JNES-SS-0619

JNES SS Report

The Interim Report of
The project of “Assessment of Cable Aging for Nuclear Power Plants”

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Incorporated Administrative Agency
Japan Nuclear Energy Safety Organization
Safety Standard Division

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The Interim Report of
The project of “Assessment of Cable Aging for Nuclear Power Plants”

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Summary

Electrical cables are installed approximately 1,000 to 2,000 km for each nuclear power plants. They transmit instrument and control signals, supply power to electric components such as motors. Some cables for safety-related systems must keep functioning up until the last stage of an in-service period during a design basis event environment. With these cables, it is known that there is a gradual effect of progressive aging by oxidation or other causes in thermal and radiation environments during normal operation and a rapid degradation of performance due to the severe environment by high temperature steam and high radiation dose during the design basis event.

For this reason, cables to be used for nuclear power plants are examined, either before being used for service, or while under usage, and their long term integrity is confirmed by tests based on the IEEJ Technical Report (Division II), No.139, “Recommended Practice for Methods of Environmental Test and Flame Resistance Test for Electrical Wires and Cables for Nuclear Power Plants” (referred to as “Recommended Practice of IEEJ” hereinafter)

However, the accelerated aging technique of the Recommended Practice of IEEJ, which assumes thermal and radiation aging during normal operation, is said to have a possibility to be inadequate to simulate the actual phenomenon, according to the most recent knowledge.

Furthermore, the environmental conditions of normal operation and the present method of the withstand voltage test to judge cable integrity are considered to be too conservative for the actual operating conditions. In particular, the withstand voltage test values for low voltage cables are in actuality higher than the values designated by the JIS Code.

In view of these facts, the project of “Assessment of Cable Aging for Nuclear Power Plants” (referred to as the “ACA project” hereinafter) has been initiated from FY2002(1), with the following objectives:

- to obtain thermal aging data and simultaneous thermal and radiation aging (referred to as “simultaneous aging” hereinafter) data of safety-related cables,
- to conduct comprehensive evaluations of aging characteristics of the cables while taking into consideration the most recent knowledge,

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(1) The Japanese FY starts in April and ends in March. Namely, FY2002 starts April 2002 and ends March 2003.

- to establish cable aging evaluation methods corresponding to the actual operating conditions including the actual aging for cables of nuclear power plants, based on the study of suitable accelerated aging technique, appropriately assumed environmental conditions and integrity judgment methods,
- to contribute to the development of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants”.

This document has been compiled from the results of the technical evaluation study as an interim report.

The essential part of the ACA project is the cable aging evaluation test to obtain thermal and simultaneous aging data for the cables. However, prior to the cable aging evaluation test, the preliminary test was conducted to determine the test conditions. The preliminary test included seven test items; namely, the preliminary thermal aging test as well as the comparative test of aging sequence and others. Based on the results of the preliminary test, the cable aging evaluation test conditions have been developed.

For the cable aging evaluation test, cross-linked polyethylene, flame-retardant cross-linked polyethylene, ethylene propylene rubber, flame-retardant ethylene propylene rubber, silicone rubber and special heat-resistant polyvinyl chloride were selected from the safety-related cables used in the nuclear power plants. Furthermore, an additional 2 to 3 kinds of cables with insulators of different manufacturers were accepted making a total of 14 kinds of cable specimens for the test.

In the cable aging evaluation test, aging periods were selected as parameters for aging specimens. For thermal aging specimens, three temperature conditions were selected whereas for simultaneous aging specimens, a combination of combined nine conditions of three temperatures had been fabricated with three dose rates. The tensile tests for these aging specimens have been conducted to obtain the thermal and the simultaneous aging data.

In addition, the LOCA test for nine kinds of cables was also conducted using the simultaneous aging specimens.

Furthermore, the investigation of applicability of non-destructive degradation diagnostic technologies for aged cables was conducted to confirm the validity of cable aging evaluation at actual operating plants. In this investigation, non-destructive degradation diagnostic data has been obtained from simultaneous aging specimens made of cross-linked polyethylene, flame-retardant cross-linked polyethylene, ethylene propylene rubber and flame-retardant ethylene propylene rubber insulating materials using four kinds of non-destructive degradation diagnostic technologies. Based on the correlations between the data obtained from these technologies and the data of elongation at break of tensile tests, applicability of the non-destructive degradation diagnostic technique to actual operating plants was investigated.

At the current stage, thermal and simultaneous aging data up to approximately 21,000 hours of aging time was obtained.

The summary of the interim assessment based on the data and investigations is described as follows:

a. Progress of degradation may be significantly different among various manufacturers, even for the same kind of insulator.

b. There were some cables indicating significantly rapid progress of degradation at low dose during simultaneous aging, and many other cables indicating relatively rapid progress of degradation during simultaneous aging.

c. Activation energy values calculated from the thermal aging test data are smaller than those currently used. Furthermore, as a result of collation of sampling cables for actual operating plants with the results of the thermal aging tests, it is possible to suppose that the activation energy in the temperature region of actual operating plants would become even smaller. Based on these results, the principles of calculation and application were developed for the activation energy to be used for evaluation.

d. The technique of “superposition of time dependent data” is applicable to establish accelerated aging conditions of the cables corresponding to various actual operating plant conditions and to predict degradation of the cables used in actual operating plants.

e. Based on the results of investigation and tests, the outlines of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)” were developed.

f. A tentative assessment for seven kinds of cables used for the safety-related systems was made using data acquired at present based on “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)”. According to this result, there were some cables that would have difficulty to maintain safely functions during and following the design basis event depending on the specific normal operating environment.

g. As a result of the investigation of the applicability of non-destructive degradation diagnostic technique to actual operating plants, it was evaluated that the indenter was applicable to insulators of the cross-linked polyethylene family and the ethylene propylene rubber family except insulators made by certain manufacturers.

ACA project is scheduled to continue the following activities up to FY2008:

- to conduct cable aging evaluation tests,
- to obtain thermal and simultaneous aging data,
- to revise the interim evaluation based on the results of the tests, and
- to establish the cable aging evaluation methods based on the actual operating conditions including the actual aging for cables in nuclear power plants.

Contents

Abbreviations

ACA	Assessment of Cable Aging for Nuclear Power Plant
ASTM	American Society for Testing and Materials
BWR	Boiling Water Reactor
CR	Polychloroprene
CSPE	Chlorosulfonated polyethylene
DBE	Design basis event
EPR	Ethylene-propylene rubber
FR	Flame-retardant
HPVC	Heat-resistant polyvinyl chloride
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IEEJ	Institute of Electrical Engineering of Japan
JAERI	Japan Atomic Energy Research Institute (currently JAEA: Japan Atomic Energy Agency)
JIS	Japanese Industrial Standards
LOCA	Loss of Coolant Accident
MIL	Military Specifications and Standards
PE	Polyethylene
PLM	Plant Life Management
PVC	Polyvinyl chloride
PWR	Pressurized Water Reactor
SIR	Silicone rubber
SHPVC	Special heat-resistant polyvinyl chloride
XLPE	Cross-linked polyethylene
XMA	X-ray micro analyzer

I. Introduction

1. Foreword

In Japan, there are 55 units of commercial nuclear power plants, including both pressurized and boiling water reactors. Together, these units supply approximately one third of national electric power generation. Nuclear power is considered to continue to play an important role as a key source of the national energy in the future.

On the other hand, along with an increase in the service period, aging of nuclear power plants has become more apparent. The number of 12 units had exceeded their 30 years in service periods as of the end of 2006. Therefore, the aging management will be a significant issue to ensure the continued safety and reliability of nuclear power plants.

In April, 1998, PLM Technical Study Committee (The first term), chaired by Dr. Yasumasa Tokou, Professor Emeritus of Tokyo University was organized. This committee was succeeded by the committee of the same name (The second term), chaired by Professor Yasuhide Asada of Tokyo University from October of the same year. A discussion/review related to issues of aging of nuclear power plants was conducted. An aging measure-related technical development program compiled by these committees has been assessed by the Nuclear Technology Assessment Committee of MITI (currently METI), chaired by Dr. Hideo Ohashi, President of Kougakuin University in FY1999. As a result of the review made by the third party, who included academic experts of knowledge and experience, a response from the Committee was submitted. They recommended that the following three topics are technical development items which must be implemented by the government as soon as possible: (a) development of assessment technology for irradiation-assisted stress corrosion cracking, (b) development of assessment technology for progression of Ni-base alloy stress corrosion cracking, (c) development of assessment technology for the aging of cables for nuclear power plants.

Based on the results, the Cable Aging Assessment Technical Task Group, chaired by Professor Yoshimichi Ohki of Waseda University, was organized in FY2001 to identify the issues related to the cable aging evaluation technique based on the results of technical investigations in these fields.

Through such circumstances, the project of “Assessment of Cable Aging for Nuclear Power Plants” (ACA project) was started in FY2002. The objectives of ACA project are;

- to establish a cable aging evaluation method based on the actual operating conditions including the actual aging for cables of nuclear power plants, and
- to contribute to the development of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plant”.

To achieve the above objectives, this project plans to have the following contents:

- obtaining data for thermal aging and simultaneous aging specimens used for safety-related systems of nuclear power plants, and
- conducting a comprehensive assessment of cable aging characteristics with the acquired data while adding the recently obtained knowledge.

This interim report describes the results and the contents conducted up to the first half of FY2006.

2. Background

2.1 Necessities and their backgrounds

Cables with a total length of approximately 1,000 to 2,000 km are used in a typical nuclear power plant. These cables have functions to supply electric power to electric components such as motors and to transmit instrument and control signals working as a nerve system, if compared to the human body. (A conceptual layout of the cable in the nuclear power plant is shown in Figure 2.1.1) It is known that aging of cables progresses slowly by the oxidation and other causes in thermal and radiation environments during normal operation, and that their performance degradation would progress rapidly due to a severe environment with high temperature steam and high dose radiation during the DBE (Ref. 1).

For this reason, the long-term integrity of cables used in nuclear power plants is confirmed by taking out the cables either before in-service or during in-service and by testing them based on the Recommended Practice of IEEJ (Ref. 1), which was basically based on IEEE Std.323 $_{-1974}$ and 383$_{-1974}$.

However, accelerated aging method in the Recommended Practice of IEEJ which assumed aging due to thermal and radiation environment during normal operation may not necessarily simulate actual operating plants correctly, according to the latest knowledge. The method of the withstand voltage test to determine the integrity of cables and the assumed thermal and radiation environmental conditions, are considered too conservative for the actual service conditions. In particular, for the withstand voltage test values for low voltage cables, higher values are set compared to JIS Code values. (Ref. 2)

Also, in overseas countries, there are some examples where cable functions could not be maintained in the long-term integrity assessment test of cables which included the DBE environment by approximately the same assessment method. Future responses such as enhancement of the design method are being researched (Refs. 3, 4).

For this reason, it would be required to make assumed environmental conditions and integrity determination methods appropriate, and to establish the cable aging evaluation methods corresponding to the actual operating conditions including the actual aging for cables of nuclear power plants. In addition it is necessary to understand cable aging characteristics of actual operating plants with the most recent knowledge.

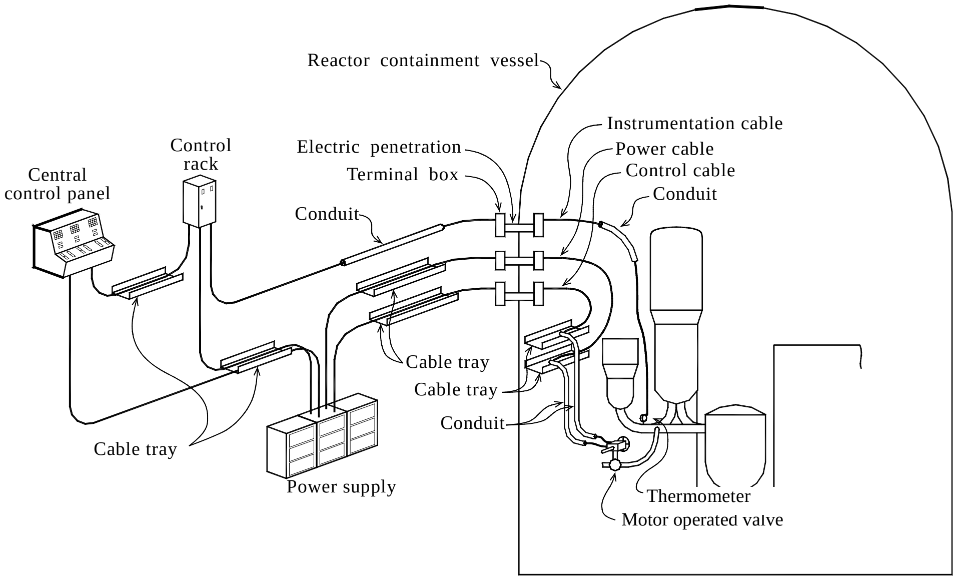

Fig. 2.1.1 Schematic Diagram of Major Cable Layout at a Nuclear Power Plant (An example of PWR Nuclear Power Plants)

2.2 Objectives

Cables being used in nuclear power plants are roughly classified to medium voltage, low voltage, and coaxial cables, although more than 90% are low voltage cables. Typical construction of the cable consists of a conductor, insulator, filler, tape and jacket. Among these, the insulator that maintains the insulating function of the cable is made of polymer material such as XLPE, EPR, and SIR. The filler and tape are used for fitting them into the cable, and the jacket is for the protection of the insulator from external force that might be applied during cable installation.

This project is first to select various types of cables equivalent to the safety-related system cables used in nuclear power plants as specimens, and then to obtain both thermal and simultaneous aging data for each insulator. This would allow a comprehensive assessment of the aging characteristics by incorporating the latest acquired knowledge. The objective of this project would be achieved by establishing the cable aging evaluation methods which form indicators for the cable aging management from the points of view of maintaining reliability and safety assurance of nuclear power plants. It would be aimed at contributing to early establishment of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants”.

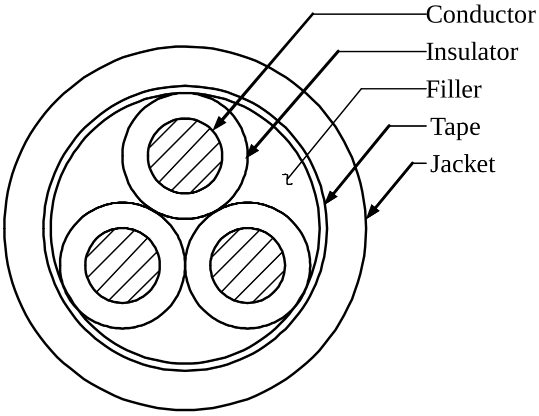

Fig. 2.2.1 Typical Cable Construction

3. Overall implementing program

3.1 Overall program

The schedule of this project is carried out FY2002 to FY2008. This project obtains thermal aging data, as well as simultaneous aging data of various cable insulators. This data is the basis of the aging assessment of the cables, and establishes an aging assessment method that will also form indicators for the cable aging management.

In this project, fabrication is done for the thermal and simultaneous aging test specimens that have specific aging periods as their parameters followed by tensile tests and the LOCA test consisting of radiation and steam exposure tests equivalent to the DBE. As an aging indicator, elongation at break was adopted(1).

The overall program schedule of this project is shown in Table 3.1-1.

As shown in the Table 3.1-1, the span of seven years is divided into two parts: The first 4-year term and the next 3-year term.

In the first term, the cable aging evaluation test is conducted to acquire data, and the tentative aging evaluation for several cables is executed.

In the second term, the cable aging evaluation method is developed based on the expanded data from continuous tests, and the aging evaluation for the all cables is implemented. In addition, the draft of guidelines for the environmental qualification test for cables is proposed.

The overall schedule includes a re-evaluation of the issues based on the results of the first term and the latest acquired knowledge, as an interim assessment at the end of the 4th year. There is the possibility to re-examine the implementation plan, later as needed.

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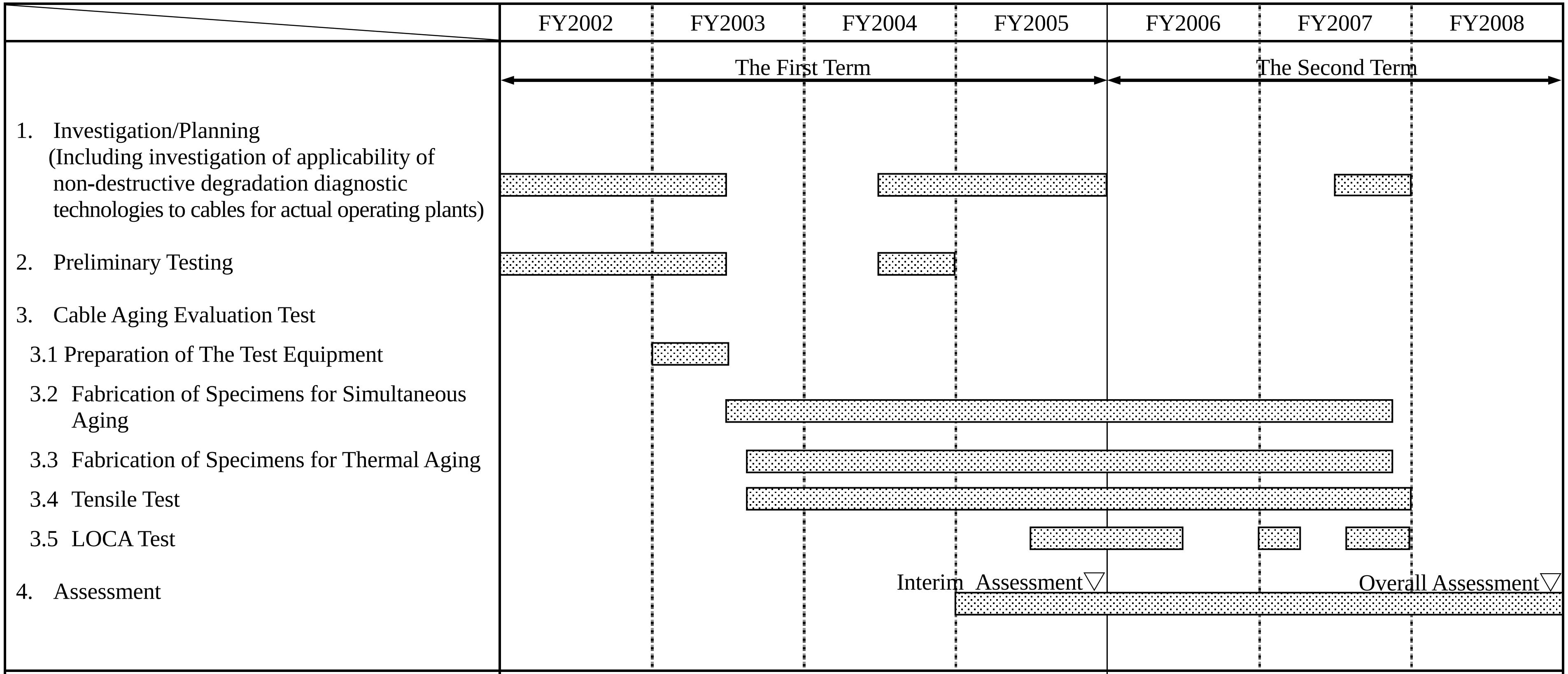
(1) For maintaining signal transmitting functions to be required for cables, it is necessary to maintain the insulating function of insulators, which can be confirmed by insulation resistance or breakdown voltage. However, insulation resistance or breakdown voltage is difficult parameters to utilize as aging indicators. For this reason, at the Cable Aging Assessment Technical Task Group in FY2001 (Ref. 2), it was decided to be appropriate to take “Elongation at break” as the aging indicator. The tensile test is to be executed to obtain the elongation at break of the aging specimens.

Table 3.1-1 Overall schedule for the project of assessment of cable aging of nuclear power plants (ACA)



<Goal for Achievement>	・Development of detailed planning, and start of the test ・Aging assessment of the cables (tentative) (Cables insulated by XLPE, FR-XLPE, EPR and FR-EPR)	・Aging assessment for the cables (Cables insulated by XLPE, FR-XLPE, EPR, FR-EPR, SIR and SHPVC) ・Development of methods for aging assessment for the cables ・Proposal of the guideline for the environmental qualification test for cables (Draft)

3.2 Investigation and planning

(1) Investigation

Regarding the aging assessment technology of cables, the latest technical trend is to be investigated and the result of the investigation is to be fed back into the planning and implementation of the test program.

Also, applicability to actual operating plants of non-destructive degradation diagnostic technologies for cables which have been proposed by cable manufacturers and others is to be investigated to verify validity of the assessment of cable aging in those plants.

(2) Planning

Planning was made based on the results of the Cable Aging Assessment Technical Task Group in FY2001 (referred to as Task Group in FY2001 hereinafter). Comments proposed in discussions for implementation were added to make detailed test plans for each necessary test.

However, topics clarified during the ACA study, will be reviewed as appropriate, including feasibility of the tests necessary to solve the problems and additions or modifications of the test plan that may be considered to be necessary.

3.3 Preliminary test

The cable aging evaluation test to be conducted in this project has a specific problem. As the aging specimens for this test need a long period of time for fabrication, a change of fabrication conditions in the midway of this period would go on a fool’s errand. Also, fabrication of aging specimens and LOCA test use a method that is partly different from the method from the Recommended Practice of IEEJ in order to execute the test in a reasonable manner. Furthermore, the aging specimen is planned to be fabricated in a way that limits the aging factors to only the insulation resistance degradation by thermal and irradiation effects.

Based on these facts, pre-confirmed items are selected and a preliminary test was to be executed to confirm them.

Pre-confirmed items were examined on basis of the results of study by the Task Group in FY2001 (Ref. 2). Further the preliminary test was performed to clarify test conditions for the cable aging evaluation test and their bases.

3.4 Cable aging evaluation test

In the cable aging evaluation test, the following activities were planned:

- fabrication of the thermal aging specimens as a function of aging period. Their objectives are to obtain the activation energy as well as to assess thermal aging characteristics,
- fabrication of the simultaneous aging specimens as a function of aging period. Their objectives are to assess the progress of cable aging in actual operating plants as well as to assess simultaneous aging characteristics,
- aging data acquisition from thermal aging specimens and simultaneous aging specimens by tensile tests, and
- LOCA tests using simultaneous aging specimens. Their objectives are to obtain the assessment for aging cables as well as to confirm the LOCA test method.

The maximum fabrication periods for the thermal aging and the simultaneous aging specimens will tentatively aim for 4 years, due to their fabricating conditions of low temperature (approximately 80 to 100°C minimum) and low dose rate (approximately 3 Gy/h minimum).

3.5 Assessment

This project is to contribute to the development of the “Guideline for the environmental qualification test for cables (Draft)” by establishing the cables integrity assessment methods that correspond directly to the actual operating conditions, based on the data obtained by the tests and technical trend investigation of domestic and overseas examples.

The cables for nuclear power plants are installed in various environments from those assumed to be the severest conditions to those having relatively mild conditions. Among them, the cables used in the severest environment are of a rather very small portion, while the majority of the cables are used in a relatively mild environment. Therefore, although the cable aging assessment in the severest cable-installed environment may be important, it would be necessary, according to plant aging, to develop the assessment methods which enable them to be assessed in various cable-installed environments including such a severe environment.

The image example of the achievement to be expected and to be obtained by the results of this project is shown in Figure 3.5-1.

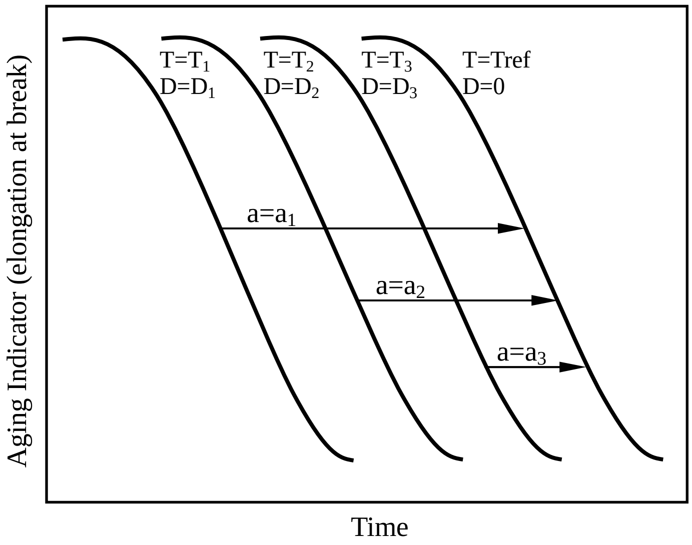


Fig. 3.5-1: Image of Accomplishments that can be Expected with the Cable Aging Assessment (Example)

T: Temperature for fabricating aging specimen
D: Dose rate for fabricating aging specimen
a; Shift factor

Fig. 3.5-1 shows that in cases where the depredated data obtained from the specimen to be aged by various temperatures and dose rates are able to superpose on the basic aging curve (master curve) by a shift factor (accelerated factor), as a function of temperature and dose rate, cable aging assessment in the environment of actual operating plants becomes possible (Refs. 5, 6). This also shows that the accelerated aging conditions corresponding to the installed environment and the in-service period of the cable are able to be set.

II. Preliminary Test

1. Test Planning

1.1 Test Objective

The cable aging evaluation test to be conducted in this project requires a long period of time to fabricate aging specimens for obtaining test data. This means that a change of design/fabrication conditions in the midway of this period would be a fool’s errand.

Also, aging test specimens will cover only the aging factors in thermal and irradiation effects. Furthermore, specimens that will be used at the LOCA test are in part different from the Recommended Practice of IEEJ so as to execute the test reasonably.

Based on these facts, basic aging features such as geometry of the test specimens and aging factors were to be clarified by the preliminary test antecedent to the cable aging evaluation test.

1.2 Test item and others

Test items to be implemented in the preliminary test, specimens and test conditions are shown in Table 1.2-1.

Specimens for the preliminary thermal aging tests envelop those cables to be used for safety-related systems of nuclear power plants. The specimens to be used in the other tests were selected in the following manner.

The representative cables were selected from the group having the highest ranking among the cables which were ranked by importance (whether any action was required or not in the environment during DBE), installed environment, degree of difficulty/ease of maintenance and progressing speed of aging based on the available knowledge. In particular, specimens for the length confirmation test and the size comparative test were represented by the FR-EPR insulated cables which have the highest rank. Also, the specimens for the installing procedures comparative test were represented by EPR and FR-EPR insulated cables. These have the highest possibility to receive effects by the installing procedures during the test.

The heating temperatures in the preliminary thermal aging tests are selected at 3 points in total, in 10ºC steps from the maximum continuous allowable operating temperature of the specimen insulator, +20ºC. Concerning the SIR, however, the aging is recognized to start from a relatively low temperature although its maximum continuous allowable operating temperature is high (Ref. 7, 8). Therefore, the heating temperatures are selected with 20ºC steps from the highest continuous allowable operating temperature of the specimen insulator, +10ºC. For PE insulator, the maximum temperature is set as 100ºC by considering its melting point.

The heating temperature for the comparative tests of aging sequence is determined to be the lowest temperature of the preliminary thermal aging tests. The dose rate for the tests is determined by referring to the former JAERI data (Ref. 9) and by the condition that the elongation at break of the specimen is expected to be less than half of its initial value during fabrication.

The heating temperatures for the mechanical stress-loading tests, the comparative tests of the tubular type and cable type specimens and the comparative tests of thickness of the specimen are determined to be less than the lowest temperature of the preliminary thermal aging tests. The dose rates are also based on the former JAERI data, and provided that the elongations at break of the specimens are less than half of their initial values. (This is also applicable for the temperature mentioned above.) These conditions for temperature and dose rate are also applied to all specimens so as to be able to envelop them.

The heating temperature for the comparative tests of installation procedure to oven specimens is determined to be the highest temperature in the preliminary thermal aging tests.

Table 1.2-1 Implemented items, cable specimens and test conditions of the preliminary test

Classified items	Items in the preliminary test	Requirements	Specimens	Test Conditions
1. Thermal aging conditions	1.1 Preliminary thermal aging tests	Fabrication of thermal aging specimens is required to be done in temperature regions where degradation by oxidization progresses from the surface to the inside of insulator and the temperature regions should be confirmed for each insulator material.	SIR insulated cable	Thermal aging: 135ºC, 155ºC, 175ºC
			XLPE and FR-XLPE insulated cables	Thermal aging: 110ºC, 120ºC, 130ºC
			EPR, FR-EPR and SHPVC insulated cables	Thermal aging: 100ºC, 110ºC, 120ºC
			PVC and PE insulated cables	Thermal aging: 80ºC, 90ºC, 100ºC
2. Accelerated aging sequence	2.1 Comparative tests of aging sequence	Although the Recommended Practice of IEEJ described “sequential aging from thermal to radiation”, the technical trend investigation in its FY2001 Study Task revealed that “sequential aging from radiation to thermal” produced more severe results and “simultaneous aging” than the intermediate results. Therefore, the simultaneous aging was planned in the cable aging evaluation test. It is required to confirm the effect on the accelerated aging test sequence before the cable aging evaluation test.	SIR insulated cable	Thermal: 135ºC Radiation: 50Gy/h
			XLPE insulated cables	Thermal: 110ºC Radiation: 100Gy/h
			FR-EPR insulated cables	Thermal: 100ºC Radiation: 100Gy/h
3. Aging factor (Aging stress)	3.1 Mechanical stress-loading tests	The cable aging evaluation test program is considering only the degradation in insulation due to thermal and radiation effect as an aging phenomenon for low voltage cables. By reviewing the cable layout, however, it is also required to examine effects of stress on cable aging under thermal and radiation environment.	SIR insulated cable	Simultaneous aging: 100ºC, -100Gy/h Radiation dose in room temperature: 100Gy/h
			XLPE insulated cables	
			FR-EPR insulated cables	
			SHPVC insulated cables	
4. Shape of specimen	4.1 Comparative tests of tubular type and cable type specimen	It is planned to measure the elongation at break of the insulator aging specimen as the indicator of cable aging. However, it is supposed difficult in case of aging specimens of cable to pull out the conductor from the core of insulator because of sticking between conductor and insulator. For this reason it is planned to prepare specimens of insulator only (tubular specimens) by pulling out conductors before fabrication of aging specimens. In this case, however, it should be confirmed that there is no difference in the aging progress between specimens of cable and tubular specimens.	SIR insulated cable	Simultaneous aging: 100ºC, -100Gy/h
			XLPE insulated cables	
			FR-EPR insulated cables	
	4.2 Comparative tests of length of specimen for LOCA test	Although the Recommended Practice of IEEJ recommends to use specimens of more than 3 m long for the LOCA test, it is considered reasonable from the viewpoint of test facility to make the specimen length shorter in order to prepare a uniformly aging specimen (for radiation aging) over the total length. Therefore, it is planned to use specimens about 60 cm long in the evaluation test of cable aging. It should be confirmed that the evaluation is possible by use of the specimens with such length.	FR-EPR insulated, FR-CR jacketed cable	Simultaneous aging: 100ºC, -100Gy/h LOCA test: BWR condition
			FR-EPR insulated, FR-CSPE jacketed cable	Simultaneous aging: 100ºC, -100Gy/h LOCA test: BWR condition
	4.3 Comparative tests of thickness of specimen	It is reasonable from the viewpoint of test facility that specimen should have the insulator thickness of 0.8 mm for the thinnest case. Therefore, it should be confirmed that the cables with a thin insulator envelop thicker insulator cables in terms of aging.	FR-EPR insulated cables (Thickness of insulator: 0.8 mm, 1.0 mm, 1.5 mm, 2.0 mm)	Simultaneous aging: 100ºC, -100Gy/h
5. Specimen installing procedure	5.1 Comparative tests of installation procedure to oven specimens	There are many specimens for the group of cables insulated by XLPE, FR-XLPE and PE and for the group of cables insulated by EPR and FR-EPR. In setting specimens in the oven, it is needed from the physical restriction that new specimen is required to be set during the fabrication of aging specimens, which might influence the aging. Therefore, the degree of such influence should be confirmed.	EPR insulated cables	Thermal aging: 120ºC
			FR-EPR insulated cables	

The geometries of specimens for the mechanical stress-loading tests are determined by referring to the portions of the cables on which the stress is supposedly imposed in a representative cable layout of actual operating plants shown in Fig. 1.2-1.

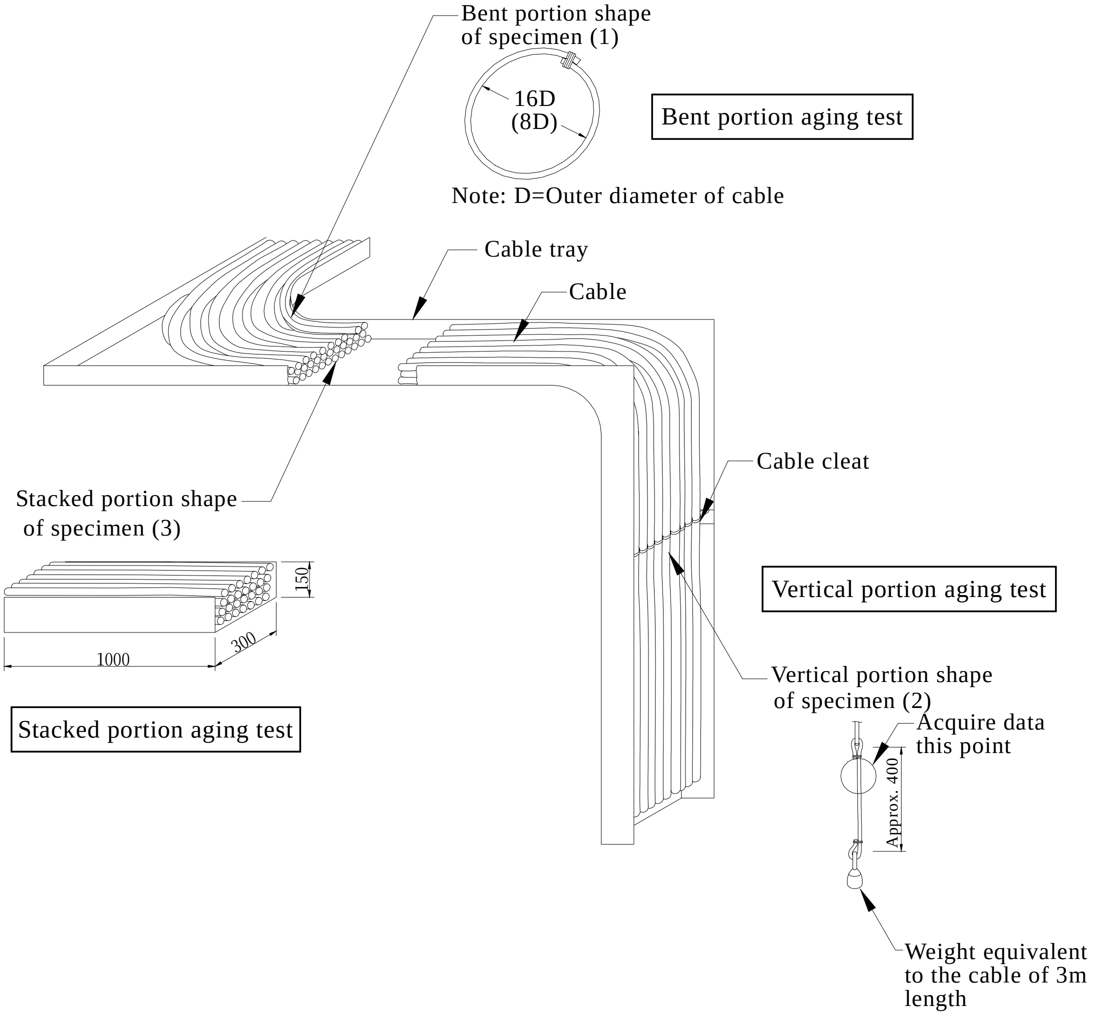


Figure 1.2-1 Representative cable layout in actual operating plants and specimen geometry used in tests (Unit: mm)

1.3 The manner to proceed with the test

There is a total of seven items in the preliminary tests as shown in table 1.3 -1. The contents of the tests are roughly classified into preparation of tubular specimens, fabrication of thermal aging specimens, fabrication of simultaneous aging specimens including radiation aging specimens at room temperature, tensile tests, profiling analyses and LOCA tests.

Therefore, it is considered reasonable to carry out the preliminary test for each of the contents to be included for the same step of execution as shown in Table 1.3-1 rather than to execute these items individually.

Table 1.3-1 Classification of the preliminary test contents

Con tents Test items	Preparation of tubular specimens	Fabrication of thermal aging specimens	Fabrication of simultaneous aging specimens[*1]	Tensile tests	Profiling analyses	LOCA tests
1. Preliminary thermal aging tests	○	○		○(Reference)	○	
2. Comparative tests of aging sequence	○	○	○	○	○(Reference)	
3. Mechanical stress-loading tests			○	○		
4. Comparative tests of tubular type and cable type specimen	○	(○[*2])	○	○(Reference)	○	
5. Comparative tests of length of specimen for LOCA test			○	○(Reference)	○	○
6. Comparative tests of thickness of specimen	○[*3]		○	○		
7. Comparative tests of installation procedure to oven specimens	○	○		○		
Remarks	To work tabular specimens of cable insulator prescribed in the JIS C 3005, Section 4.16	To set specimens in the oven and heat them at fixed temperatures.	To set specimens in the oven placed in irradiation facility and to fabricate them at fixed temperatures and dose rates.	To make aging specimens as the test pieces and execute the tensile test prescribed in the JIS C 3005, Section 4.16.	To examine and analyze aging degrees of specimens from their surface to the inside by using X-ray micro-analyzer and others.	To execute equivalent irradiation during DBE, and execute steam atmospheric exposure. Then, to execute the bend submerged withstand voltage test.

*1: Including fabrication of radiation aging specimens.

*2: Being executed in the preliminary thermal aging tests.

*3: Preparation of tubular specimens which have conductors with the conductor size of 5.5 mm^2

2. Test

2.1 Preparation of specimens

(1) Specimens

On the basis of the test planning, the cables listed in Table 2.1-1 are used as the specimens for the preliminary test.

Table 2.1-1 Specimens for the preliminary test

No.	Insulation material	Jacket material	Conductor size	No. of core	Insulation thickness	Cable code
1	SIR	SIR	1.25mm^2	4	0.76mm	KK-1.25
			60mm^2	1	1.8mm	KK-60
2	XLPE	PVC	2.0mm^2	3	0.8mm	CV-2.0
			60mm^2	1	1.5mm	CV-60
3	FR-XLPE	FR-PVC	2.0 mm^2	3	0.8 mm	FR-CV-2.0
4	EPR	Braided with glass fiber	2.0 mm^2	3	0.8 mm	PG-2.0
5	FR-EPR	FR-CSPE	2.0 mm^2	3	0.8 mm	FR-PH-2.0
			5.5 mm^2	3	1.0 mm	FR-PH-5.5
			60 mm^2	1	1.5 mm	FR-PH-60
			100 mm^2	1	2.0 mm	FR-PH-100
6	FR-EPR	FR-CR	2.0 mm^2	3	0.8 mm	FR-PN-2.0
7	SHPVC	SHPVC	2.0 mm^2	3	0.8 mm	SHVV-2.0
			60 mm^2	1	1.5 mm	SHVV-60
8	PVC	PVC	2.0 mm^2	3	0.8 mm	VV-2.0
9	PE	PVC	2.0 mm^2	3	0.8 mm	EV-2.0

(2) Preparation of specimens

Cables were processed by the steps shown as follows.

a. After disassembling each cable specimen, tubular insulator pieces about 15 cm long were made by pulling out the conductor from the insulated core (in total 9 pieces in case of triple-core cable), by connecting three of them in every core color by using glass fiber and by bundling the connected pieces. A total of 121 tubular specimen assemblies designated as Type A specimen, were prepared. (Figure 2.1-1 shows the geometry of the specimen and Table 2.1-2 lists the specimens.)

b. After cutting each specimen into the prescribed length, 86 assemblies, 35 assemblies and 4 assemblies respectively of Types B1, B2 and B3 specimens, which are specimens of cable finished-products, were prepared. (Figures 2.1-2 through 4 show the geometry of the specimens and Table 2.1-2 lists these specimens.) In addition, required numbers of Type B4 specimens of cable finished-products will be prepared in order to include them in the specimen, designated by Type E, for aging tests described later. (The geometry of the specimen is shown in Figure 2.1-5.)

c. After cutting each specimen in the prescribed length, 12 assemblies for each of Types C, D1 and D2 specimens and 4 assemblies for Type E specimen were prepared. Here, Type C is the specimen for the vertical portion aging tests used in the mechanical stress-loading tests, Types D1 and D2 are the specimens for the bent portion aging test and Type E is the specimen in stacked portion aging test. (The geometry of the specimens is shown in Figure 2.1-6 through 9 and Table 2.1-2 lists the specimens.)

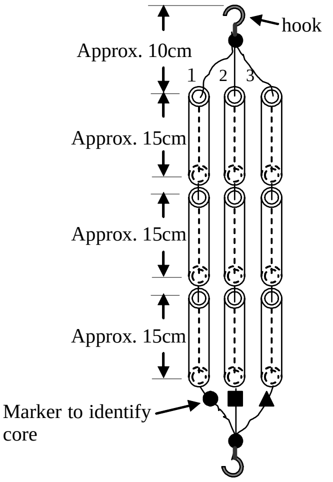


Figure 2.1-1 Type A specimen

(A-A-00, A-A-01~09, A-A-11~15, A-A-31~33 are composed of 4 core conductors.)

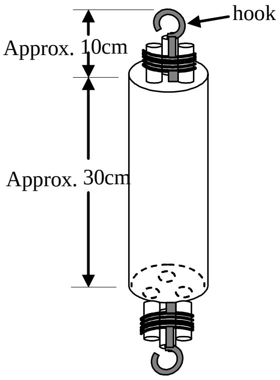


Figure 2.1-2 Type B1 specimen

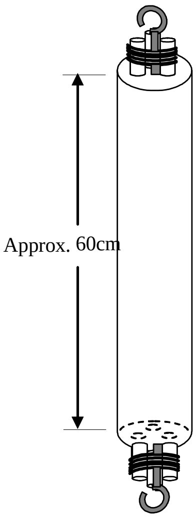


Figure 2.1-3 Type B2 specimen

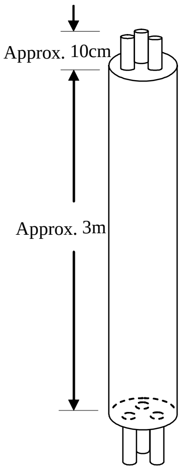


Figure 2.1-4 Type B3 specimen

(Type B3 specimen is bundled in a ring-shape with about 40 cm diameter)

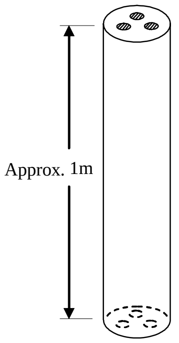
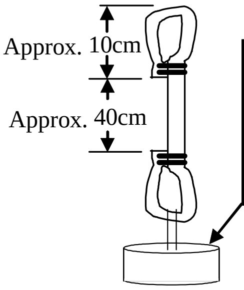


Figure 2.1-5 Type B4 specimen



Type of specimen	Balance weight
KK-60	2.3kg
CV-60	2.0kg
FR-PH-60	2.3kg
SHVV-60	2.3kg

Note: Balance weight is equivalent to 3m long cable.

Figure 2.1-6 Type C specimen

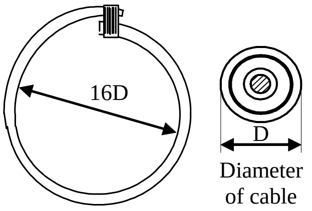


Figure 2.1-7 Type D1 specimen

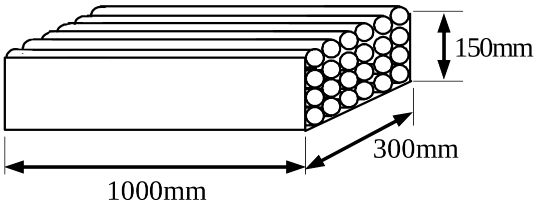


Figure 2.1-9 Type E specimen

(About 100 Type B4 specimens are laid in a cable tray.)

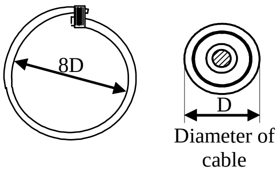


Figure 2.1-8 Type D2 specimen

Table 2.1-2 List of specimens in the preliminary tests

Kind of specimen	Specimen type	Test items								Total number of specimens
		For confirming initial value	Preliminary thermal aging tests (Thermal aging)	Comparative tests of aging sequence (Thermal aging/ simultaneous aging)	Mechanical stress-loading tests (Simultaneous aging)	Comparative tests of tubular type and cable type specimen (Simultaneous aging)	Comparative tests of length of specimen for LOCA test (Simultaneous aging)	Comparative tests of thickness of specimen (Simultaneous aging)	Comparative tests of installation procedure to oven specimens (Thermal aging)	
KK-1.25	Type A	A-A-00	A-A-01 to 09	A-A-11 to 15 11: Thermal aging only 12: From thermal aging to irradiation 13: Irradiation only 14:: From irradiation to thermal aging 15: Simultaneous aging		A-A-31 to 33				18
	Type B1		A-B1-01 to 09			A-B1-31 to 33				12
KK-60	Type B1	A-B1-00								1
	Type B2				A-B2-21 to 26					6
	Type C				A-C-21 to 23					3
	Type D1				A-D1-21 to 23					3
	Type D2				A-D2-21~23					3
	Type E (Type B4)				A-E-21 (A-E-21-01 to 06)					1 (6)
CV-2.0	Type A	B-A-00	B-A-01 to 09	A-A-11 to 15 11: Thermal aging only 12: From thermal aging to irradiation 13: Irradiation only 14: From irradiation to thermal aging 15: Simultaneous aging		B-A-31 to 33				18
	Type B1		B-B1-01 to 09			B-B1-31 to 33				12
CV-60	Type B1	B-B1-00								1
	Type B2				B-B2-21 to 23 B-B2-24 to 26					6
	Type C				B-C-21 to 23					3
	Type D1				B-D1-21 to 23					3
	Type D2				B-D2-21 to 23					3
	Type E (Type B4)				B-E-21 (B-E-21-01 to 06)					1 (6)
FR-CV-2.0	Type A	C-A-00	C-A-01 to 09							10
	Type B1		C-B1-01 to 09							9
PG-2.0	Type A	D-A-00	D-A-01 to 09						D-A-61 to 64	14
	Type B1		D-B1-01 to 09							9
FR-PH-2.0	Type A	E-A-00-2.0	E-A-01 to 09	A-A-11to 15 11: Thermal aging only 12: From thermal aging to irradiation 13: Irradiation only 14: From irradiation to thermal aging 15: Simultaneous aging		E-A-31 to 33	E-A-41 to 42		E-A-61 to 64	24
	Type B1		E-B1-01 to 09			E-B1-31 to 33				12
	Type B2						E-B2-41 to 44			4
	Type B3						E-B3-41 to 42			2
FR-PH-5.5	Type A	E-A-00-5.5						E-A-51 to 53		4
FR-PH-60	Type B1	E-B1-00-60								1
	Type B2				E-B2-21 to 26					6
	Type C				E-C-21 to 23					3
	Type D1				E-D1-21 to 23					3
	Type D2				E-D2-21 to 23					3
	Type E (Type B4)				E-E -21 (E-E-21-01 to 06)					1 (6)
FR-PH-100	Type B1	E-B1-00-100								1
	Type B2							E-B2-51 to 53		3
FR-PN-2.0	Type A	F-A-00					F-A-41,42			3
	Type B2						F-B2-41, 43 F-B2-42, 44			4
	Type B3						F-B3-41,42			2
SHVV-2.0	Type A	G-A-00	G-A-01 to 09							10
	Type B1		G-B1-01 to 09							9
SHVV-60	Type B1	G-B1-00								1
	Type B2				G-B2-21 to 26					6
	Type C				G-C-21 to 23					3
	Type D1				G-D1-21 to 23					3
	Type D2				G-D2-21 to 23					3
	Type E (Type B4)				G-E-21 (G-E-21-01 to 06)					1 (6)
V-2.0	Type A	H-A-00	H-A-01 to 09							10
	Type B1		H-B1-01 to 09							9
EV-2.0	Type A	J-A-00	J-A-01 to 09							10
	Type B1		J-B1-01 to 09							9

2.2 Fabrication of thermal aging specimens

Thermal aging specimens, prepared on Section 2.1 were fabricated by putting them into a constant temperature oven (referred to as “oven” hereinafter) and heating them for specified periods. Table 2.2-1 shows fabrication conditions of thermal aging specimens. The fabrication steps of the thermal aging specimens are shown as follows.

a. To suspend the specimens listed in Table 2.2-1 in each oven. Figure 2.2-1 shows an outline of specimen suspension in the oven.

b. To establish the temperatures in each oven as listed in Table 2.2-1.

c. To remove each specimen at the end of the period as designated in Table 2.2-1.

d. To cool down the removed specimens to the room temperature.

For fabrication of thermal aging specimens, ovens corresponding to the B-type test equipment specified in JIS K 7212$_{-1999}$ were used. The following are special items relating to the ovens:

a. Ovens should be of electrical heating with forced or unforced air recirculation.

b. The frequency of ventilation should be more than once per hour.

c. It is permissible to employ ovens other than the gear-driven type by which specimens are rotated.

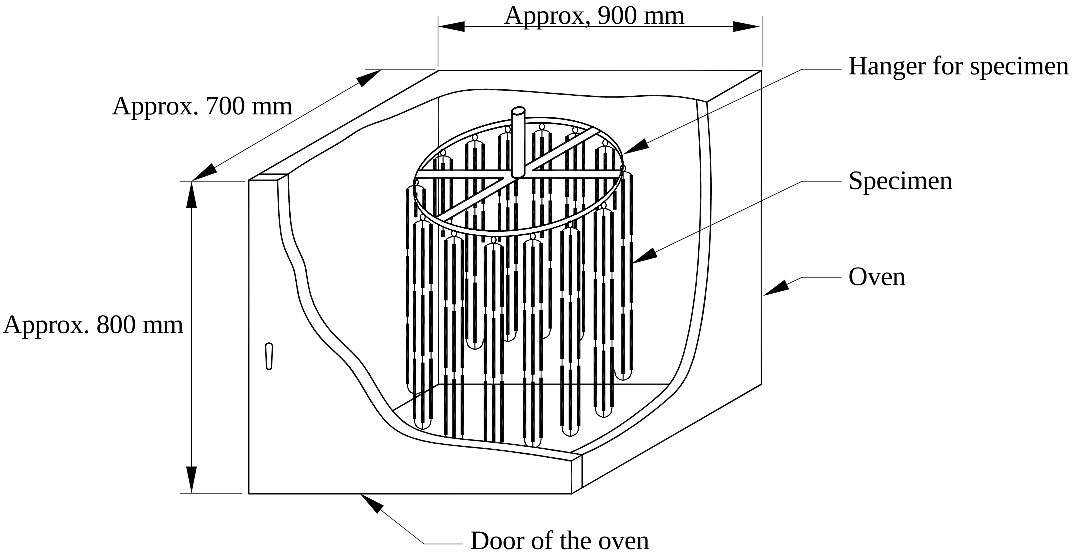


Figure 2.2-1 Outline of specimen suspension in the oven

Table 2.2-1 Fabricating conditions of thermal aging specimens

Oven number	Oven temperature	Specimens put into the oven					Remarks
		Kind of specimen	Specimen number	Thermal aging periods (days)			
No.1-1	135°C	KK-1.25	A-A-01,02,03	146	194	243	
			A-A-11,12,14[*1]	106	106	106	*1: To insert during heating
			A-B1-01,02,03	146	194	243	
No.1-2	155°C	KK-1.25	A-A-04,05,06	146	194	243	
			A-B1-04,05,06	146	194	243	
No.1-3	175°C	KK-1.25	A-A-07,08,09	124	182	243	
			A-B1-07,08,09	124	182	243	
No.2-1	110°C	CV-2.0	B-A-01,02,03	146	194	243	
			B-A-11,12,14[*1]	106	106	106	*1: To insert during heating
			B-B1-01,02,03	146	194	243	
		FR-CV-2.0	C-A-01,02,03	146	194	243	
			C-B1-01,02,03	146	194	243	
No.2-2	120°C	CV-2.0	B-A-04,05,06	146	194	243	
			B-A-05-2,06-2	37	64	-	
			B-B1-04,05,06	146	194	243	
			B-B1-05-2,06-2	37	64	-	
		FR-CV-2.0	C-A-04,05,06	146	194	243	
			C-B1-04,05,06	146	194	243	
No.2-3	130°C	CV-2.0	B-A-07,08,09	146	194	243	
			B-A-08-2,09-2	35	62	-	
			B-B1-07,08,09	146	194	243	
			B-B1-08-2,09-2	35	62	-	
		FR-CV-2.0	C-A-07,08,09	146	194	243	
			C-B1-07,08,09	146	194	243	
No.1-4	100°C	PG-2.0	D-A-01,02,03	146	194	243	
			D-B1-01,02,03	146	194	243	
		FR-PH-2.0	E-A-01,02,03	146	194	243	
			E-A-11,12,14[※1]	106	106	106	*1: To insert during heating
			E-B1-01,02,03	146	194	243	
No.1-5	110°C	PG-2.0	D-A-04,05,06	146	194	243	
			D-B1-04,05,06	146	194	243	
		FR-PH-2.0	E-A-04,05,06	146	194	243	
			E-B1-04,05,06	146	194	243	
No.1-6	120°C	PG-2.0	D-A-07,08,09	146	194	243	
			D-B1-07,08,09	146	194	243	
		FR-PH-2.0	E-A-07,08,09	146	194	243	
			E-B1-07,08,09	146	194	243	
No.2-4	100°C	SHVV-2.0	G-A-01,02,03	146	194	243	
			G-B1-01,02,03	146	194	243	
		VV-2.0	H-A-07,08,09	146	194	243	
			H-A-08-2,09-2	37	64	-	
			H-B1-07,08,09	146	194	243	
			H-B1-08-2,09-2	37	64	-	
No.2-5	110°C	SHVV-2.0	G-A-04,05,06	146	194	243	
			G-B1-04,05,06	146	194	243	
No.2-6	120°C	SHVV-2.0	G-A-07,08,09	146	194	243	
			G-B1-07,08,09	146	194	243	
No.1-7	80°C	VV-2.0	H-A-01,02,03	146	194	243	
			H-B1-01,02,03	146	194	243	
No.1-8	90°C	VV-2.0	H-A-04,05,06	146	194	243	
			H-B1-04,05,06	146	194	243	
No.2-7	80°C	EV-2.0	J-A-01,02,03	146	194	243	
			J-B1-01,02,03	146	194	243	
No.2-8	90°C	EV-2.0	J-A-04,05,06	146	194	243	
			J-B1-04,05,06	146	194	243	
No.2-9	100°C	EV-2.0	J-A-07,08,09	146	194	243	
			J-B1-07,08,09	146	194	243	
No.1-9	120°C	PG-2.0	D-A-61,62	194	194	-	
			D-A-63,64	194	194	-	*1: To insert during heating
		FR-PH-2.0	E-A-61,62	194	194	-	
			E-A-63,64	194	194	-	*1: To insert during heating

2.3 Fabrication of simultaneous aging specimens

Simultaneous aging specimens were fabricated by putting them, prepared in Section 2.1, into ovens which were simultaneously heated and irradiated for a specified period. In addition, radiation aging specimens were fabricated by putting the specimens in an irradiation facility at room temperature for a specified period.

The fabrication conditions of simultaneous aging specimens at room temperature are listed in Table 2.3-1. Their fabrication steps are outlined as follows.

(1) Fabrication steps of simultaneous aging specimens

The fabrication steps of simultaneous aging specimens are shown as follows.

a. To place specimens into the ovens in a gamma ray radiation facility using Cobalt 60 as a radiation source. And to adjust the dose rates in the ovens by putting shielding materials so that the dose rate becomes the value shown in Table 2.3-1. The dispersion in the values of dose rate (eight representative points at maximum) in the ovens should be within ±15%. To record these rates and to designate the averages of them as the definite initial dose rates.

b. To suspend specimens listed in Table 2.3-1 in each oven, above. The outlines of specimen suspension in the oven are same as those for fabrication of thermal aging specimens in Section 2.2.

c. To set oven temperatures at the prescribed temperatures in Table 2.3-1.

d. To start irradiation.

e. To rotate horizontally the specimen positions in the oven by 90 degree twice per week and to spin around specimens upside down at every horizontal rotation.

f. To remove each specimen at the end of irradiated period shown in Table 2.3-1. Irradiation is temporarily interrupted at every removal. The period excluding interruption is defined as the definite irradiation period.

g. To cool down removed specimens to room temperature.

(2) Fabrication steps of radiation aging specimens at room temperature

The fabrication steps of radiation aging specimens, excluding Type E specimens, at room temperature are shown in the following.

a. To suspend dummy specimens at their position in a gamma ray radiation facility using Cobalt 60 as a radiation source. And to adjust the dose rates by positioning specimen and putting shielding materials so that the dose rate becomes the value shown in Table 2.3-1. The difference of the dose rate at the top and bottom positions of suspended specimen should be within ±15%. To record these rates and to designate the averages of them as the definite initial dose rates.

b. To suspend specimens listed in Table 2.3-1 at the positions where the dose rates were adjusted.

c. To start irradiation.

d. To turn the specimens upside down twice per week.

e. To remove each specimen at the end of irradiated period shown in Table 2.3-1. Irradiation is temporarily interrupted at every removal. The period excluding interruption is defined as the definite irradiation period.

Also, the following shows the fabrication steps of Type E radiation aging specimens at room temperature.

a. To place Type E specimens in a gamma ray radiation facility, using Cobalt 60 as a radiation source, and to adjust the dose rates at top and bottom positions of specimens by positioning specimens and putting shielding materials so that the dose rates become the values shown in Table 2.3-1. Moreover, the measuring positions of dose rates for adjustment should be four points in a longitudinal direction from the specimen top (the part “a” in Figure 2.3-1) and the dispersion in the values of dose rate should be within ±15%. These dose rates should be recorded after adjustment. The averages of them are designated as the definite initial dose rates.

b. To measure the dose rates at four positions at the bottom of the removed Type E specimens (the part “b” in Figure 2.3-1) and to designate the averages of dose rates as the definite initial dose rate for the specimens under stress.

c. To replace the cables of Type E specimens for new ones at the predetermined positions after the removal (three cables at bottom and three cables at top).

d. To start irradiation.

e. To rotate horizontally specimens in 180^{o} twice per week.

f. To remove each specimen at the end of irradiation period shown in Table 2.3-1. Irradiation is temporarily interrupted at every removal. The period excluding interruption is defined as the definite irradiation period.

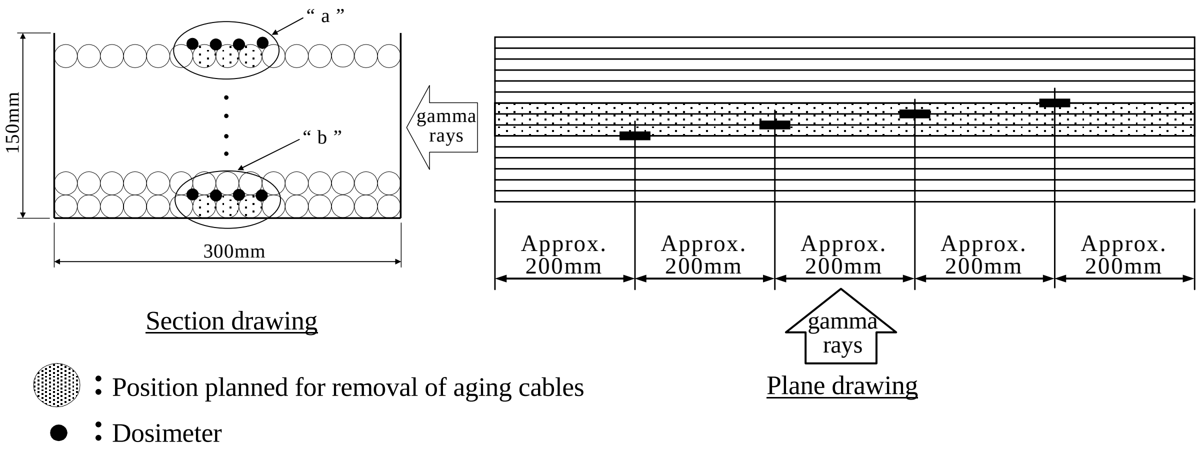


Figure 2.3-1 Positions of radiation measurement and of removed aging cables of type E specimen

Table 2.3-1 Fabricating conditions of simultaneous aging specimens

	Oven number	Preset temperature in the oven	Dose rate in the oven or at the place of installed specimen	Specimens put into the oven					Remarks
				Kind of specimen	Specimen number	Plan of aging periods (days)			
Simultaneous aging specimens	No.1	135ºC	Approx. 50 Gy/h	KK-1.25	A-A-15	106	-	-	
	No.2-1	100ºC	Approx. 100 Gy/h	KK-1.25	A-A-31,32,33	50	74	100	
					A-B1-31,32,33	50	74	100	
				KK-60	A-B2-21,22,23	50	74	100	
					A-C-21,22,23	50	74	100	
					A-D1-21,22,23	50	74	100	
					A-D2-21,22,23	50	74	100	
	No.2-2	110ºC	Approx. 100 Gy/h	CV-2.0	B-A-15	106	-	-	Execute aging after irradiation of No. 2-1
	No.3	100ºC	Approx. 100 Gy/h	CV-2.0	B-A-31,32,33	91	135	183	
					B-B1-31,32,33	91	135	183	
				CV-60	B-B2-21,22,23	91	135	183	
					B-C-21,22,23	91	135	183	
					B-D1-21,22,23	91	135	183	
					B-D2-21,22,23	91	135	183	
	No.4	100ºC	Approx. 100 Gy/h	FR-PH-2.0	E-A-15	106	-	-	
					E-A-31,32,33	120	183	238	
					E-A-41, 42	84	113	-	
					E-B1-31,32,33	120	183	238	
					E-B2-41, 42	84	84	-	
					E-B2-43, 44	113	113	-	
				FR-PH-5.5	E-A-51,52,53	120	183	238	
				FR-PH-60	E-B2-21,22,23	120	183	238	
					E-C-21,22,23	120	183	238	
				FR-PH-100	E-B2-51,52,53	120	183	238	
				FR-PN-2.0	F-A-41, 42	62	93	-	
					F-B2-41, 42	62	62	-	
					F-B2-43, 44	93	93	-	
	No.5	100ºC	Approx. 100 Gy/h	FR-PH-2.0	E-B3-41, 42	84	113	-	
				FR-PN-2.0	F-B3-41, 42	62	93	-	
				FR-PH-60	E-D1-21,22,23	120	183	238	
					E-D2-21,22,23	120	183	238	
	No.6	100ºC	Approx. 100 Gy/h	SHVV-60	G-B2-21,22,23	50	74	100	
					G-C-21,22,23	50	74	100	
					G-D1-21,22,23	50	74	100	
					G-D2-21,22,23	50	74	100	
Radiation aging specimens at room temperature	-	Room temperature	Approx. 50 Gy/h	KK-2.0	A-A-12^{*1}, 13, 14	106	106	106	*1: Insert during irradiation.
			Approx. 100 Gy/h	CV-2.0	B-A-12^{*1}, 13, 14	106	106	106	
				FR-PH-2.0	E-A-12^{*1}, 13, 14	106	106	106	
				KK-60	A-E-21-01,02,03^{*2}	50	74	100	Designate the number of aging cables taken out from Type E specimen. *2: Dose rate is lowered due to taking out from the bottom of Type E specimens (approx. 30 - 35 Gy/h).
					A-E-21-04,05,06	50	74	100	
				CV-60	B-E-21-01,02,03^{*2}	120	183	238	
					B-E-21-04,05,06	120	183	238	
				FR-PH-60	E-E-21-01,02,03^{*2}	120	183	238	
					E-E-21-04,05,06	120	183	238	
				SHVV-60	G-E-21-01,02,03^{*2}	120	183	238	
					G-E-21-04,05,06	120	183	238	
			Approx. 30 to 35 Gy/h	KK-60	A-B2-24,25,26	50	74	100	
				CV-60	B-B2-24,25,26	120	183	238	
				FR-PH-60	E-B2-24,25,26	120	183	238	
				SHVV-60	G-B2-24,25,26	120	183	238	

2.4 Tensile test

Tensile tests were executed for thermal aging and simultaneous aging specimens fabricated in Sections 2.2 and 2.3, based on Section 4.16 “Tensile of insulation and sheath” of JIS C 3005$_{-2000}$ “Test methods for rubber and plastic insulated wires and cables” and data of elongation at break was obtained. Table 2.4-1 shows the details of specimens for which tensile tests were executed.

Table 2.4-1 Specimens for tensile test

Kind of specimen	Specimen type	Shape of test piece for tensile test	Specimen number in tensile test								Total number of specimens for tensile test
			Initial value measurement	Preliminary thermal aging tests	Comparative tests of aging sequence	Mechanical stress-loading tests	Comparative tests of tubular type and cable type specimen	Comparative tests of length of specimen for LOCA test	Comparative tests of thickness of specimen	Comparative tests of installation procedure to oven specimens	
KK-1.25	Type A	Tubular	A-A-00	A-A-01 to 09	A-A-11 to 15		A-A-31,32,33				72
KK-60	Type B1	Dumbbell	A-B1-00								2
	Type B2	Dumbbell				A-B2-21 to 26					12
	Type C	Dumbbell				A-C-21,22,23					6
	Type D1	Dumbbell				A-D1-21,22,23					12
	Type D2	Dumbbell				A-D2-21,22,23					12
	Type B4	Dumbbell				A-E-21-01,02,03 A-E-21-04,05,06					18
CV-2.0	Type A	Tubular	B-A-00	B-A-01 to 09 B-A-05-2 B-A-06-2 B-A-08-2 B-A-09-2	B-A-11 to 15		B-A-31to 33				66
CV-60	Type B1	Dumbbell	B-B1-00								2
	Type B2	Dumbbell				B-B2-21 to 26					12
	Type C	Dumbbell				B-C-21,22,23					6
	Type D1	Dumbbell				B-D1-21,22,23					12
	Type D2	Dumbbell				B-D2-21,22,23					12
	Type B4	Dumbbell				B-E-21-01,02,0, B-E-21-04,05,06					18
FR-CV-2.0	Type A	Tubular	C-A-00	C-A-01 to 09							30
PG-2.0	Type A	Tubular	D-A-00	D-A-01 to 09						G-A-61 to 64	42
FR-PH-2.0	Type A	Tubular	E-A-00-2.0	E-A-01 to 09	E-A-11 to 15		E-A-31,32,33	E-A-41,42		E-A-61 to 64	72
FR-PH-5.5	Type A	Tubular	E-A-00-5.5						E-A-51,52,53		12
FR-PH-60	Type B1	Dumbbell	E-B1-00-60								2
	Type B2	Dumbbell				E-B2-21 to 26					12
	Type C	Dumbbell				E-C-21,22,23					6
	Type D1	Dumbbell				E-D1-21,22,23					12
	Type D2	Dumbbell				E-D2-21,22,23					12
	Type B4	Dumbbell				E-E-21-01,02,03 E-E-21- 4,05,06					18
FR-PH-100	Type B2	Dumbbell	E-B1-00-100						E-B2-51,52,53		4
FR-PN-2.0	Type A	Tubular	F-A-00					F-A-41,42			9
SHVV-2.0	Type A	Tubular	G-A-00	G-A-01 - 09							30
SHVV-60	Type B1	Dumbbell	G-B1-00								2
	Type B2	Dumbbell				G-B2-21 - 26					12
	Type C	Dumbbell				G-C-21,22,23					6
	Type D1	Dumbbell				G-D1-21,22,23					12
	Type D2	Dumbbell				G-D2-21,22,23					12
	Type B4	Dumbbell				G-E-21-01,02,03 G-E-21-04,05,06					18
VV-2.0	Type A	Tubular	H-A-00	H-A-01 to 09 H-A-08-2 H-A-09-2							36
EV-2.0	Type A	Tubular	J-A-00	J-A-01 - 09							30
Total number of specimens for tensile test			41	243	50	240	30	12	15	24	655

Remarks: Tubular specimens have test pieces for each core. Dumbbell specimens have insulator test piece and jacket test piece.

