BIW BOSTRAD CABLES

FLAME AND RADIATION RESISTANT CABLES FOR NUCLEAR POWER PLANTS

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I. INTRODUCTION

The need for improvement in the fire-resistant characteristic of electrical cables has been strongly emphasized by utility companies and agencies directly concerned with the development of nuclear power. This action appears all the more urgent as a result of serious fires in nuclear power stations over the past few years . In most cases, the utilities accept standard cables for nuclear power plants. Such cables are neoprene-jacketed with rubber, polyvinyl chloride or cross-linked polyethylene insulated conductors. However, because of recent events, the utilities and engineering firms have indicated that conventional standard cables are not satisfactory.

The fire hazards present in industrial or nuclear plants are not duplicated by standard flame tests required by Underwriters' Laboratories or others. This contention has been recognized as a fact for some time. C. F. Hedlund points out that cables grouped together in large numbers present far different conditions for the propagation of fire than those for a single wire or cable.[1]

A program for the development of cables to withstand so-called "incidents" due to malfunction of equipment or other factors associated with abnormally high ambient temperatures or nuclear radiation related to these "incidents" has been undertaken by the Boston Insulated Wire & Cable Co. This program continues BIW's historical background in the development of fire-resistant cable. The results are a wide range of wires and cables particularly suited to installation in nuclear power plants, identified as BIW BOSTRAD[7] and BOSTRAD[7S].

II. SUMMARY

This report presents a specification for cable constructions designed primarily to meet the particular requirements encountered in nuclear power plants with the intention that the cables will serve an installed life of 40 years.

A description of the performance tests applicable to these cables is given. Where standard tests are considered inadequate, revised or new procedures are included.

Results of exposing samples of cables to these tests are shown with some comparative data from various constructions. These results show the outstanding performance of BIW BOSTRAD[7] and BOSTRAD[7S] constructions to warrant unquestionable acceptance for installation in the nuclear power plants and in critical environments of fossil-fueled power plants.

Finally, a tabulation of BIW cable installations is provided.

[1] "Grouped Combustible Wires and Cables", *Fire Journal,* March, 1966.

III. BACKGROUND

When called upon to supply television monitoring cables for permanent installation during the building of the plutonium plant at Hanford, Washington in 1962, BIW became intensively involved with radiation-resistant cable.

The requirements for these cables were an expected life of thirty years, with several "incident" failures of equipment expected that would expose the cable to a total radiation dose of 5.5×10^7 rads over this period. In addition to radiation, other ambient conditions included:

A. A temperature rise to 150°C
B. Steam cooling without damage to insulation in case of accident
C. Possibility of fire.

A number of cables meeting the specification requirements were developed and manufactured by BIW. These cables, named BOSTRAD[7], were installed in 1963 and have been in operation ever since without a reported failure.

BIW has been the leader in the manufacture of inorganic cables capable of direct radiation exposure inside of reactors and other high-radiation environments.

The engineering experience in the development of this unique class of cables has made possible a complete range of wires and cables backed by the knowledge of their capabilities.

IV. DESIGN PARAMETERS

Reports from utilities and consulting engineering firms have been studied to provide the basis for designing cables to meet essential requirements. In addition, personal interviews on the subject were made with several utility engineers. As a result, the following criteria have been set tentatively by BIW as a basis for design parameters for nuclear power plant cables:

A. Cables must conform to established accepted industry standards insofar as possible. IPCEA is taken as the acceptable standard.

B. In addition to previously-accepted standards, the following additional requirements must be included:
   1. The cables must be radiation resistant with an exposure of 10^8 rads total radiation dose.
   2. The cables must be fire resistant beyond normally required tests established by IPCEA or Underwriters' Laboratories, and . . .
      a. They must not propagate flame.
      b. They must be capable of transmitting power and instrument signals for a period of time while in contact with direct flames.
      c. They must be flame resistant after exposure to radiation.

3. Cables must be capable of withstanding pressures of 90 p.s.i. and super-heated steam.
4. Cables must be capable of withstanding a dilute mixture of sodium hydroxide and boric acid.
5. Cables must be capable of transmitting current for a period of hours in case of equipment malfunction that brings ambient temperatures in the range of 316°F with copper carrying full-load current.
6. The insulating and jacketing materials must have low water absorption.
7. The insulating and jacketing materials should be heat resistant beyond what is now accepted as standard.
8. The dimensions of cables must be as small as possible commensurate with performance capabilities.
9. There is a very wide range of cables needed from small thermocouple to huge circulating pump power cable.
10. Costs must be maintained at a minimum level to allow nuclear power to compete with other sources.

V. CONFORMANCE TO IPCEA STANDARDS S-19-81[2] and/or S-61-402[3]

BOSTRAD[7] cables manufactured by BIW for nuclear plants conform to accepted standards established by IPCEA, as far as applicable. Selected sections from IPCEA standards which deal with materials and constructions are indicated below and on the following page.

A. Conductors

1. Individual strands of conductors are tinned or alloy coated and conform to paragraph 2.1.
2. The conductors are in accordance with Tables 2-1 through 2-6 of IPCEA S-19-81, and the class is as specified by the user. Class B stranded conductors are adopted for BIW standard cables.

[2] Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
[3] Thermoplastic Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

B. Insulation Thickness

The insulation thickness, depending on requirements, is in accordance with Table 7-6 or Table 3-2 of S-61-402, corresponding to rated circuit voltages from 0-600 volts.

Table of Insulation Thickness

	Control Cables		*Power Cables*
	300 v. *Mils*	*600 v.* *Mils*	*600 v.* *Mils*
Single Conductor			
14–9			30
8			45
1–4/0			60
Multi-Conductor			
18–14	25		
18–16		30	
14–9		30	30
8		35	45
7–2			45
1–4/0			55

C. Insulation Grades and Requirements

1. BOSTRAD[7]

The insulation of BOSTRAD[7] is a vulcanized, thermosetting, synthetic compound, the characteristic constituent of which is a chlorosulfonated polyethylene. The insulation is a properly-cured compound and is so applied that it will cover completely and concentrically the conductor, or the separator if one is used.

The insulation is properly compounded with ingredients to provide flame resistance, water resistance, radiation resistance, insulation resistance and heat-aging characteristics to meet the test requirements of Section VI.

The insulation is capable of a rating of 90°C as required for Type RHH and for wet and dry locations as required for Type RHW cables.

2. BOSTRAD^{7S}

The insulation of BOSTRAD^{7S} is a double-layer construction, the total thickness of the two layers meeting the minimum adopted thickness.

The inner layer is a silicone rubber vulcanized, thermosetting, synthetic compound the characteristic constituent of which is polyorganosiloxane. The insulation is a properly cured compound and is so applied that it will cover completely and concentrically the conductor, or the separator if one is used.

The physical properties of the silicone rubber are such that the performance of unaged and aged specimens will meet the tests of Section F and be rated at 125°C as required for Class S cable.

The outer layer of BOSTRAD^{7S} is a protective insulating jacket of vulcanized chlorosulfonated polyethylene as described in "1".

The composite of the two layers of materials offers an insulation possessing the qualities of each, the result being an insulation having superior characteristics to either material alone to meet the particular requirements for nuclear power plant cables.

D. Electrical Requirements

Electrical tests are made in accordance with standard IPCEA procedures, except that the final electrical test on multi-conductor cables may be made without immersion in water.

Table of Test Voltages

	Control Cables		*Power Cables*
	300 v.	*600 v.*	*600 v.*
Single Conductor			
14–9			4500
8–4/0			6000
Multi-Conductor			
Applied Between Conductor			
18–14	1000		
18–16		2500	
14–9		3000	4000
8		3500	4500
7–2			4500
1–4/0			5500

The insulation resistance of conductors in sizes 14 AWG and larger has a value not less than that corresponding to a constant of 2000 at 15.6°C (60°F) for both BOSTRAD^{7} and BOSTRAD^{7S} cables.

When the temperature at which the insulation is tested differs from 15.6°C, the measured value shall be corrected to 15.6 in accordance with the graph of insulation resistance temperature coefficients on the opposite page.

The usual reduction in the constant applicable to composite insulations is not necessary in the case of BOSTRAD^{7S} cable.

E. Circuit Identification

All multi-conductor cables have circuit identification by means of printed marking in accordance with Method 3 of IPCEA Specification for Rubber Insulated Wire and Cables S-19-81.

This method uses a single color insulation or covering on all conductors with printed conductor numbers and color designations for the first 21 numbers. For cables with more than 21 conductors, the 21 numbers and color combinations are repeated in regular sequence.

For power cables, the identification is:

1 Black	3 Red
2 White	4 Blue

For control cables, the identification is:

1 Black	5 Orange
2 White	6 Blue
3 Red	7 White/Black
4 Green	8 Red/Blue

F. Jackets

All single and multi-conductor cables for nuclear power plants have suitable protective jackets. The material of the jacket consists of a thermosetting or a thermoplastic compound having adequate properties of . . .

moisture resistance
flame resistance
abrasion resistance
heat resistance
ozone resistance
radiation resistance

Jackets for BOSTRAD7 and BOSTRAD7S single and multi-conductor cables are available in thermosetting material (vulcanized chlorosulfonated polyethylene) and thermoplastic material (polyvinyl chloride). Both these jacket materials are compounded to possess the above properties and to meet the test requirements of Section VI and VII.

The jackets are normally furnished in black except where the cable identification is required in segregated control systems. In such systems, where all cables in a control group or tray are to have a distinctive color, the jackets are colored or striped in the following colors:

yellow, red, brown, orange

Surface Markings

When specified, a surface marking of a contrasting color is continuously printed along the surface of the jacket. This may indicate a cable number, the number and size of conductor, and a prefix letter "E" to designate that the cable has met the performance tests for accident environmental conditions within a reactor. The name or initials of the cable manufacturer may also be shown.

G. Jacket Thickness

The jacket thicknesses adopted are for cables installed in racks or trays or pulled into conduits and underground ducts.

The thicknesses conform to the adopted IPCEA Standards for Rubber and Thermoplastic Insulated Cables.

Jackets are required on single conductor cables but no jacket is required on the individual conductors of multi-conductor cables. This is the adopted IPCEA practice for PVC and polyethylene insulated cables.

The average thickness of jackets is no less than the dimension in the following table. The minimum thickness at any point is not less than 80% of the specified thickness.

