EPRI

Training Aids for Visual/Tactile Inspection of Electrical Cables for Detection of Aging

This report describes research sponsored by EPRI and the U.S. Department of Energy under the Nuclear Energy Plant Optimization (NEPO) Program.

Technical Report

Training Aids for Visual/Tactile Inspection of Electrical Cables for Detection of Aging

1001391

Final Report, March 2002

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This report describes research sponsored by EPRI and the U. S. Department of Energy under the Nuclear Energy Plant Optimization (NEPO) Program.

The report is a corporate document that should be cited in the literature in the following manner:

Training Aids for Visual/Tactile Inspection of Electrical Cables for Detection of Aging, EPRI, Palo Alto, CA and U. S. Department of Energy, Washington, D.C.: 2002. 1001391.

REPORT SUMMARY

The assessment of the condition of low-voltage instrumentation, control, and power cables in nuclear power plants is of increasing importance as plants age and license renewal is implemented. This program developed training aids containing cables of various types with progressive aging levels, from unaged through four steps of aging. Section 1 of this report details the development of the training aids and describes the accelerated aging regimen. Section 2 describes the conclusions that can be reached from examining the training aids.

Background
Most low-voltage cables are located in environments that cause little or no significant aging—even through the end of the license renewal period. However, some cables are in locations where the normal environment is severe and can cause significant aging, which is often observable through visual and tactile means. To support the examination and assessment by plant personnel of cables located in severe environments, prospective assessors can gain hands-on knowledge by visual and tactile inspection of the training aid specimens.

Objective
- To develop a set of cable training aids
- To document the regimen used to prepare them so that additional sets could be prepared if desired

Approach
Cables were obtained from nuclear utilities and a manufacturer that supports the industry. Cable sections and individual insulated wires were prepared and subjected to four steps of aging. Ten training kits were prepared by assembling and tagging an unaged specimen and a specimen from each of the four aging steps for each of the three cable and three wire types in the program.

Results
The kits provide tactile and visual evidence relating to the aging of Rockbestos cross-linked polyethylene (XLPE) insulated wires and cables and Okonite and Boston Insulated Wire (BIW) ethylene propylene rubber/chlorosulfonated polyethylene (EPR/CSPE) insulated wires and cables. Each of the cables has discernable aging characteristics. The kits also help the users to see the unaged condition of the jackets and insulations and to comprehend the relationship of the aging of the overall cable to the aging of the insulation used in it.

EPRI Perspective
The program was intended to provide information about the aging of cable through the use of low-rate accelerated aging. In addition to providing training aids for the industry, many

additional conclusions concerning cable aging resulted from the preparation of the specimens and their physical assessment after aging. The kits will provide a much-needed training aid for plants that would like to implement an aging management program for their cable systems or to understand the as-found condition of plant cables.

Keywords
Electrical cables
Visual examination
Tactile examination
Training

ACKNOWLEDGEMENTS

EPRI would like to thank Barbara Pribek, Nuclear Management Corporation; Quong Duong, The Detroit Edison Company; David Epperson, AmerenUE; and Jeffrey Mulvehill, Southern Nuclear Operating Company for supplying cable for use in the development of the cable training aids.

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1
DEVELOPMENT OF CABLE TRAINING AIDS

1.1 Introduction and Summary

This section of the report describes the development of sets of cable specimens, aged through accelerated means to varying levels of degradation, for use as training aids for visual and tactile cable inspection. Specimens of commonly used 600 V power and control cable and wire were used to develop the training aids. The specimens included wire with ethylene propylene rubber (EPR)/chlorosulfonated polyethylene[1] (CSPE) composite insulation, cable with EPR/CSPE insulation and a CSPE jacket, wire with cross-linked polyethylene (XLPE) insulation, and cable with XLPE insulation and a CSPE jacket. The manufacturers of the specimens were Boston Insulated Wire (BIW), Okonite, and Rockbestos.

Five aging steps or levels were established; the first step was unaged; and the other four steps had aging times starting at 756 hours (step 1) and ending with 3042 hours (step 4) at 246°F (119°C). Indenter tests were performed on specimens from each aging step to document the degree of aging in terms of the indenter modulus (N/mm).

The groups of specimens were tagged with labels describing the cable configurations and the aging step. Section 2 of this report describes the condition of the cables and the conclusions that can be reached from inspection and manipulation of the specimens.

If readers of this report would like to develop further sets of training aids, the basic concepts presented here can be used. However, the aging in this program was at a deliberately slow pace to achieve results that were as close to normal aging as reasonably possible. Because this effort was a research project, aging periods up to 3442 hours (20 weeks) were used. Such long aging periods may not be practical if the training aids are to be produced on a commercial basis.

Also, if additional training-aid kits are to be produced, other cable types with differing aging characteristics may be selected. Accordingly, the aging regimen should be adjusted to meet practical constraints and the aging characteristics of the cable types that are included in the new kits.

1.2 Specimen Description

Cable and wire specimens for the program were obtained from three utilities and Nutherm International's inventory. All specimens were taken from new material; however, some material

[1] CSPE is commonly called Hypalon, a trademark of E. I. du Pont de Nemours and Company.

had been in storage for several years, and the dates of original delivery are identified where available.

The BIW cable and wire specimens were made from BIW instrumentation cable supplied by a utility. The shielded 600 V cable has three 10 AWG, seven-strand conductors with a composite insulation that has an 0.8-mm (30-mil) EPR layer and a bonded 0.4-mm (15-mil) CSPE (Hypalon) conductor jacket with an overall 1.1-mm (45-mil) black Hypalon jacket.

The BIW cable specimens are 39 cm (15.5 in.) in length. The BIW wire specimens were made by removing the wires from 15-cm (6-in.) lengths of cable. The imprint on the cable jacket is "BIW Cable Systems Inc (1987) 600V 1 SH Triple # 10AWG." The conductor insulation colors are black, red, and white. This cable was received by the utility in 1987.

Okonite wire specimens were made from Okonite Loxarmor cable supplied by a utility. The armored cable has three 10 AWG, seven-strand insulated conductors and a 12 AWG ground wire with rubber fill, double-wrap tape, and galvanized steel armor. The wire specimens were made by removing the cable armor and tape and cutting the wire to 15-cm (6-in.) lengths. The conductors are insulated with 0.8-mm (30-mil) Okonite (EPR) and 0.4-mm (15-mil) bonded Okolon (Hypalon). Color codes of # 1 black, # 2 white, and # 3 red are printed on the black insulation of the conductors.

Each 39-cm (15.5-in.) specimen of Okonite cable was cut from cable supplied by a utility. The cable has three 12 AWG, seven-strand insulated conductors. The conductors have a composite insulation with an 0.8-mm (30-mil) EPR layer and a bonded 0.4-mm (15-mil) layer. The three conductors have an overall 1.1-mm (45-mil) Hypalon black jacket. The imprint on the cable jacket is "Okonite 4 3/C 12 AWG CU Okonite (EP) CSPE-CSPE 063 600V." Codes of "1-ONE," "2-TWO," and "3-THREE" are printed on the black insulation of the conductors. This material was received by the utility in 1995.

The Rockbestos wire specimens were made from 15-cm (6-in.) lengths of wire supplied by Nutherm International. The 12 AWG, seven-strand Firewall NEC Type SIS, 600 V 194°F (90°C) wire has gray, 0.8-mm (30-mil) XLPE insulation. The imprint on the wire reads: "#12 Rockbestos G Firewall Type SIS 600V (UL) VW-1 Nuclear Gray 1992." The wire was received by Nutherm in December 1992.