2.5 Profiling analysis

Profiling analysis for each insulator material was executed for thermal aging and simultaneous aging specimens fabricated in Sections 2.2 and 2.3. Data was obtained by the analysis methods listed in Table 2.5-1. Table 2.5-2 shows the details of the specimens for which the profiling analysis was executed.

Table 2.5-1 Profiling analysis method

Insulation material	Profiling analysis method
SIR	Surface hardness
XLPE	X-ray microanalyser*
FR-XLPE	
PE	
EPR	
FR-EPR	
SHPVC	Surface hardness and Observation of color change
PVC	

Remarks (*)
The X-ray microanalyser (XMA) is an analysis method to measure oxidation aging distribution from the surface to inner part of insulator. The count number of XMA reflects the concentration of the element potassium in potassium hydroxide which results quantitatively in a chemical reaction with oxidation products.

Table 2.5-2 Specimens for profiling analysis

Kind of specimen	Insulator material	Specimen type	Shape of specimen	Specimen number for profiling analyses					Total number of specimens
				Initial value measurement	Preliminary thermal aging tests	Comparative tests of aging sequence	Comparative tests of tubular type and cable type specimen	Comparative tests of length of specimen for LOCA test	
KK-1.25	SIR	Type A	Tubular type	A-A-00	A-A-01 to 09	A-A-12,14,15	A-A-31,32,33		16
		Type B1	Cable type		A-B1-01 to 09		A-B1-31,32,33		12
CV-2.0	XLPE	Type A	Tubular type	B-A-00	B-A-01 to 09 B-A-05-2 B-A-06-2 B-A-08-2 B-A-09-2	B-A-12,14,15	B-A-31,32,33		20
		Type B1	Cable type		B-B1-01 to 09 B-B1-05-2 B-B1-06-2 B-B1-08-2 B-B1-09-2		B-B1-31,32,33		16
FR-CV-2.0	FR-XLPE	Type A	Tubular type	C-A-00	C-A-01 to 09				10
		Type B1	Cable type		C-B1-01 to 09				9
PG-2.0	EPR	Type A	Tubular type	D-A-00	D-A-01 to 09				10
		Type B1	Cable type		D-B1-01 to 09				9
FR-PH-2.0	FR- EPR	Type A	Tubular type	E-A-00	E-A-01 to 09	E-A-12,14,15	E-A-31,32,33		16
		Type B1	Cable type		E-B1-01 to 09		E-B1-31,32,33		12
		Type B2	Cable type					E-B2-41, 43[*1]	10
FR-PN-2.0	FR- EPR	Type A	Tubular type	E-A-00					1
		Type B2	Cable type					F-B2-41, 43[*1]	10
SHVV-2.0	SHPVC	Type A	Tubular type	G-A-00	G-A-01 to 09				10
		Type B1	Cable type		G-B1-01 to 09				9
VV-2.0	PVC	Type A	Tubular type	H-A-00	H-A-01 to 09 H-A-08-2 H-A-09-2				12
		Type B1	Cable type		H-B1-01 to 09 H-B1-08-2 H-B1-08-2				11
EV-2.0	PE	Type A	Tubular type	J-A-00	J-A-01 to 09				10
		Type B1	Cable type		J-B1-01 to 09				9
Total number of specimens				9	156	9	18	20	212

*1: Execute profiling analysis at 5 points in longitudinal direction of each specimen.

2.6 LOCA test

LOCA tests were performed using simultaneous aging specimens shown in Table 2.6-1.

In the LOCA test, the steam exposure was carried out after irradiation. These condtions of assuming DBE are shown in Table 2.6-1. The bend submerged withstand voltage test was then performed based on the Recommended Practice of IEEJ. In addition, the breakdown voltage test was performed as a reference test after the bend submerged withstand voltage test. The results of this test are shown in Table 2.6-2.

Table 2.6-1 LOCA test specimens

Kind of specimen	Cable specification				Equivalent aging conditions for normal operation		Specimen number	Specimen length	LOCA test conditions
	Insulator materials	Jacket materials	Conductor size [mm^2]	No. of cores	Temperature & dose rate	Period (days)			
FR-PN-2.0	FR-EPR	FR-CR	2.0	3	100°C 96.5 Gy/h	56.83	F-B2-42	0.6 m	Radiation exposure: Approx. 10 kGy/h - 260 kGy Steam exposure: Max. 171ºC, 0.4 MPa
					100°C 97.2 Gy/h		F-B3-41	3.0 m	
					100°C 95.9 Gy/h	83.83	F-B2-44	0.6 m	
					100°C 96.5 Gy/h		F-B3-42	3.0 m	
FR-PH-2.0	FR-EPR	FR-CSPE	2.0	3	100°C 96.0 Gy/h	77.08	E-B2-42	0.6 m	Radiation exposure: Approx. 10 kGy/h - 1500 kGy Steam exposure: Max. 190ºC, 0.4 MPa
					100°C 96.7 Gy/h		E-B3-41	3.0 m	
					100°C 95.5 Gy/h	103.83	E-B2-44	0.6 m	
					100°C 96.2 Gy/h	101.67	E-B3-42	3.0 m	

Table 2.6-2 Results of bend submerged withstand voltage test

	Specimen number	Specimen length	Equivalent accelerated aging conditions during normal operation			Core color	Results of bend submerged withstand voltage test		Breakdown voltage test results
			Temperature	Average dose rate	Aging period		Test conditions	Determined results	
1	F-B2-42	0.6 m	100°C	96.5 Gy/h	1364 hours	Black	2600V-5 min.	Good	17 kV
						White	2600V-5 min.	Good	14 kV
						Red	2600V-5 min.	Good	15 kV
2	F-B3-41	3 m	100°C	97.2 Gy/h	1364 hours	Black	2600V-5 min.	Good	10 kV
						White	2600V-5 min.	Good	7 kV
						Red	2600V-5 min.	Good	7 kV
3	F-B2-44	0.6 m	100°C	95.9 Gy/h	2012 hours	Black	2600V-5 min.	Good	14 kV
						White	2600V-5 min.	Good	12 kV
						Red	2600V-5 min.	Good	15 kV
4	F-B3-42	3 m	100°C	96.5 Gy/h	2012 hours	Black	2600V-5 min.	Good	11 kV
						White	2600V-5 min.	Good	10 kV
						Red	2600V-5 min.	Good	*1
5	E-B2-42	0.6 m	100°C	96.0 Gy/h	1850 hours	Black	2600V-5 min.	Good	6 kV
						White	2600V-5 min.	Good	7 kV
						Red	2600V-5 min.	Good	6 kV
6	E-B3-41	3 m	100°C	96.7 Gy/h	1850 hours	Black	2600V-5 min.	Good	8 kV
						White	2600V-5 min.	Good	9 kV
						Red	2600V-5 min.	Good	7 kV
7	E-B2-44	0.6 m	100°C	95.5 Gy/h	2492 hours	Black	2600V-5 min.	Good	9 kV
						White	2600V-5 min.	Good	7 kV
						Red	2600V-5 min.	Good	6 kV
8	E-B3-42	3 m	100°C	96.2 Gy/h	2440 hours	Black	2600V-5 min.	Good	7 kV
						White	2600V-5 min.	Good	6 kV
						Red	2600V-5 min.	Good	6 kV

*1: Since the breakdown occurred at the red core during the breakdown voltage test of the black or white core that was previously performed, the breakdown voltage test of the red core was not able to be executed.

3. Evaluation

3.1 Preliminary thermal aging test

Maximum heating temperature of each insulator material was evaluated from profiling analysis results in the preliminary thermal aging test, as shown in Table 3.1-1.

Table 3.1-1 Evaluation of maximum thermal aging temperature of each insulator material

Insulation material	Evaluation of maximum thermal aging temperature	Representative test results
1. SIR	From the surface hardness measurement result, an almost uniform degradation also progressed into the inside even at 175°C. In addition, the fact that degradation progressed even if heating temperature was comparatively low, is considered to be the result of a high penetration rate of oxygen in the SIR.	Fig. 3.1-1.
2. XLPE	Although degradation was progressing into the inside of insulator even at 130°C from the XMA analysis result, little uneven distribution was observed at 130°C. In addition, when progress of degradation was large with the cable type specimen (elongation 0% at break), its uneven distribution was observed even at 120°C.	Fig.3.1-2.
3. FR-XLPE	From the XMA analysis result, an almost uniform degradation was observed to progress into the inside even at 130°C. In addition, acceleration of degradation was observed at the contacted domain of conductors for cable type specimens.	Fig. 3.1-3.
4. EPR	From the XMA analysis result, an almost uniform degradation was progressing into the inside even at 120°C.	Fig. 3.1-4.
5. FR-EPR	Although almost uniform degradation was progressing to the inside even at 120°C, a little uneven distribution was observed at 120°C.	Fig. 3.1-5.
6. SHPVC	From the color observation results, an almost uniform degradation progressed into the inside even at 120°C. In addition, although the amount of surface hardness change was small, it was shown that an almost uniform degradation progresses into the inside in a similar pattern to the color observation result. However, the color change became large at the contacted domain of conductors for cable type specimens, and especially the coloring domain was enlarged if temperature was elevated. This phenomenon is considered to be caused by promotion of coloring due to the catalytic effect of the copper conductor.	Fig. 3.1-6.
7. PVC	From the color observation results, an almost uniform degradation progressed into the inside even at 100°C. Although the amount of surface hardness change was small, it was shown that almost uniform degradation also progressed into the inside in similar pattern to color observation result.	Fig. 3.1-7.
8. PE	From the XMA analysis result, an almost uniform degradation progressed into the inside even at 100°C.	Fig. 3.1-8.

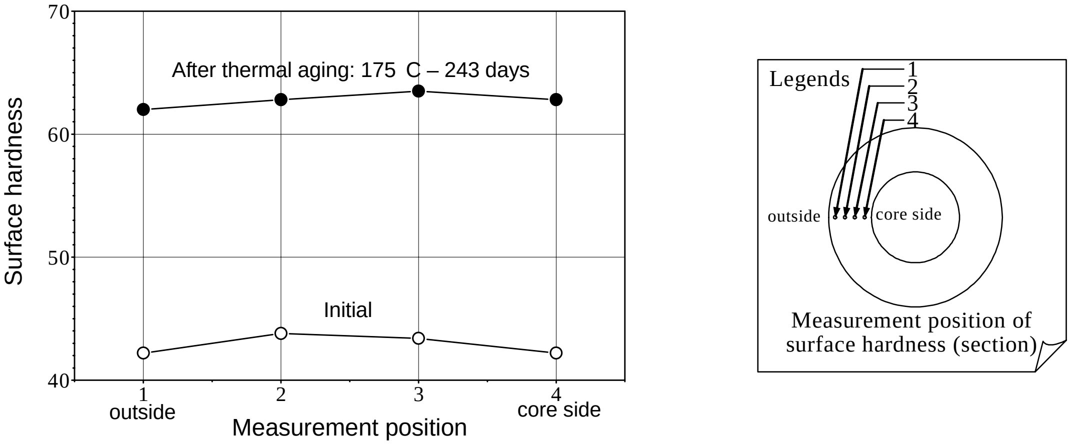


Fig. 3.1-1 Degradation situation inside of insulator after thermal aging (175°C-243 days) of SIR insulator (surface hardness)

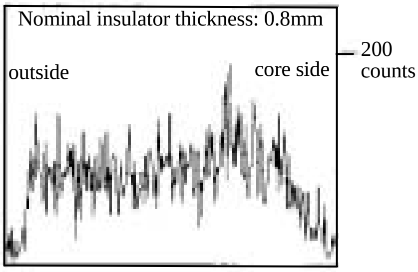


Fig.3.1-2 Degradation situation inside insulator at the thermal aging (130°C - 194 days) of XLPE insulator (XMA analysis)

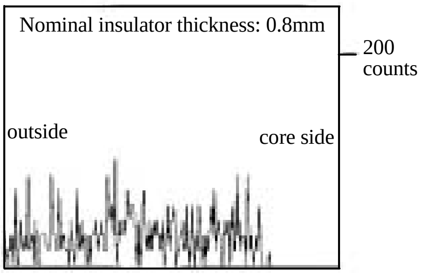


Fig.3.1-3 Degradation situation inside insulator at the thermal aging (130°C - 194 days) of FR-XLPE insulator (XMA analysis)

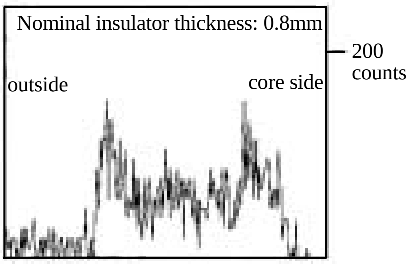


Fig.3.1-4 Degradation situation inside insulator at the thermal degradation (120°C - 243 days) of EPR insulator (XMA analysis)

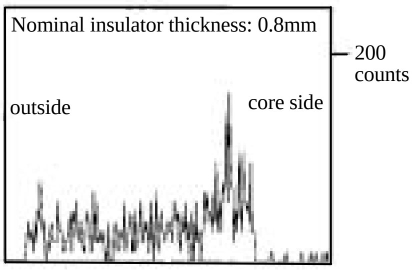


Fig.3.1-5 Degradation situation inside insulator at the thermal aging (120°C to 243 days) of FR-EPR insulator (XMA analysis)

(146 days) (194 days) (243 days)

Fig. 3.1-6 Degradation situations inside insulator at the thermal aging (120°C) of SHPVC insulator (color change)

(64 days) (146 days) (194 days)

Fig. 3.1-7 Degradation situations inside insulator at the thermal aging (100°C) of PVC insulator (color change)

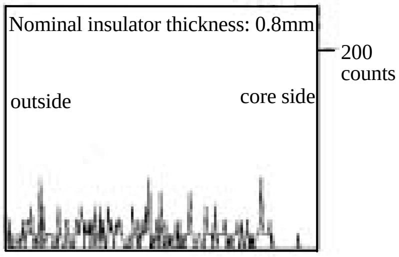


Fig. 3.1-8 Degradation situations inside insulator at the thermal aging (100°C - 243 days) of PE insulator (XMA analysis)

3.2 Comparative tests of aging sequence

Table 3.2-1 shows aging evaluation pursuant to accelerated aging procedure for every type of cable insulator based on the comparative tests of aging sequence.

As shown in Table 3.2-1, it was verified that every insulator had the minimum progress of degradation in the radiation exposure following thermal aging (it is called sequential aging), and had a larger progress in a reversely sequential aging and simultaneous aging at the same time. Simultaneous aging should be performed to simulate cable aging at the actual operating plant.

Fig 3.2-1 Aging evaluation based on aging sequence

Insulator materials	Evaluation of accelerated aging sequence	Representative test result
SIR	From elongation at break and surface hardness measurements, progress of degradation was smaller in order of simultaneous aging (maximum), radiation aging followed by thermal aging (reversely sequential), and thermal aging followed by radiation aging (sequential). These differences were also the largest in the three kinds of the insulator materials.	Fig. 3.2-1 Fig. 3.2-2
XLPE	From elongation at break and surface hardness measurements, progress of degradation was smaller in the order of simultaneous aging (maximum), radiation aging followed by thermal aging (reversely sequential), and thermal aging followed by radiation aging (sequential). These differences were also the smallest in the three kinds of the insulator materials.	Fig. 3.2-3 Fig. 3.2-5
FR-EPR	Although a significant difference caused by aging procedure had not came out in a XMA analysis result, elongation at break showed that progress of aging became smaller in order of radiation aging followed by thermal aging (reversely sequential), simultaneous aging, and thermal aging followed by radiation aging (sequential). These differences were also in the middle degree in the three kinds of insulator materials.	Fig. 3.2-4

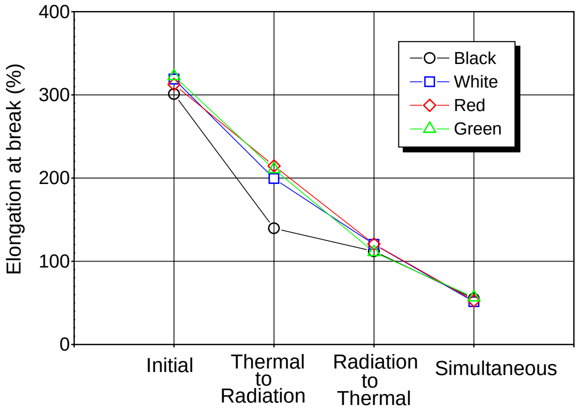


Fig. 3.2-1 Result of comparative tests of aging sequence for SIR insulator (Elongation at break)
(Aging condition: 135°C- approx. 50 Gy/h- approx. 100 days)

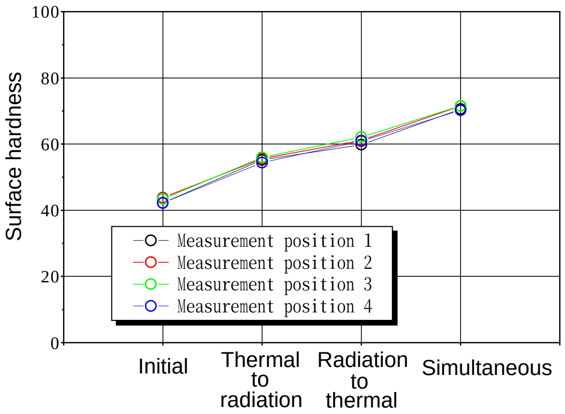


Fig.3.2-2 Result of comparative tests of aging sequence for SIR insulator (Surface hardness)
(Aging condition: 135°C- approx. 50 Gy/h- approx. 100 days)

Notes: Refer to legend in Fig. 3.1-1 for measurement positions.

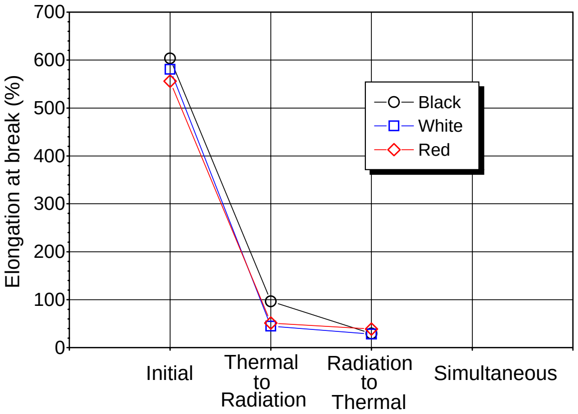


Fig.3.2-3 Result of comparison tests of aging sequence for XLPE insulator (Elongation at break)
(Aging condition: 110°C- approx. 100 Gy/h- approx. 100 days)

Notes: Since Simultaneous aging had significant progression of degradation, its tensile test could not be conducted.

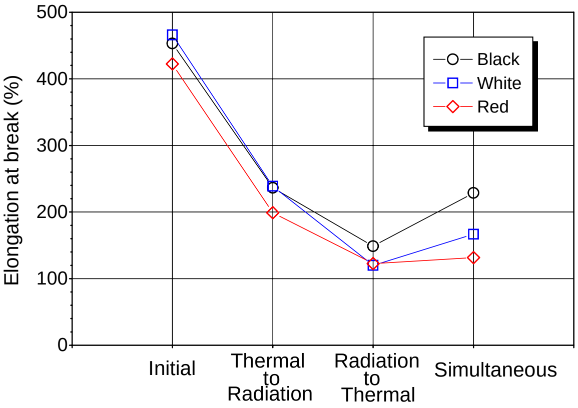
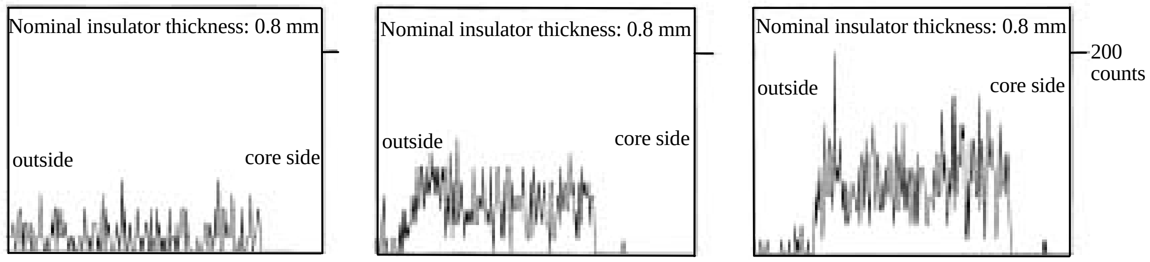


Fig. 3.2-4 Result of comparative tests of aging sequence for FR-EPR insulator (Elongation at break)
(Aging condition: 100°C- approx. 100 Gy/h- approx. 100 days)



From thermal aging to irradiation   From irradiation to thermal aging   Simultaneous aging

Fig. 3.2-5 Results of comparative tests of aging sequence for XLPE insulator (XMA analysis)
(Aging condition: 110°C- approx. 100 Gy/h- approx. 100 days)

3.3 Mechanical stress-loading tests

Evaluation results of effect of each insulator on mechanical stress-loading are shown in Table 3.3-1.

In addition, when the cables are stacked this creates a greater shielding effect, the cables located in the highest layer show the tendency to progress in degradation earlier than those located in the lowest layer. This is solely due to shielding effect. In this case, the dose rates for the cables in the lowest layer are reduced to approximately one third than that of the top. Therefore, aging specimens were manufactured subject to a radiation level equivalent to the dose rate at the lowest layer without force, and effect of the cable stacked portion loading at the lowest layer was evaluated in comparison with those aging specimens.

Table 3.3-1 Evaluation of effect on mechanical stress-loading

Insulator materials	Evaluation of effect on mechanical stress-loading tests	Test results
SIR	Stress levels caused by vertical and bent portions are considered to give no significant effect on insulator degradation. Progress of degradation is slow in the case of stacked portions, but it is considered that there is almost no significant effect of stacked portion loading on insulator degradation.	Fig. 3.3-1 Fig. 3.3-2 Fig. 3.3-3
XLPE	Stress level caused by the bent portion gives no significant effect on insulator degradation. Progress of degradation is slow in the case of vertical and stacked portions, but it is considered that there is almost no significant effect of vertical and stacked portion loading on insulator degradation.	Fig. 3.3-4 Fig. 3.3-5 Fig. 3.3-6
FR-EPR	Stress levels caused by either the vertical portion or the bent portion has no significant effect on insulator degradation. Progress of degradation is slow in the case of the stacked portion, but it is considered that there is almost no significant effect of the stacked portion on insulator degradation.	Fig. 3.3-7 Fig. 3.3-8 Fig. 3.3-9
SHPVC	Stress levels caused by either the vertical portion or the bent portion has no significant effect on insulator degradation. Progress of degradation is much slow in the case of stacked portion. However, from evaluation of this insulator material in the vertical and bent portion or the result of other insulators in the stacked portion, it can be estimated that there is almost no significant effect of stacked portion loading on insulator degradation.	Fig. 3.3-10 Fig. 3.3-11 Fig. 3.3-12

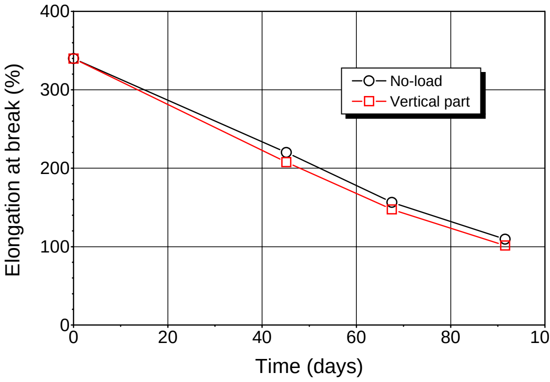


Fig. 3.3-1 Result of vertical portion mechanical stress-loading tests for SIR insulator (Aging condition: 100°C- approx. 100 Gy/h)

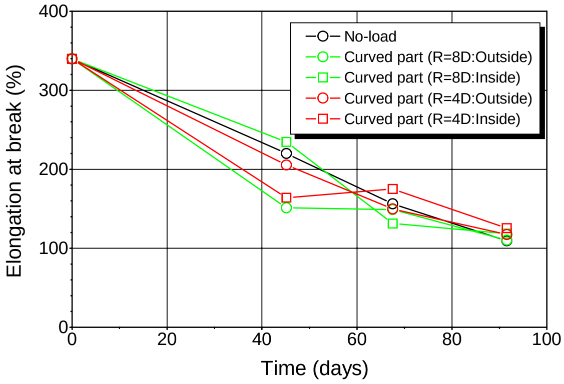


Fig. 3.3-2 Result of bent portion mechanical stress-loading tests for SIR insulator (Aging condition: 100°C- approx. 100 Gy/h)

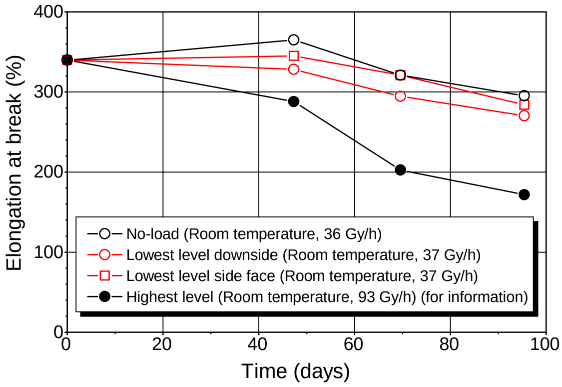


Fig. 3.3-3 Result of stacked portion mechanical stress-loading tests for SIR insulator

Note: The dose rate of the no-load specimen was set to the dose rate of the lowest level specimen.

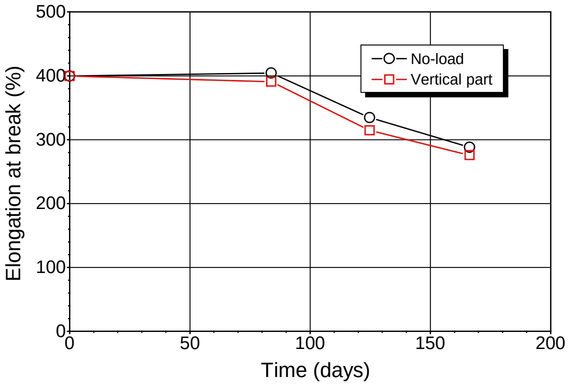


Fig 3.3-4 Result of vertical portion mechanical stress-loading tests for XLPE insulator (Aging condition: 100°C- approx. 100 Gy/h)

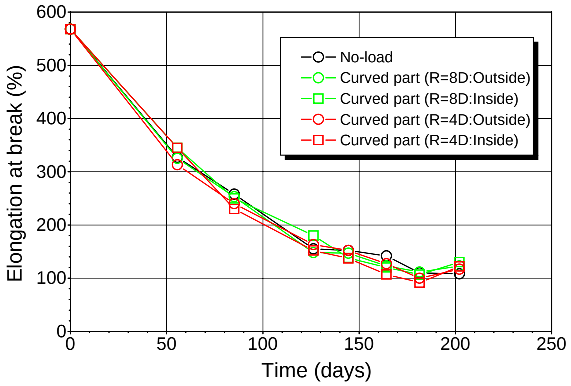


Fig. 3.3-5 Result of bent portion mechanical stress-loading tests for XLPE insulator (Aging condition: 100°C- approx. 100 Gy/h)

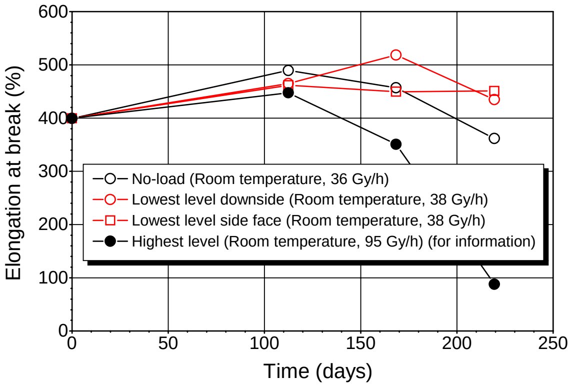


Fig.3.3-6 Result of stacked portion mechanical stress-loading tests for XLPE insulator

Note: The dose rate of the no-load specimen was set to the dose rate of the lowest level specimen.

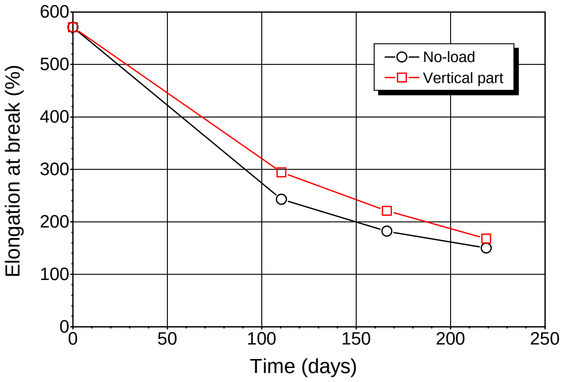


Fig. 3.3-7 Result of vertical portion mechanical stress-loading tests for FR-EPR insulator (Aging condition: 100°C- approx. 100 Gy/h)

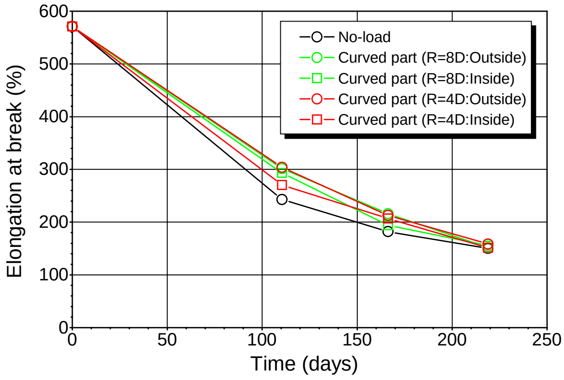


Fig. 3.3-8 Result of bent portion mechanical stress-loading tests for FR-EPR insulator (Aging condition: 100°C- approx. 100 Gy/h)

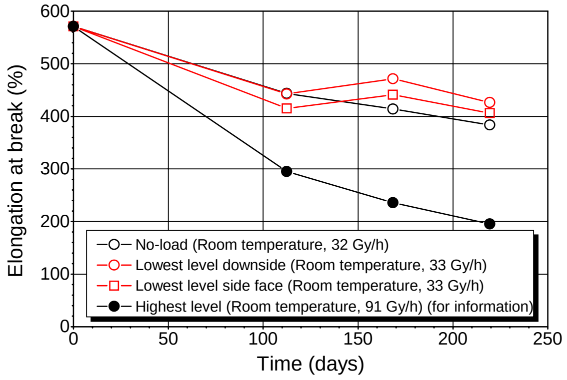


Fig. 3.3-9 Result of stacked portion mechanical stress-loading tests for FR-EPR insulator

Note: The dose rate of the no-load specimen was set to the dose rate of the lowest level specimen.

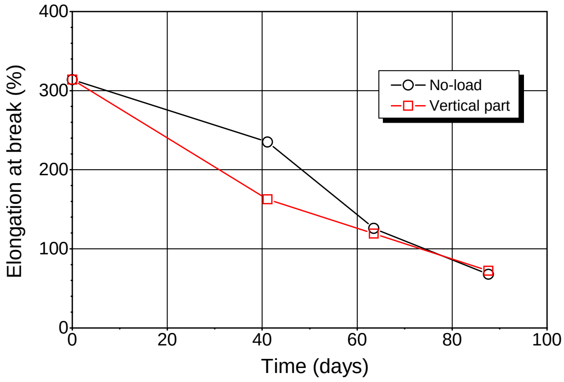


Fig. 3.3-10 Result of vertical portion mechanical stress-loading tests for SHPVC insulator (Aging condition: 100°C- approx. 100 Gy/h)

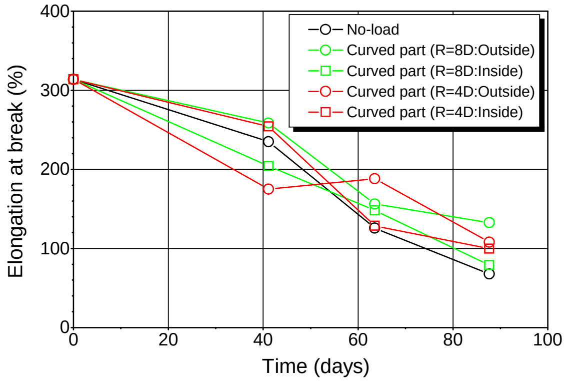


Fig. 3.3-11 Result of bent portion mechanical stress-loading tests for SHPVC insulator (Aging condition: 100°C- approx. 100 Gy/h)

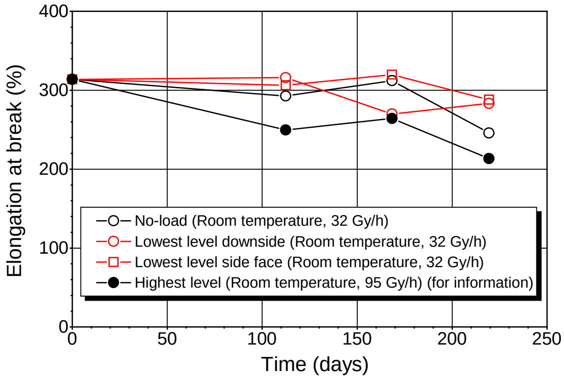


Fig. 3.3-12 Result of stacked portion mechanical stress-loading tests l for SHPVC insulator

Note: The dose rate of the no-load specimen was set to the dose rate of the lowest level specimen.

3.4 Comparative tests of tubular type and cable type specimens

A comparison was made of the progressing degree of degradation between the tubular type and cable type specimens. Those evaluation results are shown in Table 3.4-1.

Table 3.4-1 Comparison of the degree of degradation between the tubular type and cable type specimens

Insulator material	Evaluation	Representative test result
SIR	Tubular type and cable type specimens are considered to happen at almost the same degradation from the surface hardness measurement results of simultaneous aging specimens.	Fig. 3.4-1
XLPE	Tubular type and cable type specimens are considered to happen at almost the same degradation from XMA analysis results of simultaneous aging specimens. In addition, when the degradation of thermal aging in cable type specimens is large (elongation at break is 0%), the uneven distribution of degradation different from tubular type specimens is observed.	Fig. 3.4-2 Fig. 3.4-3
FR-XLPE	Although some large degradation is observed at the contacting parts of conductors in cable type specimen from the XMA analysis result of thermal aging specimen, tubular type and cable type specimens are considered to happen at almost the same degradation.	Fig. 3.4-4
EPR	The tubular type and cable type specimens are considered to happen at almost the same progress of degradation from the XMA analysis results of thermal aging specimens.	Fig. 3.4-5
FR-EPR	The tubular type and cable type specimens are considered to happen at almost the same degradation from the XMA analysis results of simultaneous aging specimens.	Fig. 3.4-6
SHPVC	The tubular type and cable type specimens are considered to happen at almost the same degradation from color observation results of thermal aging specimens. However, the color change became significant at the parts contacting with conductors of cable type specimen, and especially the coloring area was enlarged at elevated temperatures. This coloring may be promoted by the catalytic effect of the copper conductor. The change of the surface hardness from the non aging specimen was small. The surface hardness is considered to be an insignificantly correlated with the thermal aging period.	Fig. 3.4-7
PVC	The tubular type and the cable type specimens are considered to happen at almost the same degradation from the color observation results of thermal aging specimens. The change of the surface hardness from the non aging specimen was small. The surface hardness is considered to be an insignificant correlation with the thermal aging period.	Fig. 3.4-8
PE	The tubular type and cable type specimens are considered to happen at almost the same degradation from XMA analysis results of thermal aging specimens.	Fig. 3.4-9

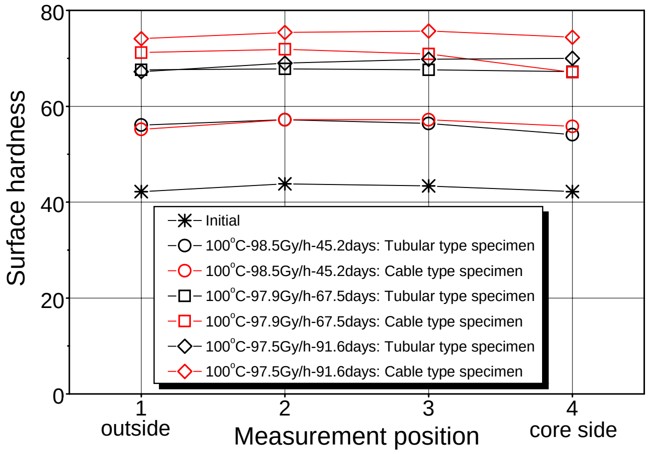
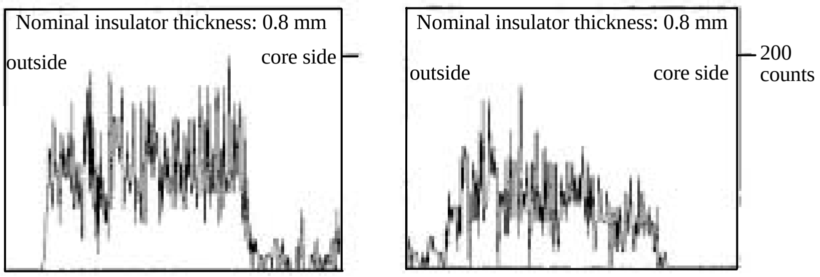


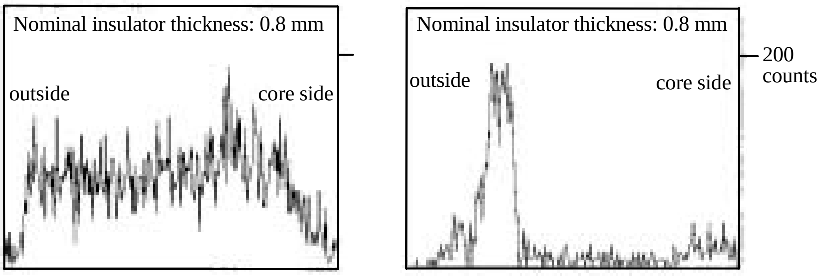
Fig. 3.4-1 Result of comparative tests of tubular type and cable type specimens for SIR insulator (surface hardness)

Notes: Refer to legend of Fig. 3.1-1 for measured positions.



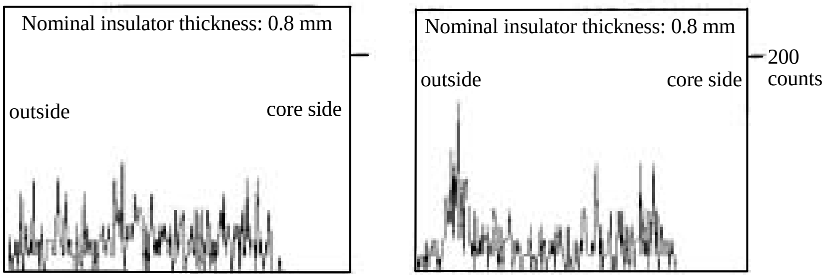
Tubular type specimen: B-A-32 Cable type specimen: B-B1-32

Fig. 3.4-2 Result of comparative tests of tubular type and cable type specimens for XLPE insulator, Aging condition: 100°C-98 Gy/h-124.8 days (XMA)



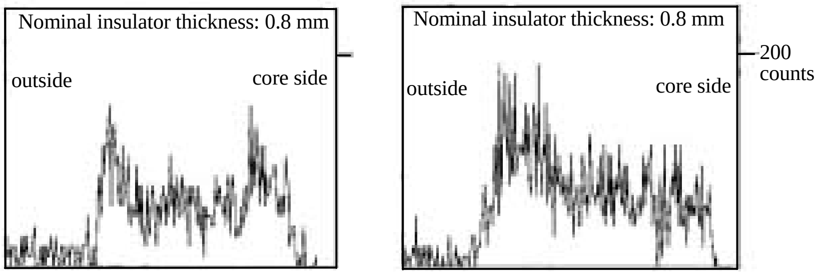
Tubular type specimen: B-A-08 Cable type specimen: B-B1-08

Fig. 3.4-3 Result of comparative tests of tubular type and cable type specimens for XLPE insulator, Aging condition: 130°C-194 days (XMA)



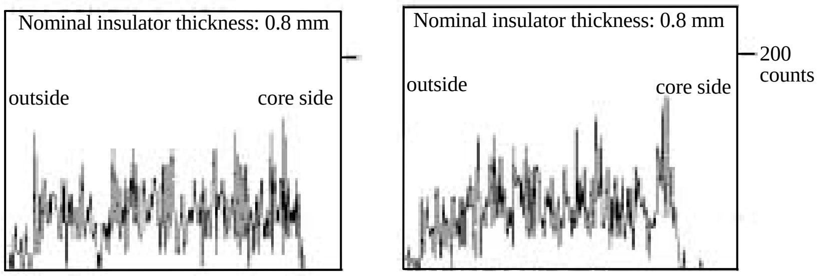
Tubular type specimen: C-A-08 Cable type specimen: C-B1-08

Fig. 3.4-4 Result of comparative tests of tubular type and cable type specimens for FR-XLPE insulator, Aging condition: 130°C - 194 days (XMA)



Tubular type specimen: D-A-09 Cable type specimen: D-B1-09

Fig. 3.4-5 Result of comparative tests of tubular type and cable type specimens for EPR insulator, Aging condition: 120°C- 243 days (XMA)



Tubular type specimen: E-A-32 Cable type specimen: E-B1-32

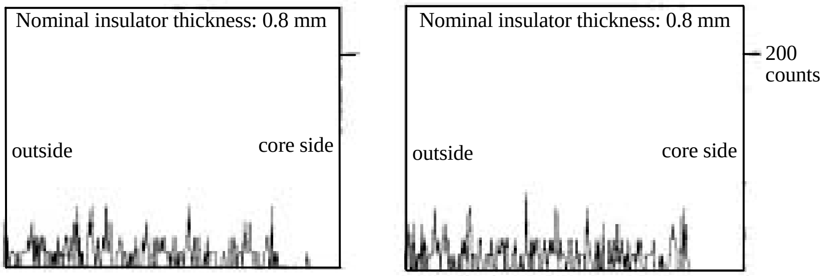
Fig. 3.4-6 Result of comparative tests of tubular type and cable type specimens for FR-EPR insulator, Aging condition: 100°C-94.4 Gy/h-166.3 days (XMA)

Tubular type specimen: G-A-08 Cable type specimen: G-B1-08

Fig. 3.4-7 Result of comparative tests of tubular type and cable type specimens for SHPVC insulator, Aging condition: 120°C-194 days (color change)

Tubular type specimen: H-A-07 Cable type specimen: H-B1-07

Fig. 3.4-8 Result of comparative tests of tubular type and cable type specimens for PVC insulator, Aging condition: 100°C-146 (color change)



Tubular type specimen: J-A-08 Cable type specimen: J-B1-08

Fig. 3.4-9 Result of comparative tests of tubular type and cable type specimens for PE insulator, Aging condition: 100°C-194 days (XMA)

3.5 Comparative tests of length of specimen for LOCA test

A 60 cm long cable specimen was degraded by simultaneous aging equivalent to those during normal operation, and then, exposed to the LOCA test including radiation exposure equivalent to that of DBE, and then subjected to a bend submerged withstand voltage test. As a result, the following items have been confirmed:

a. The 60 cm long cable specimen underwent uniform degradation throughout the cable length by simultaneous aging equivalent to those during normal operation. (A representative test result is shown in Fig. 3.5-1.);

b. The steam exposure test in the LOCA test is not dependant on the cable's length by connecting an additional cable;

c. For the bend submerged withstand voltage test, although a 60 cm long cable specimen was not long enough to be wound once around a mandrel, the required bending operation is practicable; and

d. As a reference, a comparison of break-down voltage values were made for 3 m long cable specimens and 60 cm long cable specimens, both of which were subjected to simultaneous aging , and then to the LOCA test under almost the same conditions. The result showed that there were some specimens without significant difference in break-down voltage values and some 3 m specimens with a larger reduction in break-down voltage values. However, the integrity of the cables could be justified by a 60cm long cable specimen.

The above results indicate that the cable aging evaluation using a 60 cm long cable specimen is practical. However, the same test will also be performed at the time of LOCA tests in the cable aging evaluation test. The length of cable for the LOCA tests in the guideline for the environmental qualification test for cables shall be determined based on the test results and the overseas.

Cracks have also occurred in the jacket of FR-PN cable during LOCA test. It was thought that the reason for these cracks was caused by ozone degradation of the jacket material or more specifically polychloroprene (1). Paraffin wax is effective in prevention against ozone damage, but where it was applied prior to the LOCA test, the decrease in cracks was only slightly improved.

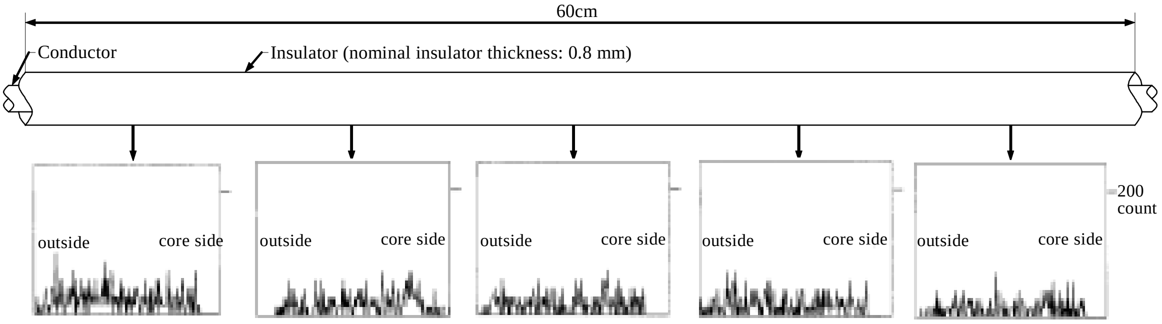


Fig. 3.5-1 Degradation situation of longitudinal direction of FR-PH-2.0 cable (insulator: FR-EPR), Aging conditions: 100°C - 96.0 Gy/h-77 days (XMA)

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(1) When polychloroprene is irradiated rapidly in air, ozone degradation occurs, but ozone degradation is considered to be very small in steam atmosphere which is equivalent to actual LOCA environment.

3.6 Comparative tests of thickness of specimen

As shown in Fig. 3.6-1 and 3.6-2, 0.8 and 1.0 mm thick insulators have almost the same progress of degradation, but the progress decreases relative to the increased thickness of 1.5 mm and 2.0 mm. This is considered to be caused by an uneven degradation progress into the inside of the insulator under the same aging conditions, if the insulator becomes thicker.

It has been confirmed in Section 3.4 that aging of approximately a 1 mm thick specimen was almost uniformly progressing into the inside under this test condition (100°C- 100 Gy/h). Testing with insulator of small thickness can be evaluated to be appropriate under the test condition of 100°C- 100 Gy/h.

In addition, a factor, which causes difference of the initial value of "elongation at break" even if a specimen is of the same manufacturer and consists of the same insulator material, is considered to depend on delicate differences of the degree of cross-linkage at the time of manufacturing.

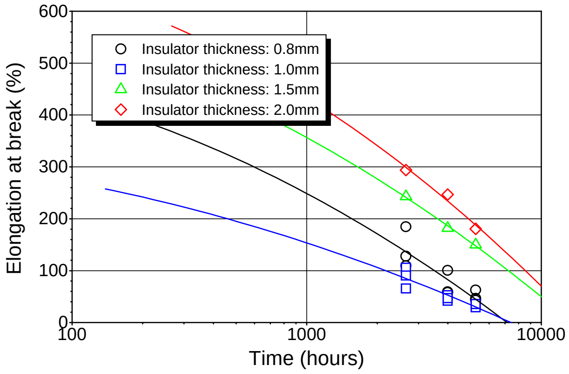


Fig. 3.6-1 Result of comparative tests of thickness of specimen for FR-EPR insulator (Aging condition: 100°C - approx. 100 Gy/h)

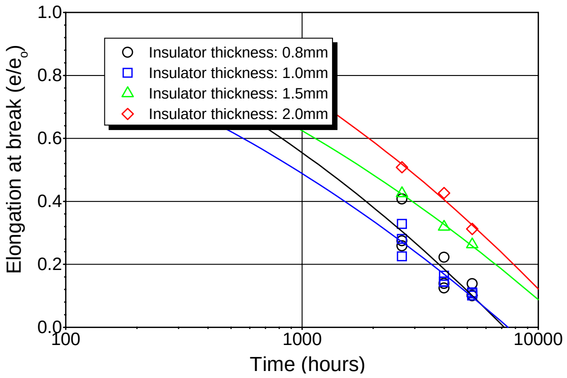


Fig. 3.6-2 Result of comparative tests of thickness of specimen for FR-EPR insulator (Aging condition: 100°C - approx. 100 Gy/h)

3.7 Comparative tests of installation procedure to oven specimens

Degradation of EPR was observed to be considerably more advanced, as compared with FR-EPR, as indicated by the tensile test results of the degraded specimen of EPR and FR-EPR insulators. These specimens were fabricated in accordance with the fabrication procedures of aging specimens shown in Table 3.7-1 (The aging condition is 120°C). However, even if either specimen of EPR or FR-EPR is installed in the process of heating, it is indicated that there is no significant difference of degradation among the specimens shown in Table 3.7-1.

Table 3.7-1 Preparation procedures of aging specimens in comparative test of installation procedure to oven specimens

Oven used	Installation procedures of Specimens	Thermal aging periods
No. 1-6	No additional specimen	Install ▼ 194 days ▼ Remove
No. 1-9	Pre-installed specimen	Install ▼ 194 days ▼ Remove
	Additionally installed specimen	49 days Install ▼ 194 days ▼ Remove

3.8 Fabrication conditions of aging specimen in cable aging evaluation test

Fig. 3.8-1 through 10 show thermal aging characteristics and simultaneous aging characteristics of each of the insulators which express the elongation at break obtained by the tensile test as an aging parameter.

From these results, it was determined that fabrication conditions shown in Table 3.8-1 and 3.8-2, respectively, were appropriate for fabrication of thermal aging specimen and simultaneous aging specimen used in the cable aging evaluation test.

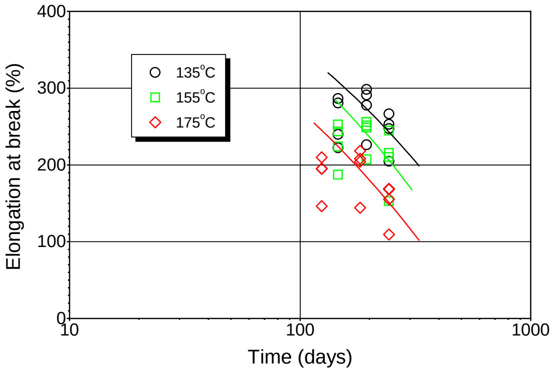


Fig. 3.8-1 Thermal aging characteristics of SIR insulator

Note: Data at the point of 135°C and 155°C -146 days and 175°C -124 days were considered as unique data consistent with the data following these data, and evaluation of thermal aging characteristics was performed except for these data.

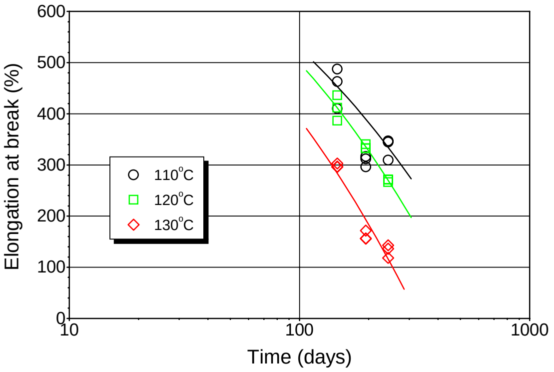


Fig. 3.8-2 Thermal aging characteristics of FR-XLPE insulator

Note: Data at the point of 110°C -194 days was considered as unique data consistent with the data before and after this data, and evaluation of thermal degradation characteristics at the 110°C was performed except for this data.

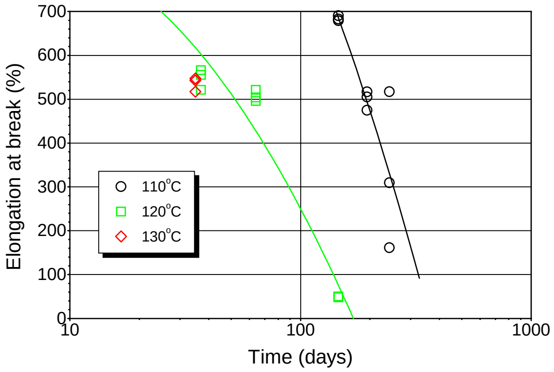


Fig. 3.8-3 Thermal aging characteristics of PE insulator

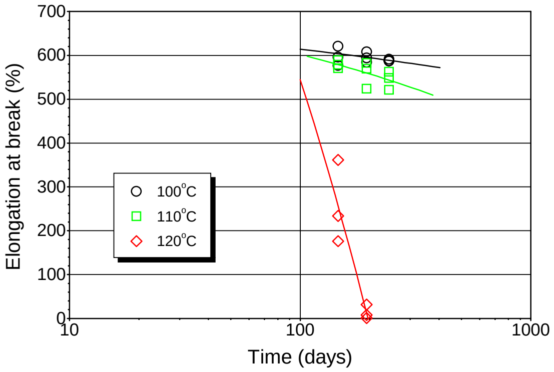


Fig. 3.8-4 Thermal aging characteristics of EPR insulator

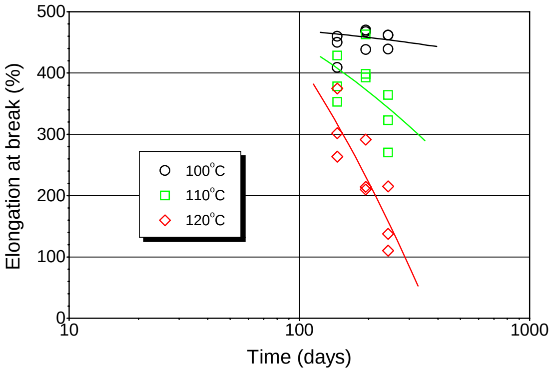


Fig. 3.8-5 Thermal aging characteristics of FR-EPR insulator

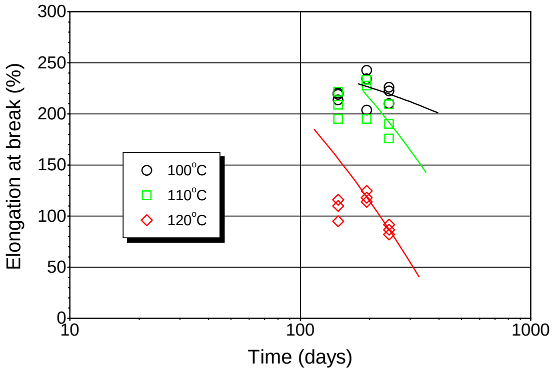


Fig. 3.8-6 Thermal aging characteristics of SHPVC insulator

Note: Data at the points of each temperature-146 days were considered as unique data consistent with the data following these data, and evaluation of thermal aging characteristics was performed except for this data.

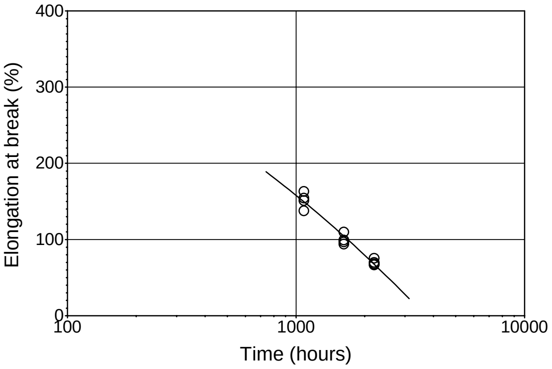


Fig. 3.8-7 Simultaneous aging characteristics of SIR insulator
(Aging condition: 100°C - approx. 100 Gy/h)

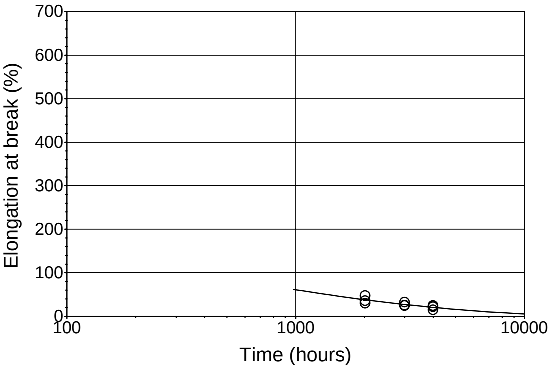


Fig. 3.8-8 Simultaneous aging characteristics of XLPE insulator
(Aging condition: 100°C - approx. 100 Gy/h)

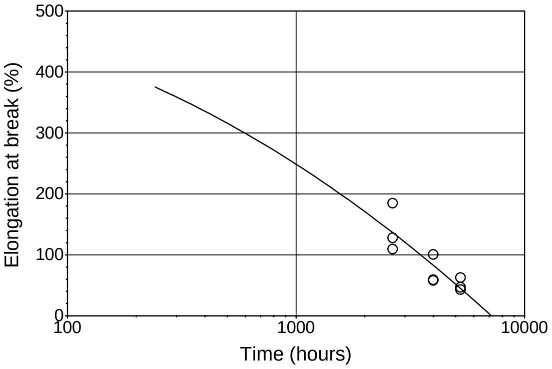


Fig. 3.8-9 Simultaneous aging characteristics of FR-EPR insulator
(Aging condition: 100°C - approx. 100 Gy/h)

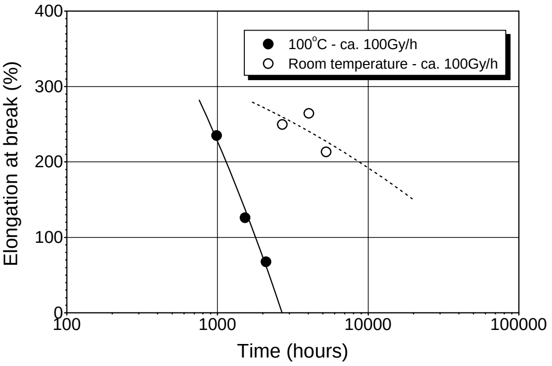


Fig. 3.8-10 Simultaneous aging characteristics of SHPVC insulator (60mm^2)

Table 3.8-1 Fabrication conditions of thermal aging specimens in the cable aging evaluation test

	1st condition		2nd condition		3rd condition	
	Temp.	Max. period	Temp.	Max. period	Temp.	Max. period
SIR insulated cable	135°C	4 yrs.	155°C	2 yrs.	175°C	1 yr.
XLPE insulated cable	100°C	4 yrs.	110°C	2 yrs.	120°C	1 yr.
FR-XLPE insulated cable	100°C	4 yrs.	110°C	2 yrs.	120°C	1 yr.
EPR insulated cable	100°C	4 yrs.	110°C	2 yrs.	120°C	1 yr.
FR-EPR insulated cable	100°C	4 yrs.	110°C	2 yrs.	120°C	1 yr.
SHPVC insulated cable	100°C	4 yrs.	110°C	2 yrs.	120°C	1 yr.

Table 3.8-2 Fabrication conditions of simultaneous aging specimens in the cable aging evaluation test

	1st - 3rd conditions			4th - 6th conditions			7th - 9th conditions		
	Temp.	Dose rate	Max. period	Temp.	Dose rate	Max. period	Temp.	Dose rate	Max. period
SIR insulated cable	100°C 115°C 135°C	3 Gy/h	48 mos.	100°C 115°C 135°C	18 Gy/h	15 mos.	100°C 115°C 135°C	100 Gy/h	9 mos.
XLPE insulated cable	80°C 90°C 100°C	3 Gy/h	48 mos.	80°C 90°C 100°C	18 Gy/h	15 mos.	80°C 90°C 100°C	100 Gy/h	9 mos.
FR-XLPE insulated cable	80°C 90°C 100°C	3 Gy/h	48 mos.	80°C 90°C 100°C	18 Gy/h	15 mos.	80°C 90°C 100°C	100 Gy/h	9 mos.
EPR insulated cable	80°C 90°C 100°C	3 Gy/h	48 mos.	80°C 90°C 100°C	18 Gy/h	15 mos.	80°C 90°C 100°C	100 Gy/h	9 mos.
FR-EPR insulated cable	80°C 90°C 100°C	3 Gy/h	48 mos.	80°C 90°C 100°C	18 Gy/h	15 mos.	80°C 90°C 100°C	100 Gy/h	9 mos.
SHPVC insulated cable	80°C 90°C 100°C	3 Gy/h	48 mos.	80°C 90°C 100°C	18 Gy/h	15 mos.	80°C 90°C 100°C	100 Gy/h	9 mos.

III. Cable Aging Evaluation Test

1. Test Program

1. 1 Selection of cable specimens

(1) Safety-related cables used in the nuclear power plant

The types of safety-related cable currently used in the nuclear power plant are shown in Table 1.1-1. In addition, although types of the safety-related cable are as shown in Table 1.1-1, each type of cable used is manufactured by several different cable manufacturers respectively.

Table 1.1-1 Safety-related cables used in the nuclear power plant

Classification of cable construction	Classification of insulator materials	Name of cable	Used area			
			PWR	BWR	IN*1	OUT*2
High voltage cable	XLPE	High voltage CA cable	○			○
		High voltage CV cable		○		○
		FR-High voltage CSV cable	○			○
		FR-High voltage CV cable		○		○
Low voltage cable	SIR	KA cable	○		○	
		KK cable	○		○	
		KGB cable		○	○	○
		FR-KK cable	○		○	
	XLPE	CV cable		○	○	○
		CN cable		○	○	
	FR-XLPR	FR-CV cable		○		○
	EPR	PA cable	○		○	
	FR-EPR	FR-PH cable	○		○	
		FR-PSHV cable	○			○
		FR-PN cable		○	○	
	SHVV	SHVA cable	○			○
		SHVV cable		○		○
		FR-SHVV cable	○			○
	PVC	VA cable	○			○
		VV cable	○	○		○
		FR-VV cable	○			○
	PE	EV cable		○		○
Coaxial cable	PE	Triaxial cable	○		○	○
		Coaxial cable		○		○
		Coaxial cable (double braid)		○		○
	XLPE	Coaxial cable		○	○	○
		Coaxial cable (double braid)		○	○	○
		FR-Coaxial cable		○	○	○
		FR-Coaxial cable (double braid)		○		○
		FR-Coaxial cable (triple braid)		○		○
		FR-Triaxial cable	○	○	○	○
		FR-Multiple coaxial Cable	○			○

*1：Inside of the reactor containment vessel　*2：Outside of the reactor containment vessel

(2) Selection policy of the specimens

There are about 40 types of safety-related cables currently used in the nuclear power plants, as shown in Table 1.1-1. Although all their aging assessment was necessary to be performed, the number of cable specimens was determined by screening those cables as candidates for evaluation from a viewpoint of importance to perform a reasonable number of tests.

In selection of the specimens, a cable is classified by its construction and insulator material for which functional maintenance is required. The classified cable is ranked sequentially in the order of higher importance by four judgment factors as shown below. The number of specimens was determined in accordance with the rank of cable.

a. Is there the functional requirement in the environment during a DBE?

b. Is the normal operational environment severe?

c. Is the maintenance difficult?

d. Is the progress of aging rapid from a conventional knowledge?

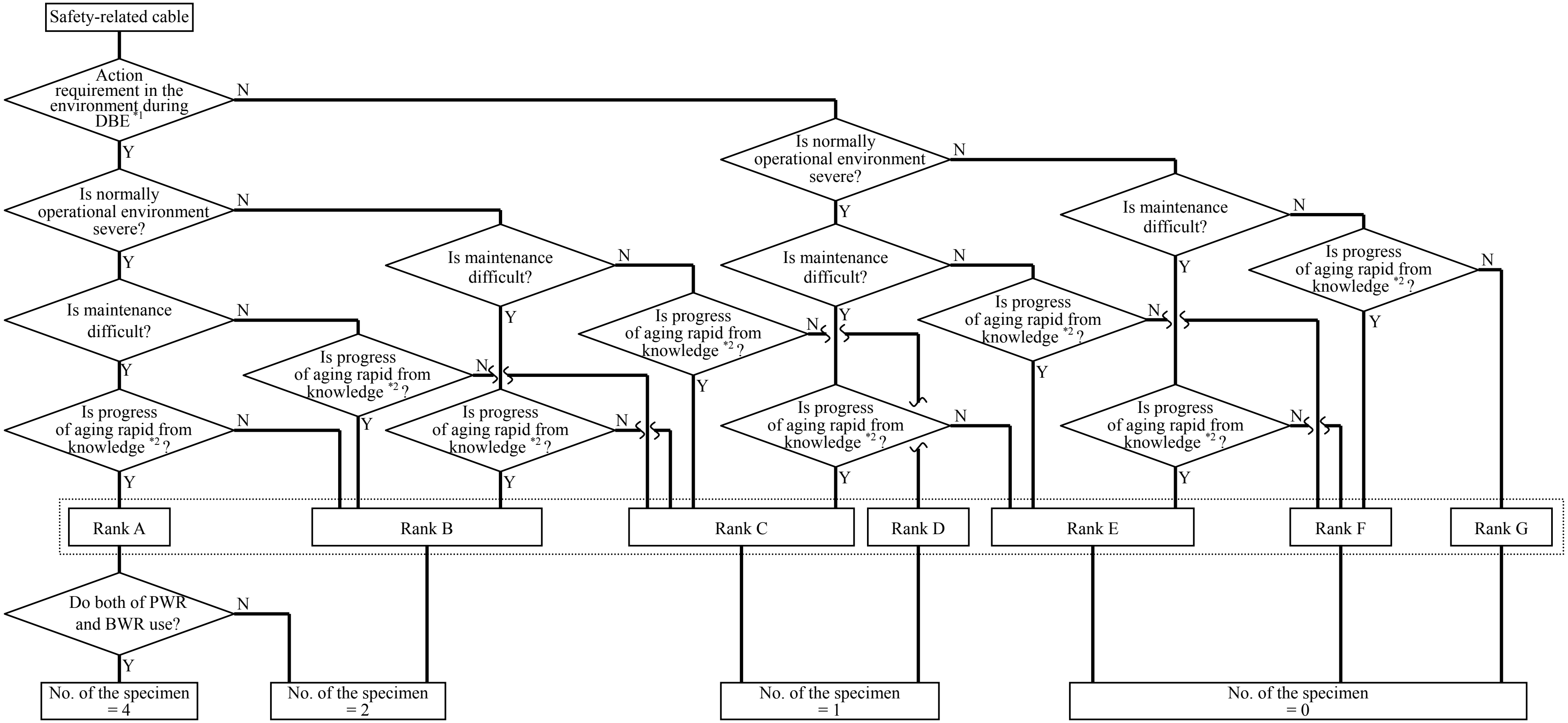
A flow chart for selection of the specimens is shown in Fig. 1.1-1.

