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The Impact of Thermal Aging on the Flammability of Electric Cables

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Operated by
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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

An investigation of the impact of thermal aging on the flammability of two common types of nuclear grade electrical cables has been performed. Four large-scale flammability tests were performed with each of the two cable types tested in both an unaged (i.e., new off the reel) and a thermally aged (artificially aged) condition. In all cases, the fire was observed to consume virtually all of the combustible cable jacket and insulation material present. However, for both cable types tested, the thermal aging process caused a decrease in the cable flammability as demonstrated by decreases in the rate of fire growth, peak fire intensity, total heat released and near fire temperatures. This result is consistent with past cable aging studies because it has been observed that the thermal aging process will drive off certain of the more volatile constituents of a polymeric material. Presumably, when these aged materials are subjected to a fire, the evolution of volatile combustible gases is reduced as compared to the unaged materials, and hence, flammability is reduced. The results of these tests indicate that, at least for the two cable types tested, the evaluation of cable flammability using unaged cable samples will remain a conservative indicator of cable flammability in a thermally aged condition.

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ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance provided by D. Mike Ramirez in the preparation for and performance of the large-scale fire tests described in this report, and the assistance of Mark Jacobus and Larry Bustard in establishing the thermal aging protocol.

EXECUTIVE SUMMARY

The tests described in this report were performed as a part of the U.S. Nuclear Regulatory Commission (USNRC) sponsored Fire Vulnerability of Aged Electrical Components Program at Sandia National Laboratories (SNL). The objective of this program is to identify and investigate issues of plant aging which might result in an increased fire risk at commercial nuclear power plants. The particular issue investigated through the tests described in this document is the impact of thermal aging on the flammability of electrical cables.

This issue was identified as a significant potential concern because cable insulation represents the dominant source of combustible fuels in most nuclear power plant areas. Current USNRC standards require the use of low-flame-spread cables, as certified by the IEEE-383 qualification standard, in all new installations. This requirement is expected to reduce the likelihood of significant cable fires. However, should these cables lose their fire retardant properties as a result of material aging, then a significant increase in fire risk would likely result because of the importance cable installations have played in past fire risk assessments.

To assess this issue, four large-scale cable flammability tests were performed. Two commonly used types of nuclear grade electrical cable were tested, each in both its unaged (i.e. new off the reel) and a thermally aged (through accelerated aging techniques) condition. The two cable types tested were:

(1) Rockbestos FIREWALL III, 3-conductor, 12 AWG, Neoprene jacketed, cross-linked polyethylene (XPE) insulated light power or control cable, and

(2) Boston Insulated Wire (BIW) Bostrad 7E, 2-conductor with shield and drain, 16 AWG, Hypalon jacketed, ethylene-propylene rubber (EPR) insulated instrumentation cable.

Both of these cable types are certified nuclear grade cables, including certification as low flame spread cables. These cable types have been found to be two of the most commonly utilized cable types currently installed in U. S. commercial reactors [1].

Because both of the cable types being evaluated were certified as low flame spread, a fire exposure which was more conservative (i.e., more severe) than the standard exposure test was utilized during testing. This exposure was based on work performed by Factory Mutual Research Corporation (FMRC) [2]. FMRC found that by utilizing a different configuration for the gas burner fire source, and by utilizing two cable trays placed face to face with insulating backer boards (as compared to a single open ladder tray used in the standard test), enhanced fire propagation was observed. The tests described here utilized a similar configuration to induce flame spread in the sample cables. In essence, if the cables did not burn during testing, then little would be learned,

so a configuration expected to result in significant burning was utilized.

During each of the four fire tests performed, it was observed that essentially all of the available combustible materials (the cable insulation and jacket materials) were consumed by the fires. Flame propagation to the full height of the 16 foot vertical cable trays was observed in all cases. However, upon examination of the test data, it was found that for both cable types, the aged cable samples displayed a reduced flammability as compared to the unaged cable samples. This was reflected in reductions in both the rate of rise and the peak value of the measured fire heat release rates for the aged cable samples as compared to the unaged cable samples.

These results indicate that, at least for the two cable types tested, thermal aging resulted in a decrease in material flammability. Hence, for these two cable types, the issue of material aging and cable flammability is not of concern. The use of material flammability parameters obtained from tests of unaged cable samples will provide conservative assessments of material flammability in a thermally aged condition.

This result is consistent with past cable aging study results. It has been observed that the process of thermal aging will tend to drive off certain of the more volatile constituents of the cable insulation materials. This loss of volatiles during aging implies that there are less of these compounds available during fire exposure to support the combustion process, and hence, flammability is reduced somewhat. While other cable types have not been tested, it is expected that similar results would be obtained. No further investigation of this issue is recommended.

1.0 INTRODUCTION AND OBJECTIVES

The tests described in this document were performed as a part of the U.S. Nuclear Regulatory Commission (USNRC) sponsored Fire Vulnerability of Aged Electrical Components Program at Sandia National Laboratories (SNL). The objective of this program is to identify and investigate issues of plant aging which might result in an increased fire risk at commercial nuclear power plants. A number of issues have been identified [3].

One of the fire aging issues identified was a concern that cables might lose some of their fire retardant properties as a result of the aging process. In past work [4,5] the loss of flame retardant additives was observed in polymer samples subjected to artificial accelerated aging. However, no direct correlation between flame retardant loss and material flammability was established in these past efforts.

The impact of aging on cable flammability was identified as potentially significant from the perspective of fire risk and plant aging. This was because (1) cables represent the dominant source of combustible fuels in most nuclear power plant areas and (2) cables have played an important role in past fire risk assessments, both as sources of combustible fuels and as important safety components subject to fire damage.

The tests described in this document were performed to assess the impact of thermal aging on the flammability of two of the most common [1] nuclear grade cables currently utilized by the U. S. nuclear industry. (No radiation aging was performed as a part of these tests as the dominant fire safety concerns identified in past fire risk assessments have focussed on noncontainment areas of the plant.) The objective of these tests was to determine whether thermal aging might result in an increase in the flammability of the cable samples. The two cable types evaluated are:

(1) Rockbestos FIREWALL III, 3-conductor, 12 AWG, Neoprene jacketed, cross-linked polyethylene (XPE) insulated light power or control cable, and

(2) Boston Insulated Wire (BIW) Bostrad 7E, 2-conductor with shield and drain, 16 AWG, Hypalon jacketed, ethylene-propylene rubber (EPR) insulated instrumentation cable.

2.0 EXPERIMENTAL PROCEDURES

2.1 Accelerated Thermal Aging Protocol

Thermal aging of the test specimens was performed based on the Arrhenius theory of accelerated aging. For each of the two cable batches, a thermal oven was used to provide a constant elevated temperature environment for a period of 28 days. The two cable types were aged separately. No deviations from the anticipated aging protocol were experienced for either of the two cable types utilized. For the Rockbestos cables, an aging temperature of 150°C was utilized. For the BIW cables, an aging temperature of 125°C was utilized. Using the Arrhenius theory, these artificial aging conditions correspond to normal life exposure conditions as described in Table 2.1.

Table 2.1: Equivalent Normal Life Exposure Conditions Corresponding to the Accelerated Aging Conditions Imposed Upon the Aged Cable Test Specimens

Cable/Material:	Accel. Aging Conditions:	Equivalent 40 Year Life:
Rockbestos FIREWALL III:		
Neoprene Jacket[1]	28 days @ 150°C	59°C
XPE Insulator[2]	28 days @ 150°C	82°C
BIW BOSTRAD 7E:		
Hypalon Jacket[3]	28 days @ 125°C	52°C
EPR Insulator[4]	28 days @ 125°C	60°C

1. Assumes an activation energy of 0.83 Electron Volts
2. Assumes an activation energy of 1.2 Electron Volts
3. Assumes an activation energy of 0.95 Electron Volts
4. Assumes an activation energy of 1.1 Electron Volts

Note that the Rockbestos cable product was aged to somewhat more severe conditions than was the BIW cable product. The reason for this difference is that the Rockbestos cable is utilized as a light power or control cable whereas the BIW cable is primarily an instrumentation or signal cable. Therefore, because the light power cable would be subject to higher levels of self-heating, it was considered appropriate to utilize a more severe aging end condition for the Rockbestos cable.

In each case, it was desirable to age the cables in straight segments. Because the materials become embrittled during aging, straightening of the cables after aging could result in significant damage to the cable jacketing (particularly in the case of the neoprene jacketed Rockbestos cable). Aging the cables in straight segments meant that damage to the cables that might result from installation in the fire test array would be minimized. However, this also required that the cable samples be cut into shorter lengths than the 17.25-foot fire test array cable tray length to fit within the aging ovens available. Thus, cable samples were cut to 27 and 45 inches, lengths consistent with the size of the aging oven (48 inches), with the spacing of support rungs on the ladder type cable trays in the fire test array (9 inches), and with the desire to stagger the cable break points within the test array (hence two different lengths of cable). (As will be discussed further, for consistency between tests, both the aged and unaged cable samples were cut and installed in the fire test array in the same manner.)