	Jacket Thickness	
Calculated Diameter of Cable under Jacket	*Single Conductor Cables Mils*	*Multiple Conductor Cables Mils*
.250" or less	15	45
.251"– .425"	30	45
.426"– .700"	45	60
.701"–1.500"		80
1.500"–2.500"		110

H. Shielding

Suitable shielding is provided as required by the specification and may be provided by any of three constructions:

1. Aluminum or copper polyester foil tape applied with 50% minimum overlap. A stranded copper drain wire no smaller than #18 gauge is helically applied so as to be in continucus contact with the metallic side of the foil tape.
2. One or two solid copper tapes with a minimum thickness of 5 mils and with rounded edges applied with a 10% minimum overlap.
3. Braided tinned copper shield of #34 AWG minimum size wires applied with a coverage of between 80 and 90%.

Shielding may be applied over twisted pairs, over groups of conductors, or groups of twisted pairs. Suitable barrier layers are furnished to protect insulation from physical deformation.

VI. STANDARD TESTS (1)

	Insulation			*Jacket*	
	BOSTRAD 7		*Silicone*	*BOSTRAD 7*	*PVC*
	Black	*White & Colors*			
A. Physical Properties (2)					
Tensile Strength p.s.i. minimum	2000	1500	600	2300	1500
Elongation % minimum	325	500	250	400	100
B. Oven Aging (2)					
After Air Oven at 121°C for 168 Hours					
Tensile Strength minimum % of Unaged	85	85	80	85	70
Elongation minimum % of Unaged	65	65	65	65	65
C. Oil Immersion Aging					
After Oil Immersion at 121°C for 18 Hours					
Tensile Strength minimum % of Unaged	85	85	N.A.	80	80°
Elongation minimum % of Unaged	85	85	N.A.	70	60°

(1) The values presented in this section are typical and should be used only as a guide. Consult BIW Engineering before establishing specification limits for any parameter or combination of properties.

(2) Bostrad 7 is approved as Class CP rubber under UL 44 for types RHH and RHW wires. The minimum requirements for UL 44 are 1500 psi and 200% elongation unaged and 85% and 50% retention of tensile strength and elongation respectively after aging @ 121°C for 168 hours.

° Temperature at 70° C for 4 hours.

D. Ozone Exposure

The insulation shows no cracks after three hours' exposure to an ozone concentration of not less than .025%, nor more than .030% by volume, when bent around a mandrel no larger than the following:

Outside Diameter of Insulation	*Mandrel Diameter as a Multiple of the O. D. of Insulation*
Less than .500″	4
.500″–.750″	5

E. Low Temperature Conditions

Specimens of completed cable are held at a temperature of —25°C for approximately one hour. While remaining in the cooling chamber, the specimen is wrapped, under the load of suspended tension weight, for 3 turns around a mandrel. The maximum size of the mandrel is governed by the following:

Outside Diameter of Cable	*Gauge Size*	*Mandrel Diameter as a Multiple of Cable Diameter*
Less than .500″	All	3
.501″–1.00″	Up to 4/0	4
.501″–1.00″	Over 4/0	6
1.01″ –1.50″	Up to 4/0	6
1.01″ –1.50″	Over 4/0	8
Over 1.50″	All	12

After removal, no cracks are visible on either the insulated conductors or the jacket.

F. Accelerated Water Absorption

The middle of a 15 ft. sample of the insulation immersed in a circulating water bath, controlled at a temperature of 75°C shall be subjected to the following electrical tests and comply with the values listed. IPCEA limits are tabulated for comparison.

Increase in Capacitance Maximum, Per Cent	*IPCEA RHW*	*BOSTRAD[7]* *Insulation Grades*	*BOSTRAD[7]* *Jacket Grade*	*BOSTRAD[7s]* *Insulation*
1 to 14 days	10.0	7-8	5	3
7 to 14 days	4.0	3	2	2
Dielectric Constant after 24 hours maximum	*	8	8	4

*No value established.

VII. UNIQUE TESTS PROPOSED BY UTILITY ENGINEERS

This specification is intentionally prepared to provide a complete presentation of the tests and performance characteristics of cables intended for installation in nuclear power plants.

Utility engineers and consulting engineering firms who have made a specialty of preparing specifications over the past few years have proposed a variety of test procedures. Wire and cable engineers have been confronted with conducting tests under the various methods and have had an opportunity of evaluating the merits of the different methods and materials.

As a result of the San Onofre fire, all engineers involved in design and manufacture of electrical components have been awakened to the realization that new standards and more severe testing have to be adopted if a nuclear power plant is to be finally accepted and approved by the Atomic Energy Commission.

Several committees have been appointed and have conferred with the objective of preparing specifications having the degree of severity and comprehensive performance requirements which will provide a degree of safety and reliability under the variety of conditions which may be imposed within a nuclear power plant over its expected life during the next forty years.

Boston Insulated Wire & Cable Co. has studied the numerous specifications for cables for nuclear power plants for both inside and outside containment areas. Specific requirements and procedures are presented for the following four environmental conditions:

A. Inside Containment Environmental Test
B. Vertical Laboratory Flame Test
C. Bonfire Tests with Burning Oil as a Source of Flame
D. Nuclear Radiation Exposure Tests

A. Inside Containment Environmental Test

Requirement

Cables are designed to withstand without failure, once in their lifetime, the coincident pressure and temperature transients which are likely to occur within the containment areas of a nuclear reactor in the event of a Loss of Coolant Accident (L.O.C.A.). The particular pressure and temperatures estimated by nuclear engineers have differed. The more severe conditions have been adopted for test purposes as follows:

Time After L.O.C.A.	*Temperature Degrees F.*	*Pressure PSI*	*R.H. %*
Within 10 secs.	318°	60–70	100
15–75 min.	318°	90	100
75–150 min.	286°	60	100
150 min.–24 hrs.	216°	20	100
After 24 hrs.	152°	10	100

Electrical Performance

Insulation resistance measurements made during the tests must meet or exceed the following minimum requirements:

1. *Power and Control Cables*

   All 600 volt power and control cables when exposed to the steam environment tests are equal to or better than the minimum insulation resistance of 1×10^7 ohms/ft. at the peak temperature and pressure conditions of the test cycles.

   All power cables must withstand a "hipot" test of two times the cable's rated voltage plus 1000 volts for three minutes duration at the peak temperature and pressure conditions of the test cycles.

2. *Instrumentation Cables*

   All multi-conductor shielded or unshielded instrumentation cables meet or exceed the following specification for insulation resistance, measured at peak temperature and pressure conditions of the test cycle:

   Conductor-to-conductor resistance equals or is better than 1×10^6 ohms/ft. (Cable shield is considered a conductor.)

   All coaxial and triaxial instrumentation cables meet or exceed the following specification for insulation resistance measured at peak temperature and pressure of the cycle:

   Conductor-to-conductor shield must have an insulation resistance equal to or greater than 1×10^6 ohms/ft.

Procedure

To fulfill the requirements of this paragraph, a test vessel was assembled consisting of a 2-inch pipe, 14 inches in length, fitted with pipe caps to accommodate silicone rubber washers. The washers were supplied with proper size holes to allow the sample inserted to be pressure tight and withstand the ambient temperature involved.

A ¼-inch air pressure pipe with a pressure gauge and control valve was tapped into the test chamber. This pressure-tight attachment was of sufficient length to extend through vents in the electric oven, allowing the pressure gauge and valve to be outside the oven. A 1-inch mandrel, 12 inches long, was prepared to fit inside this pipe pressure vessel.

A sample of proper length was wound with close turns around the mandrel and tied in place, allowing the ends of the sample to extend through the pipe caps. The length of the cable within the pressure chamber was 7 feet and, within the oven, 10 feet.

To provide 100% humidity, 85 milliliters of water were inserted in the vessel prior to closing. At one end of the vessel, the cable sample extended a few inches. The other end was approximately 4 feet in length which, when the vessel was installed in the oven, extended out of the oven for electrical measurements.

Results

Insulation resistance readings were taken periodically during the test under temperatures and pressures specified.

Insulation resistance values were read at 500 V DC.

BIW Part No. 7244-H-002 — Single Pair Inside Containment Cable — BOSTRAD7

BIW Part No. B7244-H-002 — Single Pair Inside Containment Cable — BOSTRAD7S

Results are plotted on a curve in which temperature, pressure and time are indicated. See pages 13 and 14.

Effect of Irradiation

In order to provide information with respect to the effect of exposure of radiation on the behavior of the cable under this containment environmental condition, a sample of the two-pair instrument cable, BIW Part No. 7245-H-004, was submitted to the containment environmental test after exposure of 5.5×10^7 integrated rads dose of radiation.

The sample was similarly mounted in the containment vessel.

A graph of the results is presented on page 15.

B. Flame Test

1. *Laboratory Flame Test in Accordance with IPCEA Specifications, Supplemented by Additional Flame Exposure and Insulation-Resistance Measurements.*

Observations and criticisms of the IPCEA Vertical Flame Test are presented below with the intention of presenting a constructive basis for improvement of the procedure and test requirements. The adoption of a universally acceptable Vertical Flame Test Procedure is the ultimate objective.

