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MAY 23 1991

U.S. Nuclear Regulatory Commission
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Gentlemen:

In the Matter of the Application of	)	Docket No. 50-438
Tennessee Valley Authority	)	50-439

BELLEFONTE NUCLEAR PLANT (BLN) - TRANSMITTAL OF TVA POSITION REGARDING CABLE BEND RADIUS (TAC #79284)

In accordance with TVA's letter to the NRC staff dated December 4, 1990, enclosed for staff review is the TVA position paper regarding cable bend radius. A written staff position on the enclosure is requested by July 29, 1991.

As discussed with the NRC staff and management, timely resolution of key issues, such as noted in the enclosure, is important to TVA's consideration of the nuclear option at BLN. Should TVA continue construction of BLN after staff resolution of this and other positions, the agreement reached will be used to govern design, construction, and operations of BLN and will be incorporated into the BLN Final Safety Analysis Report, as appropriate.

Bruce S. Schofield will be contacting the BLN project manager to schedule a working level meeting to assist in the staff's review of this position.

A001

MAY 23 1991

U.S. Nuclear Regulatory Commission

If you have any questions, please telephone Mr. Schofield at (205) 574-8058.

Very truly yours,

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ENCLOSURE

BELLEFONTE POSITION PAPER

REGARDING

CABLE BEND RADIUS

TABLE OF CONTENTS

1.0 PURPOSE

This position paper presents TVA's approach to providing reasonable assurance that the safety-related systems of the Bellefonte Nuclear Plant (BLN) will not be subject to failures caused by bending of their electrical cables. TVA requests NRC concurrence with this approach and, specifically, with the acceptance criteria and inspection plans for existing installations described in this paper.

2.0 SUMMARY OF POSITION

Until 1983 TVA's cable installation specifications did not specifically include minimum bend radius limits for permanently trained cables. In 1983 TVA issued its specification DS-E12.1.5 - Minimum Radius for Field-Installed Insulated Cables Rated 15,000 Volts or Less - to establish such limits. In 1987 the NRC raised concerns regarding cable bends in safety-related systems at Watts Bar Nuclear Plant (WBN) and Sequoyah Nuclear Plant (SQN) (Ref. 1 and 2). To address these concerns at BLN and ensure the reliability of the plant's safety-related systems, TVA has evaluated the issue of cable bend radius at BLN in light of applicable experience, manufacturer recommendations, tests, and inspection results.

Based on its evaluation, TVA has developed acceptance criteria for cable bends in existing safety-related installations at BLN. When satisfied, these acceptance criteria are sufficient to ensure that the cables will not experience insulation failures due to bending. TVA will perform inspections and implement necessary actions to provide reasonable assurance that existing installations satisfy this acceptance criteria. The acceptance criteria and inspection plans are described in the following sections of this paper.

Future installations will be in accordance with TVA engineering specifications which were revised in 1987 to reflect Insulated Cable Engineers Association (ICEA) cable bend radii recommendations.

3.0 BACKGROUND

Severe bending of electrical cables can result in degradation of its insulation. In the case of shielded medium-voltage cables, severe bending can disrupt their corona protection system and lead to insulation damage from corona activity. Low voltage cable insulation may be affected by the compressive and tensile stresses associated with tight bends. Excessive mechanical stresses may lead to insulation failures, particularly when coupled with exposure to high temperature, radiation, and moisture.

The ICEA and cable manufacturers have published minimum values for permanent training radii, i.e. radii to which cables may be left bent for the duration of their rated service life. In general, little guidance has been provided regarding minimum radii for temporary bending of the cables, such as during storage or cable installation.

At BLN, TVA has used cables that have either silicone rubber, crosslinked polyethylene, or ethylene propylene rubber insulation. ICEA publications S-19-81, S-66-524, and S-68-516 specify minimum permanent training radii for these types of cables (Ref. 3, 4, and 5). In 1987 TVA's engineering specifications were revised to reflect these ICEA standards for BLN. However, it is generally recognized that smaller radii have been used in industrial and nuclear applications without inducing premature insulation failure. The conservatism of the ICEA standards is substantiated by the TVA analysis described later in this paper.