2.2 Fire Exposure Test Apparatus and Procedures

The four fire exposure tests were performed at the SNL fire test facility. Figure 2.1 provides a schematic representation of the burn facility. This facility is an earth sheltered quonset structure with a burn chamber measuring 24x25x18 feet (wxlxh). A forced air push-type ventilation system provides fresh air in a distributed network around the perimeter of the burn chamber. For the purposes of this experimental program, the ventilation rate was established at approximately 2300 CFM. Combustion products are exhausted though an opening in the roof of the burn chamber and are channeled to an exhaust instrumentation stack for measurement of velocity, temperature and composition. All instrumentation signals are routed into a second, outer chamber of the burn facility and recorded through the use of Hewlett-Packard data loggers and minicomputer systems. Tests are monitored from a remote instrumentation trailer.

For the purposes of the tests described here, a special cable support structure was built within the fire test chamber. Figure 2.2 provides a schematic representation of the test structure. This structure was comprised of two galvanized steel open ladder cable trays, each measuring 17.25 feet long by 18 inches wide by 4 inches deep. Each tray was mounted vertically with the trays oriented face to face with a separation distance of 12 inches (as measured from cable tray support rung to support rung). Insulating mineral fiber boards measuring ½ inch in thickness were mounted to the backs of each of the two cable trays.

The test specimens (cable sections) were mounted in a single layer on the inner surface of the cable tray support rungs in a 50% packing density. That is, a single layer of cables was laid in the tray such that each individual cable was separated from its neighbor by a distance of one cable diameter. For the two cable types tested, the outside diameter of the cable assembly was essentially identical (0.5 inches). Thus, 18 lengths of cable were used in each of the two cable trays during each of the four tests for a total cable length of 621 feet per test.

As discussed in Section 2.1, because of the size of the oven available for the performance of accelerated thermal aging, it was necessary to cut the cable specimens into shorter lengths than the 17.25-foot cable tray length. Cable specimens were cut into lengths of 27 and 45 inches.

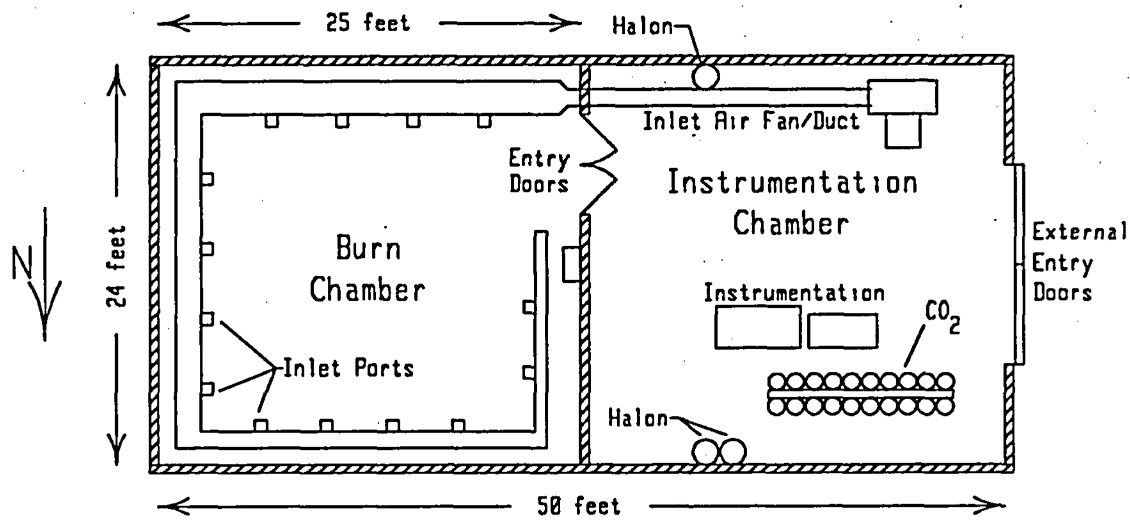

Figure 2.1: Schematic Representation of the SNL Fire Test Facility Used in the Performance of Fire Exposure Tests

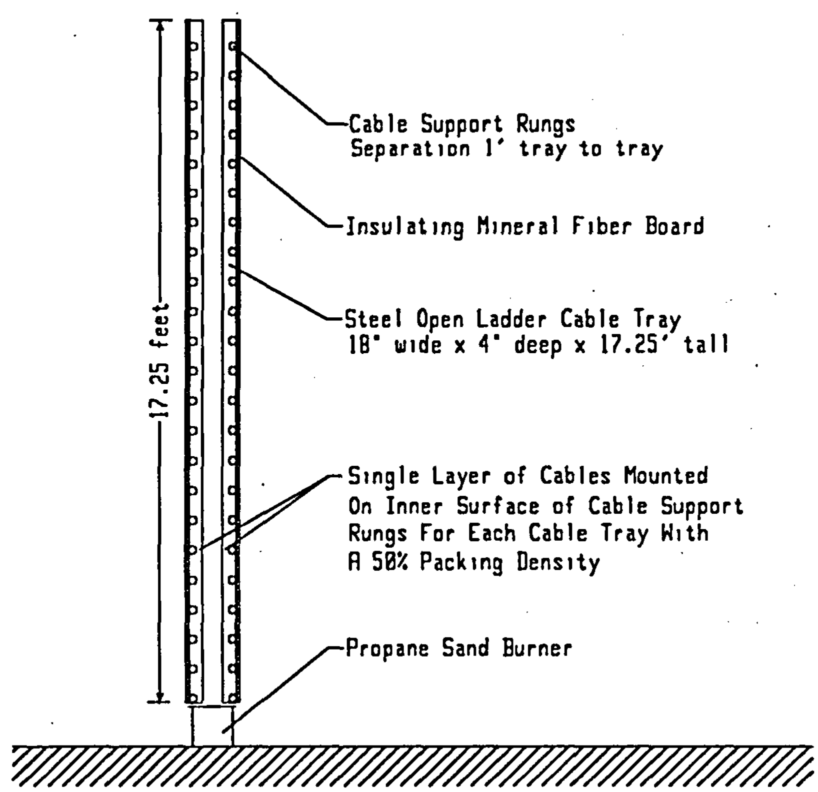

Figure 2.2: Schematic Representation of the Cable Test Support Array

These lengths were chosen to correspond to multiples of the cable tray support rung spacing (9 inches). For each individual vertical cable run, three 45 inch sections and one 18 inch section were utilized. The single shorter 27 inch section in each successive run was alternated from the top of the array to the bottom of the array so that the cable break points were staggered within the array. At each break point or joint location, the cables were clamped to the cable tray support rungs using small sections of steel bar stock. Both the aged and unaged cables were installed in this manner to insure consistency between tests.

The exposure fire was supplied from a 12x18x12 inch (wxlxh) propane sand burner. This burner is essentially a percolator box in which propane is forced though a gravel and sand bed. This configuration results in the development of a surface diffusion flame (as compared to the premixed gas jet flame typical of the IEEE-383 standard flame spread test). The intensity of the diffusion flame is controlled by the rate of propane flow to the burner. The intensity utilized in these tests is identical to that of the IEEE-383 standard exposure source, namely, 61 kW (210,000 Btu/hr).

Instrumentation utilized in these tests was relatively simple. The ventilation inlet air temperature and velocity (flow rate) were both monitored and recorded. Measurements in the vicinity of the cables included only the measurement of the temperature midway between the cable trays at elevations of 3, 6, 9 and 12 feet. These measurements were made with sheathed thermocouples and no attempt was made to shield these thermocouples from thermal radiation. For the outlet gases, the gas temperature, velocity (flow rate), and oxygen concentration were monitored and recorded. In each case measurements were made at intervals of five seconds throughout the test.

2.3 <u>Basis of the Fire Test Exposure</u>

In establishing the fire exposure conditions, a more conservative (i.e., more severe) exposure condition was utilized than that of the standard IEEE-383 flame spread test. In the standard test, a single open ladder vertical cable tray with a single layer of cables installed is exposed to a propane ribbon burner at the base of the cable tray. If flames are observed to propagate to the top of the cable tray, then the cable fails the test. If flames do not propagate to the top of the array, then the cables pass the standard test. Because both of the cable types utilized in the test described here were certified low flame spread cables by this standard test, a more severe fire exposure condition was established. The objective of the test program, assessment of the impact of aging on the cable flammability, would only be met by inducing a self-sustaining fire in the cables. If the cables failed to burn, then little would be learned regarding relative flammability changes.