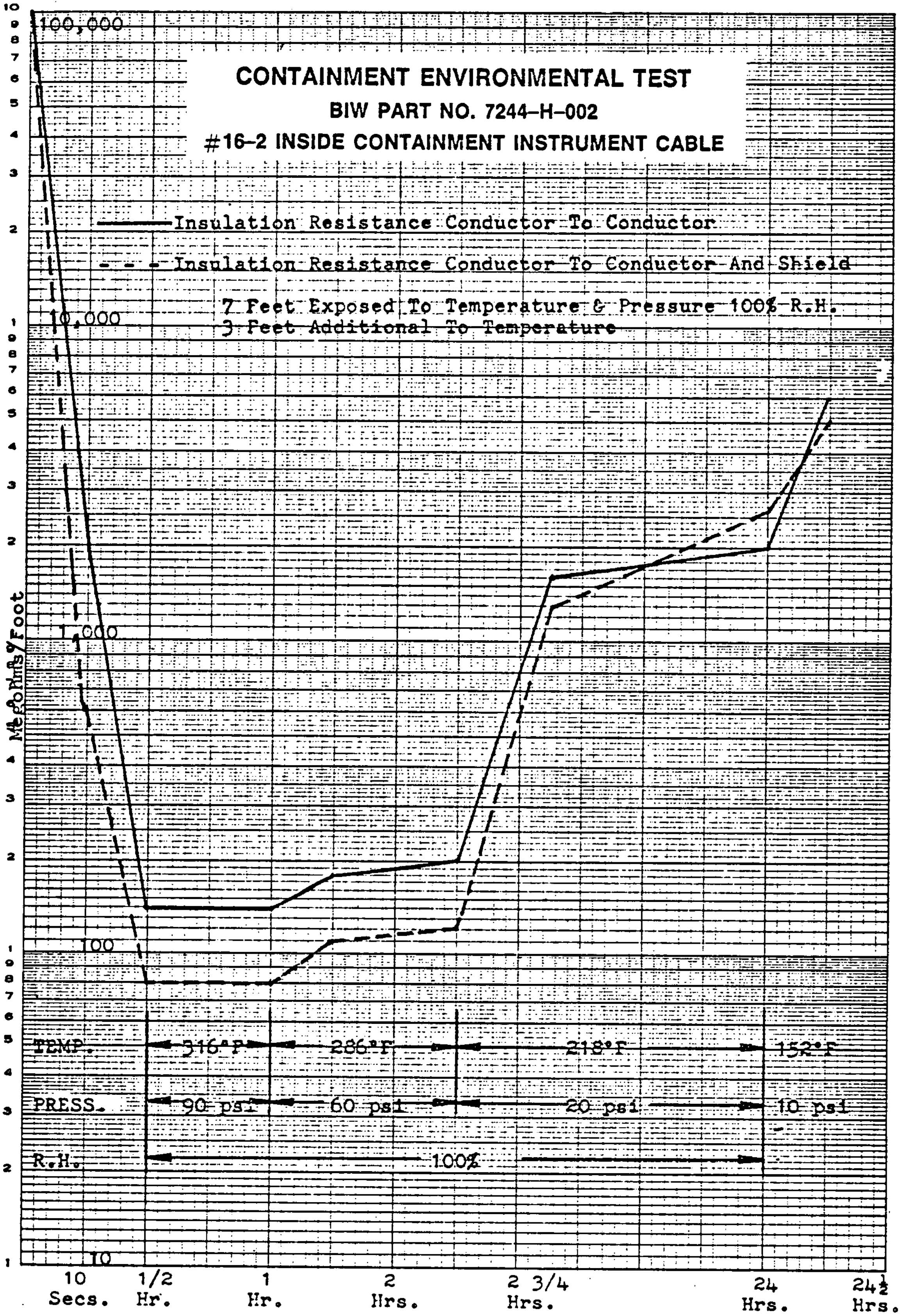
a. *Suspended Weight*

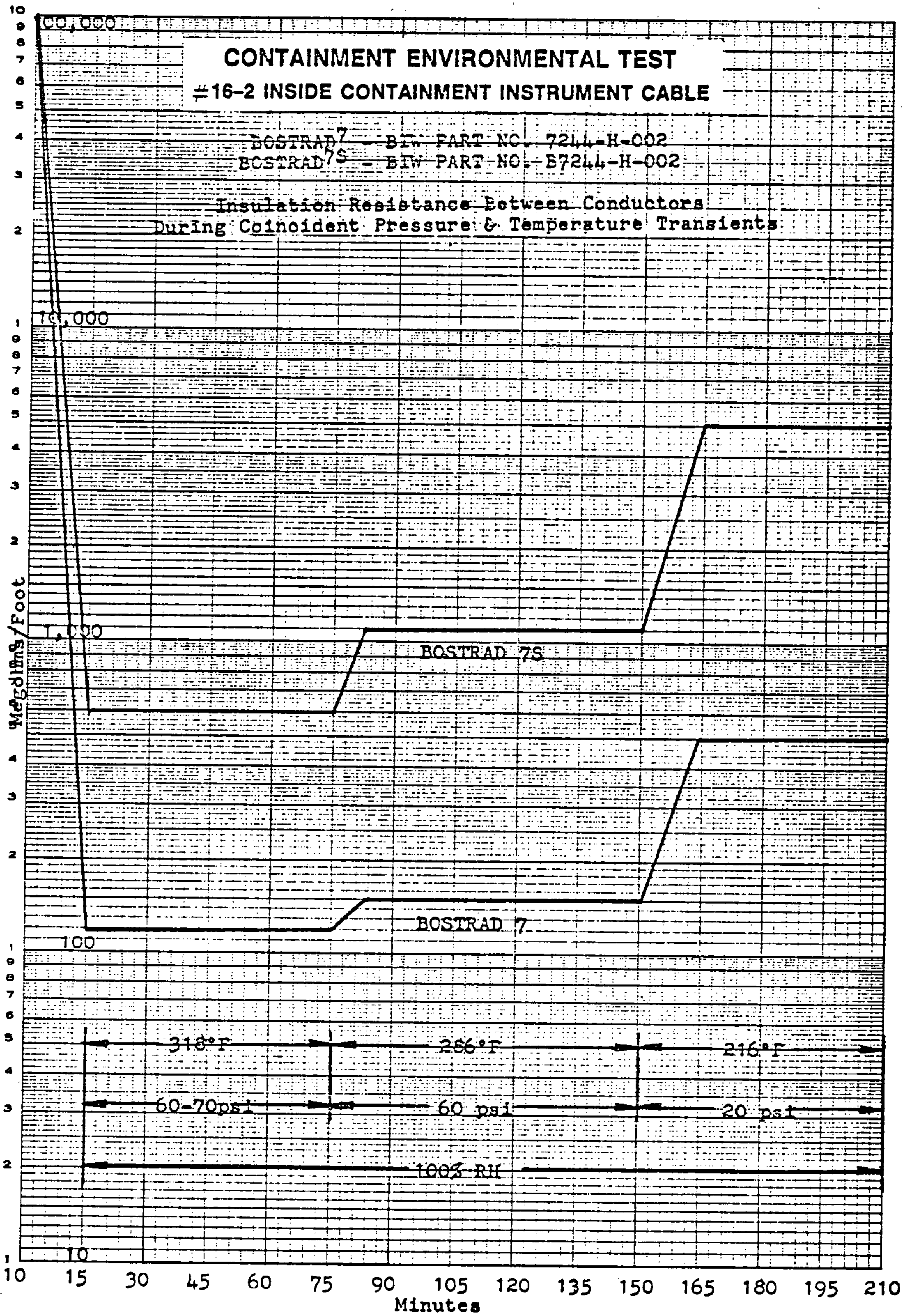
The adoption of a weight of a suitable size such as 3 or 4 pounds is considered an advisable modification.

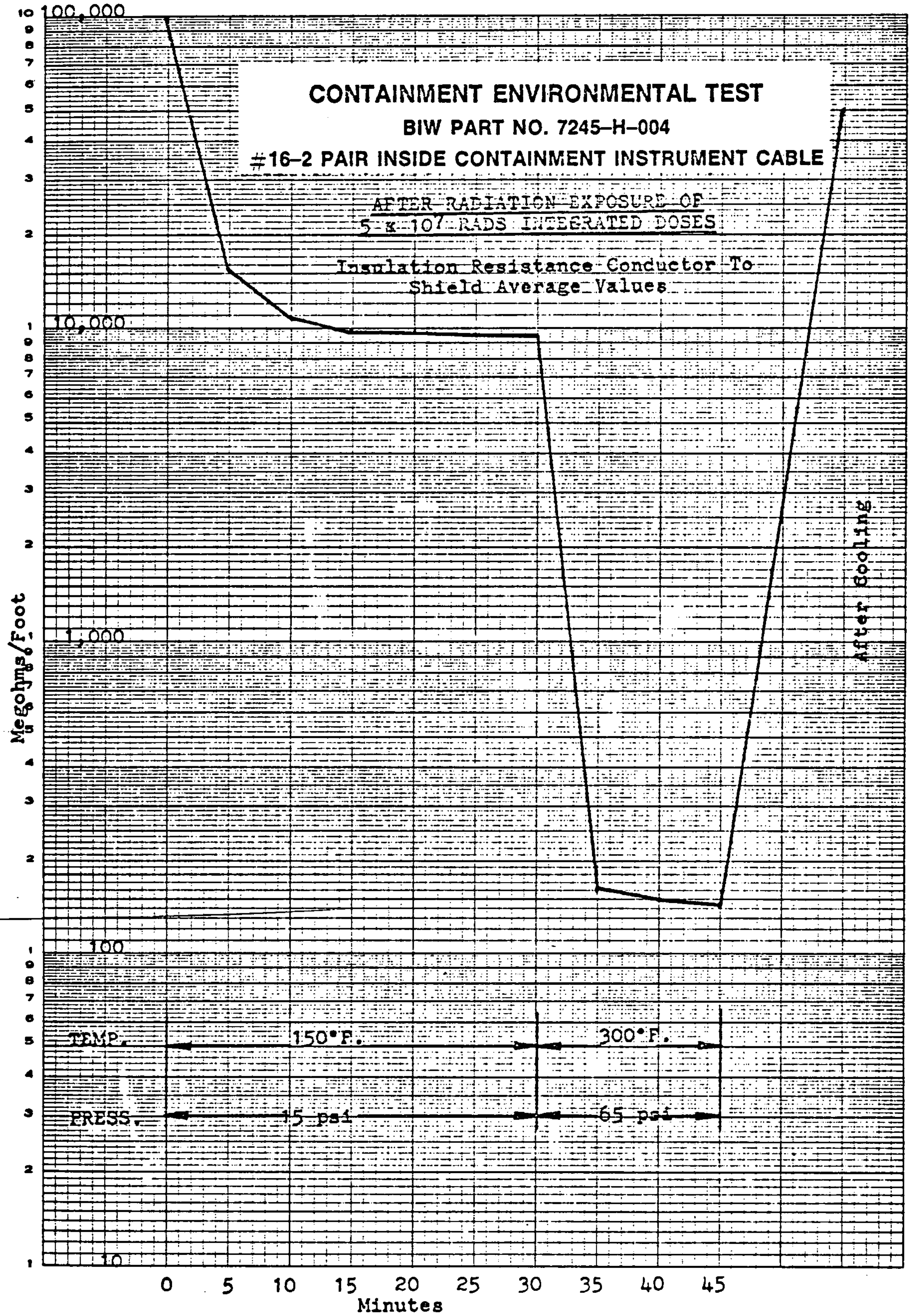
Precedence for adoption of this ~~weight is a 4-pound weight adopted in the latest~~ revision of IPCEA Specification S-61-402. It is believed that 4 pounds is too heavy for #16 gauge 2 conductor cable and, therefore, a 3-pound weight is considered adequate.