Rockbestos cable specimens, 39 cm (15.5 in.) in length, were cut from cable supplied by Nutherm. The cable has three 16 AWG, seven-strand conductors insulated with 0.8-mm (30-mil) flame-retardant cross-linked polyethylene (FR-XLPE) with an aluminized Mylar shield and drain wire, and a 1.1-mm (45-mil) CSPE black jacket. The imprint on the cable jacket reads: "16 AWG 3/C Rockbestos 600V 90°C Dry 75°C Wet Firewall III NEC Type TC (UL) Copper FRXLPE Shielded CSPE 1988-8C 712." The conductor insulation colors are gray, red, and white. The wire was shipped to Nutherm in July 1988.

Specimens were prepared according to Nutherm "Engineering Instruction 8529-EI-1, Rev. 0 included in Appendix I." The quantity of specimens originally placed into five groupings based on specimen aging time is shown in Table 1-1. Specimens in aging steps 3 and 4 for each cable and wire type had at least one additional specimen included for bend testing. Each individual specimen had an uninsulated ring tongue terminal installed on a conductor for later use in attaching specimen identification tags.

Table 1-1 provides a list of the specimens included in the program. The aging conditions for each aging step are discussed in Section 1.3. For the more highly aged steps (steps 3 and 4), additional specimens were aged to allow the training kits to be refurbished. Specimens from steps 3 and 4 can crack during training sessions when manipulated by trainees. Accordingly, if numerous cracks have occurred, the extra specimens can be used to replace those that are overly damaged.

Table 1-1
Aging Steps and Quantities of Specimens

Aging Step	Quantity	Bend Test Samples
BIW Wire Specimens		
0	10	0
1	10	0
2	10	0
3	25	3
4	25	3
BIW Cable Specimens		
0	10	0
1	10	0
2	10	0
3	25	1
4	25	1
Okonite Wire Specimens		
0	10	0
1	10	0
2	10	0
3	50	3
4	50	3
Okonite Cable Specimens		
0	10	0
1	10	0
2	10	0
3	25	3
4	25	3
Rockbestos Wire Specimens		
0	10	0
1	10	0
2	10	0
3	50	3
4	50	3
Rockbestos Cable Specimens		
0	10	0
1	10	0
2	10	0
3	50	3
4	50	3

1.3 Aging Conditions and Testing

1.3.1 Aging Conditions

The thermal aging incremental steps were designed to place the specimens in varying levels of aging conditions, ranging from limited through severe, that could occur in power plants. A lower accelerated aging temperature than commonly used in environmental qualification programs was used to provide a lower acceleration factor and to more closely approximate natural aging. Age conditioning was performed at 119°C (246°F) for various periods. Table 1-2 lists the initial increments for each aging condition. Following the initial aging conditioning, additional aging was performed on the BIW cable and wire specimens to provide more insights into severe aging. This aging was performed at 124°C (255°F).

Table 1-2
Thermal Aging of Specimens and Equivalent Lives

Material	Aging Step	Aging (Hours) 119°C (246°F)	Aging (Hours) 124°C (255°F)	Activation Energy of 1.1 Equivalent Time in Years at		
				122°F (50°C)	140°F (60°C)	158°F (70°C)
BIW Cable	1	780		92	28	9
	2	1559		185	56	18
	3	2278	384	340	104	34
	4	3042	400	434	132	43
BIW Wire	1	780		92	28	9
	2	1559		185	56	18
	3	2278	384	340	103	34
	4	3042	400	434	132	43
Okonite Cable	1	780		92	28	9
	2	1441		171	52	17
	3	2278		271	82	27
	4	3042		362	110	36
Okonite Wire	1	780		92	28	9
	2	1441		171	52	17
	3	2278		271	82	27
	4	3042		362	110	36
Rockbestos Cable	1	780		92	28	9
	2	1441		171	52	17
	3	2278		271	82	27
	4	3042	400	434	132	43
Rockbestos Wire	1	780		92	28	9
	2	1441		171	52	17
	3	2278		271	82	27
	4	3042		362	110	36

Note: The listed equivalent time in years figures are approximate periods required to attain the degree of damage sustained by the specimens. They do not directly represent qualified lives.

1.3.2 Age Conditioning Testing

The specimens were placed in a convection oven for thermal aging. The cables were placed on racks in parallel rows to allow air circulation around each specimen. The temperature inside the chamber was monitored by thermocouples located at the mid-plane of the cable bodies in the space between the rows of cables.

Following the originally specified thermal aging, no visible hardening or cracking of the cable specimens had occurred, even to those specimens subjected to bend testing. Consequently, indenter testing was performed to determine the degree of aging. After the results of the preliminary bend testing and indenter testing were reviewed, thermal aging time was increased for selected aging steps to achieve the desired aging conditions as shown in Table 1-2.

1.4 Bend Test

1.4.1 Test Setup

Aging steps 0 through 2 specimens for all cables and wires are highly pliable and can be bent on themselves without causing cracking. However, all of the aging steps 3 and 4 cables and the EPR/CSPE wire specimens hardened significantly. Bend testing was performed to identify the degree of bending that would cause a crack in the materials. These tests were performed to provide an indication of handling problems that might occur either during inspection or maintenance. Each manufacturer's cable/wire configuration was subjected to bend testing after aging. There were three bend specimens for each wire/manufacturer configuration except for the BIW cable. Material availability limited the BIW cable to one bend specimen each for aging steps 3 and 4.

The bend test after the initial thermal aging period was performed according to Nutherm's "Engineering Instruction 8529-EI-3, Rev. 0 included in Appendix IV." Prior to testing, each specimen was visually inspected for signs of cracking or other abnormalities. The mandrels used for each cable and wire type during the bend tests are shown in Table 1-3. Figure 1-1 shows a bend test in progress.

Table 1-3
Bend Test Setup Information

Cable Type	Specimen Diameter in mm (Inches)	Mandrel Diameter in mm (Inches)
BIW wire, #10	5.309 (0.209)	76.20–82.55 (3.0–3.25)
BIW cable	14.859 (0.585)	254.0–266.7 (10.0–10.5)
Okonite wire #12	4.826 (0.190)	76.20–82.55 (3.0–3.25)
Okonite cable	16.510 (0.650)	254.0–266.7 (10.0–10.5)
Rockbestos wire #12	4.013 (0.158)	63.50–69.85 (2.5–2.75)
Rockbestos cable	9.525 (0.375)	165.10–169.54 (6.5–6.675)

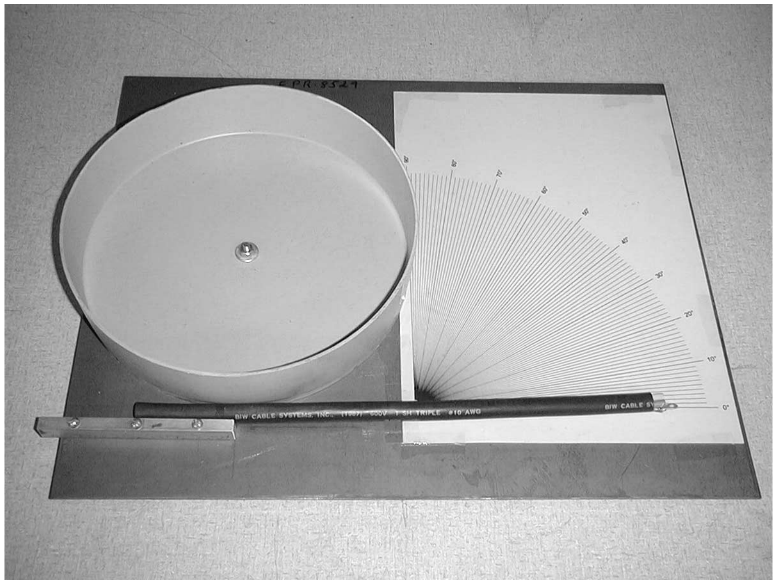

Figure 1-1
Bend Test Fixture with BIW Cable

1.4.2 Test Results

No cracking occurred with the mandrel diameters shown in Table 1-3 and the original aging increments. Therefore, additional thermal aging time was added to each aging condition for every cable and wire configuration to place the cables in a more aged state for demonstration purposes.

