GEND-INF-023
Volume II

GEND-INF--023-Vol.2

DE83 005355

# ESTIMATED TEMPERATURES OF ORGANIC MATERIALS IN THE TMI-2 REACTOR BUILDING DURING HYDROGEN BURN

H. W. Schutz
P. K. Nagata

December 1982



Technically Edited and Published
on Behalf of the GEND Group
by
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415



Prepared for the
U.S. DEPARTMENT OF ENERGY
Three Mile Island Operations Office
Under DOE Contract No. DE-AC07-76ID01570

## ABSTRACT

Maximum surface temperatures attained by certain materials during the hydrogen burn associated with the March 1979 accident at TMI-2 are estimated, using photographs and material samples from the reactor building. Thermal degradation, melting, and charring noted in the photographs, and the chemical and thermal analyses of polymeric and organic materials indicated an increase in temperature with elevation in the reactor building. The maximum material surface temperatures estimated ranged from 360 to 500°F (455 to 533 K). Analyses were performed to estimate the damage to electrical cables and insulation. Based on temperatures reached and approximate duration, greater than 90% of cable insulation life remains.

## CONTENTS



## FIGURES

TABLES

# ESTIMATED TEMPERATURES OF ORGANIC MATERIALS IN THE TMI-2 REACTOR BUILDING DURING HYDROGEN BURN

## INTRODUCTION

On March 28, 1979, the TMI-2 reactor core was partially uncovered, with subsequent core damage. During the accident, the highest temperatures occurred inside the reactor vessel, but enough heat was liberated, due to a discharge of steam and hot gas[1] to raise the reactor building temperatures above normal operating conditions. A hydrogen burn that occurred inside the reactor building caused high temperatures for a short period of time. The first entries into the reactor building revealed that various organic materials had sustained thermal damage.

The primary purpose of this report is to estimate surface temperatures of certain thermally affected materials from various locations inside the reactor building. A corollary purpose is to determine the extent to which the auxiliary equipment and control cables in the reactor building may have been damaged by exposure to the higher-than-normal temperatures. Since most of the electrical insulation involved consists of organic polymers, analysis of the condition of such polymers should help establish the degree of damage to the control and communication systems inside the reactor building and to other systems where similar insulating materials are used. By April 1981, six entries had been made into the reactor building, photographs taken, and material samples removed. The 305-ft elevation was examined during the first entry and the 347-ft elevation during the second entry. Refer to Figure 1 for the elevation arrangement of the TMI-2 reactor building. Black and white copies of the color photographs taken during these entries are presented in Appendix A along with a description of the thermal damage.

Thermal degradation, melting, and charring observed in photographs, as well as chemical and thermal analyses of the samples of damaged materials performed at the Idaho National Engineering Laboratory (INEL), were used to estimate maximum surface temperatures. Polymeric and organic materials provided the best estimates of surface temperatures, as they were the most prevalent indicators of thermal effects in the reactor building.

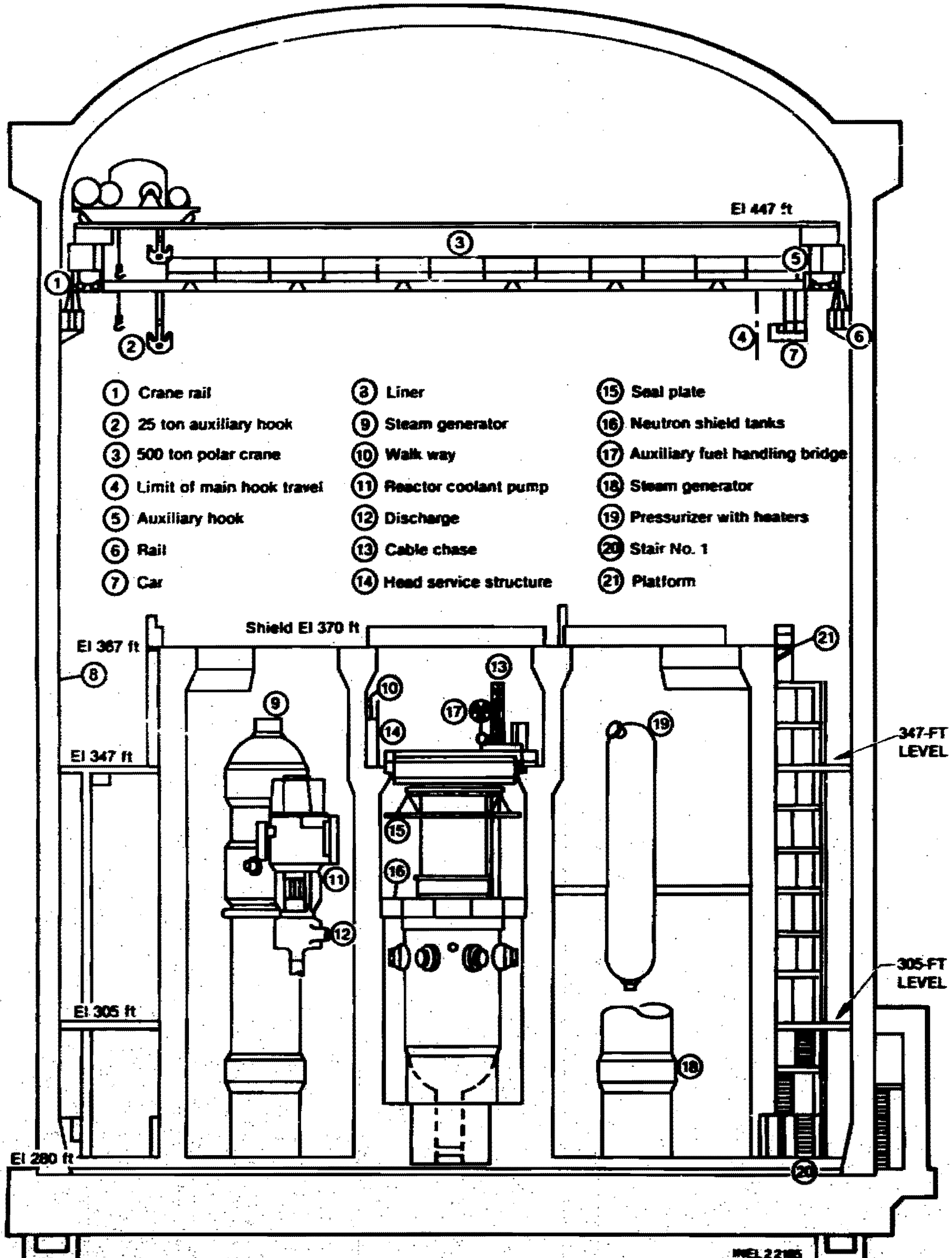



Figure 1. Elevation arrangement of the TMI-2 reactor building.

It is important to understand that material surface temperatures were probably quite different from temperatures existing in the main body of gases during hydrogen combustion. Temperatures attained by solid materials were determined by heat transfer considerations such as temperature and time history of gases involved; thermal conductivity, heat capacity, and gas-to-surface heat transfer coefficients for the particular material examined; and heat sinks or heat shields located in proximity to the material examined.

Estimated material surface temperatures are based on the best information available after the first few entries. Because few data were available from standard reference sources, qualified experts and limited laboratory experiments provided necessary information.

## MATERIALS USED FOR TEMPERATURE ESTIMATES

Organic materials, usually in the form of polymers, were used to estimate temperatures reached in the TMI-2 reactor building. Inorganic materials were not useful because no physical changes occurred at temperatures reached during the accident.

The main organic polymer groups are described below and include the practicability of using the various polymer groups for temperature estimation. Although the groups overlap considerably, they provide a useful means of describing the thermal characteristics of polymers. Thermoplastics and natural fibers were the most useful polymers for estimating temperatures; elastomers and thermosetting polymers were of little use.

### Elastomers

Elastomers are rubber or rubber-like elastic polymers, which have the capability of stretching and returning to their original shape. They vary widely in their response to temperature. Such useful low-temperature properties as high elastic elongation and low compression set may disappear totally at temperatures as low as 200°F (366 K) in some elastomers.[2] Elastomers were omitted from temperature estimates, but are discussed in connection with estimated life of the control cable electrical insulation. Since these laboratory-measurable properties are almost impossible to relate to the maximum temperature seen by the elastomer, the charring temperature (if its formulation chars rather than melts) was the only other temperature-related characteristic available. In general, the postaccident condition of elastomers was not found useful in estimating temperatures from available photographic evidence because no melting or charring was observed.

### Thermoplastics

A clear distinction between elastomers and thermoplastics is sometimes difficult. Some thermoplastics have characteristics similar to those of elastomers; others are more like plastics. A thermoplastic also could exhibit any gradation of characteristics between one extreme or the other. This vast range of possible differences results from the various methods used to copolymerize or formulate thermoplastics.[3,4] An example of a thermoplastic with elastomeric properties is polyvinyl chloride (PVC).

These polymers are hard at room temperature, but on heating, become less viscous and can be molded, e.g. acrylics and polystyrene. If cooled from an elevated temperature to a lower temperature, e.g. room temperature, then thermoplastics will retain their shape. Upon reheating, the thermoplastic can be remolded to another shape, cooled, and used for another purpose. These characteristics are in contrast to elastomers and thermosetting polymers which cannot be reheated and remolded. An example of a thermoplastic is the ABS[a] telephone base and headset. Temperatures corresponding to specific changes for identified thermoplastics commonly found in TMI-2 applications are listed in Table 1.

## Thermosetting Polymers

Thermosetting polymers can be molded at room temperature, but upon heating, undergo extensive cross-linking, and become hard and rigid. Upon returning to room temperature, they remain hard and rigid and will not become soft and less viscous with increasing temperature, but will remain hard and rigid until they char and burn.

The main synthetic thermosetting polymers present in the TMI-2 reactor building are the epoxies, typically copolymers of epichlorohydrin and bisphenol A, perhaps cross-linked with relatively short-chain polyamide resins or amines.[5] Epoxies may be used in potting compounds or for sealing penetrations, but most of the use was in the form of coatings, e.g., paints. Degradation of the epoxy occurs only when the temperature becomes high enough to degrade the polymer by pyrolysis, oxidation, or both. Scorching, charring, smoking, or ignition may then be evident, but are difficult to correlate with a definite temperature. Because of the above

---

a. ABS is a copolymer of acrylonitrile, butadiene, and styrene.

TABLE 1. TEMPERATURE INDICATED BY CHANGES IN THERMOPLASTICS IN TMI-2

| Temperature °F | K | Identified Change | Reference |
|---|---|---|---|
| 165 | 347 | PCV phone cord straightens | 6 |
| 170 | 350 | Maximum allowable temperature for acrylic plastic | 7 |
| 200 | 366 | Acrylic shrinks badly | 7 |
| 200 | 366 | Foam polystyrene insulation begins surface softening | 8 |
| 200 | 366 | Tygon tubing (standard grade) loses elasticity, softens | 9 |
| 200 | 366 | ABS phone plastic has 264 psi (1820 kPa) strength | 10 |
| 205 | 369 | ABS phone plastic has 66 psi (455 kPa) strength | 10 |
| 220 | 378 | ABS phone plastic has 1 psi (6.9 kPa) strength (extrapolation of above data) | |
| 252 | 395 | High density polyethylene buckets begin softening | 11 |
| 260 | 400 | Polypropylene rope begins to contract lengthwise | 12 |
| 275 | 408 | High density polyethylene melts | 13 |
| 320 | 433 | Polypropylene rope melts | 12 |
| 335 | 441 | Exit sign begins to turn brown | INEL Experiment |
| 365 | 458 | Nylon 66 rope begins to turn brown | 12 |
| 450 | 505 | Acrylic, polystyrene begins to char | Storey Electric Co. |
| 480 | 522 | Nylon 66 melts | 14 |

characteristics, the thermosetting polymers were not useful in estimating temperatures and have been omitted from further discussion.

## Natural Fibers

Some natural fibers behave like man-made thermosetting polymers in that they burn rather than melt. Several items in this category were found in the reactor building. Degradation temperatures of wood and some natural fibers are summarized in Table 2.

TABLE 2. THRESHOLD DEGRADATION TEMPERATURES OF WOOD AND NATURAL FIBERS IN TMI-2

| Temperature | | | |
|---|---|---|---|
| °F | K | Changes | Reference |
| 200 to 400 | 366 to 478 | Wood turns brown | 15 |
| 450 | 505 | Bond paper scorches | 16 |
| 410 to 554 | 483 to 563 | Rayon scorches | 17 |
| 482 to 572 | 523 to 573 | Cotton scorches | 17 |

## TEMPERATURE ESTIMATES

The temperature estimates derived from photographs, and those derived from material samples sent to the INEL for analysis, are treated separately. Figures 2 and 3 show locations, by reactor building elevation, of samples and items photographed, and compile material surface temperature estimates. The temperatures estimated in this report are representative of material surface temperatures only and do not represent gas or flame temperatures.