During the burning, the tension on the conductors will cause the conductors to untwist and become shorted to one another. This occurs in cable constructions where melting or complete disappearance of the insulation results from burning.

(*Continued on Page 16*)


CONTAINMENT ENVIRONMENTAL TEST
BIW PART NO. 7244-H-002
#16-2 INSIDE CONTAINMENT INSTRUMENT CABLE
Insulation Resistance Conductor To Conductor
Insulation Resistance Conductor To Conductor And Shield
7 Feet Exposed To Temperature & Pressure 100% R.H.
3 Feet Additional To Temperature
100,000
10,000
1,000
100
10
Megohms/Foot
TEMP.
316°F
286°F
218°F
152°F
PRESS.
90 psi
60 psi
20 psi
10 psi
R.H.
100%
10 Secs.
1/2 Hr.
1 Hr.
2 Hrs.
2 3/4 Hrs.
24 Hrs.
24½ Hrs.


CONTAINMENT ENVIRONMENTAL TEST
#16-2 INSIDE CONTAINMENT INSTRUMENT CABLE
BOSTRAD 7 - BIW PART NO. 7244-H-002
BOSTRAD 7S - BIW PART NO. B7244-H-002
Insulation Resistance Between Conductors
During Coincident Pressure & Temperature Transients
100,000
10,000
1,000
100
10
Megohms/Foot
BOSTRAD 7S
BOSTRAD 7
318°F
286°F
216°F
60-70psi
60 psi
20 psi
100% RH
10
15
30
45
60
75
90
105
120
135
150
165
180
195
210
Minutes


CONTAINMENT ENVIRONMENTAL TEST
BIW PART NO. 7245–H–004
#16–2 PAIR INSIDE CONTAINMENT INSTRUMENT CABLE
AFTER RADIATION EXPOSURE OF
5 x 10^7 RADS INTEGRATED DOSES
Insulation Resistance Conductor To
Shield Average Values
100,000
10,000
1,000
100
10
Megohms/Foot
After Cooling
TEMP.
150°F.
300°F.
PRESS.
15 psi
65 psi
0
5
10
15
20
25
30
35
40
45
Minutes

b. *Fisher Burner*

The adoption of the Fisher Burner to provide higher temperatures up to 1800° or 1900°F and a much larger flame cone is considered an appropriate change in the specifications over the lower temperature and smaller flame of the Tirrill or Bunsen Burner.

It is obvious that if a laboratory test is ever to approximate the severity of the fire conditions occurring in the Bonfire or Tray Test, a flame source of greater intensity and larger area is the best solution.

Another advantage is that this allows for a flame of sufficient size to envelop the complete cable and provide an extremely high-temperature, localized spot. This approximates the situation of actual origin of a fire in cables.

Still another advantage of this is that a temperature of 1900°F ±5% can be attained by the use of natural and manufactured gas, as normally available, without the necessity for using LP propane gas.

c. *Performance Criteria*

The purpose of cables is to carry electrical current at a given voltage potential. It would, therefore, seem that the criterion for the performance of the cable exposed to flame should be the cable's capability of transmitting the electrical signals or power during the flame exposure.

All other considerations, such as time of ignition, time of burning, extent of burning, and physical appearance, are of secondary importance to the primary objective of transmitting the electrical signals.

Therefore, the procedures which have been followed in this report have taken this into consideration and have adopted the principle of two series circuits of adjacently positioned wires to form two continuous series circuits. This 110 volt circuit is connected between these alternate conductors through a pair of indicator lamps.

d. *Indicator Lamps*

There is a precedence in the adoption of indicator lamps in several proposed flame tests for cables including one by the Philadelphia Electric Company.

In each case, the indicator lamps have been only in series and the wattage of the lamp has not been indicated. It is obvious under these conditions that it will take a very low resistance between conductors during this flame test to indicate any degree of illumination in such a circuit. For example, considering the 60 watt lamp, a resistance of 2000 ohms in the insulation would be necessary to cause the lamp to be illuminated. Any resistance between 2000 and 5000 ohms would not pass sufficient current to partially illuminate the lamp.

BIW has, therefore, adopted the principle of a pair of lamps — a 100 watt lamp in series and a 7½ watt lamp in parallel across the line — as a positive indicator of the electrical integrity of this 110 V circuit.

The continual illumination of this small lamp in parallel indicates the capability of the insulated conductors to transmit electricity at the applied voltage.

The length of time during which this lamp remains lighted is a more meaningful indication of the capability of the cable construction than any other method which we can recommend.

e. *Megohms*

The megohm readings between the series circuits are made a requirement for the first time. No other specification has yet been adopted with this requirement. No minimum values have been specified; and, therefore, it is interpreted as a means of evaluating cable constructions.

It is considered important that the megger readings be conducted as long as possible during the exposure — before and during the flame test and until the values reach below the range of a megger. At that point, the megger is disconnected and the indicator lamp circuit used in its place.

Following the flame test, immediately after the removal of the flame source, the megger is again connected and readings taken during the cooling cycle of the specimen.

Insulation resistance is so drastically affected by temperature that recovery of insulation resistance through a cooling cycle is an excellent indication of the cable's relative performance.

An important element of reliability in the event of a fire in a power plant is the capability of limited use of the cable during and after the fire. Recovery of insulation resistance upon cooling, to allow for limited use of the cables before replacement measures can be undertaken, provides a degree of reliability heretofore unavailable except by very costly installations.

f. *Criteria of Acceptance*

Considering that the factors of ignition time, burning time and physical appearance of the specimen are difficult to establish as criteria of acceptance, it is proposed that the following Acceptance Test be adopted as a requirement:

"Specimens of completed cable are subjected to the Vertical Flame Test Procedure described using the Fisher Burner with a flame temperature of 1900°F for a continuous exposure of 5 minutes."

"With all adjacent conductors in the cable connected in two series circuits, the insulation resistance between them, after the flame test and adequate time for cooling, is not less than 10% of the insulation resistance before the test."

"During the test, the insulation resistance is monitored within the range of the megger, after which a pair of indicator lamps in series and in parallel in a 110 V circuit indicates that a short circuit does not occur during the test."

2. *Vertical Flame Test — Fisher Burner*

Procedure

A convenient length of cable is to be tested (not less than 3 feet). It will be suspended at one end and held reasonably straight by a weight at the other. The flame from a Fisher Burner, propane torch, or similar device will be applied at approximately a 20° angle at a point on the specimen, approximately 12 inches from the bottom, for five minutes. Flame temperature striking the specimen will be 1900°F ± 5°.

Weight Used = 3 lbs.

Flame temperature of the Fisher Burner is as shown on page 19.

Setup for the electrical measurements (see page 20) was as follows:

A 30″ vertical sample was suspended with a 3-pound weight attached at the bottom.

The conductors were divided into two series circuits with the shield and ground wire disconnected.

A twin lamp circuit, that is 75–100 watts in series and 7½ watts across the line, is connected during the test to form an indicator circuit, 110 Volts A.C. between the two series circuits of conductors.

Insulation resistance was measured at 500 volts before and directly after removal of the flame, and again after complete cooling of the sample.

The following data was recorded:

a. Time for specimen to ignite following application of flame.
b. Length of time specimen continues to burn following removal of flame.
c. The length of visual burning portions of the specimen and its physical appearance after the test.
d. Insulation resistance between conductors:
   Prior to the test;
   As soon as possible upon removal of the flame;
   After complete cooling of the sample.
e. Illumination of the 7½ watt indicator lamp during the test.

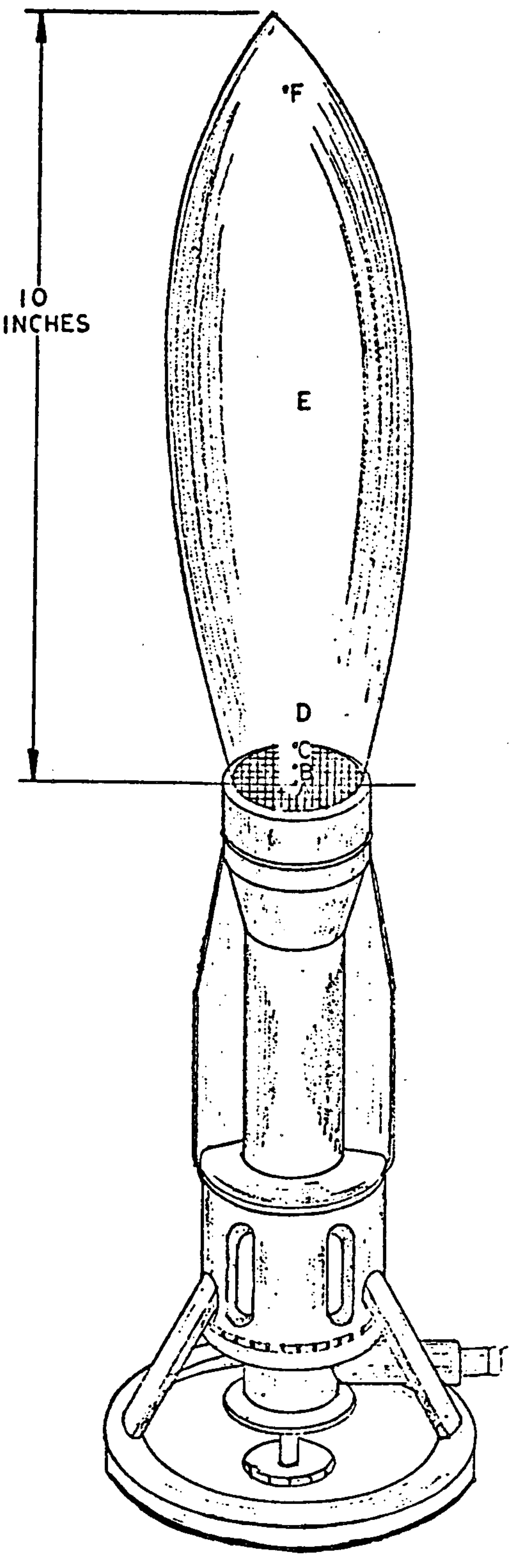
(Continued on Page 22)

STANDARD FISHER BURNER

FLAME INFORMATION
Height 10″
Inner Cone Height ¼″

Height from Top of Burner	*Point*	*Temperature °F*
Top of Barrel	a	1450
¼″	b	1850
½″	c	1900
1″	d	1800
5″	e	1750
9″	f	1350