Following the period of additional thermal aging, bend testing was again performed on the same specimens used for the first bend tests. Again, no visible cracking occurred when the mandrels shown in Table 1-3 were used.

After a third thermal period of thermal aging, no visible cracking occurred as well, and testing was then performed with smaller diameter mandrels to determine if cracking would occur. Mandrels as small as 19.05-mm (0.75-in.) diameter were used; however, cracking was observed only in the jacket of the BIW cable from aging step 4.

During the development of the program, the bend tests were perceived as useful indications of loss of flexibility after severe aging. However, bending to conform to the larger mandrels is not representative of the stress caused by manual bending. As described in Section 2, aging steps 3 and 4 BIW and Okonite cables and Okonite wire crack when manipulated. A distributed bend around a mandrel does not simulate the point forces that occur when cables and wire are bent by hand.

1.5 Indenter Test

1.5.1 Test Setup

Indenter testing was performed on one specimen from each aging step of each cable/wire configuration that was aged.

Indenter testing was performed near the midpoint of each specimen. The probe speed was 12.7 mm/min (0.5 in/min), the force limit was 8 N, and the modulus was calculated with 1 and 4 N as the range.

1.5.2 Test Results

The results of the indenter testing are summarized in Table 1-4.

Table 1-4
Indenter Results

Wire/Manufacturer Configuration	Aging Step	Indenter Modulus (N/mm)
BIW Wire	0	11.0
	1	10.9
	2	11.5
	3	12.0
	4	12.9
BIW Cable Jacket	0	8.2
	1	7.4
	2	8.8
	3	44 (Initial Aging) 180 (384 Hours Additional at 124°C [255°F])
	4	190 (Initial Aging) 246 (400 Hours Additional at 124°C [255°F])
Okonite Wire	0	10.0
	1	11.0
	2	13.7
	3	68.7
	4	96.1
Okonite Cable Jacket	0	8.7
	1	10.3
	2	10.9
	3	93.6
	4	104.7
Rockbestos Wire	0	100.0
	1	93.2
	2	92.4
	3	95.6
	4	92.3
Rockbestos Cable Jacket	0	7.7
	1	6.5
	2	7.4
	3	7.8
	4	10.8

1.6 Conclusions

Section 2 provides the conclusions that can be reached from evaluation and manipulation of the specimens. The development of this set of training aids proved that a significant amount of useful information can be gained concerning the condition of unaged and aged cables and insulated conductors.

1.7 References

Project Plan No.8529P, “Project Plan to Develop Cable Sensory Inspections Training Aids, Revision 0, Nutherm International, Inc, March 22, 2001.

2
USE OF CABLE AGING TRAINING AIDS

2.1 Introduction

The cable training-aid sets contain three sets of cables and three associated sets of insulated individual insulated wires. Each set of specimens contains an unaged specimen and four aged specimens. Much can be learned from examining each set of specimens by itself, from comparing the cables to each other and the wires to each other, and from relating the wires to their parent cable.

This section describes what can be learned from evaluating the specimens. Figures 2-1 and 2-2 show pictures of sets of specimens. Figures 2-3 and 2-4 present the detailed labeling of the specimens. The labeling system of the training aids is user-friendly and provides the degree of information needed to use the specimens. The color coding of the labels by manufacturer readily identifies the cable and the wire from the same manufacturer.

The specimens have been prepared to demonstrate the following:

- The construction of typical low-voltage cables
- The hardness, flexibility, and texture of unaged cable and wire
- The hardness, flexibility, and texture of cable and wire aged to varying levels
- The condition of insulation aged excessively
- The behavior of bonded jacket, composite insulation

The following information describes the attributes of the cables and insulated conductors. Although the text can provide some information independent of the training aids, it is intended for use with them.

Examination and manipulation of the specimens will provide immediate benefit and understanding of the key attributes of aging. However, evaluation of the specimens in conjunction with the information described here will lead to further insights that are not obvious on the initial inspection.