Recent cable flame spread testing performed by the Factory Mutual Research Corporation (FMRC) [2] was utilized as the basis for establishing the fire exposure conditions. As a part of an effort to establish a new cable flammability certification standard for use by FMRC, several large-scale cable flame spread tests were performed to validate the small-scale flammability assessment test under development. The apparatus used in the tests described in this report, and described above in Section 2.2, is quite similar to the FMRC large-scale test configuration.

There are two significant differences between the FMRC configuration used in the tests described here and the standard IEEE-383 configuration. First, the FMRC configuration uses two longer (18 feet), closed back cable trays place face to face as compared to a single 8-foot long open tray used in IEEE-383. This modification results in enhanced thermal feedback and interchange within the fuel package (i.e., the cables). Second, the gas burner is changed from a ribbon burner to a sand burner with no change in burner intensity. In the standard test, the ribbon burner produces a premixed air/propane jet flame which impinges on the cables essentially horizontally and perpendicular to the cable length. The sand burner is essentially a percolator box which produces a diffusion flame over the surface of the burner (12x18 inches in our case). While the gross intensity of both exposure sources is identical, 61 kW, the diffusion flame results in an increase in the area of exposure for the cables because of an increase in the physical boundaries of the flame zone and an increase in radiative heat exchange.

In the FMRC test effort, it was found that many of the cables that were certified as low flame spread by the IEEE-383 test standard would burn intensely when subjected to the more severe exposure conditions. FMRC found that tests using the more severe exposure condition were able to demonstrate significant differences in actual fire performance between various cables certified as low flame spread cables in the IEEE-383 pass/fail test.

2.4 Test Performance Procedures and Conditions

Prior to the performance of each test, the prevailing atmospheric conditions were measured. All tests were initiated at approximately one-o'clock in the afternoon. Table 2.2 provides a summary of the ambient conditions for each test. As shown in this table, the conditions varied little between tests. All of the tests were performed on fair to clear and dry days when the ambient temperature was between 68°F and 77°F (20°C and 25°C). Relative humidity varied from 11% to 21%. This eases the analysis of the test data because there are no significant variations in ambient conditions.

In the performance of the fire tests, the cables were first loaded into the test array and clamped in place. The insulating backer boards were then installed on the outside of each cable tray. All instrumentation was checked and verified to be operational prior to testing. The gas analysis system was started and calibrated the morning of the test, allowed to warm up for a minimum of 3 hours, and then recalibrated just prior to test initiation. During actual test performance, one minute of base line data was recorded prior to ignition of the burner. Once ignited, the gas burner was allowed to burn for fifteen minutes or until all open flaming in the cable array had ceased.

Table 2.2: Ambient Conditions Prevailing During the Performance of Each of the Four Fire Tests.

Test ID:	Date:	Ambient Temp. (°F\°C)	Ambient Pres. (in-Hg)	Relative Humidity (%)	Wind Dir/Spd (MPH)	General
1-Unaged BIW	5/14/90	74 \ 23	29.92	12%	S/22	Clear, Dry
2-Aged BIW	5/17/90	77 \ 25	30.12	21%	E/14	Fair, Dry
3-Unaged Rockbestos	5/23/90	73 \ 23	30.01	11%	SW/18	Fair, Dry
4-Aged Rockbestos	5/25/90	68 \ 20	29.97	11%	NW/5	Clear, Dry

3.0 TEST RESULTS

3.1 BIW Bostrad 7E Fire Test Results

A major factor which provides a direct indication of a fire's intensity and growth rate is the heat release rate behavior. Figures 3.1 and 3.2 provide the measured heat release rate for the unaged and aged BIW cables, respectively. (These heat release rates are based on oxygen consumption calorimetry measurements.) Note that in both cases, the first evidence of significant contributions by the cable to the fire intensity appears at approximately 7-8 minutes after burner ignition. The fires then developed quickly, peaking in intensity at approximately 8-9 minutes.

Three significant differences can be noted between the heat release rate behavior in these two tests. First, as shown in Figures 3.1 and 3.2, the peak heat release rate for the unaged cable fire was 588 kW while that of the aged cable fire was 329 kW. Second, the peak rate of increase in fire intensity is significantly higher for the unaged cables, 21 kW/s, as compared to the aged cables, 3 kW/s. This is illustrated in Figures 3.3 and 3.4 which provide the time derivative of the heat release rate, a measure of the rate of growth or decline in fire intensity, for the unaged and aged cables respectively.

Third, the total amount of heat released by the unaged cables, 302 MJ, was significantly greater that that of the aged cables, 139 MJ. This is illustrated in Figures 3.5 and 3.6 which provide the time integral of the heat release rate, a measure of the total heat released up to a given time, for the unaged and aged cables respectively. In both cases, it was observed that virtually all of the combustible insulation and jacketing material was consumed in the fires. This implies that the aging process resulted in either a reduction in combustion efficiency, and/or a reduction in the material's heat of combustion per foot of cable.

Figures 3.7 and 3.8 provide the measured temperatures recorded directly between the two cable trays at various elevations during each of the two tests. Note that the peak temperature recorded during the unaged cable fire test, 954°C, exceeds that measured during the aged cable fire 872°C.

In all of the measures of flammability discussed, that is, peak heat release rate, rate of fire growth, total heat release, and near fire temperatures, the fire observed in the aged cables was significantly less severe than that observed in the unaged cables. These results indicate that thermal aging will not increase the flammability of this cable type, and will, in fact, reduce flammability. Flammability parameters obtained based on the testing of unaged cable samples will represent conservative estimates of aged cable performance.

3.2 Rockbestos FIREWALL III Fire Test Results

As in the previous case, the primary indicator of fire performance for the Rockbestos cable is observation of the heat release rate behavior. Figures 3.9 and 3.10 show the actual measured heat release rates for the unaged and aged Rockbestos cables, respectively. Note that the behavior observed in the two tests is markedly different. The profile for the unaged cable fire appears to indicate a contribution to fire intensity from the cables within 1-2 minutes of ignition of the gas burner. For the aged cables, the cable material does not appear to appreciably contribute to the fire until 14 minutes after ignition of the burner. The peak intensity observed during the unaged cable burn was 985 kW while that of the aged cable was 752 kW. This peak intensity occurred at approximately 10 minutes for the unaged cable and 18 minutes for the aged cable.

Figures 3.11 and 3.12 provide the time derivative of the heat release rate. This is a measure of the rate of fire growth (or decline). Note that the peak rate of increase for the unaged cables, 11 kW/s, is somewhat higher than the peak rate of increase recorded for the aged cables, 8 kW/s.

Figures 3.13 and 3.14 provide the time integral of the heat release rate profile for the unaged and aged cables, respectively. This is a measure of the total amount of heat released by the fire up to a given time. Note that the total heat released by the unaged cable fire, 540 MJ, is greater than that released by the aged cable fire, 429 MJ. In both cases, it was observed that virtually all of the combustible insulation and jacketing material was consumed in the fires. This implies that the aging process resulted in either a reduction in combustion efficiency, and/or a reduction in the material's heat of combustion per foot of cable.

Figures 3.15 and 3.16 provide the measured temperatures at various elevations directly between the cable trays during the unaged cable fire and the aged cable fire, respectively. These plots indicate that peak temperatures in the immediate vicinity of the fire were higher in the case of the unaged cable, 975°C, than in the case of the aged cable, 750°C.

In all of the measures of the flammability discussed (that is, peak fire intensity, rate of fire growth, total heat release and near fire temperatures) the aged Rockbestos cables displayed less flammability than did the unaged cables. For this cable type, aging is not expected to result in an increase in material flammability, and in fact, is likely to decrease material flammability. The use of flammability parameters developed using unaged material samples will continue to represent conservative estimates of material flammability in an aged condition.

3.3 Summary of Experimental Results

The test results are summarized in Table 3.1. For both cable types it was found the the aged cables displayed a reduced flammability as compared to unaged samples of the same cable. This was illustrated by observation of the peak rate of heat release, the peak rate of fire growth, the total heat released, and near fire temperatures. These results indicate that the assessment of cable flammability parameters based on the testing of unaged cable samples will provide conservative estimates of cable fire performance in an aged condition, at least for the two cable types tested.

In observing the test results it is also apparent that the aging process had a greater impact on the flammability of the BIW cable product than the Rockbestos cable product. While flammability was reduced for both products due to aging, the changes were much greater in the case of the BIW product. This may be, in part, due to the fact that the Rockbestos cable was aged to a more severe life condition than was the BIW cable.

