left(\frac{4.88}{5.79}\right)^{0.5}\left(\frac{t}{37}\right)^{0.9}$$

$$q_t(t) = 8.908\left(\frac{t}{37}\right)^{0.9} = \frac{9.081}{(37)^{0.9}}\, t^{0.9}$$

$$q_t(t) = 0.345t^{0.9}$$

Substitute (6) into (5) and perform integration:

$$E_1 = \int_{61.15}^{84.8} 0.345t^{0.9}dt = 0.345\, \frac{t^{1.9}}{1.9}\Bigg|_{61.15}^{84.8}$$

$$E_1 = \frac{0.345}{1.9}\left[(84.8)^{1.9} - (61.15)^{1.9}\right] = \frac{0.345}{1.9}\left[2134.37\right]$$

$$E_1 = 387.6 \text{ kJ/m}^2$$

Therefore, the total energy deposited on the cable over the burn time, E, is:

$$E = E_1 + E_2 = 387.6 + 16,585 = 16,972.6 \text{ kJ/m}^2$$

Notice that the energy deposited on the cable is approximately 23 kJ/m^2 more than the required damage energy to fail the cable. This difference is less than 1% and is considered to be primarily due to round-off error.

6.6 Radiation

Assuming the presence of an impingement baffle beneath "green" Tray 2SG-LB17, this analysis provides a basis for concluding that the effects of radiation from the fire plume do not fail the cables in the tray. Computer analysis of these effects indicate that a pool containing 82.71 gallons of acetone in a diameter of 3.62 m is required to achieve this failure criteria.

The radiation analysis considers the flame to be in the shape of a right cylinder defined by the Stavrianidis (1980) critical height and the pool diameter. The following terms are used in the analysis to demonstrate how this fuel quantity and geometry achieves the failure criteria:

T = gas temperature = $1800^{\circ}F$ = $1255.6^{\circ}K$

PCO_2 = Partial Pressure of CO_2 = 0.131

S = Stefen-Boltzmann Constant = $5.67X10^{-11}$ $kW/m^2 \cdot {}^oK^4$

es = Soot emissivity = 0.1 (Hottel and Sarofim, 1967)
(Felske and Tien, 1973)

CF = Configuration factor (shape factor)

D = Fire diameter = 3.62 m

eg = Gas emissivity = $600\ (0.94\ PCO_2\ D)^{0.412}/T$ (1)

q_r = Radiative heat flux

q_r = $CF\ [eg + es]\ ST^4$, $[kW/m^2]$ (2)

The gas emissivity depends on the spill diameter and temperature. Thus, (1) may be simplified to:

$$eg = 253.2\ D^{0.412}/T$$

or

$$eg = (253.2)(3.62)^{0.412}/1255.6 = 0.3426$$

After substituting soot emissivity and the Stefan-Boltzmann Constant, (2) may be simplified to:

$$q_r = CF\ [0.3426 + 0.1][5.67X10^{-11}]\ T^4$$

or

$$q_r = CF\ [0.3426 + 0.1][5.67X10^{-11}][1255.6]^4$$

The remaining term, the configuration factor, is defined as the fraction of the glowing cylinder as seen by the object and depends on distance and elevation of the object; since the cable tray is baffled, the radiation from the part of the flame cylinder below the tray elevation does not reach the object.

The configuration factor is determined by a fairly long expression which describes the radiant effects of the visible cylinder as a function of horizontal and vertical separation. For a tray subjected to radiation from fire plume and protected by an impingement baffle, CF is calculated to be approximately 0.465 yielding a radiant heat flux from the visible portion of the acetone fire of 29 kW/m^2.