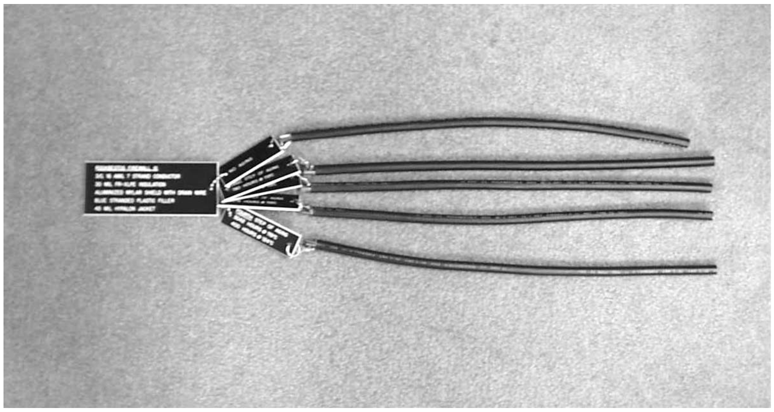

Figure 2-1
Typical Cable Set

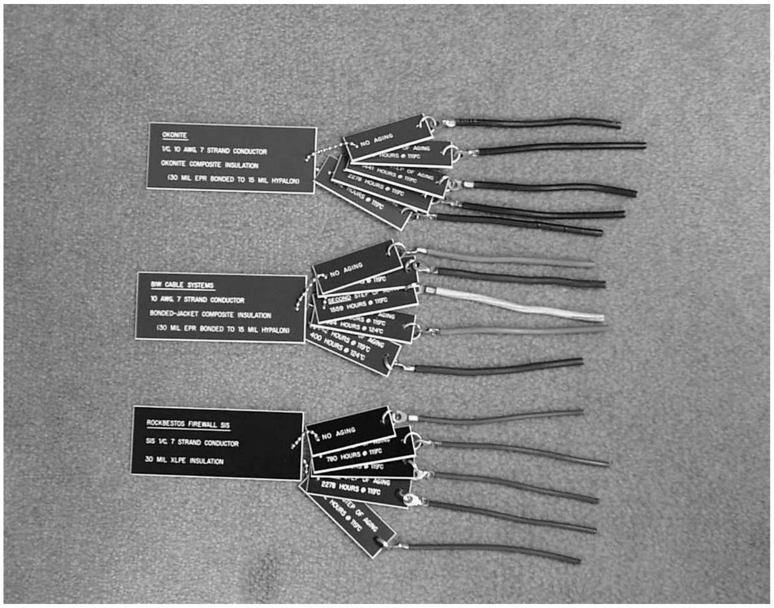

Figure 2-2
Wire Sets

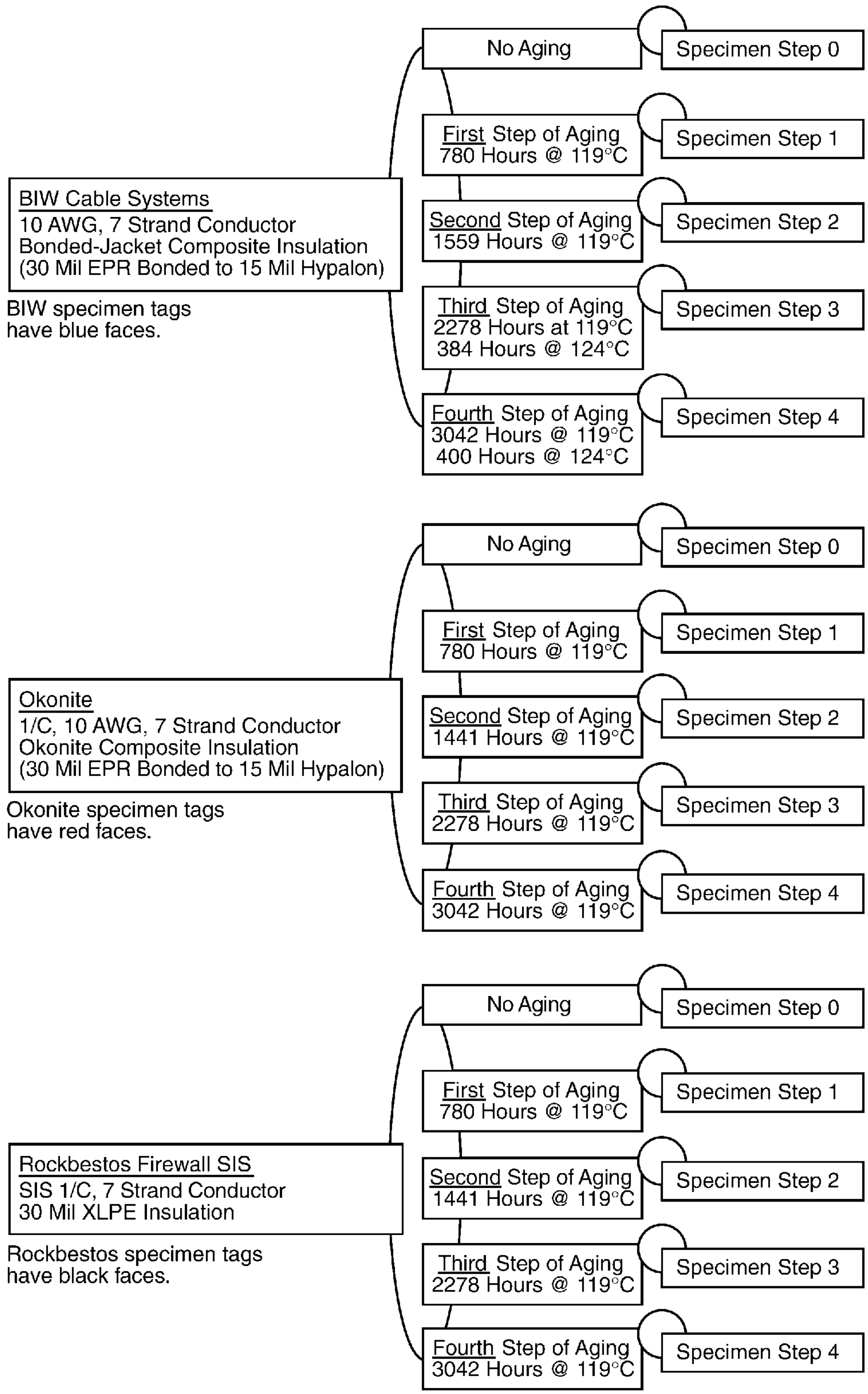

Figure 2-3
Wire Labeling

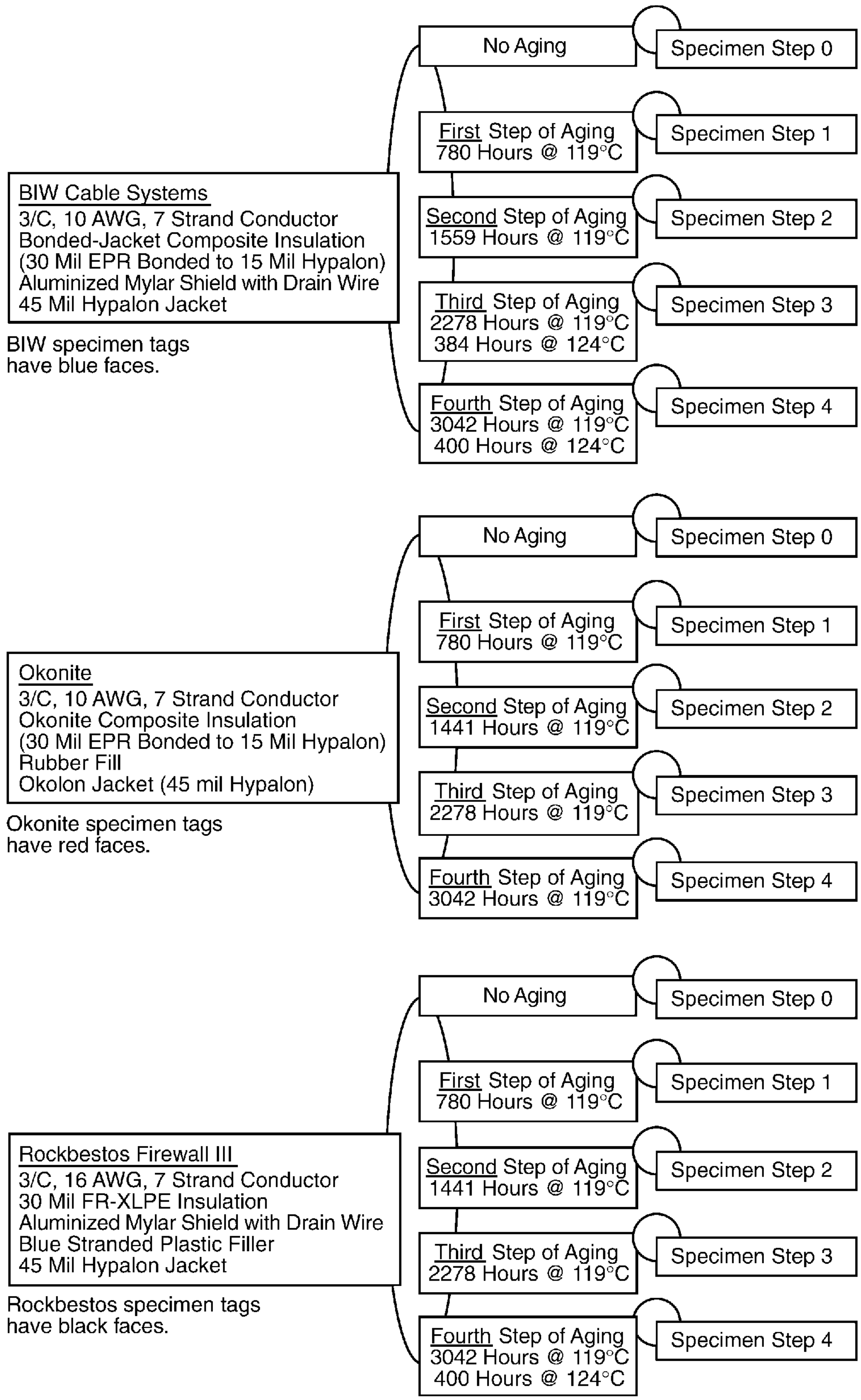

Figure 2-4
Cable Labeling

2.2 Cable Condition and Construction

Each of the cables has an overall Hypalon jacket with a nominal 1.1-mm (45-mil) thickness. Although the jackets of each of the three manufacturers' cables have a similar hardness and flexibility when unaged, they all behave differently through the aging process as reflected in Tables 2-1 and 2-2.