In the flow chart as shown in Fig. 1.1-1, cables for evaluation are alternatively determined by each judgment factor in the above order, and classified in the order of highest importance into seven ranks of A, B, C, D, E, F, and G.

As a result, the cable with which all the items are considered as "Yes" by determination of each judgment factor is classified into "Rank A" with the highest importance. That is, there is the functional requirement in the environment during the DBE, the normal operational environment is severe, the detection of aging indication by inspections is hard (maintenance is difficult), and it is considered that the aging progress comparatively rapid from a conventional knowledge. To the contrary, the cable is classified into "Rank G" for which there is not the functional requirement in the environment during the DBE, the normal operational environment is comparatively mild, the detection of aging indication by inspections is easy (maintenance is easy), and it is considered that the aging progress comparatively slow from a conventional knowledge. Also, although there is the functional requirement in the environment of DBE, the cable is classified into the middle "Rank D" which is determined to be included in the lowest rank by the other judgment factors.

Regarding the number of the specimens, greater number of specimens should be selected for the cables with higher importance. Finally, the number of the specimens was determined to include four (or two) specimens from Rank A, two specimens from Rank B, and one specimen from Ranks C and D. For this reason, since the level of difference between cable manufacturers should be verified for the cables with higher importance, two or more manufacturers' specimens were to be selected for each type of insulator material of the high rank cables (Ranks A and B). In this case, considering the scope of application, the number of specimens for the cable of top Rank A included four specimens when they were used in the PWR and BWR plants, and two specimens when using in both of them.

On the other hand, the cable of a lower rank than "E" in the ranking of the cables without a functional requirement in the environment during the DBE (i.e. the cables for which the normal operational environment is comparatively mild, or the cables for which the maintenance is easy or the progress of aging is slow from a conventional knowledge even if the normal operational environment is severe) was not added to the specimens, because testing was not considered to be urgent.



*1：DBE in C/V and MS tunnel

*2：Knowledge based on plant data and accelerated test data up to now

Fig. 1.1-1 Flow chart for selection of the specimens

(3) Result of selection of the specimens

Fig. 1.1-2 and Table 1.1-2 show the specimens for the cable aging evaluation test selected based on the flow chart for selection of the specimens shown in Fig. 1.1-1. As shown in Fig. 1.1-2 and Table 1.1-2, a total of 14 types of cables also including two or more manufacturers' cables of the same type are provided for the specimens for the cable aging evaluation test.

In addition, cables with high importance (Ranks A and B) were planned to be selected from two or more manufacturers' cables in the flow chart for selection of the specimens. However, with regard to the cables for PWR plants, since it became difficult for some manufacturers to supply the equivalent cables because one main company of cable manufacturers stopped manufacturing cable for nuclear power plants, cable specimens were determined to be selected from cables of only the one company which is still now continuing to manufacture. The construction and others of these specimens are given in Appendix 1.

Table 1.1-2 The specimens in cable aging evaluation test

Name of cable	Cable specification				Used areas				Manufacturers	Cable code
	Insulator material	Jacket material	Conductor size [mm^2]	No. of cores	BWR	PWR	IN*1	OUT*2		
CV cable	XLPE	PVC	2.0	3	○		○	○	A Company	CV-2.0-A
									B Company	CV-2.0-B
FR-CV cable	FR-XLPE	FR-PVC or FR-SHPVC	2.0	3	○			○	A Company	FR-CV-2.0-A
									B Company	FR-CV-2.0-B
FR-Triaxial cable	XLPE	FR-XLPE	—	—		○	○	○	C Company	TRIAX
PA cable	EPR	Glass braid*3	2.0	3		○	○		C Company	PG-2.0
FR-PN cable	FR-EPR	FR-CR	2.0	3	○		○		A Company	FR-PN-2.0-A
									B Company	FR-PN-2.0-B
FR-PH cable	FR-EPR	FR-CSPE	2.0	3		○	○		C Company	FR-PH-2.0
KGB cable	SIR	Glass braid	2.0	3	○		○	○	A Company	KGB-2.0-A
									B Company	KGB-2.0-B
KK cable	SIR	SIR	1.25	4		○	○		C Company	KK-1.25
SHVV cable	SHPVC	FR-HPVC or HPVC	2.0	3	○			○	A Company	SHVV-2.0-A
									B Company	SHVV-2.0-B

*1：Inside containment vessel
*2：Outside containment vessel
*3：Although jacket material is originally asbestos braid, it is replaced with glass braid because of difficult manufacture.

Safety-related cables ⇨

Construction	Classification			Importance	Installation environment		Present Maintenance	Present knowledge*1		Number of cable specimens		
Categorized by the kind of construction ⇨	Classified by the kinds of insulators ⇨			Action requirement in environment during DBE ⇨	Inside or outside reactor containment vessel ⇨		Difficulty of maintenance ⇨	Degree of progress of thermal and radiation aging ⇨	Rank			
Categories	Kinds of Insulator	Cable names			Inside	Outside				Total	PWR	BWR
High-voltage cables	XLPE	High-voltage CA cable	PWR	No		○	Comparatively easy by electrical technique	Progress of aging is comparatively slow	G	–	–	–
		High-voltage CA cable	BWR			○						
		FR-High voltage CHA cable	PWR			○						
		FR-High voltage CV cable	BWR			○						
Low-voltage cables	SIR	KA cable	PWR	Yes	○		Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	A	3	1*2 (2)	2
		KK cable	PWR		○							
		KGB cable	BWR		○	○						
		FR-KK cable	PWR		○							
	XLPE	CV cable	BWR	Yes	○	○	Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	A	2	0	2
		CN cable	BWR		○							
	FR-XLPE	FR-CV cable	BWR	Yes		○	Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	B	2	0	2
	EPR	PA cable	PWR	Yes	○		Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	A	1	1*2 (2)	0
	EPR	FR-PH cable	PWR	Yes	○		Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	A	3	1*2 (2)	2
		FR-PSHV cable	PWR			○						
		FR-PN cable	BWR		○							
	SHVV	SHVA cable	PWR	Yes (BWR only)		○	Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	B	2	0	2
		SHVV cable	BWR			○						
		FR-SHVV cable	PWR			○						
	PVC	VA cable	PWR	No		○	Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	E	–	–	–
		VV cable	PWR/BWR			○						
		FR-VV cable	PWR			○						
	PE	EV cable	BWR	No		○	Comparatively difficult by electrical technique	Progress of aging is comparatively rapid	E	–	–	–
Coaxial cables	PE	Triaxial cable	PWR	No	○	○	Comparatively easy by electrical technique	Progress of aging is comparatively slow	F	–	–	–
		Coaxial cable	BWR			○						
		Coaxial cable (double braid)	BWR			○						
	XLPE	Coaxial cable	BWR	Yes	○	○	Comparatively easy by electrical technique	Progress of aging is comparatively slow	C	1	1	0
		Coaxial cable (double braid)	BWR		○	○						
		FR-Coaxial cable	BWR		○	○						
		FR-Coaxial cable (double braid)	BWR			○						
		FR-Coaxial cable (triple braid)	BWR		○	○						
		FR-Triaxial cable	PWR		○	○						
		FR-Multiple coaxial cable	PWR			○						
									Total	14	4	10

Notes *1：Knowledge based on actual operating data and accelerated test data up to now .

*2：The number of specimens is "2" from the flow chart for selection of cable specimens. However, since one main company of cable manufacturers of cables for the PWR plants stopped manufacturing cable and those equivalent cable products are not available, therefore, the number was determined to be "1".

Fig. 1.1-2 Results of selected cable specimens in the cable aging evaluation test

1.2 Testing conditions

The program of the cable aging evaluation test includes:

- fabrication of the thermal aging specimens as a parameter of aging period to evaluate thermal aging characteristics and activation energies of cable insulators;
- fabrication of the simultaneous aging specimens as a parameter of aging period to evaluate simultaneous aging characteristics of cable insulators; and
- successive acquisition of data by tensile testing of the specimens aged in a given period.

Here, the conditions of fabrication for the thermal aging specimens and the simultaneous aging specimens were investigated, and the detailed conditions for fabricating aging specimens were developed.

1. 2. 1 Conditions for fabrication of thermal aging specimens

(1) Heating temperature

The thermal aging specimens should be fabricated at three heating temperatures (at least 10 °C intervals) in the temperature zone where oxidization degradation progresses from the surface to the inside. One of these temperatures should be coincident with heating temperature used in fabricating the simultaneous aging specimens mentioned below.

The heating temperatures in fabricating thermal ageing specimens are shown in table 1.2.1-1(1).

Table 1.2.1-1 Heating temperature in fabricating thermal aging specimens

Insulation material	Conditions for fabricating thermal aging specimens			Remarks
	Minimum temperature	Intermediate temperature	Maximum temperature	
SIR	135 °C	155 °C	175°C	Max. continuous allowable operating temperature of insulator (ICEA)：125ºC
XLPE	100°C	110 ºC	120 ºC	Max. continuous allowable operating temperature of insulator：90 ºC
FR-XLPE	100 ºC	110 ºC	120 ºC	Max. continuous allowable operating temperature of insulator：90 ºC
EPR	100 ºC	110 ºC	120 ºC	Max. continuous allowable operating temperature of insulator：80 ºC
FR-EPR	100 ºC	110 ºC	120 ºC	Max. continuous allowable operating temperature of insulator：80 ºC
SHPVC	100 ºC	110 ºC	120 ºC	Max. continuous allowable operating temperature of insulator：80 ºC

In addition, the heating temperature shown in Table 1.2.1-1 was defined as temperature in the zone where oxidization degradation in the insulator progresses from the surface to the inside based on the preliminary test result, and also temperature at which significant progress of degradation was considered to be observed (Elongation at break reduces to approximately half of the initial value) in the below-mentioned fabrication

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(1)Maximum continuous allowable operating temperature of each insulator given in the remarks column of Table 1.2.1-1 is the temperature defined in the Table "Upper limit of Operating Temperature of Insulators used for Electrical Appliances and Materials" attached with the “Ordinance Concerning Technical Requirements for Electrical Appliances and Materials”. However, since temperature for SHPVC was not described in this table, temperature of 80°C given in the Standard of Electric Power B202 (this standard was enacted in December, 1969, and was subsequently unified by B206 and B9209) was applied. Temperature for SIR is also 90°C or 180°C in the attached table (180°C is applied, provided it is used for electric apparatus installed at the limited area where nobody may touch). Although SIR is considered to be usable up to 180°C in the nuclear power plant, U.S. ICEA (Insulated Cable Engineers Association) standard provides 125°C. 125°C was defined as the maximum continuous allowable operating temperature of SIR insulated cable used for low-voltage electric power cable in the Japanese PWR plants.

period (Minimum temperature: four years, intermediate temperature: two years, maximum temperature: one year).

(2) The number of specimens

The number of tensile test pieces fabricated in one heating period at one heating temperature is the number of cable cores x 3 (refer to this as one specimen), and the number of specimens at one heating temperature of one type of cable insulator is, in principle, 10 specimens.

In addition, the number of test pieces for acquiring one datum in the tensile test carried out after fabrication of aging specimens is three pieces based on Section 4.16 "Tensile Tests for Insulators and Jackets" in JIS C 3005$_{-2000}$ "Test Methods for Rubber or Plastic Insulated Wires and Cables".

(3) Geometry of specimens

The specimens for low-voltage cable have the thinnest insulator thickness (approximately 0.8 mm) in cables currently used, taking into account the diffusion velocity of oxygen in the insulator. Also, taking into account the number of acquired data in one heating-period at one heating-temperature, a triple-core cable is, in principle, used.

In this case, if a thermal aging specimen is fabricated from such a specimen as a cable finished-product, it is supposed that tensile test for the aging specimen could not be carried out because of firm sticking of the conductor with the insulator. Thus, except for coaxial cable, the cable is disassembled and the insulated core is cut into approximately 15cm in length, and the conductor is drawn out from the insulator before fabrication of thermal aging specimens. This tubular specimen is used for tensile testing.

In addition, the preliminary test verifies that the thinnest insulator (0.8 mm) in low-voltage cables currently used envelope the thicker insulators in terms of progress of degradation, and there is no significant difference between the cable finished-product and the tubular specimen.

An example of geometry of typical tubular specimen is shown in Fig. 1.2.1-1.

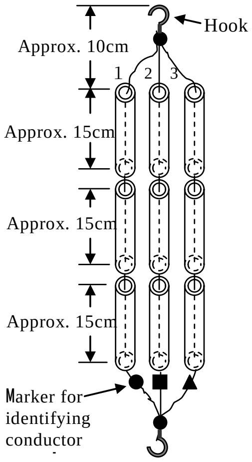


Fig. 1.2.1.-1 An example of geometry of a typical tubular specimen (Example of a triple-conductor cable)

(4) Heating period

The maximum heating period is four years at the minimum temperature in three heating temperatures. In addition, the heating period of four years will be equivalent to 60°C- 60 years, even if the heating temperature is 100°C , and the activation energy is estimated quite low (69.9 kJ/mol = 16.7 kcal/mol). If only heating is limited, it can be said that the period it envelops is 60 years at almost in all areas in the nuclear power plants.

Moreover, since the maximum heating periods at the intermediate temperature and at the maximum temperature for most of specimens are programmed by 10°C intervals from the minimum temperature, two years at the intermediate temperature and one year at the highest temperature are aimed respectively.

In addition, the heating period for specimens taken out from the oven in the way at each heating temperature is determined by assuming the period which provides as much equally progressing data of degradation as possible from the progressing percent of degradation in the preliminary test. The subsequent heating period should be, if needed, re-checked from the progressing percent of degradation of the aging specimens taken out from the oven on the way.

(5) Oven

The oven in accordance with B type testing equipment specified in JIS K 7212$_{-1999}$ is used for fabrication of the thermal aging specimens.

a. Oven should be a forced or non-forced air circulating type electric heating oven.

b. Air change rate should be more than one time per one hour.

c. Oven is not necessary to be gear-type oven for rotating the specimens.

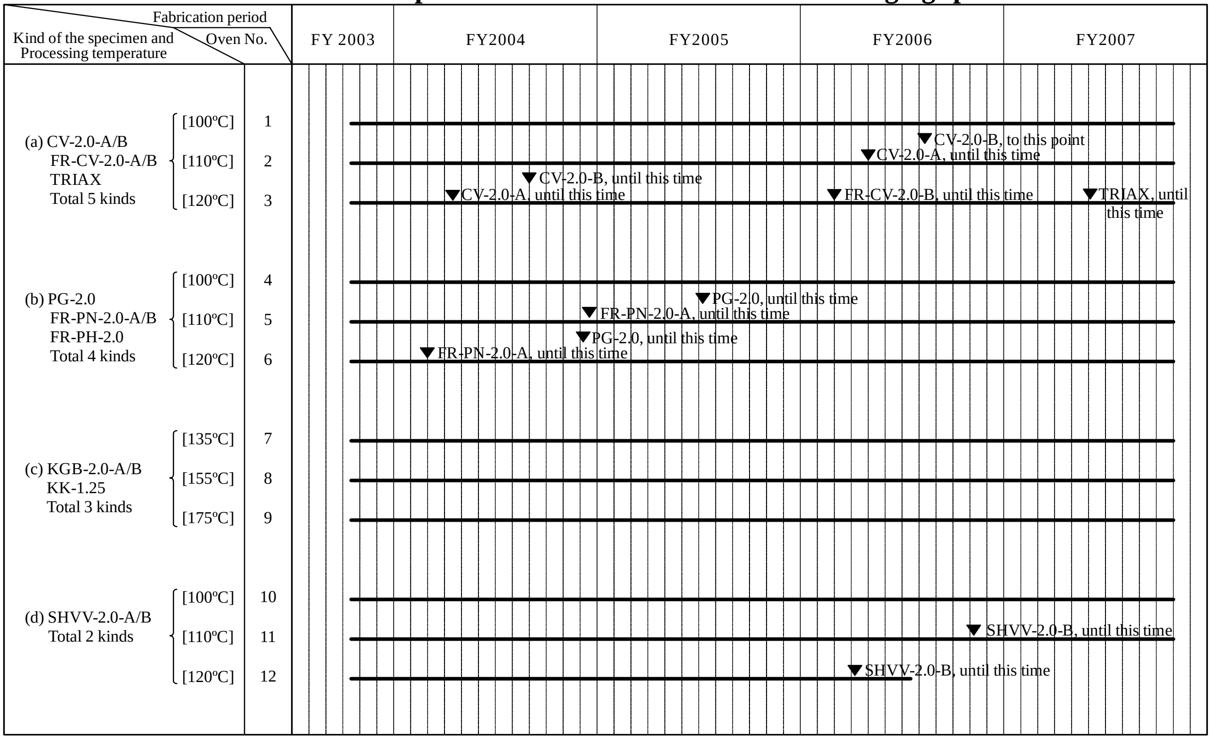
In addition, ovens are classified into four groups by insulator types; i.e. XLPE (FR-XLPE is included), EPR (FR-EPR is included), SIR, and SHPVC. As a result, a total of 12 sets of ovens will be used.

(6) Schedule planned for fabrication of thermal aging specimens

The schedule planned for fabrication of thermal aging specimens is shown in Table 1.2.1-2.

In addition, since some specimens had slow progress in their time of degradation, the fabrication periods of the thermal aging specimens at the intermediate and the maximum temperatures have been reviewed in process of fabrication, as appropriate.

Table 1.2.1-2 Schedule planned for the fabrication of thermal aging specimens



1.2.2 Conditions for fabrication of simultaneous aging specimens

It is considered that cable integrity evaluation under one assumed environmental condition can be performed by the simultaneous aging test. However, the combined environment of various thermal and radiation exposures exists in the nuclear power plants, resulting in necessity to perform the cable integrity evaluation corresponding to such various thermal and radiation environment in the future. Accordingly, it is desired to develop a cable aging predictive model; i.e. cable aging master curve (referred to as master curve hereinafter).

The techniques of “superposition of time dependent data”, “superposition of DED (dose to equivalent damage) data” and others have been proposed as the techniques to develop the master curve in IEC 1244-2 (Ref. 5) or IAEA-TECDOC-1188 (Ref. 6). Development of the master curve requires aging parameter data of “elongation at break" obtained by a combination of various dose rates with various temperatures. In addition, applicability of “superposition of time dependent data” has been studied for EPR and SIR, and a prospect of the applicability is reported to have been obtained (Ref. 10, 11).

Based on above, simultaneous aging specimens are fabricated by a combination of various dose rates with various temperatures so that the data necessary for development of the master curve (which is used as cable aging predictive model) can be acquired in fabricating of simultaneous aging specimens.

Conditions for fabricating these simultaneous aging specimens are shown below.

(1) Dose rate

Three kinds(2) of dose rates are used on the basis of the proposal of IEC 1244-2 and IAEA- TECDOC-1188. In this case, the same dose rate is used for each insulator material to fabricate the simultaneous aging specimens.

The maximum value in these dose rates is less than the maximum allowable dose rate to the thickness for every insulator material proposed by Seguchi and others (Ref. 9), and 100 Gy/h is used which envelops the maximum value of each insulator material.

The minimum dose rate is also determined to be 3 Gy/h. According to the investigating results of conditions for fabricating aging specimens, significant progress of degradation was concluded to be observed in each insulator (Reduction in elongation at break is 1/2 or less of the initial value as a standard: the residual elongation is 0.5 or less) even at the lowest temperature shown in the following section.

Furthermore, the intermediate dose rate is determined to be 18 Gy/h. The intermediate dose rate set to a value between the maximum and the minimum dose rates exponentially is considered to present easier evaluation in the future.

(2) Heating temperature

Three kinds (3) of heating temperatures are determined for each dose rate based on the proposal of IEC 1244-2 and IAEA-TECDOC-1188.

In this case, the minimum heating temperature is, in principle, the maximum continuous allowable operating temperature of each insulator. The intermediate and the maximum heating temperatures are the maximum continuous allowable operating temperature +10°C, and the maximum continuous allowable operating temperature +20°C respectively. However, regarding XLPE and FR-XLPE, since progress of simultaneous aging is a little earlier in tendency, those heating temperatures were determined to be by 10°C lower than each heating temperature determined as a general rule. Although the maximum continuous allowable operating temperature of SIR is as high as 125°C, its progress of degradation is also reported to be rapid at quite a low

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(2) In "superposition of time dependent data", at least three kinds of dose rates are proposed to be used. Also, although the dose rate became a parameter in "superposition of dose to equivalent damage data", it was considered that evaluation could be performed if there were three points.

(3) Two to three kinds of temperatures are proposed to be used in "superposition of time dependence data", and two or more temperatures are also proposed in "superposition of dose to equivalent damage data"

temperature in the case of simultaneous aging (Ref. 7, 8). Accordingly, each heating temperature (the minimum, the intermediate and the maximum) of SIR is determined to be 100°C, 115°C, and 135°C respectively. (Since dependability of SIR aging on heating is considered to be small, those intervals are determined to be 15°C and 20°C)

From above result, the heating temperature in fabricating the simultaneous aging specimens is determined as shown in Table 1.2.2-1.

Table1.2.2-1 Heating temperatures in fabricating simultaneous aging specimens

Insulation material	Heating temperatures		
	Minimum	Intermediate	Maximum
XLPE and FR-XLPE	80oC	90oC	100oC
EPR and FR-EPR	80oC	90oC	100oC
SIR	100oC	115oC	135oC
SHPVC	80oC	90oC	100oC

(3) The number and geometry of specimens

The number and geometry of simultaneous aging specimens are the same as those of the thermal aging specimens, geometry of which is of the tubular type, except for the specimens for LOCA test. In addition, cable finished-product type specimens are used for LOCA test.

(4) Fabrication period

The maximum fabrication period based on the minimum dose rate is determined to be four years (48 months) for fabricating the simultaneous aging specimens. In addition, if they are irradiated for four years with the minimum dose rate, the integrated dose rate will be 93 kGy (availability factor of irradiation facility is 90 %). When the integrated dose rate is simply divided by 60 years, the average dose rate will be 197 mGy/h (plant availability factor is 90 %). This average dose rate is a value enveloping the dose rates at most areas where the cable is installed in the nuclear power plant.

The maximum fabrication periods with the intermediate and the maximum dose rates are also determined to be 15 months and 9 months respectively. These fabrications can be performed more reasonably than the whole fabrication period. [(the maximum fabrication period with the intermediate dose rate＋the maximum fabrication period with the maximum dose rate) x 2 = 48 months: four years]. In this case, the integrated dose rates are 175 kGy for the intermediate dose rate (availability factor of irradiation facility is 90 %) and 583 kGy for the maximum dose rate (availability factor of irradiation facility is 90 %).

In addition, the fabrication period of specimens taken out on the way from the oven under each fabrication condition is determined by assumption of the period when more equally progressing data of degradation, if possible, can be acquired from the previous aging data and others. Then the subsequent fabrication period should be, if needed, re-checked by the progressing percent of degradation of the aging specimens removed on the way from the oven.

(5) Irradiation facility

The irradiation facility, which fabricates the simultaneous aging specimens, can utilize gamma irradiation, and the oven is installed in the facility. The dose rate in the facility can be appropriately adjusted by a distance from the radiation source, and shielding materials.

In addition, the dose rate distribution variation should be less than ±15 %(4) at each position of each specimen in the oven.

(6) Oven

The oven in accordance with B type testing equipment specified in JIS K 7212$_{\text{-1999}}$ is used for fabrication of the simultaneous aging specimens.

In addition, the ovens should be classified into four groups by insulator classification; i.e. XLPE (FR-XLPE is included), EPR (FR-EPR is included), SIR, and SHPVC.

As a result, if the fabrication period is taken into consideration, the number of ovens used in fabrication of the simultaneous aging specimens will be a total of 18 sets based on:

- 12 sets of 3 temperatures times 4 groups of insulators for fabrication with the minimum dose rate; and
- 6 sets of 3 temperatures times 2 groups used in series for fabrication with the maximum and intermediate dose rates.

In addition, the two new ovens will be added for fabrication of the specimens for LOCA test from the end of FY2004.

(7) Schedule planned for fabrication of simultaneous aging specimens

Table 1.2.2-2 shows the schedule planned for fabrication of simultaneous aging specimens.

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(4) Based on JEC-6152-1996 "Determination of the Effects of Ionizing Radiation on Electrical Insulating Materials".

Table 1.2.2-2 Schedule planned for fabrication of simultaneous aging specimens

Kind of the specimen and Process temperature/dose rate		Fabricating period Oven No.	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
(1) 3Gy/h								
1) CV-2.0-A/B FR-CV-2.0-A/B TRIAX Total of 5 kinds	[80°C	1	━	━	━	━	━	
	[90°C]	2	━	━	━	━	━	
	[100°C]	3	━	━	━	━	━	
2) PG-2.0 FR-PN-2.0-A/B FR-PH-2.0 Total of 4 kinds	[80°C]	4	━	━	━	━	━	
	[90°C]	5	━	━	━	━	━	
	[100°C]	6	━	━	━	━	━	
3) KGB-2.0-A/B KK-1.25 Total of 3 kinds	[100°C]	7	━	━	━	━	━	
	[115°C]	8	━	━	━	━	━	
	[135°C]	9	━	━	━	━	━	
4) SHVV-2.0-A/B Total of 2 kinds	[80°C]	10	━	━	━	━	━	
	[90°C]	11	━	━	━	━	━	
	[100°C]	12	━	━	━	━	━	
(2) 18Gy/h								
1) CV-2.0-A/B FR-CV-2.0-A/B TRIAX Total of 5 kinds	[80°C]	13-1	━	━				
	[90°C]	14-1	━	━				
	[100°C]	15-1	━	━				
2) PG-2.0 FR-PN-2.0-A/B FR-PH-2.0 Total of 4 kinds	[80°C]	16-1	━	━				
	[90°C]	17-1	━	━				
	[100°C]	18-1	━	━				
3) KGB-2.0-A/B KK-1.25 Total of 3 kinds	[100°C]	13-3			━	━	━	
	[115°C]	14-3			━	━	━	
	[135°C]	15-3			━	━	━	
4) SHVV-2.0-A/B Total of 2 kinds	[80°C]	16-3			━	━	━	
	[90°C]	17-3			━	━	━	
	[100°C]	18-3			━	━	━	
(3) 100Gy/h								
1) CV-2.0-A/B FR-CV-2.0-A/B TRIAX Total of 5 kinds	[80°C]	13-2			━			
	[90°C]	14-2			━			
	[100°C]	15-2			━			
2) PG-2.0 FR-PN-2.0-A/B FR-PH-2.0 Total of 4 kinds	[80°C]	16-2			━			
	[90°C]	17-2			━			
	[100°C]	18-2			━			
3) KGB-2.0-A/B KK-1.25 Total of 3 kinds	[100°C]	13-4					━	
	[115°C]	14-4					━	
	[135°C]	15-4					━	
4) SHVV-2.0-A/B Total of 2 kinds	[80°C]	16-4					━	
	[90°C]	17-4					━	
	[100°C]	18-4					━	
5) Specimens for LOCA test								
CV-2.0-A/B FR-CV-2.0-A/B TRIAX	[100°C]	19-1			━	━	━	
PG-2.0 FR-PN-2.0-A/B FR-PH-2.0	[100°C]	20-1			━	━	━	
KGB-2.0-A/B KK-1.25	[100°C]	19-2					━	
SHVV-2.0-A/B	[100°C]	20-2					━	

1.2.3 LOCA Test

(1) Basic policy of LOCA test

The basic policy of LOCA test is as follows.

a. Simultaneous aging specimens are used in LOCA test. Simultaneous aging specimens are simulated the aging of the normal operation period by simultaneous aging (100ºC- 100 Gy/h). In this case, three kinds of aging specimens with different accelerated aging periods are used as the LOCA specimens.
In addition, the same conditions (temperature and dose rate) to give equivalent aging during normal operation are used for each of the specimens. This is considered to be appropriate for comparison of the test results. Therefore, the above-mentioned conditions are regarded as the enveloping conditions for fabricating each of the simultaneous aging specimens in the cable aging evaluation test. The specimens with three kinds of different accelerated aging periods are also determined to be used so that correlation of a pre-aging level (elongation at break) with pass/fail of LOCA test can be understood.

b. Radiation and steam exposures equivalent to LOCA conditions are performed successively (steam exposure after irradiation).
In addition, almost all literature at home and overseas indicated that no significant difference existed between successive exposures (steam exposure after irradiation) and simultaneous exposures in the case of saturated steam.

c. The radiation dose equivalent to LOCA conditions is determined to be an analysis-based value of each plant.
In addition, specific radiation dose during LOCA is not described in the latest IEEE Std.323$_{-2003}$ and 383$_{-2003}$, and the dose expected to be generated during LOCA will be used.

d. Dose rate used LOCA test should be 10 kGy/h or less.
In addition, almost all literature at home and overseas indicated that there was no significant influence of the dose rate on aging in the case of saturated steam, and the average dose rate for over approximately one day from initiation of LOCA is 8 to 10 kGy/h based on LOCA analysis. The above-mentioned value was determined from these situations.

e. Temperature and pressure conditions for steam exposure should be on the analytical bases of each plant.
In addition, specific temperature and pressure conditions during LOCA are not described in the latest IEEE Std. 323-$_{2003}$, and the value with a certain margin added to analyzed value will be used.

f. The number of transient peaks in steam exposure may be defined as one time from the analytical base of each plant.
In addition, this is based on the latest IEEE Standards 323-$_{2003}$

g. Saturated steam is, in principle, used for steam exposure, and when saturated steam pressure becomes too high, heating steam is permitted to be used. This is for reasonable testing. In addition, literature reports (Ref. 10) that degradation of some materials progresses by forced air injection. Since the forced air injection was not considered to agree with the actual conditions in LOCA, it was decided not to use forced air injection.

h. Determination of integrity is performed in four steps of "Maintain the application of rated voltage during steam exposure", "JIS withstand voltage test(5) ", "IEEE withstand voltage test (with no bend operation)", and "IEEE bend submerged withstand voltage test". Final determination of the result (pass/fail) is tentatively performed by result of "JIS withstand voltage test".

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(5) Based on the withstand voltage test method specified in Section 4.6 of JIS C 3005$_{-2000}$, the test is performed with the withstand voltage value specified in each JIS per insulator type. (Example) Low-voltage PE insulated cable (XLPE is included): JIS C 3605$_{-2000}$, Low-voltage EPR insulated cable: JIS C 3621$_{-2000}$, Low-voltage SIR insulated cable: JIS C 3323$_{-2000}$, Low-voltage PVC insulated cable: JIS C 3342$_{-2000}$.

As for this point, the acceptance criteria of LOCA test is greatly different in the United States and Europe. Accordingly, acceptance tests in four steps are performed in the LOCA test of this project, and pass/fail was tentatively determined by the result of "JIS withstand voltage test". When all LOCA tests are finished, it was determined that suitable acceptance criteria would be defined by comparison of those test results.

(2) Pre-aging conditions of specimens for LOCA test

The specimens used for the LOCA test were given equivalent aging during normal operation on the conditions of 100°C- approx. 100 Gy/h (definite dose rate was determined after irradiation). The accelerated aging period was set from the plant manufacturers' recommended value based on various data acquired until now and their own data.

In this case, the specimens for LOCA test include three specimens of 60 cm short length and two specimens of 3 m long length for every cable specimen. Furthermore, three kinds of accelerated aging periods were set for each of them respectively. However, the three 3 m long specimens only were determined to be used for measurement of characteristics of triple-coaxial cable because of a measurement error of short specimens was considered to be larger. In addition, although LOCA test using the short specimens has been expected to be feasible from the preliminary test results, 3 m long specimens are applied for LOCA test as the latest trend in the United State (IEEE Std. 383_{-2003}). Accordingly, verification was made to determine again in this test whether a significant difference would arise in a test result because of the length.

At least one of the three kinds of accelerated aging periods should be a period to be considered for the specimens to pass determination of integrity after LOCA test from data up to now. The other two kinds of periods were set taking into account 60 years of service based on experiences to date.

The accelerated aging conditions equivalent to the aging of the normal operation period are shown in Table 1.2.3-1. In addition, the heating hours shown in Table 1.2.3-1 are reference data, and the irradiation hours mean simultaneous aging hours.

Table 1.2.3-1 Pre-aging conditions of LOCA test specimens

Kind of specimen	Specimen No.	Short length	Long length	Pre-aging conditions			
				Temp.	Average dose rate	Heating hours	Irradiation hours
A Company's XLPE insulated cable [CV-2.0-A]	A-B-84	○		100°C	86.8Gy/h	595Hr	591Hr
	A-B-85	○		100°C	86.7Gy/h	739Hr	734Hr
	A-B-86	○		100°C	86.7Gy/h	811Hr	805Hr
	A-B-81	○		100°C	96.7Gy/h	863Hr	852Hr
	A-B-82	○		100°C	97.0Gy/h	1,003Hr	988Hr
	A-B-83	○		100°C	97.0Gy/h	1,420Hr	1,399Hr
	A-B-93		○	100°C	89.4Gy/h	595Hr	591Hr
	A-B-94		○	100°C	89.4Gy/h	739Hr	734Hr
	A-B-95		○	100°C	89.3Gy/h	811Hr	805Hr
	A-B-91		○	100°C	99.3Gy/h	863Hr	852Hr
	A-B-92		○	100°C	99.6Gy/h	1,003Hr	988Hr
B Company's XLPE insulated cable [CV-2.0-B]	B-B-84	○		100°C	86.9Gy/h	503Hr	500Hr
	B-B-85	○		100°C	86.8Gy/h	643Hr	638Hr
	B-B-86	○		100°C	86.7Gy/h	811Hr	805Hr
	B-B-81	○		100°C	95.1Gy/h	1,007Hr	995Hr
	B-B-82	○		100°C	95.5Gy/h	1,507Hr	1,487Hr
	B-B-83	○		100°C	95.8Gy/h	2,016Hr	1,988Hr
	B-B-93		○	100°C	89.5Gy/h	503Hr	500Hr
	B-B-94		○	100°C	89.4Gy/h	643Hr	638Hr
	B-B-95		○	100°C	89.3Gy/h	811Hr	805Hr
	B-B-91		○	100°C	97.7Gy/h	1,007Hr	995Hr
	B-B-92		○	100°C	98.0Gy/h	1,507Hr	1,487Hr
A Company's FR-XLPE insulated cable [FR-CV-2.0-A]	C-B-81	○		100°C	97.4Gy/h	2,523Hr	2,500Hr
	C-B-82	○		100°C	96.9Gy/h	4,030Hr	3,987Hr
	C-B-83	○		100°C	96.6Gy/h	5,540Hr	5,476Hr
	C-B-91		○	100°C	99.3Gy/h	2,523Hr	2,500Hr
	C-B-92		○	100°C	99.0Gy/h	4,030Hr	3,987Hr
B Company's FR-XLPE insulated cable [FR-CV-2.0-B]	D-B-81	○		100°C	97.4Gy/h	2,523Hr	2,500Hr
	D-B-82	○		100°C	96.9Gy/h	4,030Hr	3,987Hr
	D-B-83	○		100°C	96.6Gy/h	5,540Hr	5,476Hr
	D-B-91		○	100°C	99.3Gy/h	2,523Hr	2,500Hr
	D-B-92		○	100°C	99.0Gy/h	4,030Hr	3,987Hr
C Company's XLPE insulated triaxial cable [TRIAX]	E-B-91		○	100°C	99.5Gy/h	2,183Hr	2,164Hr
	E-B-92		○	100°C	99.0Gy/h	4,007Hr	3,965Hr
	E-B-93		○	100°C	98.9Gy/h	5,752Hr	5,686Hr
C Company's EPR insulated cable [PG-2.0]	F-B-81	○		100°C	94.8Gy/h	4,744Hr	4,700Hr
	F-B-82	○		100°C	94.8Gy/h	5,897Hr	5,836Hr
	F-B-83	○		100°C	94.7Gy/h	7,065Hr	6,990Hr
	F-B-91		○	100°C	98.8Gy/h	4,744Hr	4,700Hr
	F-B-92		○	100°C	98.9Gy/h	5,897Hr	5,836Hr
A Company's FR-EPR insulated cable [FR-PN-2.0-A]	G-B-81	○		100°C	95.9Gy/h	2,009Hr	1,981Hr
	G-B-82	○		100°C	96.1Gy/h	3,023Hr	2,995Hr
	G-B-83	○		100°C	95.3Gy/h	4,030Hr	3,994Hr
	G-B-91		○	100°C	100.6Gy/h	2,009Hr	1,981Hr
	G-B-92		○	100°C	100.6Gy/h	3,023Hr	2,995Hr
B Company's FR-EPR insulated cable [FR-PN-2.0-B]	H-B-81	○		100°C	95.2Gy/h	3,017Hr	2,976Hr
	H-B-82	○		100°C	95.2Gy/h	5,032Hr	4,972Hr
	H-B-83	○		100°C	94.7Gy/h	7,065Hr	6,990Hr
	H-B-91		○	100°C	99.8Gy/h	3,017Hr	2,976Hr
	H-B-92		○	100°C	99.8Gy/h	5,032Hr	4,972Hr
C Company's FR-EPR insulated cable [FR-PH-2.0]	J-B-81	○		100°C	94.4Gy/h	4,312Hr	4,277Hr
	J-B-82	○		100°C	94.4Gy/h	5,272Hr	5,224Hr
	J-B-83	○		100°C	94.4Gy/h	6,232Hr	6,171Hr
	J-B-91		○	100°C	98.1Gy/h	4,312Hr	4,277Hr
	J-B-92		○	100°C	98.2Gy/h	5,272Hr	5,224Hr

Note: Equivalent pre-aging conditions during normal operation of specimens for LOCA test carried out after FY 2007 are being held.

(3) Procedures for LOCA test

Procedures for LOCA test are shown in Fig. 1.2.3-1.

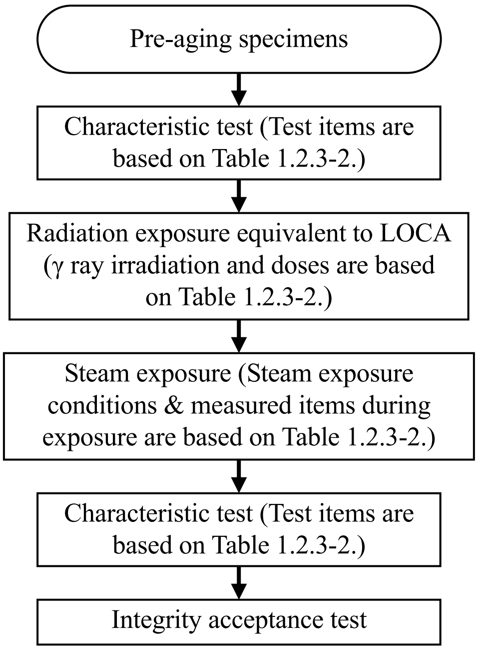


Fig. 1.2.3-1 Procedures for LOCA test

Table1.2.3-2 LOCA test conditions

Kind of specimen		Characteristic Test*[1]	Irradiation		Steam exposure	
			Dose	Dose rate	Exposure conditions	Measured items during exposure
1	CV-2.0-A CV-2.0-B	Insulation Resistance*[2]	260kGy*[5]	10kGy/h or less	Fig.1.2.3-2	Charged voltage, Leakage current
2	FR-CV-2.0-A FR-CV-2.0-B	Insulation Resistance*[2]	100kGy*[6]	1kGy/h or less	Fig. 1.2.3-3	Charged voltage, Leakage current
3	TRIAX	Insulation Resistance*[2], Characteristic impedance*[3], Attenuation*[3], Electric capacity*[4]	1500kGy*[7]	10kGy/h or less	Fig.1.2.3-4	Electric capacity, Insulation resistance
4	FR-PN-2.0-A FR-PN-2.0-B	Insulation Resistance*[2]	500kGy*[5]	10kGy/h or less	Fig.1.2.3-2	Charged voltage, Leakage current

*1：Long specimen is used.
*2：Based on the method specified in Section 4.7 of JIS C 3005-$_{2000.}$
*3：Based on the method specified in Section 5.7 of JIS C JIS C 3501$_{-1993.}$
*4：Based on the method specified in Section 4.8 of JIS C 3005-$_{2000.}$
*5：Enveloping value of dose during LOCA inside the reactor containment vessel in the BWR plant where the said cable is used.
*6：Enveloping value of dose during LOCA outside the reactor containment vessel in the BWR plant where the said cable is used.
*7：Enveloping value of dose during LOCA inside the reactor containment vessel in the PWR plant where the said cable is used.

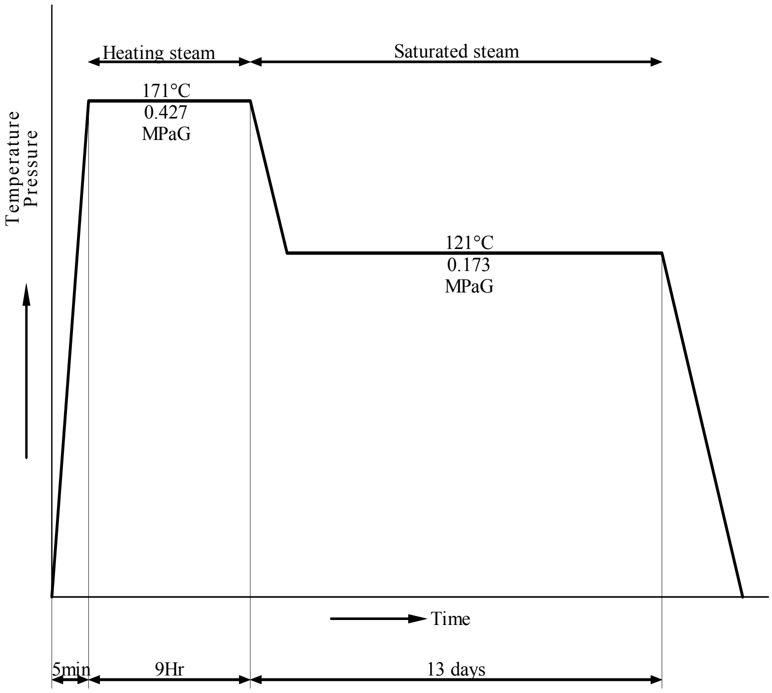


Fig. 1.2.3-2 Steam exposure test condition-1
(Enveloping test condition of inside the reactor containment vessel during LOCA of BWR plant)

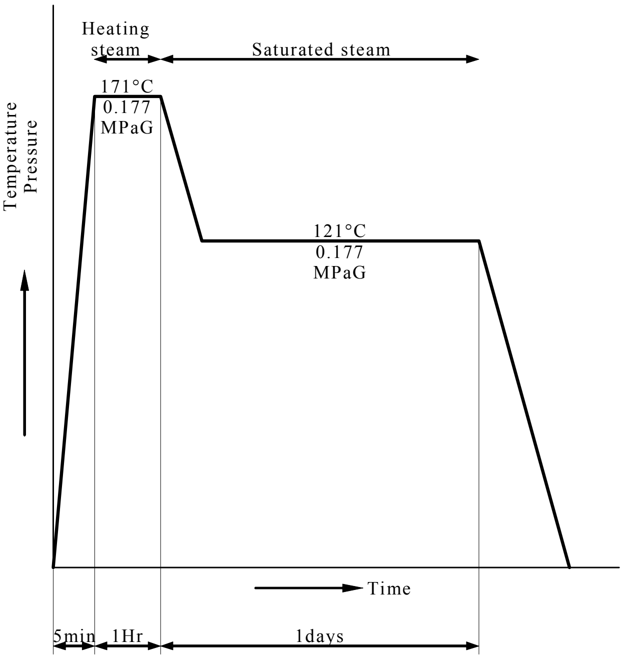


Fig. 1.2.3-3 Steam exposure test condition-2
(Enveloping test condition of outside the reactor containment vessel during LOCA of BWR plant)

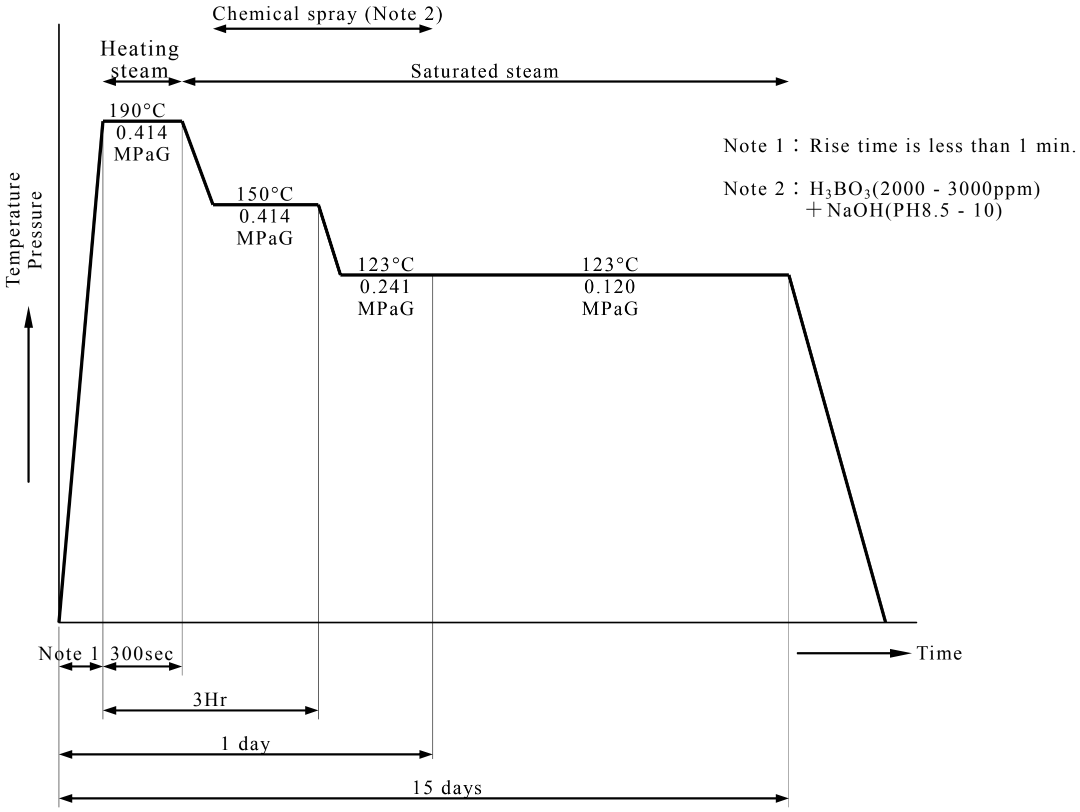


Fig. 1.2.3-4 Steam exposure test condition-3
(Enveloping test condition of inside the reactor containment vessel during LOCA of PWR plant)

(4) Schedule of LOCA test

Schedule of LOCA test to be performed by FY 2006 is shown in Table 1.2.3-3.

Table 1.2.3-3 Schedule for LOCA test

	2006 years									2007 years								Remarks
	4M	5M	6M	7M	8M	9M	10M	11M	12M	1M	2M	3M	4M	5M	6M	7M	8M	
CV-2.0-A CV-2.0-B		░	░	░				▦ ■	⊡						░ Re-test	▦ ■	⊡	Steam exposure Test condition-1
FR-CV-2.0-A FR-CV-2.0-A	░	░	░	░	░	░	░	░ ▦	■ ⊡									Steam exposure Test condition-2
TRIAX	░	░	░	░	░	░	░	░	▦ ■	■ ⊡								Steam exposure Test condition-3
FR-PN-2.0-A FR-PN-2.0-B	░	░	░	░	░	░	░	░	░	░	░ ▦	■ ⊡						Steam exposure Test condition-1
PG-2.0 FR-PH-2.0	░	░	░	░	░	░	░	░	░	░	░	░	▦	■ ⊡				Steam exposure Test condition-3

Legend: ░ Pre-aging ▦ Irradiation ■ Steam exposure ⊡ Acceptance test

2. Test

2.1 Fabrication of thermal aging specimens

2.1.1 Procedures for fabrication of thermal aging specimens

(1) Flow chart for fabrication of thermal aging specimens

Flow chart for fabrication of thermal aging specimens is shown in Fig. 2.1.1-1.

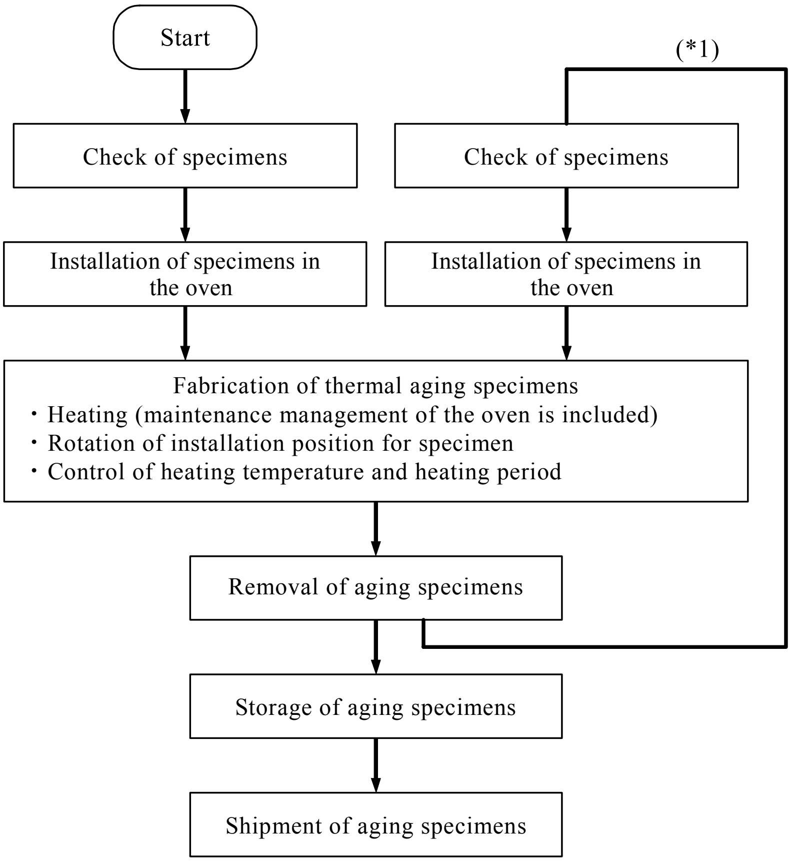


Fig. 2.1.1-1 Flow chart for fabrication of thermal aging specimens

*1：After aged specimens are removed from some ovens, new specimens may be installed.

(2) Check of specimens

For the specimens used for fabrication of thermal aging specimens, identification number, appearance, and the number of specimens should be checked before the start of fabrication.

Fig. 2.1.1-2 to 3 show the geometry of specimens used for fabrication of thermal aging specimens. Table 2.1.1-1 shows the numbering procedures of specimens.

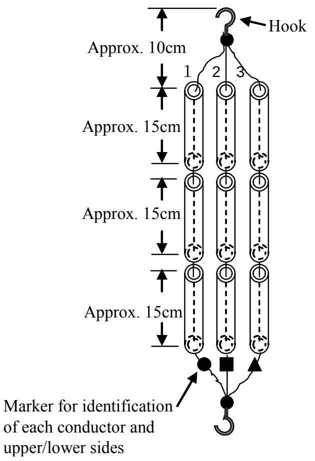


Fig. 2.1.1-2 Geometry of specimen type A

Note: Only M-A-xxx is 4-core construction

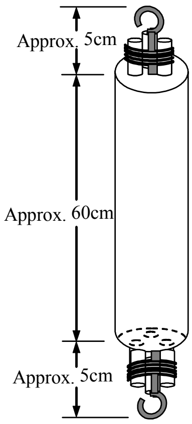


Fig. 2.1.1-3 Geometry of specimen type B

Table 2.1.1-1 Numbering procedures of thermal aging specimens

Name of cable	Cable specifications				Manufacturers	Kind of specimen	Specimen geometry	Specimen number[*2]
	Insulator material	Jacket material	Conductor size $[\mathrm{mm}^2]$	Number of cores				
CV cable	XLPE	PVC	2.0	3	A Company	CV-2.0-A	Type A	A-A-xxx
					B Company	CV-2.0-B	Type A	B-A-xxx
FR-CV cable	FR-XLPE	FR-PVC or FR-SHPVC	2.0	3	A Company	FR-CV-2.0-A	Type A	C-A-xxx
					B Company	FR-CV-2.0-B	Type A	D-A-xxx
FR-Triaxial cable	XLPE	FR-XLPE	—	—	C Company	TRIAX	Type B	E-B-xxx
PA cable	EPR	Glass braid[*1]	2.0	3	C Company	PG-2.0	Type A	F-A-xxx
FR-PN cable	FR-EPR	FR-CR	2.0	3	A Company	FR-PN-2.0-A	Type A	G-A-xxx
					B Company	FR-PN-2.0-B	Type A	H-A-xxx
FR-PH cable	FR-EPR	FR-CSPE	2.0	3	C Company	FR-PH-2.0	Type A	J-A-xxx
KGB cable	SIR	Glass braid	2.0	3	A Company	KGB-2.0-A	Type A	K-A-xxx
					B Company	KGB-2.0-B	Type A	L-A-xxx
KK cable	SIR	SIR	1.25	4	C Company	KK-1.25	Type A	M-A-xxx
SHVV cable	SHPVC	FR-HPVC or HPVC	2.0	3	A Company	SHVV-2.0-A	Type A	N-A-xxx
					B Company	SHVV-2.0-B	Type A	P-A-xxx

*1：Although asbestos braid is originally used, it is replaced with glass braid because of difficult manufacturing.
*2：xxx are three digits number. There is also xxx-y (y is also a number) as additional specimen. (Example: A-A-103-2)

(3) Fabrication conditions for thermal aging specimens

Fabrication conditions for thermal aging specimens are shown in Table 2.1.1-2.

In addition, the specimens shown in Table 2.1.1-2 were fabricated from cable specimens in Amagasaki Factory of Mitsubishi Cable Industries Company.

Table 2.1.1-2(1/3) Fabrication conditions for thermal aging specimens (No.1)

Oven number	Fabrication conditions	Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Specimen type	Specimen number		
No.1	100°C	Type A	A-A-101 to 110 A-A-103-2 to 4*9 A-A-104-2*5 B-A-101 to 110 B-A-101-2 to 5*2 C-A-101 to 110 C-A-103-2, 3*8 D-A-101 to 110 D-A-103-2, 3*8	48 months	Items without specific notice were started from January 16, 2004. *1:Started from May 5, 2004 *2: Started from October 25, 2004 *3: Started from December 1, 2004 *4:Started from December 20, 2004 *5: Started from February 17, 2005 *6: Started from March 25, 2005 *7: Started from August 3, 2005. *8: Started from September 8, 2005. *9: Started from July 24, 2006.
		Type B	E-B-101 to 110 E-B-101-2*2 E-B-106-2, 3*8		
No.2	110°C	Type A	A-A-111 to 20 A-A-111-2, 3*2 B-A-111 to 120 B-A-111-2, 3*2 B-A-112-2*2 B-A-112-3*7 B-A-113-2*4 C-A-111 to 120 C-A-116-2, 3*8 D-A-111 to 120 D-A-117-2, 3*8	48 months	
		Type B	E-B-111 to 120 E-B-111-2, 3*2 E-B-111-4*6 E-B-117-2, 3*8		
No.3	120°C	Type A	A-A-121 to 130 A-A-123-2*1 A-A-124-2*1 A-A-125-2*1 B-A-121 to 130 B-A-124-2*2 B-A-124-3*6 B-A-128-2*1 B-A-129-2*1 B-A-130-2*1 C-A-121 to 130 C-A-127-2 to 4*3 C-A-127-5*8 D-A-121 to 130 D-A-127-2 to 4*3	48 months	
		Type B	E-B-121 to 130 E-B-121-2, 3*2 E-B-130-2, 3*3 E-B-130-4*8		

Table 2.1.1-2(2/3) Fabrication conditions for thermal aging specimens (No.2)

Oven number	Fabrication conditions	Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Specimen type	Specimen number		
No.4	100ºC	Type A	F-A-101 to 110 F-A-103-2 to 4[*8] G-A-101 to 110 G-A-101-2 to 4[*3] G-A-101-5[*6] G-A-106-2[*6] H-A-101 to 110 H-A-103-2, 3[*8] J-A-101 to 110 J-A-103-2, 3[*8]	48 months	Items without specific notice were started from January 16, 2004. *1: Started from June 29, 2004. *2: Started from July 9, 2004.. *3: Started from October 25, 2004.. *4: Started from November 3, 2004.. *5: Started from December １, 2004. *6:Started from March 25、 2005. *7: Started from August 3, 2005. *8:Started from September,8,2005
No.5	110ºC	Type A	F-A-111 to 120 F-A-111-2 to 4[*4] G-A-111 to 120 G-A-111-2 to 6[*2] G-A-111-7[*3] H-A-111 to 120 H-A-116-2, 3[*8] J-A-111 to 120 J-A-118-2, 3[*8]	48 months	
No.6	120ºC	Type A	F-A-121 to 130 F-A-121-2 to 5[*4] F-A-121-6, 7[*7] G-A-121 to 130 G-A-121-2 to 9[*1] G-A-121-10[*3] G-A-121-11[*6] H-A-121 to 130 H-A-128-2 to 4[*5] H-A-129-2, 3[*8] J-A-121 to 130 J-A-128-2, 3[*5]	48 months	
No.7	135ºC	Type A	K-A-101 to 110 K-A-104-2, 3*[8] L-A-101 to 110 L-A-104-2, 3*[8] M-A-101 to 110 M-A-104-2, 3*[8]	48 months	
No.8	155ººC	Type A	K-A-111 to 120 K-A-118-2, 3[*8] L-A-111 to 120 L-A-117-2, 3[*8] M-A-111 to 120 M-A-117-2～3[*8]	48 months	
No.9	175ºC	Type A	K-A-121 to 130 K-A-128-2, 3[*5] K-A-128-4[*8] L-A-121 to 130 L-A-128-2, 3[*5] L-A-128-4[*8] M-A-121 to 130 M-A-128-2, 3[*5] M-A-128-4[*8]	48 months	

Table 2.1.1-2(3/3) Fabrication conditions for thermal aging specimens (No.3)

Oven number.	Fabrication conditions	Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Specimen type	Specimen number		
No.10	100ºC	Type A	N-A-101 to 110 N-A-104-2, 3^{*3} P-A-101 to 110 P-A-104-2,3^{*3}	48 months	Items without specific notice were started from January 16, 2004.. *1: Started from December 1 , 2004. *2: Started from March 25, 2005. *3: Started from September 8, .2005.
No.11	110ºC	Type A	N-A-111 to 120 N-A-117-2, 3^{*3} P-A-111 to 120 P-A-116-2, 3^{*3}	48 months	
No.12	120ºC	Type A	N-A-121 to 130 N-A-127-2^{*1} N-A-128-2, 3^{*1} N-A-128-4, 5^{*3} P-A-121 to 130 P-A-127-2^{*2} P-A-128-2, 3^{*1} P-A-128-4, 5^{*3}	24 months	

(4) Fabrication of thermal aging specimens

The thermal aging specimens are fabricated by heating the specimens during specified period, and maintaining a specified temperature inside the oven. Specifications for the oven used for fabrication the thermal aging specimen are given in appendix 2.

The dispersion in the values of temperature in the oven should be less than 2ºC in the range of T<100ºC, and less than 4ºC in the range of 100≤ºC < T 200ºC.

Also, differential temperature, which unites difference of temperature (temperature distribution) depending on the specimen positions in the oven and temperature fluctuated by time, should be less than 4ºC in the range of T ≤ 80ºC, and less than 5ºC in the range of 80ºC < T ≤ 180ºC.

While specimens in the oven rotate by 90 degrees on a horizontal plane at the rate of one time per a week, their upper and lower sides are reversed at every rotation (every four weeks).

Heating temperature and periods in the oven should be separately controlled by a data logger etc., and the electronic file of controlled data should be documented. In addition, when two hours or more continuous heating outage is expected because of maintenance of the oven, all specimens should be taken out from the oven, and they should be temporarily stored at room temperature. When their fabrication is resumed after heating outage, they should be installed after the temperature in the oven becomes constant.

(5) Removal and storage of aging specimens

After heating the specimens during a specified period, the aging specimens are removed from the oven, and should be temporally stored at room temperature until tensile testing is carried out.

2.1.2 Fabrication of thermal aging specimens

Fabrication of thermal aging specimens was carried out in Itami Factory of Mitsubishi Cable Industries Co. (Itami-shi, Hyogo-ken). However, the facility was transferred to the Amagasaki Factory (Amagasaki-shi, Hyogo-ken) from June, 2005, and from then fabrication of thermal aging specimens was carried out continuously. Based on the procedures for fabrication shown in the previous Section, 10 pieces of aging specimens in FY 2003, 262 pieces in FY 2004, 97 pieces in FY 2005, and 49 pieces in the first half of FY 2006 were fabricated respectively. Fabrication situation of the thermal aging specimens is shown in Fig. 2.1.2-1.

Fig. 2.1.2-1 Fabrication situation of thermal aging specimens

2.2 Fabrication of simultaneous aging specimens

2.2.1 Procedures for fabrication of simultaneous aging specimens

(1) Flow chart for fabrication of simultaneous aging specimens

A flow chart for fabrication of simultaneous aging specimens is shown in Fig. 2.2.1-1.

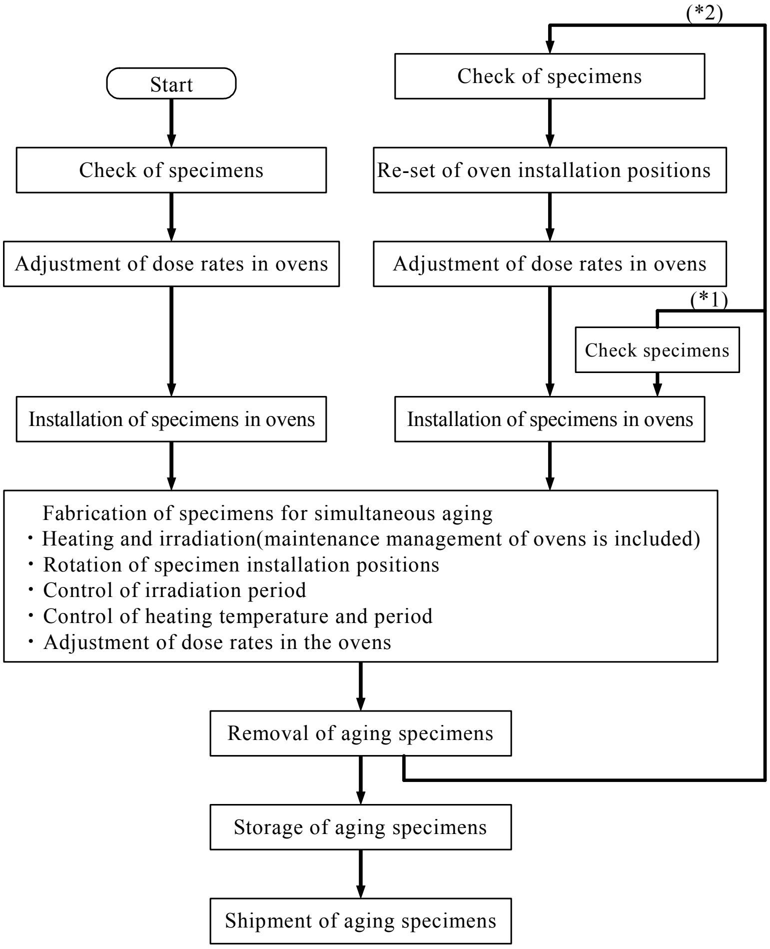


Fig. 2.2.1-1 Flow chart for fabrication of simultaneous aging specimens

*1: After the aging specimens are removed from some of the ovens, new specimens may be installed.

*2: After fabrication of one irradiation condition is finished, fabrication of the simultaneous aging specimens may be started anew, following change of the irradiation conditions.

(2) Check of specimens

Specimen number, appearance, and the number of specimens used for fabrication of simultaneous aging specimens are checked before start of fabrication.

Geometry used for fabrication of simultaneous aging specimens are shown in Fig. 2.2.1-2 and 3. The numbering procedures are shown in Table 2.2.1-1.

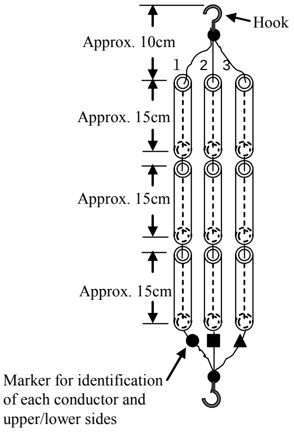


Fig. 2.2.1-2 Geometry of specimen Type A

Notes: Only M-A-xx consists of 4-cores construction

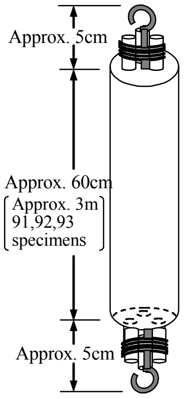


Fig. 2.2.1-3 Geometry of specimen Type B

Table 2.2.1-1 Numbering procedures of simultaneous aging specimens

Name of cable	Cable specifications				Manufacturer	Kind of specimen	Specimen geometry	Specimen number*2
	Insulator material	Jacket material	Conductor size [mm^2]	Number of cores				
CV cable	XLPE	PVC	2.0	3	A Company	CV-2.0-A	Type A	A-A-xx
							Type B	A-B-xx*3
					B Company	CV-2.0-B	Type A	B-A-xx
							Type B	B-B-xx*3
FR-CV cable	FR-XLPE	FR-PVC or FR-SHPVC	2.0	3	A Company	FR-CV-2.0-A	Type A	C-A-xx
							Type B	C-B-xx*3
					B Company	FR-CV-2.0-B	Type A	D-A-xx
							Type B	D-B-xx*3
FR-Triaxial cable	XLPE	FR-XLPE	—	—	C Company	TRIAX	Type B	E-B-xx
PA cable	EPR	Glass braid*1	2.0	3	C Company	PG-2.0	Type A	F-A-xx
							Type B	F-B-xx*3
FR-PN cable	FR-EPR	FR-CR	2.0	3	A Company	FR-PN-2.0-A	Type A	G-A-xx
							Type B	G-B-xx*3
					B Company	FR-PN-2.0-B	Type A	H-A-xx
							Type B	H-B-xx*3
FR-PH cable	FR-EPR	FR-CSPE	2.0	3	C Company	FR-PH-2.0	Type A	J-A-xx
							Type B	J-B-xx*3
KGB cable	SIR	Glass braid	2.0	3	A Company	KGB-2.0-A	Type A	K-A-xx
					B Company	KGB-2.0-B	Type A	L-A-xx
KK cable	SIR	SIR	1.25	4	C Company	KK-1.25	Type A	M-A-xx
SHVV cable	SHPVC	FR-HPVC or HPVC	2.0	3	A Company	SHVV-2.0-A	Type A	N-A-xx
					B Company	SHVV-2.0-B	Type A	P-A-xx

*1：Although asbestos braid is originally used, it is replaced with glass braid, since manufacturing is difficult.
*2：xx are double digits number. There is also xx-y (y is also a number) as additional specimen. (Example: B-A-01-2)
*3：All are simultaneous aging specimens for LOCA testing.