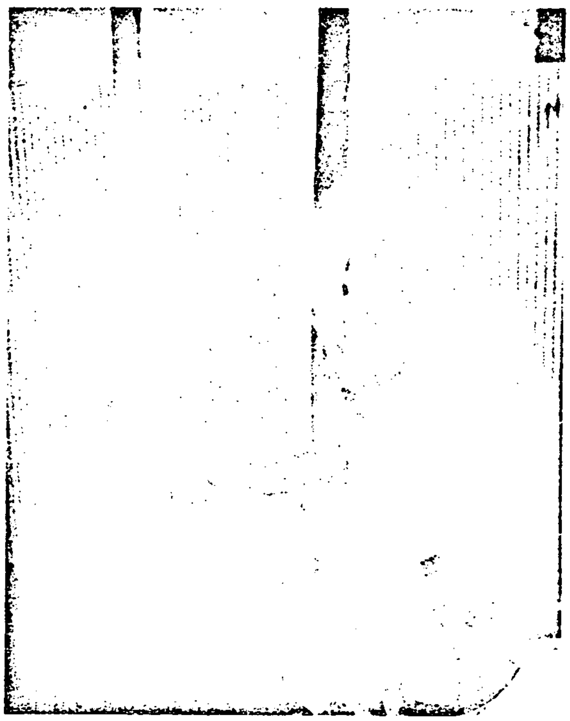
Bore Diameter: 40 MM
Combination of Natural and Produced Gas



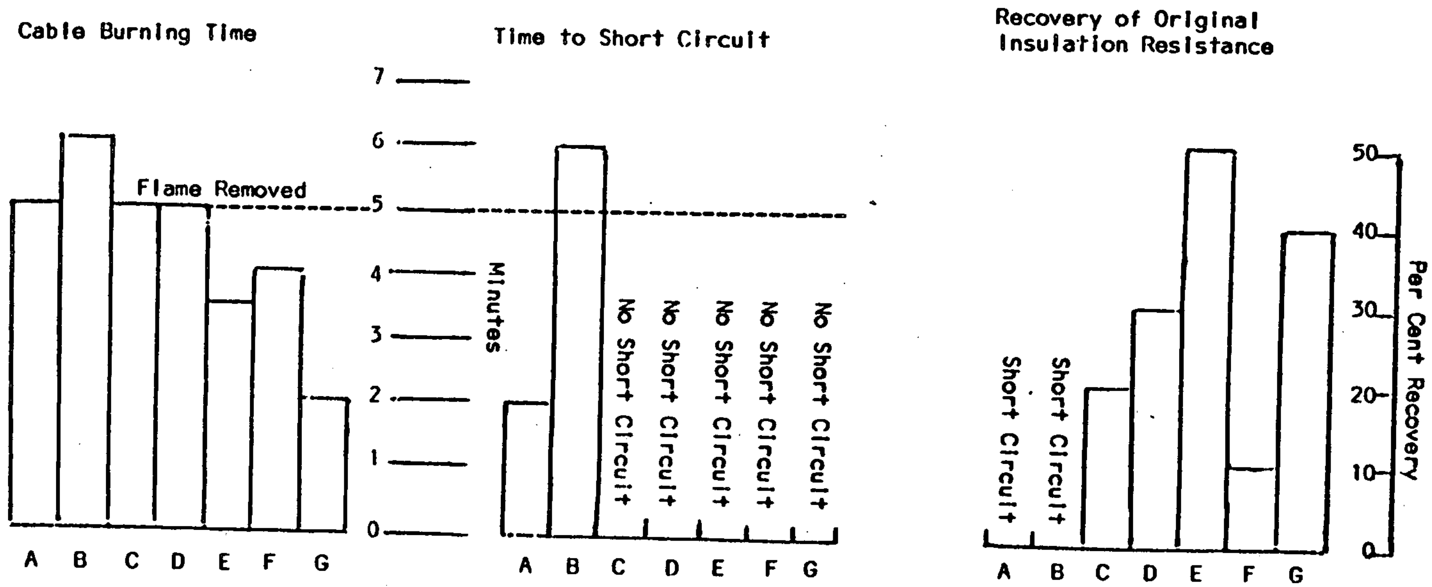
VERTICAL FLAME TEST

Set-up with suspended weight
Fisher Burner
Conductors connect to dual lamp circuit
7.5 watt in parallel
100 watt in series
Pyrometer to measure flame temperature

Flame from Fisher Burner enveloping sample.
After 4 minutes of continuous flame application, lamp in parallel remained lit.
After 5 minutes, no further burning of sample. Burned area was limited. Megger readings taken before, directly after 5-minute test and after cooling.



COMPARATIVE PERFORMANCE
FISHER BURNER VERTICAL FLAME TEST



Test Method:

1900° flame applied for five minutes to a vertical sample of multi-conductor cable. Conductors were connected into two series circuits in each cable. Throughout the test, insulation resistance measurements were made or 110 V AC was applied to show circuit integrity.

Sample Description:

	A	B	C	D	E	F	G
Insulation:	PVC	Polyethylene	BOSTRAD[7]	BOSTRAD[7]	BOSTRAD[7S]	BOSTRAD[7]	BOSTRAD[7S]
Jacket:	PVC	Neoprene	PVC	BOSTRAD[7]	BOSTRAD[7]	None	None

C. Bonfire Tests

1. Tray Fire Propagation Test

Requirement

Cable is to be installed in a ladder type cable tray. In order to be acceptable, the cable shall not propagate fire originating in or out of the cable tray, and shall maintain continuity of electrical circuits for the period the cable is exposed to the tray fire.

General Procedure

a. Erect six-inch wide metal cable tray vertically, approximately eight feet high. Protect tray from drafts or winds. (See Fig. 1, page 23).
b. Load tray with one level of 7 $\times$ 12 conductor test cables, allowing one-half cable diameter space between cables. (See Fig. 1).
c. Make electrical connections shown in Fig. 1 and energize circuit.
d. Insert crumpled burlap (24 inch by 24 inch), previously soaked with transformer oil, into the vertical cable tray approximately twelve inches above the lower cable ends. Hold burlap in place with loose metal band.
e. Ignite the oil-soaked burlap. Record elapsed time after ignition, note propagation of fire and observe lamps for circuit continuity.
f. Allow fire to burn until burlap ignitor is consumed. The cable has failed the test if a self-sustaining, propagating fire results or one electrical circuit breaks down.

Tray Cable Fire Propagation Test

For comparison purposes, the following two cables were tested:

	PVC Control Cable	*BOSTRAD[7] Cable*
Conductors	7 conductor #14 stranded .020″ wall 105°C PVC with .005″ nylon jacket	6 conductor # 12 stranded .047″ wall BOSTRAD[7]
Cabling	6 over 1	6 over filler
Barrier Tape	.015″ asbestos	rubberized cotton
Braid	Glass braid, flameproof lacquer	none
Jacket	.0625″ flame resistant neoprene	.078″ wall BOSTRAD[7]

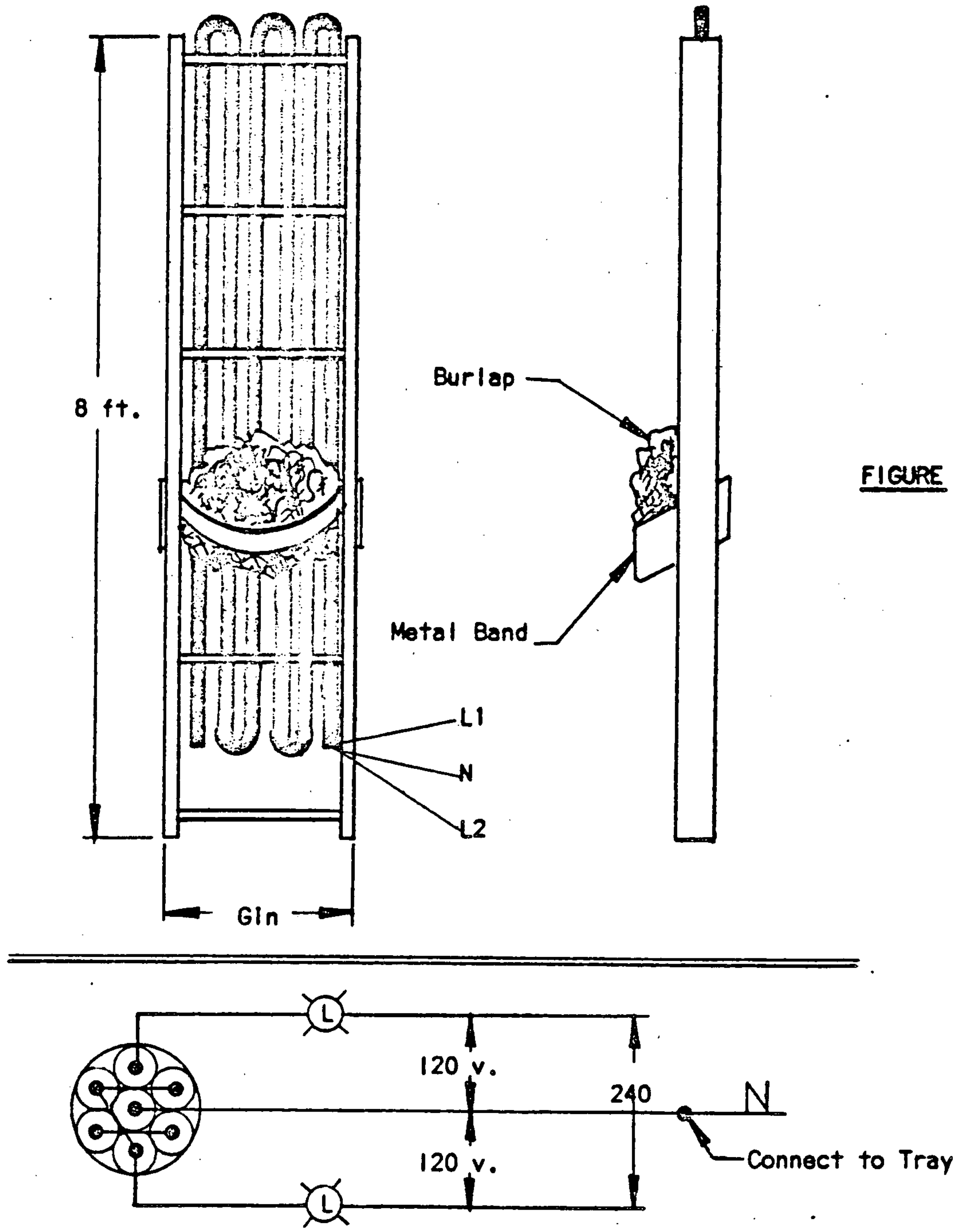

8 ft.
Burlap
Metal Band
L1
N
L2
6In
120 v.
240
N
120 v.
Connect to Tray

FIGURE 1

Results

- *PVC Control Cable*

Test #1 — Burlap heavily soaked with oil.
Cable shorted at the end of 3½ minutes.
Burlap continued to burn for 27.5 minutes.
There was no flame propagation along the cable.