Accordingly, in order to determine the acceptability of existing BLN cable installations with regard to bend radius, TVA has defined a set of acceptance criteria that eliminates some of the conservatism contained in the ICEA recommendations while ensuring protection against insulation failures due to excessive bending.

4.0 TECHNICAL POSITION AND JUSTIFICATION

The bend radius acceptance criteria defined by TVA for existing BLN installations are described hereafter and the bases for these criteria are explained. Section 4.1 addresses temporary bend radius and Section 4.2 addresses permanent training radius.

4.1 Limits for Temporary Bend Radius

TVA has completed a test program to determine the minimum radii to which single-conductor cables of different sizes can be temporarily bent without risk of mechanical degradation of the conductor or its insulation system. The tests consisted of the bending of cables, ranging in size from 16 AWG to 500 MCM, on specially constructed forms to determine the radii at which noticeable material deformation occurred (Ref. 6). Based on these results, TVA has adopted the limits shown in Table 1 for temporary bend radius of single-conductor cables (Ref. 7). These limits provide a margin of approximately one conductor diameter over the radii at which noticeable material deformation was observed to occur or over the minimum practical bends. The limits of Table 1 have been reviewed and approved by the NRC for use at WBN (Ref. 8).

The tests performed by TVA have also indicated that cables bent to the limits of Table 1 can be retrained to larger radii without damage. Load cycling and corona tests are planned to confirm these results for shielded medium voltage cables.

The tests did not cover instrument cables with braided shield, e.g. coaxial or triaxial cables. Cables of this type have not yet been installed in safety-related systems at BLN.

Based on preliminary investigations, TVA believes that multi-conductor cables can safely be bent to the same minimum radii as single-conductor cables. Additional tests are currently under way at TVA to confirm these preliminary results. Accordingly, the limits specified for temporary bends of single-conductor cables will also be applied to multi-conductor cables pending completion of the investigations. In practice, however, most multi-conductor cables, cannot be bent to these limits using normal cable handling methods.

4.2 Limits for Permanent Training Radius

The limits specified by TVA for permanent training radius at BLN are shown in Tables 2 and 3. These limits are discussed below.

Medium Voltage Cables

For safety-related medium voltage cables, TVA has specified a minimum training radius of 8 x cable OD for all environmental conditions (Table 2). This value is less restrictive than the value recommended by ICEA standards (12 x cable OD); however, it can be shown that a radius of 8 x OD produces negligible additional stresses when compared to a radius of 12 x OD. The methodology for making this comparison is contained in Reference 9. A minimum training radius of 8 x OD has been endorsed by TVA cable suppliers for BLN (Ref. 10 and 11) and has been approved by the NRC for use at WBN (Ref. 8).

Low Voltage Single-Conductor Cables

For safety-related low voltage single-conductor cables including individual conductors of multi-conductor cables, TVA has specified minimum limits for training radius which vary with the application and anticipated operating conditions of the cables (Table 2). Insulation aging caused by high operating temperatures and exposure to accident environments could increase the risks of insulation damage if the cables are trained too tightly. Accordingly, the training radius limits specified for low voltage cables are designed to ensure that, at the end of a 40-year plant life, the insulation of these cables will retain mechanical properties which are consistent with the specific application and anticipated operating conditions of these cables. The basis for TVA's acceptance criteria is described below:

- Insulation aging is normally represented by the loss of elongation at rupture experienced as a result of long-term exposure to temperature. Cables which could be exposed to accident environments are qualified by subjecting them to an accelerated aging cycle equivalent to a 40-year plant life and exposing them to LOCA conditions prior to acceptance testing. Cable manufacturers typically define the end of insulation life (pre-accident condition) as when the elongation at rupture has been reduced to less than 60 percent of its initial value (50 percent is commonly used). To evaluate the potential effect of tight bends on the insulation condition at the end of a 40-year plant life, TVA has accounted for the initial elongation caused by such bends in the aging models discussed hereafter.