It should also be noted that the differences observed between the fire performance of the two different cable types were more significant than were the changes noted due to aging. Consider, for example, that the intensity of the fire observed during testing of the aged Rockbestos cable was greater than that observed during testing of the unaged BIW cable. These two cable types are quite different both in material and intended application. None the less, the differences in fire performance between the two cable types are significant, and indicate that considerable variability in cable flammability can be expected, even among cables certified as low-flame-spread according to IEEE-383. This observation is also consistent with the observations recorded by FMRC in the performance of their own cable fire tests [6].

Table 3.1: Summary of Fire Test Results

Test Sample:	Peak Heat Release Rate (kW)	Peak Fire Growth Rate. (kW/s))	Total Heat Release (MJ)	Peak Near Fire Temp. (°C)
BIW Bostrad 7E:				
Unaged Condition	588	21	302	954
Aged Condition	329	3	139	872
Rockbestos FIREWALL III				
Unaged Condition	985	11	540	975
Aged Condition	752	8	429	750

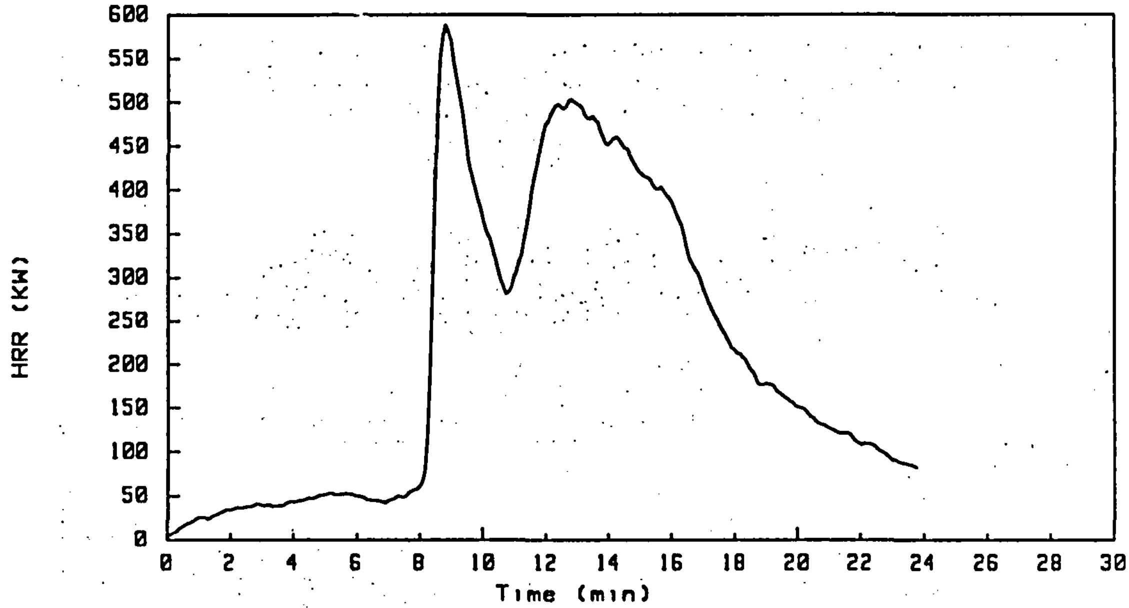

Figure 3.1: Heat Release Rate (Based on Oxygen Consumption Calorimetry) Measured During the Burning of the Unaged BIW Bostrad 7E Cable Product

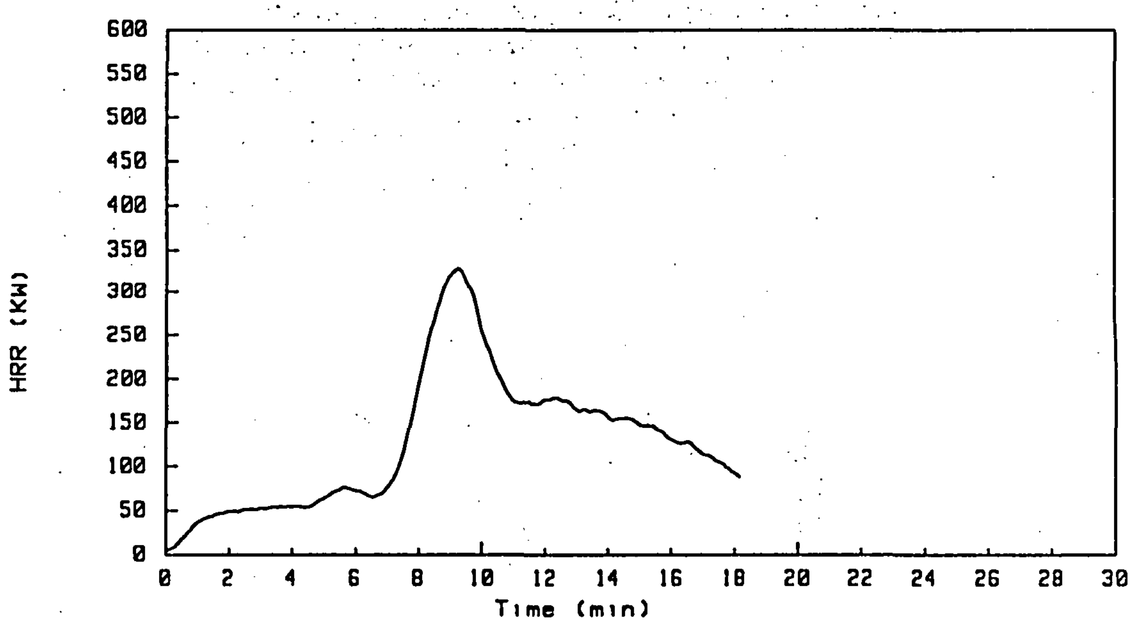

Figure 3.2: Heat Release Rate (Based on Oxygen Consumption Calorimetry) Measured During the Burning of the Aged BIW Bostrad 7E Cable Product

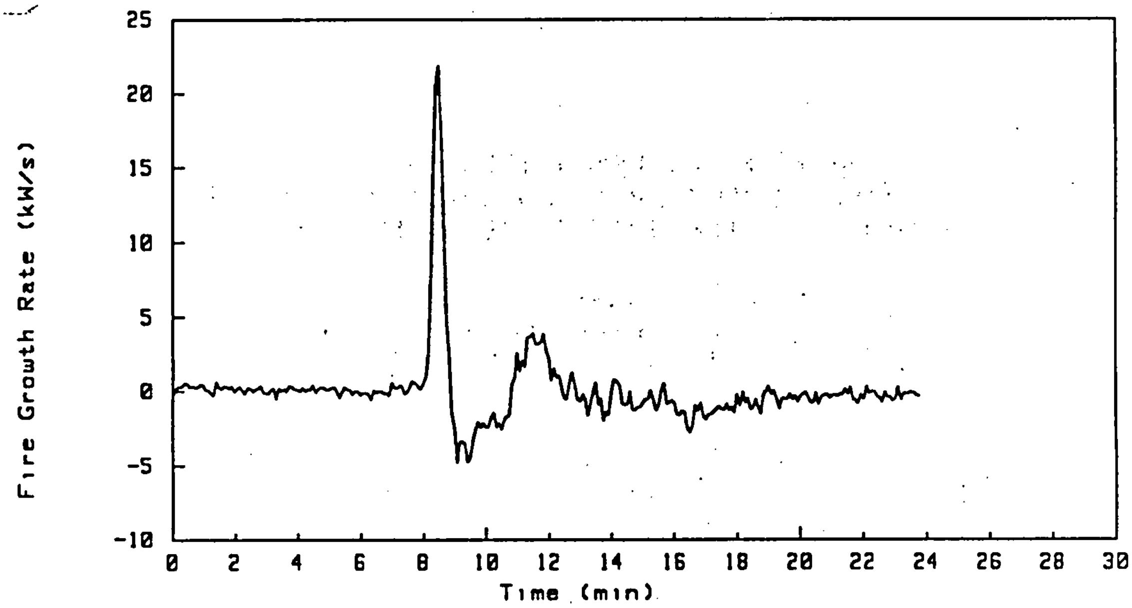

Figure 3.3: Time Rate of Change in the Heat Release Rate (Rate of Fire Intensity Growth or Decline) During the Burning of the Unaged BIW Bostrad 7E Cable Product