Table 2-1
Flexibility and Visual Attributes

Manufacturer	Condition of Jacketed Cables
BIW	The jacket and cable remain flexible through the step 2 of aging with no appreciable difference between these three (0, 1, and 2) aging steps. However, at step 3, severe hardening occurs in the outer jacket to the point where bending without cracking is not possible. Steps 3 and 4 cables also have a yellowish-brown surface coating called "bloom." Bloom indicates only that the cable has been exposed to elevated temperature, and by itself, it is not a problem. However, the severe hardening indicates that the overall jacket has aged significantly.
Okonite	The jackets and cables from steps 1 and 2 remain very flexible. In step 3, the resistance to bending increases significantly, and in step 4, the resistance to bending increases even more. If the step 3 and 4 cables are subject to hard bending with point loads rather than smooth bends, cracking of the outer jacket occurs. A small degree of discoloring of the labeling ink can be noted in the cables in steps 3 and 4. When the jacket is removed, the composite insulation can be bent toward the core of the cable without cracking on steps 3 and 4 cables. However, bending the individual wires away from the center causes cracking of the CSPE layer. (The sides of the insulation that were against each other during manufacturing have more severe aging due to residual mechanical forces.) The EPR layers in both cables retain their elongation properties, and no cracking occurs even with severe bending.
Rockbestos	The jacket and cable of all steps of aging remain flexible. However, in step 3, the resistance to bending increases significantly, and in step 4, the resistance to bending increases even more. Although the cable has aged appreciably, the overall aging is not severe. (**Note:** A small degree of discoloring of the labeling ink can be noted in the cables in aging steps 3 and 4.)

Table 2-2
End View Evaluation of Construction

Manufacturer	Construction Details
BIW	This is a three-conductor, 10 AWG cable with an aluminized Mylar tape shield and drain wire. The three insulated conductors are cabled (twisted) with the drain wire, and the aluminized tape is wrapped around the insulated conductors and drain wire. No additional fillers or materials have been applied to make the cable round. Rather, the overall jacket has been extruded with a variable thickness to achieve a round cable. The nominal thickness of the jacket is 1.1 mm (45 mils); however, some sections of the jacket are much thicker. Each of the insulations on the individual conductors has two layers. The insulation at the conductor is EPR, which is black and 0.7-mm (30-mils) thick. The conductor jacket is CSPE and 0.35-mm (15-mils) thick. The CSPE layers are black, red, and white on this cable.
Okonite	This is a three-conductor, 12 AWG cable with no shielding. Okonite has cabled the three conductors and then extruded a layer of rubber over the conductors to make the cable round. An overall jacket of CSPE has then been extruded on the cable. The nominal thickness of the overall jacket is 1.1 mm (45 mils). Careful inspection of the conductor insulation indicates that the insulation on the individual conductors has two layers. The insulation at the conductor is EPR, which is black and 0.7-mm (30-mils) thick. The conductor jacket is black CSPE, which is 0.35-mm (15-mils) thick.
Rockbestos	This is a three-conductor, 16 AWG cable with an aluminized Mylar shield and drain wire. Rockbestos has cabled the three conductors with the drain wire. Blue polyester non-hygroscopic fiber has been used to partially round the configuration. A nominal 1.1-mm (45-mil) CSPE overall jacket has been extruded on the cable. The insulation on each of the conductors is a single 0.7-mm (30-mil) layer of XLPE, which is red, white, or black.

Note: Each of the cables has seven-strand conductors. The use of stranded conductors adds more flexibility than solid conductor configurations.

2.3 Individual Insulated Conductors

Table 2-3 provides the information that can be learned from an assessment of the individual insulated conductors. The BIW and Okonite specimens have composite CSPE/EPR insulations. The Rockbestos specimens have XLPE single-layer insulation. Table 2-4 provides information with regard to a comparison of the individual insulated conductors with the associated cable.

Note: All three sets of insulated conductors have been aged to essentially the same condition. There was no intent to determine if one manufacturer’s insulation was better than another. Each insulation will eventually become over-aged if additional thermal aging is applied.

Table 2-3
Individual Conductor Insulation Conditions

Manufacturer	Condition of Insulation
BIW	No appreciable hardening of the CSPE or EPR layers can be ascertained by touching or bending. (Note: Indenter testing also indicates no appreciable change in aging.) The layers of insulation and the stranding of the conductor are also visible at the ends of the specimens.
Okonite	There is no appreciable difference in flexibility of the CSPE or EPR layers through step 2 of aging. However, steps 3 and 4 have caused severe hardening, with step 4 being harder than step 3. The difference in hardening is more appreciable when tested by the indenter with step 3 having a modulus of 68.7 N/mm and step 4 having 96.1 N/mm. When bent slightly by hand, the CSPE of steps 3 and 4 will crack. No spontaneous cracks occurred in the specimens. Any cracks in the CSPE are from manipulation in use. The layers of insulation and the stranding of the conductor are also visible at the ends of the specimens.
Rockbestos	These specimens are insulated with XLPE, a relatively hard, but flexible, plastic. (Note: The BIW and Okonite cables use rubber insulations.) Therefore, the insulation of the Rockbestos cable is hard and stiff to begin with. The XLPE also does not change hardness or stiffness until very late in its life. The degree of aging in the preparation of the specimens is insufficient to cause such a change. Other than a slight yellowing of the insulation after being subjected to thermal aging, there is no appreciable difference in the aging specimens between step 0 and step 4. The stranding and the single layer of insulation are visible at the ends of the specimens.

Table 2-4
Comparison of Insulated Conductors with Overall Cable

Manufacturer	Comparison
BIW	In the original aging for this cable, the aging step 3 specimens were not appreciably different from the steps 1 and 2 specimens, but the step 4 specimens were very severely hardened. Additional aging was performed on both the steps 3 and 4 specimens to further understand the sudden change. The as-shipped steps 3 and 4 specimens have severely aged jackets. Both have surface bloom, but the step 4 specimens have more severe bloom than the step 3 specimens. The jacket on half of each specimen has been removed. The jacket is now very hard and brittle, rather than rubber-like. The individual conductor insulations have fused to each other, and the Mylar tape is brittle. When the Mylar tape is removed and the conductor insulations are separated, the step 3 specimen conductor insulations are found to have remaining flexibility, but the step 4 specimen insulation jacket cracks when bent. The aging between steps 3 and 4 results in the insulation becoming fragile with respect to manipulation. However, removal of the outer jacket is required to allow bending that would cause cracking of the insulation. **Note:** This cabled specimens are have been subjected to significantly more aging than the BIW wires and the Okonite counterpart cable.
Okonite	The aging of this cable is subtle. Because aging has not produced bloom, the jackets of all aged specimens look almost the same. However, the elongation properties have decayed on aging steps 3 and 4. If gently bent with a continuous arc, the jackets of aging steps 3 and 4 specimens do not crack. However, a concentrated local bend will cause the cables from both aging steps to crack. The key to detecting aging of this cable is its resistance to bending. The unaged cable is very supple. The cables from aging steps 3 and 4 are quite stiff by comparison. The specimens from steps 3 and 4 resist bending much more than those from steps 0, 1, and 2. See the discussion of indenter results below for further information concerning the individual conductor insulation.
Rockbestos	The XLPE insulation in this cable is relatively hard and stiff under all conditions. The hardening of the overall jacket provides an early indication that the cable has been exposed to significant aging. However, the identification of an exact degree of thermal or radiation damage to the XLPE will require laboratory testing rather than visual/tactile or indenter testing.