### Temperature Estimates Derived from Photographs

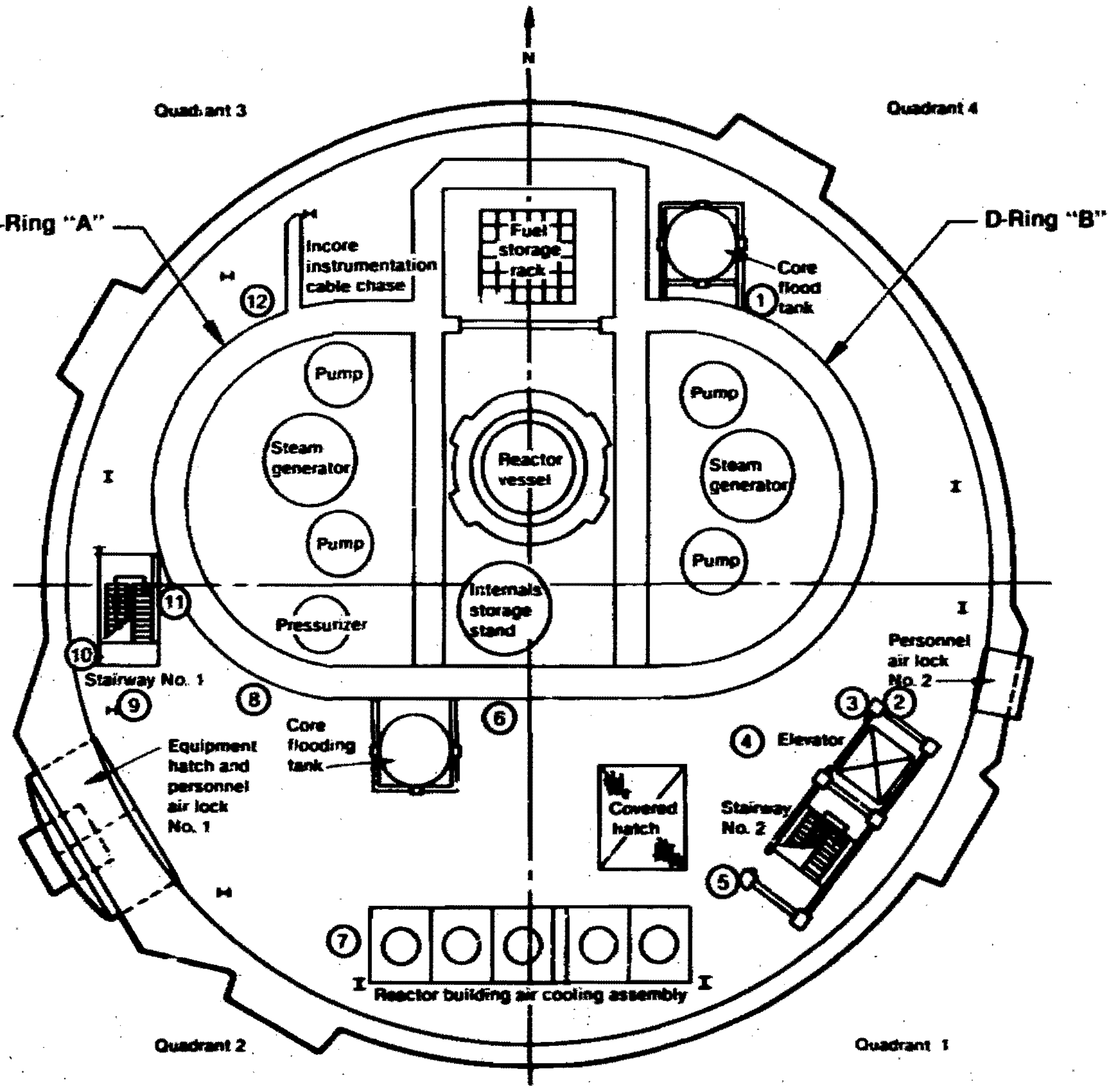
Specific photographs used in making reactor building temperature estimates are shown in Appendix A, along with an identification of the material in the photographs and the estimated temperatures. To understand the limits on accuracy in this report, two examples of temperature estimates are provided below.

Paper was left on and in a metal cabinet intended to house an instrument on top of D-ring B at about the 347-ft elevation (see Figure A-34, Appendix A). The paper outside the cabinet was charred; the part inside was not. Probable explanations are listed below.

1. The paper inside the cabinet was protected from a rapid temperature rise by the insulating effect of the cabinet. If so, the paper could have reached a maximum temperature of 450°F (505 K) without sh ng signs of charring (see Reference 16).

2. The paper outside the cabinet was ignited by a hydrogen burn which occurred in the building.

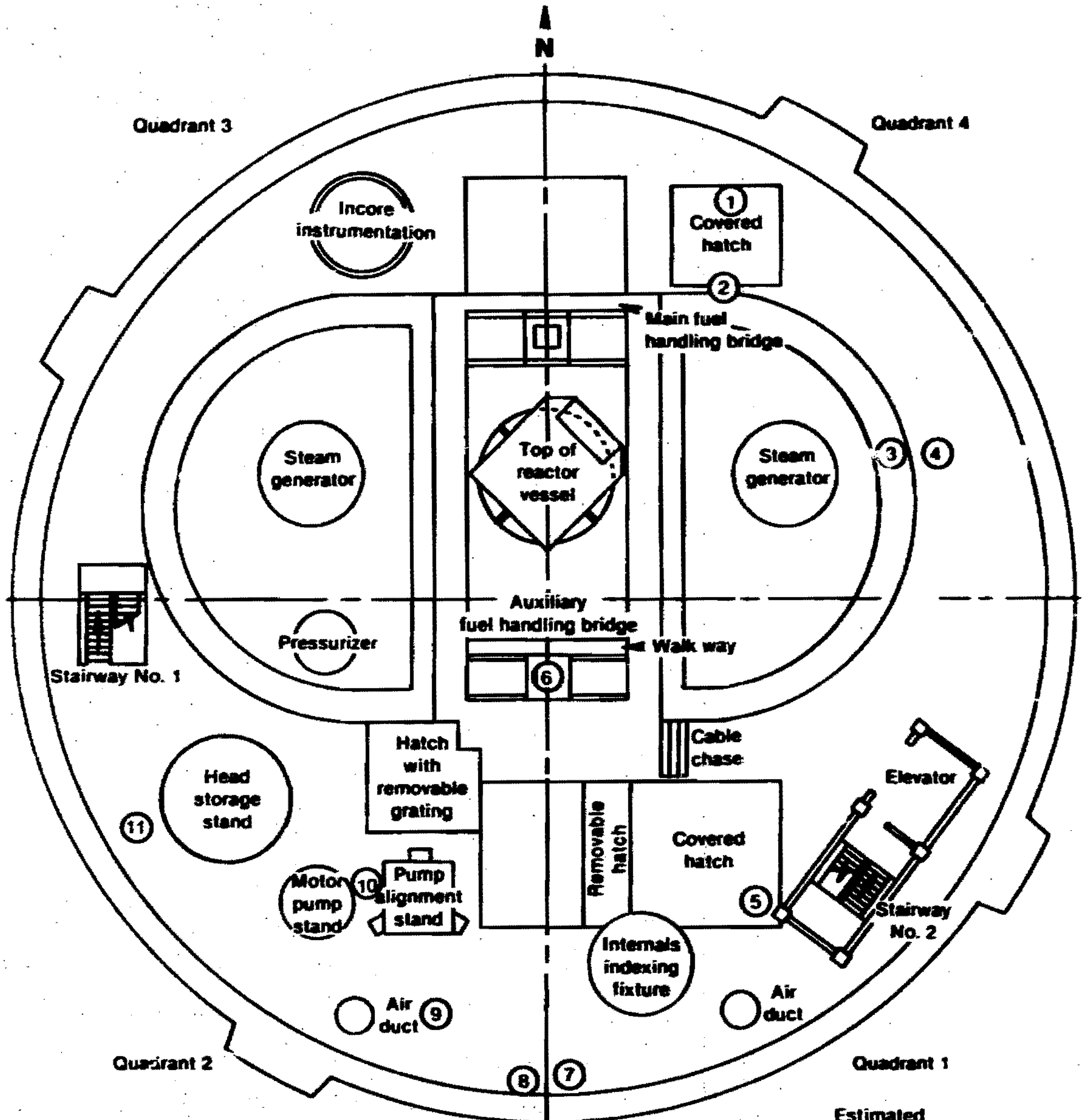
A wiping rag left on a nitrogen line became scorched (Figure A-14, Appendix A). The following conclusions were reached from discussions with experts at Cotton, Inc., New York, NY, and Raleigh, NC, and at the Textile Research Institute, Princeton, NJ. If the rag was cotton, the temperature




| Photo Location | Reference Figure | Description | Estimated Material Temperature |
|---|---|---|---|
| 1 | A-16 | Paper tags | <360°F (456 K) |
| 2 | A-4, A-15 | Telephone cord | 165-200°F (347-367 K) |
| 3 | A-20 | Telephone cord | 165-200°F (347-367 K) |
| 4 | A-2, A-5 | Plastic buckets | <275°F ( < 408 K) |
| 5 | A-1 | Styrofoam | 200°F (367 K) |
| 6 | A-7, A-8 | Gray phone | <200°F ( <367 K) |
| 7 | A-3 | Red phone | 165-200°F (347-367 K) |
| 8 | A-9 | Paper tags | 360-400°F (456-478 K) |
| 9 | A-10 | Poly rope | <260°F ( <400 K) |
| 10 | A-13 | Telephone | 165-200°F (347-367 K) |
| 11 | A-11 | Clear tubing | 200°F (367 K) |
| 12 | A-12 | Red paint | <200°F ( <367 K) |

INEL 2 4105

Figure 2. Location of photographs and samples taken on 305-ft elevation of TMI-2 reactor building.




| Photo Location | Reference Figure | Description | Estimated Material Temperature |
|---|---|---|---|
| 1 | A-21 | Plastic sign | >360°F ( >456 K) |
| 2 | A-22 | Tape tags | 250-356°F (394-453 K) |
| 3 | A-35 | Paper | 450°F (506 K) |
| 4 | A-28 | Guage window | 200°F (367 K) |
| 5 | A-26 | Exit sign | <335°F ( <441 K) |
| 6 | A-31, 25, 18, 29 | Manual | 450°F (505 K) |
| 7 | A-24 | Poly film | 250°F (394 K) |
| 8 | A-23, 30, 33, 34 | Black phone | 200° - 220°F (367-378 K) |
| 9 | A-17 | Nylon rope | 480°F (523 K) |
| 10 | A-27 | Wood, poly | 400°F (478 K) |
| 11 | A-19 | Poly rope | 260-320°F (400-433 K) |

INEL 2 4106

Figure 3. Location of photographs and samples taken on 347-ft elevation of TMI-2 reactor building.

was 482 to 572°F (523 to 573 K); if rayon, 410 to 554°F (483 to 563 K). See Reference 17. If flame retardants were incorporated into the rag, a higher scorching temperature would be indicated.[18] However, no evidence exists to suggest retardants were incorporated into the rag.

## Temperature Estimates on Objects Sent from TMI-2 to INEL

The following material samples were removed from the containment building and sent to INEL for evaluation. All were thermoplastics except the paper instruction manual.

- ABS telephone (entire phone including cord)
- Buttons (one yellow and two green buttons) from the Auxiliary Fuel Handling Bridge Control Panel
- Instruction manual
- Yellow and magenta radiation rope
- Nylon rope
- Radiation warning sign.

Evaluations of these samples are given below:

1. The ABS telephone body and headset were visually examined. They appeared to have softened and collapsed to some extent. The collapsing strength per ASTM D 648 was estimated at 1 psi (6.9 kPa). Data for ABS from Reference 10 were extrapolated to determine the temperature at which 1 psi (6.9 kPa) strength occurs. This temperature was 220°F (378 K). Thus, the temperature attained by the phone was estimated at 220°F (378 K) or greater.

2. The buttons were chemically analyzed. The green buttons were found to be polymethylmethacrylate (PMMA), the yellow ones polycarbonate. All buttons had softened and started to collapse of their own weight but had not ignited. PMMA has properties similar to ABS polymer from which the telephone body and headset above are made.

   The temperature range the buttons are estimated to have attained is governed by the polycarbonate buttons, because they deform at a higher temperature. This temperature range is 285 to 550°F (414 to 561 K), which, considering the instruction booklet nearby, can be narrowed. Temperatures of about 450°F (506 K) are needed to char paper (see Reference 16). Therefore, since the PMMA buttons had not burned and the instruction manual had charred, the estimated temperature the buttons attained was 450 to 550°F (506 to 561 K).

3. The instruction book was charred. As stated above, indications are that paper chars at 450°F (505 K) so this temperature or higher was attained by the instruction book.

4. The polypropylene yellow and magenta radiation warning rope contracted at 260°F (400 K) and melted at 320°F (433 K) during experiments performed at INEL. Since the rope in the TMI-2 containment had melted, the estimated temperature attained is 320°F (433 K) or above

5. The nylon rope cracked when it was being taken as a specimen. Nylon fiber will crack when heated to its melting point, about 480°F (522 K). In experiments performed at INEL, the nylon did not melt at 440°F (500 K). Therefore, the rope should have attained a temperature between 440 and 480°F (500 and 522 K) for the behavior observed. The rope probably reached 480°F (522 K).