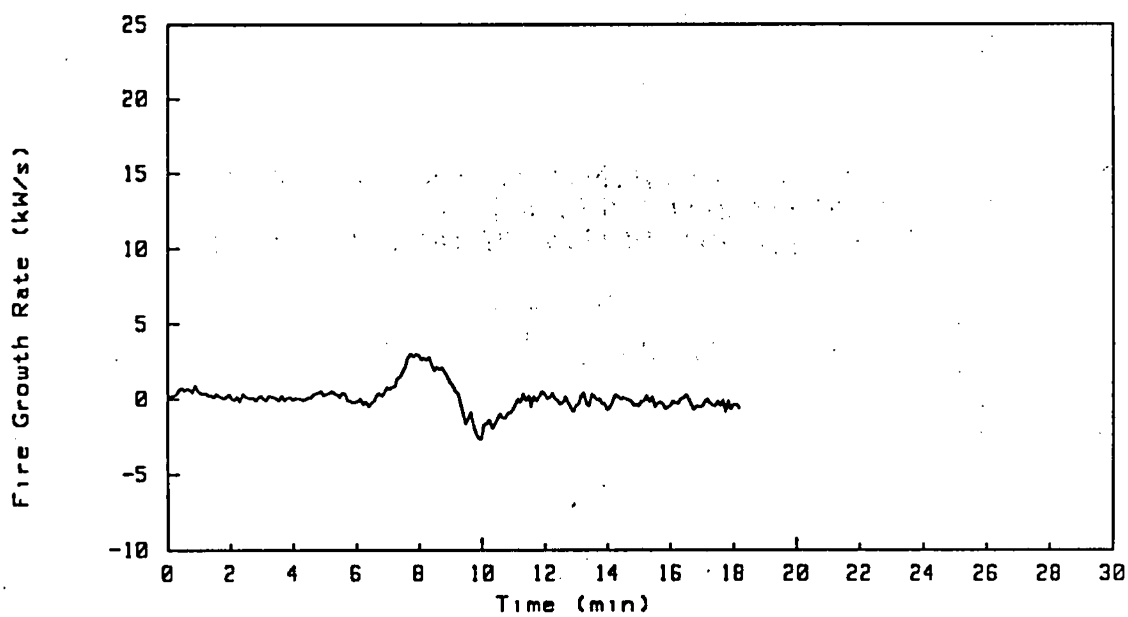

Figure 3.4: Time Rate of Change in the Heat Release Rate (Rate of Fire Intensity Growth or Decline) During the Burning of the Aged BIW Bostrad 7E Cable Product

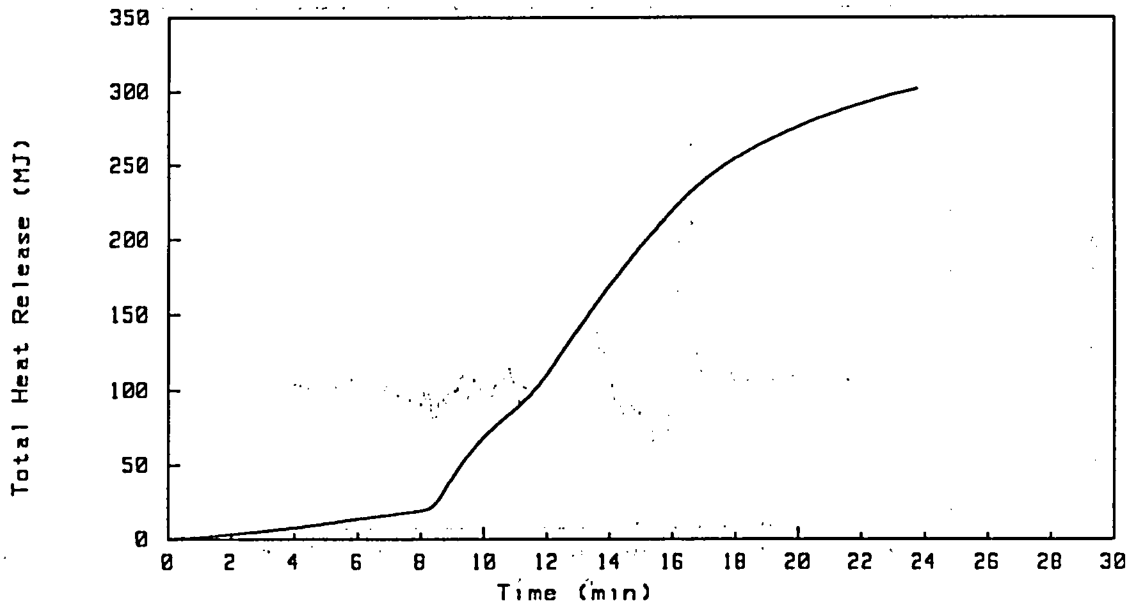

Figure 3.5: Time Integral of the Heat Release Rate (Total Cumulative Heat Release) for the Unaged BIW Bostrad 7E Cable Fire Test

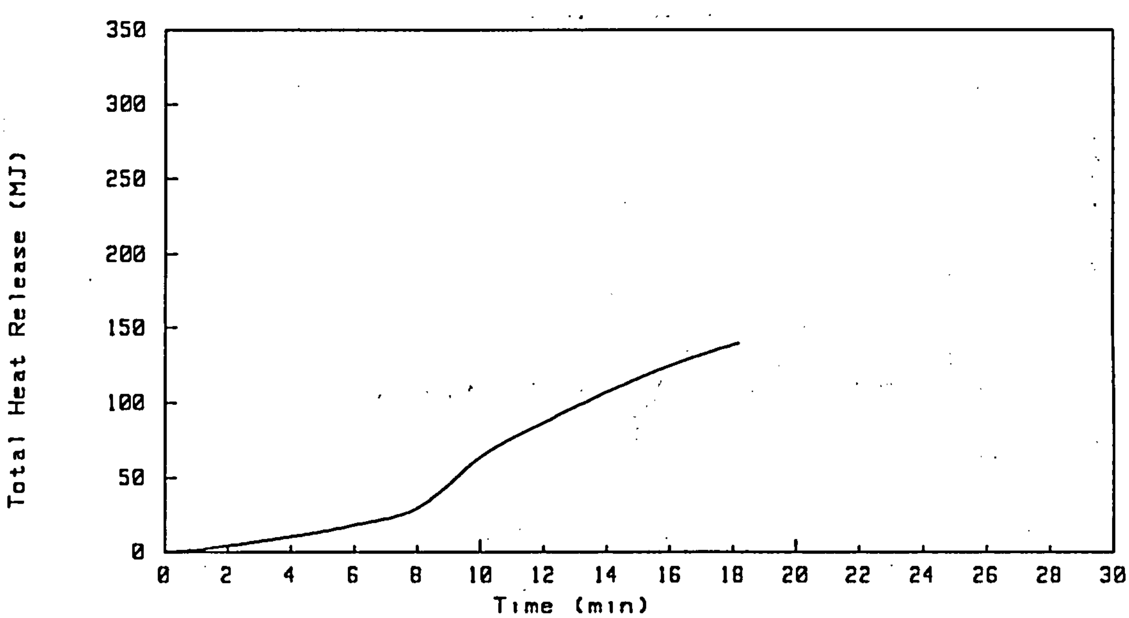

Figure 3.6: Time Integral of the Heat Release Rate (Total Cumulative Heat Release) for the Aged BIW Bostrad 7E Cable Fire Test

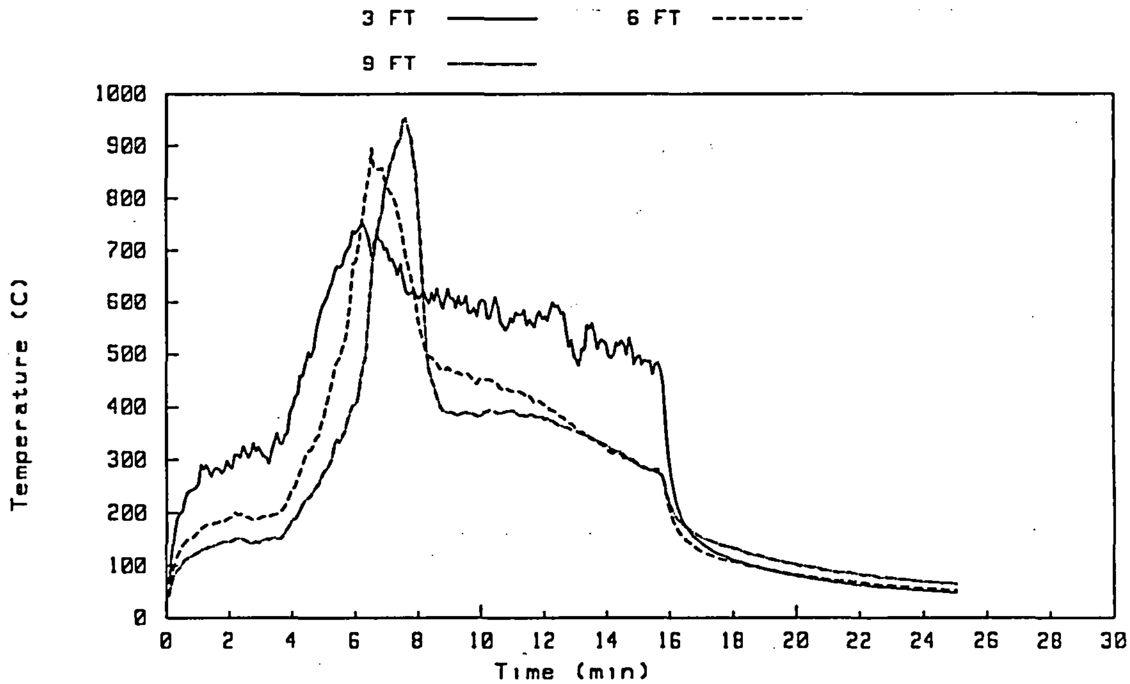

Figure 3.7: Temperatures Measured Between the Two Vertical Cable Trays During the Burning of the Unaged Bostrad 7E Cable Product