Test #2 — Excess oil was allowed to drain from burlap before installing in tray.
Cable shorted in 4 minutes, 15 seconds.
Fire continued to burn for another 5 minutes and 45 seconds. No fire propagation.

In both cases, examination of the cable after burning showed that the insulation had entirely disappeared from the conductors in the flame area.

BOSTRAD[7] Cable

Test #3 — Burlap drained of excess oil.
Cable did not short after 19½ minutes burning time.
No fire propagation.
Examination of this cable showed that the insulation was still intact although it was spongy or brittle.

2. Westinghouse Electric Fire Propagation Test

Procedure:

A bundle of cables, not less than six, of the same type and of a convenient length, are suspended at both ends approximately five inches above an open container of transformer oil. The span is approximately five feet. The container has an opening of approximately eighteen inches in diameter. The oil is ignited and the flame allowed to engulf the cables for five minutes, see page 25.

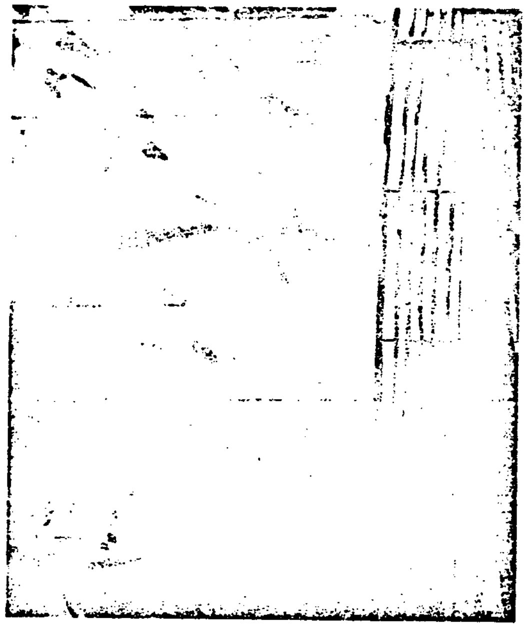
a. The conductors are divided into two series circuits with the shield and ground wire disconnected.
b. A twin lamp circuit, that is 100 watts in series and 7½ watts across the line, is to be attached during the test at the point when the insulation resistance falls below the range of the megger.
c. Observe the illumination of the two lamps during the test.
d. The insulation resistance is measured at 500 volts before the fire is started. After the fire is started, continue the reading of the insulation resistance each one-half minute until it falls below the range of the megger.
e. After five minutes, smother flame by metal cover over the oil pan to extinguish the flame source.

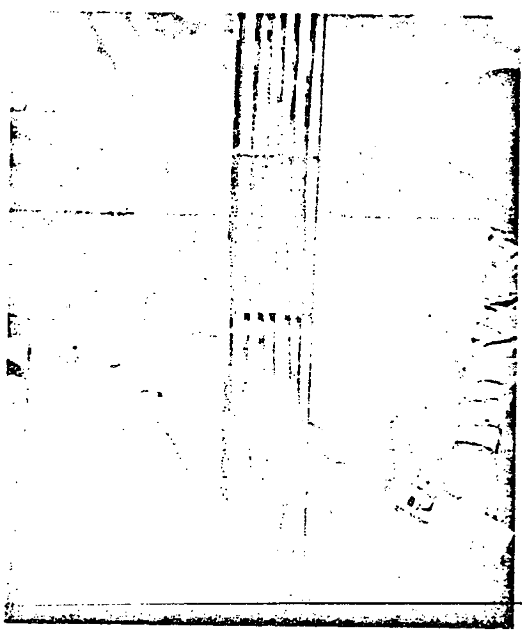
The following data was recorded:

a. Time for specimen to ignite following application of flame.
b. Length of time specimen continues to burn following removal of flame.
c. Length of visual damage to specimen and general physical appearance.
d. Megger reading on specimen prior to and following the test, and during the bonfire test within the range of the megger.
e. The time which the 7½ watt lamp remains lighted during the test to indicate the capability of the insulation to withstand 110 volts between conductors.

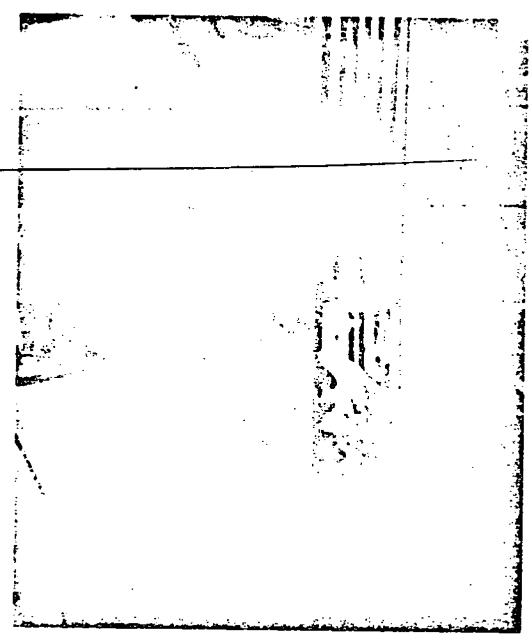
VERTICAL TRAY FIRE PROPAGATION TEST

Ladder metal tray mounted in front of cinder block wall out-of-doors. Cable in continuous lengths mounted in five layers. Burlap mounted to tray.
Two lamps in 120/240 volt circuit with alternate conductors and neutral connected to metal tray.





Igniting oil-soaked burlap.



Extent of fire propagation after one minute of burning. In all tests, the burning ceased after burlap was consumed.

3. Controlled Bonfire Test

Procedure

A bundle of 12 cabled insulated conductors of the same size and insulation and of convenient length is suspended at both ends in a nearly horizontal position. At about five inches under the center portion is placed an 18" circular shallow pan of oil.

Into the pan is poured a sufficient quantity (as determined by prior experiment) of transformer oil to burn for five minutes before being consumed. A square of burlap of proper size is immersed in the oil to serve as a wick for more uniform flaming.

A wind baffle is mounted on the windward side of the test area to provide more uniform exposure to the flames.

The same electrical tests are taken prior to, during and after the flame exposure as in the previous Bonfire Test Procedure.

The oil is ignited and allowed to burn until consumed; after which the burning of the cable is noted and the recovery of insulation resistance, if any, is measured during the cooling period.

By this procedure, the performance characteristics of various insulations are effectively compared.

Sequential photographs of the testing and graphical presentation of the results appear on pages 27 and 28. Test of Bostrad 7[S] without protective jacket appears on pages 29 and 30 with comparative results on page 31.

SEQENTIAL PICTURES OF BONFIRE TEST
BOSTRAD[7] CABLE

FIGURE 1—Electrical connection of cable conductors arranged into two adjacent circuits.

FIGURE 2—Location of megohmmeter and continuity lamp.

FIGURE 3—Arrangement of cable and oil pan.

FIGURE 4—Igniting the oil, using small amount of gasoline.

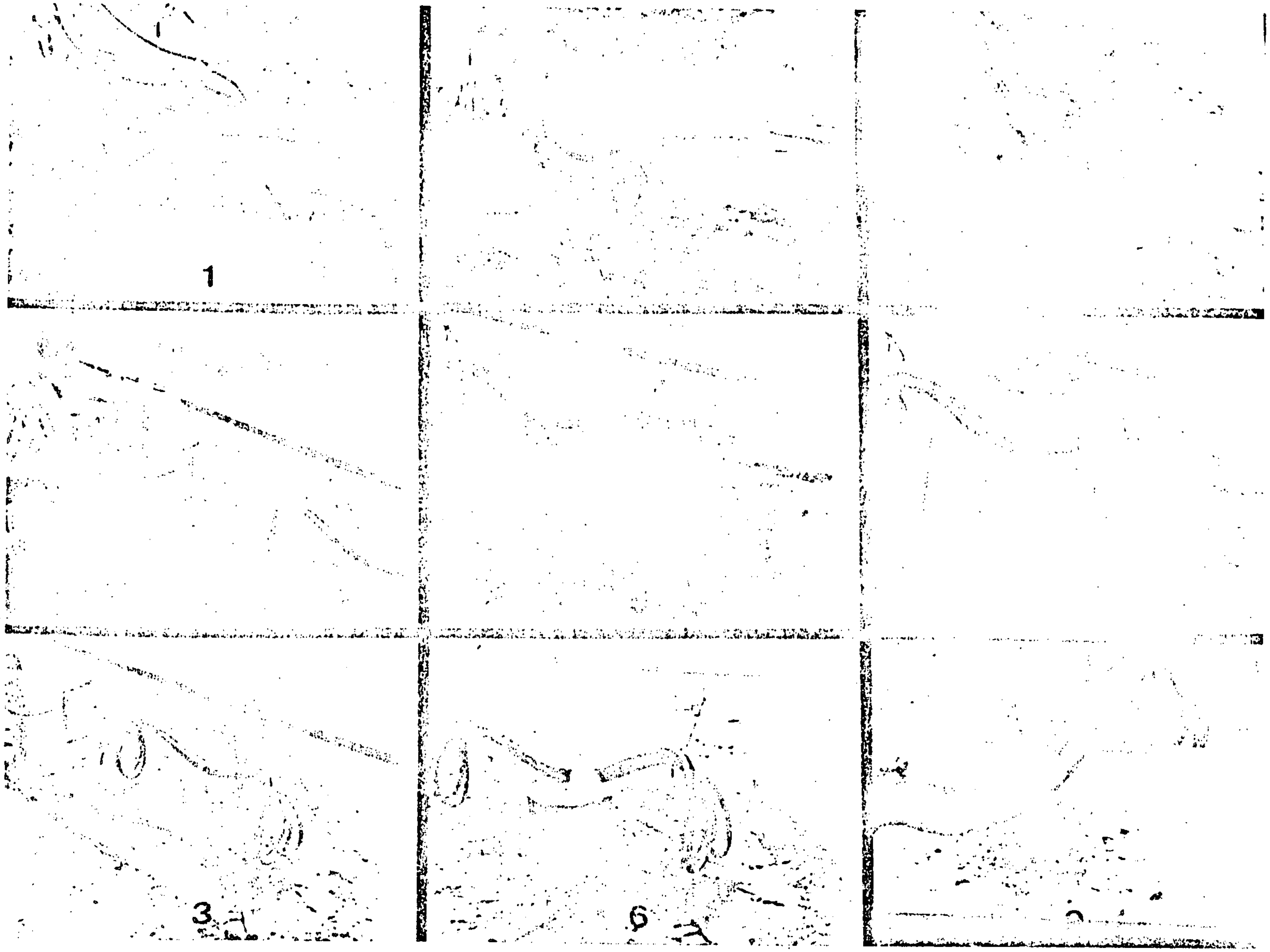
FIGURES 5, 6, and 7—Progress of fire for five minutes duration.