6. The yellow and black radiation sign was singed. The INEL experiments indicated the clear polymer covering on the sign started to become singed at 335°F (441 K). Therefore, the sign experienced a temperature of at least 335°F (441 K).

Slow heating tests were performed at the INEL on rope and sign samples similar to those removed from TMI-2. Slow heating tests cannot be considered fully representative of rapid heating conditions that apparently existed at TMI-2.

## Polymeric Electrical Insulation Degradation

Polymeric electrical insulation degradation behavior can be described by an Arrhenius equation,

$$t = Ae^{-Q/RT} \tag{1}$$

where

t = time to an arbitrary level of degradation, hours

A = pre-exponential coefficient

Q = activation energy, cal/mole

R = gas constant, 1.987 cal/mole K

T = absolute temperature, K.

For polyvinyl chloride (PVC) electrical insulation, some typical lifetime data for a given temperature (dependent on manufacturer) would be:

$$T_1 = 373\ \text{K},\ t_1 = 4{,}000\ \text{h},$$
$$T_2 = 418\ \text{K},\ t_2 = 160\ \text{h}, \tag{2}$$

then

$$Q = 22{,}160 \text{ cal},$$

$$A = 4.14 \times 10^6.$$

The equation is plotted in Figure 4 for temperatures between 380 and 430 K (224 and 314°F).[a]

## Estimate of Useful Life of an Elastomer

The useful life of polymeric electrical insulation is determined by its ability to expand and contract under electrical load, which in turn is related to its plasticizers. Low boiling point plasticizers will cause volatilization and polymer failure at a lower temperature than the same polymer with higher boiling point plasticizers (see Reference 3).

Determining the useful life of polymeric electrical insulation in TMI-2 is difficult for the following reasons:

1. Various types of polymeric electrical insulation are present in the TMI-2 reactor building

2. Some polymeric insulation compositions are proprietary to their manufacturers

3. The polymeric plasticizing agents are also proprietary.

Temperature excursions above the highest continuous service temperature are very detrimental to the polymer's insulating ability. Data on PVC appliance insulation indicate that at 373 K (212°F) expected life is 4000 hours, but at 418 K (293°F) the expected life is 160. Two possible consequences of overheating insulation are:

---

a. A Kelvin/calorie ratio is used to plot Arrhenius equations. Therefore, temperatures in this section will be given in Kelvin followed by English equivalents in parentheses.

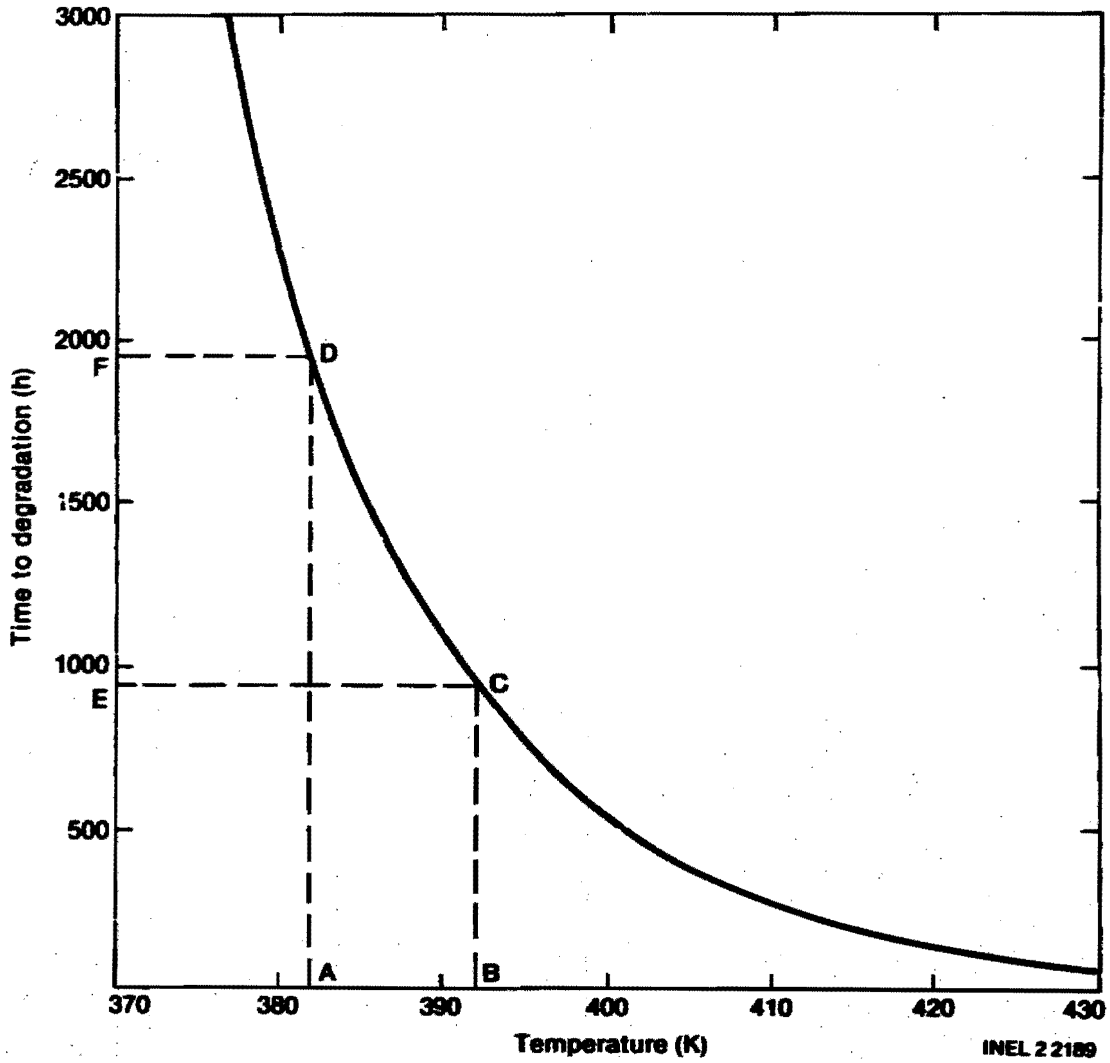



Figure 4. Time to degradation as a function of temperature.

1. Conductors having a single insulation sheath (e.g., instrumentation wiring) may be so adversely affected that they would lose their ability to flex and maintain their integrity.

2. Control cables that have a lower temperature rated (LTR) insulation around the individual conductors and, perhaps, a higher temperature rated (HTR) sheath around the bundle of LTR-insulated conductors, could have been heated into a temperature range where the LTR insulation would be adversely affected though the HTR insulation would not. Visual and tactile inspection of the HTR sheath could disclose no damage, whereas the internal LTR insulation may have failed.

## Lifetime Expenditure Calculation: Illustrative Example

One possible method of estimating elastomeric electrical insulation life involves an iteration technique. Some qualifying assumptions are that the damage is caused by plasticizer diffusion out of the polymer, that damage is cumulative, and that the containment temperature remains below the boiling point(s) of the plasticizer(s). Thus, for a typical elastomer exposed to air at 293 K (68°F) for 20,000 hours and 2 hours at 423 K (320°F), with a lifetime of $10^6$ hours at 293 K (68°F) and 100 hours at 423 K (302°F), the amount of life expended would be:

$$\frac{20,000}{1,000,000} + \frac{2}{100} = 0.02 + 0.02 = 0.04 \text{ or } 4\%. \qquad (3)$$

Table 3 was produced using the above technique, assuming a temperature history. The assumed temperature is the authors' best estimate that may be representative of that experienced at TMI. For this technique to work, an accurate temperature history must be used.

Any radiation damage to insulation, though not analyzed in this report, would be additive to the thermally induced degradation. Based on the above assumptions and temperature history, about 8% of the typical elastomeric cable covering's life has been expended, or the cable covering has about 92% of its life left.

TABLE 3. ESTIMATE OF PERCENT OF USEFUL LIFE OF TYPICAL ELASTOMERIC INSULATION CONSUMED BY EXPOSURE TO CONTAINMENT TEMPERATURE (Conditions from Startup Through the Accident)

| Temperature °F | Temperature K | Assumed Time at Temperature (h) | Calculation of Life Consumed |
|---|---|---|---|
| 68 | 293 | 8760[a] | $8760/(1 \times 10^6) = 0.00088$ |
| 86 | 203 | 720[b] | $(30 \times 24)/(6 \times 10^5) = 0.0012$ |
| 104 | 313 | 24 | $24/(3 \times 10^5) = 0.00008$ |
| 122 | 323 | 22 | $22/(1 \times 10^5) = 0.00022$ |
| 140 | 333 | 18 | $18/(6 \times 10^4) = 0.0003$ |
| 158 | 343 | 16 | $16/(3 \times 10^4) = 0.00053$ |
| 176 | 353 | 14 | $14/(1 \times 10^4) = 0.0014$ |
| 194 | 363 | 12 | $12/(7 \times 10^4) = 0.0002$ |
| 212 | 373 | 10 | $10/(3.5 \times 10^3) = 0.0029$ |
| 230 | 383 | 10 | $10/(1.7 \times 10^3) = 0.0059$ |
| 248 | 393 | 8 | $8/(8.5 \times 10^2) = 0.0094$ |
| 266 | 403 | 6 | $6/(4 \times 10^2) = 0.015$ |
| 284 | 413 | 4 | $4/(2 \times 10^2) = 0.02$ |
| 302 | 423 | 2 | $2/(1 \times 10^2) = 0.02$ |
| | | | Total Life Consumed = 0.0779 = 8% |

a. Equals 1 yr.

b. Equals 1 mo.

If the oxygen content of the reactor building was decreased by the hydrogen burn and the temperatures experienced by the elastomers occurred after the hydrogen burn, the elastomer degradation would be lessened. The life improvement factors[19] are:

- o Life in air (20% $O_2$/79% $N_2$) 1 x
- o Life in 4% $O_2$/96% $N_2$ 5 x
- o Life in 100% $N_2$ 10 x.

The proprietary nature of the characteristics of the various polymers, plasticizers, and the many types of polymeric electrical insulation of TMI-2 makes evaluation of the polymers difficult. Clearly, the status of the electrical cable insulation is inexact. The results of this analysis indicate that most of the insulation value remains; however, it is recommended that manufacturers and the specialists perform tests on cable samples removed from the TMI-2 reactor building to determine how the insulation was affected by the temperature and how much of its useful life is left.

## CONCLUSIONS AND RECOMMENDATIONS

1. Maximum material surface temperatures estimated at the three levels of the reactor building are:

| Level (ft) | Material Surface Maximum Temperature °F | Material Surface Maximum Temperature K |
|---|---|---|
| 374 | 450 | 504 |
| 347 | 374 to 500 | 463 to 533 |
| 305 | 360 to 400 | 455 to 478 |

   Based on the above estimates, increase of material surface temperature corresponds with height of location in the reactor building.

2. Preliminary calculations of percent of useful cable insulation life consumed during the incident indicate that where the maximum exposure temperature was 302°F (423 K), about 8% of the total life would have been consumed.

3. Most movable insulation (e.g., crane cables and telephone cords) may need to be replaced, but further investigation will be needed before this is resolved.

4. Samples of heat-affected cable insulation should be evaluated by the manufacturers or industrial experts and tested per new cable specifications.

## REFERENCES


1. F. J. Witt, "Sequence of Events of TMI-2 Accident Pertaining to Hydrogen Evaluation," unpublished report, 1981.

2. W. J. Kurzeka and F. Welch, Design Guide for Reactor Cover Gas Elotomeric Seals, AI-AEC-13145.

3. Hytrel Polyester Elastomer, DuPont Co. Bulletin, No. A-82197.

4. R. A. V. Raff and K. W. Doaky (eds.), Crystalline Olefin Polymers Vol. 1 and 2, New York: Interscience Publishers, 1965.

5. J. D. Roberts and M. C. Caserio, Basic Principles of Organic Chemistry, 2nd edition, Menlo Park, CA: W. A. Benjamin, Inc., 1977, pp. 1421-1422.

6. L. Drexler, "Estimated Temperature in Vicinity of Wall Phone in TMI-2 Containment," telecon record, Western Electric Co., Indianapolis, Ind. February 18, 1981.

7. K. Harvey, "Thermal Properties of Acrylic," private communication, Marshalltown Mfg. Co., Marshalltown, Iowa, March 3, 1981.

8. V. Vercol, "Softening Temperature of Styrofoam," telecon record, Dow Chemical Co. Laboratories, Gransville, Ohio, March 5, 1981.

9. H. Rock, "Tygon Tubing's Reaction to Heat," private communication, Tygon Div., Norton Co., Akron, Ohio, February 17, 1981.

10. R. Scott, "Softening Temperature of Telephone Set Plastic," telecon record, Western Electric Co., Shreveport, LA, December 16, 1980.

11. H. Flournoy, "Softening Temperature of Polyethylene and Polypropylene," telecon record, Phillips Chemical Co., Pasadena, TX, February 20, 1981.

12. H. W. Schutz, "Furnace Tests Proving that Polypropylene Rope Contracts Lengthwise at 260°F, Melts at 320°F, and that Nylon 66 Rope Turns Brown at 365°F," March 5, 1981.