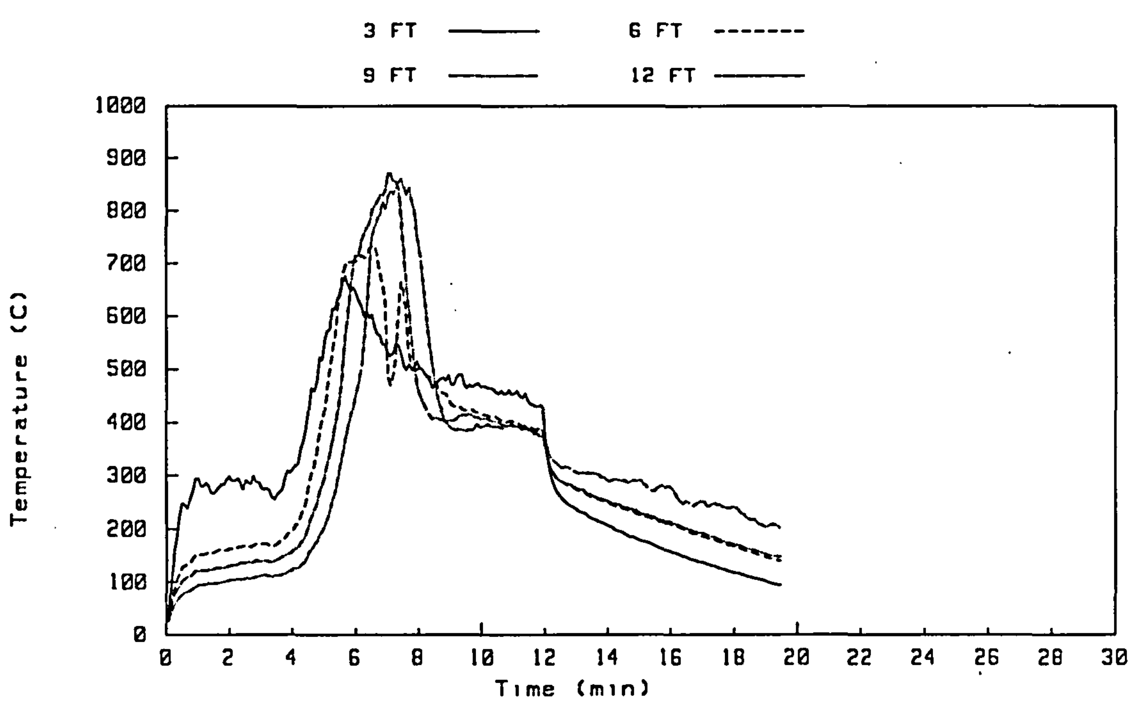

Figure 3.8: Temperatures Measured Between the Two Vertical Cable Trays During the Burning of the Aged Bostrad 7E Cable Product

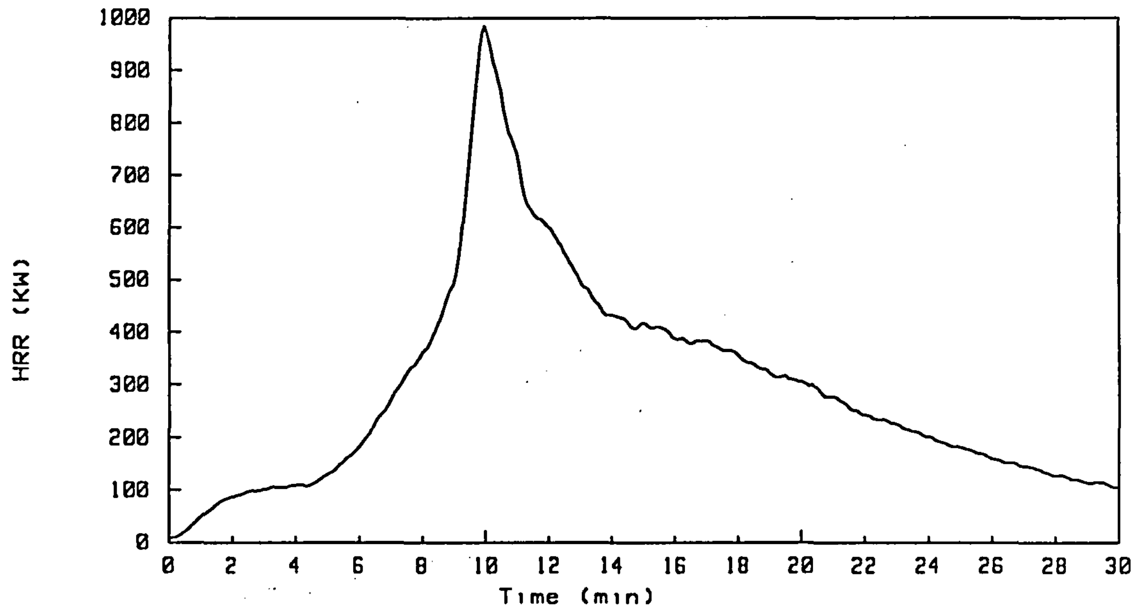

Figure 3.9: Heat Release Rate (Based on Oxygen Consumption Calorimetry) Measured During the Burning of the Unaged Rockbestos FIREWALL III Cable Product

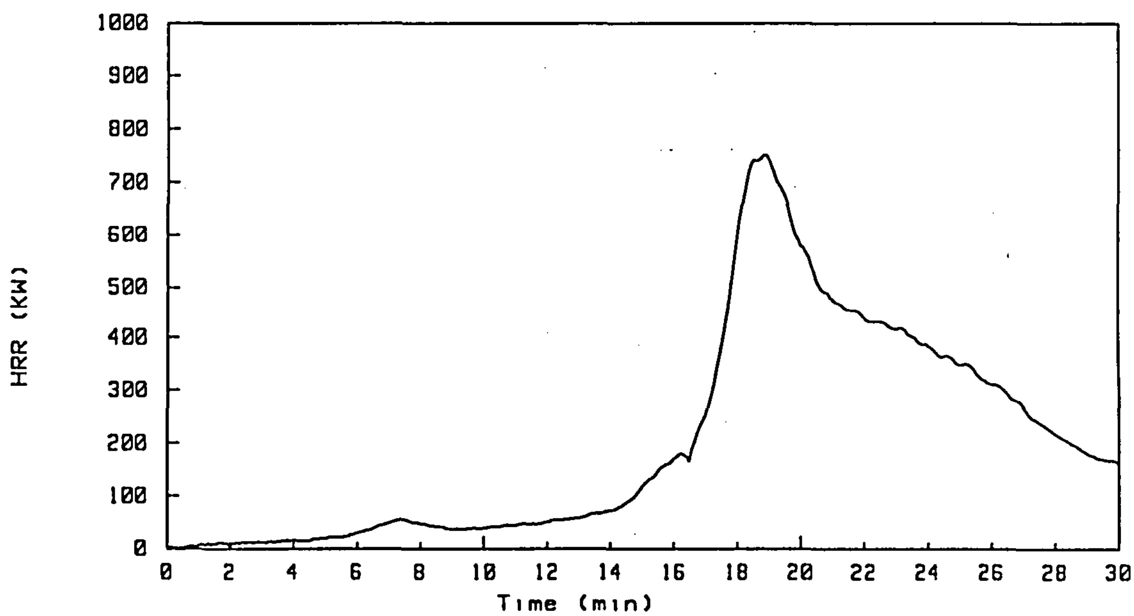

Figure 3.10: Heat Release Rate (Based on Oxygen Consumption Calorimetry) Measured During the Burning of the Aged Rockbestos FIREWALL III Cable Product