- Because of their low current loading, low voltage control signal cables operate at or near ambient temperature, i.e. well below the 90°C or 125°C temperature rating of their insulation. Over a 40-year plant life, their insulation will therefore experience only a minimal loss of elongation at rupture. Figure 1 indicates the change in residual elongation at rupture with time for ethylene propylene rubber insulation qualified for 40 years of operation at 90°C, assuming an activation energy of 1.1 eV, an initial elongation at rupture of 150 percent, and an actual operating temperature of 60°C (Ref. 9). The effect of cable bends is accounted for by subtracting the elongation caused by the bends from the initial value of elongation at rupture. As indicated in Figure 1, the insulation of a cable bent to a radius as small as 1 x OD will retain, at the end of 40 years, substantially more elongation at rupture than that required by the 60 percent end-of-life criterion. Accordingly, existing installations of low voltage control and signal cables will be considered acceptable, regardless of location, as long as the limits defined in Table 1 have not been violated.

- The effect of cable bends can be similarly evaluated for low voltage power cables operating at temperatures close to the rating of their insulation. Figure 2 indicates that the insulation of cables bent to radii smaller than the ICEA value may reach the 60 percent end-of-life value of elongation at rupture in less than 40 years. Specifically, cables bent to 1 x OD may have a qualified life of only 22 years (Ref. 9). On an interim basis, TVA will revise the qualified life of low voltage power cables located outside worst-case accident environment areas to 22 years and will consider existing installations of such cables acceptable as long as the limits specified in Table 1 have not been violated. TVA intends to perform analyses or tests as necessary to verify that the qualified life of the cables in question can be extended to 40 years. If such a demonstration cannot be made, these cables will be retrained or replaced as appropriate prior to exceeding their qualified life.

- In order to account for their particular operating requirements, low voltage power cables located inside worst-case accident environment areas will meet a minimum training radius limit of 4 x OD. This limit is consistent with the ICEA recommendation and ensures that the typical 60 percent pre-accident requirement for end-of-life elongation at rupture is satisfied. For the purpose of its evaluations, TVA has defined as worst-case accident environments those accident environments characterized by ambient temperatures higher than 200°F and/or radiation doses higher than 5.0×10^6 rads.

Low Voltage Multi-Conductor Cables

For safety-related low voltage multi-conductor cables, TVA has specified minimum limits for training radius which are independent of location but vary with the number of conductors in the cables. These limits, which are shown in Table 3, are based on the recommendations of a major cable manufacturer (Ref. 12). The minimum acceptable radius shown in Table 3 is 4 x conductor OD. This limit is consistent with the ICEA recommended radius for the individual conductors of the cables. In addition, the limits of Table 3 take into account the number of conductors in the cables so as to limit the forces applied between conductors at cable bends. These limits have been approved by the NRC for use at WBN (Ref. 8).

TVA's Acceptance Criteria are Conservative

The values of residual elongation at rupture at the end of a 40-year plant life, calculated by TVA for cables bent to radii smaller than ICEA limits, are believed to include substantial margin over typical end-of-life requirements. Several factors contribute to such a margin. For example, the results of standard acceptance tests for BLN cables indicate that, following accelerated aging, the cables retain significantly more elongation at rupture than that required by the ICEA standards. In addition, TVA's engineering specification for cable sizing includes considerable conservatism so that power cables generally will be exposed to operating temperatures substantially lower than the rating of their insulation (Ref. 13).