2.4 Evaluation of Indenter Results

2.4.1 BIW Wire

The indenter data presented in Table 1-4 of Section 1 provides a more refined definition of the degree of aging of the insulations and jackets than visual or tactile evaluation. The indenter modulus versus the aging steps is shown in Figure 2-5 for the BIW wire. While there is a gentle increase in indenter modulus, the aging of this EPR/CSPE insulation has been very limited with respect to the capability of this particular composite. The aging has not shifted the indenter modulus significantly from the unaged condition of 11 N/mm. From other tests of the BIW wire, significant hardening of the CSPE jacket of the composite insulation will ultimately occur.

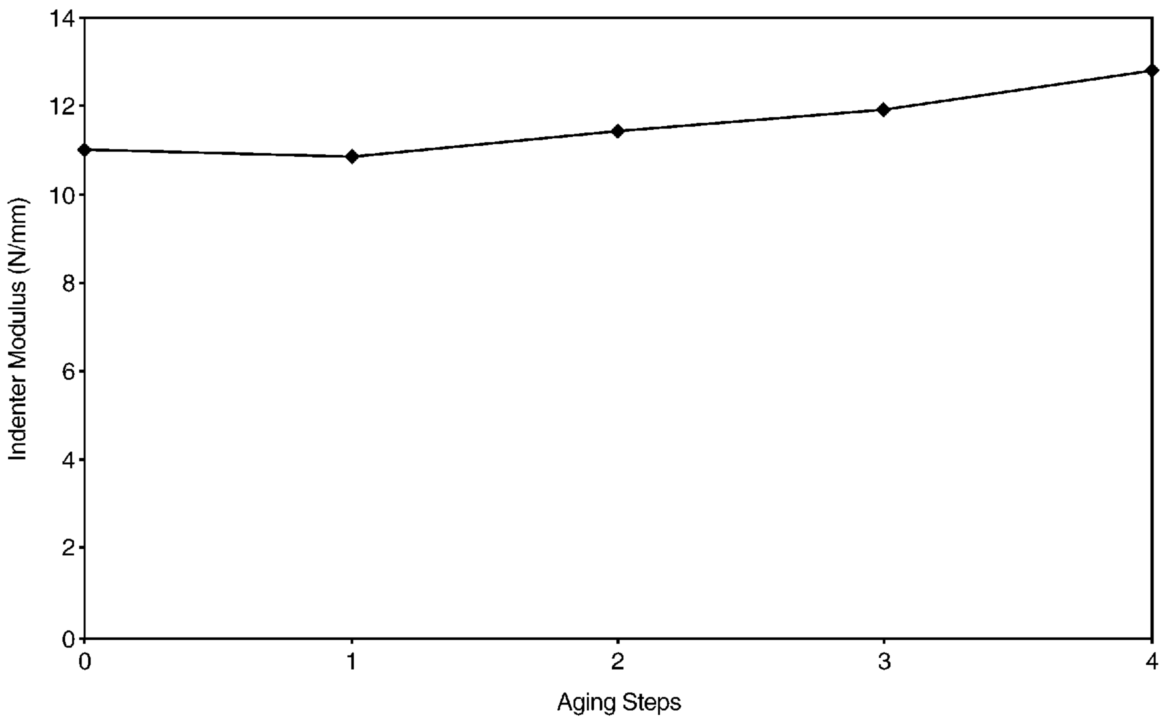

Figure 2-5
BIW Wire Indenter Modulus versus Aging Steps

2.4.2 BIW Cable

Figure 2-6 provides the indenter modulus for the BIW cable overall CSPE jacket. As described in Table 2-2, the hardening between aging steps 3 and 4 is severe. The condition of these cables has resulted from additional thermal aging by comparison with other cables in the program. Figure 2-6 shows two different indenter plots for aging steps 3 and 4. The less severe of the two is for the original aging. The more severe is with the additional aging that is representative of the jackets in the training aids. An indenter modulus of 100 N/mm or greater for CSPE indicates severe aging. A modulus of 219.6 N/mm indicates extreme aging for this cable.

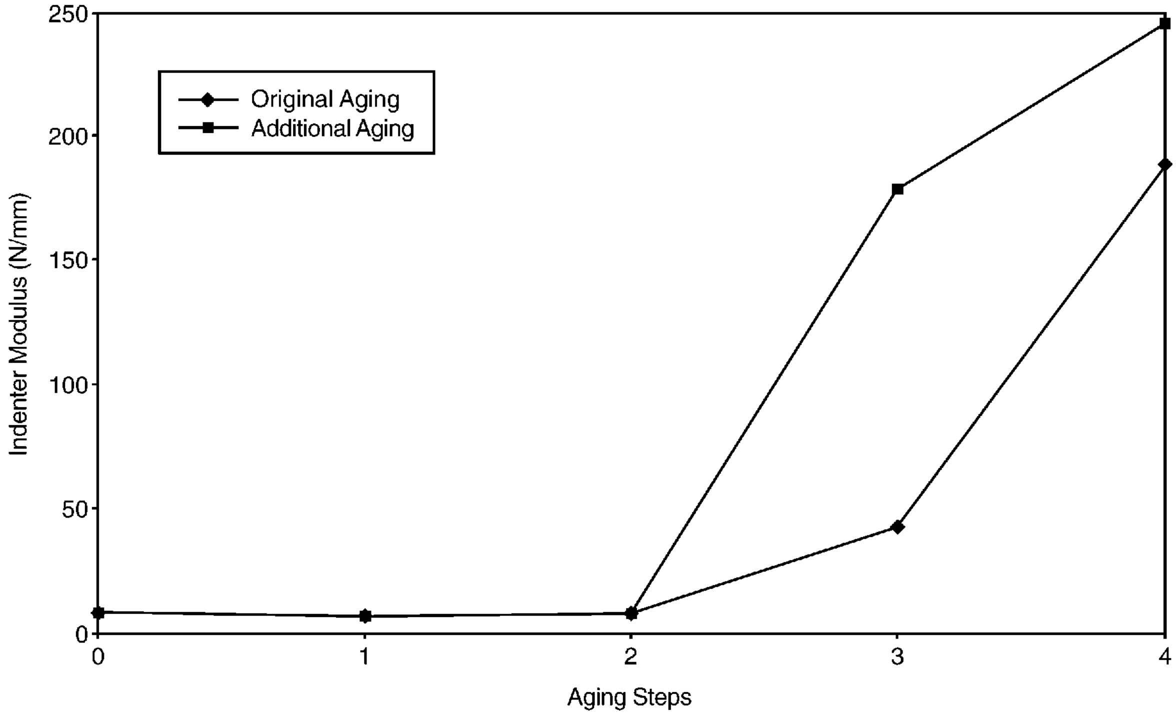

Figure 2-6
BIW Cable Indenter Modulus versus Aging Steps

The indenter evaluation of the individual conductors from the BIW aging steps 3 and 4 indicates that there is a significant difference in the degree of aging between steps 3 and 4 at the conductor composite insulation level. Table 2-5 provides the indenter results for the conductor insulation of the BIW steps 3 and 4 specimens. The indenter moduli for these specimens agree with the perceptions from manipulation. The step 3 insulations have hardened from the unaged condition of 11 N/mm, but they have not yet hardened severely even though the cable was exposed to 2278 hours (13.5 weeks) at 119°C (246°F) and an additional 384 hours (2.3 weeks) at 124°C (255°F). However, the step 4 insulations have hardened severely when aged to 3042 hours (18.1 weeks) at 119°C (246°F) and an additional 400 hours (2.4 weeks) at 124°C (255°F). The additional 4.6 weeks of aging at 119°C (246°F) received by the step 4 specimens have essentially used all of the residual life in the insulation. Where step 3 specimens had essentially doubled the unaged indenter modulus, step 4 specimens have an indenter modulus of approximately 10 times the unaged condition. At that hardness, cracking will occur with manipulation.