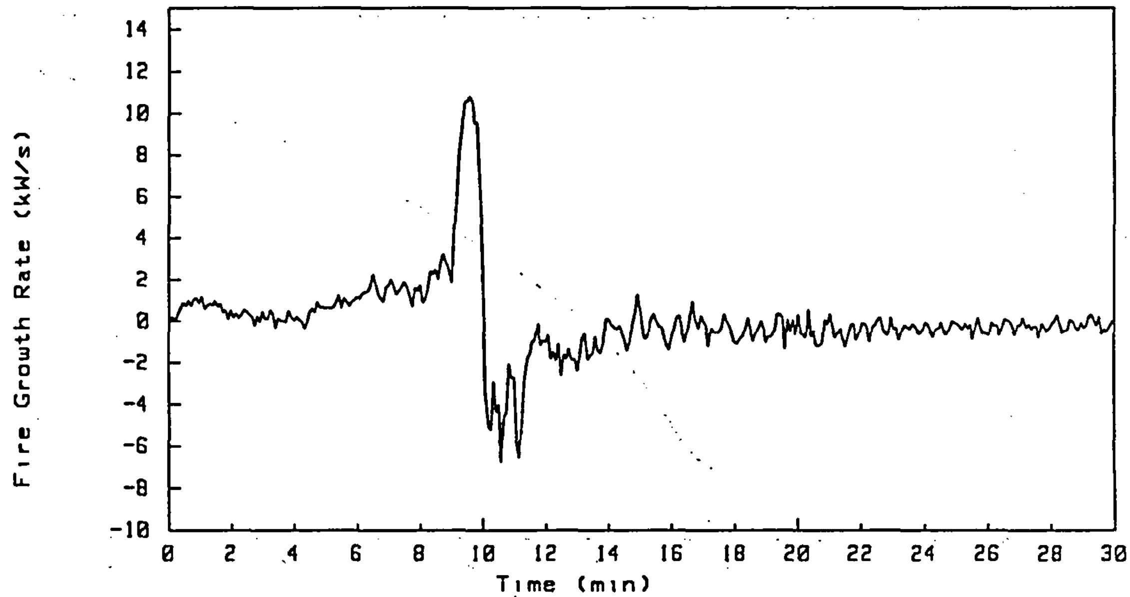

Figure 3.11: Time Rate of Change in the Heat Release Rate (Rate of Fire Intensity Growth or Decline) During the Burning of the Unaged Rockbestos FIREWALL III Cable Product

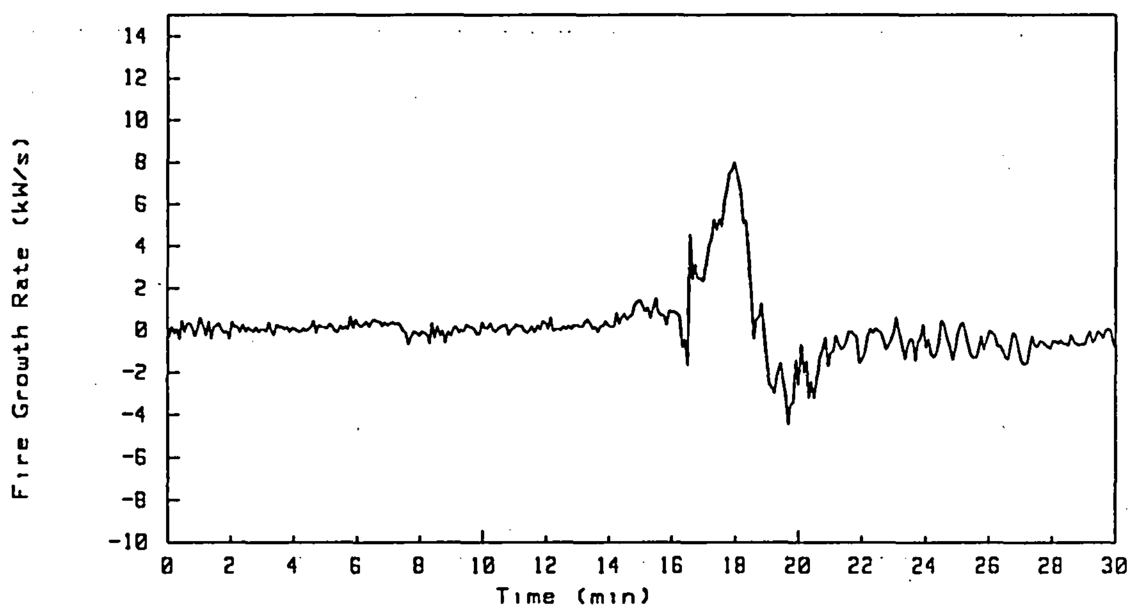

Figure 3.12: Time Rate of Change in the Heat Release Rate (Rate of Fire Intensity Growth or Decline) During the Burning of the Aged Rockbestos FIREWALL III Cable Product

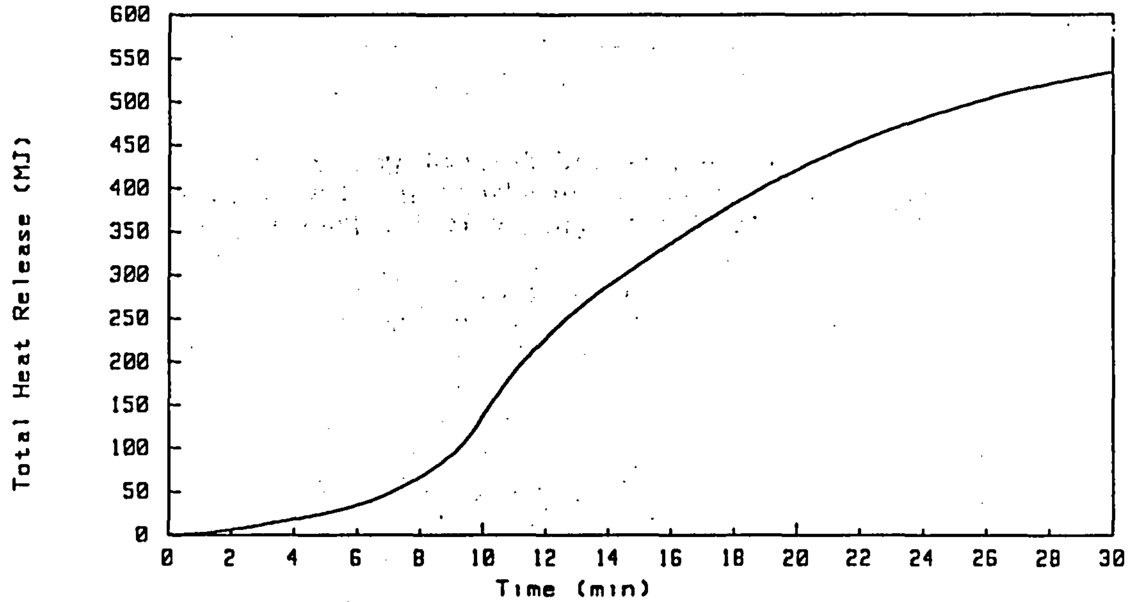

Figure 3.13: Time Integral of the Heat Release Rate (Total Cumulative Heat Release) for the Unaged Rockbestos FIREWALL III Cable Fire Test

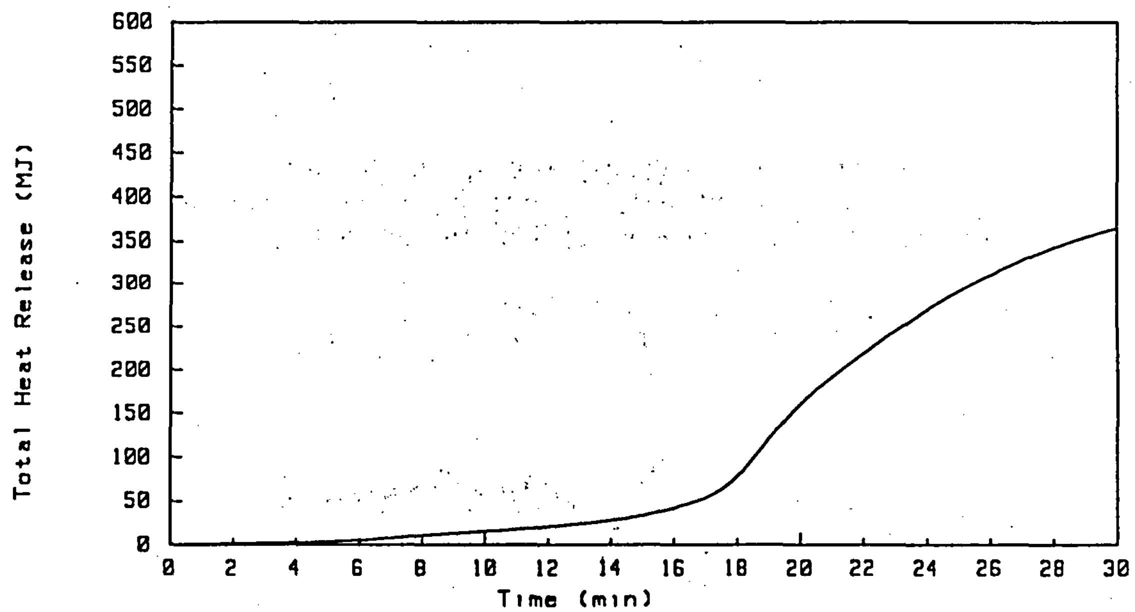

Figure 3.14: Time Integral of the Heat Release Rate (Total Cumulative Heat Release) for the Aged Rockbestos FIREWALL III Cable Fire Test