5.0 RESOLUTION METHOD FOR BELLEFONTE

BLN Inspection Plan

To provide reasonable assurance that existing BLN safety-related cable installations meet the acceptance criteria described above, TVA will perform inspections on various types of cables and cable installations. These inspections will focus particularly on cable bend radius in end devices, e.g. motor terminal boxes, instrument panels, penetrations, etc. The planned inspection program is as follows:

1. Inspect all safety-related medium voltage cables for violations of the limits of Tables 1 and 2. Cables with bends which violate the limits of Table 1 will be replaced, entirely or in parts. Cables with bends which only violate the limits of Table 2 will be retrained.

2. Inspect all safety-related low voltage power cables in worst-case accident environment areas for violations of the limits of Tables 1, 2, and 3. Cables with bends which violate the limits of Table 1 will be replaced, entirely or in parts. Cables with bends which only violate the limits of Table 2 or 3 will be retrained.

3. Inspect a sample of safety-related cable installations located in other harsh environment areas for violations of the limits of Tables 1 and 3. TVA will select a sampling plan which will provide a 95 percent assurance level that at least 95 percent of the cable bends throughout BLN safety-related cable installations located in harsh environment areas meet the limits of Tables 1 and 3.

No inspections will be performed on existing cable installations located in mild environment areas. Systems located in these areas are not exposed to accident environments. Accordingly, the margins included in the insulation specifications are considered sufficient to provide reasonable assurance that possible tight cable bends will have no safety impact.

Justification for Inspection Plan

TVA considers that the resolution method described above will provide reasonable assurance that BLN safety-related systems will not be subject to failures caused by cable bending in existing installations. This resolution method is appropriately focused on the cables which, because of their operating voltage, operating temperature, and possible exposure to worst-case accident environments, could experience degradation of their insulation as a result of tight bends (parts 1 and 2 of the inspection program).

For the balance of the existing BLN safety-related cable population, which consists mostly of low voltage control and signal cables, the probability that a tight cable bend will cause an insulation failure is considered very low. The tests performed by TVA to establish the limits of Table 1 have shown that bends as tight as practical cause little or no observable deformation of the conductor or its insulation. Furthermore, as explained in Section 4.0, the insulation of low voltage control and signal cables will experience little loss of elongation at rupture over a 40-year plant life because of the low operating temperatures of these cables. In addition, the dielectric stresses to which the insulation of these cables is subjected are very low because of low operating voltage. At cable terminations, spatial clearances further reduce the probability of an insulation failure. Based on these considerations, TVA has concluded that the demonstration of a 95/95 assurance level that the limits of Section 4.0 are met, is adequate to resolve the bend radius issue for the balance of existing BLN safety-related cable installations.

Numerous inspections have been performed on BLN cable installations during construction and more recently during the plant reassessment work. A review of inspection reports, including NRC's Construction Appraisal Inspections reports, indicates that no systematic deficiencies have been noted and that, with regard to cable bend radius and other requirements, BLN cable installations are generally consistent with installations at other nuclear plants. Accordingly, the number of violations of the acceptance criteria discussed in Section 4.0 is expected to be low, and the cable bend radius concern is expected to be readily resolved.

6.0 REFERENCES

1. TER-C5506-649; Docket No. 50-390, 50-391; Evaluation of Watts Bar Units 1 and 2 Cable Pulling and Cable Bend Radii Concerns; January 1987

2. TER-C5506-649; Docket No. 50-327, 50-328; Evaluation of Sequoyah Units 1 and 2 Cable Pulling and Cable Bend Radii Concerns; February 1987

3. ICEA Publication No. S-19-81; Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

4. ICEA Publication No. S-66-524; Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

5. ICEA Publication No. S-68-516; Ethylene-Propylene-Rubber- Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

6. TVA Central Laboratories Services Report 90-1014, Rev. 0; Test to Document Cable Bend Radius Damage

7. TVA Calculation WBPEVAR 9004013; Electrical Cable Bend Radius - Lower Bound; June 1990

8. Docket No. 50-390; Safety Evaluation by the Office of Nuclear Reactor Regulation - Corrective Action Program Plan for Cable Issues - TVA - Watts Bar Nuclear Plant, Unit 1.