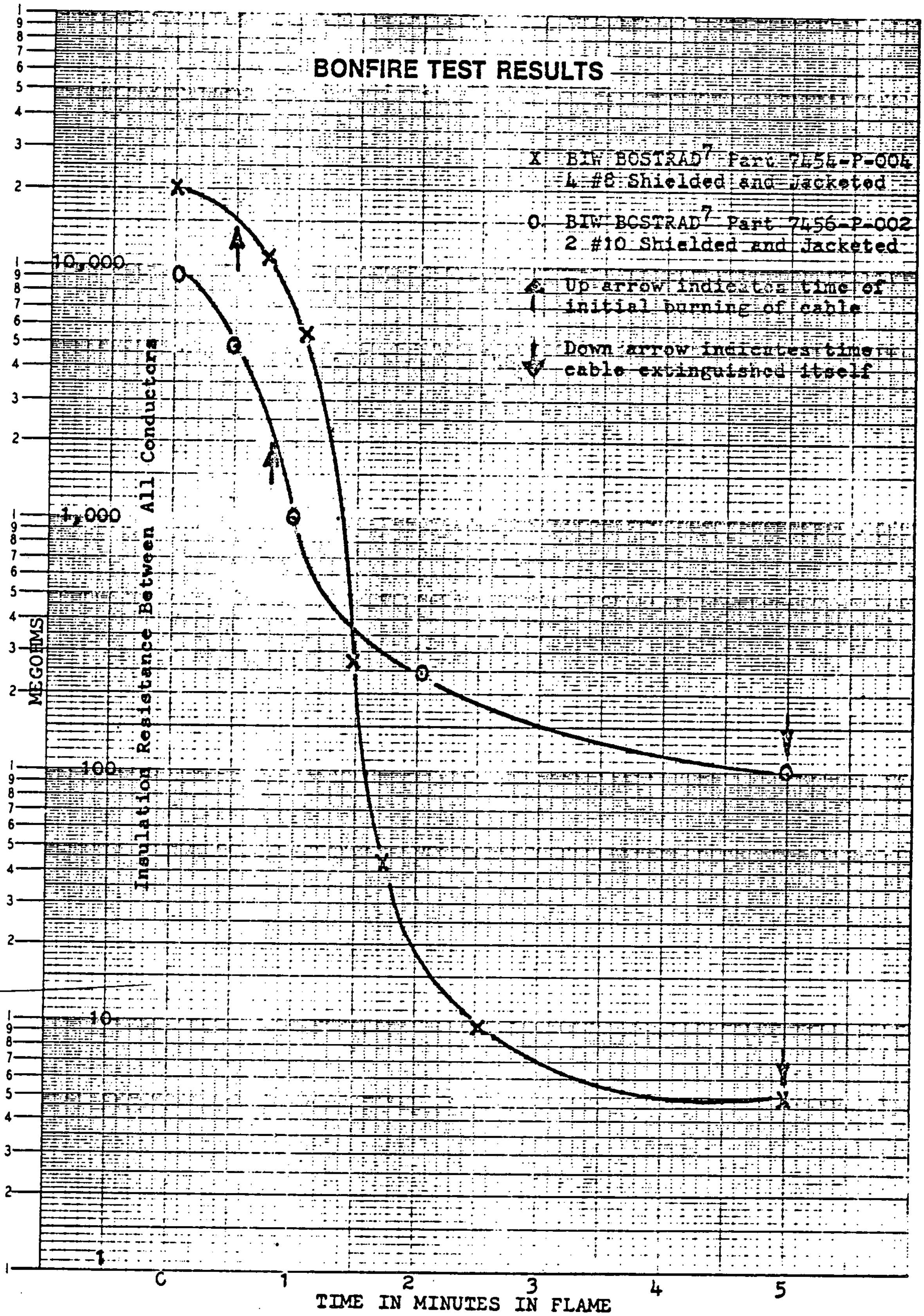
FIGURE 8—Lid placed over can to extinguish flaming oil.

FIGURE 9—View of cable bundle showing limited flame propagation and immediate extinction.

(*Continued on Page 32*)

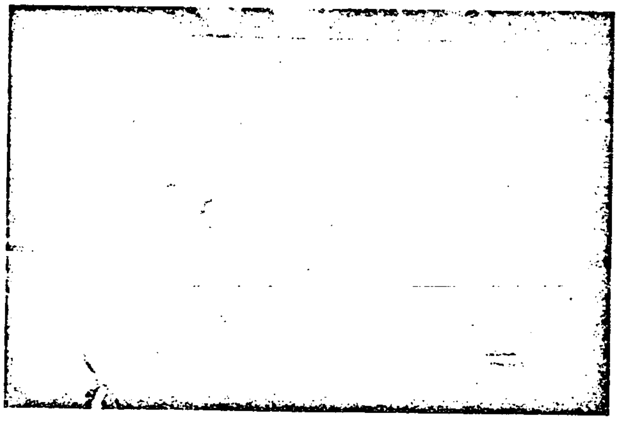
SEQUENTIAL PICTURES OF BONFIRE TEST




BONFIRE TEST RESULTS
X BIW BOSTRAD[7] Part 7456-P-004
4 #8 Shielded and Jacketed
O BIW BOSTRAD[7] Part 7456-P-002
2 #10 Shielded and Jacketed
Up arrow indicates time of initial burning of cable
Down arrow indicates time cable extinguished itself
10,000
1,000
100
10
1
MEGOHMS
Insulation Resistance Between All Conductors
0
1
2
3
4
5
TIME IN MINUTES IN FLAME

CONTROLLED BONFIRE TEST

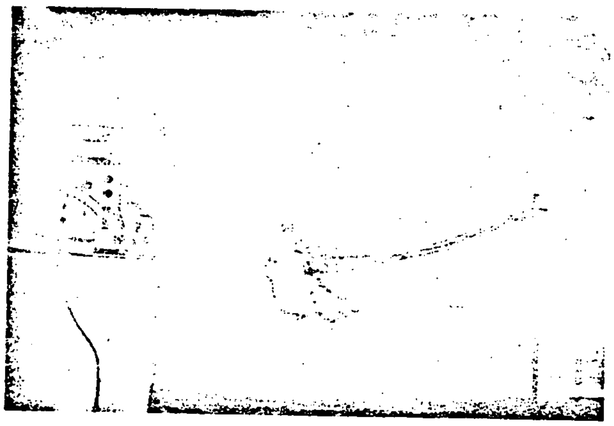
Controlled bonfire test 12 conductors #14 gauge Bostrad 7S insulation without protective jacket.



Test set-up before ignition. Proper amounts of oil in pan to burn 5 minutes. Square section of burlap placed in the pan 5" below the suspended sample. Megger to read I. R. between all conductors before, during and after flame exposure. Dual indicator lamps to show if and when shorting occurs.

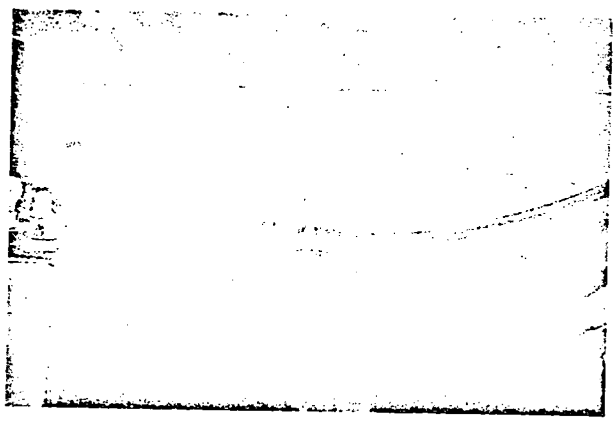
At the height of oil burning, wind tends to carry flames away from sample, despite wind baffle mounted. Picture indicates unreliability and non-uniformity of outdoor testing as a rule. However, this provides more realistic fire exposure than possible in a laboratory.

CONTROLLED BONFIRE TEST Continued



During final stage of test, the 110 volt lamps, 7½ W in parallel, 75 W in series in two circuits with all adjacent conductors . . . indicate no short circuit occurring at the height of burning and heat intensity. Testing of unjacketed cables verifies the performance capability of the insulation alone.

After bonfire is smothered, cable sample is self extinguishing. The insulation on conductors remains intact with no melting or flaking.



BOSTON INSULATED WIRE AND CABLE CO. August 4, 1969

COMPARATIVE RESULTS
CONTROLLED BONFIRE TEST

18" pan of oil-soaked burlap burning 5" below suspended cable. Quantity calculated to be consumed in 5 minutes.