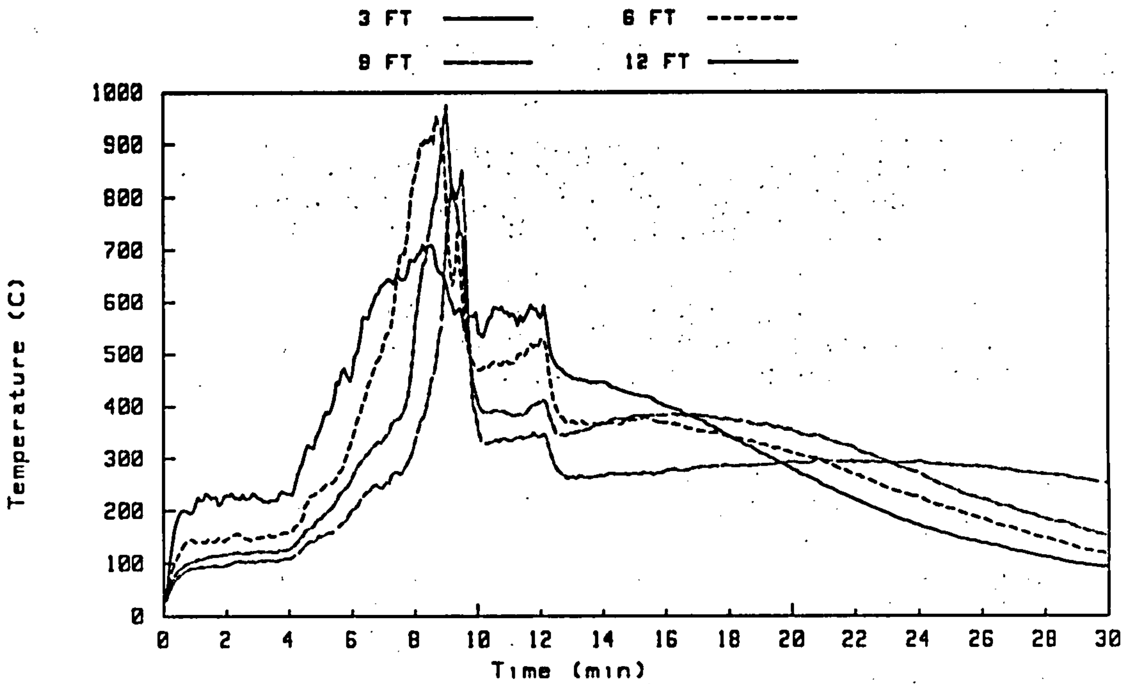

Figure 3.15: Temperatures Measured Between the Two Vertical Cable Trays During the Burning of the Unaged Rockbestos FIREWALL III Cable Product

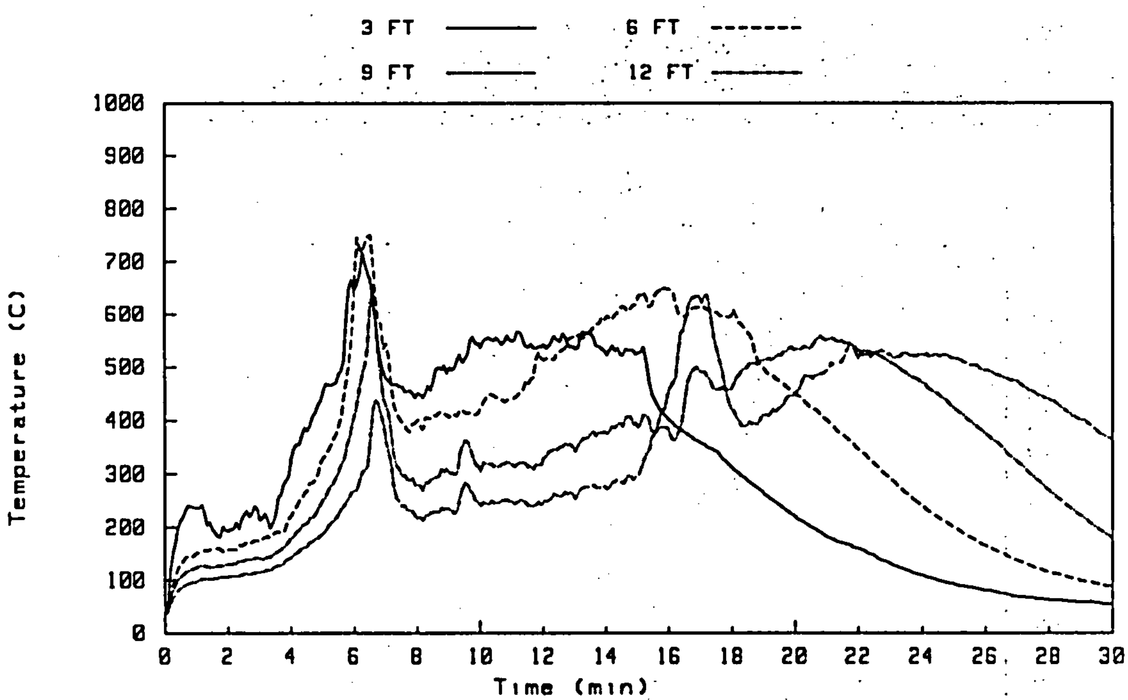

Figure 3.16: Temperatures Measured Between the Two Vertical Cable Trays During the Burning of the Aged Rockbestos FIREWALL III Cable Product

4.0 CONCLUSIONS

For both of the cable products tested, the BIW BOSTRAD 7E and the Rockbestos FIREWALL III, the aged cables displayed a significantly reduced flammability as compared to the unaged cable samples. The changes due to aging observed in the BIW cable product were much greater than those observed in the Rockbestos cable product, but in all measures discussed, flammability was reduced for both cable products. These results were consistently observed in four measures of the fire intensity, namely, peak fire heat release rate, peak rate of fire growth, total heat released, and near fire temperatures. Because of the consistency and magnitude of the differences noted, they are considered significant and not merely an artifact of the inherent variability in fire behavior.

These tests indicate that, at least for these two cable types, material flammability will not increase, and in fact will be reduced, as a result of material aging. This result is consistent with the results of past cable aging studies. It has been noted in past studies of polymer aging that the aging process will tend to "drive off" some of the more volatile constituents of the polymers. It is these same volatile compounds which are first released during a fire and which help to support the combustion process. Because the volatile compounds are driven off to some degree during aging, the flammability of the aged materials is correspondingly reduced.

While other cable materials have not been evaluated, it is expected that similar results would be obtained. That is, the flammability of most polymeric insulation and jacketing materials would likely be reduced, rather than increased, by the aging process. No further investigation of this issue is recommended.

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11. ABSTRACT *(200 words or less)*

An investigation of the impact of thermal aging on the flammability of two common types of nuclear grade electrical cables has been performed. Four large-scale flammability tests were performed with each of the two cable types tested in both an unaged (i.e., new off the reel) and a thermally aged (artificially aged) condition. In all cases, the fire was observed to consume virtually all of the combustible cable jacket and insulation material present. However, for both cable types tested, the thermal aging process caused a decrease in the cable flammability as demonstrated by decreases in the rate of fire growth, peak fire intensity, total heat released and near fire temperatures. This result is consistent with past cable aging studies because it has been observed that the thermal aging process will drive off certain of the more volatile constituents of a polymeric material. Presumably, when these aged materials are subjected to a fire, the evolution of volatile combustible gases is reduced as compared to the unaged materials, and hence, flammability is reduced. The results of these tests indicate that, at least for the two cable types tested, the evaluation of cable flammability using unaged cable samples will remain a conservative indicator of cable flammability in a thermally aged condition.

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