13. S. Hamill, "Melt Point of High Density Polyethylene," private communication, ARCO Polymers, Philadelphia, PA, January 13, 1981.

14. Zytel Nylon Resins Design Handbook, DuPont Co., 1972.

15. J. Brenden, "Possible Temperature Reached by 2 x 12 Boards in TMI Containment," telecon record, U.S. Forest Products Laboratory, Madison, Wis., January 13, 1981.

16. L. Sell, B. Andrews, and E. Malcolm, "Temperature Required to Char or Ignite Bond Paper," telecon record, Institute of Paper Chemistry, Appleton, Wis., March 16, 1981.

17. Mr. Winch, B. Baitinger, and Dr. B. Miller, "Estimated Temperature in Vicinity of Rag in TMI-2 Containment," telecon record, Cotton, Inc., New York, NY, Cotton, Inc. Laboratories, Raleigh, NC, and Textile Research Institute, Princeton, NJ, April 3, 1981.

18. R. C. Nametz, Flame-Retarding Synthetic Textile Fibers, Indiana and Engeenering Chemical 62, 3:41-53, March 1970.

19. C. Anolick, "Elastomer Degradation," communication, DuPont Company, February 1978.

# APPENDIX A

# PHOTOGRAPHS USED TO MAKE TEMPERATURE ESTIMATES

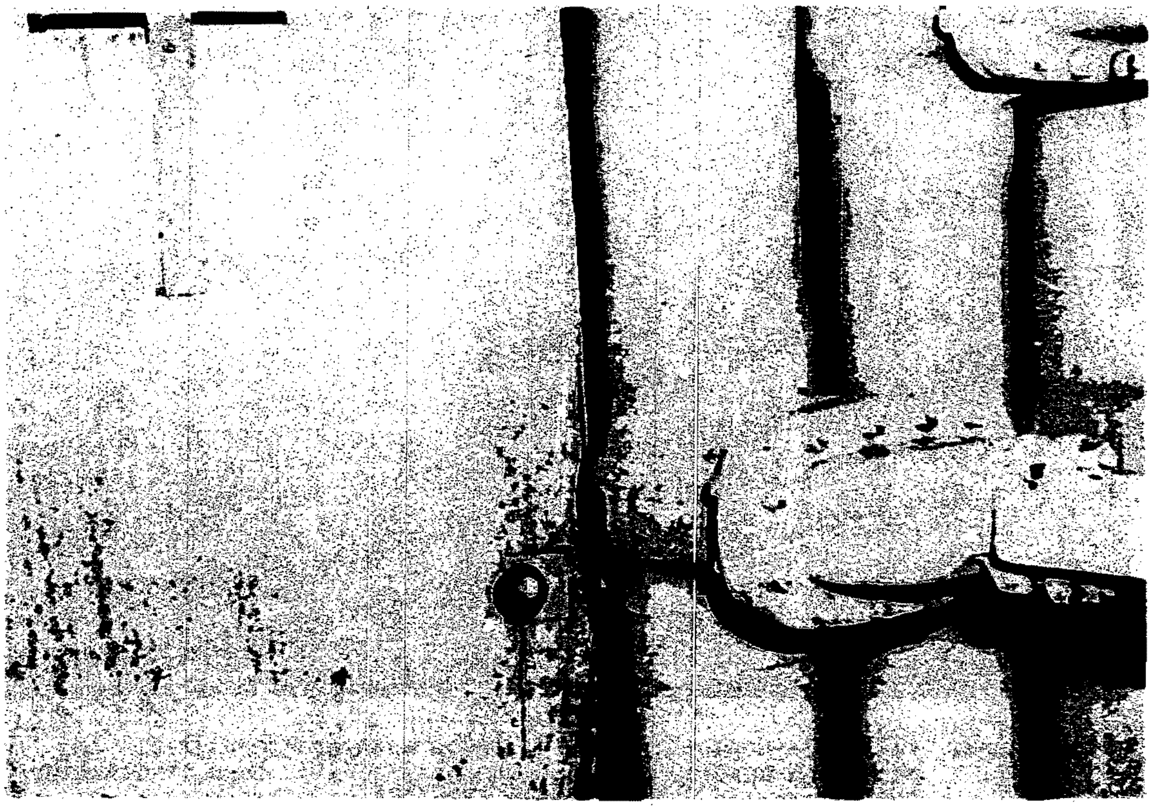


Figure A-1. Entry I, film roll 1, frame 23 (I-1-23)--Door was blown open, but material believed to be styrofoam was not singed or burned. Estimated temperature 200°F (366 K).

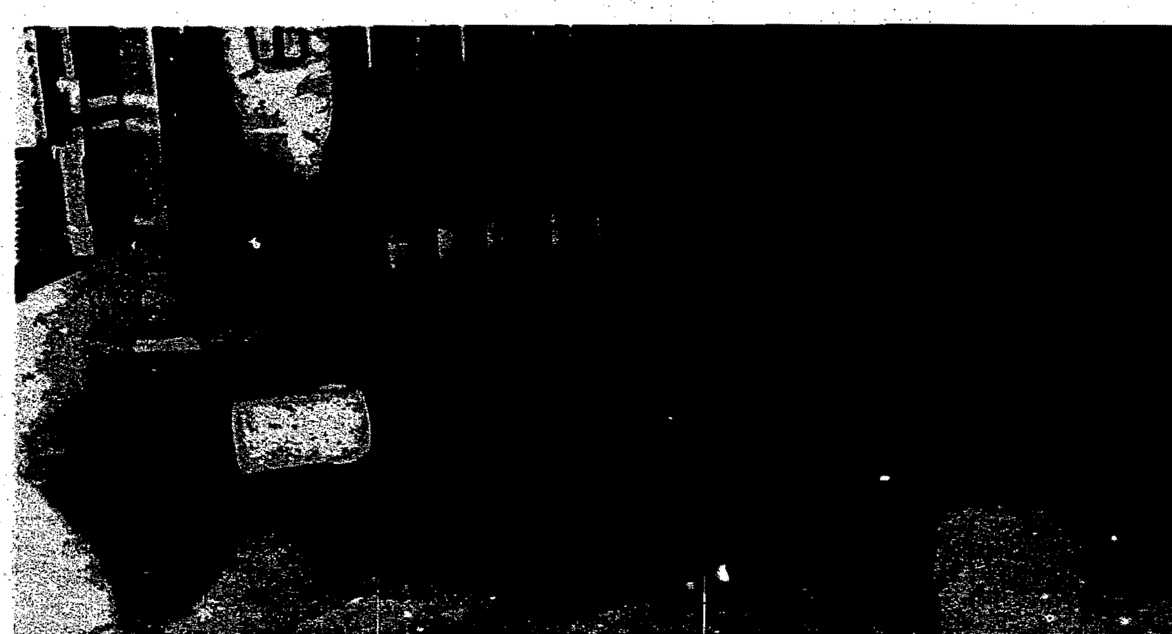


Figure A-2. (I-1-7)--Plastic eight-gallon buckets, probably made of HDPE, were not softened. Temperature was estimated at <275°F (<408 K).

Figure A-3. (I-2-20)--Conduit; red wall phone with coils relaxed. The phone and headset are ABS, the dial acrylic cord, insulation PVC. Temperature would have been 165 to 200°F (347 to 366 K).

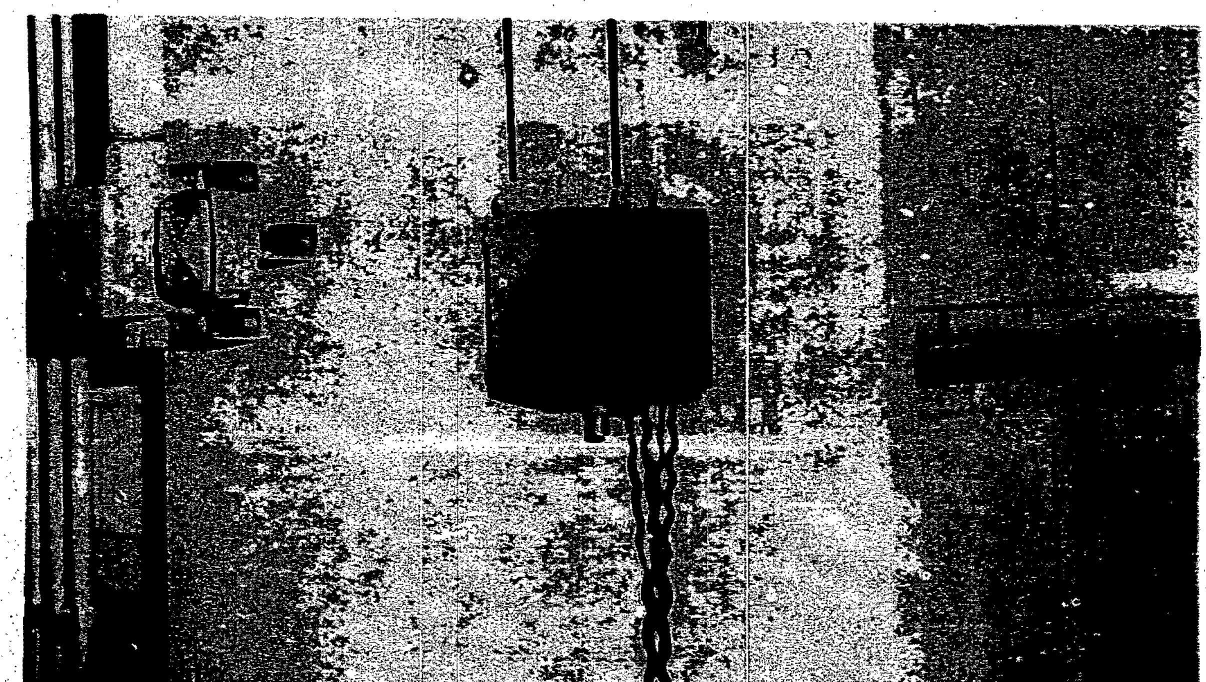


Figure A-4. (I-2-36)--The red phone, whose base and headset are ABS with an acrylic dial, is in good condition. The PVC cord coils are relaxed, indicating a temperature from 165 to 200°F (347 to 366 K).

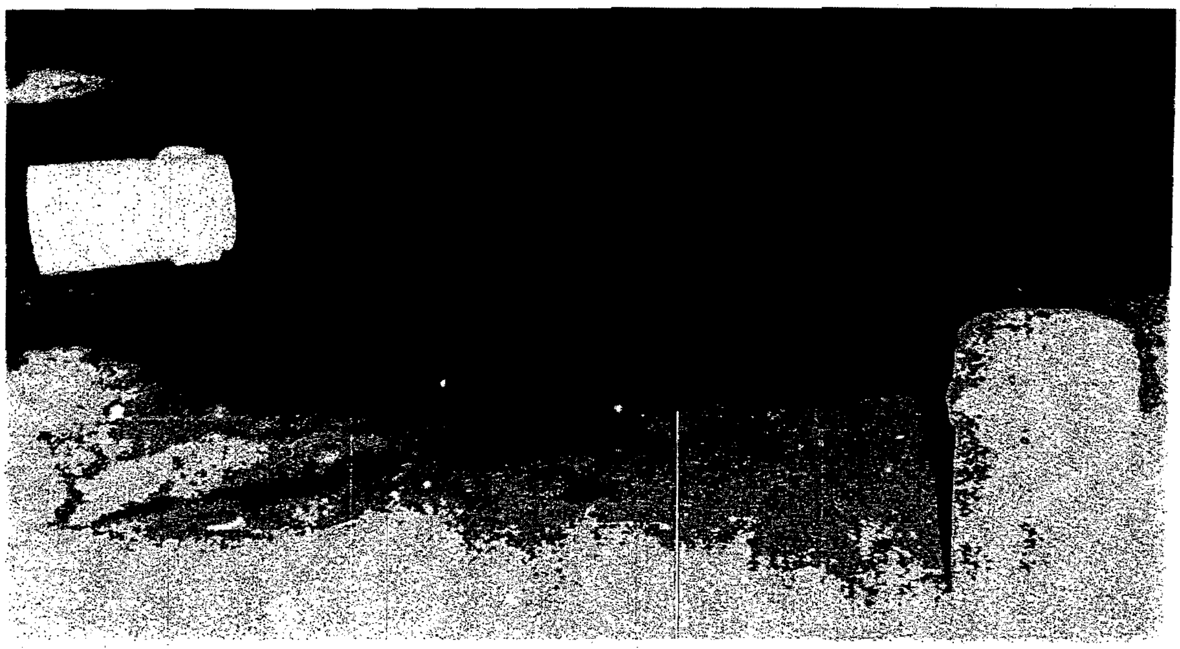


Figure A-5. (I-2-28)--The white plastic buckets, made of high density polyethylene, are untouched. Rust is apparent on the floor near hand-operated valves; the door was blown open. Temperature was demonstrated <275°F (408 K).

Figure A-6. (II-1-0)--A better view of the red telephone with relaxed cord noted in Figure A-4. Temperature was between 165 and 200°F (347 to 366 K).

Figure A-7. (II-1-2)--The gray telephone on D-ring wall does not have a relaxed cord. The temperature was <200°F (<366 K) unless support from the cabinet kept it tightly coiled.