(3) Fabrication conditions for simultaneous aging specimens

Fabrication conditions for simultaneous aging specimens are shown in Table 2.2.1-2. In addition, the specimens shown in Table 2.2.1-2 were fabricated from cable specimens in the Itami Factory or the Amagasaki Factory of Mitsubishi Cable Industries.

Table 2.2.1-2 (1/7) Fabrication conditions for simultaneous aging specimens (No. 1)

Oven Number	Fabrication conditions		Specimens stored in the oven		Maximum fabrication Period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.1	80ºC	3Gy/h	Type A	A-A-01 to 10 A-A-08-02 to 04*5 B-A-01 to 10 B-A-01-02 to 05*2 C-A-01 to 10 D-A-01 to 10	48 months	Items without specific notice were started from November 7, 2003.. *1:Started from July 12, 2004 *2:Started from October 25, 2004 *3: Started from March 25, 2005 *4: Started from August 5, 2005 *5: Started from August 7, 2006
			Type B	E-B-01 to 10		
No.2	90ºC	3Gy/h	Type A	A-A-11 to 20 A-A-14-2*5 B-A-11 to 20 B-A-11-2 to 5*2 B-A-11-6, 7*4 B-A-61-4, 5*4 C-A-11 to 20 D-A-11 to 20	48 months	
			Type B	E-B-11 to 20		
No.3	100ºC	3Gy/h	Type A	A-A-21 to 30 A-A-21-4 to 6*5 A-A-22-2, 3*3 B-A-21 to 30 B-A-21-2, 3*1 B-A-21-4 to 6*2 B-A-21-7 to 9*4 B-A-71-5*4 C-A-21 to 30 D-A-21 to 30	48 months	
			Type B	E-B-21 to 30		
No.4	80ºC	3Gy/h	Type A	F-A-01 to 10 G-A-01 to 10 H-A-01 to 10 J-A-01 to 10	48 month	
No.5	90ºC	3Gy/h	Type A	F-A-11 to 20 G-A-11 to 20 H-A-11 to 20 J-A-11 to 20	48 months	
No.6	100ºC	3Gy/h	Type A	F-A-21 to 30 G-A-21 to 30 G-A-21-2 to 4*3 H-A-21 to 30 J-A-21 to 30	48 months	
No.7	100ºC	3Gy/h	Type A	K-A-01 to 10 L-A-01 to 10 M-A-01 to 10	48 months	
No.8	115ºC	3Gy/h	Type A	K-A-11 to 20 L-A-11 to 20 M-A-11 to 20	48 months	

Table 2.2.1-2 (2/7) Fabrication conditions for simultaneous aging specimens (No. 2)

Oven number.	Fabrication conditions		Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.9	135ºC	3Gy/h	Type A	K-A-21 to 30 L-A-21 to 30 M-A-21 to 30	48 months	Started from November 7, 2003
No.10	80ºC	3Gy/h	Type A	N-A-01 to 10 P-A-01 to 10	48 months	
No.11	90ºC	3Gy/h	Type A	N-A-11 to 20 P-A-11 to 20	48 months	
No.12	100ºC	3Gy/h	Type A	N-A-21 to 30 P-A-21 to 30	48 months	
No.13-1	80ºC	18Gy/h	Type A	A-A-31 to 40 A-A-34-2 to 4*[1] B-A-31 to 40 B-A-32-2, 3*[1] C-A-31 to 40 D-A-31 to 40	15 months	Items without specific notice were started from November 7, 2003. *1: Started from July 2, 2004 Fabrication of specimens during the maximum fabrication period was scheduled to finish on March14, 2005.
			Type B	E-B-31 to 40		
No.14-1	80ºC	18Gy/h	Type A	A-A-41 to 50 A-A-43-2 to 5*[1] B-A-41 to 50 B-A-41-2 to 4*[1] B-A-43-2*[1] C-A-41 to 50 D-A-41 to 50	15 months	
			Type B	E-B-41 to 50		
No.15-1	80ºC	18Gy/h	Type A	A-A-51 to 60 A-A-52-2 to 5*[1] B-A-51 to 60 B-A-51-2 to 4*[1] B-A-52-2*[1] B-A-53-2*[1] C-A-51 to 60 D-A-51 to 60	15 months	
			Type B	E-B-51 to 60		
No.16-1	80ºC	18Gy/h	Type A	F-A-31 to 40 G-A-31 to 40 H-A-31 to 40 J-A-31 to 40	15 months	
No.17-1	80ºC	18Gy/h	Type A	F-A-41 to 50 G-A-41 to 50 G-A-41-2 to 5*[1] H-A-41 to 50 J-A-41 to 50	15 months	
No.18-1	80ºC	18Gy/h	Type A	F-A-51 to 60 G-A-51 to 60 G-A-51-2 to 5*[1] G-A-52-2 to 4*[1] H-A-51 to 60 J-A-51 to 60	15 months	

Table 2.2.1-2 (3/7) Fabrication conditions for simultaneous aging specimens (No. 3)

Oven number	Fabrication conditions		Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen umber		
No.13-2	80ºC	100Gy/h	Type A	A-A-61 to 69 B-A-61 to 69 B-A-61-2, 3*[6] C-A-61 to 69 D-A-61 to 69	9 months	Items without specific notice were started from March 25, 2005. *1: Started from May 10, 2005. *2: Started from May 31, 2005. *3: Started from June 10, 2005. *4: Started from June 21, 2005. *5: Started from August 2, 2005. *6: Started from August 5, 2005. *7: Started from August 25, 2005. Fabrication of specimens during the maximum fabrication period was scheduled to be finished on December 5, 2005.
			Type B	E-B-61 to 69		
No.14-2	90ºC	100Gy/h	Type A	A-A-71 to 79 B-A-71 to 79 B-A-71-2 to 4*[6] C-A-71 to 79 D-A-71 to 79	9 months	
			Type B	E-B-71 to 79		
No.15-2	100ºC	100Gy/h	Type A	A-A-81, 82 A-A-83, 84*[4] A-A-85, 86, 89 A-A-87*[2] A-A-88*[1] B-A-81 to 84 B-A-81-2, 3*[6] B-A-85, 85-2*[4] B-A-86, 86-2*[2] B-A-87, 87-2*[1] B-A-88, 89 C-A-81 to 84, 86 C-A-85*[5] C-A-87*[2] C-A-88, 89 D-A-81 to 84, 86 D-A-85*[5] D-A-87*[2] D-A-88, 89	9 months	
			Type B	A-B-81*[4] A-B-82*[2] A-B-83*[1] B-B-81*[4] B-B-82*[2] B-B-83*[1] C-B-81*[4] C-B-82*[2] C-B-83 D-B-81*[4] D-B-82*[2] D-B-83 E-B-81 to 83 E-B-84*[7] E-B-85, 86 E-B-87*[3] E-B-88, 89		

Table 2.2.1-2 (4/7) Fabrication conditions for simultaneous aging specimens (No. 4)

Oven number	Fabrication conditions		Specimens Stored in the Oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.16-2	80ºC	100Gy/h	Type A	F-A-61 to 69 G-A-61 to 69 H-A-61 to 69 J-A-61 to 69	9 months	Items without specific notice were started from March 25, 2005. *1: Started from May 17, 2005. *2: Started from May 26, 2005. *3: Stated from July 4, 2005. *4: Started from July 15, 2005. *5: Stated from August 12, 2005. Fabrication of specimens during the maximum fabrication period was scheduled to be finished on December 5, 2005. .However, a part of No.18-2 was transferred to No.19 -2 from December 16, 2005 and continuously fabricated. Its fabrication was finished on April 21, 2006.
No.17-2	90ºC	100Gy/h	Type A	F-A-71 to 79 G-A-71 to 79 H-A-71 to 79 J-A-71 to 79	9 months	
No.18-2 (No.19-2)	100ºC	100Gy/h	Type A	F-A-81 to 85 F-A-86*[3] F-A-86-2, 3 F-A-87*[1] F-A-88, 89 G-A-81 to 86 G-A-87, 88*[4] G-A-87-2, 88-2 G-A-89 H-A-81 to 89 H-A-84-2 J-A-81 to 84 J-A-85*[5] J-A-86*[3] J-A-85-2, 86-2 J-A-87*[2] J-A-87-2 J-A-88, 89	12 months	
			Type B	F-B-81*[3] F-B-82*[1] F-B-83 G-B-81 G-B-82, 83*[4] H-B-81 to 83 J-B-81*[5] J-B-82*[3] J-B-83*[2]		

Table 2.2.1-2 (5/7) Fabrication conditions for simultaneous aging specimens (No. 5)

Oven No.	Fabrication conditions		Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.13-3	100ºC	18Gy/h	Type A	K-A-31 to 40 L-A-31 to 40 M-A-31 to 40	15 months	Started from December 16, 2005.
No.14-3	115ºC	18Gy/h	Type A	K-A-41 to 50 L-A-41 to 50 M-A-41 to 50	15 months	
No.15-3	135ºC	18Gy/h	Type A	K-A-51 to 60 L-A-51 to 60 M-A-51 to 60	15 months	
No.16-3	80ºC	18Gy/h	Type A	N-A-31 to 40 P-A-31 to 40	15 months	
No.17-3	90ºC	18Gy/h	Type A	N-A-41 to 50 P-A-41 to 50	15 months	
No.18-3	100ºC	18Gy/h	Type A	N-A-51 to 60 P-A-51 to 60	15 months	
No.13-4	100ºC	100Gy/h	Type A	K-A-61 to 69 L-A-61 to 69 M-A-61 to 69	5 months	Scheduled to be started from July 13, 2007.
			Type B	K-B-61 to 63 L-B-61 to 63 M-B-61 to 63		
No.14-4	115ºC	100Gy/h	Type A	K-A-71 to 79 L-A-71 to 79 M-A-71 to 79	5 months	
No.15-4	135ºC	100Gy/h	Type A	K-A-81 to 89 L-A-81 to 89 M-A-81 to 89	5 months	
No.16-4	80ºC	100Gy/h	Type A	N-A-61 to 69 P-A-61 to 69	5 months	
No.17-4	90ºC	100Gy/h	Type A	N-A-71 to 79 P-A-71 to 79	5 months	
No.18-4	100ºC	100Gy/h	Type A	N-A-81 to 89 P-A-81 to 89	5 months	
			Type B	N-B-81 to 83 P-B-81 to 83		

Table 2.2.1-2 (6/7) Fabrication conditions for simultaneous aging specimens (No. 6)

Oven number	Fabrication conditions		Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.19-1	100ºC	100Gy/h	Type B (3m long)	A-B-91*^{5} A-B-92*^{3} B-B-91*^{5} B-B-92*^{3} C-B-91*^{8} C-B-92*^{3} D-B-91*^{8} D-B-92*^{3} E-B-91*^{10} E-B-92*^{4} E-B-93	8 months	Items without specific notice were started from March 25, 2005.. *1：Started from May, 17, 2005. *3：Started from May, 31 2005. *4：Started from June 10, 2005 *5：Started from June 21, 2005. *6：Started from July, 4, 2005. *7：Started from July 15, 2005. *8：Stated from August 2, 2005 *9：Started from August 12, 2005. *10：Started from August 25, 2005. Fabrication of the specimen during the maximum fabrication period in No.19-1 specimens was finished on December 5, 2005 and for No.20-1 specimens on March 14, 2006.
No.20-1	100ºC	100Gy/h	Type B (3m long)	F-B-91*^{6} F-B-92*^{1} G-B-91 G-B-92*^{7} H-B-91 H-B-92*^{8} J-B-91*^{9} J-B-92*^{6}	8 months	
No.19-2	100ºC	100Gy/h	Type A	F-A-86*^{6} F-A-86-2, 3 F-A-87*^{1} F-A-88, 89 G-A-88*^{7} H-A-87 to 89 H-A-84-2 J-A-81 to 84 J-A-85*^{9} J-A-86*^{6} J-A-87*^{6} J-A-88, 89	9 months	Items without specific notice were started from March 25, 2005. They were transferred from No.18-2 on December16, 2005. *1：Started from May 17, 2005. *2：Started from May 26, 2005. *6：Started from July 4, 2005. *7：Started from July 15, 2005. *9：Started from August 12, 2005. Fabrication of specimens during the maximum fabrication period was finished on April 21, 2006.
			Type B	F-B-81*^{6} F-B-82*^{1} F-B-83 G-B-83*^{7} H-B-83 J-B-81*^{9} J-B-82*^{6} J-B-83*^{2}		
No.19-3	100ºC	100Gy/h	Type A	A-A-82-2 A-A-83-2 A-A-84-2 B-A-82-2, 3 B-A-83-2, 3 B-A-84-2, 3	1 months	Started from May 26, 2006. Fabrication of specimens during the maximum fabrication period was finished on June 29, 2006.
			Type B	A-B-84 to 6 B-B-84 to 6		
No.20-2	100ºC	100Gy/h	Type B (3m long)	A-B-93 to 95 B-B-93 to 95		

Table 2.2.1-2 (7/7) Fabrication conditions for simultaneous aging specimens (No. 7)

Oven number	Fabrication conditions		Specimens stored in the oven		Maximum fabrication period	Remarks
	Temperature	Dose rate	Specimen type	Specimen number		
No.19-4	100ºC	100Gy/h	Type A	F-A-85-2 F-A-85-3 F-A-85-4 J-A-84-2 J-A-84-3 J-A-84-4	6 months	Started from August 7, 2006.
			Type B	F-B-84 F-B-85 F-B-86 J-B-84 J-B-85 J-B-86		
No.20-3	100ºC	100Gy/h	Type B (3m long)	F-B-94 F-B-95 F-B-96 J-B-94 J-B-95 J-B-96	6 months	
No.19-5	100ºC	100Gy/h	Type B (3m long)	K-B-91 to 93 L-B-91 to 93 M-B-91 to 93	5 months	Scheduled to be started from July 13, 2007
No.20-4	100ºC	100Gy/h	Type B (3m long)	N-B-91 to 93 N-B-91 to 93		

(4) Adjustment of dose rate

Radiation exposure is performed with gamma irradiation of cobalt 60. The distance from the radiation source and shielding materials can adjust the dose distribution (eight representative specimen-installed positions) of specimen positions in the oven installed in the irradiation facility. The dispersion in the values of dose rate should be less than ±15% of the specified dose rates. In addition, the dose rates are measured with alanine dosimeter. Each value after adjustment is also recorded, and this average value is defined as a definite dose rate. (A significant figure of the dose rate may be triple figures.)

Adjustment of the dose rate should be carried out at the time of change of dose rates in the oven, or once per a maximum of six months.

(5) Installation of specimens

After the inside of the oven, which is installed in a specified dose rate area of the irradiation facility, has been maintained at a specified temperature, specimens shown in Table 2.2.1-2 are installed in each oven. Fig. 2.2.1-4 shows image of the hanged specimens in the oven.

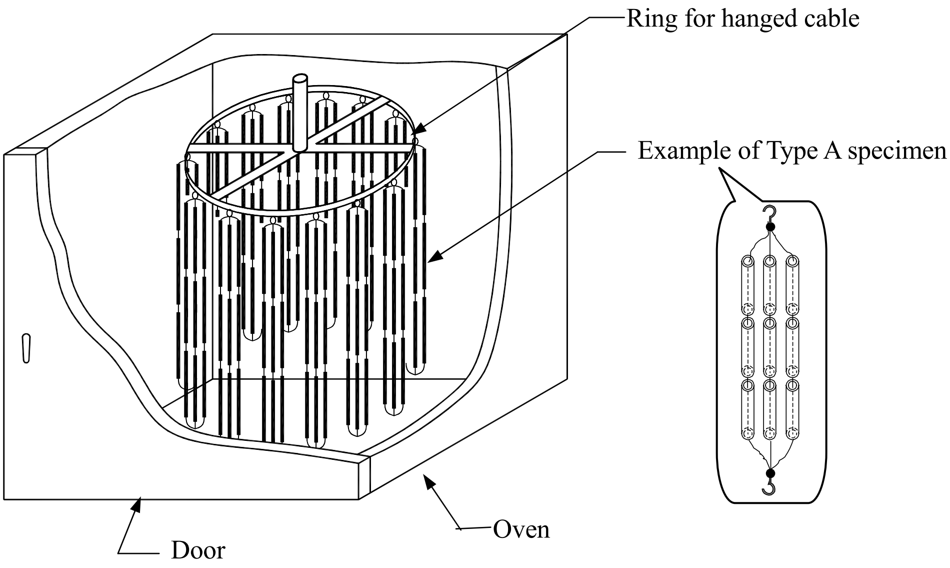


Fig. 2.2.1-4 Image of hanged specimens in the oven

(6) Procedures for fabrication of simultaneous aging specimens

The simultaneous aging specimens are fabricated by heating and irradiating the specimens during a specified period, while the inside of the oven is maintained at a specified temperature and a specified dose rate. Table 2.2.1-3 and Fig. 2.2.1-5 show specifications and geometry for the oven used for fabrication of simultaneous aging specimens, respectively. Fig. 2.2.1-6 shows arrangement of the ovens in the irradiation facility. Outline of the irradiation facility is given in appendix-3.

The dispersion in the values of temperature in the oven should be less than 2oC in the range of T≦100oC, and less than 4°C in the range of 100°C < T≦200°C. Temperature variation, which unites temperature difference (temperature distribution) depending on the specimen positions and temperature fluctuated by time in the oven, should be less than 4ºC in the range of T≦80oC, and less than 5oC in the range of 80oC < T≦180oC.

The specimens in the oven rotate by 90 degrees on a horizontal plane at the rate of one time per week, and their upper and lower sides are reversed every one rotation (every four weeks)

Heating and irradiation periods in the oven should be controlled separately. In this case, the heating period as well as the heating temperature is controlled with a data logger. Irradiation period is also controlled with a personal computer, and the electronic file of control data should be documented. In addition, heating in the oven should not be halted at the short-time outage of radiation exposure during rotation of the specimens described in the previous Section and during removal of the aging specimens. However, when two hours or more outage of radiation exposure is expected, all specimens should be taken out from the oven, and be temporarily stored at room temperature outside the irradiation facility. In this case, appropriate judgment should be made to determine whether heating in the oven is halted. However, when irradiation of the specimens is resumed after heating outage, they should be reinstalled, and irradiation should be resumed after temperature in the oven reaches to a specified temperature.

Dose rate during irradiation period (average dose rate) can be calculated by dividing the integrated dose into the irradiation period. In this case, the integrated dose was calculated from a measured dose rate and a half-life of cobalt 60. A formula is shown below.

$$R_{av} = (R \times (1-\mathrm{EXP}(-\lambda \times t))/\lambda)/t$$

R_{av}: Average dose rate (Gy/h) during irradiation period from the adjustment time of dose rate
R: Definite dose rate (Gy/h)
t: Time interval of the measurement date of dose rate (=R) to the date as a target
λ: $0.6931/(5.271 \times 365.25 \times 24) = 1.500 \times 10^{-5}$

Table 2.2.1-3 Specifications of oven used for fabrication of simultaneous aging specimens

Items	Specifications
1. Source voltage	AC200V 3 phase 50 Hz
2. Electric power consumption	2 KVA
3. Inside dimension	350W×750H×300D
4. Outside dimension	470W×810H×680D
5. Weight	74 kg
6. System	Forced hot wind circulation, Natural ventilation system
7. Performance	(Ambient temperature 20°C, Performance in Unloaded and circulated operational conditions)
a. Temperature range	Ambient temperature 20 - 140°C
b. Adjustable range of temperature	±0.2°C
c. Temperature distribution	±1.0°C
d. Rise time of temperature	45 min. or less
8. Heater	Panel heater 2 phase 200V 1.8KVA
9. Fan	Stainless propeller fan 3 phase 200V 60W
10. Damper	Natural ventilation Replaced frequency of air: 1 time/hour or more

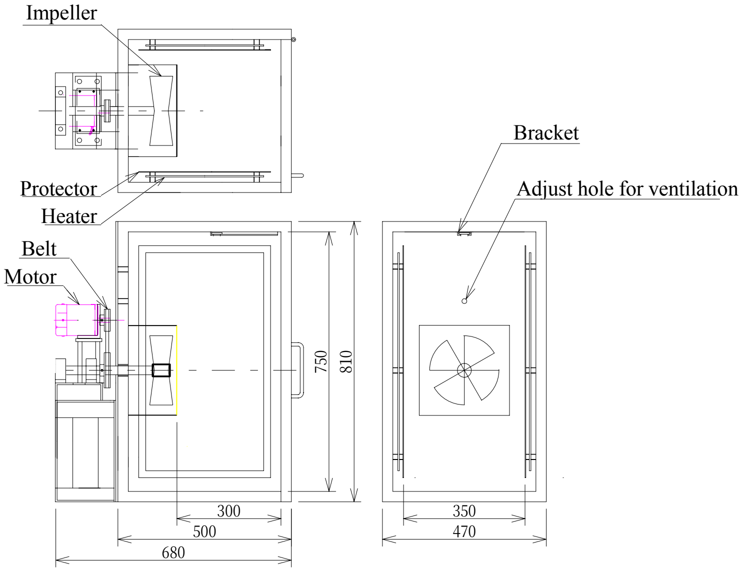
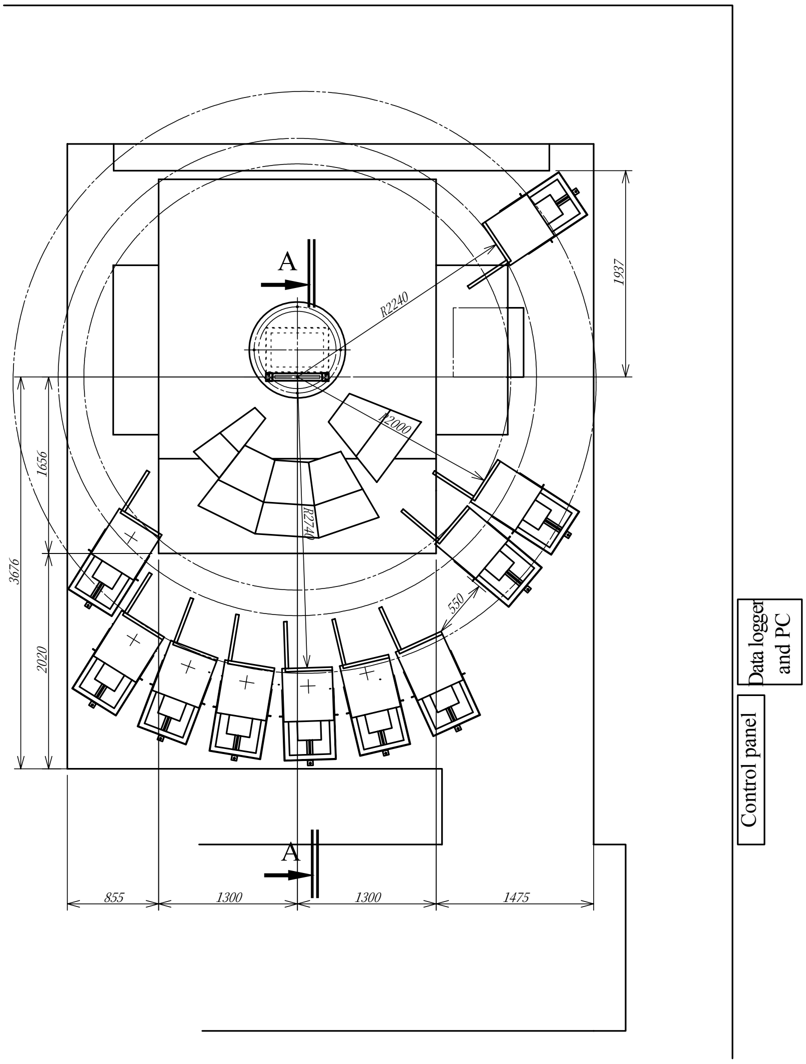
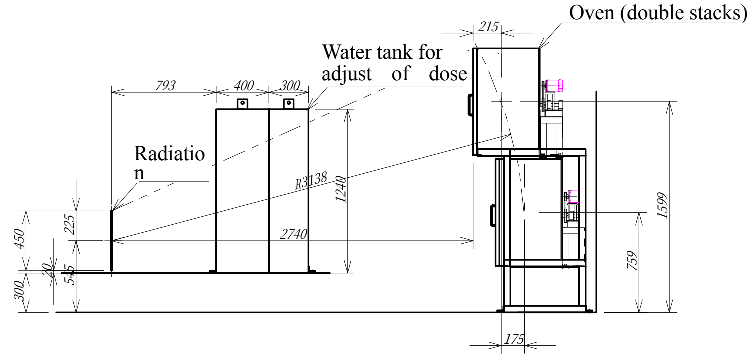


Fig. 2.2.1-5 Oven for fabrication of the simultaneous aging specimens



Plan view



A-A Section

Fig. 2.2.1-6 Oven arrangement inside the irradiation facility in fabrication of the simultaneous aging specimens

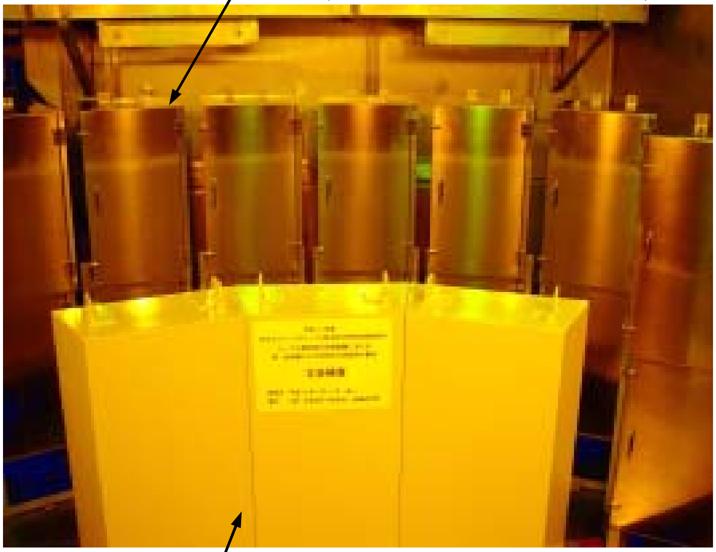
(7) Removal and storage of aging specimens

After heating and irradiating the specimens during a specified period, the aging specimens are taken out from the oven, and are temporally stored at room temperature before a tensile test is conducted.

2.2.2 Fabrication results of simultaneous aging specimens

Fabrication of the simultaneous aging specimens was carried out at the Radiation Application Development Association (Takasaki-shi, Gumma-ken). (The facility in Quantum Beam Science Directorate, Takasaki of Incorporated Administration Agency Japan Atomic Energy Agency was utilized for the irradiation facility.)

Based on the procedures for fabrication of specimens described in the previous Section, 69 pieces of simultaneous aging specimens in FY 2003, 372 pieces in FY 2004, 492 pieces in FY 2005, and 132 pieces in the first half of FY 2006 were fabricated respectively. The fabrication situation of the simultaneous aging specimens is shown in Fig. 2.2.2-1 and 2. Adjusted results of dose rates are given in appendix-4.



Oven (a total of 20 sets of double stacks)

Shielding block (gamma ray source is at this side of this

Fig. 2.2.2-1 Fabrication situation of the simultaneous aging specimens (Whole view)

Fig. 2.2.2-2 Fabrication situation of the simultaneous aging specimens
(Installation situation in the oven)

2.3 Tensile test

2.3.1 Procedures of tensile test

(1) Flow for performing tensile test

Tensile test is performed based on Section 4.16 “Tensile of insulation and sheath” of JIS C 3005$_{-2000}$ “Test methods for rubber and plastic insulated wires and cables”.

A flow chart for tensile test is shown in Fig. 2.3.1-1.

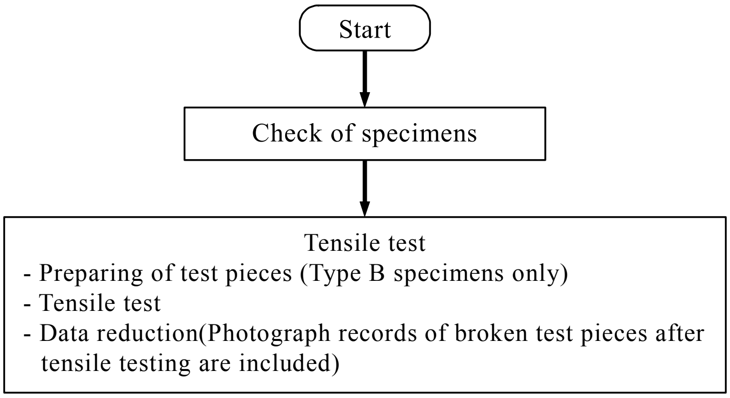


Fig. 2.3.1-1 Flow chart for performing tensile test

(2) Check of specimens

Specimen number, appearance and the number of specimens are checked before the start of tensile testing.

(3) Tensile test

(a) Preparing the process of specimens into tensile test pieces

Type A specimen (tubular specimen) is made into a test piece in the state as it is, on which lines are marked. Since Type B is cable-finished product specimen, it is machined into the shape of a dumbbell and lines are marked on it. Preparation procedures of those specimens are shown below.

- Tubular specimen (Type A)

Aging specimen of tubular type is used in the state as it is, and, as shown in Fig. 2.3.1-2, marked lines are attached at interval of 50 mm in the central part of about 150 mm in length.

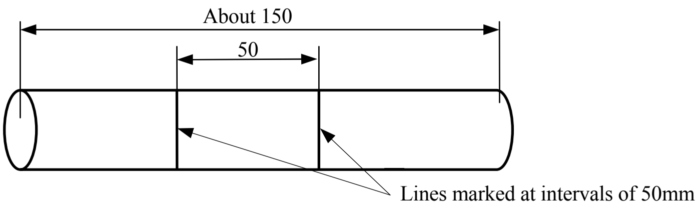


Fig. 2.3.1-2 Tubular specimen geometry for tensile test (unit: mm)

- Cable finished-product specimen (Type B)

Insulator of cable finished-product specimen is prepared into a die-cutting Dumbbell "D" type(6) specified by ASTM D412$_{-1998}$ which is shown in Fig. 2.3.1-3. Two lines are marked at intervals of 20 mm in the central part. In addition, the width of grip parts is allowed to be in a minimum of 5mm.

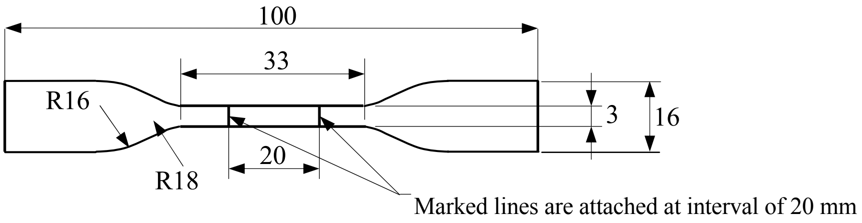


Fig. 2.3.1-3 Dumbbell test pieces geometry for tensile test (unit: mm)

(b) Procedures for tensile testing

Based on Section 4.16 "Tension of Insulator and Jackets" of JIS C 3005$_{-2000}$ "Test methods of rubber and plastic electric insulated wires", the tensile test is conducted using the testing machine specified in JIS B 7721$_{-2002}$ (tensile testing machine). In addition, the specimen should be rigidly installed and pulled with a chuck so that it may not loosen or produce any other problems during testing.

Tension rates at the time of tensile testing specified in JIS C 3005$_{-2000}$ are shown in Table 2.3.1-1.

Test pieces are pulled at tension rates shown in Table 2.3.1-1, and elongation at break and tensile strength of the specimens are measured.

Elongation and tensile strength data during tensile test are also acquired by a data logger and others, and the tensile strengths are measured at the elongations of 50% and 100% respectively.

Table 2.3.1-1 Tension rates in tensile testing

	Materials for test piece	Tension rate (mm/min)
1	SIR	500
2	XLPR	200
3	FR-XLPE	200
4	EPR	500
5	FR-EPR	500
6	SHPVC	500

---

(6) Although the specimen should be prepared according to No. 4 dumbbell specified by JIS K 6251$_{-1993}$, it is acceptable preparing according to the minimum size of dumbbell specified by ASTM, since the specimen size was small.

2.3.2 Tensile tests

The tensile test for acquiring aging data from the simultaneous aging specimens and thermal aging specimens was performed in the Japan Electric Cable Technology Center (Hamamatsu-shi, Shizuoka-ken).

Based on the test procedures shown in the previous Section, tensile test of 368 pieces in FY 2003 (In this case, triple-core The following is the same as this), 1533 pieces in FY 2004, 1756 pieces in FY 2005, and 541 pieces in the first half of FY 2006 was performed. The tensile test situation is shown in Fig. 2.3.2-1.

Fig. 2.3.2-1 Situation of tensile test

2.4 LOCA test

2.4.1 LOCA test flow chart and the specimen

(1) LOCA test flow chart and the specimen

Figure 2.4.1-1 shows LOCA test flow chart and Table 2.4.1-1 shows the specimens to be used in the test. Note that these specimens were received with the pre-aging process equivalent to normal operation as shown in Table 1.2.3-1 of Section 1.2.3 “LOCA Test”.

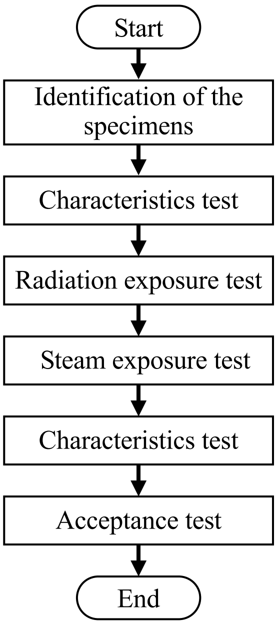


Fig. 2.4.1-1 LOCA test flow chart

Table 2.4.1-1 Specimens used in the LOCA test

	Kind of specimen	Specimen number	
		Short specimen	Long specimen
The first LOCA test	XLPE insulated cable (made by A Company) [CV-2.0-A]	A-B-81	A-B-91
		A-B-82	A-B-92
		A-B-83	-
	XLPE insulated cable (made by B Company) [CV-2.0-B]	B-B-81	B-B-91
		B-B-82	B-B-92
		B-B-83	-
The second LOCA test	FR-XLPE insulated cable (made by A Company) [FR--2.0-A]	C-B-81	C-B-91
		C-B-82	C-B-92
		C-B-83	-
	FR-XLPE insulated cable (made by B Company) [FR--2.0-B]	D-B-81	D-B-91
		D-B-82	D-B-92
		D-B-83	-
The third LOCA test	XLPE insulated triaxial cable (made by C Company) [TRIAX]	-	E-B-91
		-	E-B-92
		-	E-B-93
The fourth LOCA test	FR-EPR insulated cable (made by A Company) [FR-PN-2.0-A].	G-B-81	G-B-91
		G-B-82	G-B-92
		G-B-83	-
	FR-EPR insulated cable (made by B Company) [FR-PN-2.0-B].	H-B-81	H-B-91
		H-B-82	H-B-92
		H-B-83	-
The Fifth LOCA Test	EPR insulated cable (made by C Company) [PG-2.0]	F-B-81	F-B-91
		F-B-82	F-B-92
		F-B-83	-
	FR-EPR insulated cable (made by C Company) [FR-PH-2.0]	J-B-81	J-B-91
		J-B-82	J-B-92
		J-B-83	-
The Sixth LOCA Test	XLPE insulated cable (made by A Company) [CV-2.0-A]	A-B-84	A-B-93
		A-B-85	A-B-94
		A-B-86	A-B-95
	XLPE insulated cable (made by B Company) [CV-2.0-B]	B-B-84	B-B-93
		B-B-85	B-B-94
		B-B-86	B-B-95

Note: Short specimens and long specimens have lengths of approximately 60 cm and 3 m, respectively. The sixth LOCA test was conducted using the same kind of the specimens as the first LOCA test except for mitigated pre-aging.

(2) Characteristics test

Among the specimens, long size specimens are used in the characteristics tests as shown in Table 2.4.1-2 before radiation exposure test and after the steam exposure test.

Table 2.4.1-2 Characteristics test items

Kind of specimen	Items of characteristic test and applied standards
CV-2.0-A CV-2.0-B FR-CV-2.0-A FR-CV-2.0-B FR-PN-2.0-A FR-PN-2.0-B	Insulation resistance test (JIS C 3005$_{-2000}$ Item 4.7)
TRIAX	Insulation resistance test (JIS C 3005$_{-2000}$ Item 4.7) Characteristic impedance test (JIS C 3501$_{-1993}$ Item 5.7) Attenuation test (JIS C 3501$_{-1993}$ Item 5.7) Capacitance test (JIS C 3005$_{-2000}$ Item 4.8)

(3) Radiation exposure test

Each specimen was exposed to Gamma rays successively from the first to the sixth exposure at room temperature and radiation exposure conditions as shown in Table 2.4.1-3. Definite irradiation conditions were recorded after the test.

Table 2.4.1-3 Radiation exposure test conditions

	Kind of specimen	Specimen number		Radiation dose rate	Accumulated dose
		Short specimen[*1]	Long specimen[*1]		
The first LOCA Test	CV-2.0-A	A-B-81	A-B-91	Less than 10 kGy/h	260 kGy[*2]
		A-B-82	A-B-92		
		A-B-83	-		
	CV-2.0-B	B-B-81	B-B-91		
		B-B-82	B-B-92		
		B-B-83	-		
The second LOCA test	FR-CV-2.0-A	C-B-81	C-B-91	Less than 1 kGy/h	100 kGy[*3]
		C-B-82	C-B-92		
		C-B-83	-		
	FR-CV-2.0-B	D-B-81	D-B-91		
		D-B-82	D-B-92		
		D-B-83	-		
The third LOCA test	TRIAX	-	E-B-91	Less than 10 kGy/h	1500 kGy[*4]
		-	E-B-92		
		-	E-B-93		
The fourth LOCA test	FR-PN-2.0-A	G-B-81	G-B-91	Less than 10 kGy/h	500 kGy[*2]
		G-B-82	G-B-92		
		G-B-83	-		
	FR-PN-2.0-B	H-B-81	H-B-91		
		H-B-82	H-B-92		
		H-B-83	-		
The fifth LOCA Test	PG-2.0	F-B-81	F-B-91	Less than 10 kGy/h	1500 kGy[*4]
		F-B-82	F-B-92		
		F-B-83	-		
	FR-PH-2.0	J-B-81	J-B-91		
		J-B-82	J-B-92		
		J-B-83	-		
The sixth LOCA test	CV-2.0-A	A-B-84	A-B-93	Less than 10 kGy/h	260 kGy[*2]
		A-B-85	A-B-94		
		A-B-86	A-B-95		
	CV-2.0-B	B-B-84	B-B-93		
		B-B-85	B-B-94		
		B-B-86	B-B-95		

*1: Short specimens have approximately 60 cm length and long specimens have approximately 3 m length, respectively.

*2: Enveloped dose value inside of the reactor containment at the LOCA of the BWR plant in which the said cable is being used.

*3: Enveloped dose value outside of the reactor containment at the LOCA of the BWR plant in which the said cable is being used.

*4: Enveloped dose value inside of the reactor containment at the LOCA of the PWR plant in which the said cable is being used.

(4) Steam exposure test

After the radiation exposure test, specimens were put into the pressure vessel for the steam exposure test. The test was conducted according to the test conditions shown in Table 2.4.1-4. Temperature and pressure during the test were recorded. This test was to be conducted for each of the groups of the first to the sixth, and the specimens having their length of approximately 60 cm were connected in the LOCA proof mode to the pull-out cable (on the outside of the pressure vessel). The specimens of 3m in length were pulled out using a similar method, or pulled out directly to the outside of the vessel. The specimens were charged with electricity from the outside of the vessel as shown in Table 2.4.1-4. The electricity charging status and the leakage current during the test were recorded. For this case, the pulling out cable was selected not to give any possible effect to the measurement during steam exposure test.

Table 2.4.1-4 Steam exposure test conditions

	Kind of specimen	Specimen Number		Steam exposure conditions	Measured items during steam exposure
		Short specimen	Long specimen		
The first LOCA test	CV-2.0-A	A-B-81	A-B-91	Fig. 2.4.1-2	(a) The application of rated voltage (b) Leakage current (measurement is to be made between each of cores)
		A-B-82	A-B-92		
		A-B-83	-		
	CV-2.0-B	B-B-81	B-B-91		
		B-B-82	B-B-92		
		B-B-83	-		
The second LOCA test	FR-CV-2.0-A	C-B-81	C-B-91	Fig. 2.4.1-3	(a) The application of rated voltage (b) Leakage current (measurement is to be made between each of cores)
		C-B-82	C-B-92		
		C-B-83	-		
	FR-CV-2.0-B	D-B-81	D-B-91		
		D-B-82	D-B-92		
		D-B-83	-		
The third LOCA test	TRIAX	-	E-B-91	Fig. 2.4.1-4	(a) Electrostatic capacity (b) Insulation resistance
		-	E-B-92		
		-	E-B-93		
The forth LOCA test	FR-PN-2.0-A	G-B-81	G-B-91	Fig. 2.4.1-2	(a) The application of rated voltage (b) Leakage current (measurement is to be made between each of cores)
		G-B-82	G-B-92		
		G-B-83	-		
	FR-PN-2.0-B	H-B-81	H-B-91		
		H-B-82	H-B-92		
		H-B-83	-		
The fifth LOCA test	PG-2.0	F-B-81	F-B-91	Fig. 2.4.1-4	(a) The application of rated voltage (b) Leakage current (measurement is to be made between each of cores)
		F-B-82	F-B-92		
		F-B-83	-		
	FR-PH-2.0	J-B-81	J-B-91		
		J-B-82	J-B-92		
		J-B-83	-		
The sixth LOCA test	CV-2.0-A	A-B-84	A-B-93	Fig. 2.4.1-2	(a) The application of rated voltage (b) Leakage current (measurement is to be made between each of cores)
		A-B-85	A-B-94		
		A-B-86	A-B-95		
	CV-2.0-B	B-B-84	B-B-93		
		B-B-85	B-B-94		
		B-B-86	B-B-95		

Note: Short specimens have a length of approximately 60 cm and long specimens approximately 3 m, respectively.

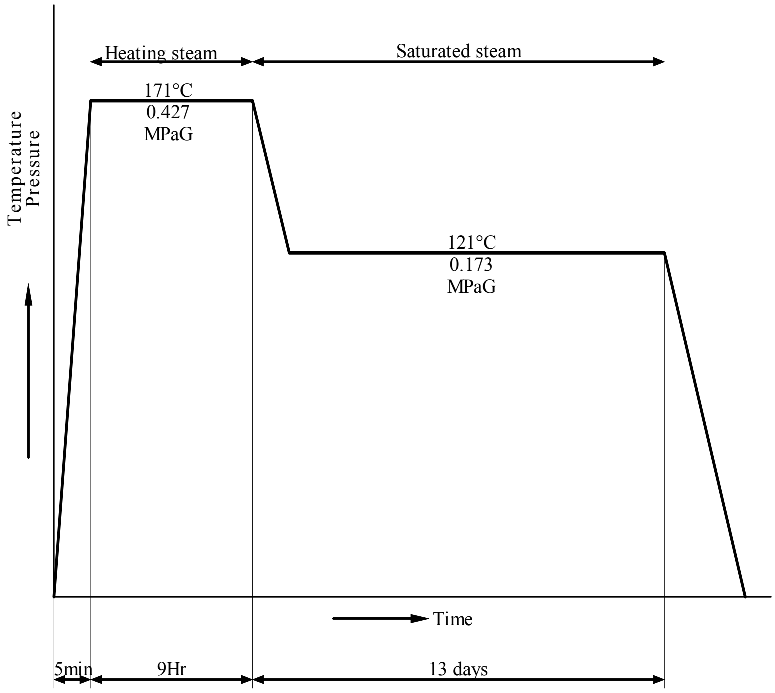


Fig. 2.4.1-2 Steam exposure test conditions - 1
(Enveloping test condition of inside the reactor containment vessel during LOCA of BWR plant)

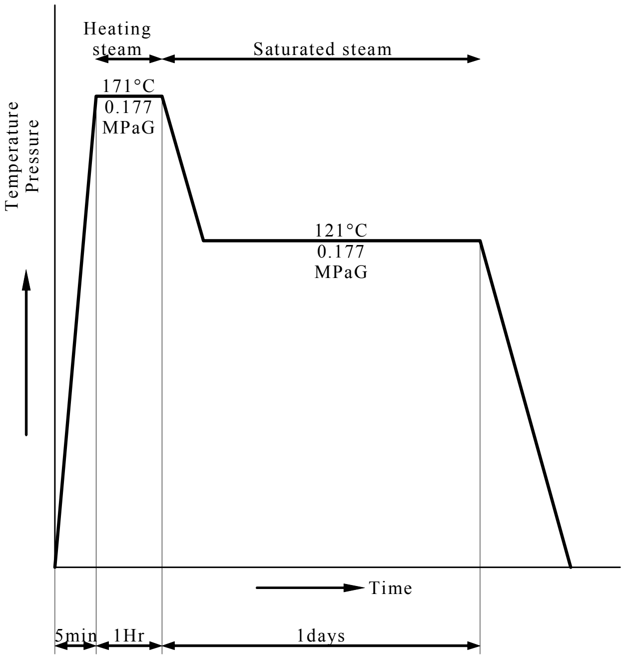
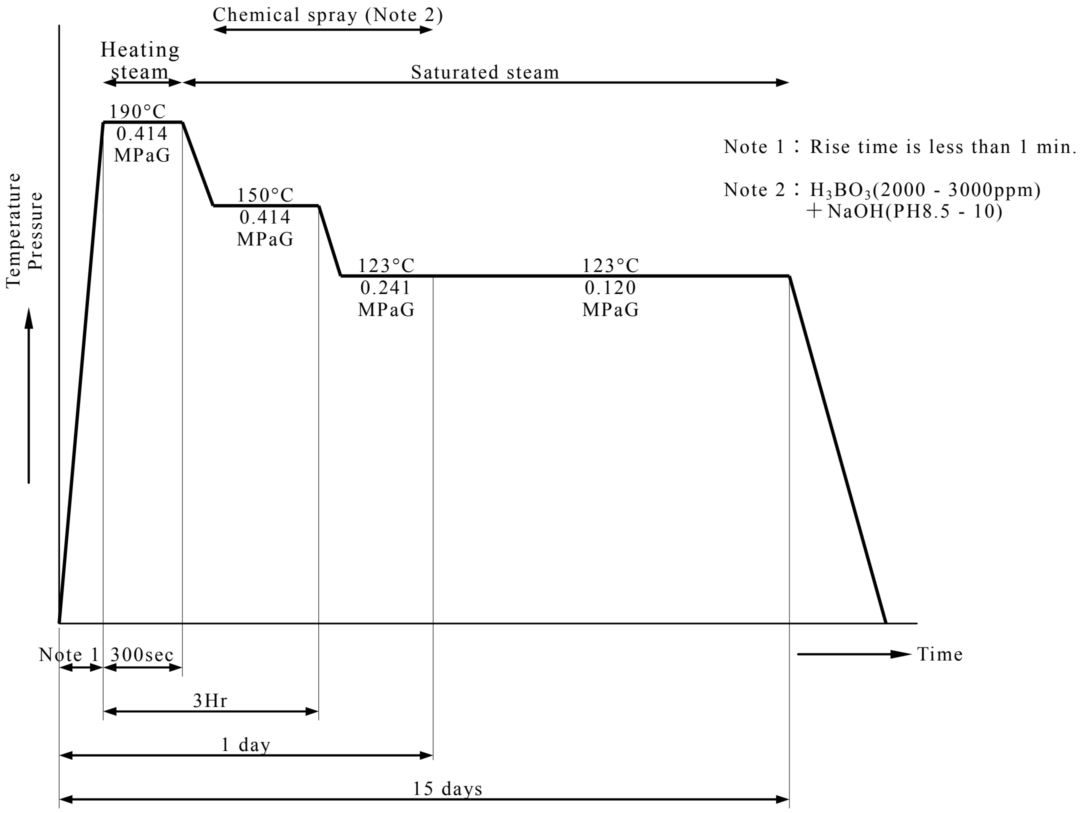


Fig.2.4.1-3 Steam exposure test conditions - 2
(Enveloping test condition of outside the reactor containment vessel during LOCA of BWR plant)



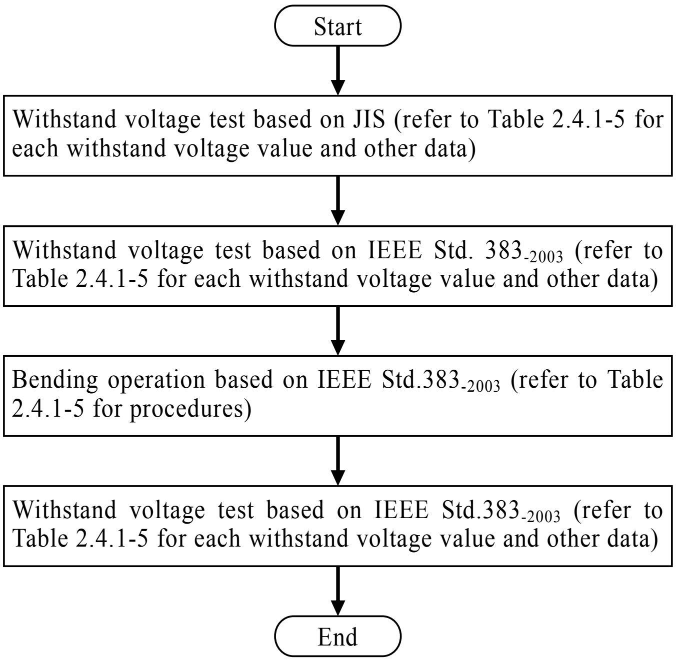
Note 1：Rise time is less than 1 min.

Note 2：H_3BO_3(2000 - 3000ppm) ＋NaOH(PH8.5 - 10)

Fig. 2.4.1-4 Steam exposure test conditions - 3
(Enveloping test condition of inside the reactor containment vessel during LOCA of PWR plant)

(5) Acceptance test

Integrity acceptance test of the specimen after the steam exposure test was to be executed in the flow as shown in Fig. 2.4.1-5.



Withstand voltage test based on JIS (refer to Table 2.4.1-5 for each withstand voltage value and other data)

Withstand voltage test based on IEEE Std. 383_{-2003} (refer to Table 2.4.1-5 for each withstand voltage value and other data)

Bending operation based on IEEE Std.383_{-2003} (refer to Table 2.4.1-5 for procedures)

Withstand voltage test based on IEEE Std.383_{-2003} (refer to Table 2.4.1-5 for each withstand voltage value and other data)

Fig. 2.4.1-5 Acceptance test flow chart

Table 2.4.1-5 Detailed procedures of the acceptance test

Kind of specimen	Specimen number		Acceptance test procedures		
	Short specimen	Long specimen	JIS withstand voltage Test	IEEE Std.383$_{-2003}$	
				Bending operation	Withstand voltage test
CV-2.0-A	A-B-81	A-B-91	1500 V- 1 min. (JIS C 3605$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	A-B-82	A-B-92			
	A-B-83	-			
	A-B-84	A-B-93			
	A-B-85	A-B-94			
	A-B-86	A-B-95			
CV-2.0-B	B-B-81	B-B-91	1500 V- 1 min. (JIS C 3605$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	B-B-82	B-B-92			
	B-B-83	-			
	B-B-84	B-B-93			
	B-B-85	B-B-94			
	B-B-86	B-B-95			
FR-CV-2.0-A	C-B-81	C-B-91	1500 V- 1 min. (JIS C 3605$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	C-B-82	C-B-92			
	C-B-83	-			
FR-CV-2.0-B	D-B-81	D-B-91	1500 V- 1 min. (JIS C 3605$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	D-B-82	D-B-92			
	D-B-83	-			
TRIAX	-	E-B-91	10 k V-1 min. duration for C-1S (MIL RG-11) 2 k V- 1min. duration for 1S-2S (maker standard) 500 V- 1min. duration for 2S-E (maker standard)	Refer to Note (2).	9.7 kV- 5 min.
	-	E-B-92			
	-	E-B-93			
FR-PN-2.0-A	G-B-81	G-B-91	1500 V- 1 min. (JIS C 3621$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	G-B-82	G-B-92			
	G-B-83	-			
FR-PN-2.0-B	H-B-81	H-B-91	1500 V- 1 min. (JIS C 3621$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	H-B-82	H-B-92			
	H-B-83	-			
PG-2.0	F-B-81	F-B-91	1500 V- 1 分間 (JIS C 3621$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	F-B-82	F-B-92			
	F-B-83	-			
FR-PH-2.0	J-B-81	J-B-91	1500 V- 1 min. (JIS C 3621$_{-2000}$)	Refer to Note (2).	2.6 kV- 5 min.
	J-B-82	J-B-92			
	J-B-83	-			

Notes: (1) Short specimens have a length of approximately 60 cm and long specimens approximately 3 m, respectively.

(2) After specimen was stretched in linear shape, it was wound to the mandrel of 40 times of the diameter of the cable and submerged into room temperature water for 1 hour as a whole except both end parts.

2.4.2 Results of the LOCA test

(1) Results of the first LOCA test

The specimens for the first LOCA test, including the XLPE insulated cable (made by A Company) and cable of the same kind (made by B Company), are shown in Table 2.4.2-1. The implementing conditions of radiation exposure and steam exposure tests are in Table 2.4.2-2, the results of characteristics test are in Table 2.4.2-3, and the results of the acceptance test for the first LOCA test are in Table 2.4.2-4.

In addition, the external view of the pressure vessel used for the steam exposure test is shown in Figure 2.4.2-1 and the status of the specimens after steam exposure test is shown in Figures 2.4.2-2 through 5.

Table 2.4.2-1 Specimens used in the first LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
XLPE insulated cable CV-2.0-A	A-B-81	100ºC- 96.7 Gy/h- 852 hours	192%
	A-B-91*	100ºC- 99.3 Gy/h- 852 hours	-
	A-B-82	100ºC- 97.0 Gy/h- 988 hours	55%
	A-B-92*	100ºC- 99.6 Gy/h- 988 hours	-
	A-B-83	100ºC- 97.0 Gy/h- 1399 hours	6%
XLPE insulated cable CV-2.0-B	B-B-81	100ºC- 95.1 Gy/h- 995 hours	55%
	B-B-91*	100ºC- 97.7 Gy/h- 995 hours	-
	B-B-82	100ºC- 95.5 Gy/h- 1487 hours	43%
	B-B-92*	100ºC- 98.0 Gy/h- 1487 hours	-
	B-B-83	100ºC- 95.8 Gy/h- 1988 hours	41%

Notes:
1. Specimens with *mark show 3m long specimen. (All specimens with no mark are 60 cm long specimens.)
2. The elongation at break of the 60 cm long specimen after pre-aging was evaluated from the characteristics at the aging conditions of the 60 cm long specimen. Although the elongation at break in the aging conditions of the 3 m long specimen was not measured, the elongation at break of the 3 m long specimen is similar to the elongation at break of the 60 cm long specimen at the same aging period.

Table 2.4.2-2 Implementing conditions for radiation and steam exposures tests in the first LOCA test

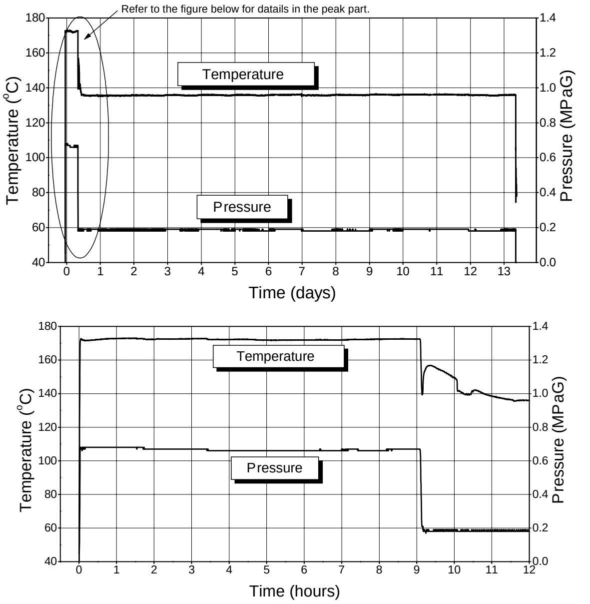
Specimen Number	Radiation Exposure	Steam Exposure
A-B-81	7.08 kGy/h- 36.74 hours 260 kGy	
A-B-82		
A-B-83		
B-B-81		
B-B-82		
B-B-83		
A-B-91	8.05 kGy/h- 32.30 hours 260kGy	
A-B-92		
B-B-91		
B-B-92		

Table 2.4.2-3 Results of characteristics test in the first LOCA test

Specimen number & color of cores		Insulation resistance MΩ[( )value shows converted value to MΩkm]	
		Before LOCA test	After LOCA test
A-B-91	Black	6.5×10^5 (2.0×10^3)	No measurement was made due to the occurrence of failure during steam exposure.
	White	5.2×10^5 (1.6×10^3)	
	Red	4.4×10^5 (1.3×10^3)	
A-B-92	Black	7.0×10^5 (2.1×10^3)	
	White	6.0×10^5 (1.8×10^3)	
	Red	4.2×10^5 (1.3×10^3)	
B-B-91	Black	3.0×10^6 (9.0×10^3)	
	White	7.0×10^6 (2.1×10^4)	
	Red	6.0×10^5 (1.8×10^3)	
B-B-92	Black	2.0×10^6 (6.0×10^3)	
	White	3.0×10^6 (9.0×10^3)	
	Red	2.0×10^6 (6.0×10^3)	

Table 2.4.2-4 Results of acceptance test in the first LOCA test

Specimen number & color of cores		Maintain the application of rated voltage during steam exposure DC 750 V	JIS withstand voltage test AC 1500 V- 1 min.	IEEE withstand voltage test AC 2600 V- 5 min	IEEE bend submerged withstand voltage test AC 2600 V- 5 min	Remarks
A-B-81	Black	Short circuit occurred between black and red cores after 146 hours. Short circuit occurred between white and black/ red cores after 224 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
A-B-91	Black	Short circuit occurred between white and red cores after 170 hours. Short circuit occurred between black and white/red cores after 194 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
A-B-82	Black	Short circuit occurred between white and red cores after 170 hours. Failure of insulator of black core was discovered at the same time.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
A-B-92	Black	Short circuit occurred between black and red cores after 168 hours. Short circuit occurred between white and black/red cores after 173 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
A-B-83	Black	Short circuit occurred between white and red cores after 191 hours. Short circuit occurred between black and white/red cores after 194 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
B-B-81	Black	Short circuit occurred between white and red cores after 190 hours. Short circuit occurred between black and white/red cores after 193 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
B-B-91	Black	Short circuit occurred between black and white cores after 201 hours. Short circuit occurred between red and black/white cores after 221 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
B-B-82	Black	Short circuit occurred between white and red cores after 36 hours. Short circuit occurred between black and white/red cores after 52 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
B-B-92	Black	Short circuit occurred between black and red cores after 161 hours. Short circuit occurred between white and black/red cores after 169 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	
B-B-83	Black	Short circuit occurred between black and white cores after 100 hours. Short circuit occurred between red and black/ white cores after 146 hours.	-	-	-	
	White		-	-	-	
	Red		-	-	-	

Fig. 2.4.2-1 Pressure Vessel for steam exposure test

Fig. 2.4.2-2 Specimen A-B-91 after steam exposure test

Fig. 2.4.2-3 Specimens A-B-81, 82 and 83 after steam exposure test (from the bottom)

Fig. 2.4.2-4 Specimen B-B-91 after steam exposure test

Fig. 2.4.2-5 Specimens B-B-81, 82 and 83 after steam exposure test (from the bottom)

(2) Results of the second LOCA test

The specimens for the second LOCA test, including the FR-XLPE insulated cable (made by A Company) and cable of the same kind (made by B Company), are shown in Table 2.4.2-5. The implementing conditions of radiation exposure and steam exposure tests are in Table 2.4.2-6, results of characteristics test are in Table 2.4.2-7 and results of acceptance test for the second LOCA test are in Table 2.4.2-8.

In addition, status of the specimens after steam exposure test is shown in Figures 2.4.2-6 through 9.

Table 2.4.2-5 Specimens used in the second LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
FR-XLPE insulated cable FR-CV-2.0 A	C-B-81	100ºC- 97.4 Gy/h- 2,500 hrs	226%
	C-B-91 *	100ºC- 99.3 Gy/h- 2,500 hrs	-
	C-B-82	100ºC- 96.9 Gy/h- 3,987 hrs	152%
	C-B-92 *	100ºC- 99.0 Gy/h- 3,987 hrs	-
	C-B-83	100ºC- 96.6 Gy/h- 5,476 hrs	109%
FR-XLPE insulated cable FR-CV-2.0-B	D-B-81	100ºC- 97.4 Gy/h- 2,500 hrs	217%, 168%, 222%
	D-B-91 *	100ºC- 99.3 Gy/h- 2,500 hrs	-
	D-B-82	100ºC- 96.9 Gy/h- 3,987 hrs	45%, 26%, 56%
	D-B-92 *	100ºC- 99.0 Gy/h- 3,987 hrs	-
	D-B-83	100ºC- 96.6 Gy/h- 5,476 hrs	15%, 9%, 20%

Notes: 1. Specimen with *mark shows 3m long specimen.(others are all 60cm Long specimens)
2. The elongation at break of the 60 cm long specimen after pre-aging was evaluated from the characteristics at the aging conditions of the 60 cm long specimen. Although the elongation at break in the aging conditions of the 3 m long specimen was not measured, the elongation at break of the 3 m long specimen is similar to the elongation at break of the 60 cm long specimen at the same aging period.
3. The elongation at break of the FR-CV-2.0-B was evaluated every core.

Table 2.4.2-6 Implementing conditions for radiation and steam exposures tests in the second LOCA test

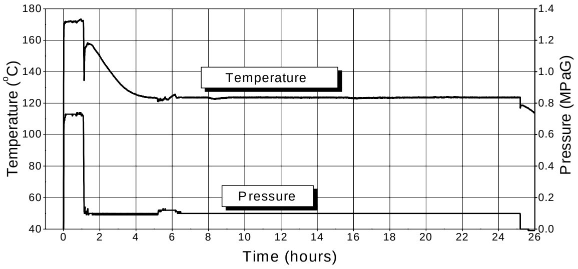
Specimen Number	Radiation Exposure	Steam Exposure
C-B-81	781 Gy/h- 128.2 hrs 100 kGy	
C-B-82		
C-B-83		
D-B-81		
D-B-82		
D-B-83		
C-B-91	757 Gy/h- 132.2 hrs 100 kGy	
C-B-92		
D-B-91		
D-B-92		

Table 2.4.2-7 Results of characteristics test in the second LOCA test

Specimen number & color of cores		Insulation resistance MΩ [( ) value shows converted value to MΩkm]		Maximum leakage current during steam exposure test
		Before LOCA test	After LOCA test	
C-B-91	Black	1.0×10^{5} (3.0×10^{2})	3.2×10^{5} (9.6×10^{2})	5 mA
	White	1.0×10^{5} (3.0×10^{2})	3.4×10^{5} (1.0×10^{3})	5 mA
	Red	1.0×10^{5} (3.0×10^{2})	3.4×10^{5} (1.0×10^{3})	4 mA
C-B-92	Black	1.0×10^{5} (3.0×10^{2})	3.0×10^{5} (9.0×10^{2})	8 mA
	White	9.0×10^{4} (2.7×10^{2})	4.5×10^{-2} (1.4×10^{-4})	5 mA
	Red	9.0×10^{4} (2.7×10^{2})	1.4×10^{-2} (4.2×10^{-5})	8 mA
D-B-91	Black	4.0×10^{6} (1.2×10^{4})	6.5×10^{6} (2.0×10^{4})	4 mA
	White	3.0×10^{6} (9.0×10^{3})	7.0×10^{6} (2.1×10^{4})	6 mA
	Red	2.5×10^{6} (7.5×10^{3})	7.5×10^{6} (2.3×10^{4})	5 mA
D-B-92	Black	1.2×10^{5} (3.6×10^{2})	1.6×10^{3} (4.8)	4 mA
	White	1.2×10^{5} (3.6×10^{2})	3.0×10^{-1} (9.0×10^{-4})	5 mA
	Red	1.2×10^{5} (3.6×10^{2})	2.0×10^{4} (6.0×10)	5 mA

Table 2.4.2-8 Results of acceptance test in the second LOCA test

Specimen number & color of core		Maintain the application of rated voltage during steam exposure DC 750 V	JIS withstand voltage test AC 1500 V- 1 min.	IEEE withstand voltage test AC 2600 V- 5 min.	IEEE bend submerged withstand voltage test AC 2600 V- 5 min	Remarks
C-B-81	Black	Good	Good	Good	Good	
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
C-B-91	Black	Good	Good	Good	Good	
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
C-B-82	Black	Short circuit occurred between white and red cores after 170 hrs. Failure of insulator of black core was discovered at the same time	-	-	-	
	White		-	-	-	
	Red		-	-	-	
C-B-92	Black	Good	No good at 800 V	-	-	
	White	Good	No good at 500 V	-	-	
	Red	Good	No good at 400 V	-	-	
C-B-83	Black	Good	Good	Good	No good at 2200 V	Because the cables C-B-82 and C-B-92 whose degree of pre-aging were less severe than this cable failed to pass the withstand voltage test during steam exposure and JIS withstand voltage test, the results of this cable are to be the reference.
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
D-B-81	Black	Good	Good	Good	Good	
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
D-B-91	Black	Good	Good	Good	Good	
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
D-B-82	Black	Good	Good	Good	Good	
	White	Good	No good at 750 V	-	-	
	Red	Good	No good at 900 V	-	-	
D-B-92	Black	Good	Good	Good	No good at 1000 V	
	White	Good	No good at 1500 V-3sec	-	-	
	Red	Good	Good	Good	No good at 600V	
D-B-83	Black	Good	No good at 1000 V	-	-	
	White	Good	No good at 600 V	-	-	
	Red	Good	No good at 500 V	-	-	

Fig. 2.4.2-6 Specimen C-B-92 after steam exposure test

Fig. 2.4.2-7 Specimen C-B-82 after steam exposure test

Fig. 2.4.2-8 Specimen D-B-92 after steam exposure test

Fig. 2.4.2-9 Specimen D-B-82 after steam exposure test

(3) Results of the third LOCA test

The specimen for the third LOCA test, the XLPE insulated coaxial cable (made by C Company), is shown in Table 2.4.2-9. The implementing conditions for radiation exposure and steam exposure tests are in Table 2.4.2-10; the results of the characteristics test are in Table 2.4.2-11, the results of the measurement of characteristics test during steam exposure test in Table 2.4.2-12, and the results of acceptance test are in Table 2.4.2-13.

In addition, status of the specimens after the steam exposure test are shown in Figures 2.4.2-11 and 12.

Table 2.4.2-9 Specimens used in the third LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
XLPE insulated triaxial cable TRIAX	E-B-91	100ºC- 99.5 Gy/h- 2,164 hrs	94%
	E-B-92	100ºC- 99.0 Gy/h- 3,965 hrs	61%
	E-B-93	100ºC- 98.9 Gy/h- 5,686 hrs	48%

Note: 1. All specimens have a length of 3 m.