In order to achieve the energy flux, it is necessary to calculate the exposure duration for 29 kW/m^2, otherwise referred to as the burn time. The burn time is itself defined by the pool depth and may be calculated by first determining the spill depth, h, as follows:

$$h = \frac{V}{(1.339X10^{-4})\ D^2}$$

where: V = volume (gal)

D = diameter (in.)

h = depth (mm)

For the 82.71 gallon fire,

$$h = \frac{82.71}{(142.52)^2(1.339 \times 10^{-4})} = 30.41 \text{ mm}$$

The burn time is therefore given by:

$$t_B = \frac{h}{BR} = \frac{30.41 \text{ mm}}{3 \text{ mm/min}} \times 60 \text{ sec/min} = 608.2 \text{ sec}$$

providing total damage energy, E, of:

$$E = q_r\ t_b = (29.004)(608.2) = 17{,}640 \text{ kJ/m}^2$$

This energy is approximately 700 kJ/m^2 more than the critical energy flux of 16,950 kJ/m^2. This error is less than 5% and is due primarily to rounding errors associated with the configuration factor.

6.7 Impingement

This analysis utilizes the Stavrianidis (1980) plume model for liquid pool fires. This is a top-hat model whereby below a specified height, referred to as the "critical height", thermal conditions (i.e., temperatures and vertical gas velocities) are fairly uniform. Above the critical height, thermal diffusion and mixing cools the gases.

The critical height for a pool fire is defined as:

$$Z_c = 0.13 \text{ m/kW } Q_c^{0.4} + Z_v \qquad (1a)$$

where: Z_c = critical height, [m]

Q_c = convective heat release rate, [kW]

Z_v = virtual source height for the fire, [m]

$$Z_v = 0.11274 \, a_c^{0.6} - 0.15 \, Q_c^{0.4} \qquad (1b)$$

where a_c = convective fraction of theorectical heat release rate (= 0.39 for acetone)

Knowing the virtual source height, gas temperatures anywhere in the plume are given by:

$$T_{(r,z)} = \begin{cases} T_a + T_a\left[0.092\ Q_c^{0.667}/(Z - Z_v)^{1.667}\right]\mathrm{Exp}\left[-71(r/Z)^2\right] & \text{(2a)} \\ \text{or} & \\ 1255.6^{o}K \text{ (when below the critical height)} & \text{(2b)} \end{cases}$$

where: T_a = ambient temperature outside the plume, [^{o}K]

Z = elevation of interest, [m]

r = radial distance off the centerline, [m]

Plume gas velocities are similarly defined:

$$V_{(r/z)} = \begin{cases} \left[1.2\ Q_c^{0.333}/(Z - Z_v)^{0.333}\right]\mathrm{Exp}\left[-96(r/Z)^2\right] & \text{(3a)} \\ \text{or} & \\ 2.1\ Q_c^{0.5} \text{ m/sec (when below the critical height)} & \text{(3b)} \end{cases}$$

For the case of a fire placed beneath a cable tray, it is assumed that the cable is on the fire centerline, hence $r = o$. Similarly, the total heat released is defined by:

$$Q = Aq = \left(\frac{\pi D^2}{4}\right)(936\ kW/m^2)$$

and $Q_c = f_Q$

when f = convective fraction of actual heat release rate (= 0.51 for acetone)

D = fire diameter, [m]

Therefore, $Q_c = (0.51)\left(\frac{\pi D^2}{4}\right)(936\ kW/m^2)$ (4)

The thermal conditions at any point within the plume is a function of area and pool recession rate. It is evident that a variety of pool volumes and diameters may be defined which fail

cables at different locations relative to the fire. The locus of points defining such a threshold is a convex function which contains an optimum. This optimum may be defined either analytically or numerically using convergence algorithms by first focusing on heat flux and then achieving the energy flux. For EPR/Hypalon cable, assumed to be 16 feet above the floor, this optimum is determined using the computer model to occur with a volume of 26.8 gallons of acetone and a diameter of 1.47 meters. That such a quantity and geometry meets the failure criteria is demonstrated in the following hand calculation.

Equation (4) yields a value of for Q_c of 810.1 kW which may be used to define fire plume conditions at the 16-foot elevation. The virtual fire height is calculated using (1b) to yield a value of $Z_v = 0.7$ m. For ambient conditions of 70°F (294°K), equation (2a) at this source height yields an air temperature of approximately 462°F (512°K) on the centerline at the 16-foot elevation. The velocity of the air at that location is determined using (3a) to be approximately 6.9 m/sec.