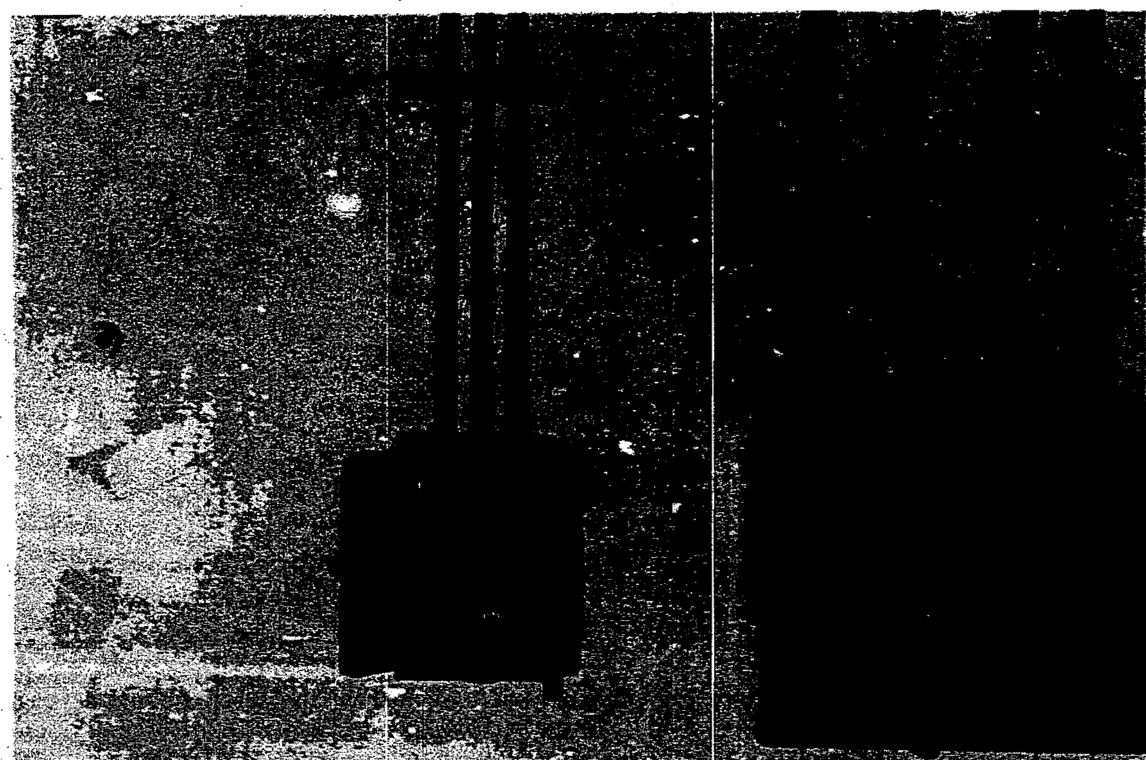


Figure A-8. (II-1-3)--A different view of the gray phone in Figure A-7.

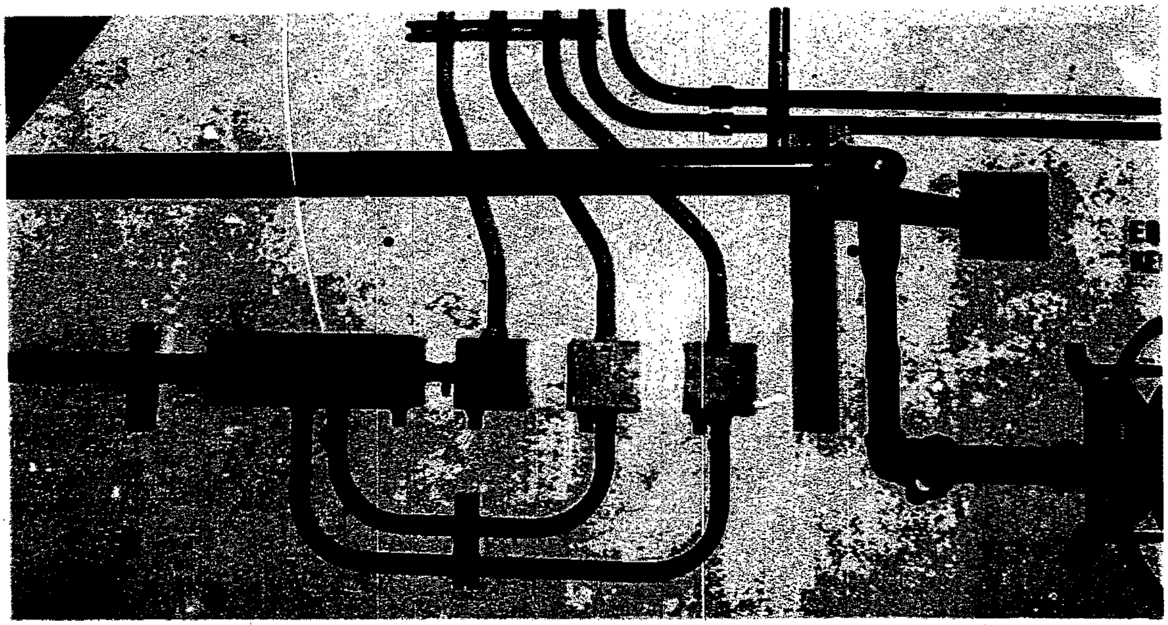


Figure A-9. (II-1-6)--Although the red paint on the fire water pipe conduit is in good condition as is the gray paint on the other pipes in the background, the paper tags are browned. The temperature here would be from 360 to 400°F (455 to 478 K).

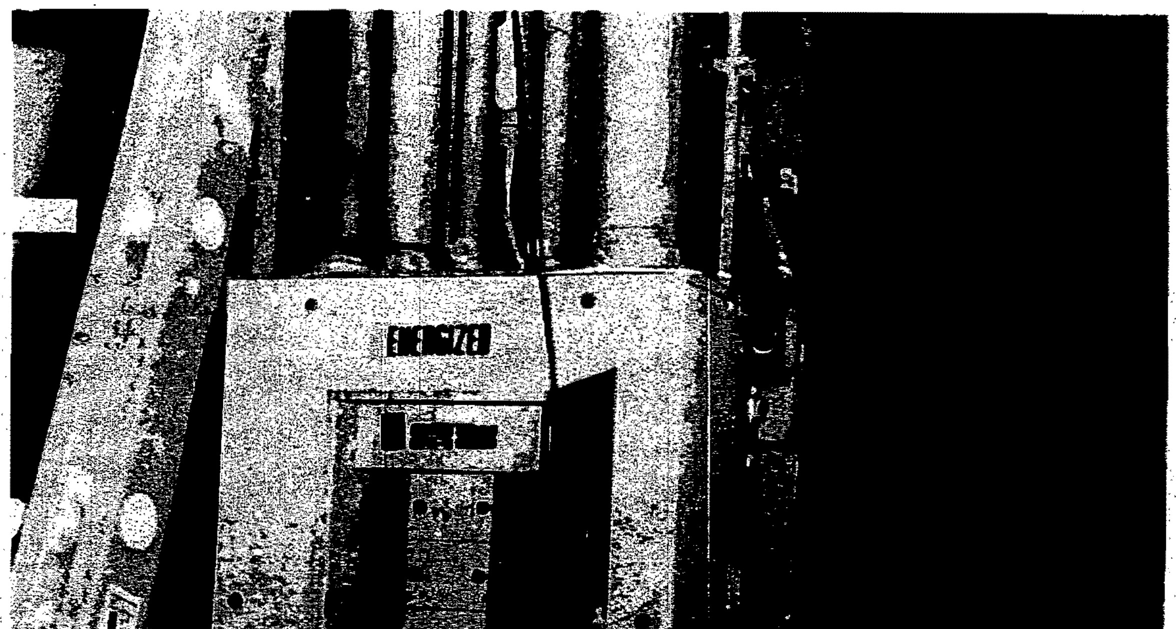


Figure A-10. (II-1-7)--The temperature in this area was <260°F (400 K). The red paint on the aluminum ladder, the polypropylene rope, and the red reset button eight feet off the floor show no ill effects from the heat.

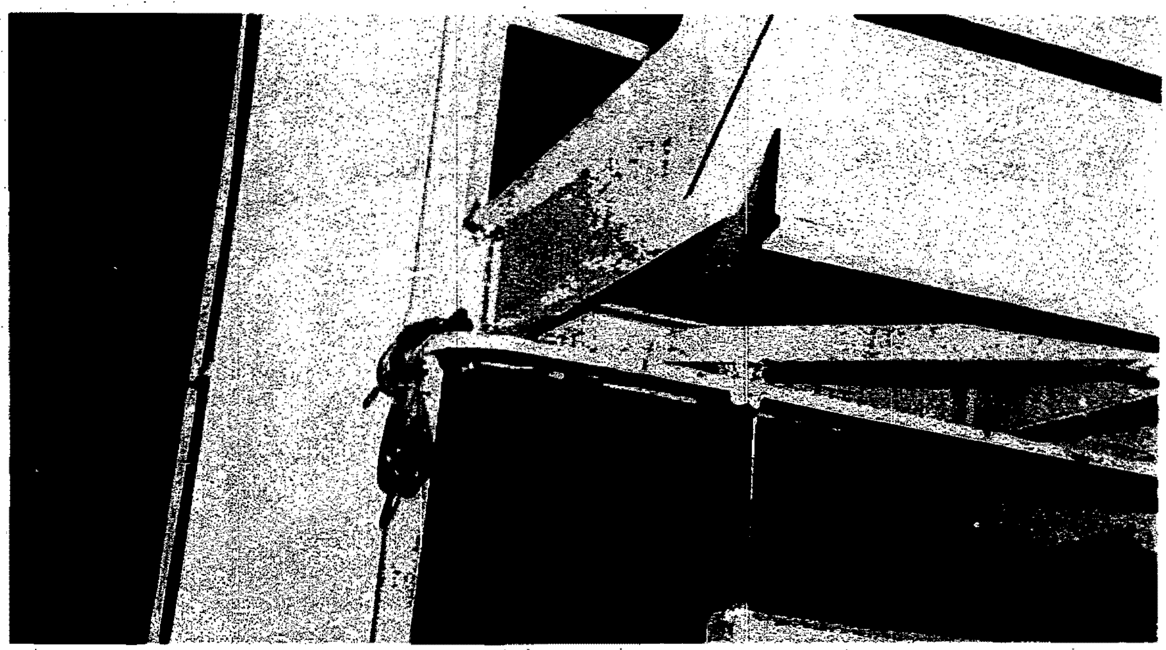


Figure A-11. (II-1-9)--The clear polymer tubing (thought to be Tygon R-3603) is unsoftened or only barely softened. This would mean the temperature was 200°F (366 K).

Figure A-12. (II-1-10)--A temperature of 200°F (366 K) or less is indicated from the undamaged red paint on the firewater pipe.

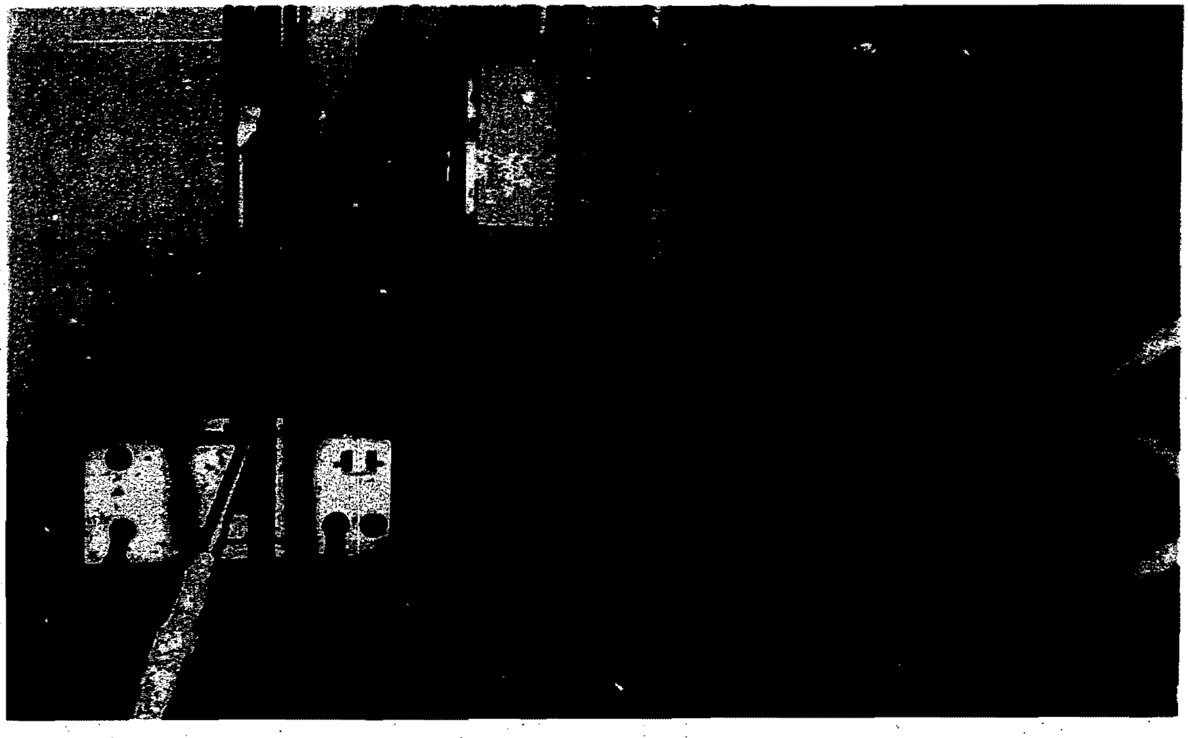


Figure A-13. (II-1-16)--The cord on the red wall phone by the stairwell is somewhat relaxed. The 220 V welder cord is cracked in five places. But the ABS telephone is undamaged. These phenomena indicate the temperature was from 165 to 200°F (347 to 366 K).