2. The elongation at break after pre-aging was evaluated from the characteristics at the aging conditions.

Table 2.4.2-10 Implementing conditions for radiation and steam exposures tests of the third LOCA test

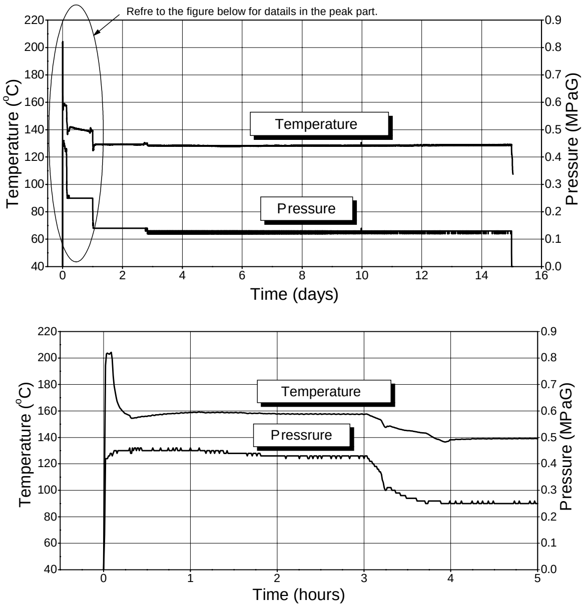
Specimen Number	Radiation Exposure	Steam Exposure
E-B-91	8.83 kGy/h- 169.88 hrs. 1500 kGy	
E-B-92		
E-B-93		

Table 2.4.2-11 Results of characteristics test in the third LOCA test

		Insulation Resistance (Ωm)		Characteristic Impedance (Ω)	Attenuation (dB/100m)		Capacitance (pF/m)
		C-1S	1S-2S		100 MHz	400 MHz	
E-B-91	Before LOCA test	9.0×10^{14}	6.0×10^{13}	72.0	14.3	44.0	74.0
	After LOCA test	7.6×10^{14}	1.5×10^{13}	72.4	17.0	46.2	75.1
E-B-92	Before LOCA test	4.8×10^{14}	4.2×10^{13}	71.4	16.0	51.3	75.0
	After LOCA test	5.1×10^{14}	1.7×10^{12}	71.3	18.8	52.7	78.1
E-B-93	Before LOCA test	3.6×10^{14}	1.8×10^{13}	71.1	18.7	65.3	77.0
	After LOCA test	3.1×10^{14}	5.1×10^{8}	71.7	14.1	49.4	74.5

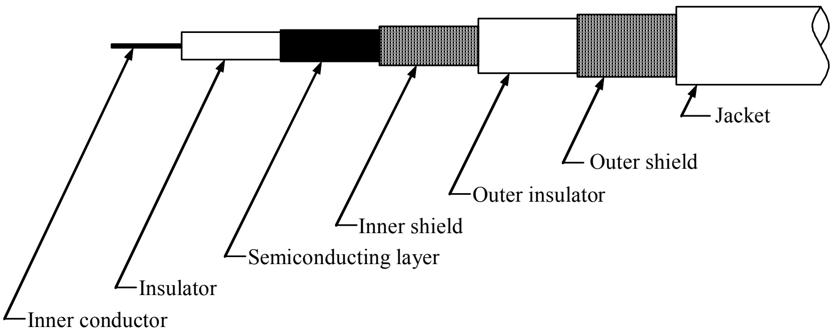


Table 2.4.2-12 Results of characteristics test measurement during steam exposure test in the third LOCA test

	Insulation Resistance (Ω m)				Capacitance (pF/m)
	C-1S		1S-2S		
E-B-91	Min.	2×10^9	Min.	2×10^7	62
	Max.	9×10^9	Max.	2×10^8	
E-B-92	Min.	7×10^8	Min.	1×10^7	63
	Max.	4×10^9	Max.	7×10^7	
E-B-93	Min.	8×10^8	Min.	4×10^6	63
	Max.	7×10^9	Max.	2×10^7	

Table 2.4.2-13 Results of acceptance test in the third LOCA test

Specimen number		During steam exposure		JIS withstand voltage test bet. C-1S AC 10 kV- 1 min. bet. 1S-2S AC 2 kV- 1 min.	IEEE withstand voltage test AC 9.7 kV- 5 min. (between C-1S only)	IEEE bend submerged withstand voltage test AC 9.7 kV- 5 min. (between C-1S only)
		Insulation resistance	Capacitance			
E-B-91	C-1S	No significant change	No significant change	Good	Good	Good
	1S-2S	No significant change	-	Good	-	-
A-B-92	C-1S	No significant change	No significant change	Good	Good	Good
	1S-2S	No significant change	-	Good	-	-
E-B-93	C-1S	No significant change	No significant change	Good	Good	Good
	1S-2S	No significant change	-	Good	-	-

Fig.2.4.2-10 Specimen E-B-92 after steam exposure test

Fig. 2.4.2-11 Specimen E-B-93 after steam exposure test

(4) Results of the fourth LOCA test

The specimens for the fourth LOCA test including the FR-EPR insulated cable (made by A Company) and cable of the same kind (made by B Company) are shown in Table 2.4.2-14. The implementing conditions of radiation exposure and steam exposure tests are in Table 2.4.2-15, the results of characteristics test are in Table 2.4.2-16 and results of acceptance test are in Table 2.4.2-17.

In addition, status of the specimens after the steam exposure test is shown in Figures 2.4.2-12 through 15.

Table 2.4.2-14 Specimens for the fourth LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
FR-EPR insulated cable FR-PN-2.0-A	G-B-81	100ºC- 95.9 Gy/h- 1,981 hrs	229%, 227%, 100%
	G-B-91*	100ºC- 100.6 Gy/h- 1,981 hrs	-
	G-B-82	100ºC- 96.1 Gy/h- 2,995 hrs	60%, 45%, 38%
	G-B-92*	100ºC- 100.6 Gy/h- 2,995 hrs	-
	G-B-83	100ºC- 95.3 Gy/h- 3,994 hrs	20%, 13%, 20%
FR-EPR insulated cable FR-PN-2.0-B	H-B-81	100ºC- 95.2 Gy/h- 2,976 hrs	401%, 366%, 394%
	H-B-91*	100ºC- 99.8 Gy/h- 2,976 hrs	-
	H-B-82	100ºC- 95.2 Gy/h- 4,972 hrs	310%, 271%, 297%
	H-B-92*	100ºC- 99.8 Gy/h- 4,972 hrs	-
	H-B-83	100ºC- 94.7 Gy/h- 6,990 hrs	239%, 203%, 222%

Notes: 1. Specimen with *mark shows 3 m long specimen. (Others are all 60 cm long specimens.)
2. The elongation at break of the 60 cm long specimen after pre-aging was evaluated from the characteristics at the aging conditions of the 60 cm long specimen. Although the elongation at break in the aging conditions of the 3 m long specimen was not measured, the elongation at break of the 3 m long specimen is similar to the elongation at break of the 60 cm long specimen at the same aging period.
3. The elongation at break was evaluated every core.

Table 2.4.2-15 Implementing conditions for radiation and steam exposures tests in the fourth LOCA test

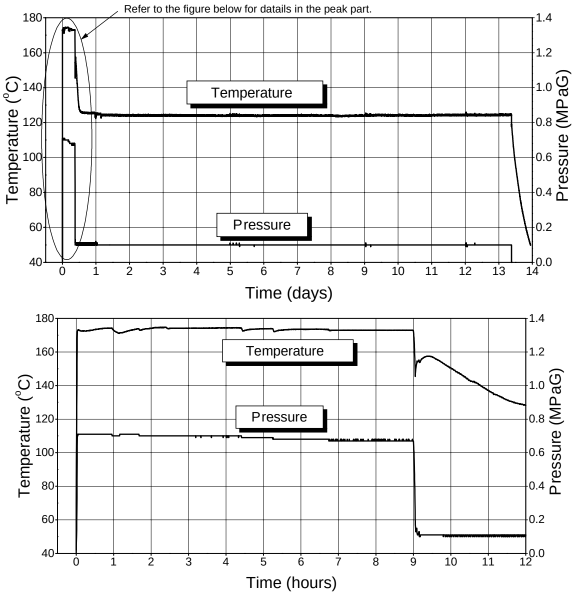
Specimen Number	Radiation Exposure	Steam Exposure
G-B-81	7.91 kGy/h- 63.22 hrs 500 kGy	
G-B-82		
G-B-83		
H-B-81		
H-B-82		
H-B-83		
G-B-91	8.18 kGy/h- 61.15 hrs 500 kGy	
G-B-92		
H-B-91		
H-B-92		

Table 2.4.2-16 Results of characteristics test in the fourth LOCA test

Specimen number & color of cores		Insulation resistance MΩ[( ) shows converted value to MΩkm]		Maximum leakage current during steam exposure test
		Before LOCA test	After LOCA Test	
G-B-91	Black	$5.6\times10^{6}\ (1.7\times10^{4})$	$1.9\ (5.7\times10^{-3})$	2 mA
	White	$4.0\times10^{6}\ (1.2\times10^{4})$	$1.0\times10^{3}\ (3.1)$	2 mA
	Red	$4.8\times10^{6}\ (1.4\times10^{4})$	$1.2\times10^{3}\ (3.6)$	2 mA
G-B-92	Black	$4.8\times10^{6}\ (1.4\times10^{4})$	$5.9\ (1.8\times10^{-2})$	4 mA
	White	$4.0\times10^{6}\ (1.2\times10^{4})$	$1.9\times10\ (5.6\times10^{-2})$	4 mA
	Red	$4.8\times10^{6}\ (1.4\times10^{4})$	$2.2\times10^{2}\ (6.7\times10^{-1})$	3 mA
H-B-91	Black	$9.6\times10^{5}\ (2.9\times10^{3})$	$4.4\times10^{5}\ (1.3\times10^{3})$	2 mA
	White	$7.2\times10^{5}\ (2.2\times10^{3})$	$5.2\times10^{4}\ (1.6\times10^{2})$	2 mA
	Red	$6.0\times10^{5}\ (1.8\times10^{3})$	$1.1\times10^{6}\ (3.3\times10^{3})$	2 mA
H-B-92	Black	$9.6\times10^{5}\ (2.9\times10^{3})$	$3.7\times10^{4}\ (1.1\times10^{2})$	2 mA
	White	$9.6\times10^{5}\ (2.9\times10^{3})$	$1.2\times10^{4}\ (3.6\times10)$	2 mA
	Red	$1.1\times10^{6}\ (3.4\times10^{3})$	$1.9\times10\ (5.8\times10^{-2})$	4 mA

Table 2.4.2-17 Results of acceptance test in the fourth LOCA test

Specimen number & color of conductors		Maintain the application of rated voltage during steam exposure DC 750 V	JIS withstand voltage test AC 1500V- 1 min.	IEEE withstand voltage test AC 2600V- 5 min.	IEEE bend submerged withstand voltage test AC 2600V- 5 min	Remarks
G-B-81	Black	Good	Good	Good	Good	Break down voltage: 4.2 kV
	White	Good	Good	Good	Good	Break down voltage: 5.0 kV
	Red	Good	Good	Good	Good	Break down voltage: 2.7 kV
G-B-91	Black	Good	Good	Good	Good	Break down voltage: 3.7 kV
	White	Good	Good	Good	Good	Break down voltage: 4.1 kV
	Red	Good	Good	Good	Good	Break down voltage: 3.0 kV
G-B-82	Black	Good	Good	Good	Good	Break down voltage: 5.0 kV
	White	Good	Good	Good	Good	Break down voltage: 3.9 kV
	Red	Good	Good	Good	Good	Break own voltage: 4.3 kV
G-B-92	Black	Good	Good	Good	Good	Break down voltage: 3.5 kV
	White	Good	Good	Good	Good	Break down voltage: 4.0 kV
	Red	Good	Good	Good	Good	Break down voltage: 2.7 kV
G-B-83	Black	Good	No good at 900 V	—	—	
	White	Good	No good at 600 V	—	—	
	Red	Good	No good at 700 V	—	—	
H-B-81	Black	Good	Good	Good	Good	Break down voltage: 12.5 kV
	White	Good	Good	Good	Good	Break down Voltage: 12.5 kV
	Red	Good	Good	Good	Good	Break down voltage: 11.0 kV
H-B-91	Black	Good	Good	Good	Good	A failure occurred on the white core. Based on the investigation of the break down voltage of other cores and results of H-B-82, H-B-92 and H-B-83, the occurrence of the failure was determined to be due to the incomplete handling (caused due to the effect of crack of the jacket). Black core break down voltage: 9.0 kV Red core break down Voltage: 8.3 kV
	White	Good	Good	Good	No good at 1800 V	
	Red	Good	Good	Good	Good	
H-B-82	Black	Good	Good	Good	Good	Break down voltage: 9.8 kV
	White	Good	Good	Good	Good	Break down voltage: 7.2 kV
	Red	Good	Good	Good	Good	Break down voltage: 9.0 kV
H-B-92	Black	Good	Good	Good	Good	Break down voltage: 8.2 kV
	White	Good	Good	Good	Good	Break down voltage: 7.2 kV
	Red	Good	Good	Good	Good	Break down voltage: 9.5 kV
H-B-83	Black	Good	Good	Good	Good	Break down voltage: 9.0 kV
	White	Good	Good	Good	Good	Break down voltage: 7.5 kV
	Red	Good	Good	Good	Good	Break down voltage: 9.2 kV

Fig. 2.4.2-12 Specimen G-B-92 after steam exposure test

Fig. 2.4.2-13 Specimen G-B-83 after steam exposure test

Fig. 2.4.2-14 Specimen H-B-91 after steam exposure test (at the bending work)

Fig. 2.4.2-15 Specimen H-B-92 after steam exposure test (after submerged withstand voltage test with bending of specimen)

(5) Results of the fifth LOCA test

The specimens for the fifth LOCA test including the EPR insulated cable (made by C Company) and the FR-EPR insulated cable (made by C Company) are shown in Table 2.4.2-18. The implementing conditions of radiation exposure and steam exposure tests are in Table 2.4.2-19, the results of characteristics test are in Table 2.4.2-20 and results of acceptance test are in Table 2.4.2-21.

Status of the specimens after the steam exposure test is also shown in Figures 2.4.2-16 through 19.

Table 2.4.2-18 Specimens for the fifth LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
EPR insulated cable PG-2.0	F-B-81	100ºC- 94.8 Gy/h- 4,700 hrs.	40%
	F-B-91*	100ºC- 98.8 Gy/h- 4,700 hrs.	-
	F-B-82*	100ºC- 94.8 Gy/h- 5,836 hrs.	18%
	F-B-92*	100ºC- 98.9 Gy/h- 5,836 hrs.	-
	F-B-83	100ºC- 94.7 Gy/h- 6,990 hrs.	10%
FR-EPR insulated cable FR-PH-2.0	J-B-81	100ºC- 94.4 Gy/h- 4,277 hrs.	174%, 130%, 122%
	J-B-91*	100ºC- 98.1 Gy/h- 4,277 hrs.	-
	J-B-82	100ºC- 94.5 Gy/h- 5,224 hrs.	127%, 86%, 89%
	J-B-92*	100ºC- 98.2 Gy/h- 5,224 hrs.	-
	J-B-83	100ºC- 94.4 Gy/h- 6,176 hrs.	95%, 60%, 67%

Notes: 1. Specimen with *mark shows 3 m long specimen. (Others are all 60 cm long specimens.)

2. The elongation at break of the 60 cm long specimen after pre-aging was evaluated from the characteristics at the aging conditions of the 60 cm long specimen. Although the elongation at break in the aging conditions of the 3 m long specimen was not measured, the elongation at break of the 3 m long specimen is similar to the elongation at break of the 60 cm long specimen at the same aging period.

3. The elongation at break of the FR-PH-2.0 was evaluated every core.

Table 2.4.2-19 Implementing conditions for radiation and steam exposures tests in the fifth LOCA test

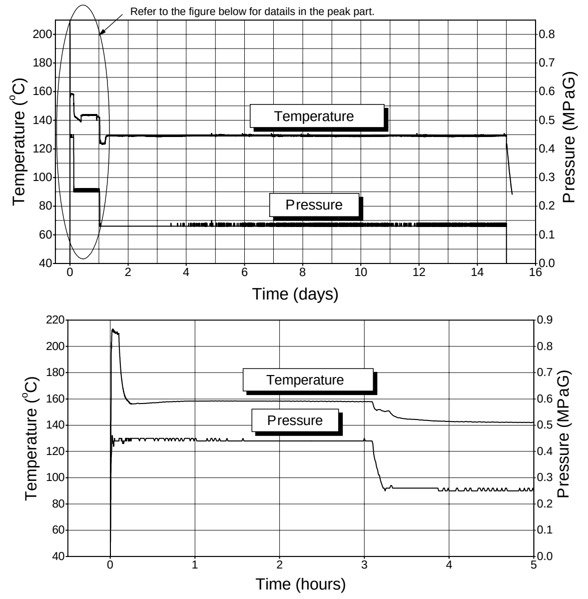
Specimen Number	Radiation Exposure	Steam Exposure
F-B-81	9.164 kGy/h- 163.69 hrs 1500 kGy	
F-B-82		
F-B-83		
F-B-91		
F-B-92		
J-B-81		
J-B-82		
J-B-83		
J-B-91		
J-B-92		

Table 2.4.2-20 Results of characteristics test in the fifth LOCA test

Specimen number & color of cores		Insulation resistance MΩ [( )value shows converted value to MΩkm]		Maximum leakage current during steam exposure test
		Before LOCA test	After LOCA Test	
F-B-91	Black	2.9×10^{6} (8.7×10^{3})	*1	-
	White	2.4×10^{6} (7.2×10^{3})	*1	-
	Red	1.9×10^{6} (5.7×10^{3})	*1	-
F-B-92	Black	1.1×10^{6} (3.3×10^{3})	*1	-
	White	9.5×10^{5} (2.9×10^{3})	*1	-
	Red	1.1×10^{6} (3.3×10^{3})	*1	-
J-B-91	Black	1.1×10^{6} (3.3×10^{3})	*1	-
	White	9.5×10^{5} (2.9×10^{3})	8.6 (2.6×10^{-2})	2mA
	Red	9.5×10^{5} (2.9×10^{3})	*1	-
J-B-92	Black	4.4×10^{5} (1.3×10^{3})	*1	-
	White	3.4×10^{5} (1.0×10^{3})	*1	-
	Red	3.8×10^{5} (1.1×10^{3})	*1	-

*1: No measurement because failure having occurred during steam exposure.

Table 2.4.2-21 Results of acceptance test in the fifth LOCA test

Specimen number & color of cores		Maintain the application of rated voltage during steam exposure DC 750 V	JIS withstand voltage test AC 1500V- 1 min.	IEEE withstand voltage test AC 2600V- 5min.	IEEE bend submerged withstand voltage test AC 2600V- 5min.	Remarks
F-B-81	Black	Good	Good	No good after 4.5 min.	-	
	White	Good	Good	No good after 30 sec.	-	
	Red	Good	Good	Good	Good	
F-B-91	Black	Failure occurred after 120 hrs	-	-	-	
	White	Failure occurred after 120 hrs	-	-	-	
	Red	Failure occurred after 120 hrs	-	-	-	
F-B-82	Black	Failure occurred after 6hrs	-	-	-	
	White	Failure occurred after 6hrs	-	-	-	
	Red	Good	No good at 800V	-	-	
F-B-92	Black	Failure occurred after 6hrs	-	-	-	
	White	Failure occurred after 6hrs	-	-	-	
	Red	Failure occurred after 6hrs	-	-	-	
F-B-83	Black	Failure occurred after 6hrs	-	-	-	
	White	Failure occurred after 6hrs	-	-	-	
	Red	Failure occurred after 6hrs	-	-	-	
J-B-81	Black	Good	Good	No good at 1800V	-	
	White	Good	Good	No good after 30 sec.	-	
	Red	Good	Good	No good at 1700V	-	
J-B-91	Black	Failure occurred after 48 hrs.	-	-	-	
	White	Good	No good at 1400V	-	-	
	Red	Failure occurred after 216 hrs.	-	-	-	
J-B-82	Black	Failure occurred after 216 hrs.	-	-	-	
	White	Failure occurred after 168 hrs.	-	-	-	
	Red	Failure occurred after 216 hrs.	-	-	-	
J-B-92	Black	Failure occurred after 168 hrs.	-	-	-	
	White	Failure occurred after 120 hrs	-	-	-	
	Red	Failure occurred after 48 hrs.	-	-	-	
J-B-83	Black	Failure occurred after 168 hrs.	-	-	-	
	White	Failure occurred after 168 hrs.	-	-	-	
	Red	Failure occurred after 168 hrs.	-	-	-	

Fig. 2.4.2-16 Specimen F-B-81 after steam exposure test

Fig. 2.4.2-17 Specimen F-B-92 after steam exposure test

Fig. 2.4.2-18 Specimen J-B-81 after steam exposure test

Fig. 2.4.2-19 Specimen J-B-92 after steam exposure test

(6) Results of the sixth LOCA test

The specimens for the sixth LOCA test including the same specimens as the first LOCA test with mitigated pre-aging are shown in Table 2.4.2-22. The implementing conditions for the radiation exposure and the steam exposure tests are in Table 2.4.2-23, the results of characteristics test are in Table 2.4.2-24 and results of acceptance test are in Table 2.4.2-25 respectively.

In addition, status of the specimens after steam exposure test is shown in Figures 2.4.2-20 through 23.

In the sixth LOCA test, a failure located at the connection point of the XLPE insulated cable made by B Company occurred. Such failure had not been recognized in previous LOCA tests. Especially, for the short length specimen, the failure at the connection point affected the overall length of the specimen. For this reason, the withstand voltage tests in JIS code and others for the XLPE insulated cable made by B Company were performed after cutting off the connection point from the long length specimen. The withstand voltage tests for the short length specimen were not conformed.

The main cause of the failure was believed to be that the insulator in the connecting processed part had failed due to some stress caused by exposing the specimen in high temperature environment at steam exposure test.

Also, a part of the core conductors of the short length specimens of XLPE insulated cable made by A Company showed a low withstand voltage value (break at 2200 to 2400 V), while similarly pre-aged long length specimens showed a very high breakdown voltage value (26 to 38 kV). From these facts, it was decided to be appropriate to make these short length specimens' data as part of the reference data.

Table 2.4.2-22 Specimens used in the sixth LOCA test

Kind of specimen	Specimen number	Pre-aging conditions	Elongation at break after pre-aging
XLPE insulated cable CV-2.0-A	A-B-84	100ºC- 86.8 Gy/h- 591 hrs.	539%
	A-B-93*	100ºC- 89.4 Gy/h- 591 hrs.	-
	A-B-85	100ºC- 86.7 Gy/h- 734 hrs.	406%
	A-B-94*	100ºC- 89.4 Gy/h- 734 hrs.	-
	A-B-86	100ºC- 86.7 Gy/h- 805 hrs.	275%
	A-B-95*	100ºC- 89.3 Gy/h- 805 hrs.	-
XLPE insulated cable CV-2.0-B	B-B-84	100ºC- 86.9 Gy/h- 500 hrs.	221%
	B-B-93*	100ºC- 89.5 Gy/h- 500 hrs.	-
	B-B-85	100ºC- 86.8 Gy/h- 638 hrs.	126%
	B-B-94*	100ºC- 89.4 Gy/h- 638 hrs.	-
	B-B-86	100ºC- 86.7 Gy/h- 805 hrs.	76%
	B-B-95*	100ºC- 89.3 Gy/h- 805 hrs.	-

Notes: 1. Specimen with *mark shows 3m long specimen. (Others are all 60cm Long specimens)

2. The elongation at break of the 60 cm long specimen after pre-aging was evaluated from the characteristics at the aging conditions of the 60 cm long specimen. Although the elongation at break in the aging conditions of the 3 m long specimen was not measured, the elongation at break of the 3 m long specimen is similar to the elongation at break of the 60 cm long specimen at the same aging period.

Table 2.4.2-23 Implementing conditions for radiation and steam exposures tests in the sixth LOCA

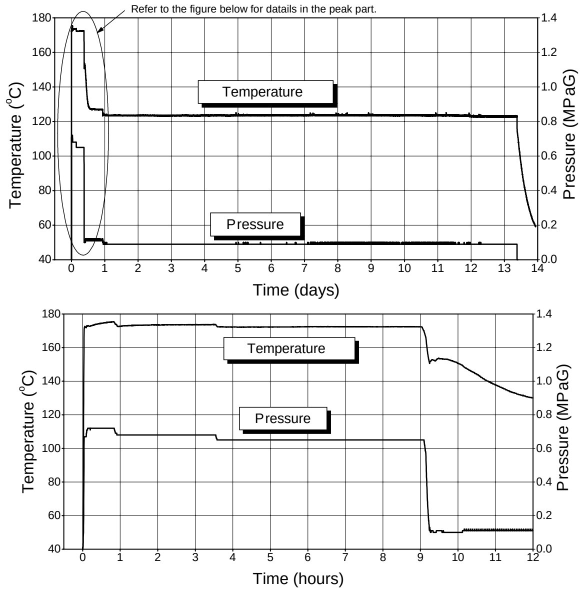
Specimen number	Radiation exposure	Steam exposure
A-B-84	8.11 kGy/h- 32.07 hrs. 260 kGy	
A-B-85		
A-B-86		
A-B-93		
A-B-94		
A-B-95		
B-B-84		
B-B-85		
B-B-86		
B-B-93		
B-B-94		
B-B-95		

Table 2.4.2-24 Results of characteristics test in the sixth LOCA test

Specimen number & color of cores		Insulation resistance MΩ [( ) value shows converted Value to MΩkm]		Maximum leakage current during steam exposure test
		Before LOCA Test	After LOCA Test	
A-B-93	Black	3.8×10^6 (1.1×10^4)	2.9×10^4 (8.7×10)	Approx. 0mA
	White	3.6×10^6 (1.1×10^4)	1.2×10^7 (3.6×10^4)	Approx. 0mA
	Red	4.0×10^6 (1.2×10^4)	8.0×10^6 (2.4×10^4)	Approx. 0mA
A-B-94	Black	4.6×10^6 (1.4×10^4)	8.0×10^5 (2.4×10^3)	Approx. 0mA
	White	4.6×10^6 (1.4×10^4)	5.4×10^6 (1.6×10^4)	Approx. 0mA
	Red	4.8×10^6 (1.4×10^4)	4.0×10^6 (1.2×10^4)	Approx. 0mA
A-B-95	Black	5.6×10^6 (1.7×10^4)	9.0×10^6 (2.7×10^4)	Approx. 0mA
	White	5.0×10^6 (1.5×10^4)	9.0×10^6 (2.7×10^4)	Approx. 0mA
	Red	5.8×10^6 (1.7×10^4)	8.0×10^6 (2.4×10^4)	Approx. 0mA
B-B-93	Black	2.8×10^6 (8.4×10^3)	2.5×10^6 (5.9×10^3)	No measurement could be made because of an occurrence of a failure at the connecting processed part.
	White	3.4×10^6 (1.0×10^4)	1.2×10^7 (2.8×10^4)	
	Red	1.6×10^6 (4.8×10^3)	2.2×10^6 (5.2×10^3)	
B-B-94	Black	1.4×10^6 (4.2×10^3)	8.0×10^6 (1.9×10^4)	
	White	4.4×10^6 (1.3×10^4)	1.2×10^6 (2.8×10^3)	
	Red	4.0×10^6 (1.2×10^4)	1.4×10^7 (3.3×10^4)	
B-B-95	Black	6.5×10^6 (2.0×10^4)	2.1×10^5 (4.9×10^2)	
	White	8.0×10^6 (2.4×10^4)	3.6×10^5 (8.4×10^2)	
	Red	8.0×10^6 (2.4×10^4)	3.0×10^6 (7.0×10^3)	

Note: Insulation resistance measurement after LOCA test for B-B-93 through 95 was made by cutting off the connecting processed part.

Table 2.4.2-25 Results of acceptance test in the sixth LOCA test

Specimen number & color of cores		Maintain the application of rated voltage during steam exposure DC 750 V	JIS withstand voltage test AC 1500V - 1min.	IEEE withstand voltage test AC 2600V - 5min.	IEEE bend submerged withstand voltage test	Remarks
A-B-84	Black	Good	Good	Good	Good	
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
A-B-93	Black	Good	Good	Good	Good	Break down voltage: 36kV
	White	Good	Good	Good	Good	Break down voltage: 36kV
	Red	Good	Good	Good	Good	Break down voltage: 26kV
A-B-85	Black	Good	Good	Good	Good	This result is to be a reference data based on the results and other facts of A-B-94 which had similar pre-aging.
	White	Good	Good	No good at 2200V	-	
	Red	Good	Good	Good	Good	
A-B-94	Black	Good	Good	Good	Good	Break down voltage: 40 kV
	White	Good	Good	Good	Good	Break down voltage: 38 kV
	Red	Good	Good	Good	Good	Break down voltage: 22 kV
A-B-86	Black	Good	Good	No good at 2400V	-	This result is to be a reference data based on the results and other facts of A-B-95 which had similar pre-aging.
	White	Good	Good	Good	Good	
	Red	Good	Good	Good	Good	
A-B-95	Black	Good	Good	Good	Good	Break down voltage: 26 kV
	White	Good	Good	Good	Good	Break down voltage: 29 kV
	Red	Good	Good	Good	Good	Break down voltage: 32 kV
B-B-84	Black	-	-	-	-	Test was not possible due to the failure at the connecting processed part.
	White	-	-	-	-	
	Red	-	-	-	-	
B-B-93	Black	-	Good	Good	Good	Break down voltage: 46 kV
	White	-	Good	Good	Good	Break down voltage: 42 kV
	Red	-	Good	Good	Good	Break down voltage: 46 kV
B-B-85	Black	Good	No good at 1400 V	-	-	A failure occurred in the connection processed part was considered to be a main factor of wrong charging in JIS withstand voltage test.
	White	Good	No good at 1350V	-	-	
	Red	Good	No good at 1400V	-	-	
B-B-94	Black	-	Good	Good	Good	Break down voltage: 42 kV
	White	-	Good	Good	Good	Break down voltage: 42 kV
	Red	-	Good	Good	Good	Break down voltage: 42 kV
B-B-86	Black	-	-	-	-	Test was not possible due to the failure at the connecting processed part.
	White	-	-	-	-	
	Red	-	-	-	-	
B-B-95	Black	-	Good	Good	Good	Break down voltage: 44 kV
	White	-	Good	Good	Good	Break down voltage: 42 kV
	Red	-	Good	Good	Good	Break down voltage: 46 kV

Notes: Failures occurred for B-B-84, B-B-86, B-B-93 to 95 in their connection processed part during steam exposure test.
Tests after JIS withstand voltage test for B-B-93 to 95 were conducted by cutting off the connection processed part.

Fig. 2.4.2-20 Specimen A-B-93 after steam exposure test

Fig. 2.4.2-21 Specimen A-B-95 after steam exposure test

Fig. 2.4.2-22 Specimen B-B-93 after steam exposure test

Fig. 2.4.2-23 Specimen B-B-95 after steam exposure test

3. Evaluation

An evaluation of simultaneous aging characteristics, as well as thermal aging characteristics, was made based on the results of the tensile test by using thermal aging and simultaneous aging specimens which were obtained up to the first half of FY2006, as described below.

3.1 Thermal aging characteristics

Thermal aging characteristics of each specimen, based on the data obtained up to the last half of FY2006, are shown in Figures 3.1-1 through 20. In the case where thermal aging characteristic for each specimen differ by the core color, aging characteristics are shown by their respective core color. Note that the EPR insulator made by C Company (all black), the SIR insulators made by A and B Companies (all white) are of the same core color.

As shown in Figures 3.1-1 through 20, thermal aging characteristics of the cables do differ according to the manufacturer, even for the same kind of insulator material. Especially, the thermal aging characteristics for FR-EPR differ significantly according to the manufacturers. Also, there is a trend in which thermal aging characteristics for each FR-EPR differs by their core color.

The trend of thermal aging characteristics is classified into the following four trends: (a) Almost no progress of degradation (Here, this means decrease in elongation at break. This meaning is the same in the following sentences) is recognized in the early period, but the progress of degradation becomes rapid from a certain time point; (b) Though almost no progress of degradation is recognized in the early period, the progress of degradation becomes less rapid from a certain time point; (c) Though the progress of degradation is recognized from a relatively early period, the progress of degradation has a slow tendency; (d) Though almost no progress of degradation is recognized in the early period, the degradation makes slow progress from a certain time point. However, these trends do not have significant differences even for insulators having a different degradation trend by core color. These trends for each cable specimen are shown in Table 3.1-1.

Table 3.1-1 Trends of thermal aging characteristics

Trend of degradation	The specimens to be applied to the respective trend
(a)Though almost no progress of degradation is recognized in the early point, the progress of degradation becomes rapid from a certain time point	XLPE insulated cable made by A Company XLPE insulated cable made by B Company EPR insulated cable made by C Company FR-EPR insulated cable made by A Company
(b)Though almost no progress of degradation is recognized in the early point, the progress of degradation becomes less rapid from a certain time point.	FR-XLPE insulated cable made by B Company FR-EPR insulated cable made by C Company SHPVC insulated cable made by A Company SHPVC insulated cable made by B Company
(c)Though the progress of degradation is recognized from a relatively early period, the progress of degradation has a slow tendency.	FR-XLPE insulated cable made by A Company XLPE insulated triaxial cable made by C Company SIR insulated cable made by A Company SIR insulated cable made by B Company SIR insulated cable made by C Company
(d)Though almost no progress of degradation is recognized in the early point, the degradation makes slow progress from a certain time point.	FR-EPR insulated cable made by B Company

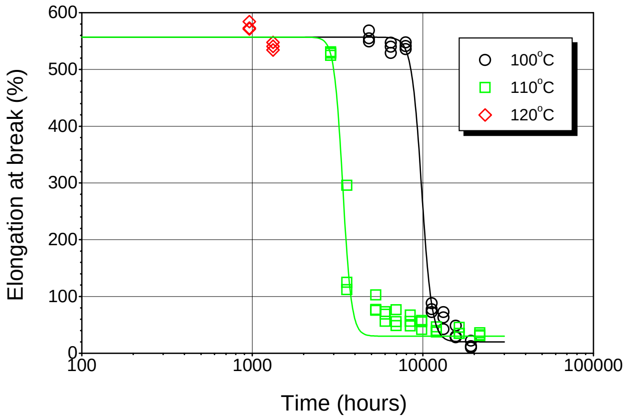


Fig. 3.1-1 Thermal aging characteristics of the XLPE insulator made by A Company

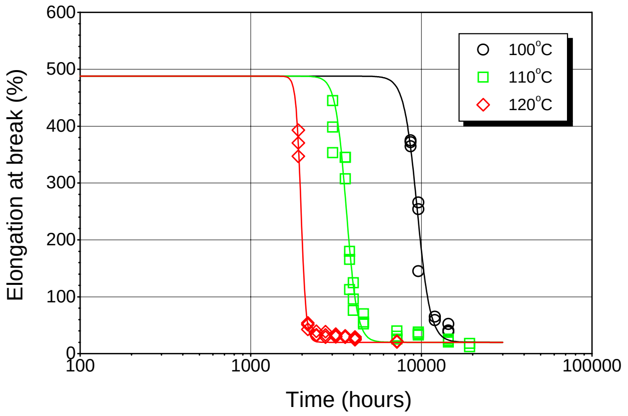


Fig. 3.1-2 Thermal aging characteristics of the XLPE insulator made by B Company

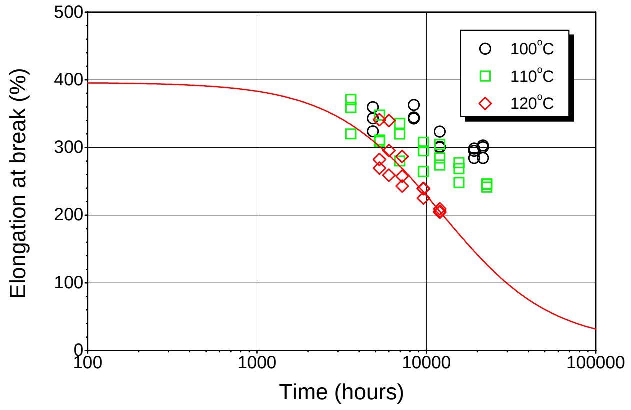


Fig. 3.1-3 Thermal aging characteristics of the FR-XLPE insulator made by A Company

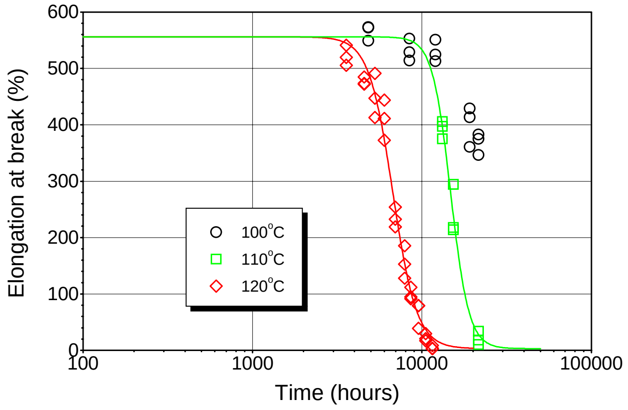


Fig. 3.1-4 Thermal aging characteristics of the FR-XLPE insulator made by B Company

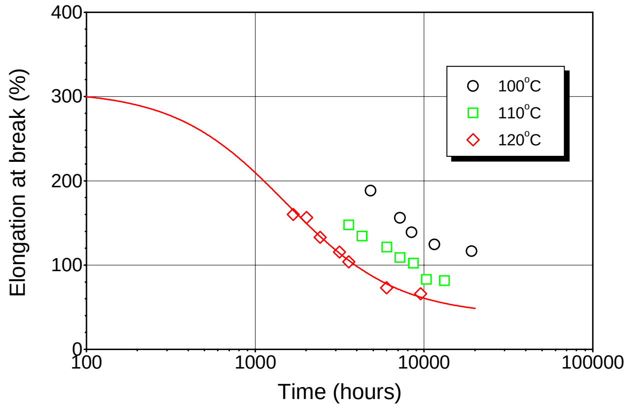


Fig. 3.1-5 Thermal aging characteristics of the XLPE insulator of triaxial cable made by C Company

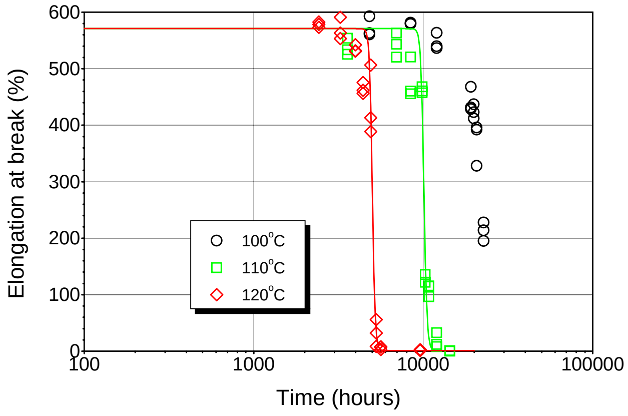


Fig. 3.1-6 Thermal aging characteristics of the EPR insulator made by C Company

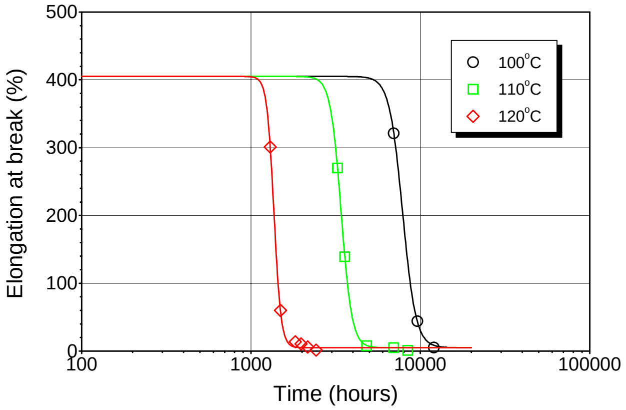


Fig. 3.1-7 Thermal aging characteristics of the FR-EPR insulator (black core) made by A Company

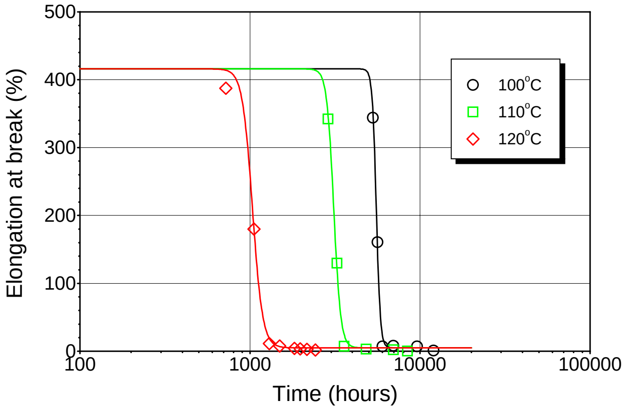


Fig. 3.1-8 Thermal aging characteristics of the FR-EPR insulator (white core) made by A Company

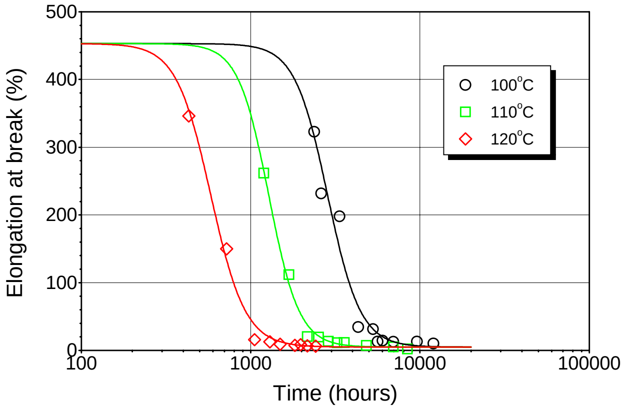


Fig. 3.1-9 Thermal aging characteristics of the FR-EPR insulator (red core) made by A Company

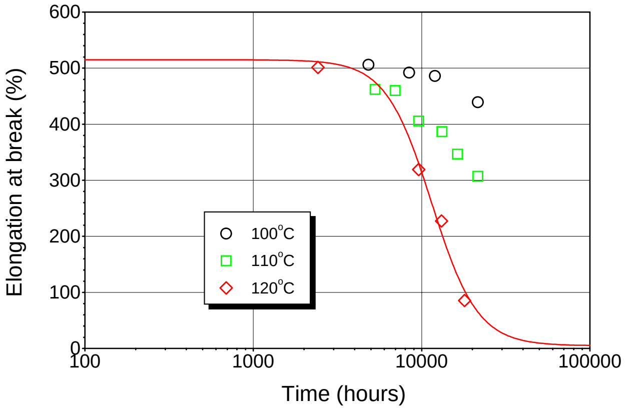


Fig. 3.1-10 Thermal aging characteristics of the FR-EPR insulator (black core) made by B Company

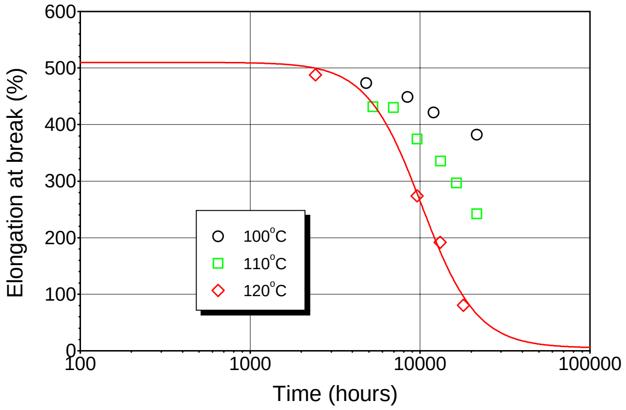


Fig. 3.1-11 Thermal aging characteristics the FR-EPR insulator (white core) made by B Company

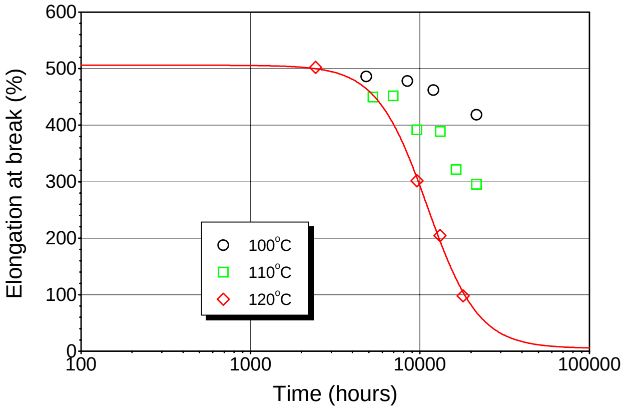


Fig. 3.1-12 Thermal aging characteristics of the FR-EPR insulator (red core) made by B Company

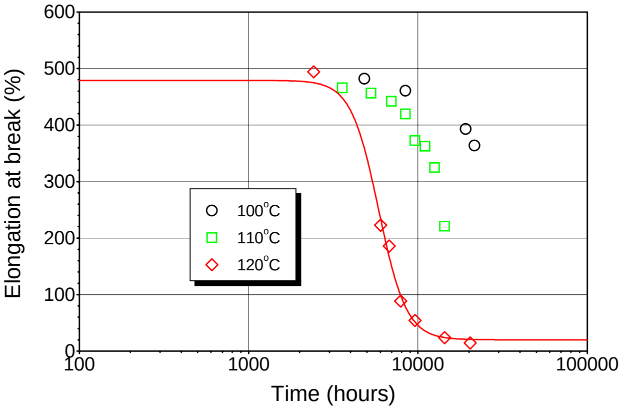


Fig. 3.1-13 Thermal aging characteristics of the FR-EPR insulator (black core) made by C Company

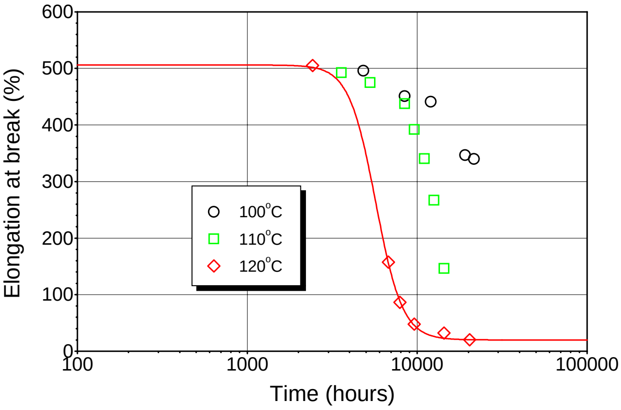


Fig. 3.1-14 Thermal aging characteristics of the FR-EPR insulator (white core) made by C Company

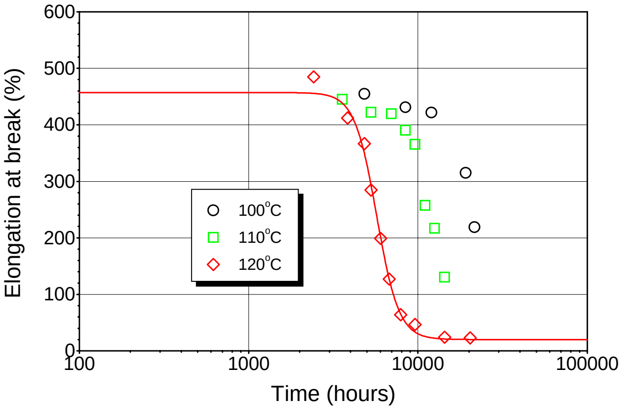


Fig. 3.1-15 Thermal aging characteristics of the FR-EPR insulator (red core) made by C Company

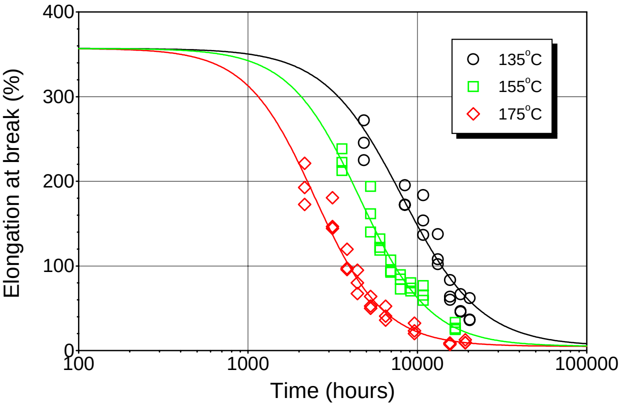


Fig. 3.1-16 Thermal aging characteristics of the SIR insulator made by A Company

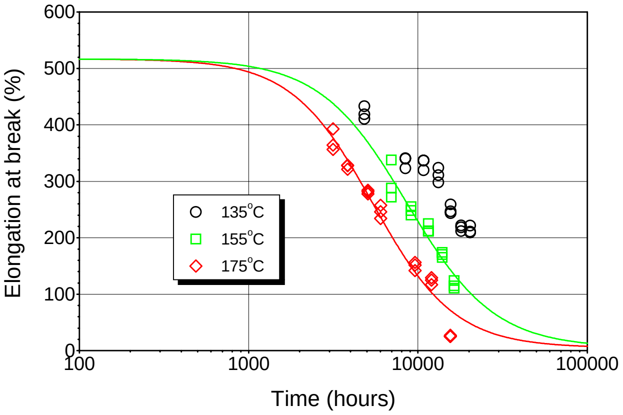


Fig. 3.1-17 Thermal aging characteristics of the SIR insulator made by B Company

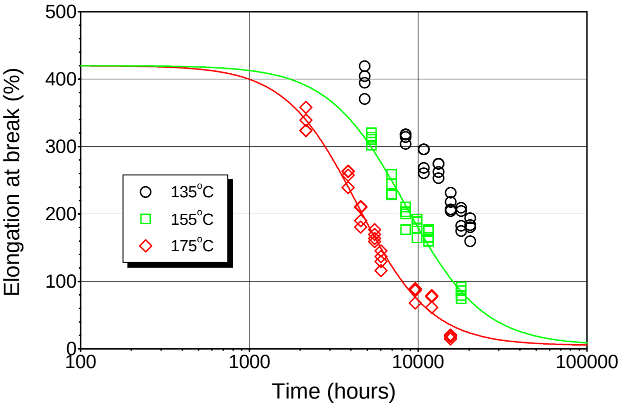


Fig. 3.1-18 Thermal aging characteristics of the SIR insulator made by C Company

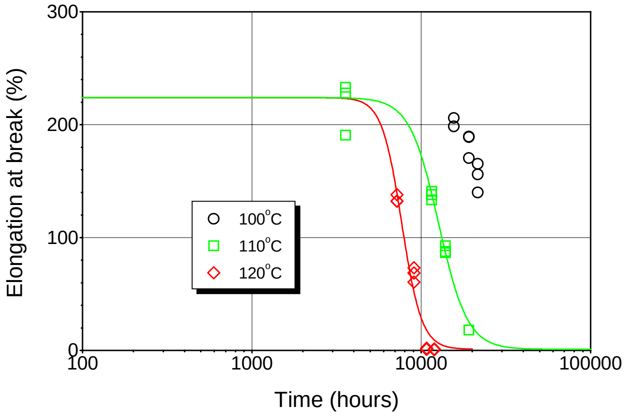


Fig. 3.1-19 Thermal aging characteristics of the SHPVC insulator made by A Company

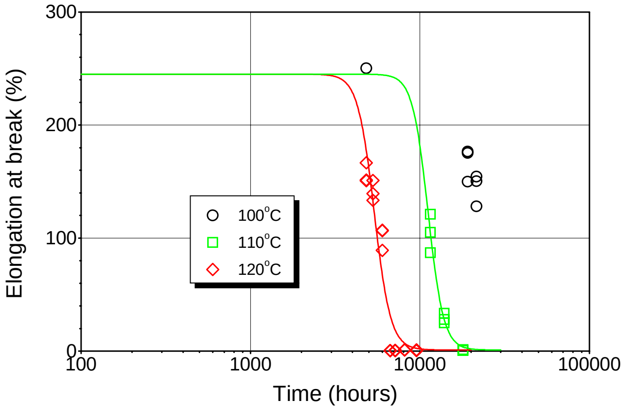


Fig. 3.1-20 Thermal aging characteristics of the SHPVC insulator made by B Company

3.2 Simultaneous aging characteristics

Simultaneous aging characteristics of each specimen based on the data obtained during the period up to the first half of FY2006 are shown in Figures 3.2.1 through 44. For the case where simultaneous aging characteristics of each specimen differ by the core color, aging characteristics are shown for each core color, similar to the thermal aging characteristics in the preceding item.

As shown in Figures 3.2.1 through 44, similar to thermal aging characteristics, simultaneous aging characteristics differ by the manufacturer even for the same kind of insulator. Notably, the results for FR-EPR differ significantly by the manufacturer. Also, the FR-XLPR made by B Company and the the FR-EPR made by each company have a trend to differ in their simultaneous characteristics by the core color.

The trend of simultaneous aging characteristics is generally classified into the following four cases: (a) Though almost no progress of degradation (here, this means decrease in the elongation at the break. This meaning is the same in the following sentence) is recognized in the early period, the progress of degradation becomes rapid from a certain time point; (a') The progress of degradation is recognized from a relatively early period, then, the progress of degradation has a rapid tendency; (b) Though almost no progress of degradation is recognized in the early period, the progress of degradation becomes less rapid from a certain time point; (c) Though the progress of degradation is recognized from a relatively early period, the progress of degradation has a slow tendency; (d) Though almost no progress of degradation is recognized in the early period, the degradation makes slow progress from a certain time point. However, these five trends have no significant differences even for insulators having different degradation trends by core color. These trends for each cable specimen are shown in Table 3.2-1. Trends of simultaneous aging characteristics for each specimen compared with thermal aging characteristics are almost the same as thermal aging characteristics, except that only the XLPE made by B Company is newly classified as (a').

Also, progress of degradation is considerably earlier in the simultaneous aging, especially for the XLPE insulated cables made by both A and B Companies and for the FR-EPR insulated cable made by A Company.

Table 3.2-1 Trend of Simultaneous Aging Characteristics

Trend of degradation	The specimens to be applied to the respective trend
(a)Though almost no progress of degradation is recognized in the early point, the progress of degradation becomes rapid from a certain time point.	XLPE insulated cable made by A Company EPR insulated cable made by C Company FR-EPR insulated cable made by A Company
(a')The progress of degradation is recognized from a relatively early point and the progress of degradation has a rapid tendency.	XLPE insulated cable made by B Company
(b)Though almost no progress of degradation is recognized in the early point, the progress of degradation becomes less rapid from a certain time point.	FR-XLPE insulated cable made by B Company FR-EPR insulated cable made by C Company SHPVC insulated cable made by A Company SHPVC insulated cable made by B Company
(c)Though progress of degradation is recognized from a relatively early period, the progress of degradation has a slow tendency.	FR-XLPE insulated cable made by A Company XLPE insulated triaxial cable made by C Company SIR insulated cable made by A Company SIR insulated cable made by B Company SIR insulated cable made by C Company
(d)Though almost no progress of degradation is recognized in the early point, the degradation makes slow progress from a certain time point.	FR-EPR insulated cable made by B Company

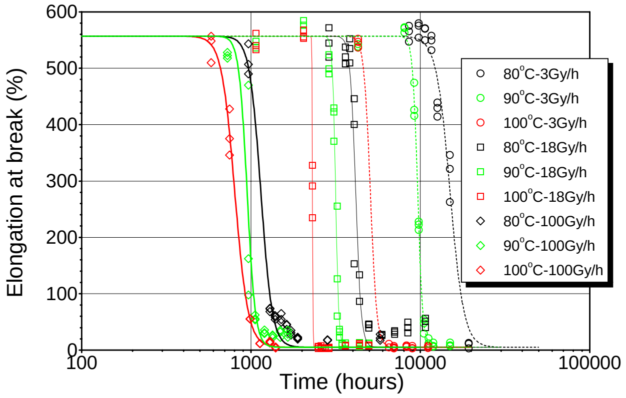


Fig. 3.2-1 Simultaneous aging characteristics I of the XLPE insulator made by A Company

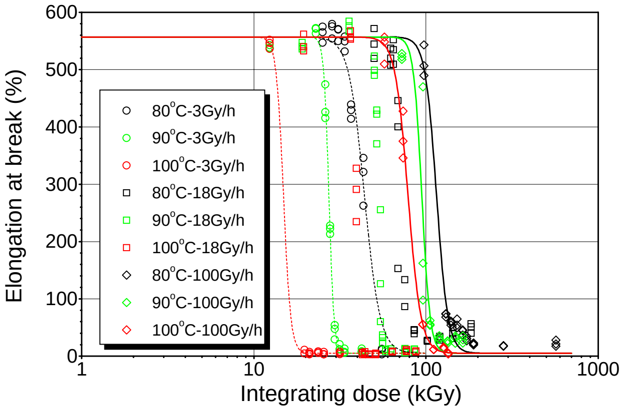


Fig. 3.2-2 Simultaneous aging characteristics II of the XLPE insulator made by A Company

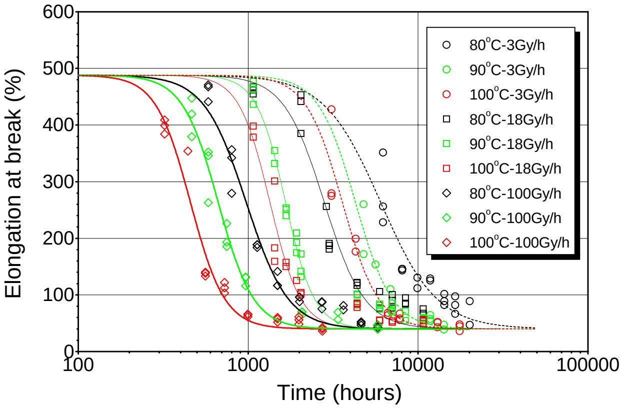


Fig. 3.2-3 Simultaneous aging characteristics I of the XLPE insulator made by B Company

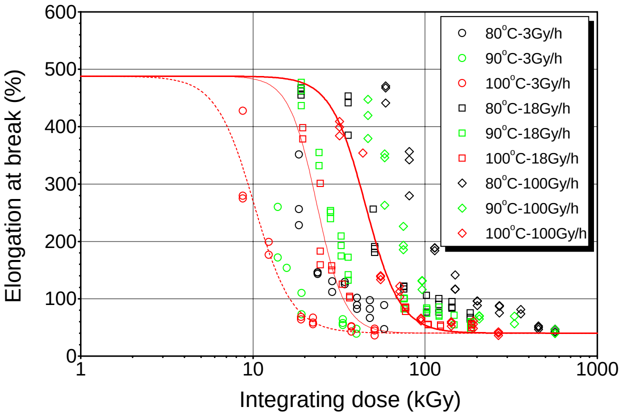


Fig. 3.2-4 Simultaneous aging characteristics II of the XLPE insulator made by B Company

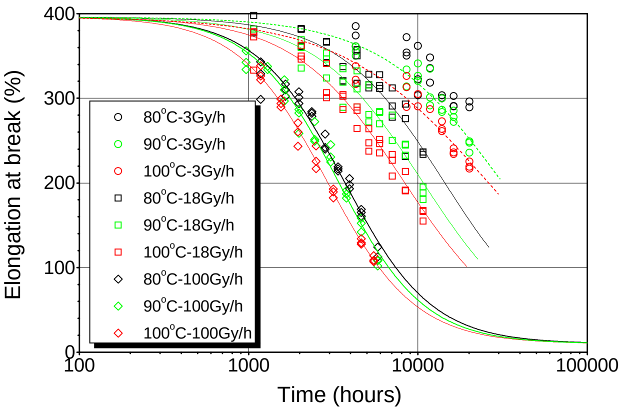


Fig. 3.2-6 Simultaneous aging characteristics I of the FR-XLPE insulator made by A Company

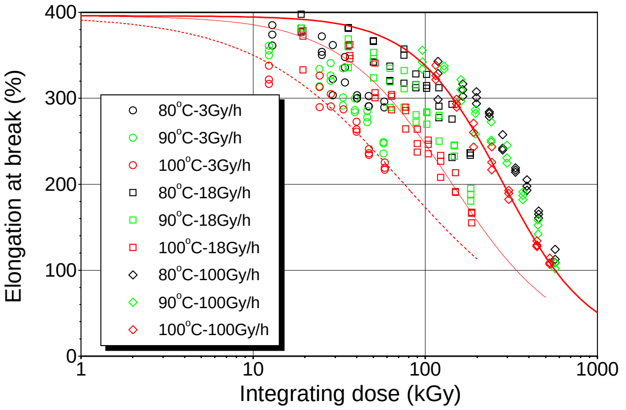
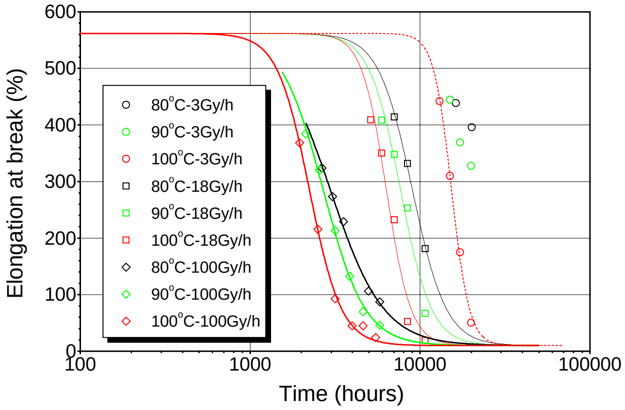


Fig. 3.2-6 Simultaneous aging characteristics II of the FR-XLPE insulator made by A Company



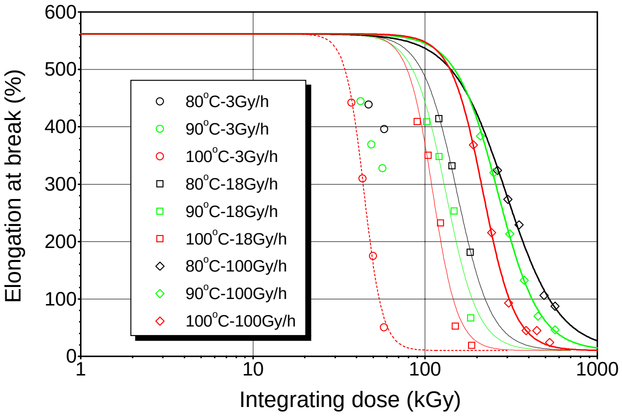
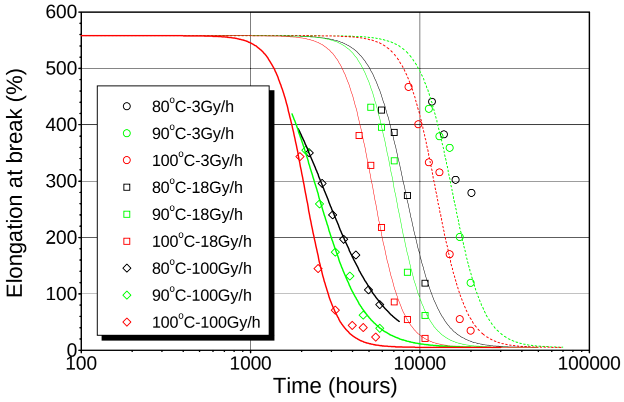


Fig. 3.2-7 Simultaneous aging characteristics I of the FR-XLPE insulator (black core) made by B Company

Fig. 3.2-8 Simultaneous aging characteristics II of the FR-XLPE insulator (black core) made by B Company



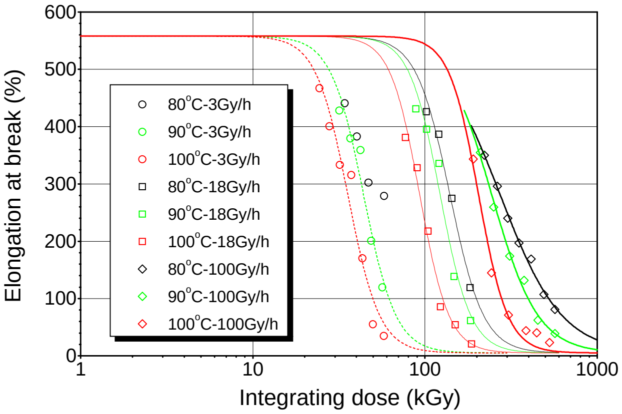
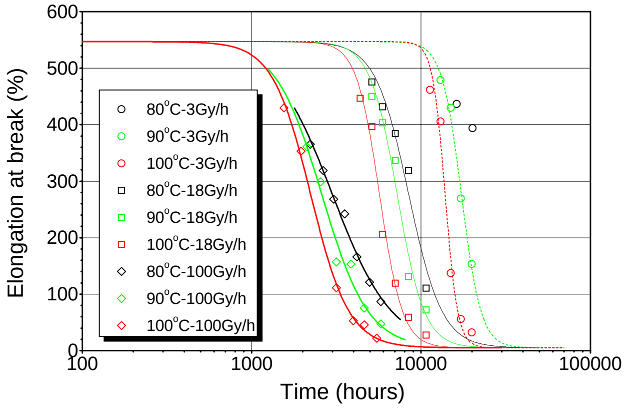


Fig. 3.2-9 Simultaneous aging characteristics I of the FR-XLPE Insulator (white core) made by B Company

Fig. 3.2-10 Simultaneous aging characteristics II of the FR-XLPE insulator (white core) made by B Company



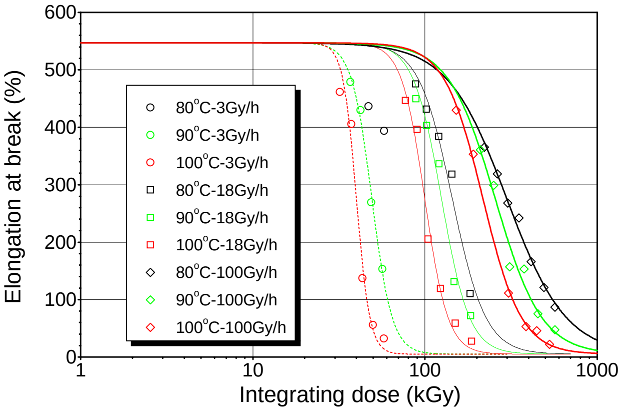


Fig. 3.2-11 Simultaneous aging characteristics I of the FR-XLPE insulator (red core) made by B Company

Fig. 3.2-12 Simultaneous aging characteristics II of the FR-XLPE insulator (red core) made by B Company

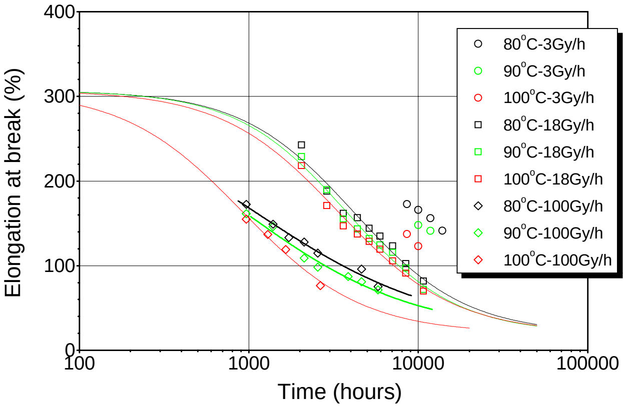


Fig. 3.2-13 Simultaneous aging characteristics I of the XLPE insulator of triaxial cable made by C Company