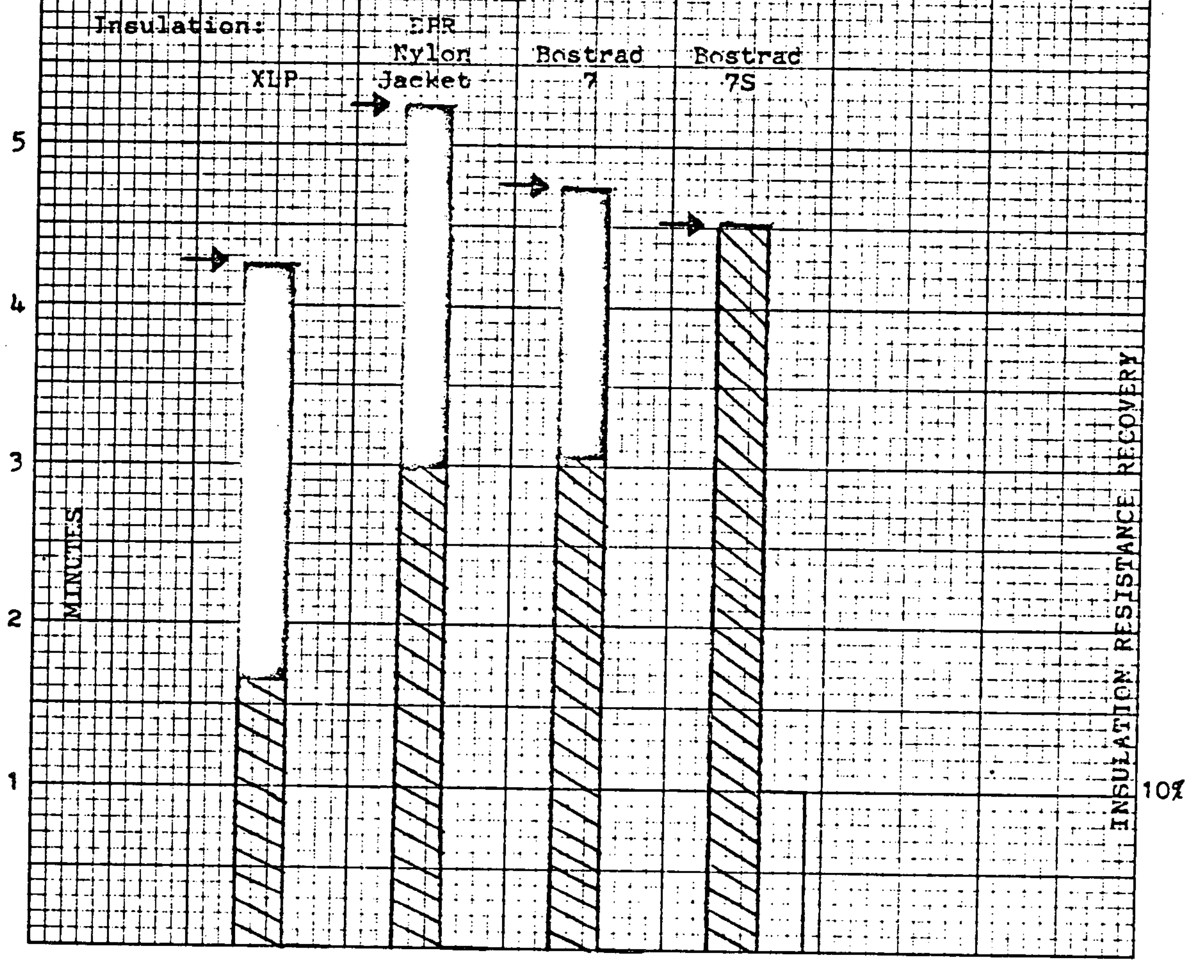
Samples: Unjacketed 12 conductor insulated wires arranged in two series circuits. I.R. readings on 110 volts applied throughout duration of test.

Burning time without electrical short

Burning time after electrical short

Recovery of Insulation Resistance after cooling (Percent of original)

Time when oil-soaked burlap stopped burning



D. Nuclear Radiation Exposure

Cables that are specified for installation within the inside containment area of nuclear power plants are exposed to a radiation level estimated from 15 to 100 rads per hour throughout the life of the power plant.

Based on an anticipated life of forty years, this amounts to a cumulative exposure of:

Rads/hr.	*Total Exposure*
15	5.25×10^6
100	3.5×10^7

In the event of a Loss Of Coolant Accident, a very high intensity of radiation occurs which exposes the cables to additional radiation to be added to the normal.

Time After L.O.C.A.	*Radiation Rads/hr.*	*Total Exposure*
3 hrs.	3.5×10^6	1.0×10^7
3 to 24 hrs.	2×10^5	4.2×10^6
24 hrs. to 180 days	2.5×10^4	1.1×10^8

From the above estimates, the maximum total exposure during a forty-year life and one incident is 1.6×10^8 rads. The insulation and jackets of cables must retain adequate levels of physical properties after this exposure. Loss of elongation of the compounds is the primary means of determining deterioration. A level of 50% elongation, that is a 1″ specimen capable of stretching 1½ inches before breakage, is a desirable objective, and 25% could be accepted as a minimum value.

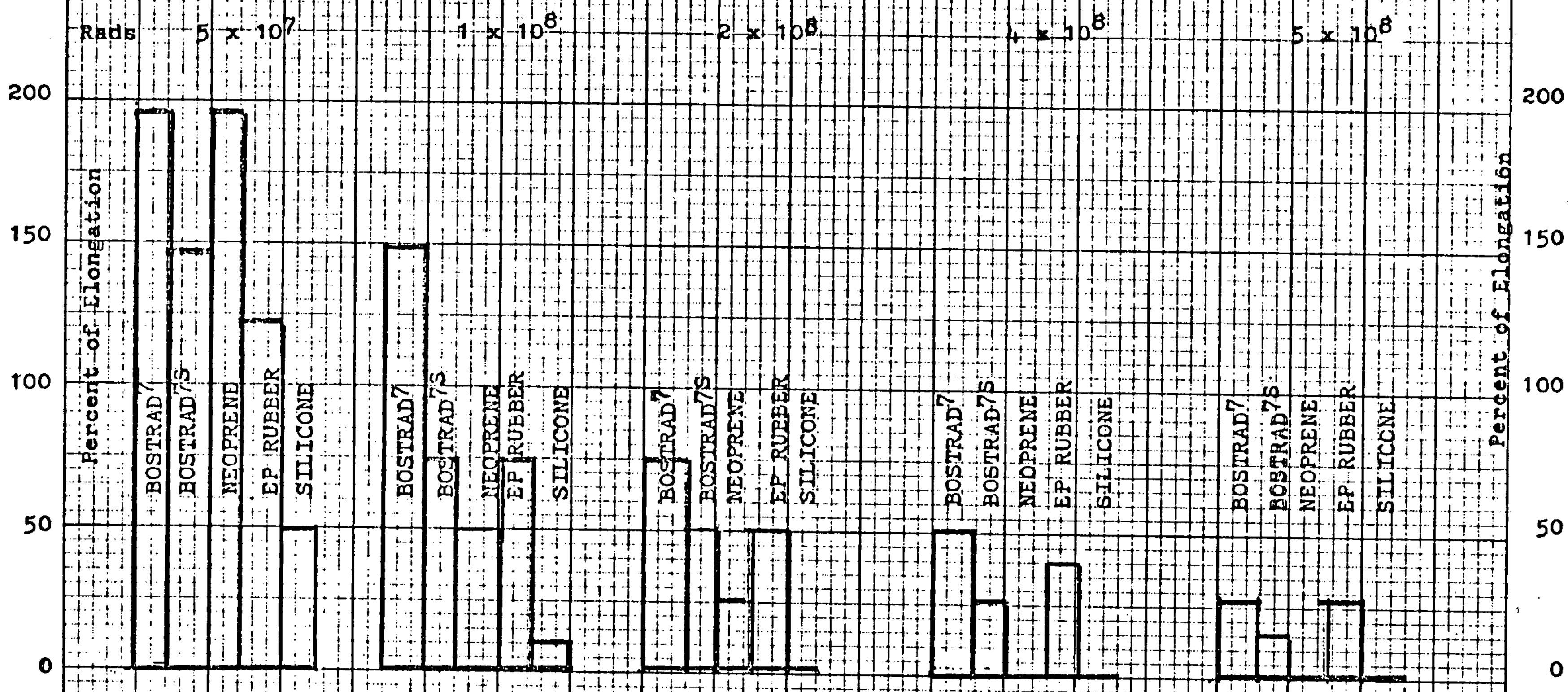
BOSTRAD7 is one of the few materials that retains 75% elongation and BOSTRAD7S meets the minimum level adopted in accordance with the following table:

Radiation Dose	*BOSTRAD7*	*BOSTRAD7S*
1×10^8	150%	75%
2×10^8	75%	50%
4×10^8	50%	25%
5×10^8	25%	

Tabulation of test results of other materials is compared with BOSTRAD7 and BOSTRAD7S in the graph on page 33.

ELONGATION OF VARIOUS MATERIALS AFTER EXPOSURE TO RADIATION

BIW COMPOUNDS PRESENTLY USED IN OUR PRODUCTS



Test Method

Molded ASTM slabs of material were subjected to various levels of electron radiation at room ambient temperature. Elongation was measured in accordance with ASTM Procedure D-412.

CABLES DESIGNED AND MANUFACTURED FOR WORLD NUCLEAR PLANT INSTALLATIONS BY BIW

Purchaser — Project	*Application*	*Type of Cable*
Dage Television Michigan City HANFORD WORKS Hanford, Washington	Incore TV monitoring cables throughout buildings.	BOSTRAD[7] thermosetting insulation and jacket.
Gulf General Atomic San Diego PEACHBOTTOM 1 HTGR	Incore TV monitoring cables.	BOSTRAD[19] inorganic coaxial cables.
FT. ST. VRAIN	Fuel handling. Fuel transfer. TV monitoring. Tube plugging machine.	BOSTRAD[19] inorganic cables and BOSTRAD KF polyimide insulation.
Sargent & Lundy Chicago SEFOR SODIUM COOLED REACTOR	Temperature monitoring of sodium coolant loop.	BOSTRAD[19] inorganic insulation thermocouple wire.
CEA France	TV monitoring.	BOSTRAD[22] inorganic coaxial cables.
Westinghouse Electronic Tube Division Elmira, New York POINT BEACH 1 & 2 (PWR)	Cable penetrations.	BOSTRAD[7] flame and radiation resistant thermosetting insulation and jacket.
KANSAI, JAPAN	Cable penetrations.	BOSTRAD[7]
NOK, Nordostschweiz. Kraftwerke, Switzerland	Neutron detection, proportional counter.	BOSTRAD[22] inorganic triax, complete assemblies.
Combustion Engineering Windsor, Connecticut PALISADES REACTOR (PWR) Consumers Power Company	Instrumentation and controls. Control rod drives.	BOSTRAD[7] insulation and PVC jacket. BOSTRAD KF polyimide insulation silicone jacket.
Argonne National Lab Idaho Falls Research Project	Nuclear instrumentation.	BOSTRAD[19] coaxial and triaxial cables.
Bechtel Corporation San Francisco POINT BEACH REACTOR (PWR) Wisconsin-Michigan Power Company	Inside containment instrumentation and control. Rod mechanism.	BOSTRAD[7]
	Inside and outside containment temperature monitoring.	BOSTRAD[7] thermocouple extension wire.