With these parameters it is possible to define the rate of convective heat transfer by computing the kinematic viscosity:

$$nu = 6.721\times10^{-11}\ T^2 + 5.765\times10^{-8}\ T - 7.762\times10^{-6} \qquad (5)$$

For a temperature of 512°K, (5) yields a value of $nu = 3.94\times10^{-5}$ m^2/sec. This value may be used to determine the Reynolds number via:

$$Re = \frac{dV}{nu} \qquad (6)$$

when d = cable diameter = 0.6 in. = 0.01524 m (by assumption)

v = plume velocity [m/s]

Knowing the Reynolds number, a heat transfer coefficient for cylindrical cross-flow conditions is given by:

$$h = \frac{[0.4\ Re^{0.5} + 0.06\ Re^{0.67}][3.174 \times 10^{-8}\ T + 1.402 \times 10^{-5}]}{d} \qquad (7)$$

From this expression, a convective heat flux may be calculated assuming the cable is obtained at 70°F by:

$$q_c = h(T-294.4) \qquad (8)$$

For this particular case, the following values are determined:

$Re = 2668.9$ by (6)

$h = 6.5 \times 10^{-2}\ kW/m^2 \cdot K$ by (7)

$q_c = 14.1\ kW/m^2$ by (8) for T = 508°K

For a heat flux of this magnitude, it is then possible to determine the quantity of fuel necessary to burn sufficiently long to deposit the energy flux for failure. Since this volume is already known, it will be demonstrated that this criteria is met.

The pool depth is given by:

$$\text{pool depth} = \frac{26.8 \text{ gallons}}{\frac{\pi D^2}{4}}$$

$$= 59 \text{ mm}$$

For a recession rate of 3 mm/min, this indicates a burn time of 1189 seconds. This exposure time, therefore, yields:

$$\dot{E}'' = \dot{q}''t_b = [14.1\ kW/m^2]\ [1189\ seconds] = 16765\ kJ/m^2$$

Although this energy flux is actually less than the failure criteria by a small amount, this difference is less than 5% and is considered to be associated with round-off error. It is clear that 26.8 gallons of acetone in this configuration is capable of achieving the electrical failure criteria at the 16 foot elevation. Protection against this event may be afforded through the use of an impingement baffle on the underside of the safe shutdown tray at this elevation. This modification is assumed to be present in subsequent analysis and effectively removes electrical cables in its wake from potential damage due to direct exposure to the fire plume.

6.8 Other Issues

The Staff's consultants raised an issue in their review of the Prairie Island submittal regarding possible discrepancies in the analysis. These discrepancies are related to differences in the time to failure for a 17 kW/m^2 external heat flux and the effects of ventilation on determining minimal fuel quantities for several zones. Additional information is provided to clarify these issues.

In analyzing the effects of an external heat flux on Sample 8, the consultants report a time to failure of 5400 seconds which

contrasts with 880 seconds determined in the stratification analysis for Fire Zone 31. As a review of the Stratification Section of the enclosed sample calculation illustrates, the heat flux in the Prairie Island stratification model builds up to a steady state value which is in excess of the critical heat flux. Once the imposed heat flux equals or exceeds the specified critical heat flux for the cable, the model accumulates damage energy at a rate based upon the total imposed heat flux and not the difference between the imposed and critical heat flux. This approach contains a significant degree of conservatism when the imposed heat flux approximates the critical heat flux.

An important additional conservatism in the Prairie Island analysis should also be highlighted at this point. This concerns the use of an energy flux determined experimentally for elevated fluxes under less stressful conditions. It may be recalled that above the critical heat flux, it is possible to define a critical energy flux on the basis of the inverse slope of the regression of data points on a q_e''-t_f diagram. As the external heat flux is decreased towards the critical heat flux, variance is noted from the linear regression generating the critical energy flux. This variance indicates that a significantly elevated energy flux is necessary for failure under less stressful thermal conditions. The Prairie Island analysis takes no credit for this higher energy requirement for failure and consistently uses the same value of critical energy flux presented in the literature irrespective of heat flux.

Concerning the consultant's difficulty in reproducing minimum fuel quantities for the various ventilation rates, it is noted that this difficulty is due to the fact that no credit was taken in the Prairie Island analysis for the cooling effects of ventilation at any time. Hence, no effect of ventilation should be evident in the heat flux.