9. TVA Calculation WBPEVAR 9006007; Determination of Remaining Life of Cable due to Lowered Bend Radius Installations; June 1990

10. Letter from Collyer Insulated Wire to TVA dated September 16, 1986; TVA record B43 860922 001

11. Letter from The Okonite Company to TVA dated August 19, 1986; TVA record B43 860821 003

12. Rockbestos Products; Technical Bulletin No. 28, Revision 5; November 1988

13. TVA Electrical Design Standard DS-E12.6.3; Ampacity Tables for Auxiliary and Control Power Cables (0-15,000V)

TABLE 1

MINIMUM ALLOWABLE RADIUS[1,2,5] FOR TEMPORARY BENDS

CABLE TYPE	RADIUS/COND.OD
Medium Voltage[3]	4
Low Voltage Single- and Multi-Cond.[3,4] Size 8 AWG and Larger	2
Low Voltage Single- and Multi-Cond.[3,4] Size 10 AWG and Smaller	1

NOTES:

1. Radius based on conductor OD. For single-conductor cables, the radius specified refers to the cable OD. For multi-conductor cables, the radius specified refers to the individual conductors OD over insulation (or jacket, if any). In all cases, the radius specified refers to the inner surface of the component and not to its axis.

2. Not applicable to low voltage cables with braided shield. The minimum allowable radius for coaxial and triaxial cables shall be 8 x OD (Ref. 12).

3. At BLN, safety-related medium voltage cables are rated 8 KV and low voltage cables are rated 600 V or 300 V.

4. For most multi-conductor cables, the lower limit specified is lower than the minimum radius achievable using normal cable handling methods.

5. Cable installations located in mild environments will not be inspected for compliance with these limits for the reasons explained in Section 5.0 of the text.

TABLE 2

MINIMUM ALLOWABLE TRAINING RADIUS FOR SINGLE-CONDUCTOR CABLES AND INDIVIDUAL CONDUCTORS OF MULTI-CONDUCTOR CABLES[1,4]

CABLE TYPE	ENVIRONMENT	
	WORST-CASE ACCIDENT[2]	OTHER
Medium Voltage	A	A
Low Voltage Power	B	C
Low Voltage Control and Signal[3]	C	C

A: Training radius not less than 8 x OD

B: Training radius not less than 4 x OD

C: Training radius not less than limits of Table 1

NOTES:

1. Radius based on conductor OD over insulation (or jacket, if any). The radius specified refers to the inner surface of the conductor and not to its axis.
2. Accident environment with ambient temperature higher than 200°F and/or radiation dose higher than 5.0×10^6 rads.
3. Training radius for coaxial and triaxial cables not less than 8 x OD (Ref. 12).
4. Cable installations located in mild environments will not be inspected for compliance with these limits for the reasons explained in section 5.0 of the text.

TABLE 3

MINIMUM ALLOWABLE TRAINING RADIUS FOR MULTI-CONDUCTOR CABLES[1,2]