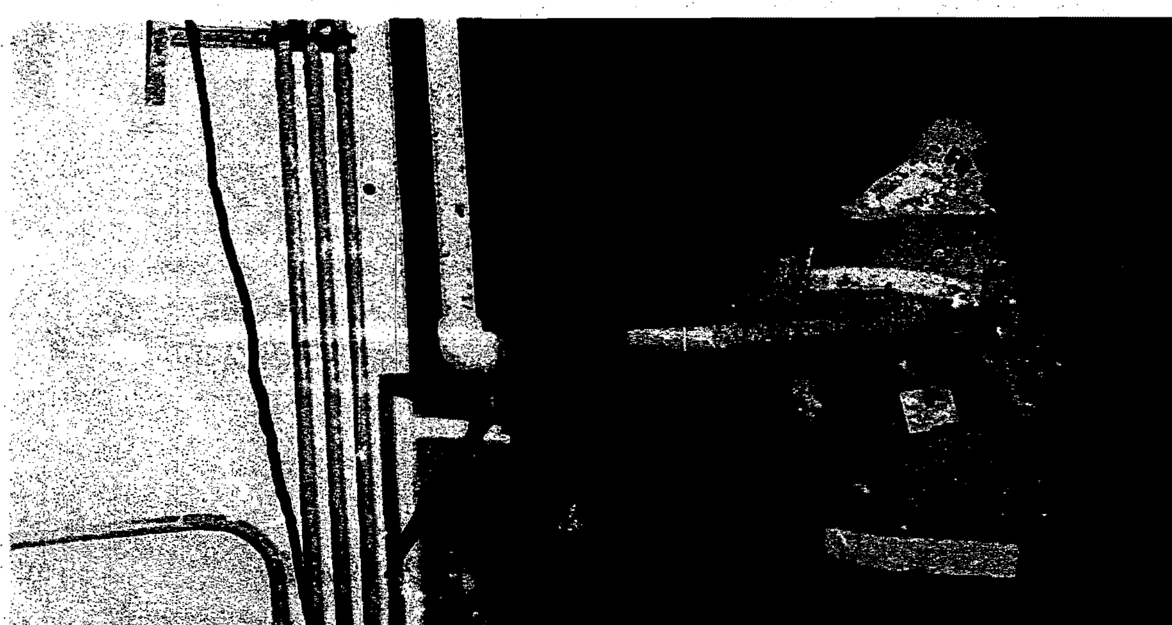


Figure A-14. (II-1-27)--Although the paint on the steel surfaces remains undamaged, proof of temperatures from 375 to 500°F (464 to 533 K) exists. There are rough edges on the electrical cord in the foreground. The rag (probably cotton) wrapped around the pipe ignited.

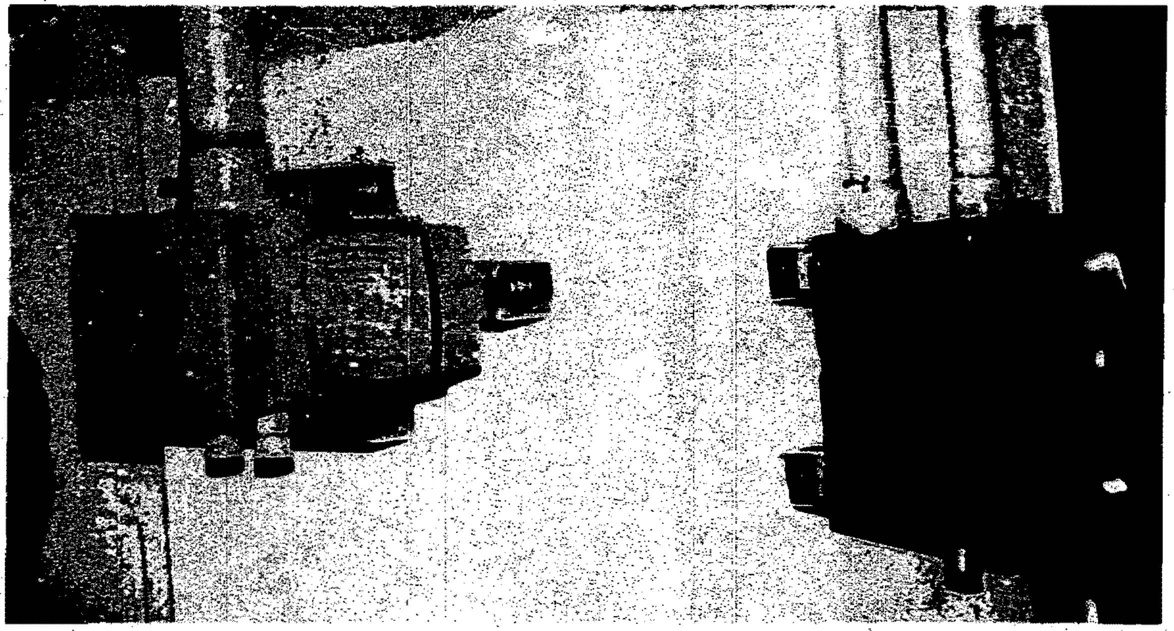


Figure A-15. (II-2-1)--The condition of the telephone forms the basis for estimating the temperature from 165 to 200°F (347 to 366 K). Again, the (ABS) telephone and surrounding paint are in good condition, while the PVC cord is relaxed.

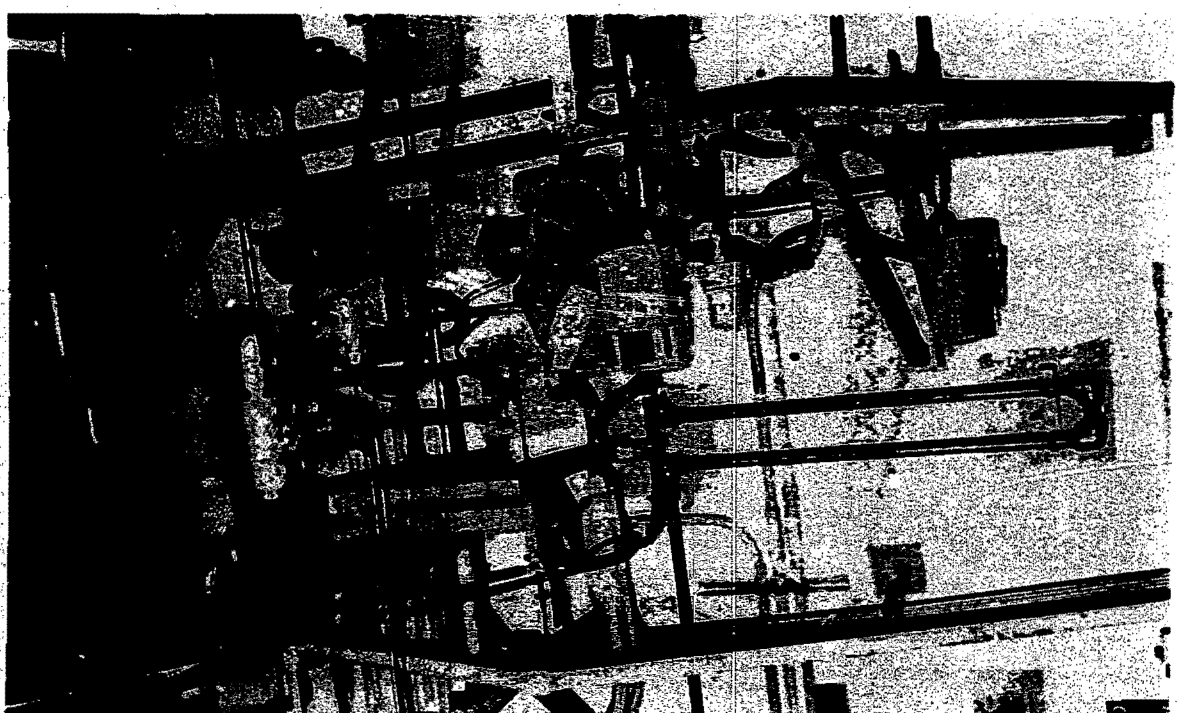


Figure A-16. (II-2-4)--This picture of some motorized valves shows damage from rust rather than heat. Even the paper tags were unbrowned. The temperature, then, was <360°F (455 K).

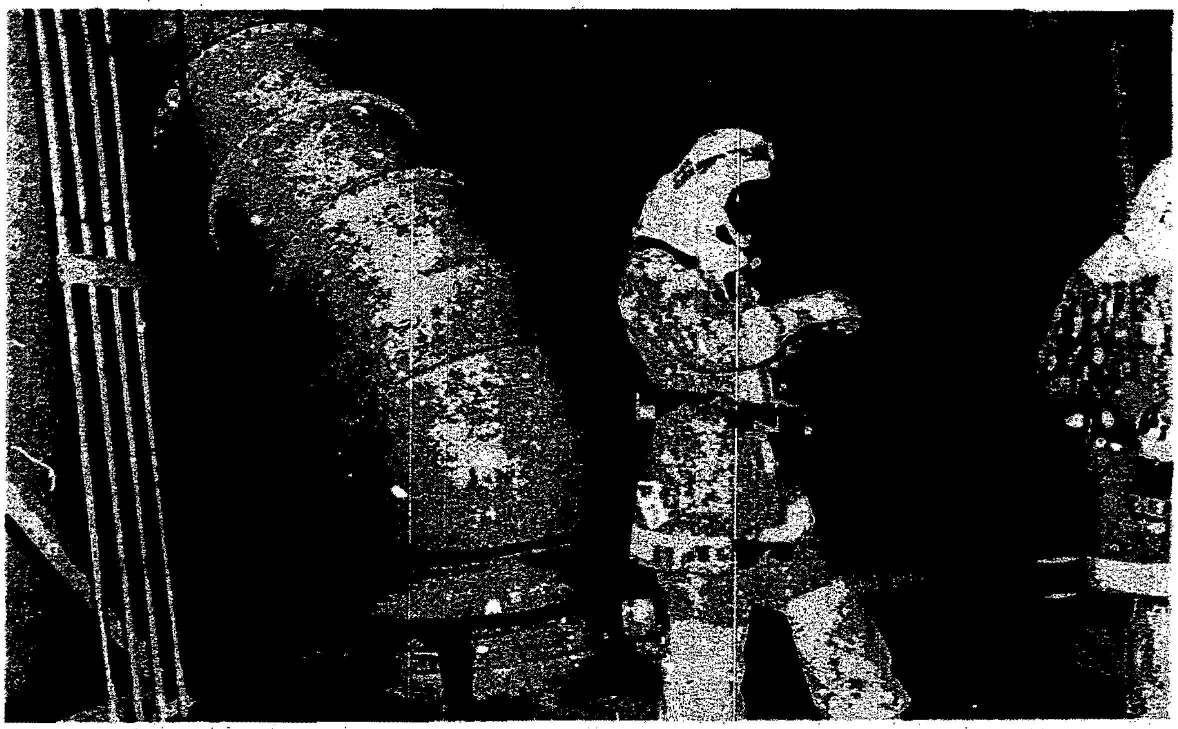


Figure A-17. (II-2-16)--The nylon rope in this picture was taken to the INEL for inspection. Its condition, as well as the paint loss on the gray walls, indicate the temperature was 480°F (522 K).

Figure A-18. (II-2-26)--A temperature of 450°F (505 K) is evidenced in the Auxiliary Fuel Handling Bridge (AFHB) and nitrogen line area. The operating manual was scorched; control buttons melted; a cloth (believed to be cotton) on the pipe line was charred; the telephone cable was charred in the area of penetration; and the ventilator area was darkened.