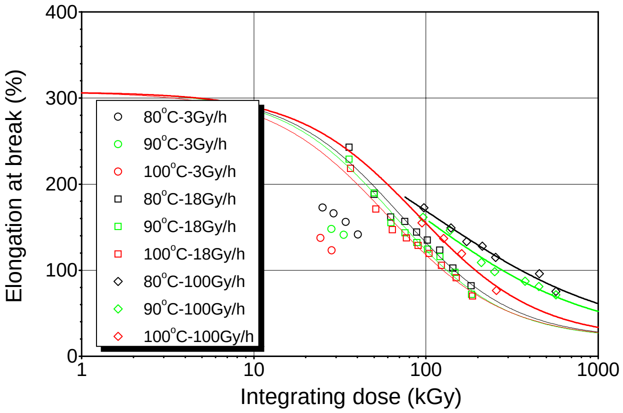


Fig. 3.2-14 Simultaneous aging characteristics II of the XLPE insulator of triaxial cable made by C Company

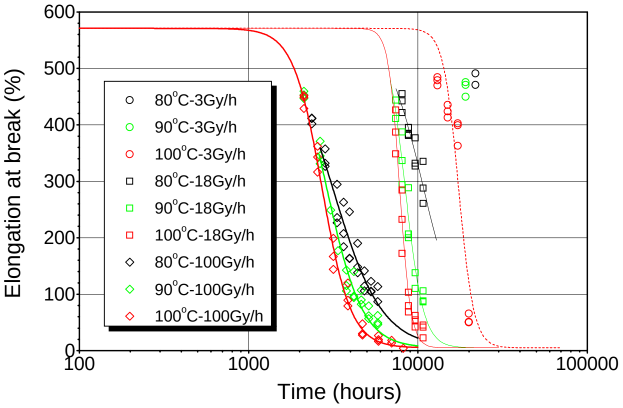


Fig. 3.2-15 Simultaneous aging Characteristics I of the EPR insulator made by C Company

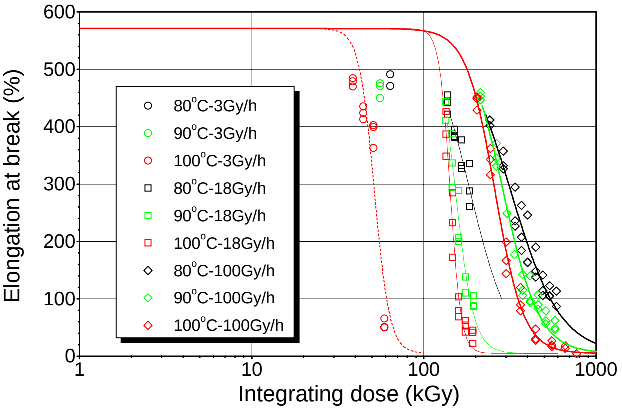
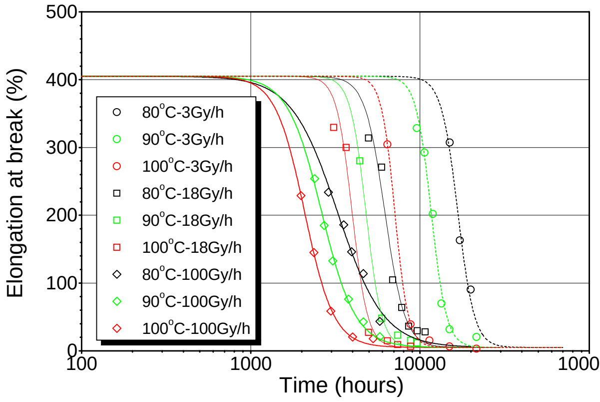


Fig. 3.2-16 Simultaneous aging characteristics II of the EPR insulator made by C Company



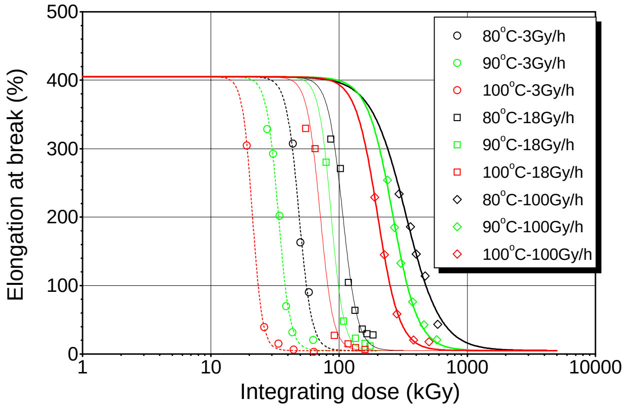
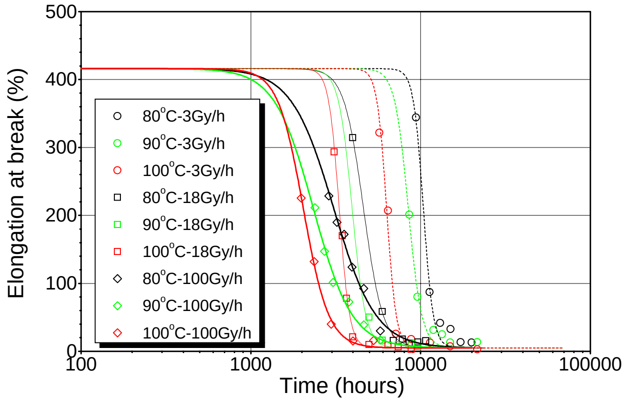


Fig. 3.2-17 Simultaneous aging characteristics I of the FR-EPR insulator (black core) made by A Company

Fig. 3.2-18 Simultaneous aging characteristics II of the FR-EPR insulator (black core) made by A Company



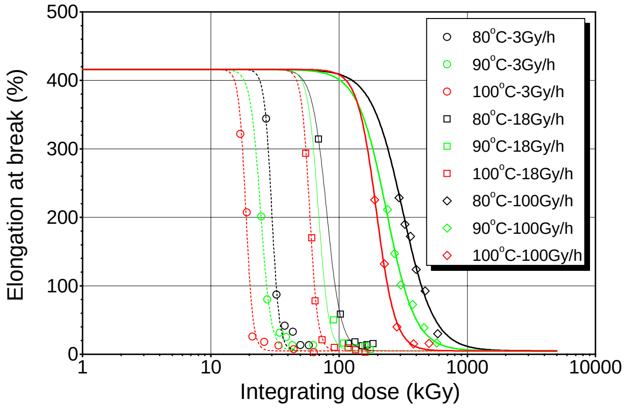
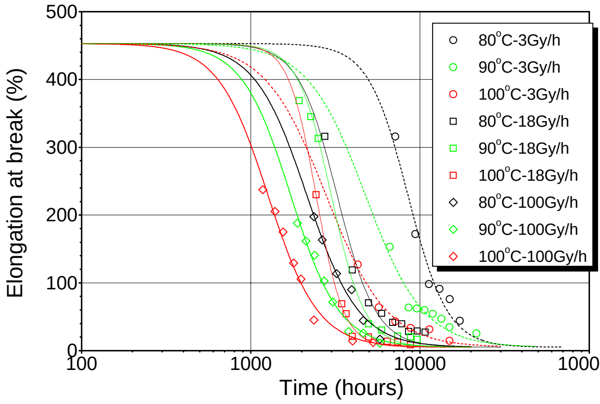


Fig. 3.2-19 Simultaneous aging characteristics I of the FR-EPR insulator (white core) made by A Company

Fig. 3.2-20 Simultaneous aging characteristics II of the FR-EPR insulator (white core) made by A Company



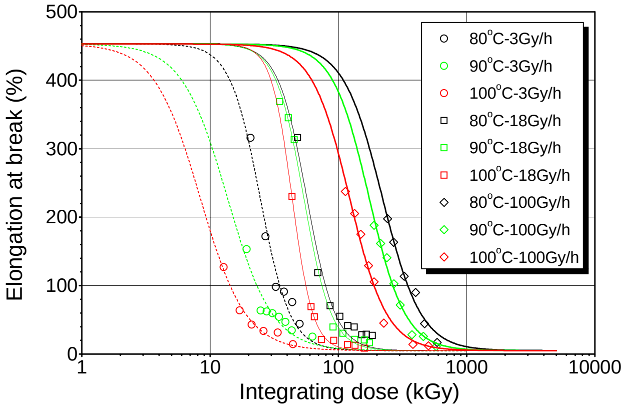


Fig. 3.2-21 Simultaneous aging characteristics I of the FR-EPR insulator (red core) made by A Company

Fig. 3.2-22 Simultaneous aging characteristics II of the FR-EPR insulator (red core) made by A Company

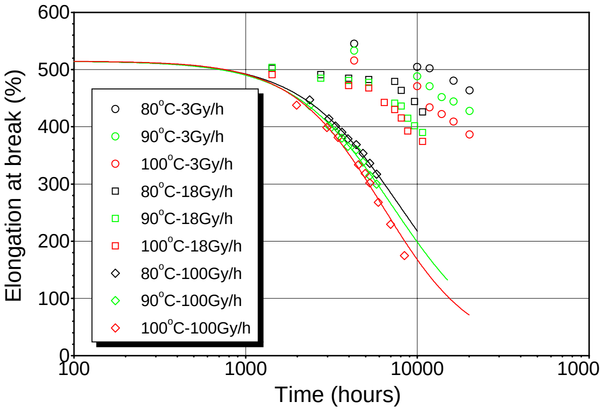


Fig. 3.2-23 Simultaneous aging characteristics I of the FR-EPR insulator (black core) made by B Company

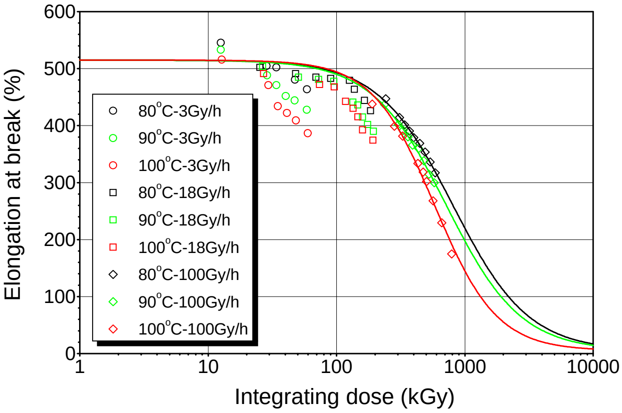


Fig. 3.2-24 Simultaneous aging characteristics II of the FR-EPR insulator (black core) made by B Company

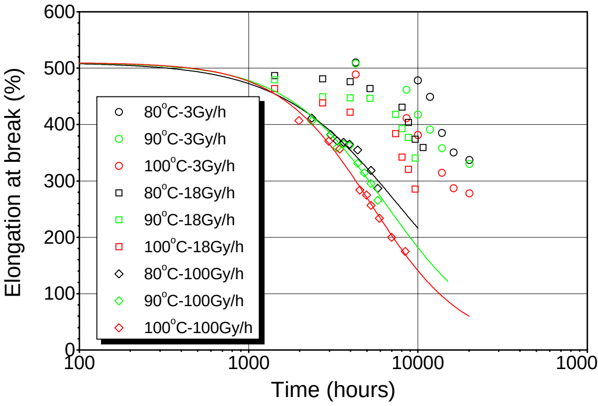


Fig. 3.2-25 Simultaneous aging characteristics I of the FR-EPR insulator (white core) made by B Company

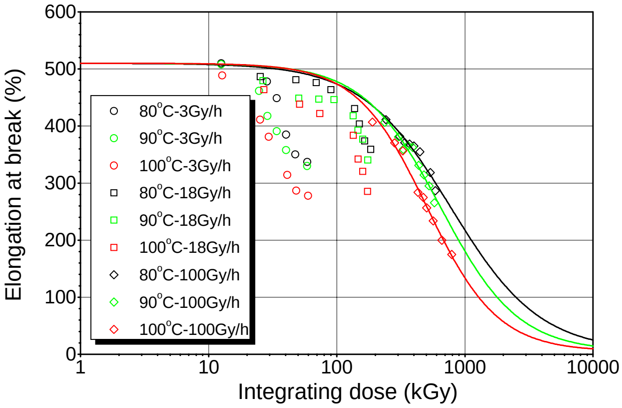


Fig. 3.2-26 Simultaneous aging characteristics II of the FR-EPR insulator (white core) made by B Company

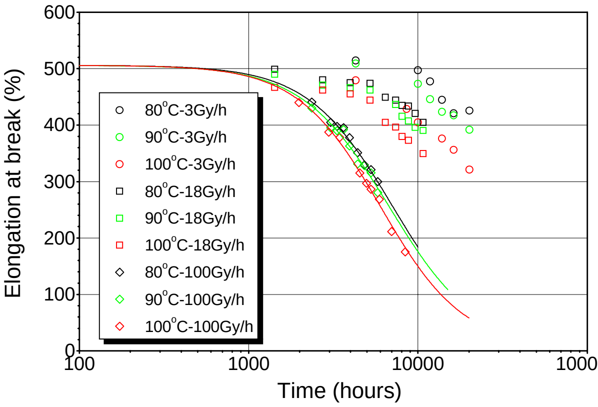


Fig. 3.2-27 Simultaneous aging characteristics I of the FR-EPR insulator (red core) made by B Company

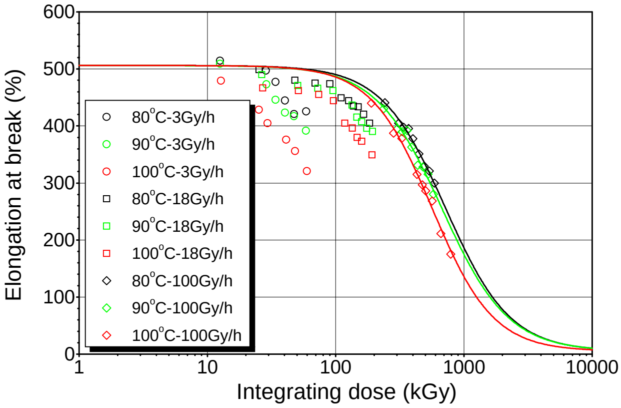


Fig. 3.2-28 Simultaneous aging characteristics II of the FR-EPR insulator (red core) made by B Company

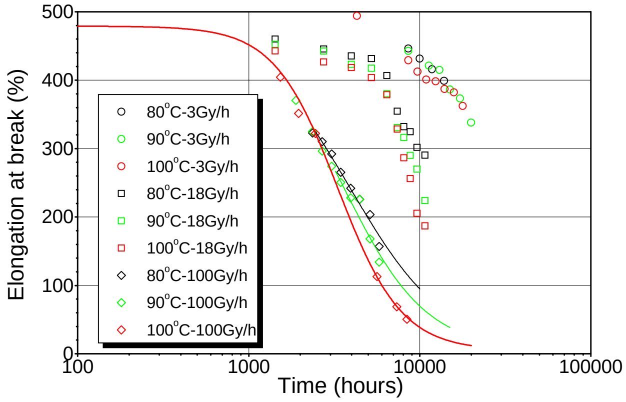


Fig. 3.2-29 Simultaneous aging characteristics I of the FR-EPR insulator (black core) made by C Company

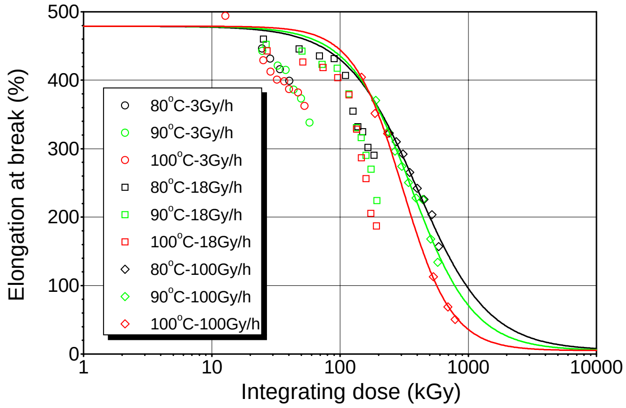


Fig. 3.2-30 Simultaneous aging characteristics II of the FR-EPR insulator (black core) made by C Company

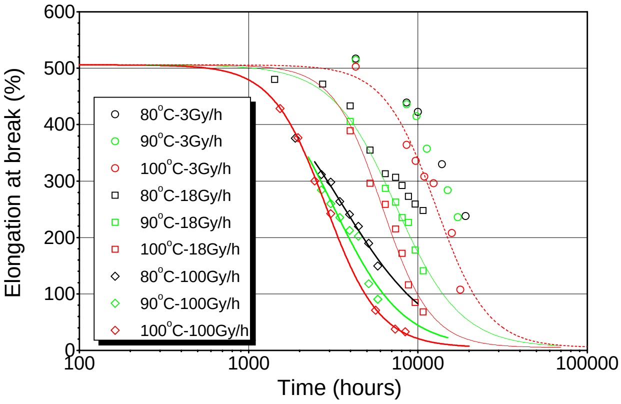


Fig. 3.2-31 Simultaneous aging characteristics I of the FR-EPR insulator (white core) made by C Company

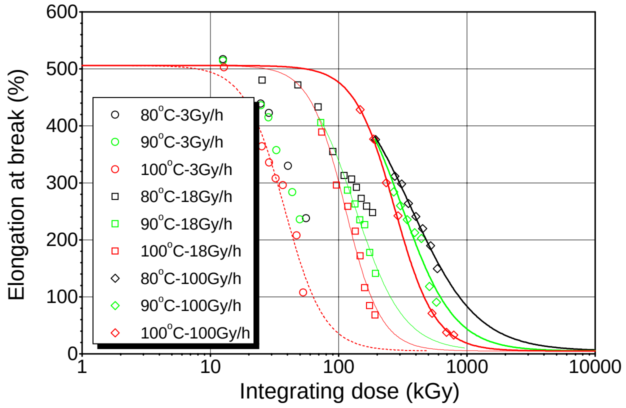


Fig. 3.2-32 Simultaneous aging characteristics II of the FR-EPR insulator (white core) made by C Company

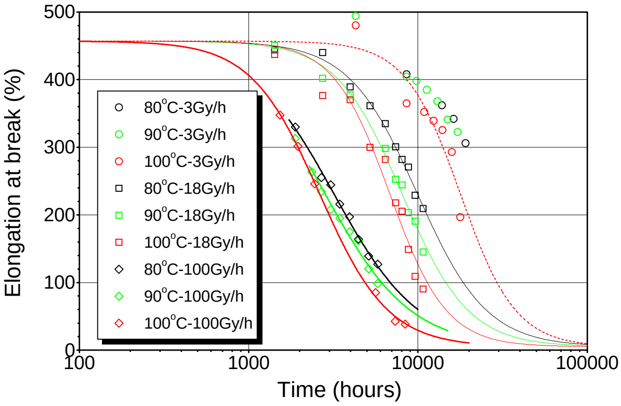


Fig. 3.2-33 Simultaneous aging characteristics I of the FR-EPR insulator (red core) made by C Company

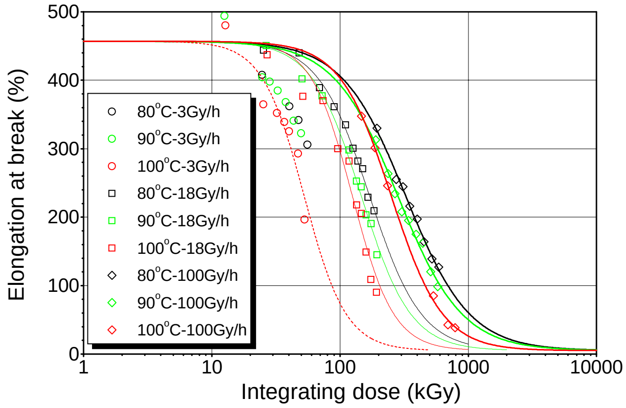


Fig. 3.2-34 Simultaneous aging characteristics II of the FR-EPR insulator (red core) made by C Company

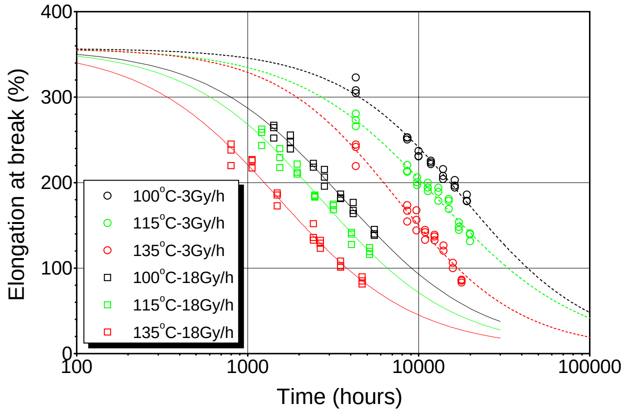


Fig. 3.2-35 Simultaneous aging characteristics I of the SIR insulator made by A Company

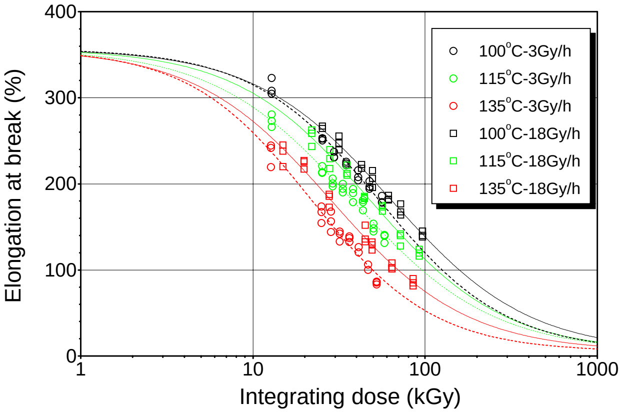


Fig. 3.2-36 Simultaneous aging characteristics II of the SIR insulator made by A Company

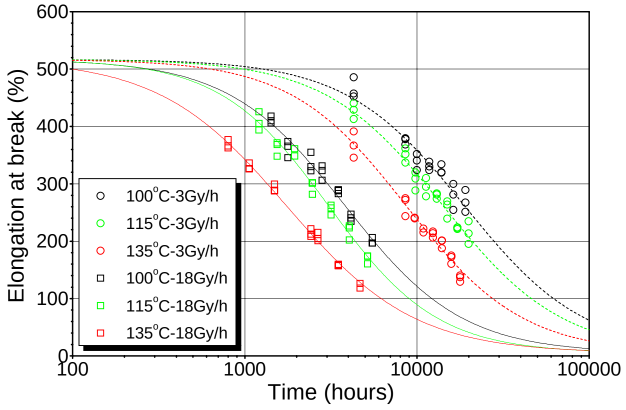


Fig. 3.2-37 Simultaneous aging characteristics I of the SIR insulator made by B Company

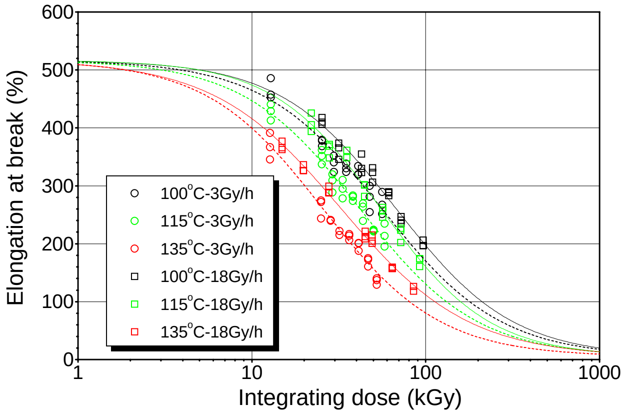


Fig. 3.2-38 Simultaneous aging characteristics II of the SIR insulator made by B Company

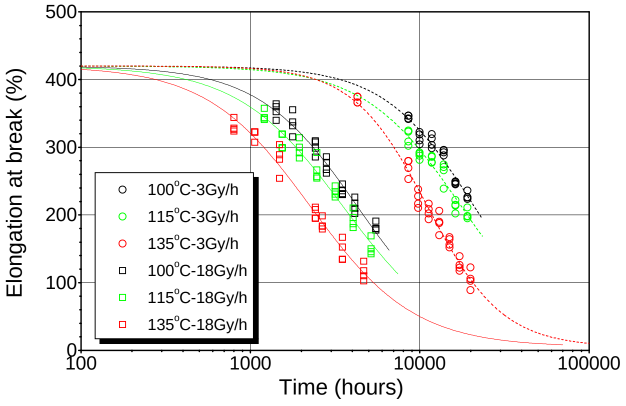


Fig. 3.2-39 Simultaneous aging characteristics I of the SIR insulator made by C Company

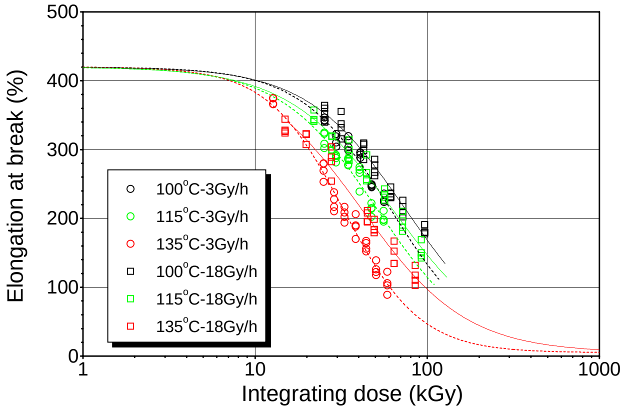


Fig. 3.2-40 Simultaneous aging characteristics II of the SIR insulator made by C Company

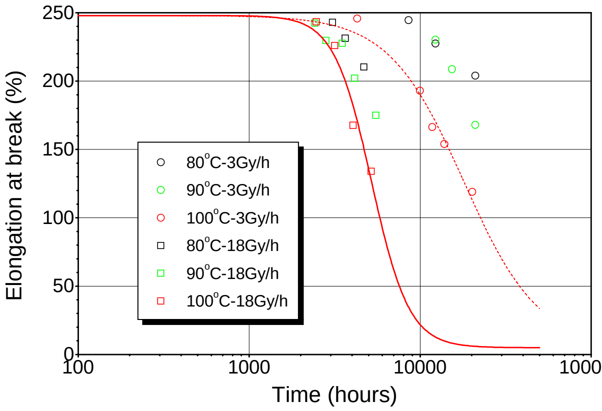


Fig. 3.2-41 Simultaneous aging characteristics I of the SHPVC insulator (black core) made by A Company

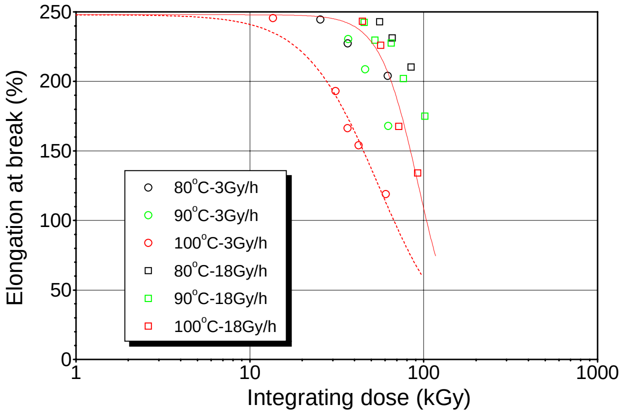


Fig. 3.2-42 Simultaneous aging characteristics II of the SHPVC insulator (black core) made by A Company

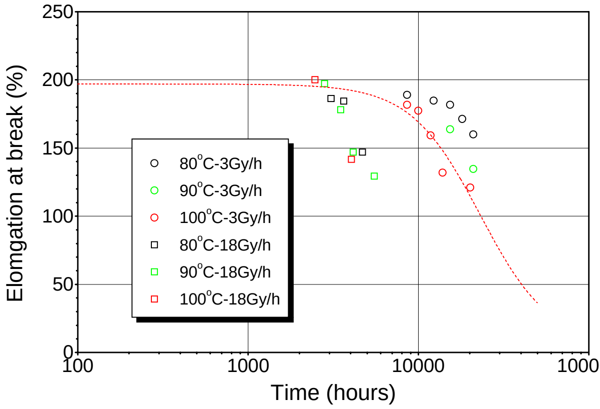


Fig. 3.2-43 Simultaneous aging characteristics I of the SHPVC insulator (white core) made by A Company

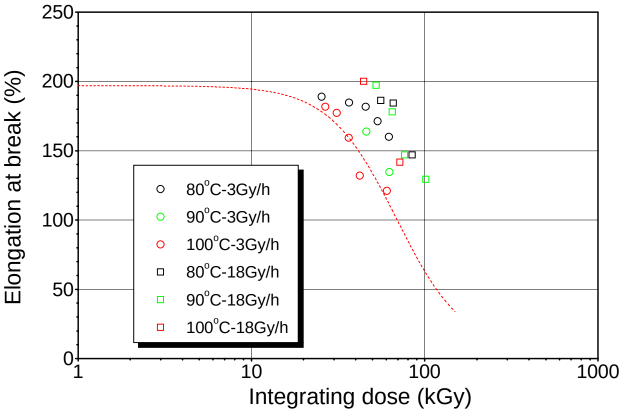


Fig. 3.2-44 Simultaneous aging characteristics II of the SHPVC insulator (white core) made by A Company

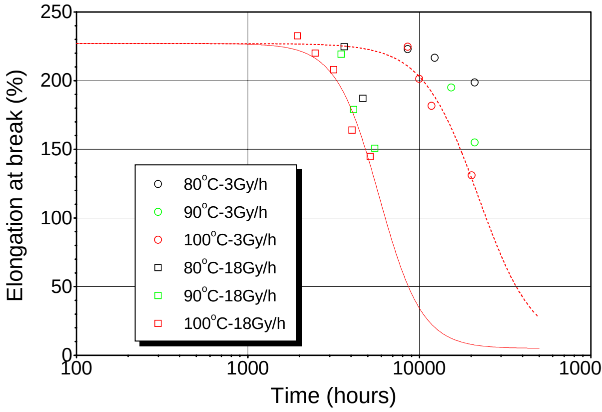


Fig. 3.2-45 Simultaneous aging characteristics I of the SHPVC insulator (red core) made by A Company

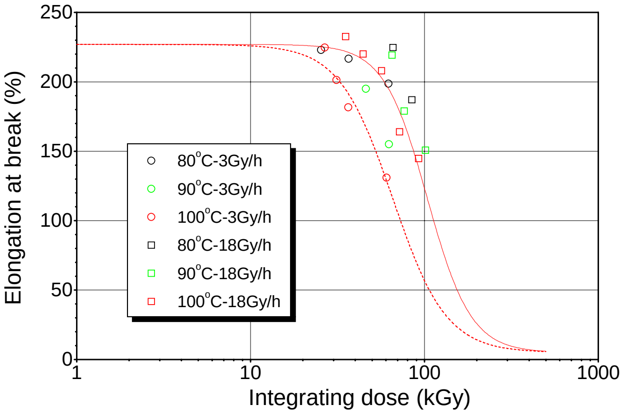


Fig. 3.2-46 Simultaneous aging characteristics II of the SHPVC insulator (red core) made by A Company

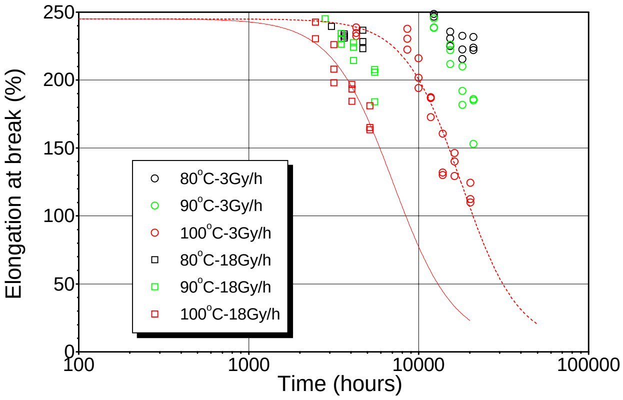


Fig. 3.2-47 Simultaneous aging characteristics I of the SHPVC insulator made by B Company

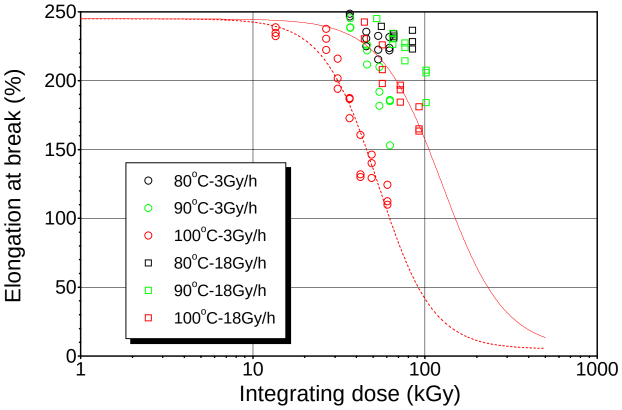


Fig. 3.2-48 Simultaneous aging characteristics II of the SHPVC insulator made by B Company

IV. Investigation of Applicability of Non-Destructive Degradation Diagnostic Technology to the Cables for Actual Operating Plants

The objective of this project is to develop the evaluation technology for aging of the cables adapted to the actual operating conditions of nuclear power plants. As the method to confirm appropriateness of the evaluation technology in the actual operating plants, in another words, as a method to confirm the progress of aging in the actual plants, applicability of the non-destructive degradation diagnostic technology to the cables for actual operating plants, which are currently proposed by the cable manufacturers and others, were investigated.

In this Chapter, results of investigation in the period up to the first half of FY 2006 are described.

1. Investigation procedures

Procedures for the investigation of applicability of the non-destructive degradation diagnostic technologies to the cables for the actual plants are shown as follows:

a. Non-destructive degradation diagnostic technologies for cables to be the objects of investigation are selected from among applicants. The selected technologies must have the prospect of the practical application no later than FY2009.

b. Cable insulators to be the objects of investigation are to be eight kinds in total, which were tested as the cable specimens in this project, including two kinds of XLPE, two kinds of FR-XLPE, one kind of EPR and three kinds of FR-EPR. In addition to these, a total of approximately 70 different kinds of specimens for each kind of cable with different levels of aging (including specimens of different core colors) are used. Other insulators (SIR, SHPVC) are scheduled to be investigated in a similar way in FY2007.

c. Specimens to be used for non-destructive degradation diagnostics are fabricated in the same condition of 100°C- 100 Gy/h as tensile test specimens among the simultaneous aging specimens in this project. The elongation at break values, which are the aging index of each specimen, are to be obtained beforehand.

d. Diagnostic data (measuring parameters by each diagnostic technology) of the selected non-destructive degradation diagnostic technologies are to be acquired by the organizations having diagnostic technologies in a round robin test.

e. After acquiring diagnostic data of each specimen by the organizations having diagnostic technologies, assessment is to be made for correlation between diagnostic data and elongation at break in a tensile test, and applicability of this non-destructive degradation diagnostic technology to the actual operating plant cables, which is the object of this investigation, is determined based on the above mentioned correlation.

2. Non-destructive degradation diagnostic technologies for cables

For the diagnostic technologies to be made as objects of this investigation of applicability by the open application, there were four cases. There was no application in addition to these cases.

(1) The indenter

The indenter is to measure the indenter modulus as the non-destructive degradation diagnostic parameter. In this project, the originally manufactured indenter type measuring unit was by AEA Technology Inc. in UK and it was improved upon jointly by AEA technology Inc. and the Institute of Nuclear Safety System, Inc., and then used to measure the parameters (Ref. 11).

The indenter is the gradient of load (forced power) to the traveling amount (forced depth) at probe insertion, whose unit is shown in N/mm. Also, load at the start of measurement and load at the end of measurement are specified for each material.

External appearance of the measuring unit used in the test is shown in Fig.2.1and 2.2.

Fig. 2-1 External appearance of the Indenter measuring unit

Fig. 2-2 Specimen holding part of the measuring unit

(2) Ultrasonic degradation diagnostic method

The ultrasonic diagnostic method is the technology that has been developed by Mitsubishi Cable Industries, Ltd. as the degradation diagnostic technology for insulators or jackets of the cables and to measure ultrasonic propagation velocity for axial direction of materials as the non-destructive degradation diagnostic parameter (Ref. 12). The diagnostic equipment for low-voltage cables in nuclear power stations has been developed jointly with Mitsubishi Heavy Industries, Ltd. The ultrasonic probes of this equipment moves automatically by the sequential control to measure accuracy in a short time and to decrease exposure dose of the operators.

External appearance of the degradation diagnostic equipment for low voltage cables in nuclear power plants is shown in Figure 2-3.

Figure 2-3 Degradation diagnostic equipment for low voltage cables of nuclear power stations

(3) Optical diagnostic method

This technology has been developed by Hitachi, Ltd. as a degradation diagnostic method for the organic materials used in the cables. The basic concept of this method is that color-changed organic materials due to aging are exposed to two optical beams with different wavelengths and their absorptance is quantitatively estimated to diagnose the degradation (Ref. 13). In this diagnosis, the difference of absorptance between 405 and 1310 nm were measured as the diagnosing parameters.

External appearance of the portable optical diagnostic equipment for cables is shown in Fig. 2-4.

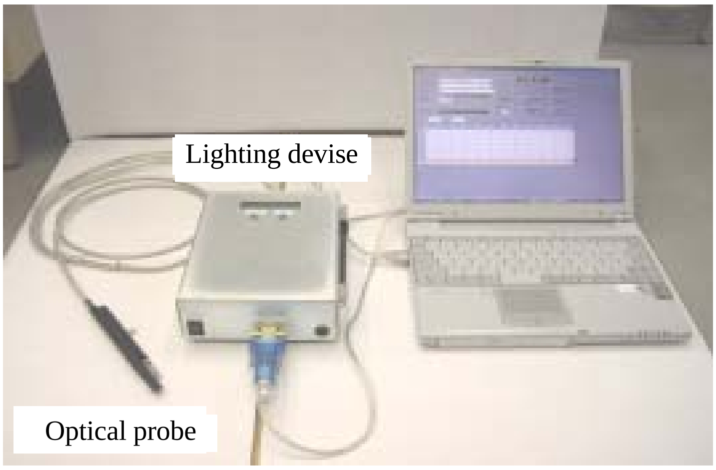


Fig. 2-4 Portable Optical Diagnostic Equipment for Cables

(4) Surface hardness measuring method

Surface hardness measuring method is to push cylindrical needle onto the surface with spring and its squeezed depth is measured as a surface hardness in relative value. A simplified micro hardness meter for rubber (JIS A hardness meter) which has been developed as the degradation diagnostic technology for rubber system materials used for the insulators of cables by Mitsubishi Cable Industries Ltd., was integrated into the equipment. These materials are measured with this equipment in this program (Ref. 12). As this equipment was developed for aging diagnostic purposes, diagnostic data was obtained for EPR and FR-EPR specimens only.

External appearance of the surface hardness meter for cable degradation diagnosis is shown in Figure 2-5.

Fig. 2-5 Surface Hardness Meter for Cables Degradation Diagnosis

3. Results of the Investigation

(1) Assessment of correlativity between diagnostic data and elongation at break

Correlativity between diagnostic data and elongation at break are shown in Figures 3-1 through 20. These diagnostic data was obtained by the organizations having diagnostic technologies in a round robin test using the same specimen. In these Figures, coefficient of correlation (R) for linear regression and coefficient of determination (R^2) for polynomial regression were marked. For the data having no significant correlation between diagnostic data and elongation at break, figures concerning the correlativity were omitted.

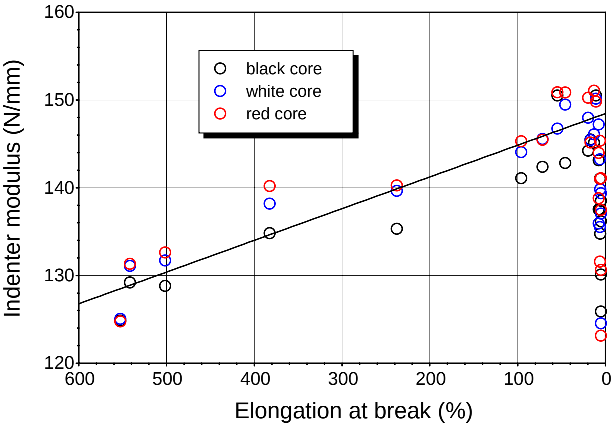


Fig. 3-1 The XLPE insulator made by A Company
The Indenter: R=0.94

(Data of less than 10% elongation at break was excluded for linear regression)

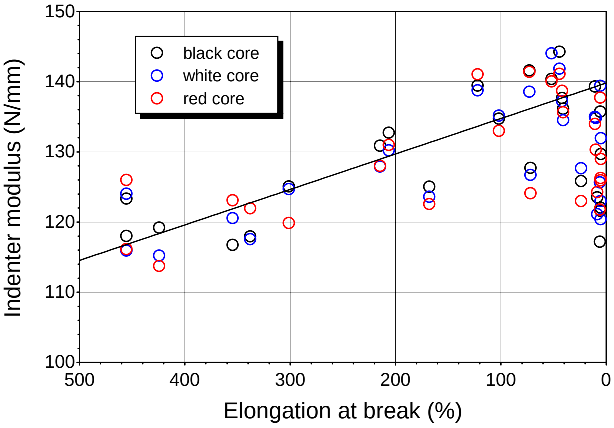


Fig. 3-2 The XLPE insulator made by B Company
The indenter : R=0.85

(Data of less than 30% elongation at break was excluded for linear regression)

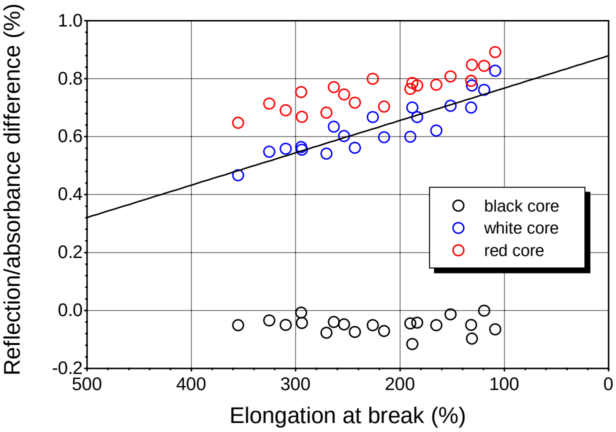


Fig. 3-3 The FR-XLPE insulator made by A Company
Optical diagnostic method: R=0.85

(Linear regression for white core only)

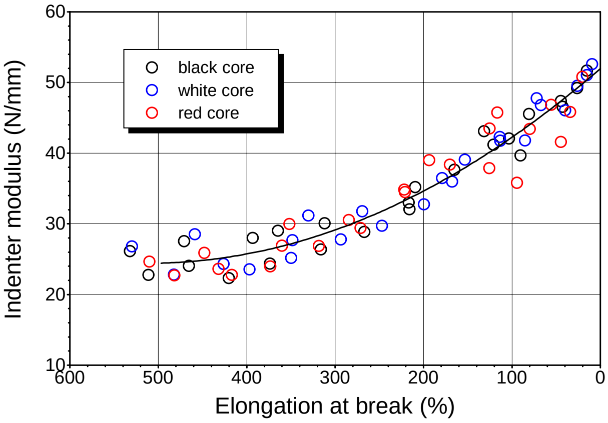


Fig. 3-4 The FR-XLPE insulator made by B Company
The indenter R^2=0.94

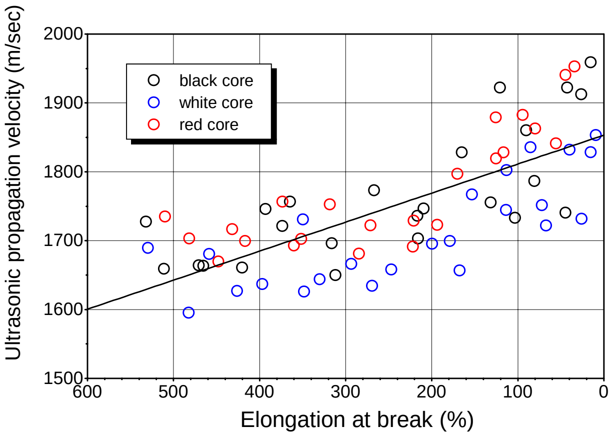


Fig. 3-5 The FR-XLPE insulator made by B Company
Ultrasonic diagnostic technique: R=0.71

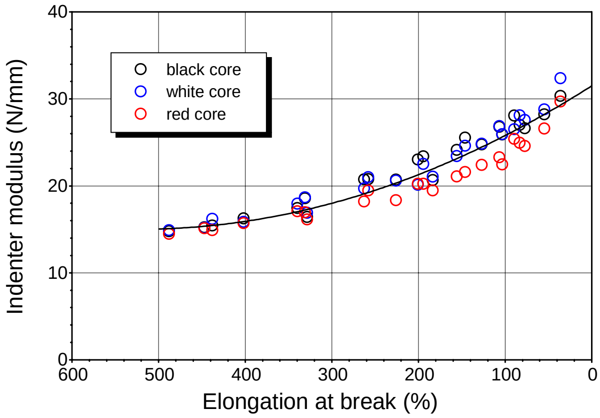


Fig. 3-6 The EPR insulator made by C Company
The Indenter: R^2=0.93

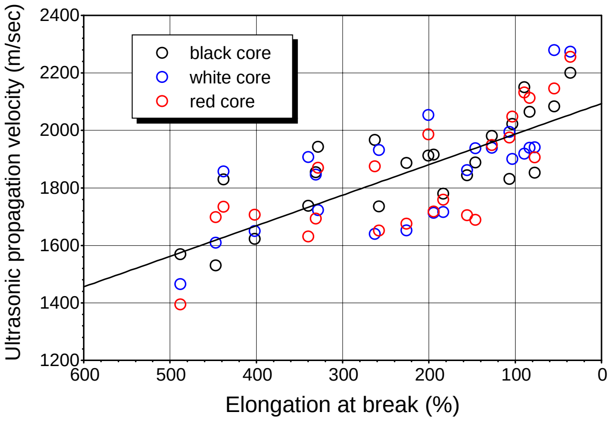


Fig. 3-7 The EPR insulator made by C Company
Ultrasonic diagnostic technique: R=0.75

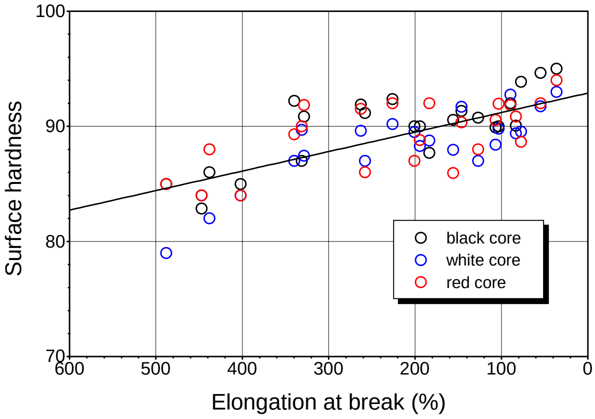


Fig. 3-8 The EPR insulator made by C Company
Surface hardness measuring method: R=0.72

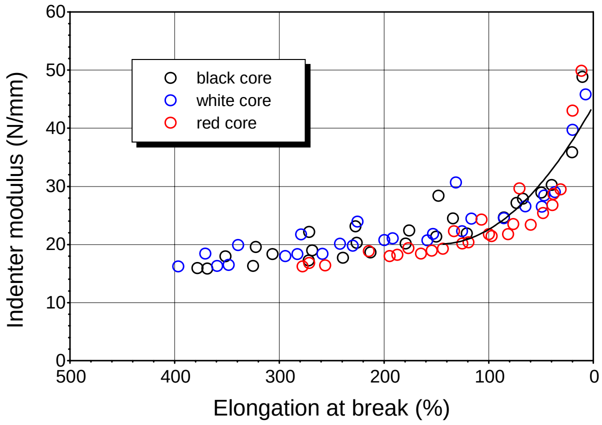


Fig. 3-9 The FR-EPR insulator made by A Company
The Indenter : R^2=0.75

(Data of more than 200% elongation at break was excluded for polynomial regression)

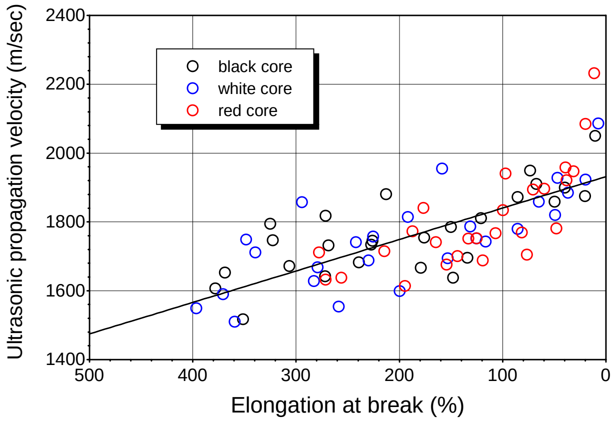


Fig. 3-10 The FR-EPR insulator made by A Company
Ultrasonic diagnostic technique: R=0.73

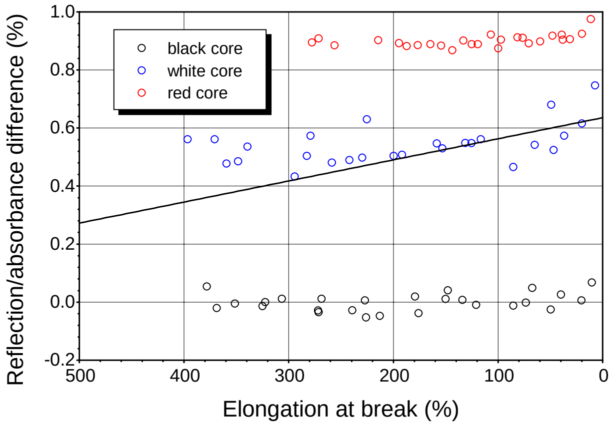


Fig. 3-11 The FR-EPR insulator made by A Company
Optical diagnostic method: R=0.63

(Linear regression is for white core only and data of more than 200% elongation at break was excluded)

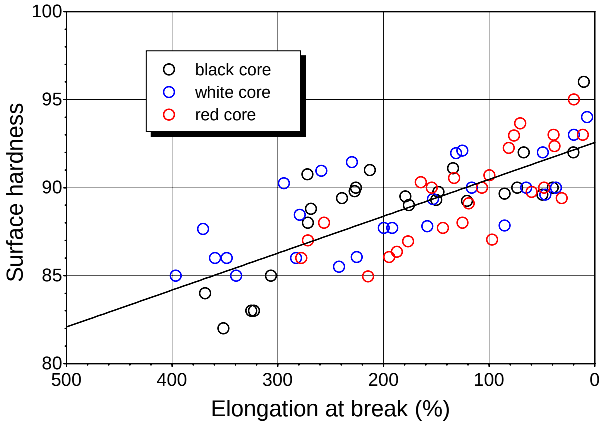


Fig. 3-12 The FR-EPR insulator made by A Company
Surface hardness diagnostic method: R=0.76

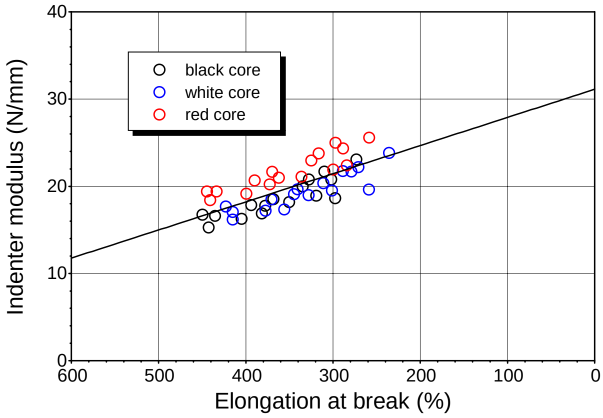


Fig. 3-13 The FR-EPR insulator made by B Company
The Indenter: R=0.75

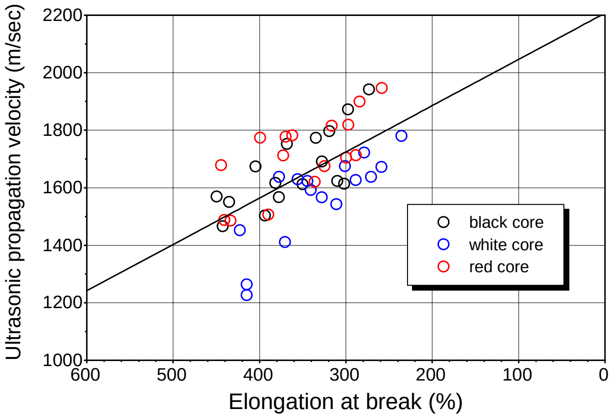


Fig. 3-14 The FR-EPR insulator made by B Company
Ultrasonic diagnostic technique: R=0.61

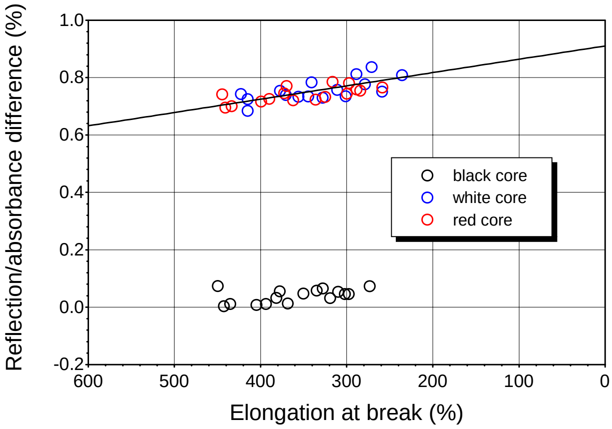


Fig. 3-15 The FR-EPR insulator made by B Company
Optical diagnostic method: R=0.70

(Linear regression is for white core only)

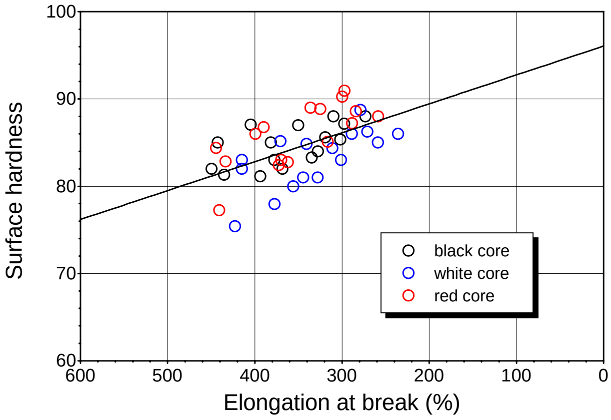


Fig. 3-16 The FR-EPR insulator made by B Company
Surface hardness measuring method: R=0.58

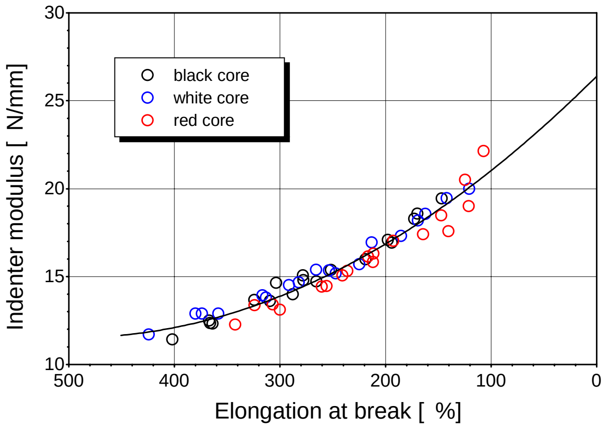


Fig. 3-17 The FR-EPR insulator made by C Company
The indenter: R^2=0.96

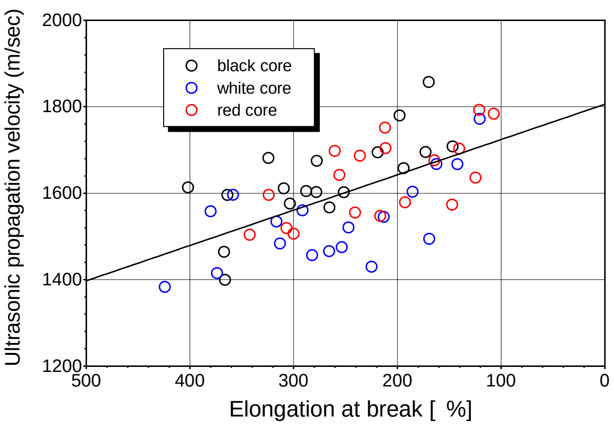


Fig. 3-18 The FR-EPR insulator made by C Company
Ultrasonic diagnostic method: R=0.62

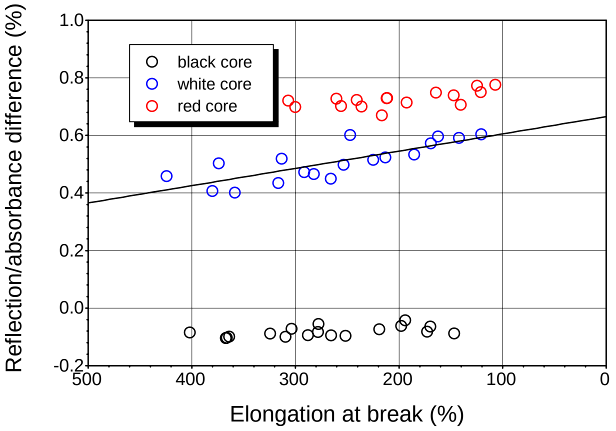


Fig. 3-19 The FR-EPR insulator made by C Company
Optical diagnostic method: R=0.80
(Linear regression is for white core only)

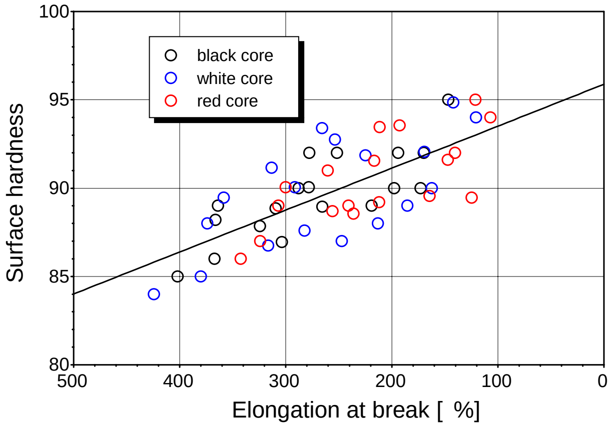


Fig. 3-20 The FR-EPR insulator made by C Company
Surface hardness measuring method: R=0.73

(2) Summary of investigation of applicability to actual operating plants

Based on the correlativity between diagnostic data and elongation at break shown in Figures 3-1 through 20, investigated applicability of non-destructive degradation diagnostic technologies for cables to the actual operating plants is evaluated as follows:

a. The indenter is applicable to the XLPE family and the EPR family except insulators made by certain manufacturers.

b. Though the optical diagnostic method is applicable to white color insulators, it will be necessary to improve it as the result shows a somewhat large dispersion.

c. Though the ultrasonic degradation diagnostic technology is applicable to the EPR family, improvement will be necessary as the result shows a somewhat large dispersion.

d. Though the surface hardness measuring method is applicable to the EPR family, improvement will be necessary as the result shows a somewhat large dispersion.

V. Interim Assessment

1. Discussion of techniques for assessment

The techniques of “superposition of time dependent data” and “superposition of dose to equivalent damage data” will be highly applicable as techniques for expanding the simultaneous aging data acquired in this project into the environment of actual operating plants. These results of investigation were obtained in the first half of FY 2003.

The method for application of these techniques to the simultaneous aging data obtained in this project is described in this section.

1.1 Superposition of time dependent data

IEC 1244-2 (Ref. 5) or IAEA-TECDOC-1188 (Ref. 6) proposes a technique which superposes aging characteristics (time dependent data) to predict the progress of degradation in a radiation environment of very low dose rate in actual operating plants. This data is acquired under conditions of various temperatures and dose rates and are merged into one aging characteristic. This technique is called the technique of “superposition of time dependent data”, and the aging characteristic curve obtained here is called “the master curve”.

Usually, the master curve is superposed on only thermal aging characteristic curve. Degree of progress of future degradation under various environmental conditions can be predicted by use of the master curve and specific shift factors based on the environmental conditions. In this case, the aging period multiplied by a shift factor turns into the aging period in a master curve (Refer to Fig. 1-1).

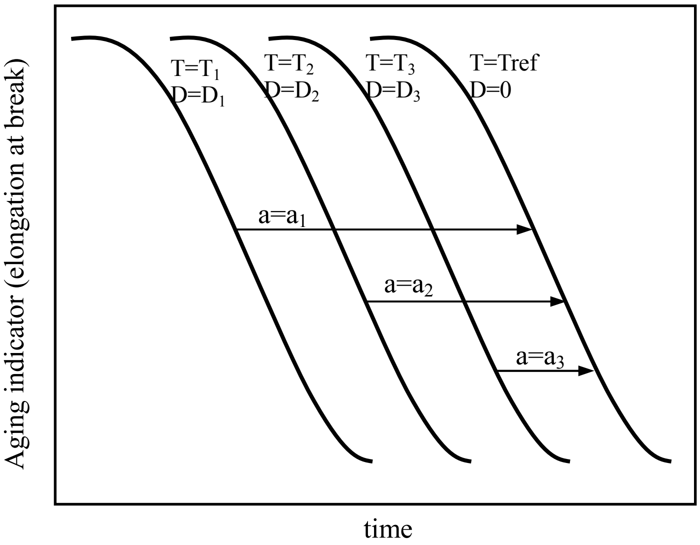


Fig. 1-1 Image of “the superposition of time dependent data”

[“T” shows the processing temperature for an aging specimen, D shows the processing dose rate for an aging specimen, and “a” shows the shift factor.]

A shift factor is obtained from by formula 1. “x”and “k”in this formula are the constants for each of the materials. Also, when $T = T_{ref}$, a shift factor is obtained from formula 2.

$$a = \exp\left[\frac{-E}{R}\left(\frac{1}{273+T} - \frac{1}{273+T_{ref}}\right)\right] \cdot \left[1 + kD^{x} \exp\left[\frac{Ex}{R}\left(\frac{1}{273+T} - \frac{1}{273+T_{ref}}\right)\right]\right]$$

·················· Formula 1

$$a = 1 + kD^{x}$$ ·· Formula 2

T: Evaluation temperature [°C]

T_{ref}: Reference temperature [°C]

E: Activation energy [kJ/mol (kcal/mol)]

R: Gas constant [0.009314 kJ/mol (0.001987 kcal/mol)]

D: Evaluation dose rate [Gy/s]

Therefore, constants “x” and ”k” for each material (these constants are called “model parameter” hereinafter) can be obtained from the shift factor "a" to be calculated from aging characteristics at a reference temperature and radiation exposure test (a ratio of the period in each radiation exposure test to the period at the reference temperature when it reaches the same degree of degradation), and each test conditions for radiation exposure.

Technique for calculating the model parameters “x”and”k”are shown below.

When $\exp\left[\frac{-E}{R}\left(\frac{1}{273+T} - \frac{1}{273+T_{ref}}\right)\right]$ in formula 1 is defined as A, formula 1 is expressed as follows.

$$a = A\left(1 + kD^{x}A^{-x}\right)$$ ·· Formula 1-1

If formula 1-1 is rearranged, it is expressed as follows.

$$\frac{a}{A} - 1 = k\left(\frac{D}{A}\right)^{x}$$ ·· Formula1-2

Where, if both sides of formula 1-2 are expressed with logarithm, they are expressed as follows.

$$\log\left(\frac{a}{A} - 1\right) = x\log\left(\frac{D}{A}\right) + \log k$$ ·· Formula1-3

Model parameters “x”and”k”can be calculated from a linear regression of a log-log graph of $\left(\frac{a}{A} - 1\right)$ and $\frac{D}{A}$ obtained from the simultaneous aging test.

1.2 Superposition of dose to equivalent damage data

Since “superposition of dose to equivalent damage data” as well as “superposition of time dependent data” may predict the progress of degradation in radiation exposure atmosphere of a very low dose rate in actual operating plants, it is one of the techniques proposed by IEC 1244-2 (Ref. 5) or IAEA-TECDOC-1188 (Ref. 6).

However, in the technique of “superposition of time dependent data”, the period resulting in any degree of damage in any temperature and radiation environment related to one master curve for a certain material can be predicted by the shift factor determined by the model parameter and environmental conditions. However, with regard to the master curve used for “superposition of dose to equivalent damage data”, the period in any radiation environment resulting in a certain degree of damage in a certain temperature environment can be directly predicted through the integrated dose. That is, a master curve will exist for every combination of temperature and the degree of damage in “superposition of dose to equivalent damage data”.

The method to produce the master curve used for “superposition of dose to equivalent damage data” is shown below.

The period resulting in a certain degree of damage (e.g. elongation at break is 100 %) at each temperature (T_1, T_2, •T_3,) is calculated from aging characteristics acquired under conditions of a variety of different temperature and dose rates. A value of the period multiplied by the dose rate at that time is defined as an equivalent damage dose, and the dose rate and the equivalent damage dose at each given temperature are considered as a set of data.

Next, temperature (T_{ref}) for predicting degradation is decided, and temperature factor ($b(T)$) for each temperature and T_{ref} is calculated using activation energy. The dose rate of each data is multiplied by this ($b(T)$), and each data is shifted one by one. This work is performed by change of activation energy until each data shifted can be superposed by the best fitted master curve. Finalized result of superposition becomes the master curve in the degree of damage at T_{ref}. (Refer to Fig.1-2)

In addition, if equivalent damage dose, which is a multiplication of the dose rate with the period when degradation due to the thermal aging only at a temperature of T_{ref} results in the same degree of degradation as above, and the dose rates are plotted in this figure, they will be on a straight line of slope 1. This straight line is connected with the above-mentioned master curve at a certain point, and the dose rates less than this point show a range on which radiation does not result in any effect.

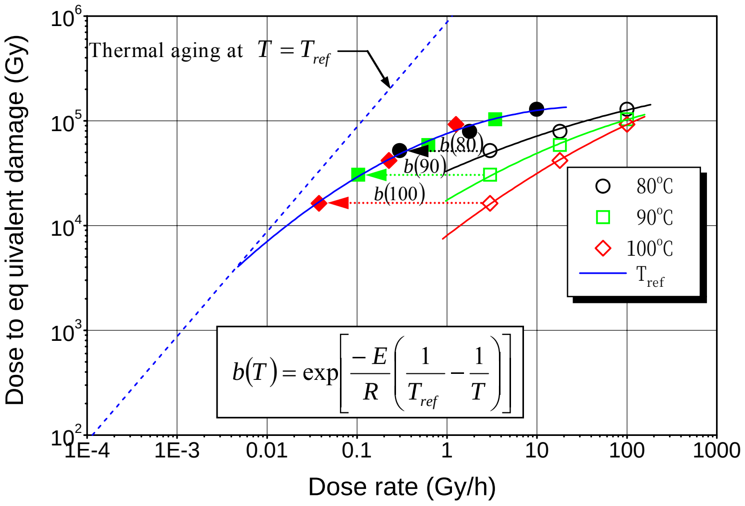


Fig.1-2 Image of “the superposition of dose to equivalent damage data”

(Degree of damage: elongation at break is of XX %)

IEC 1244-2 states that activation energy used by “superposition of dose to equivalent damage data” may become the same as activation energy calculated from only thermal aging characteristics.

It also states that the “superposition of dose to equivalent damage data” has a wider applicability compared with “ the superposition of time dependent data ” .