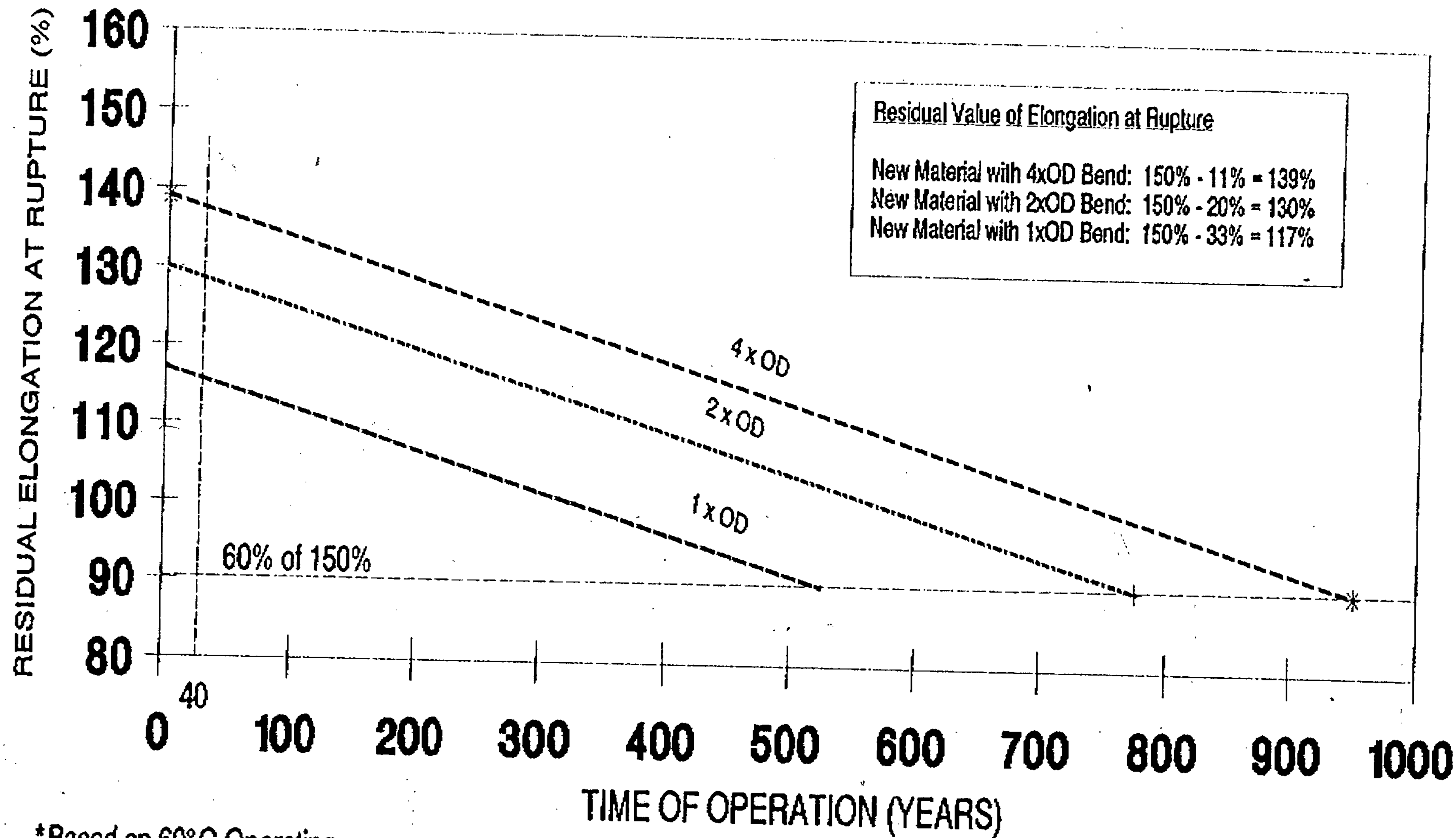
CABLE TYPE	RADIUS/COND.OD
Multi-cond. with 9 and fewer cond.	4
Multi-cond. with 10 to 19 cond.	8
Multi-cond. with more than 19 cond.	12

NOTES:

1. Radius based on individual conductors OD over insulation (or jacket, if any). The radius specified refers to the inner surface of the conductor and not to its axis.

2. Cable installations located in mild environments will not be inspected for compliance with these limits for the reasons explained in section 5.0 of the text.