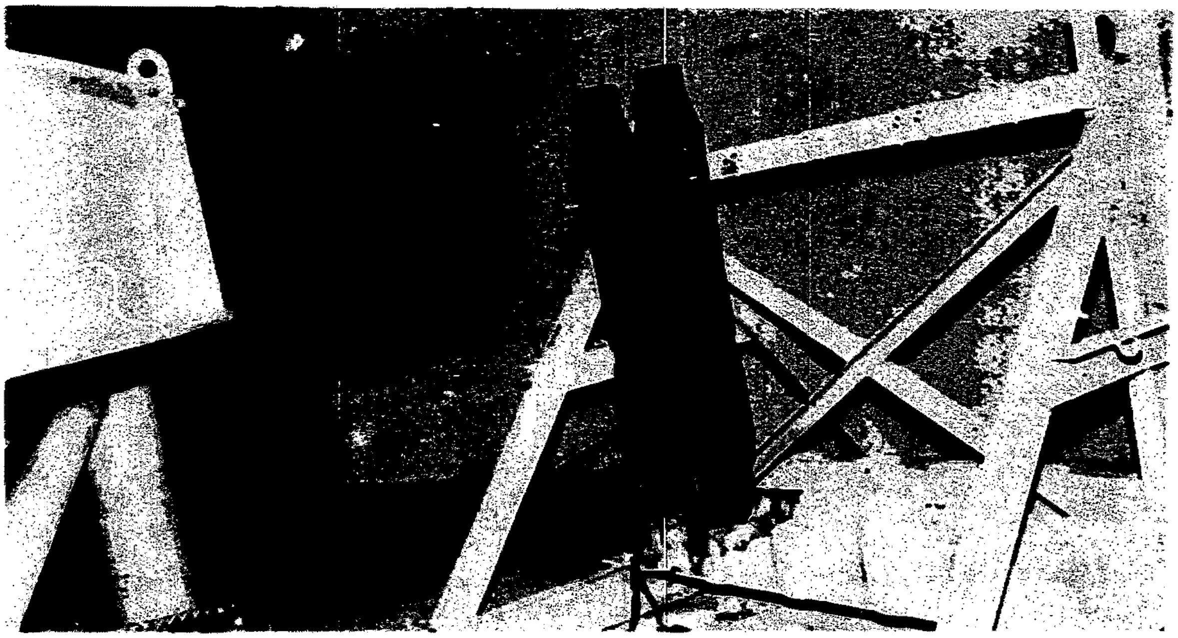


Figure A-19. (II-2-32)--Inspection of the polypropylene rope at INEL, as well as the 36-in. high rust damage throughout the area, indicates a temperature from 260 to 320°F (400 to 433 K).

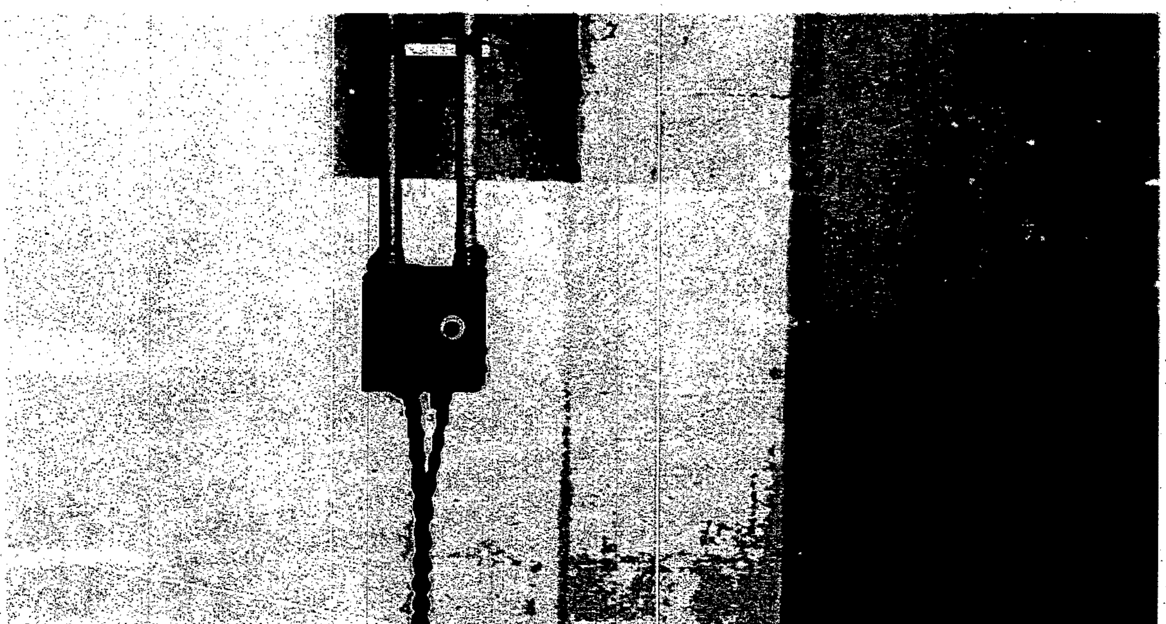


Figure A-20. (IV-1-1)--A telephone, this one next to the elevator, shows the temperature to have been 165 to 200°F (347 to 366 K). The headset is fine, the PVC cord relaxed and somewhat cracked.

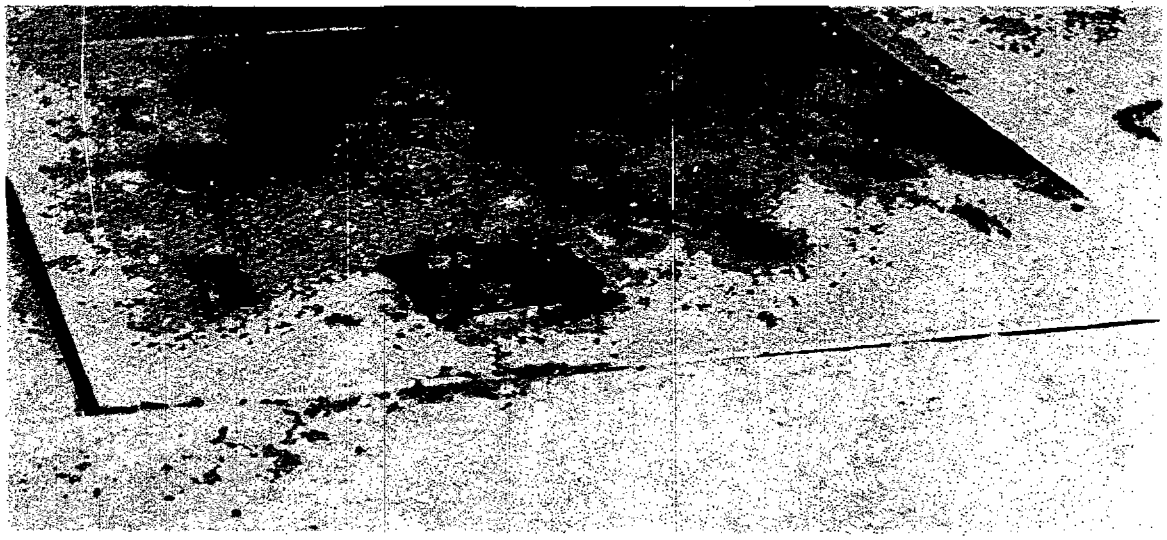


Figure A-21. (IV-1-12)--A yellow HRA notice, "RWP required for entry," is shown. The paper or clear plastic protector on this sign was singed in the upper left hand corner. The sign, one of the items taken to the INEL for inspection, must have fallen from somewhere above. Furnace tests proved the singeing occurred at 360°F (455 K).

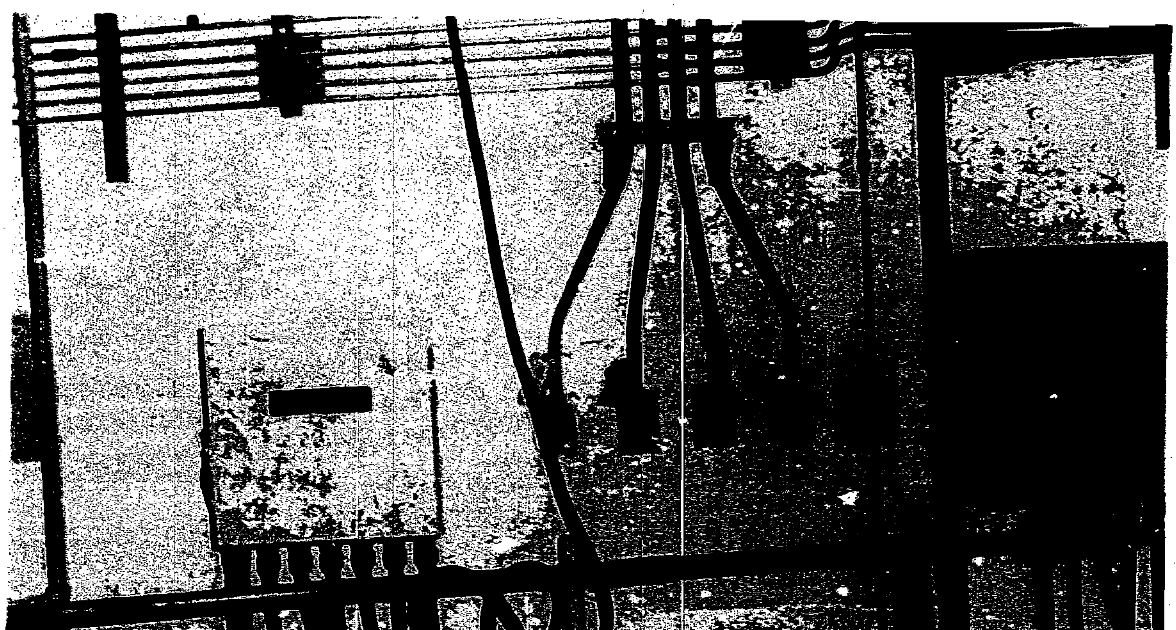


Figure A-22. (IV-1-13)--Evidence in this photograph of the 480 V junction box places the temperature from 250 to 356°F (394 to 453 K). The paper tags on the 120 V outlets were not brown, while the "480 V" tape tags were slightly browned.

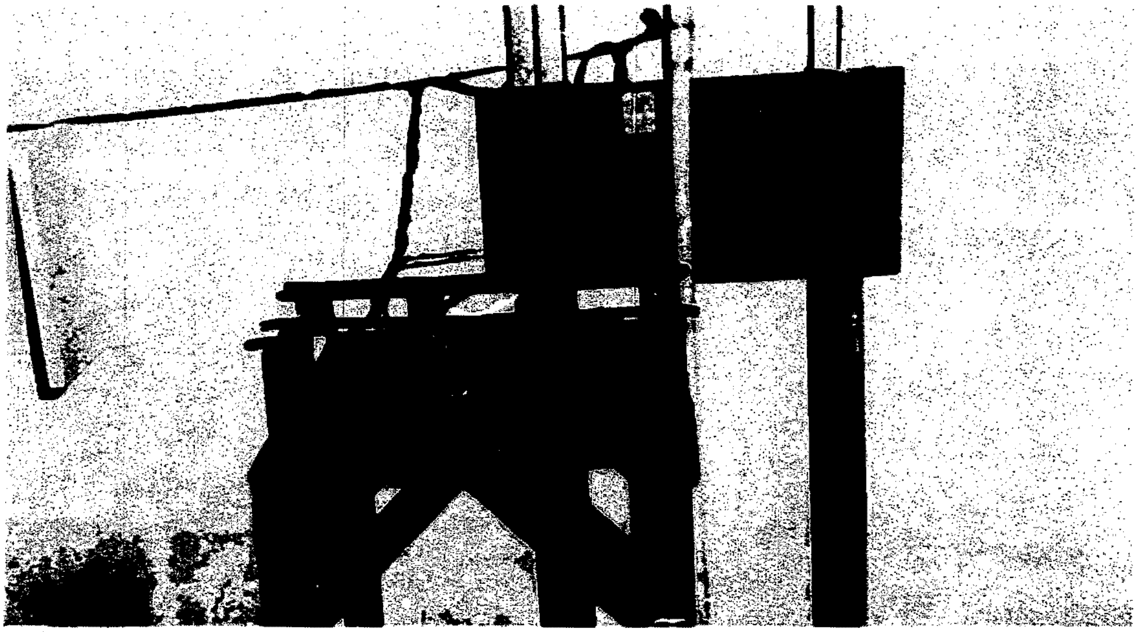


Figure A-23. (IV-1-18)--This ABS phone and headset were sent to the INEL for inspection. The black phone on the bench sustained enough damage to estimate the temperature from 200 to 220°F (366 to 378 K). The case, numeral ring, and dial were distorted, the cord coils relaxed.

Figure A-24. (IV-1-19)--The temperature estimate was 250°F (394 K). The polyethylene sheet on the floor wrinkled slightly. The areas of polyethylene that had been covering the two blocks of wood had melted to the floor.

Figure A-25. (IV-i-25)--The softened plastic buttons on the auxiliary fuel handling bridge control panel indicated high temperatures, but the charred operators manual determined the temperature was at paper's burning point, 450°F (505 K). The manual, as well as the polycarbonate and polymethyl-methacrylate control buttons, were taken to INEL for inspection. Additional evidence included the partly melted headset on the sound-powered phone and the good condition of the heavy plastic lens light and cable tags.