Table 2-5
Indenter Modulus of Insulations of BIW Cable Aging Steps 3 and 4

Aging Step	Conductor	Indenter Modulus (N/mm)	Range of Measurements (N/mm)
3	Black	22.3	20.6–23.3
3	Pink	24.6	23.5–25.8
3	White	19.7	19.5–20
4	Black	96	71–133
4	Pink	113	95–131
4	White	104	72–131

2.4.3 Okonite Wire

Figure 2-7 provides the indenter modulus for the Okonite wires. Between aging steps 2 and 3, significant hardening occurs so that the jacket of the composite insulation becomes brittle. The hardening is extreme for aging step 4 on the Okonite wires so that no flexibility is available and cracking occurs immediately under manipulation. The indenter modulus of the composite insulation is shown in Figure 2-7 with 70 N/mm for step 3 and 95 for step 4.

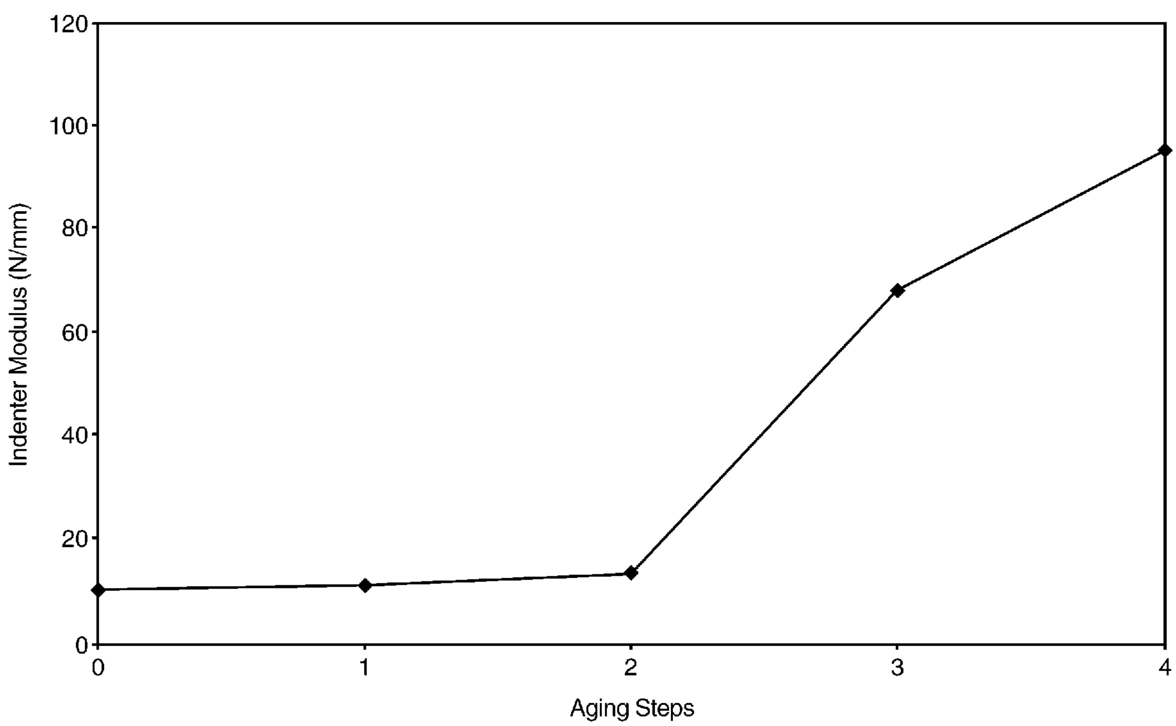

Figure 2-7
Okonite Wire Indenter Modulus versus Aging Steps

2.4.4 Okonite Cable

As described above, the Okonite cable does not appear to have aged significantly upon initial inspection. However, Figure 2-8 indicates that severe hardening of the CSPE occurred between aging steps 2 and 3 and further hardening occurred at step 4. Careful manipulation of the specimens proves that the aging of steps 3 and 4 has caused significant hardening and loss of elongation properties. Sharp bending of the cable causes cracking at steps 3 and 4.

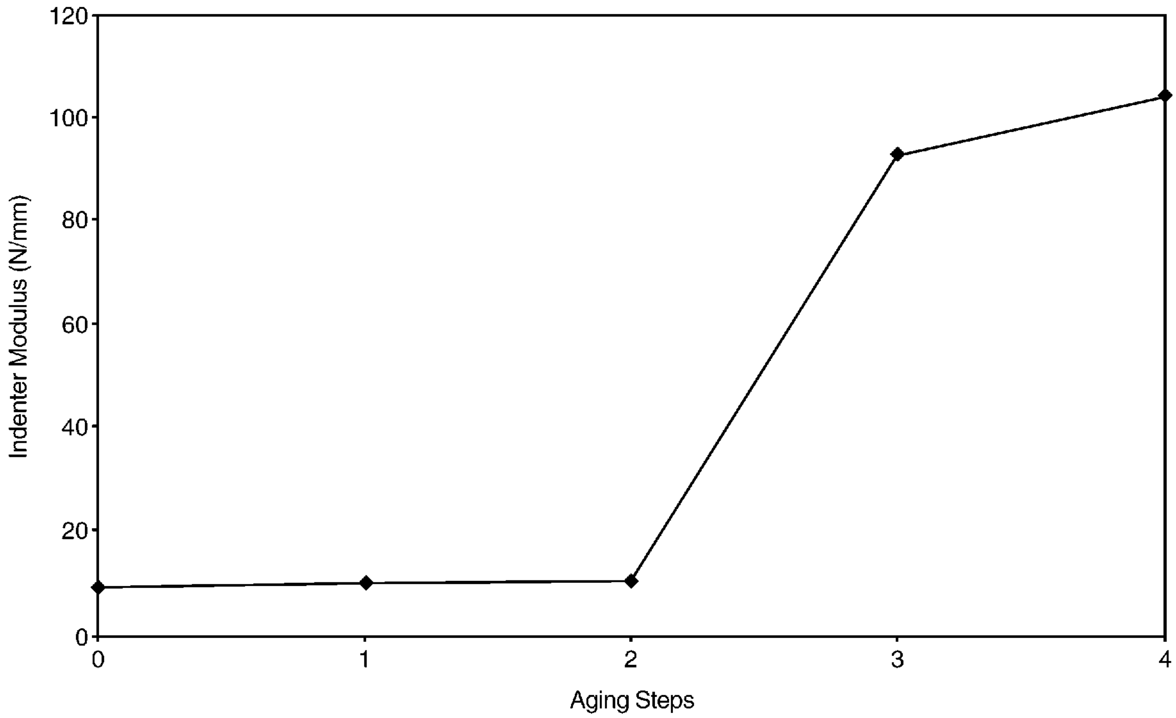

Figure 2-8
Okonite Cable Indenter Modulus versus Aging Steps

A section of the jacket was removed from the aging steps 3 and 4 cables, and the composite insulation was evaluated. For the step 3 specimens, the average indenter modulus was 22.9 N/mm on the three leads. Even though all three conductors have black pigmentation, there were noticeable differences in results. Conductor 1 measured 24.6 N/mm, conductor 2 measured 18.1 N/mm, and conductor 3 measured 26.1 N/mm. For the step 4 specimens, the average reading was 24.6 N/mm. Conductor 1 measured 25.4 N/mm, conductor 2 measured 23.4, and conductor 3 measured 26.1.