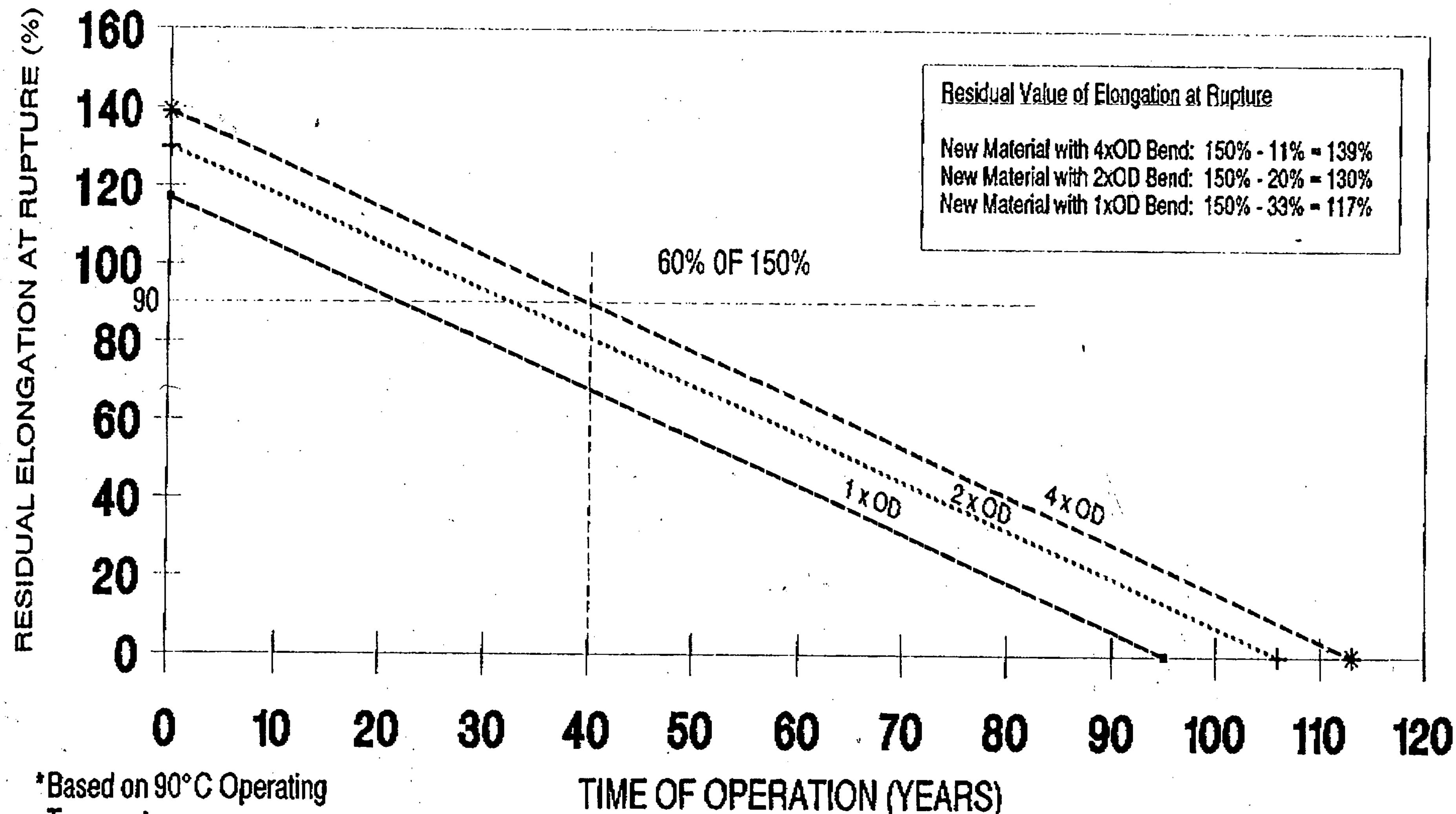
EFFECT OF CABLE BEND ON INSULATION CONDITION AT 40 YEARS
TYPE II EPR INSULATION - CONTROL CABLE*



*Based on 60°C Operating Temperature

Figure 1

EFFECT OF CABLE BEND ON INSULATION CONDITION AT 40 YEARS
TYPE II EPR INSULATION - POWER CABLE*



*Based on 90°C Operating Temperature.

Figure 2