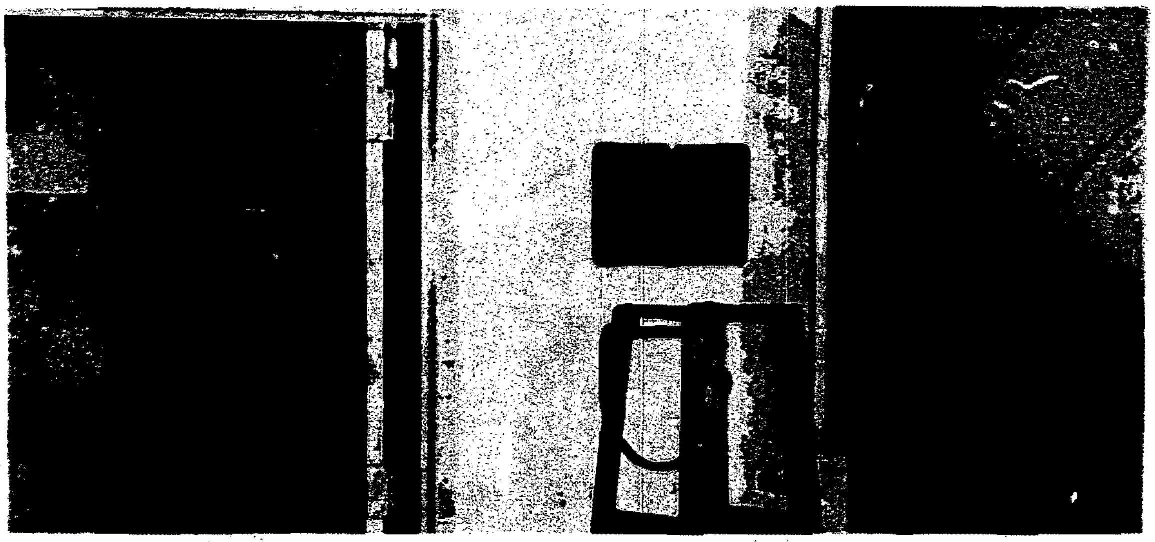


Figure A-26. (IV-1-29)--The singed EXIT sign was the key to the estimate of <335°F (441 K). The sign is made of an unknown polymer. H. W. Schutz's March 5, 1981, furnace tests were the bases for this estimate.

Figure A-27. (IV-2-14)--The crossed boards had been covered with a polyethylene sheet. The sheet was burned away, and the boards were darkened in places. The wood, probaoly spruce, indicated the temperature was slightly less than 400°F (478 K).

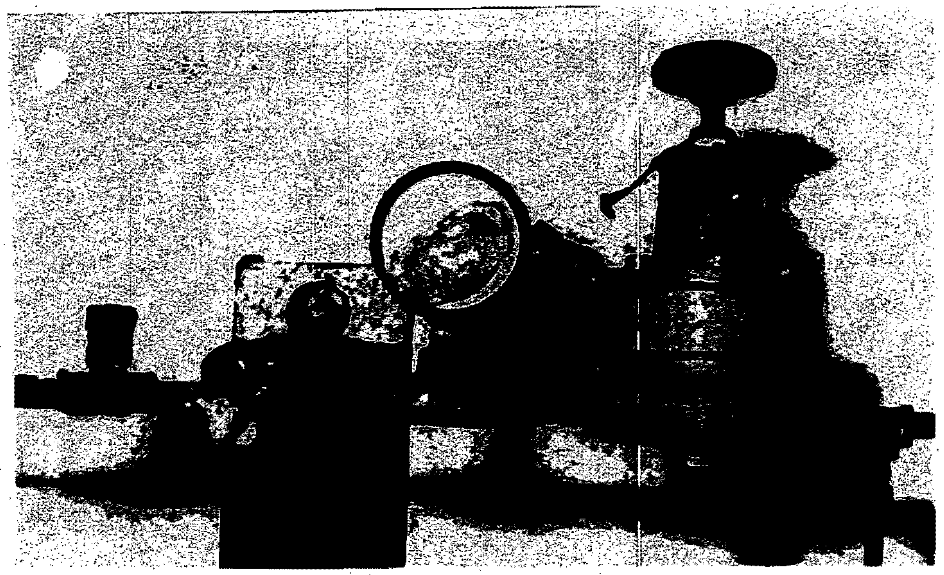


Figure A-28. Entry IV, NRC-2 (IV-NRC-2)--The "clear-look" acrylic observation window downstream of the pressure gage is almost all melted, but the plastic adjusting knob on the pressure reducer did not appear to have melted. Thus, the temperature estimate was 200°F (366 K); although if the reducer knob is made of a thermosetting polymer, the temperature could have been higher.

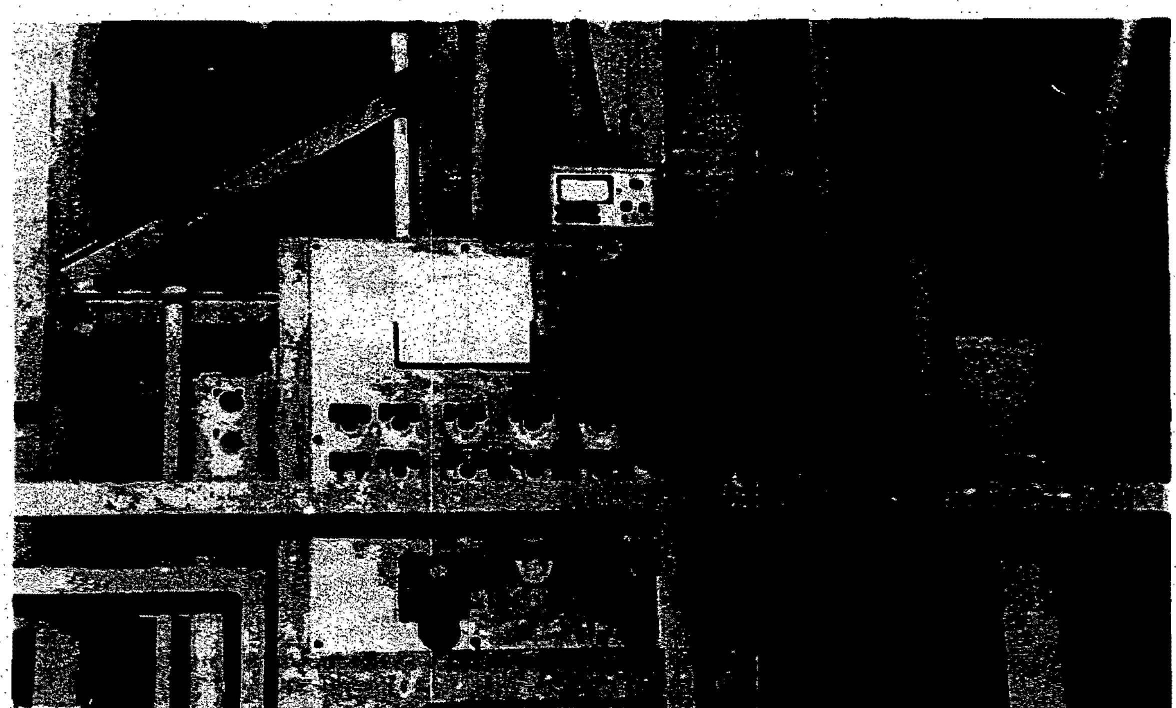


Figure A-29. (IV-NRC-3)--Another view of the auxiliary fuel handing bridge control panel buttons shown in Figure A-25.

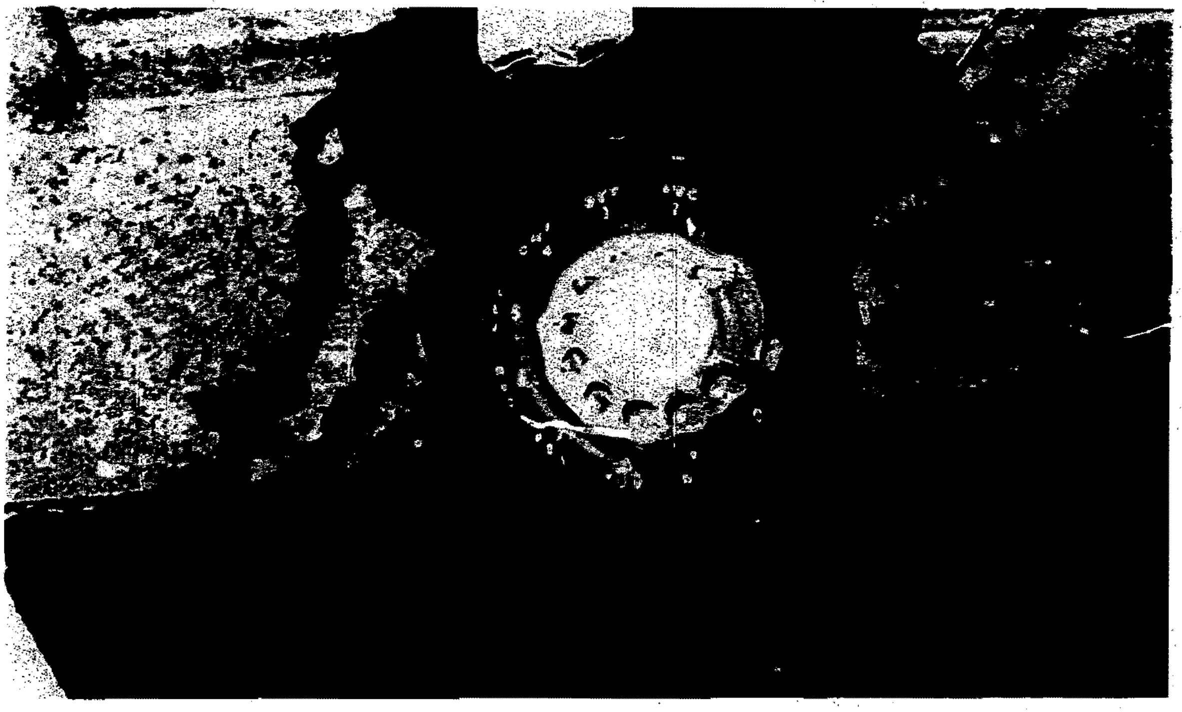


Figure A-30. (IV-NRC-15)--A close-up of the telephone described in Figure A-23; temperature was from 200 to 220°F (366 to 378 K).

Figure A-31. (V-2-1)--A close-up of the softened buttons on the auxiliary fuel handling bridge control panels. See Figures A-25 and A-29.

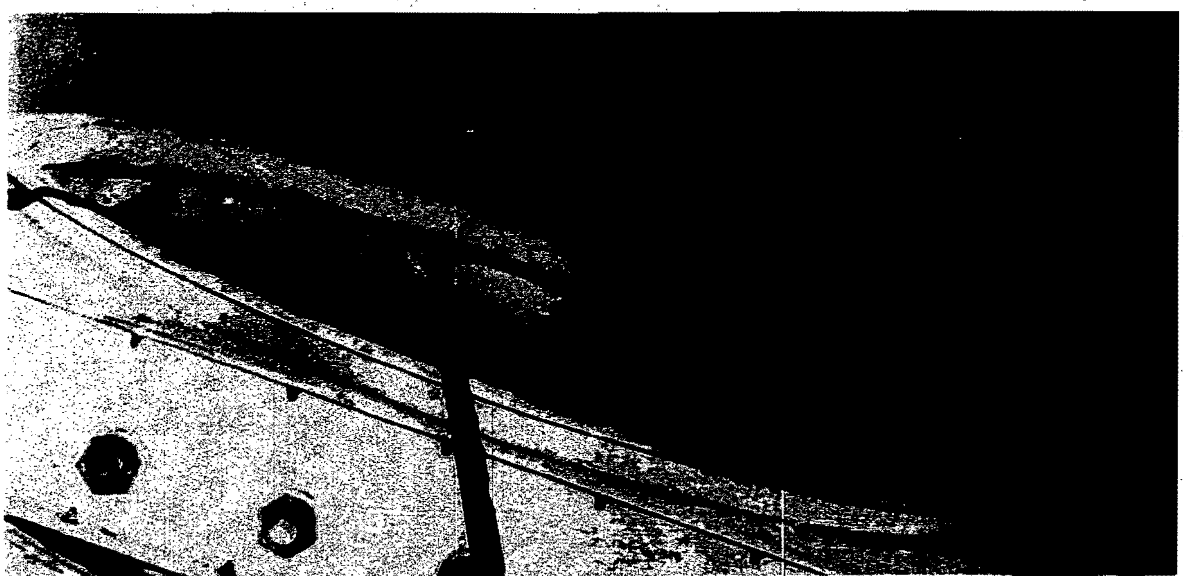


Figure A-32. (V-2-21)--The apparently undamaged black cotton tape on the ventilator entry louvers demonstrates the area's temperature was 250°F (394 K).

Figure A-33. (V-2-37)--Another close-up of the melted black telephone on the welded steel "desk" (see Figures A-23 and A-30).

Figure A-34. (V-3-17)--A different view of the telephone described in Figure A-23, also shown in Figures A-30 and A-33.

Figure A-35. (V-3-28)--The cabinet in the background contains the charred remnants of a pile of paper, indicative of temperatures from 392 to 572°F (473 to 573 K). Because more paper inside the cabinet was found intact, 200°F (366 K), it was concluded that temperatures of 450°F (505 K) existed there for a short time.

Figure A-36. (V-3-36)--The only damaged items noted in this photograph were the junction box, with flaked paint and a browned 480 V sign of unknown polymer. H. W. Schutz performed experiments at ARA-I, which demonstrated that the temperature range probably was from 300 to 400°F (422 to 478 K).