Although further deterioration of the overall jacket had occurred, only moderately more deterioration of the conductor jackets had occurred. Because very similar aging had occurred to the insulations in aging steps 3 and 4, the jacket of a step 2 cable was removed as well to evaluate the degree of aging. The step 3 insulation was completely supple. The indenter measurement for the step 2 conductor insulations was 6.5 N/mm with a range of 5.6 to 7.4 N/mm. Table 2-6 summarizes the results.

Table 2-6
Okonite Cable/Conductor Insulation Evaluation Summary

Aging Step	Cable Jacket Indenter Modulus (N/mm)	Conductor Insulation Modulus (N/mm)	Comments
2	10.9	6.5	Insulation is very flexible
3	93.6	22.9	CSPE layer of insulation is flexible when bent toward the cable core, but it cracks when bent away from the core. EPR does not crack when the insulation is bent further.
4	104.7	24.6	CSPE layer of insulation is flexible when bent toward the cable core, but it cracks when bent away from the core. EPR does not crack when the insulation is bent further.

2.4.5 Rockbestos Wire

Figure 2-9 shows the indenter modulus for the XLPE insulation of the Rockbestos wires. There is a very limited softening trend in the data; however, this trend is probably more related to changes in the crystalline melt curve from heating and cooling during the oven exposure than to actual aging. The differences in indenter modulus are not significant in this curve. Severe aging, well beyond that in the program, would ultimately lead to severe, sudden hardening. However, the aging of these specimens is not significant with respect to overall aging. The specimens have been provided to show that XLPE material is hard at room temperature and remains that way during aging.

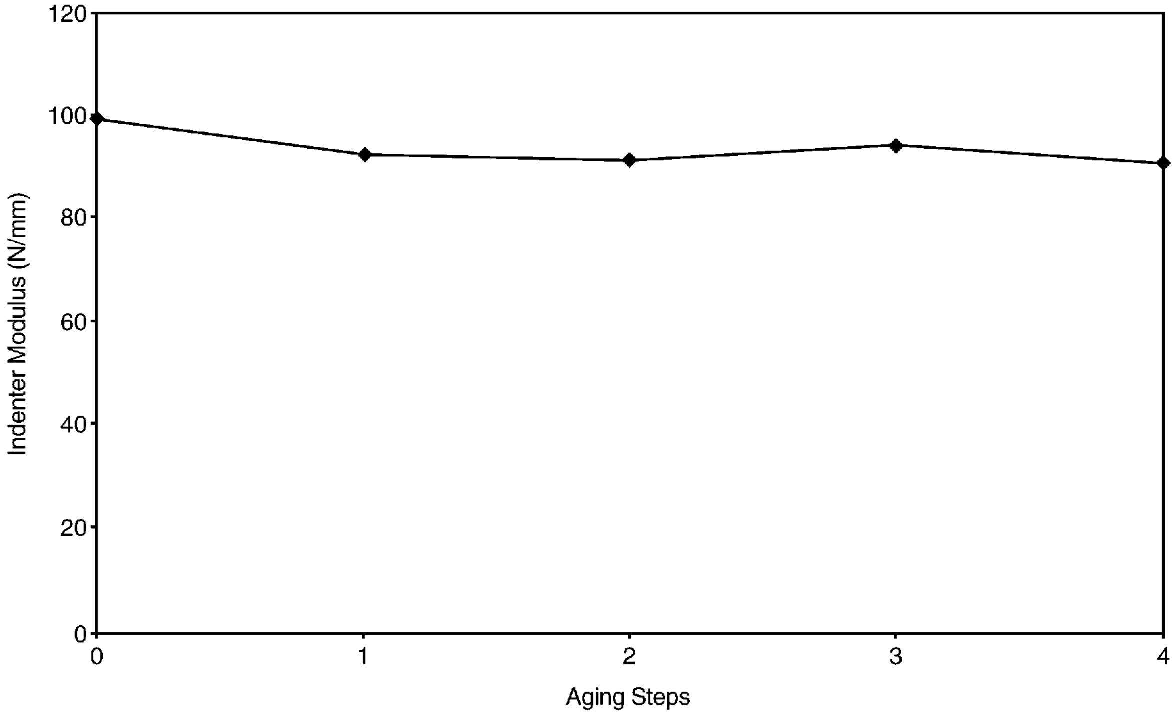

Figure 2-9
Rockbestos Wire Indenter Modulus versus Aging Steps

2.4.6 Rockbestos Cable

The CSPE overall jacket has not been significantly aged in the development of the specimens. A small increase in the indenter modulus is noted for aging step 4, as can be seen in Figure 2-10. More aging would cause this jacket to age as did the Okonite overall jacket. Further aging, as occurred for the BIW cable in steps 3 and 4, would cause the jacket to harden severely.

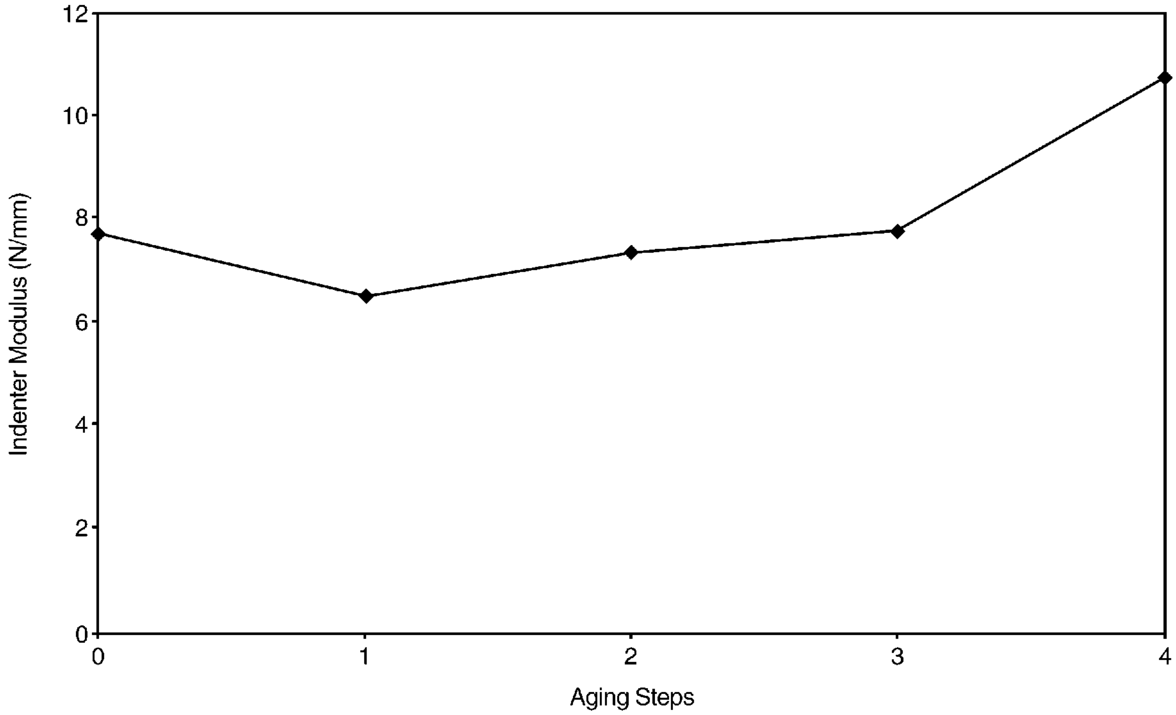

Figure 2-10
Rockbestos Cable Indenter Modulus versus Aging Steps

Target:
Nuclear Power

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