2. Activation energy (1)

2.1 Calculation of activation energy from acquired data

Fig. 2.1-1 through 22 show Arrhenius plots of the calculation of activation energy based on thermal aging characteristics in Chapter Ⅲ Section 3.1, or thermal aging characteristics in the low temperature region based on the assumed activation energy. In this case, data for slow-progressing degradation in data in the low-temperature region (100 °C, 110 °C or 135 °C) currently acquired were determined by estimation of thermal aging characteristics in the low temperature region from those in the high temperature region based on the assumed activation energy. The values of activation energy calculated by the Arrhenius plot should also be dealt with as tentative values, since all thermal aging data for each specimen has not been acquired.

The tentative or estimated values of activation energy for each insulator currently acquired are shown in Table 2.1-1.

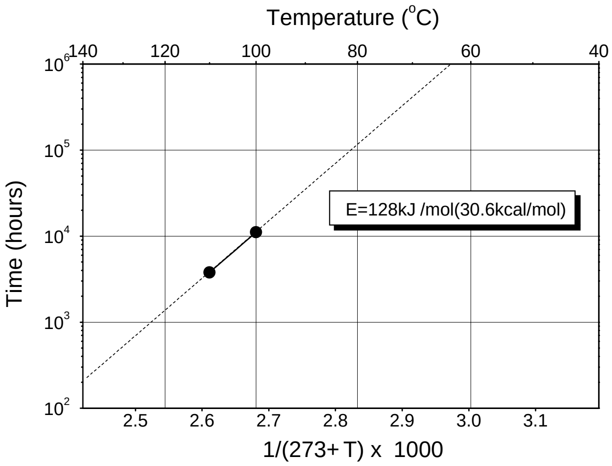


Fig. 2.1-1 Arrhenius plot of the XLPE insulator made by A Company (100 to 110°C)

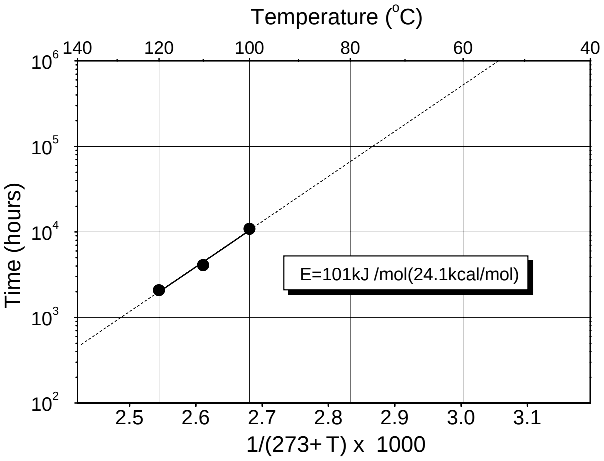


Fig. 2.1-2 Arrhenius plot of the XLPE insulator made by B Company (100 to120°C)

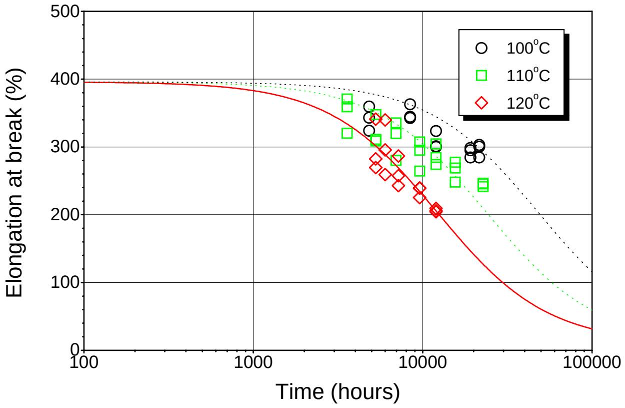


Fig. 2.1-3 Thermal aging characteristics at 100 °C and 110 °C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-XLPE insulator made by A Company

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(1) Activation energy treated here is apparent activation energy in progress of degradation, and should be distinguished from physicochemical activation energy.

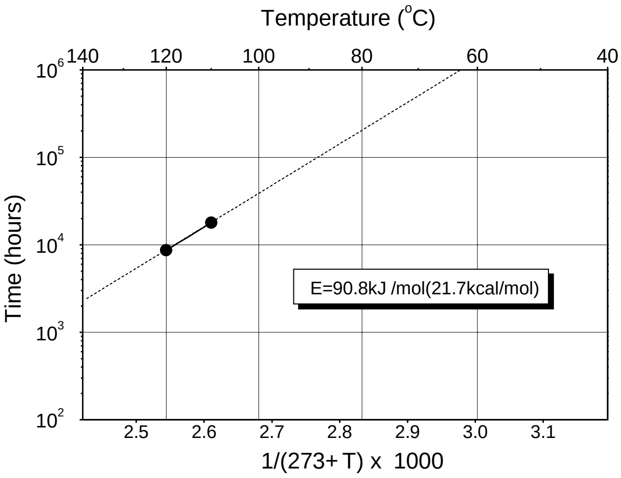

Fig. 2.1-4 Arrhenius plot of the FR-XLPE insulator made by B Company (110 to 120°C)

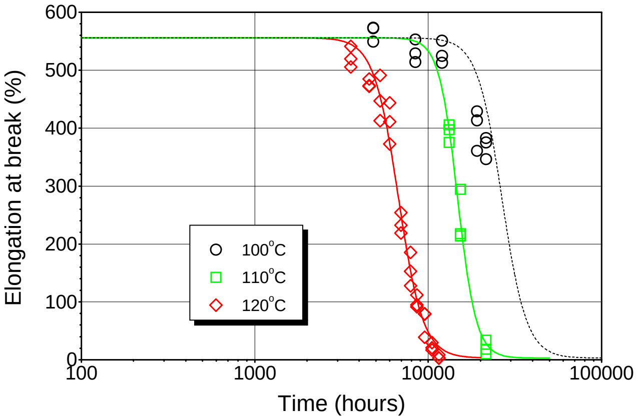

Fig. 2.1-5 Thermal aging characteristics at 100 °C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-XLPE insulator made by B Company

Note: Although the activation energy in the range of 110 to 120 °C was 90.8 kJ/mol, the estimated activation energy value was set to 83.7 kJ/mol from the aging trend at 100 °C.

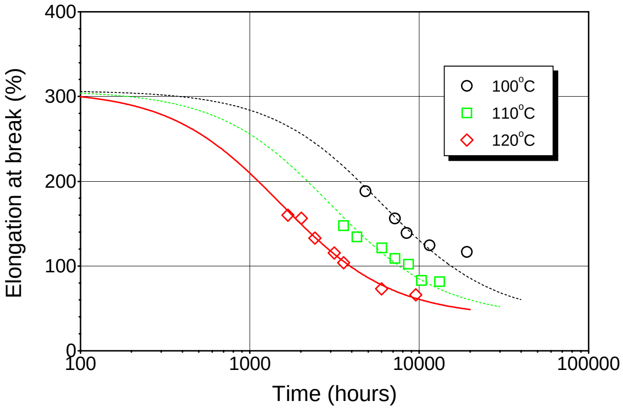

Fig. 2.1-6 Thermal aging characteristics at 100°C and 110°C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the XLPE insulator (coaxial cable) made by C Company

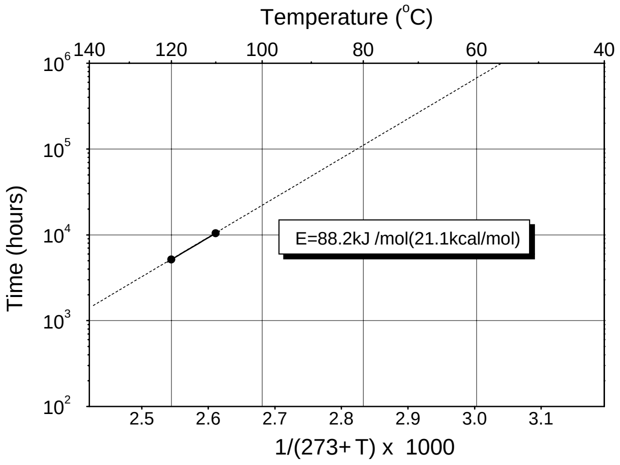

Fig. 2.1-7 Arrhenius plot of the EPR insulator made by C Company (110 to 120°C)

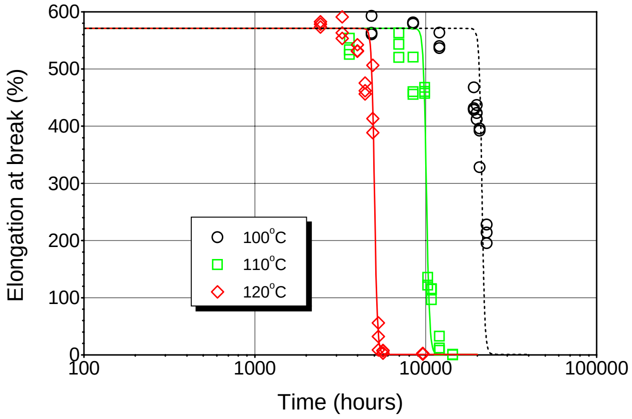

Fig. 2.1-8 Thermal aging characteristics at 100°C predicted with activation energy of 88.3 kJ/mol (21.1kcal/mol) for the EPR insulator made by C Company

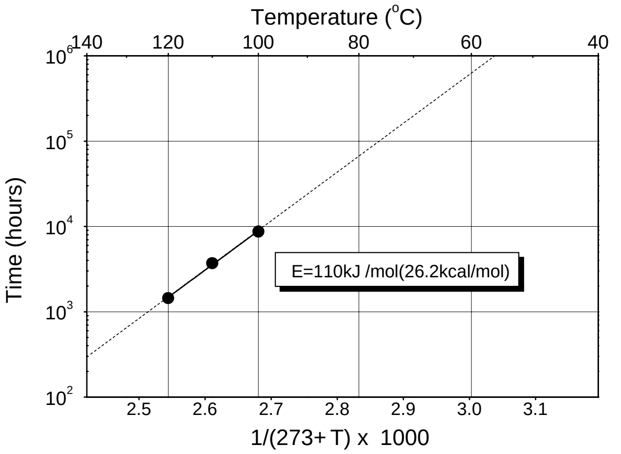

Fig. 2.1-9 Arrhenius plot of the FR-EPR insulator (black core) made by A Company (100 - 120°C)

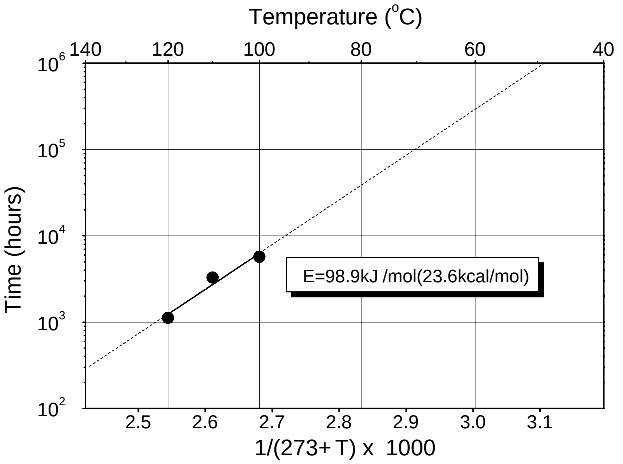

Fig. 2.1-10 Arrhenius plot of the FR-EPR insulator (white core) made by A Company (100 - 120°C)

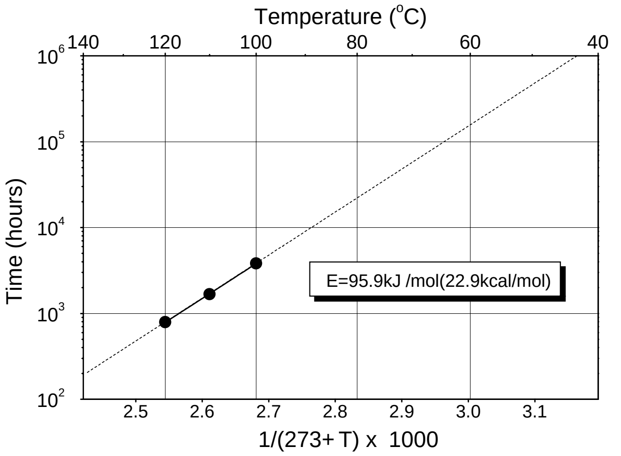

Fig. 2.1-11 Arrhenius plot of the FR-EPR insulator (red core) made by A Company (100 - 120°C)

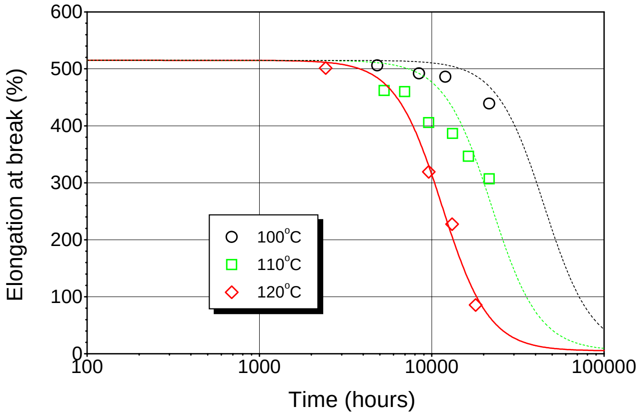

Fig. 2.1-12 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-EPR insulator (black core) made by B company

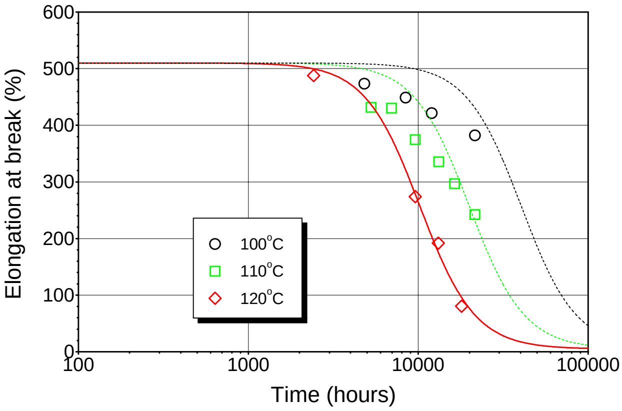

Fig. 2.1-13 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-EPR insulator (white core) made by B company

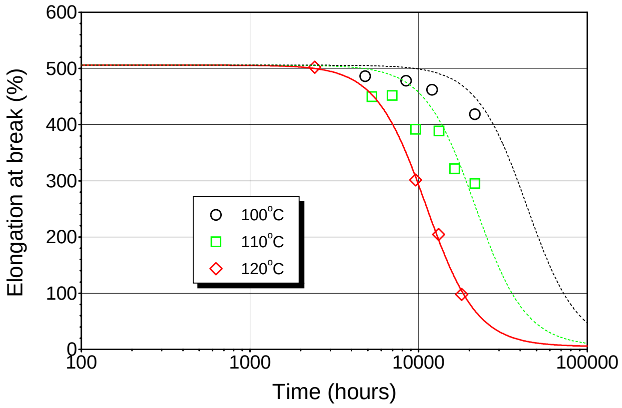

Fig. 2.1-14 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-EPR insulator (red core) made by B company

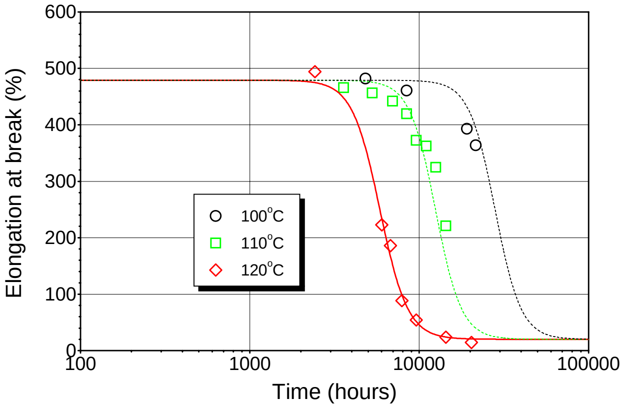

Fig. 2.1-15 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 96.3 kJ/mol (23kcal/mol) for the FR-EPR insulator (black core) made by C company

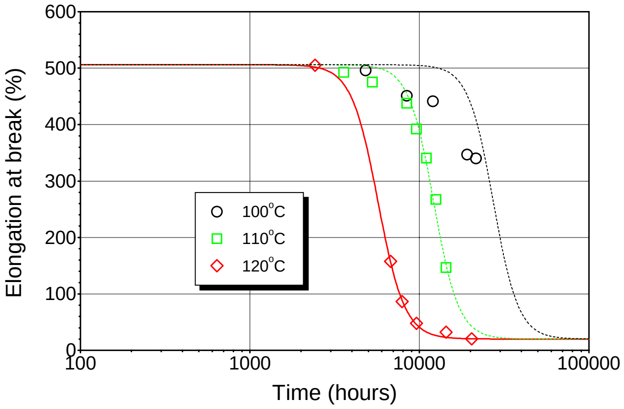

Fig. 2.1-15 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 96.3 kJ/mol (23kcal/mol) for the FR-EPR insulator (white core) made by C company

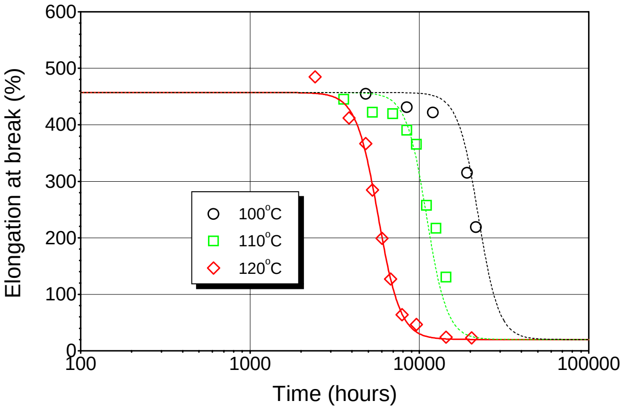

Fig. 2.1-17 Thermal aging characteristics at 100 °C and 110°C predicted with activation energy of 83.7 kJ/mol (20kcal/mol) for the FR-EPR insulator (red core) made by C company

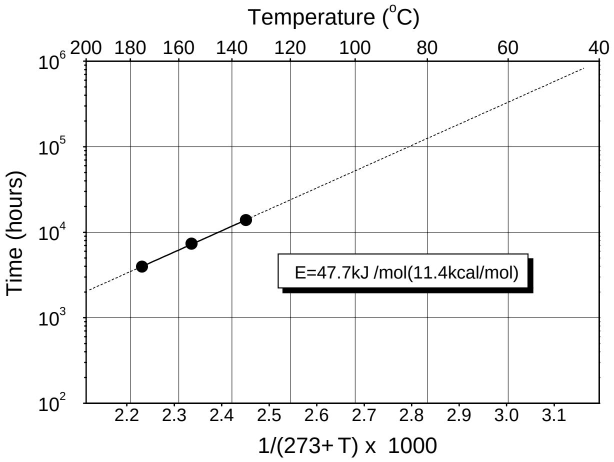

Fig. 2.1-18 Arrhenius plot of the SIR insulator

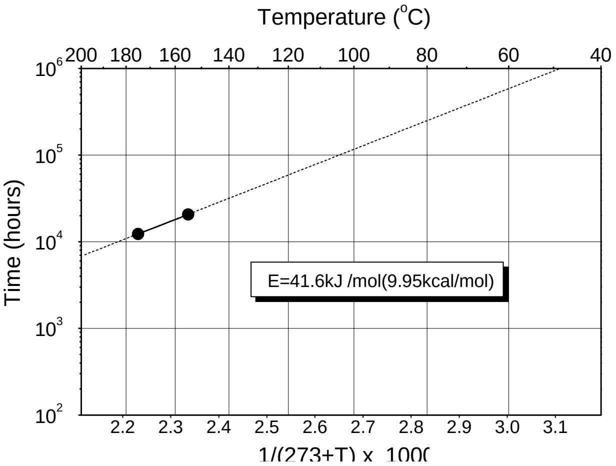

Fig. 2.1-19 Arrhenius plot of the SIR insulator made by B Company (155 to 175 °C)

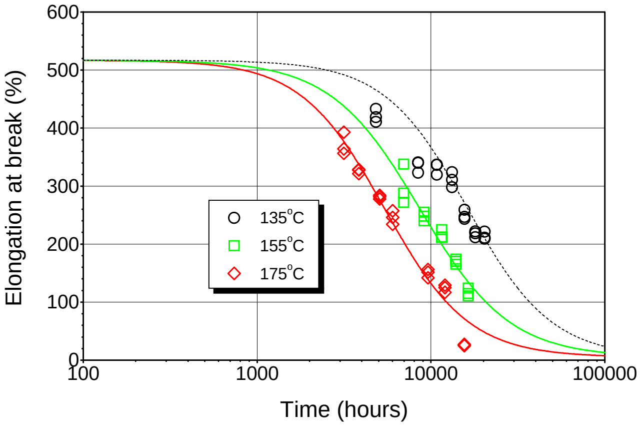

Fig. 2.1-20 Thermal aging characteristics at 135 °C predicted with activation energy of 41.9 kJ/mol (10kcal/mol) for the SIR insulator made by B Company

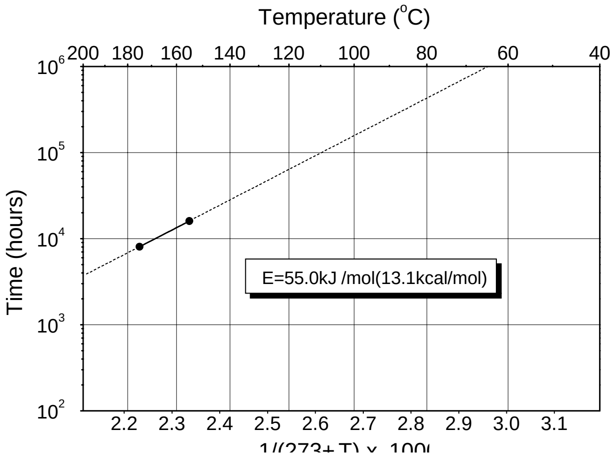

Fig. 2.1-21 Arrhenius plot of the SIR insulator made by C Company (155 to 175 °C)

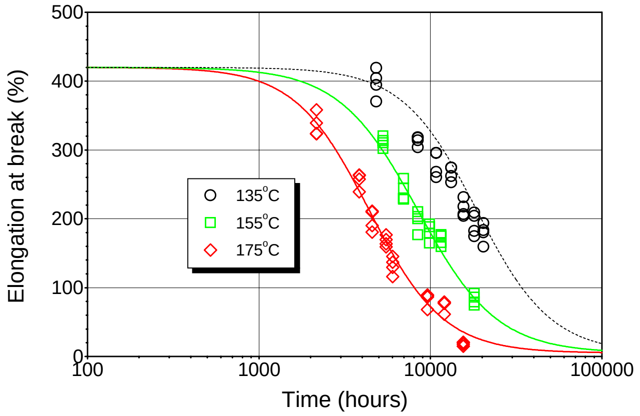

Fig. 2.1-22 Thermal aging characteristics at 135 °C predicted with activation energy of 54.8 kJ/mol (13.1kcal/mol) for the SIR insulator made by C Company

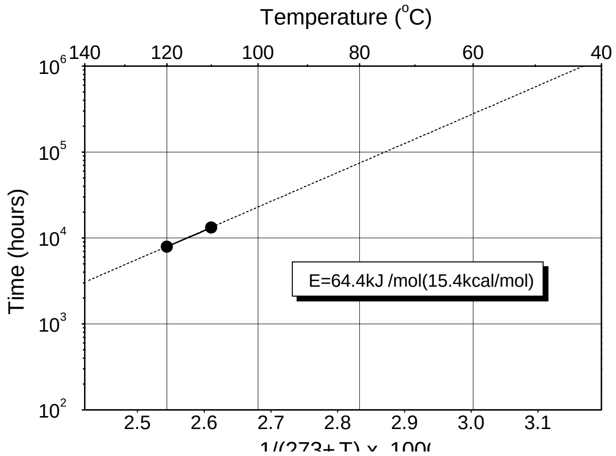

Fig. 2.1-23 Arrhenius plot of the SHPVC insulator made by A Company (110 to 120 °C)

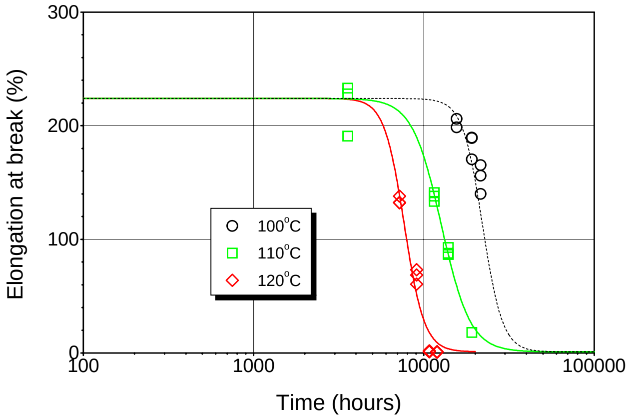

Fig. 2.1-24 Thermal aging characteristics at 100 °C predicted with activation energy of 64.5 kJ/mol (15.4kcal/mol) for the SHPVC insulator made by A Company

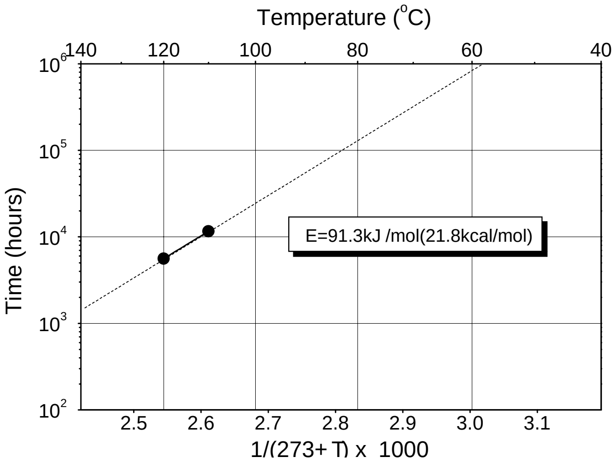

Fig. 2.1-25 Arrhenius plot of the SHPVC insulator made by B Company (110 to 120 °C)

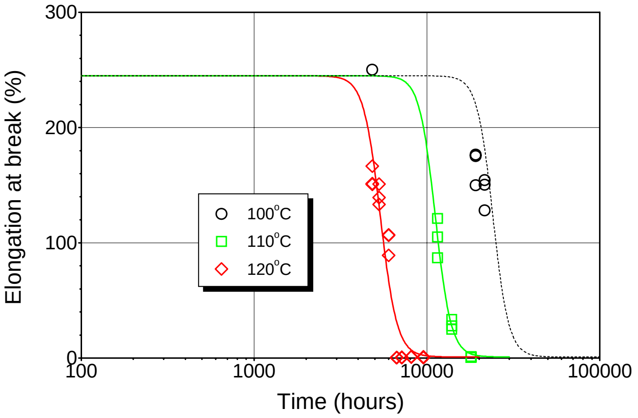

Fig. 2.1-26 Thermal aging characteristics at 100 °C predicted with activation energy of 91.3 kJ/mol (21.8kcal/mol) for the SHPVC insulator made by B Company

Table 2.1-1 Activation energy for each insulator at present time

Kind of insulator and color of core		Activation energy	Remarks
1. XLPE insulator made by A Company		128 kJ/mol(30.6 kcal/mol)	Preliminary value
2. XLPE insulator made by B Company		101 kJ/mol(24.1 kcal/mol)	Preliminary value
3. FR-XLPE insulator made by A Company		83.7 kJ/mol(20 kcal/mol)	Estimate value
4. FR-XLPE insulator made by B Company		83.7 kJ/mol(20 kcal/mol)	Estimate value
5. XLPE insulator made by C Company (coaxial cable)		83.7 kJ/mol(20 kcal/mol)	Estimate value
6. EPR insulator made by C Company		88.3 kJ/mol(21.1 kcal/mol)	Estimate value
7. FR-EPR insulator made by A Company	Black core	110 kJ/mol(26.2 kcal/mol)	Preliminary value
	White core	98.9 kJ/mol(23.6 kcal/mol)	Preliminary value
	Red core	95.9 kJ/mol(22.9 kcal/mol)	Preliminary value
8. FR-EPR insulator made by B Company	Black core	83.7 kJ/mol(20 kcal/mol)	Estimate value
	White core	83.7 kJ/mol(20 kcal/mol)	Estimate value
	Red core	83.7 kJ/mol(20 kcal/mol)	Estimate value
9. FR-EPR insulator made by C Company	Black core	96.3 kJ/mol(23 kcal/mol)	Estimate value
	White core	96.3 kJ/mol(23 kcal/mol)	Estimate value
	Red core	83.7 kJ/mol(20 kcal/mol)	Estimate value
10. SIR insulator made by A Company		47.7 kJ/mol(11.4 kcal/mol)	Preliminary value
11. SIR insulator made by B Company		41.9 kJ/mol(10 kcal/mol)	Estimate value
12. SIR insulator made by C Company		54.8 kJ/mol(13.1 kcal/mol)	Estimate value
13. SHPVC insulator made by A Company		64.5 kJ/mol(15.4 kcal/mol)	Estimate value
14. SHPVC insulator made by B Company		91.3 kJ/mol(21.8 kcal/mol)	Estimate value

2.2 Collation with sampling data in actual operating plants

Sampling data in actual operating plants could be acquired for the XLPE insulated cable made by A Company, the XLPE insulated cable made by B Company and the FR-EPR insulated cable made by A Company which were used within the reactor containment vessel. Collation of data from these with activation energy calculated from data obtained in this project has been performed.

(1) The XLPE insulated cable made by A Company

(a) Sampling data in actual operating plants

The sampling data of the XLPE insulator made by A Company is shown in Fig. 2.2-1. In addition, the periods given in Fig. 2.2-1 of the operating hours of plant and the periods from the start of commercial operation are approximately from 22 to 28 years (an availability factor of 63.9 to 66.7%). The initial value of an elongation at break of the XLPE insulator is the average value of 557 % (524 to 586 %) in this project.

As shown in Fig. 2.2-1, the sampling data has quite a large dispersion. Those elongation at break values have been reversed with either the operating period or the dose rate in many cases. Dispersion at the early stage of degradation, measurement of error of temperature, difference between dose rates at a part of a tensile test piece and at a measured point, error of tensile testing and others all can be considered as factors contributing to data dispersion.

In addition, since the maximum temperature was measured with the irreversible temperature indicating label (referred to as “thermo-label” hereinafter), actual mean temperature was considered to be by 2 to 3°C lower than the measured temperature. (This idea is common in all the sampling data.)

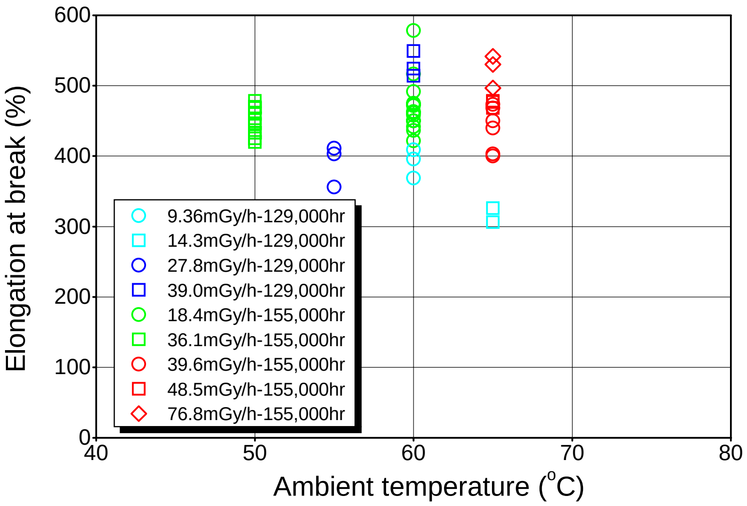

Fig. 2.2-1 Sampling data of the XLPE insulator made by A Company

(b) Predicted progress of degradation by the data in this project

The activation energy for the XLPE insulator made by A Company is assumed at 128 kJ/mol (30.6kcal/mol) as calculated in Section 2.1, and, if the aging periods are predicted when the elongation at break for the XLPE insulator reduces to 400% with thermal aging on the basis of thermal aging characteristics at 100°C obtained in this project, they will be approx. 670,000 hours at 65°C and approx. 1,320,000 hours at 60°C.

(c) Calculation of activation energy using sampling data in actual operating plants

The activation energies for the XLPE insulator made by A Company can be calculated by the sampling data at 55°C (elongation at break is 403 %), at 60°C (elongation at break is 369 %), and at 65°C (elongation at break is 306 %) to be a comparatively early reduction in time (plant operating hours of approx. 129,000 hours, availability factor of 66.7 % and approx. 22 years from the start of commercial operation for all data) and the thermal aging characteristics at 100°C acquired in this project. The resulting activation energies will be 61.30 kJ/mol (14.64 kcal/mol), 68.62 kJ/mol (16.39 kcal/mol), and 77.92 kJ/mol (18.61 kcal/mol) respectively (refer to Fig 2.2-2). Although the activation energy itself has a rate of dispersion, 77.92 kJ/mol (18.61 kcal/mol), the worst elongation at break value, is considered to be the most reliable value. In addition, although such activation energies are also calculated taking into consideration the degree of degradation for the duration of a plant outage (temperature of 30°C), radiation aging is disregarded. If radiation aging is also taken into consideration, the activation energies will be a little larger than those values. (This also is the same in other evaluations as shown below.)

In addition, if actual the environmental temperature (mean temperature) is considered to be 3°C lower than the measured temperature, "306 % at 65°C" will be set to "306 % at 62°C", and the activation energy in this case will be 71.47 kJ/mol (17.07kcal/mol).

Also, degradation of the XLPE insulator is assumed to progress successively after approx. 22 years from the start of commercial operation as shown in Fig. 2.2-2, the elongation at break will be reduced to 100% in the approx. 146,000 hours (approx. 25 years from the start of commercial operation at the availability factor of 66.7 %) operation at 65°C.

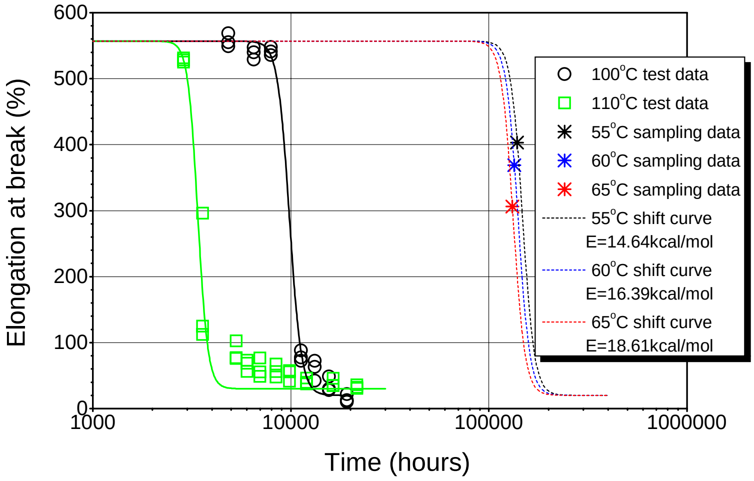

Fig. 2.2-2 Calculation of activation energy from sampling data of the XLPE insulator made by A Company

(d) Evaluation by superposition of time dependent data

The activation energy for the XLPE insulator made by A Company is set to 128 kJ/mol (30.6 kcal/mol) as calculated in Section 2.1. If elongation at break for the sampled equivalent cables in the actual operating plant are predicted from the result of "superposition of time dependent data" for the simultaneous aging data acquired in this project, all elongation at break will be near the initial values. However, if the activation energy for the XLPE insulator is 81.2 kJ/mol (19.4 kcal/mol), the elongation at break in the condition of 65°C- 14.3 mGy/h in the region of approx. 129,000 hours will be predicted to be 315 % by " the superposition of time dependent data ". This value is almost equivalent to the data for the actual operating plant. Fig. 2.2-3 shows the result (2) of a "superposition of time dependent data" in this case. However, the predicted elongation at break in 50°C and 60°C in the same period will be close to the initial values, irrespective of the dose rate. In addition, in this prediction, the environment during a plant outage is set at a temperature of 30°C with a dose rate of 0.01 mGy/h, also the aging during the outage is also taken into consideration. (This also is the same in the following comparison.)

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(2) Although a horizontal axis in Fig. 2.2-3 for the result of "superposition of time dependent data" shows the period (time), this period shows the period to which each simultaneous degradation data was shifted (the same for figures of superposition of time dependent data in which simultaneous degradation data are plotted hereafter).

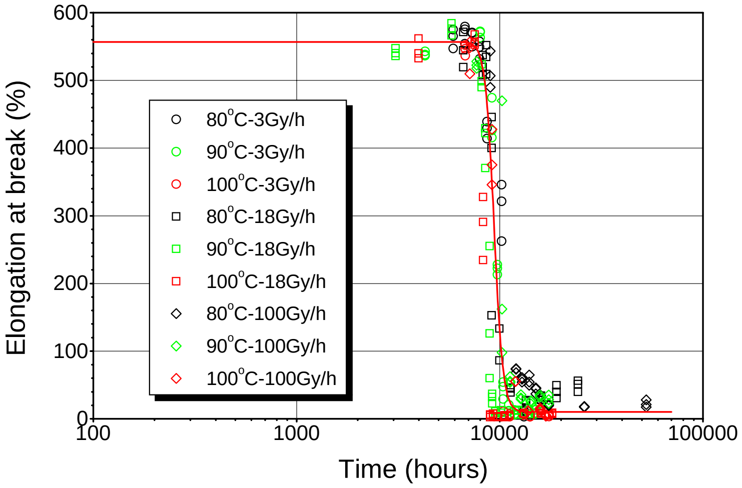


Fig. 2.2-3 Superposition of time dependent data of the XLPE insulator made by A Company (E=19.4 kcal/mol , x=0.841, k=232)

In addition, predicted progress of degradation by “the superposition of time dependent data” in the case of activation energy set to 81.2 kJ/mol (19.4 kcal/mol) is considered to be quite conservative. For example, the elongation at break at 141,000 hours of operation (24.2 years after the start of commercial operation at 66.7 % of availability factor) will be approx. 100 % in the environment of 65°C-14.3 mGy/h.

Furthermore, when actual environmental temperature is considered to be 3°C lower than the measured temperature (from 65 to 62°C), assuming the activation energy is 74.9 kJ/mol (17.9 kcal/mol), the elongation at break in the condition of 62°C- 14.3 mGy/h in the region of approx. 129,000 hrs will be predicted to be 352 % by “the superposition of time dependent data”. This value is almost in agreement with the data in the actual operating plant. For this case, the predicted elongation at break in 62°C-14.3mGy/h- approx. 149,000hrs (66.7% availability factor and after approx. 25.3 years after the start of commercial operation) will be approx. 100%.

(e) Evaluation by superposition of dose to equivalent damage data

Fig. 2.2-4 shows the result of “the superposition of dose to equivalent damage data” at 65°C for the XLPE insulator made by A Company (Equivalent damage is set to the elongation at break of 306 %). This figure shows that if the thermal aging is considered to be dominant in the condition of 65°C-14.3 mGy/h, the elongation at break of the sampling data will be in close agreement with the test data. In addition, the data in the actual operating plant has been corrected as to its aging period, taking into account the aging for the duration of plant outage (also the same in the following comparison).

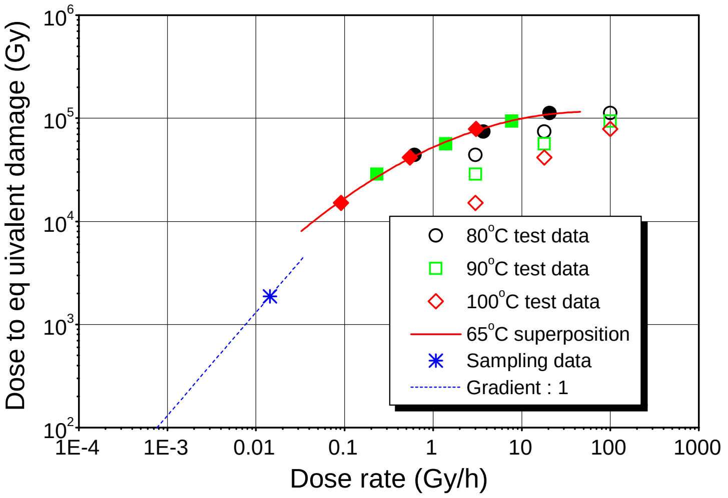


Fig. 2.2-4 Superposition of dose to equivalent damage data of the XLPE insulator made by A Company (Equivalent damage: 306% in elongation at break)

(f) Summary of the XLPE insulator made by A Company

Since present sampling data for the XLPE insulator made by A Company in the actual operating plant has considerable dispersion and small progress of degradation as a whole, appropriate evaluation of activation energy in the actual operating plant's temperature region is difficult to attain from this data. However, if activation energy used for predicting the progress of degradation by "the superposition of time dependent data" is estimated from comparatively progressing the sampling data of degradation (elongation at break is 306 %, and ratio to the initial value is 0.54), approx. 75.4 kJ/mol (18 kcal/mol) this will be considered appropriate for the activation energy of the XLPE insulator. (Correction for temperature measured with the thermo-label was taken into consideration for this value.)

In addition, when progress of degradation is predicted by "the superposition of time dependent data" for the XLPE insulator obtained in this project using the activation energy of 75.4 kJ/mol (18 kcal/mol), it will almost be in agreement with the most progressing sampling data of degradation in actual operating plants. However, the prediction of subsequent progress of degradation seems to be quite conservative. It should be improved by further more progressing the sampling data of degradation in the future.

(2) The XLPE insulator made by B Company

(a) Sampling data in actual operating plants

The sampling data of the XLPE insulator made by B Company is shown in Fig. 2.2-5. In addition, the periods given in Fig. 2.2-5 of the operating hours of the plant and the periods from the start of commercial operation are approx. 19.4 years (75 % of the availability factor). The initial value of an elongation at break of the XLPE insulator is the average value of 488 % (460 to 508 %) in this project, and the sampling data shown in Fig. 2.2-5 is in the range where the degradation is comparatively not progressing. Accordingly, the sampling data for the XLPE insulator was dealt with as uncertainty data for collation, and the following collations were carried out for additional information.

In addition, as shown in Fig. 2.2-5, the XLPE insulator has less sampling data compared with the XLPE insulator made by A Company, but their dispersion is slightly larger and the elongation at break is reversed by the dose rate. Factors of this dispersion can be considered due to the dispersion at the early stages of degradation, differences of dose rates at the part of a tensile test piece and at the measured point, and others.

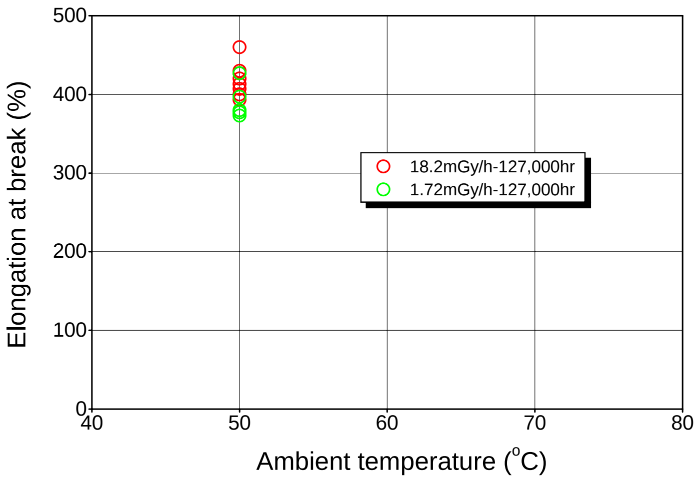


Fig. 2.2-5 Sampling data for the XLPE insulator made by B Company

(b) Predicted progress of degradation by the data in this project

The activation energy for the XLPE insulator made by B company is assumed at 101 kJ/mol (24.1kcal/mol) as calculated in Section 2.1, and, if the aging periods are predicted when the elongation at break for the XLPE insulator reduces to 400 % with thermal aging on the basis of thermal aging characteristics at 100°C obtained in this project, the aging periods will be approx. 1,270,000 hours at 50°C and approx. 241,000 hours at 65°C.

(c) Calculation of activation energy using the sampling data in actual operating plants (for additional information)

The activation energy for the XLPE insulator made by B Company is calculated by the sampling data at 50°C (elongation at break is 373 %) to be the earliest reduction in time (approx. 127,000 hours operating period, 75 % of availability factor, and approx. 19.4 years after the start of commercial operation) and the thermal aging characteristics at 100°C obtained in this project. The resulting activation energy will be 55.77 kJ/mol (13.32 kcal/mol) (refer to Fig. 2.2-6).

In addition, if degradation of the XLPE insulator is assumed to progress successively after approx. 19.4 years from the start of commercial operation as shown in Fig. 2.2-6, the elongation at break will reduce to 100 % in approx. 162,000 hours (approx. 24.6 years after the start of commercial operation at 75 % of availability factor) operation at 50°C.

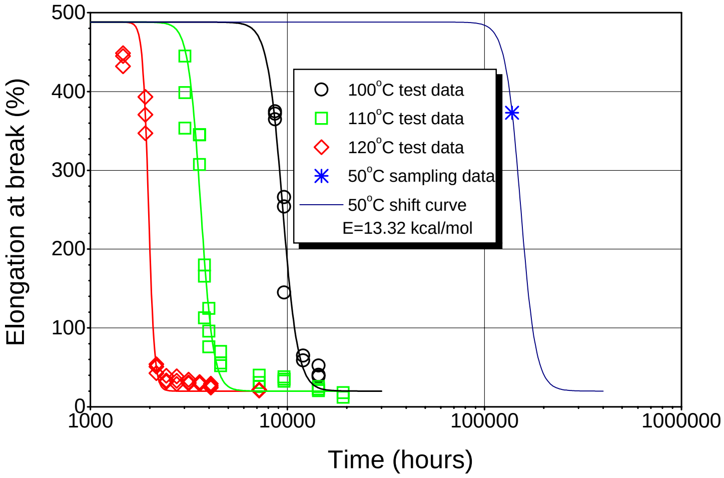


Fig. 2.2-6 Calculated activation energy from sampling data for the XLPE insulator made by B Company

(d) Evaluation by superposition of time dependent data (for additional information)

The activation energy for the XLPE insulator made by B Company is set to 101 kJ/mol (24.1 kcal/mol) as calculated in Section 2.1. If elongation at break for the sampled equivalent cables in the actual operating plant are predicted from the result of a "superposition of time dependent data" for the simultaneous aging data obtained in this project, all elongation at break will be near the initial value. However, if the activation energy for the XLPE insulator is 63.6 kJ/mol (15.2 kcal/mol), the elongation at break in the condition of 50°C- 1.72 mGy/h in the region of approx. 127,000 hours will be predicted to be 367 % by "the superposition of time dependent data". This value is in close agreement with the data in the actual operating plant (result of "the superposition of time dependent data" in this case is shown in Fig. 2.2-7). Also, the predicted elongation at break in the condition of 50°C- 18.2 mGy/h in the region of approx. 127,000 hours will be 263 %.

In addition, the predicted progress of degradation by "the superposition of time dependent data" in the case of activation energy set to 63.6 kJ/mol (15.2 kcal/mol) is considered to be quite conservative. For example, since any elongation at break values will be predicted to be 100 % for:

- approx. 274,000 hours of operation (approx. 41.7 years after the start of commercial operation at 75 % of availability factor) in environments of 50°C- 1.72 mGy/h;
- approx. 210,000 hours of operation (approx. 31.9 years after the start of commercial operation at 75 % of availability factor) in the environment of 50°C- 18.2 mGy/h;
- approx. 144,000 hours of operation (approx. 21.9 hours after the start of commercial operation at 75 % of availability factor) in the environment of 60°C- 1.72 mGy/h.; and
- approx. 119,000 hours of operation (approx. 18.1 hours after the start of commercial operation at 75 % of availability factor) in the environment of 60°C- 18.2 mGy/h.

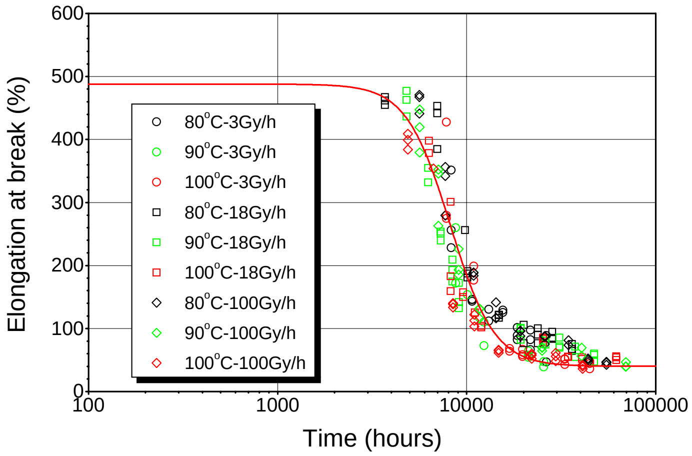


Fig. 2.2-7 Superposition of time dependence data of the XLPE insulator made by B Company (E=15.2 kcal/mol, x=0.627, k=135)

(e) Evaluation by superposition of dose to equivalent damage data (for additional information)

Fig. 2.2-8 shows the result of "the superposition of dose to equivalent damage data" at 50°C for the XLPE insulator made by B Company (Equivalent damage is set to the elongation at break of 373 %). This figure shows that if thermal aging is considered to be dominant in the condition of 50°C- 1.72 mGy/h, the elongation at break of the sampling data will be in close agreement with the test data.

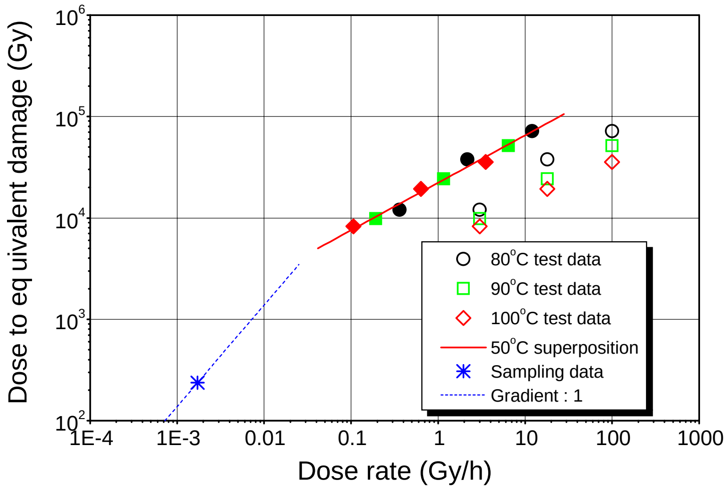


Fig. 2.2-8 Superposition of dose to equivalent damage data of the XLPE insulator made by B Company (Equivalent damage: 373% of elongation at break)

(f) Summary of the XLPE insulator made by B Company

Since present sampling data for the XLPE insulator made by B Company in the actual operating plant has a considerable dispersion and small progress of degradation, evaluation of activation energy in the actual operating plant's temperature region is difficult to attain from this data. However, if such dispersion and small progress of degradation are neglected, and the activation energy used for predicting the progress of degradation by "the superposition of time dependent data" is estimated from most progressing the sampling data of degradation (elongation at break is 373 %, and ratio to the initial value is 0.76), 63.6 kJ/mol (15.2 kcal/mol) this will be considered for the activation energy of the XLPE insulator. In addition, this activation energy is a temporary value, and predicted progress of degradation by this value is quite conservative.

(3) The FR-EPR insulated cable made by A Company

(a) Sampling data in actual operating plants

The sampling data for the FR-EPR insulator made by A Company is shown in Fig. 2.2-9. In addition, the plant operating hours for all sampling cables shown in Fig. 2.2-9 are approx. 104,000 hours, and the period from the start of commercial operation is approx. 14.5 years (81.3 % of availability factor). The average initial values of an elongation at break for the FR-EPR insulator are 405 % (396 to 421 %) for the black core, 416 % (393 to 429 %) for the white core, and 453 % (431 to 475 %) for the red core. The sampling data (except for some of them) is in the region of comparatively less progress of degradation. Accordingly, the sampling data for the FR-EPR insulator is treated as uncertainty data for collation, and the following collations were carried out for additional information.

Progress of degradation for the FR-EPR insulator is also clarified to differ from the color of each core, and the tendency appears for data at 80°C as shown in Fig. 2.2-9. Therefore, a collation was made for every core color for additional information.

In addition, the sampling data for the black core at 60°C has slightly larger dispersion as shown in Fig. 2.2-9. Dispersion at the early stage of degradation, a difference between dose rates at a part of a tensile test piece and at a measured point, and all others are considered as factors contributing to data dispersion.

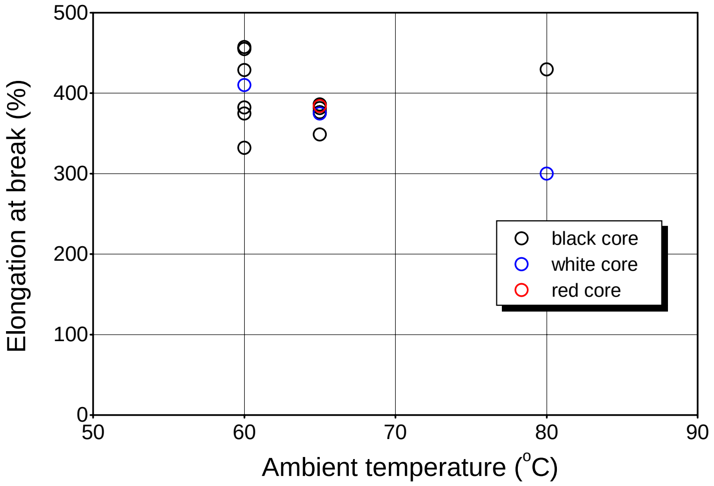


Fig. 2.2-9 Sampling data for the FR-EPR insulator made by A Company
(All dose rates are 20 mGy/h)

Also, although the sampling data at 80°C has one point each of black and white cores respectively, the progress of degradation is slow when the plant's operating period is taken into consideration. If activation energy for the white core is calculated from the thermal aging characteristics at 100°C acquired in this project, the value will be 162 kJ/mol (38.7 kcal/mol) (data for black core is near the initial value). This value is unexpected even from the thermal aging data at 100 to 120°C in this project, and it is considered that temperature for the duration of the plant's operation is very likely to have been lower than 80°C. Accordingly, two such points of the data at 80 °C were determined to be excluded from this collation.

The collated results are shown below for all core colors.

(b) The black core of FR-EPR insulator made by A Company

a. Predicted progress of degradation by the data in this project

The activation energy for the black core of FR-EPR insulator made by A Company is assumed at 110 kJ/mol (26.2 kcal/mol) as calculated in Section 2.1. Then, if the aging periods are predicted when the elongation at break for the black core insulator reduces to 350 % with thermal aging on the basis of the thermal aging characteristics at 100°C obtained in this project, they will be approx. 465,000 hours at 60°C and approx. 259,000 hours at 65°C.

b. Calculation of activation energy using the sampling data in actual operating plants (for additional information)

The activation energy for the black core of FR-EPR insulator made by A Company is calculated by the sampling data at 60°C (elongation at break is 332 %) to be the quickest reduction data and the thermal aging characteristics at 100°C obtained in this project. The resulting activation energy will be 70.59 kJ/mol (16.86 kcal/mol) (refer to Fig. 2.2-10).

In addition, if degradation of the black core insulator (as shown in Fig. 2.2-10) is progressing successively after approx. 14.5 years from the start of commercial operation, then for example, the elongation at break at 60°C in the region of approx. 132,000 hours (approx. 18.5 years after the start of commercial operation at 81.3 % of availability factor) will reduce to 100 %.

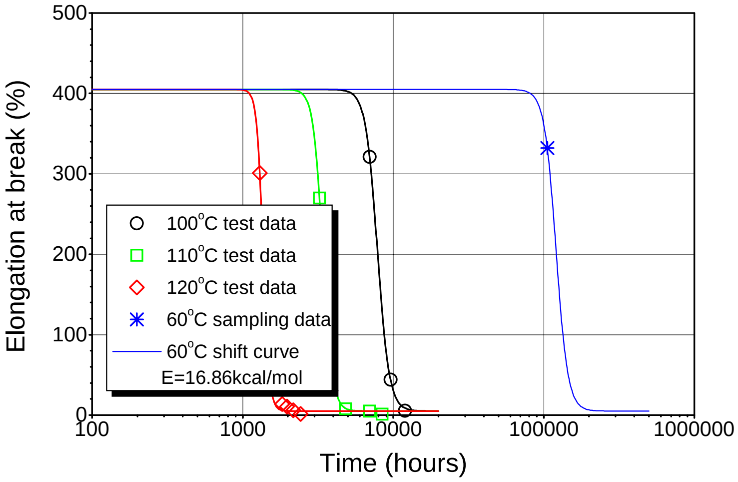


Fig. 2.2-10 Calculation of activation energy from sampling data for the black core of FR-EPR insulator made by A Company

c. Evaluation by superposition of time dependent data (for additional information)

The activation energy for the black core of FR-EPR insulator made by A Company is set to 110 kJ/mol (26.2 kcal/mol) calculated in Section 2.1. If elongation at break for the sampled equivalent cables in the actual operating plant are predicted from the result of a "superposition of time dependent data" for the simultaneous aging data obtained in this project, all elongation at break will be near the initial value. However, if the activation energy for the black core insulator is 71.2 kJ/mol (17 kcal/mol), the elongation at break in the condition of 60°C - 20 mGy/h in the region of approx. 104,000 hours will be predicted to be 322 % by "the superposition of time dependent data". Although this is a trial case, this value is in close agreement with the sampling data in the actual operating plant (the result of "superposition of time dependent data" in this case is shown in Fig. 2.2-11).

In addition, if the progress of degradation is predicted by "the superposition of time dependent data" in the case of activation energy set to 71.2 kJ/mol (17 kcal/mol), the elongation at break will be 100 % at approx. 130,000 hours (approx. 18.2 years after the start of commercial operation at 81.3 % of availability factor) in the environment of 60°C - 20 mGy/h.

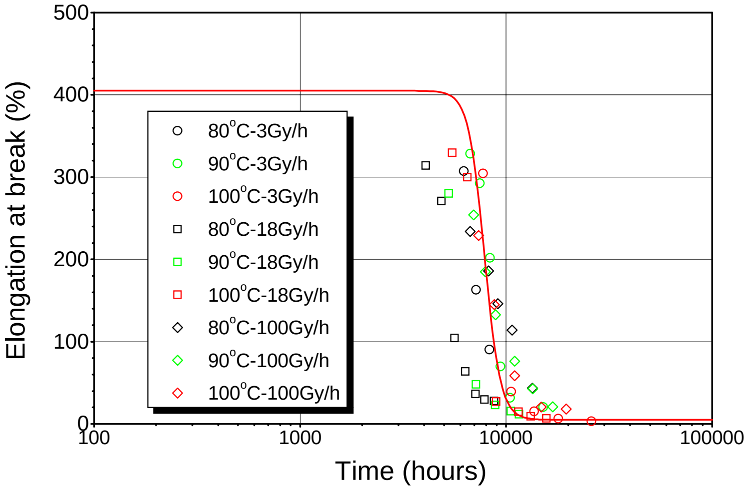


Fig. 2.2-11 Superposition of time dependent data for the black core of FR-EPR insulator made by A Company (E=17 kcal/mol, x=0.748, k=40.9)

d. Evaluation by superposition of dose to equivalent damage data (for additional information)

Fig. 2.2-12 shows the result of "the superposition of dose to equivalent damage data" at 60°C for the black core of FR-EPR insulator made by A Company (Equivalent damage is set to the elongation at break of 332 %). Although this is a trial case, the predicted progress of degradation in 60°C - 20 mGy/h - approx. 104,000 hours (approx. 14.5 years after the start of commercial operation at 81.3% of availability factor) is in close agreement with the sampling data in the actual operating plant. In addition, the condition of 60°C- 20 mGy/h is observed to be in the range subjected to thermal and radiation effect.

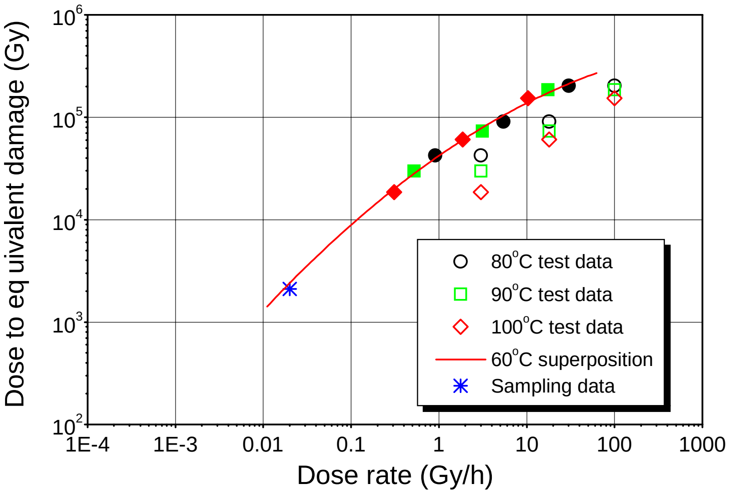


Fig. 2.2-12 Superposition of dose to equivalent damage data for the black core of FR-EPR insulator made by A Company (Equivalent damage: 332% of elongation at break)

e. Summery for the black core of FR-EPR insulator made by A Company

Since present sampling data in the actual operating plant for the black core of FR-EPR insulator made by A Company has dispersion and the progress of degradation is small, it is difficult to evaluate activation energy in the actual operating plant's temperature region from this data. However, if such dispersion and small progress of degradation are neglected, and the activation energy used for predicting the progress of degradation by "the superposition of time dependent data" is estimated from the most progressive of the sampling data of degradation (elongation at break is 332 %, and ratio to the initial value is 0.82), 71.2 kJ/mol (17 kcal/mol) this will be considered for the activation energy of the black core insulator. This activation energy is a temporary value.

(c) The white core of FR-EPR insulator made by A Company

a. Predicted progress of degradation by the data in this project

The activation energy is for the white core of FR-EPR insulator made by A Company assumed at 98.8 kJ/mol (23.6 kcal/mol) calculated in Section 2.1, and if the aging periods are predicted when the elongation at break for the white core insulator reduces to 350 % with thermal aging on the basis of thermal aging characteristics at 100°C acquired in this project, they will be approx. 242,000 hours at 60°C, and approx. 143,000 hours at 65°C.

b. Calculation of activation energy using the sampling data in actual operating plants (for additional information)

The activation energy for the white core of FR-EPR insulator made by A Company is calculated by the sampling data at 65°C (elongation at break is 375 %) to be the early reduction data and the thermal aging characteristics at 100°C obtained in this project. The resulting activation energy will be 89.76 kJ/mol (21.44 kcal/mol) (refer to Fig. 2.2-13).

In addition, if degradation of the white core insulator as shown in Fig. 2.2-13 is progressing successively after approx. 14.5 years from the start of commercial operation, then for example, the elongation at break at 65°C in the region of approx. 114,000 hours (approx. 15.9 years after the start of commercial operation at 81.3 % of availability factor) will reduce to 100 %.

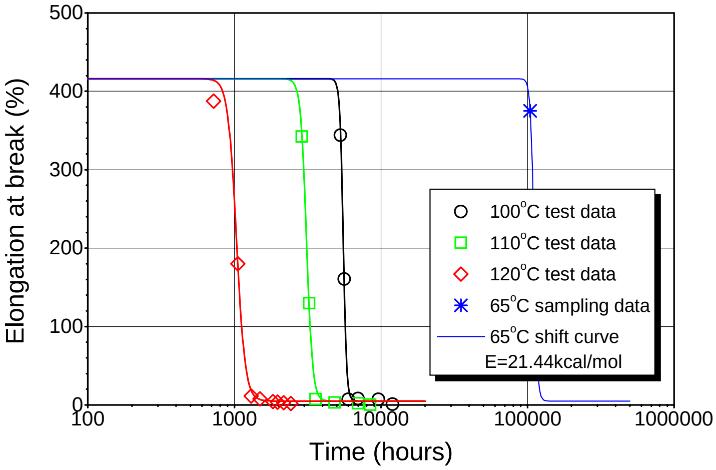


Fig. 2.2-13 Calculation of activation energy from sampling data for the white core of FR-EPR insulator made by A Company

c. Evaluation by superposition of time dependent data (for additional information)

The activation energy for the white core of FR-EPR insulator made by A Company is set to 98.8 kJ/mol (23.6 kcal/mol) calculated in Section 2.1. If elongation at break for the equivalently sampled cables in the actual operating plant are predicted from the result of a "superposition of time dependent data" for the simultaneous aging data obtained in this project, the elongation at break values will be close to the initial value. However, if the activation energy for the white core insulator is 90.9 kJ/mol (21.7 kcal/mol), the elongation at break in the condition of 65°C- 20 mGy/h in the region of approx. 104,000 hours will be predicted to be 380 % by "the superposition of time dependent data". Although this is a trial case, this value is in close agreement with the sampling data in the actual operating plant (the result of "superposition of time dependent data" in this case is shown in Fig. 2.2-14).

In addition, if the progress of degradation is predicted by "the superposition of time dependent data" in the case of activation energy set to 90.9 kJ/mol (21.7 kcal/mol), the elongation at break will be 100 % at approx. 114,000 hours (approx. 16.0 years after the start of commercial operation at 81.3 % of availability factor) in the environment of 65°C- 20 mGy/h.

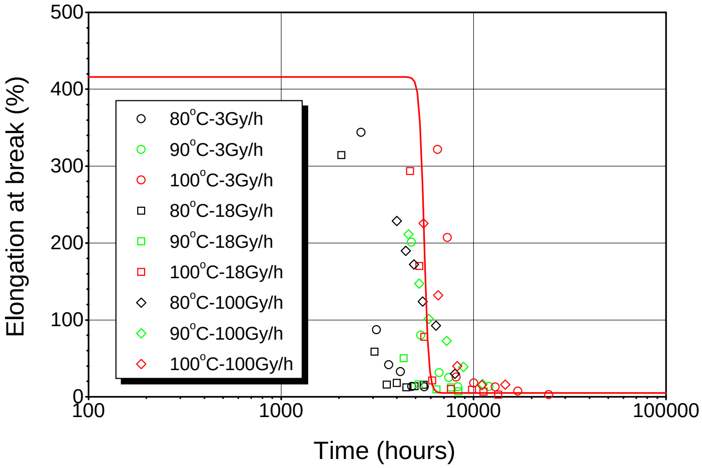


Fig. 2.2-14 Superposition of time dependent data for the white core of FR-EPR insulator made by A Company (E=21.7 kcal/mol, x=0.734, k=25.5)

d. Evaluation by superposition of dose to equivalent damage data (for additional information)

Fig. 2.2-15 shows the result of "the superposition of dose to equivalent damage data" at 65°C for the white core of FR-EPR insulator made by A Company (Equivalent damage is set to the elongation at break of 375 %). Although this is a trial case, the predicted progress of degradation in 65°C- 20 mGy/h - approx. 104,000 hours (approx. 14.5 years after the start of commercial operation at 81.3% of availability factor) is in close agreement with the sampling data in the actual operating plant. In addition, the condition of 65°C- 20 mGy/h is observed to be in the range subjected to thermal and radiation effect.

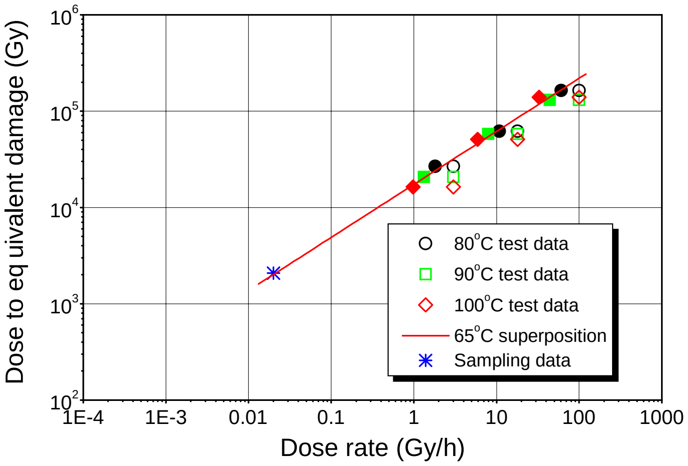


Fig. 2.2-15 Superposition of dose to equivalent damage data for white core of FR-EPR insulator made by A Company (Equivalent damage: 375% of elongation at break)

e. Summary for the white core of FR-EPR insulator made by A Company

Since only two effective sampling data in the actual operating plant for the white core of FR-EPR insulator made by A Company is currently available and the progress of degradation is small, it is difficult to evaluate activation energy in the actual operating plant's temperature region from this data. However, if the activation energy used for predicting the progress of degradation by "the superposition of time dependent data" is estimated from progressing the sampling data of degradation (elongation at break is 375 %, and ratio to the initial value is 0.90), 90.9 kJ/mol (21.7 kcal/mol) this will be considered for the activation energy of the white core insulator. This activation energy is a temporary value.

(d) Red core of FR-EPR insulator made by A Company

a. Predicted progress of degradation by this project

The activation energy is for the red core of FR-EPR insulator made by A Company assumed at 95.9 kJ/mol (22.9 kcal/mol) calculated in Section 2.1, and if the aging periods are predicted when the elongation at break for the red core insulator reduces to 350 % with thermal aging on the basis of thermal aging characteristics at 100°C acquired in this project, they will be approx. 89,000 hours at 60°C, and approx. 53,000 hours at 65°C.

b. Calculation of activation energy using the sampling data in actual operating plants (for additional information)

The activation energy for the red core of FR-EPR insulator made by A Company is calculated by the sampling data at 65°C (elongation at break is 384 %) and the thermal aging characteristics at 100°C obtained in this project. The resulting activation energy will be 119.2 kJ/mol (28.46 kcal/mol) (refer to Fig. 2.2-16).

In addition, the activation energy is quite large even if it is compared with the activation energy of 95.9 kJ/mol (22.9 kcal/mol) evaluated from the thermal aging characteristics at 100 to 120°C acquired in this project. Also, the sampling data has a big difference in "superposition of dose to equivalent damage data" in the next Section. Consequently, the sampling data for the red core insulator is considered to have lower reliability, and such activation energy cannot also be dealt with as a reference value.

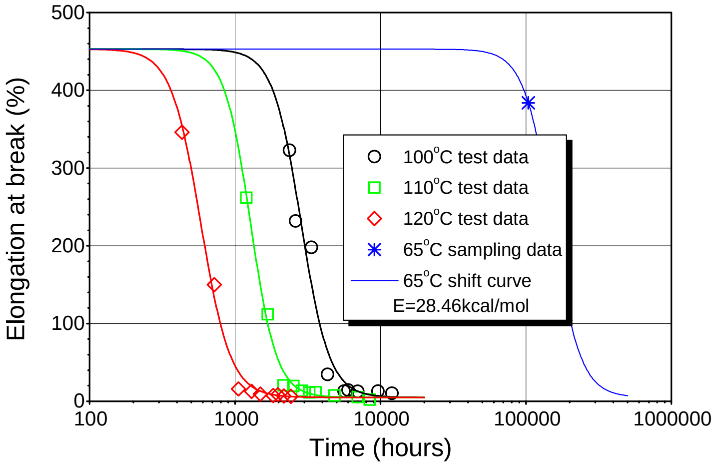


Fig. 2.2-16 Calculation of activation energy from sampling data for the red core of FR-EPR insulator made by A Company

c. Evaluation by superposition of dose to equivalent damage data (for additional information)

Fig. 2.2-17 shows the result of “the superposition of dose to equivalent damage data” at 65°C for the red core of FR-EPR insulator made by A Company (Equivalent damage is set to the elongation at break of 384 %).

Although this evaluation is a trial for the FR-EPR insulator, the predicted progress of degradation by “the superposition of dose to equivalent damage data” is in close agreement with the data in the actual operating plant in the case of black and white core insulators, but the red core insulator data shows a big difference.

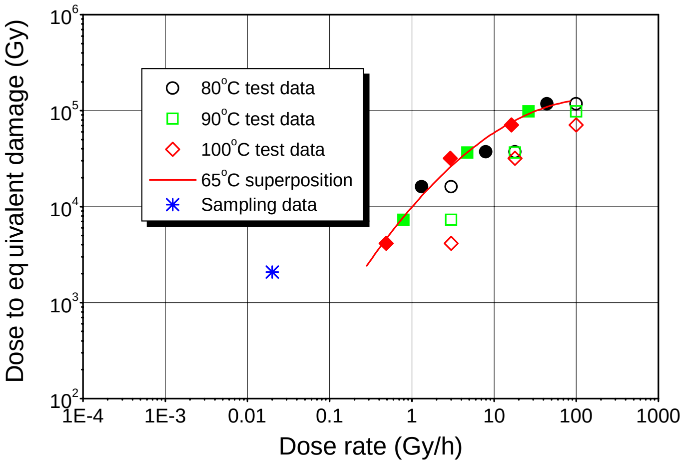


Fig. 2.2-17 “Superposition of dose to equivalent damage data” for the red core of FR-EPR insulator made by A Company (Equivalent damage: 384% in elongation at break)

d. Summary for the red core of FR-EPR insulator made by A Company

Since only one sampling data in the actual operating plant for the red core of FR-EPR insulator made by A Company is currently available and the progress of degradation is small, it was determined that evaluation of the activation energy was difficult in the actual operating plant’s temperature region from this data, even as a temporary value.

2.3 Principles of calculation and application for activation energy

The following knowledge was obtained by calculation of activation energy based on the data acquired in this project and evaluation of activation energy based on collation with sampling data in actual operating plants.

- When the activation energy of each insulator is calculated from thermal aging test data acquired at this time, most of the data is in the order of 100 kJ/mol (20 or more kcal/mol), and some of it is also 40 or more kJ/mol (a little more than 10 kcal/mol). In addition, a large portion of thermal aging test data used for calculation of activation energy is data ranging from 100 to 120°C.
- If a collation is made between the sampling data in actual operating plants and the data acquired in this project, the activation energy in actual operating plants temperature region (from 50 to 60°C) shows to be in another smaller trend other than the value calculated from the thermal aging test data acquired in this project.

Also, although it differs from elongation at break, some literature states that around 60 kJ/mol (approx. 15 kcal/mol) it can be assumed to be appropriate for the activation energy in a region of uniform oxidization acquired with chemo-luminescence analysis (Ref. 14, and 15).

Based on the above, the principles of calculation and application for the activation energy used for future assessment as shown below were determined to be appropriate.

a. Applicable region of activation energy calculated by thermal aging tests is limited up to the minimum temperature in thermal aging tests.
   However, when the calculated activation energy is 62.8 kJ/mol (15 kcal/mol) or less, the value can be applied up to the operating temperature region of actual operating plants.

b. The activation energy in the region between the minimum temperature in thermal aging tests and the temperature of actual operating plants is evaluated from the investigation results of degradation in actual operating plants (sampling inspection) and the thermal aging characteristics at the minimum temperature in the thermal aging tests.

c. When the activation energy cannot be evaluated from the investigation results of degradation in actual operating plants, 62.8 kJ/mol (15 kcal/mol) is used as a tentative value for the activation energy in the region between the minimum temperature in the thermal aging tests and the temperature of actual operating plants.

Fig. 2.3-1 shows a calculated example for the accelerated thermal aging condition from the Arrhenius plot in the case the mentioned above,

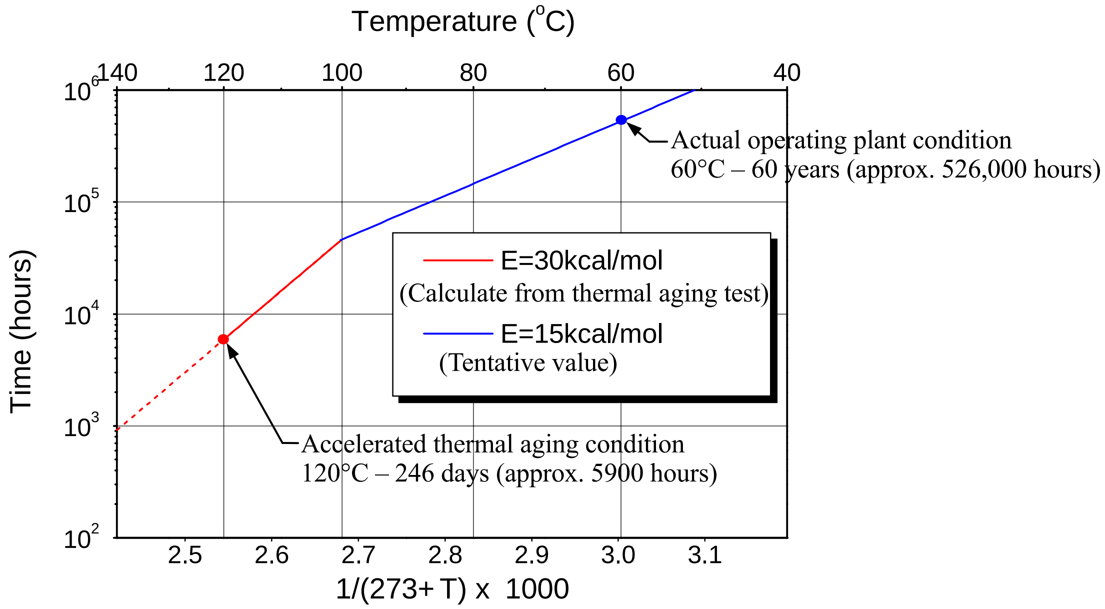


Fig. 2.3-1 Calculation example of accelerated thermal aging conditions from Arrhenius plot based on calculation of activation energy and application plan

Also, an acceleration factor of the accelerated thermal aging is calculated by formula 1, when the activation energy at the accelerated thermal aging test temperature and the activation energy at actual operating plants temperature are the same.

$$a = \exp\left[\frac{-E}{R}\left(\frac{1}{(273+T_{exam})} - \frac{1}{(273+T_{real})}\right)\right] \cdots\cdots\cdots\cdots \text{Formula 1}$$

where,

E : Activation energy, R :Gas constant, T_{real} :Temperature in the actual operating plant,

T_{exam} : Test temperature

However, In the case above activation energies differ in the value, if 100 °C is assumed as the minimum temperature in the thermal aging tests to calculate the activation energy, the acceleration factor for accelerated thermal aging will be as shown in a formula 2,

$$a = a_{real} \times a_{exam}$$

$$a_{real} = \exp\left[\frac{-E_{real}}{R}\left(\frac{1}{(273+100)} - \frac{1}{(273+T_{real})}\right)\right]$$

$$a_{exam} = \exp\left[\frac{-E_{exam}}{R}\left(\frac{1}{(273+T_{exam})} - \frac{1}{(273+100)}\right)\right]$$

$$a = \exp\left[\frac{E_{real}}{R(273+T_{real})} + \frac{E_{exam}-E_{real}}{R(273+100)} - \frac{E_{exam}}{R(273+T_{exam})}\right] \cdots\cdots\cdots\cdots \text{Formula 2}$$

where,

a_{real} : Accelerated temperature factor of 100°C against the actual operating plant temperature.

a_{exam} : Accelerated temperature factor of the test temperature against 100°C.

E_{real} : Activation energy in the region between the temperature of actual operating plant and 100°C.

E_{exam} : Activation energy calculated from the results of the thermal aging test in which minimum temperature was 100°C.

Table 2.3-1 shows the activation energies used for the evaluation at the present time based on the principles of calculation and application of new activation energies.

Table 2.3-1 The activation energies to be used for the assessment at this time

Kind of insulator		100～120℃ Activation energy	100℃ or less Activation energy
1. XLPE insulator made by A Company		128 kJ/mol (30.6 kcal/mol)	75.4 kJ/mol (18 kcal/mol)
2. XLPE insulator made by B Company		101 kJ/mol (24.1 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
3. FR-XLPE insulator made by A Company		83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
4. FR-XLPE insulator made by B Company		83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
5. XLPE insulator made by C Company (coaxial cable)		83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
6. EPR insulator made by C Company		88.3 kJ/mol (21.1 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
7. FR-EPR insulator made by A Company	Black core	110 kJ/mol (26.2 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	White core	98.9 kJ/mol (23.6 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	Red core	95.9 kJ/mol (22.9 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
8. FR-EPR insulator made by B Company	Black core	83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	White core	83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	Red core	83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
9. FR-EPR insulator made by C Company	Black core	96.3 kJ/mol (23 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	White core	96.3 kJ/mol (23 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
	Red core	83.7 kJ/mol (20 kcal/mol)	62.8 kJ/mol (15 kcal/mol)
10. SIR insulator made by A Company		47.7 kJ/mol (11.4 kcal/mol)	Same as left
11. SIR insulator made by B Company		41.9 kJ/mol (10 kcal/mol)	Same as left
12. SIR insulator made by C Company		54.8 kJ/mol (13.1 kcal/mol)	Same as left
13. SHPVC insulator made by A Company		64.5 kJ/mol (15.4 kcal/mol)	Same as left
14. SHPVC insulator made by B Company		91.3 kJ/mol (21.8 kcal/mol)	62.8 kJ/mol (15 kcal/mol)

3. Outlines of "The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (draft)"

3.1 Applicability study of the technique of superposition of time dependent data

Applicability of the technique of "superposition of time dependent data" was studied using the simultaneous aging data acquired in this project. In addition, an applicability study of the technique of "superposition of time dependent data" followed nine kinds of XLPE family and EPR family insulators for which simultaneous aging data due to dose rates of 3 Gy/h to 100 Gy/h have been acquired. The following two cases were treated in superposing data; one is the case of activation energy calculated from thermal aging data (from 100 to 120°C), and the other is the case of activation energy at 100°C or less rather than simultaneous aging data at 80 to 100°C.

As shown in Fig. 3.1-1-34, "the superposition of time dependent data" has been essentially performed in a satisfactory manner for simultaneous aging data of each of XLPE family and EPR family insulators. Therefore, "the superposition of time dependent data" was determined to be applicable to the setup of accelerated aging conditions adapted to the environment of actual operating plant. Also, since use of activation energy at 100°C or less as shown in Section 2.3 provide relatively satisfactory superposition, calculation of and an application plan for activation energy in Section 2.3 was observed to be appropriate.

In addition, with regard to "the superposition of dose rate to equivalent damage data", the applicability was observed to be significantly good in collation with sampling data in actual operating plants of Section 2.2. However, since data for the progress of degradation in simultaneous aging with a low dose rate were obtained for only some insulators, applicability was examined during the acquisition of these required data.

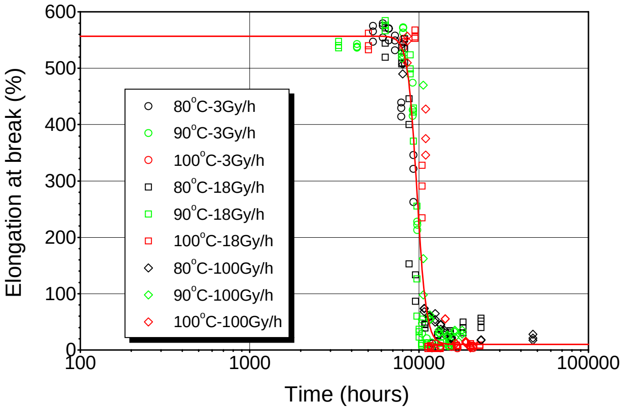


Fig. 3.1-1 Superposition of time dependent data for the XLPE insulator made by A Company E=30.6 kcal/mol, k=221, x=0.774

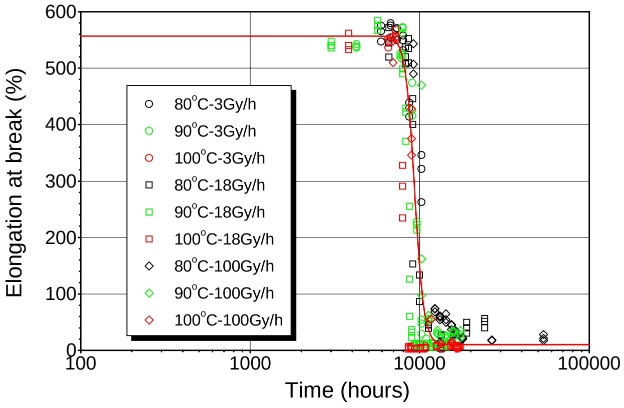


Fig.3.1-2 Superposition of time dependent data for the XLPE insulator made by A Company E=18 kcal/mol, k=244, x=0.862

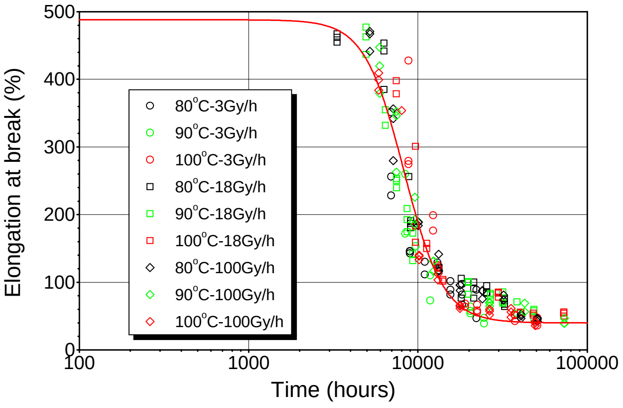


Fig. 3.1-3 Superposition of time dependent data for the XLPE insulator made by B Company E=24.1 kcal/mol, k=164, x=0.627

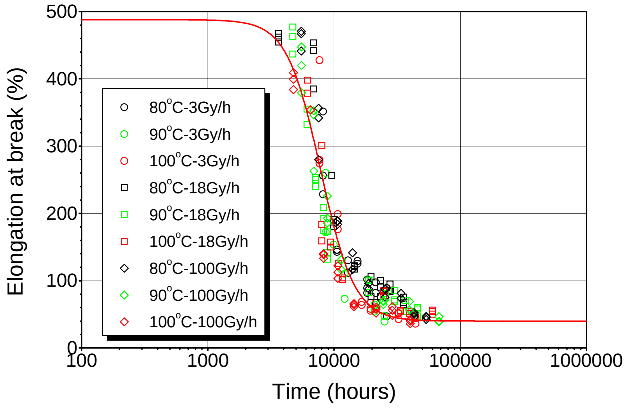


Fig.3.1-4 Superposition of time dependent data for the XLPE insulator made by B Company E=15 kcal/mol, k=132, x=0.628

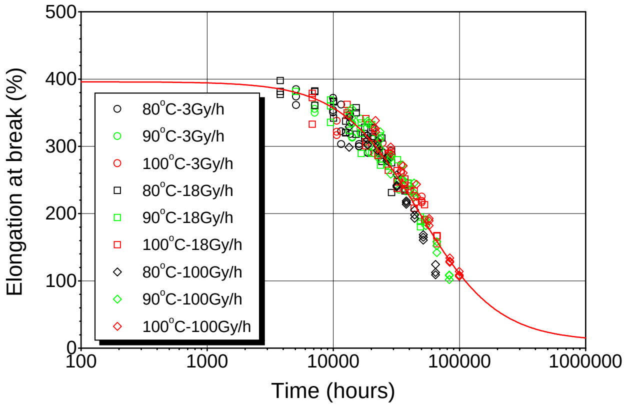


Fig. 3.1-5 Superposition of time dependent data for the FR-XLPE insulator made by A Company E=20 kcal/mol, k=214, x=0.697

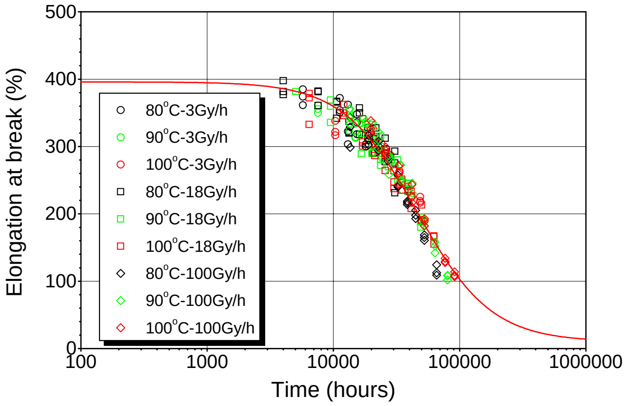


Fig.3.1-6 Superposition of time dependent data for the FR-XLPE insulator made by A Company E=15 kcal/mol, k=186, x=0.684

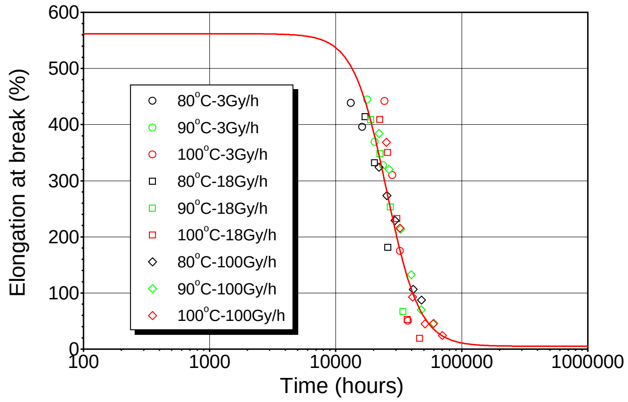


Fig. 3.1-7 Superposition of time dependent data for the FR-XLPE insulator (black core) made by B Company E=20 kcal/mol, k=173, x=0.741

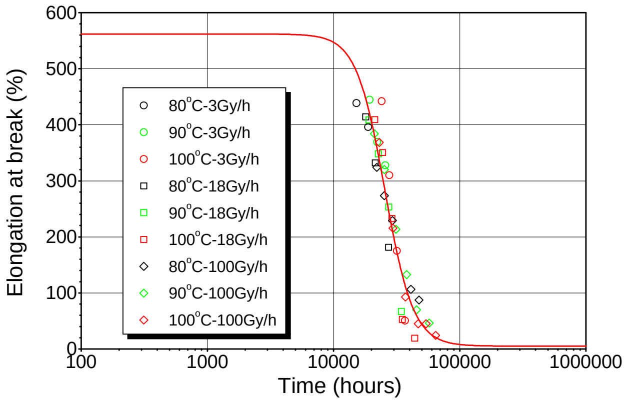


Fig.3.1-8 Superposition of time dependent data for the FR-XLPE insulator (black core) made by B Company E=15 kcal/mol, k=147, x=0.723

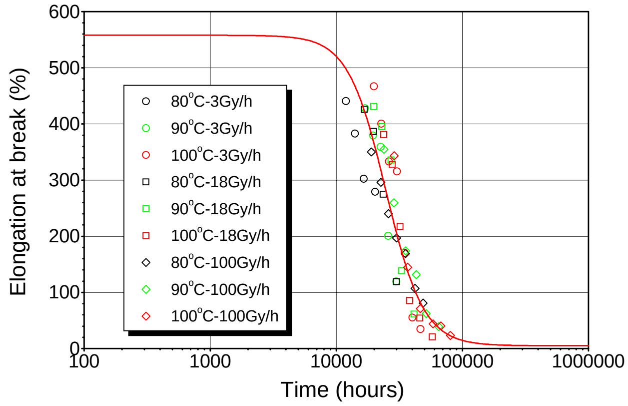


Fig. 3.1-9 Superposition of time dependent data for the FR-XLPE insulator (white core) made by B Company E=20 kcal/mol, k=150, x=0.662

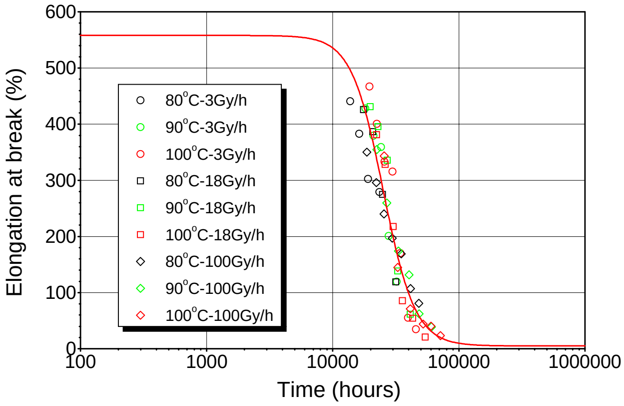


Fig.3.1-10 Superposition of time dependent data for the FR-XLPE insulator (white core) made by B Company E=15 kcal/mol, k=120, x=0.635

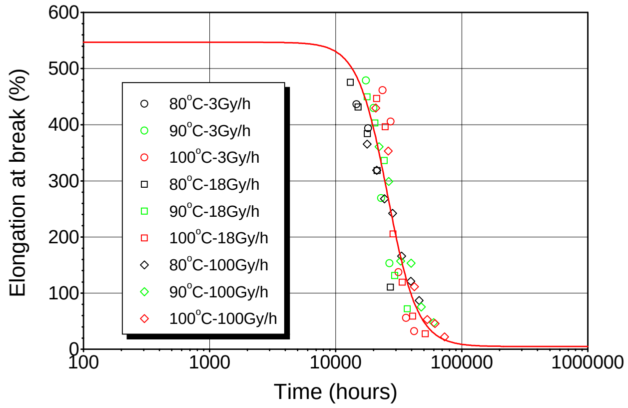


Fig. 3.1-11 Superposition of time dependent data for the FR-XLPE insulator (red core) made by B Company E=20 kcal/mol, k=148, x=0.687

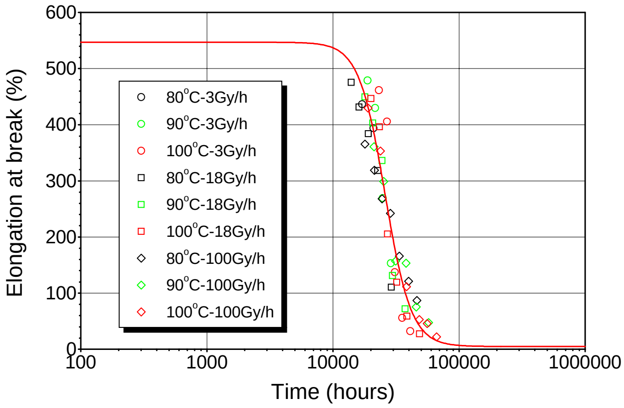


Fig.3.1-12 Superposition of time dependent data for the FR-XLPE insulator (red core) made by B Company E=15 kcal/mol, k=125, x=0.668

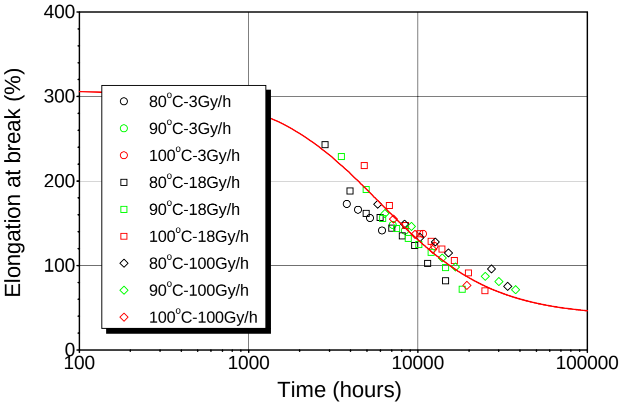


Fig. 3.1-13 Superposition of time dependent data for the XLPE insulator of coaxial cable made by A Company E=20 kcal/mol, k=172, x=0.914

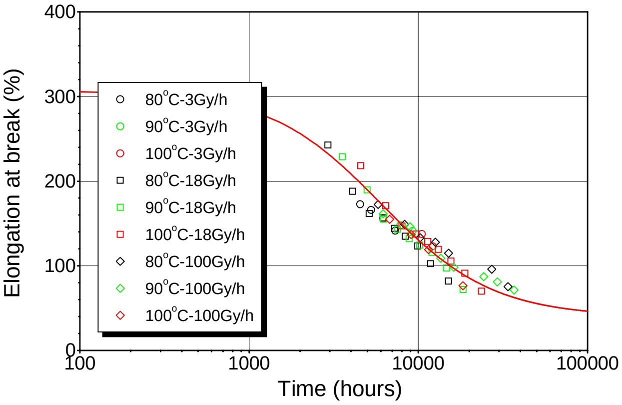


Fig. 3.1-14 Superposition of time dependent data for the XLPE insulator of coaxial cable made by A Company E=15 kcal/mol, k=171, x=0.929

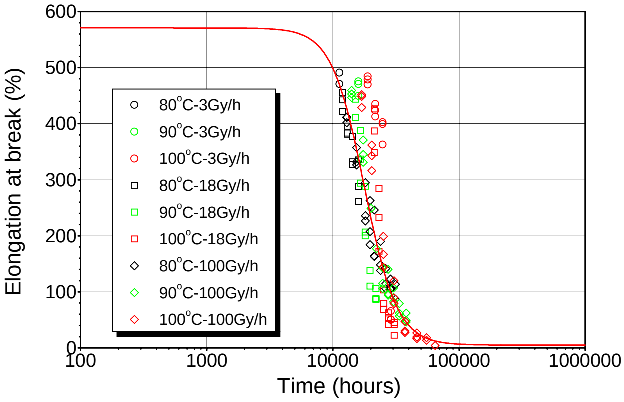


Fig. 3.1-15 Superposition of time dependent data for the EPR insulator made by C Company E=21 kcal/mol, k=123, x=0.790

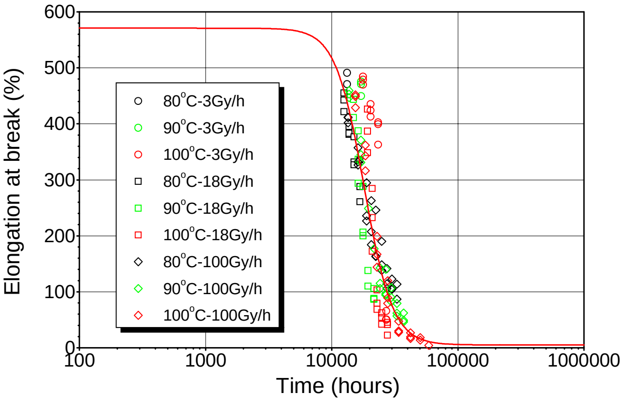


Fig. 3.1-16 Superposition of time dependent data for the EPR insulator made by C Company E=15 kcal/mol, k=124, x=0.822

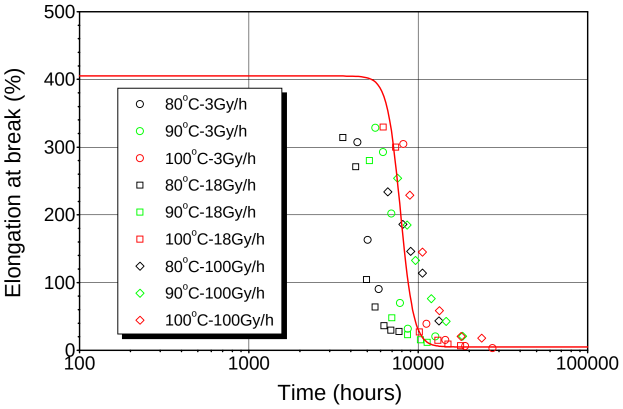


Fig. 3.1-17 Superposition of time dependent data for the FR-EPR insulator (black core) made by A Company
E=26.2 kcal/mol, k=50.6, x=0.740

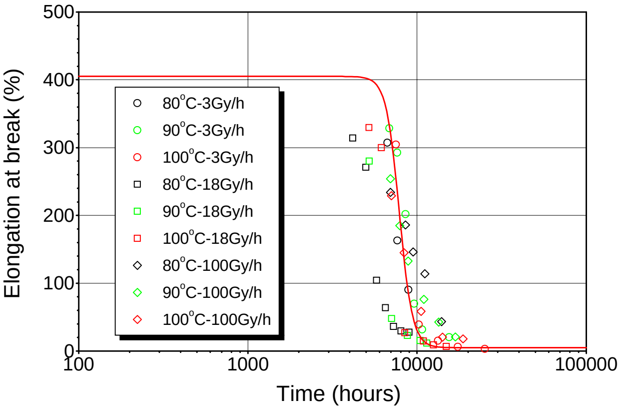


Fig.3.1-18 Superposition of time dependent data for the FR-EPR insulator (black core) made by A Company
E=15 kcal/mol, k=44.2, x=0.786

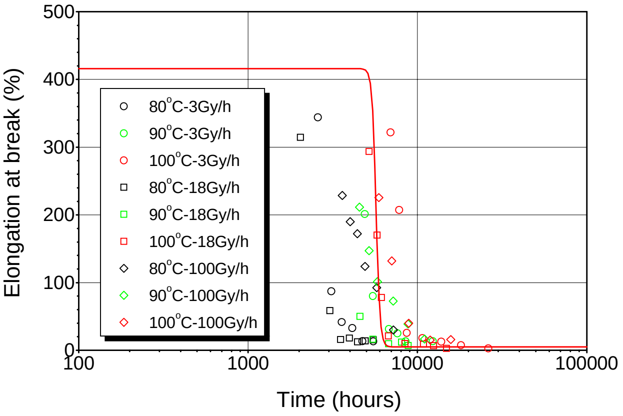


Fig. 3.1-19 Superposition of time dependent data for the FR-EPR insulator (white core) made by A Company
E=23.6 kcal/mol, k=20.4, x=0.641

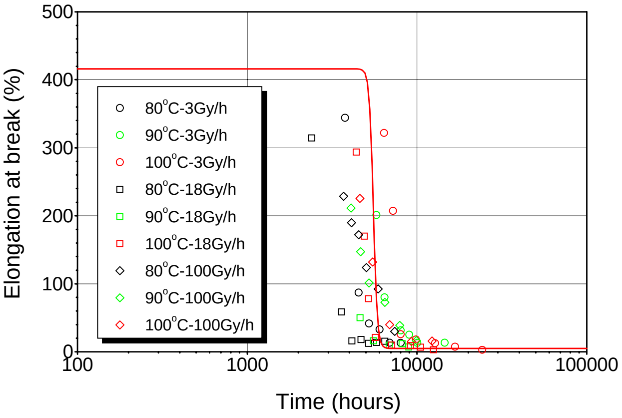


Fig.3.1-20 Superposition of time dependent data for the FR-EPR insulator (white core) made by A Company
E=15 kcal/mol, k=15.9, x=0.686

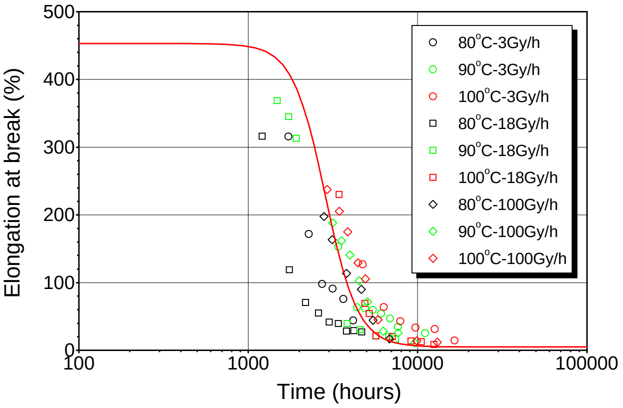


Fig. 3.1-21 Superposition of time dependent data for the FR-EPR insulator (red core) made by A Company
E=22.9 kcal/mol, k=22.9, x=0.755

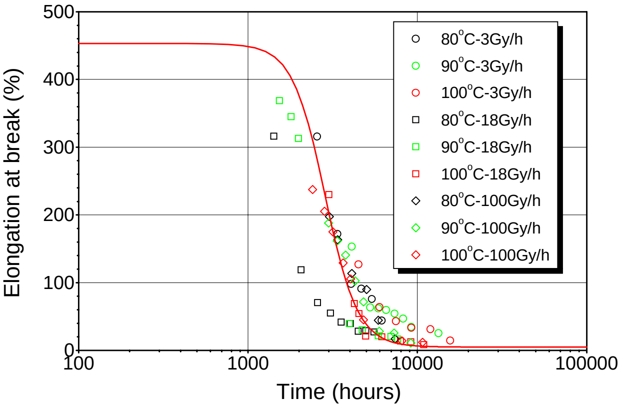


Fig.3.1-22 Superposition of time dependent data for the FR-EPR insulator (red core) made by A Company
E=15 kcal/mol, k=25.7, x=0.885

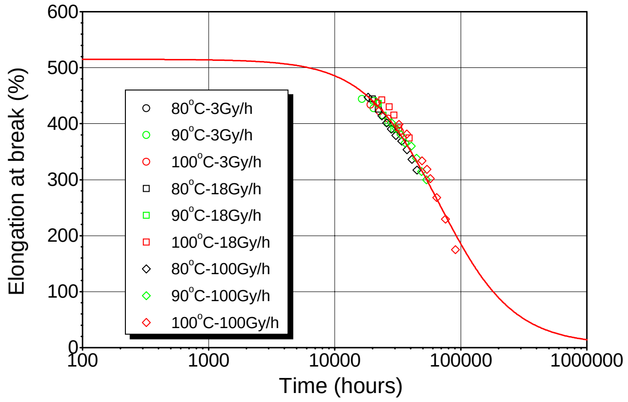


Fig. 3.1-23 Superposition of time dependent data for the FR-EPR insulator (black core) made by B Company E=20 kcal/mol, k=174, x=0.791

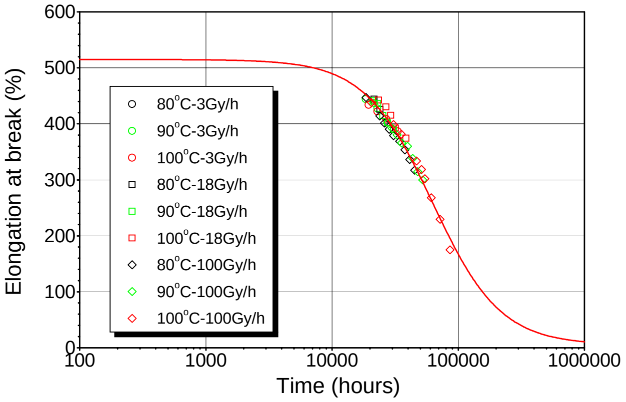


Fig.3.1-24 Superposition of time dependent data for the FR-EPR insulator (black core) made by B Company E=15 kcal/mol, k=151, x=0.767

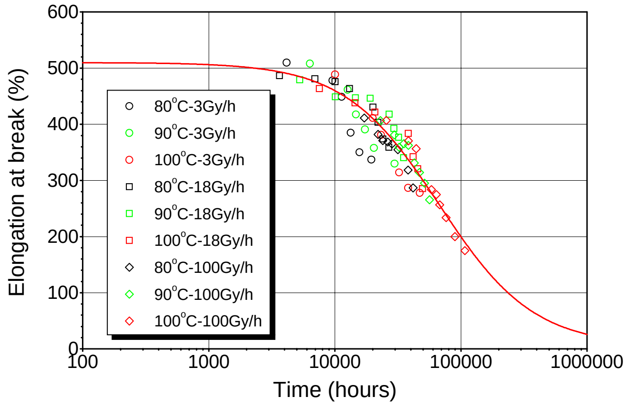


Fig. 3.1-25 Superposition of time dependent data for the FR-EPR insulator (white core) made by B Company E=20 kcal/mol, k=116, x=0.629

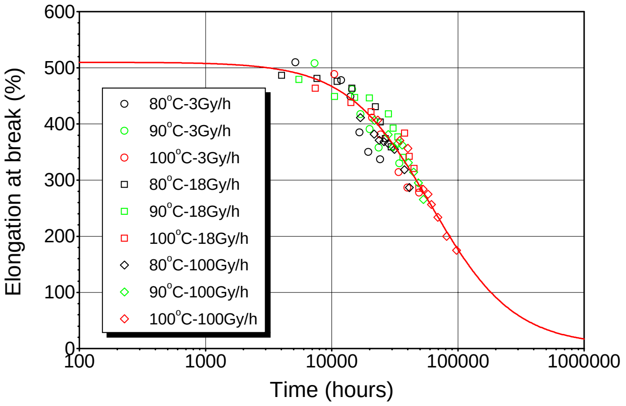


Fig.3.1-26 Superposition of time dependent data for the FR-EPR insulator (white core) made by B Company E=15 kcal/mol, k=86.4, x=0.576

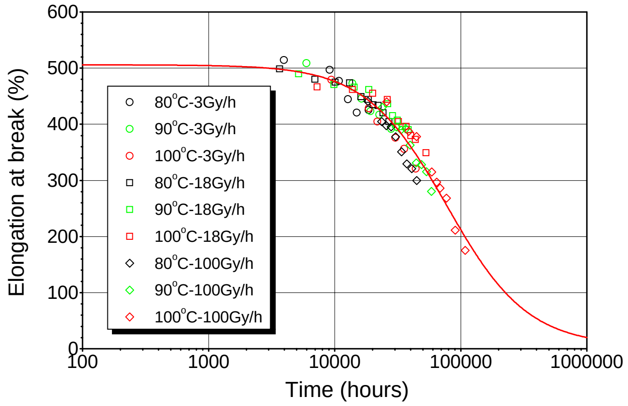


Fig. 3.1-27 Superposition of time dependent data for the FR-EPR insulator (red core) made by B Company E=20 kcal/mol, k=135, x=0.666

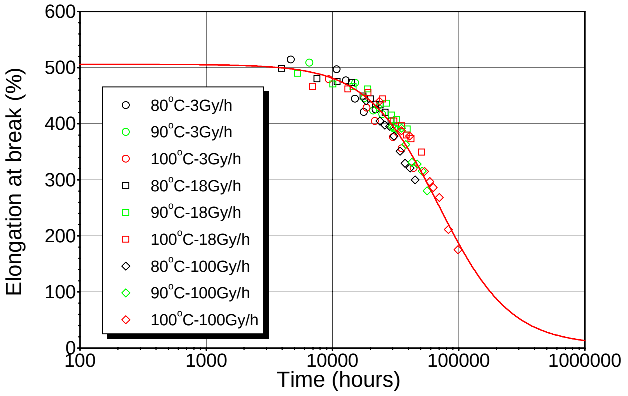


Fig.3.1-28 Superposition of time dependent data for the FR-EPR insulator (red core) made by B Company E=15 kcal/mol, k=111, x=0.640

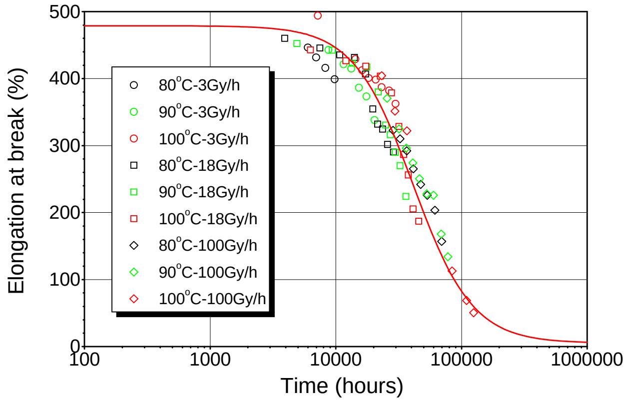


Fig. 3.1-29 Superposition of time dependent data for the FR-EPR insulator (black core) made by C Company E=23 kcal/mol, k=334, x=0.873

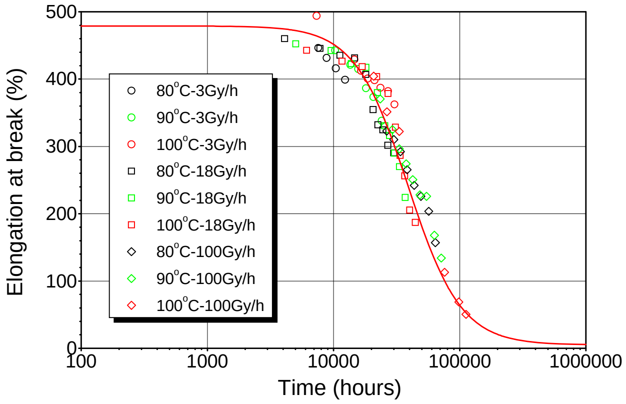


Fig.3.1-30 Superposition of time dependent data for the FR-EPR insulator (black core) made by C Company E=15 kcal/mol, k=251, x=0.826

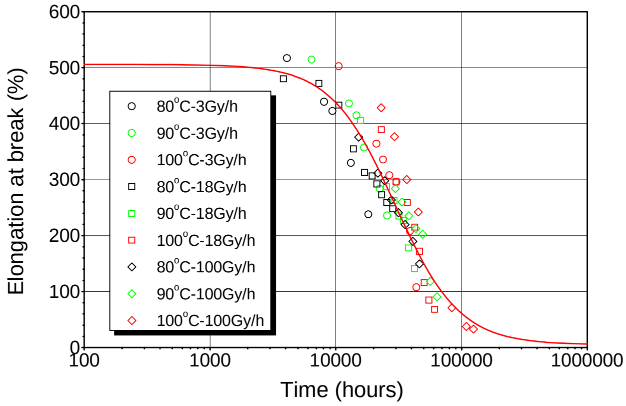


Fig. 3.1-31 Superposition of time dependent data for the FR-EPR insulator (white core) made by C Company E=23 kcal/mol, k=148, x=0.659

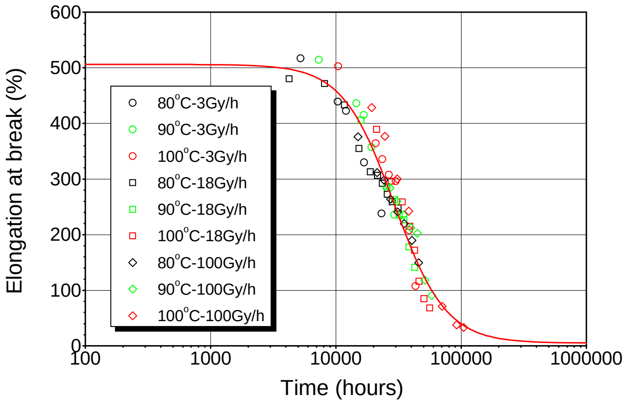


Fig.3.1-32 Superposition of time dependent data for the FR-EPR insulator (white core) made by C Company E=15 kcal/mol, k=103, x=0.602

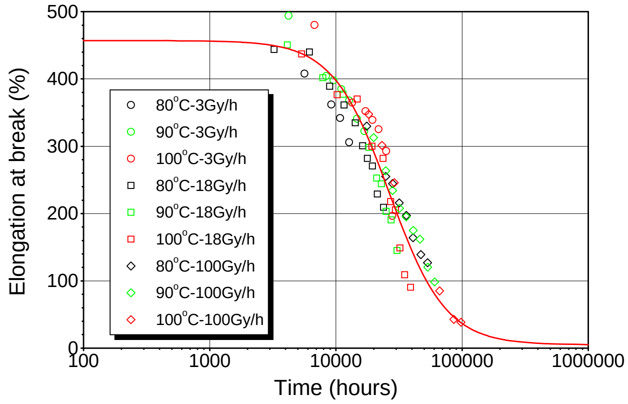


Fig. 3.1-33 Superposition of time dependent data for the FR-EPR insulator (red core) made by C Company E=20 kcal/mol, k=232, x=0.844

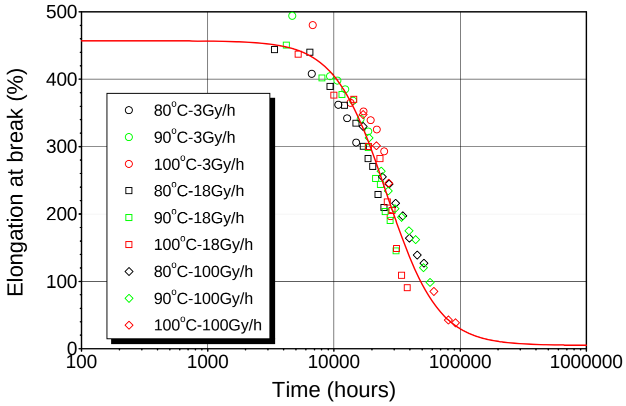


Fig.3.1-34 Superposition of time dependent data for the FR-EPR insulator (red core) made by C Company E=15 kcal/mol, k=198, x=0.821

3.2 Outlines of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)”

Based on the results of investigation and evaluation in the past, the outlines of “The Guidelines for Environmental Qualification Test for cables for Nuclear Power Plants (draft)”are as follows:

(a) Accelerated aging equivalent to aging during normal operation is defined as simultaneous aging. In addition, the maximum dose rate for simultaneous aging is 100 Gy/h, and an upper limit of the maximum temperature is not specified. Also, the insulator thickness of the specimen is, in principle, determined less than 1mm so that oxidization degradation may progress into the inside of the insulator. When the specimen exceeding this thickness is used, it shall be verified that oxidization degradation does progress into the inside of the insulator.

(b) Activation energy used for accelerated aging is as follows.

a. Applicable region of activation energy calculated by thermal aging tests is limited up to the minimum temperature in thermal aging tests. However, when the calculated activation energy is less than 62.8 kJ/mol (15 kcal/mol), the value can be applied up to the operating temperature region of actual operating plants.
In addition, 83.7 kJ/mol (20 kcal/mol) may be used for the activation energy in the region at 100 to 120°C for XLPE, FR-XLPE, EPR and FR-EPR. A value of 41.9 kJ/mol (10 kcal/mol) may be used for activation energy at any temperature region for SIR. However, these activation energies are tentative values. (Activation energy in the region of 100 to 120°C is being held at present for the SHPVC.)

b. Activation energy in the region between the minimum temperature in thermal aging tests and the temperature of actual operating plants are evaluated from the investigation results of aging in actual operating plants (sampling inspection) and thermal aging characteristics at the minimum temperature in thermal aging tests.

c. When activation energy cannot be evaluated from the investigation results of aging in actual operating plants, 62.8 kJ/mol (15 kcal/mol) is used as a tentative value for the activation energy in the region between the minimum temperature in thermal aging tests and the temperature of actual operating plants.

(c) Condition of accelerated simultaneous aging equivalent to aging during normal operation is established by the technique of “superposition of time dependent data” or the technique of “same acceleration factor” (which has been verified to be equivalent to the former) based on the condition of actual operating plants.

(d) The withstand-voltage value (tentative) in JIS is used as a method for determination of integrity after LOCA test. In addition, this withstand voltage test should be carried out underwater.

Fig. 3.2-1 shows a comparison of the methods for cable integrity evaluation based on the outlines of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)” with the present evaluation (evaluation based on the Recommended Practice of IEEJ).

Fig. 3.2-2 also shows the method for the determination of test condition using the technique of “superposition of time dependent data”.

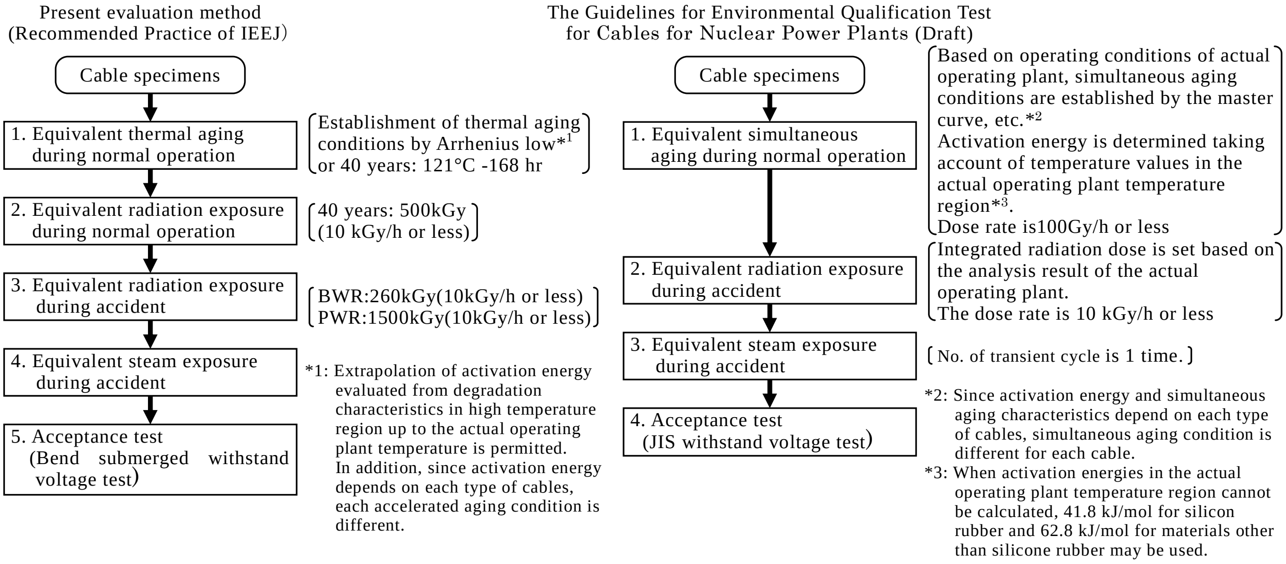
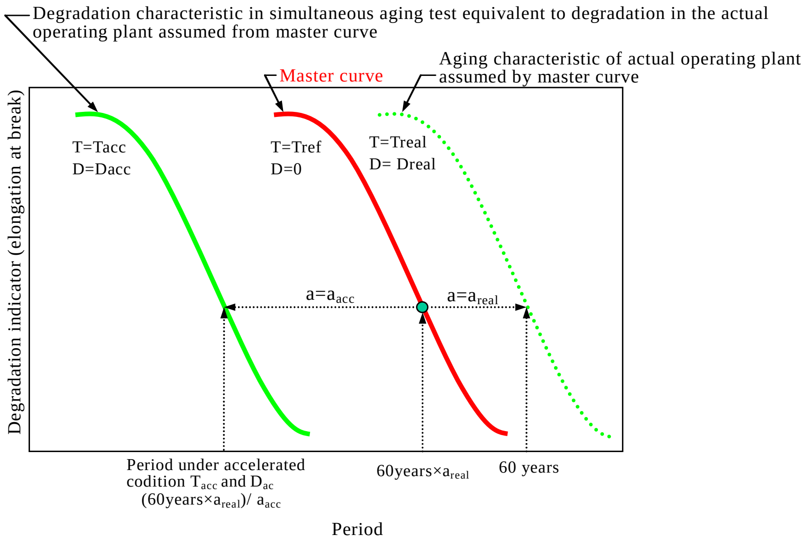


Fig 3.2-1 Comparison of evaluation methods of cable integrity



a : Shift factor

$$a_{real}=\exp\left[\frac{-E}{R}\left(\frac{1}{273+T_{real}}-\frac{1}{273+T_{ref}}\right)\right]\cdot\left[1+kD_{real}{}^{x}\exp\left[\frac{Ex}{R}\left(\frac{1}{273+T_{real}}-\frac{1}{273+T_{ref}}\right)\right]\right]$$

$$a_{acc}=\exp\left[\frac{-E}{R}\left(\frac{1}{273+T_{acc}}-\frac{1}{273+T_{ref}}\right)\right]\cdot\left[1+kD_{acc}{}^{x}\exp\left[\frac{Ex}{R}\left(\frac{1}{273+T_{acc}}-\frac{1}{273+T_{ref}}\right)\right]\right]$$

E : Activation energy, R :Gas constant
T_{ref} : Reference temperature
T_{real} : Environmental temperature of actual operating plant
D_{real} : Environmental dose rate of actual operating plant
T_{acc} : Test temperature, D_{acc} : Test dose rate
k , x : model parameter

Fig. 3.2-2 Determination of test condition by superposition of time dependent data

The determination of test conditions using “the superposition of time dependent data” shown in Fig. 3.2-2 requires an acquisition of almost the same simultaneous aging data as those acquired by this project, and will also require very large amounts of time and money.

On the other hand, “the technique of same acceleration factor” is used as a simple technique for determination of the same test conditions as those determined by use of “the superposition of time dependent data". The procedure of "the technique of same acceleration factor" is shown below. However, although determination of test conditions by use of "the superposition of time dependent data" makes it possible to produce test conditions of a combination of various temperatures with various dose rates, "the technique of same acceleration factor" differs in terms of being restricted to one radiation condition (dose rate) only to one temperature condition.

Method for determination of testing conditions by "the technique of same acceleration factor"

Testing conditions for t-years integrity evaluation under environmental conditions T_{real}, D_{real} of the actual operating plant can be obtained as follows, if test acceleration factor and activation energy are defined as a and E respectively.

If test temperature is defined as T_{exam}, thermal acceleration factor is

$$a = \exp\left[\frac{-E}{R}\left(\frac{1}{273+T_{exam}} - \frac{1}{273+T_{real}}\right)\right]$$

and test temperature, T_{exam}, is

$$T_{exam} = \frac{1}{\frac{1}{273+T_{real}} - \frac{R}{E}Ln(a)} - 273$$

In addition, test dose rate, D_{exam}, is $D_{exam} = D_{real} \times a$, and accelerated aging period, t_{exam}, is $t_{exam} = \frac{t}{a}$.

Also, when activation energies differ in actual operating plants temperature and the test temperature regions, if those activation energies are defined as E_{real} and E_{exam} respectively, test temperature, T_{exam}, is

$$T_{exam} = \frac{E_{exam}}{\frac{E_{real}}{273+T_{real}} + \frac{E_{exam}-E_{real}}{273+100} - RLn(a)} - 273$$

Where, test dose rate, D_{exam}, and accelerated aging period , t_{exam}, are the same as above.

The example of calculated testing conditions by the accelerated factor technique is shown below.

The activation energies in the ranges of 100 to 120°C (testing temperature is in this region) and of 100°C to actual operating plants temperature region are assumed as 104.7 kJ/mol (15 kcal/mol) and 62.8 kJ/mol (15 kcal/mol) respectively. Then, the testing conditions in 50°C- 0.5 Gy/h- 60 years can be calculated as below by use of the acceleration factor of 100.

$$T_{exam} = \frac{25}{\frac{15}{273+T_{real}} + \frac{25-15}{273+100} - 0.001986 \times Ln(100)} - 273 = 117\,^{\circ}\mathrm{C}$$

$$D_{exam}\text{=0.5x100=50Gy/h,} \quad t_{exam} = \frac{60 \times 365.25}{100} = 220 days$$

4. Tentative assessment of finished LOCA test cables

LOCA test of nine kinds of cable specimens as shown below was carried out by the first half of FY 2006:

- XLPE insulated cable made by A Company,
- XLPE insulated cable made by B Company,
- FR-XLPE insulated cable made by A Company,
- FR-XLPE insulated cable made by B Company,
- XLPE insulated triaxial cable made by C Company,
- EPR insulated cable made by C Company,
- FR-EPR insulated cable made by A Company,
- FR-EPR insulated cable made by B Company, and
- FR-EPR insulated cable made by C Company.

Among these, the EPR insulated cable made by C Company and the FR-EPR insulated cable made by C Company were not accepted because of the determination of their integrity in LOCA test. Accordingly, a tentative evaluation for the remaining seven kinds of cables was performed by using data acquired at present based on outlines of “the guideline for the environmental qualification test for cables (draft)”. In addition, for EPR insulated cable made by C Company and FR-EPR insulated cable made by C Company, LOCA test of mitigated pre-aging condition is scheduled to be carried out in FY 2007.

The pre-aging conditions of each specimen used for LOCA test have been transformed into the actual plant operating conditions, using the results at present of “superposition of time dependent data”. Those results are shown in Table 4-1.

Table 4-1 Evaluation of pre-aging conditions for cable specimens used for LOCA test

Cables for preliminary evaluation	The maximum pre-aging conditions for cable to have passed LOCA testing	Transformation of pre-aging conditions into actual plant operating conditions using the results at present of superposition of time dependent data
XLPE insulated cable made by A Company	100℃- 89.3 Gy/h- 805 hours	66℃- 0.5 Gy/h- 5.9 years 40℃- 0.04 Gy/h- 62 years
XLPE insulated cable made by B Company	100℃- 89.3 Gy/h- 805 hours	66℃- 0.5 Gy/h- 3.5 years 40℃- 0.0001 Gy/h- 60 years
FR-XLPE insulated cable made by A Company	100℃- 97.4 Gy/h- 2,500 hours	40℃- 0.1 Gy/h- 76 years 58℃- 0.001 Gy/h- 60 years
FR-XLPE insulated cable made by B Company	100℃- 97.4 Gy/h- 2,500 hours	40℃- 0.1 Gy/h- 64 years (white core) 54℃- 0.001 Gy/h- 61 years (white core)
XLPE insulated triaxial cable made by C Company	100℃- 98.9 Gy/h- 5,686 hours	50℃- 0.34 Gy/h- 66 years 56℃- 0.1 Gy/h- 61 years
FR-EPR insulated cable made by A Company	100℃- 96.1 Gy/h- 2,995 hours	66℃- 0.5 Gy/h- 5.0 years (red core) 66℃- 0.01 Gy/h- 5.2 years (red core) 32℃- 0.001 Gy/h- 63 years (red core)
FR-EPR insulated cable made by B Company	100℃- 94.7 Gy/h- 6,990 hours	66℃- 0.5 Gy/h- 26 years (white core) 66℃- 0.01 Gy/h- 60 years (white core) 60℃- 0.08 Gy/h- 60 years (white core)

Note: For EPR insulated cable made by C company and FR-EPR insulated cable made by C company, since they did not pass LOCA testing after pre-aging of 4,700 hours or 4,277 hours, they were out of evaluation here.

The tentative assessment of these cables was performed from the evaluation results at present of pre-aging conditions for the specimens used for LOCA test shown in Table 4-1. The tentative evaluation results are shown in Table 4-2.

As shown in Table 4-2, the tentative evaluation indicates that the integrity of some cables can be maintained even if taking into consideration 60 years or more of normal operation in the severest environment from where the cable concerned is used, and the DBE environmental conditions. However, there were some cables which would have difficulty to safely function during and following the DBE depending on the specific normal operating environment.

This evaluation was performed by conservatively considering the progress of degradation in the environment of actual operating plants, and the period when cable integrity is considered to be maintainable (including the DBE environment), is greatly changed by the operating environment. These should be sufficiently taken into consideration in the evaluation. Therefore, it is necessary to acquire the aging data of the cables used for long term in actual operating plants for this evaluation. Moreover, it is necessary to understand the environmental conditions to which the cables are installed accurately.

Table 4-2 Tentative evaluation of finished LOCA test cables

Cables for assessment	Tentative assessment
XLPE insulated cable made by A Company	If the design basis event is taken into consideration after use of cables in the environment considered to be the severest in BWR reactor containment vessel, cable integrity is maintainable only in a considerably short term of normal operation. In addition, when used in the mild environment, the integrity can be maintained even if 60 years or more normal operation and the design basis event are taken into consideration. → It is necessary to investigate the installed environment of the cable concerned and take replacement into consideration if needed.
XLPE insulated cable made by B Company	
FR-XLPE insulated cable made by A Company	The integrity is maintainable even if 60 years or more normal operation in the environment to be considered the severest in BWR reactor building and the design basis event are taken into consideration.
FR-XLPE insulated cable made by B Company	
XLPE insulated triaxial cable made by C Company	The integrity is maintainable even if 60 years or more normal operation in the environment to be considered the severest in PWR reactor containment vessel and the design basis event are taken into consideration.
FR-EPR insulated cable made by A Company	If the design basis event is taken into consideration after use of cables in the environment to be considered the severest in BWR reactor containment vessel, integrity is maintainable for considerable short duration. In addition, if the environment is mitigated, the period when the integrity can be maintained in consideration of the design basis event, will be prolonged. → It is necessary to investigate the installed environment of the cable concerned and take its replacement into consideration if needed.
FR-EPR insulated cable made by B Company	The pre-aging conditions for this test do not result in those corresponding to 60 years operation in the environment to be considered the severest in BWR reactor containment vessel. Therefore, 60 years integrity evaluation can not be performed taking account of the design basis event after use of cable. However, if the design basis event is taken into consideration after use in the environment to be considered the severest in BWR reactor containment vessel, the period when the integrity can be maintained will be 26 years. In addition, the integrity is maintainable even if 60 years normal operation and the design basis event are taken into consideration in the mitigated operating environment. → While investigating the installed environment of the cable concerned in the actual operating plant, testing for prolonged pre-aging period is necessary for evaluation of the integrity during more prolonged period in the environment to be considered the severest.

Note: For EPR insulated cable made by C Company and FR-EPR insulated cable made by C Company, since they did not pass LOCA test after pre-aging of 4,700 hours or 4,277 hours, they were out of tentative evaluation in the interim assessment.

VI. Conclusion

The project of “Assessment of Cable Aging for Nuclear Power Plants” was started on FY2002. At the end of the first half of FY2006, approximately 80% of the planned aging data has been acquired by the cable aging evaluation test. The LOCA test for nine kinds of cables was also conducted using the simultaneous aging specimens. In addition, an investigation of the applicability of four kinds of non-destructive degradation diagnostic technologies for cables has been executed for XLPE family and EPR family insulators. Furthermore, the interim assessment, based on these results, was implemented to obtain satisfactory results as planned.

Major results up to this time are as follows:

a. Progress of degradation may be significantly different among various manufacturers, even for the same kind of insulator.

b. There were some cables that indicated significantly rapid progress of degradation at low dose during simultaneous aging, and many other cables also indicated relatively rapid progress of degradation during simultaneous aging.

c. Activation energy values calculated from the thermal aging test data are smaller than those currently used. Furthermore, as a result of collation of sampling cables for actual operating plants with the results of the thermal aging tests, it is possible to suppose that the activation energy in the temperature region of actual operating plants would become even smaller. Based on these results, the principles of calculation and application were developed for the activation energy to be used for evaluation.

d. The technique of “superposition of time dependent data” is applicable to establish accelerated aging conditions of the cables corresponding to various actual operating plant conditions and to predict degradation of the cables used in actual operating plants.

e. Based on the results of investigation and tests, the outlines of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)” were developed.

f. A tentative assessment for seven kinds of cables used for the safety-related systems was made using data acquired at present based on “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants (Draft)”. According to this result, there were some cables that would have difficulty to maintain the safely functions during and following the DBE depending on the specific normal operating environment.

g. As a result of investigation of the applicability of non-destructive degradation diagnostic technique to actual operating plants, it was evaluated that the indenter was applicable to insulators of the XLPE family and the EPR family except insulators made by certain manufacturers.

The following activities are planned to continue for this project until FY2008. Further cable aging evaluation tests will be conducted to establish the cable aging evaluation technology based on the actual operating conditions including the actual aging for cables of nuclear power plants. These activities include to:

- Expand simultaneous thermal and radiation aging data and others,
- Verify the aging trends in actual operating plantss, and
- Review, as appropriate, the above interim assessment based on those results

In addition, a Final Report which compiles all the achievements of this project will be issued in FY2008. Furthermore, these final achievements would greatly contribute to commercial standardization of “The Guidelines for Environmental Qualification Test for Cables for Nuclear Power Plants”.

VII. Reference List

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Acknowledgements

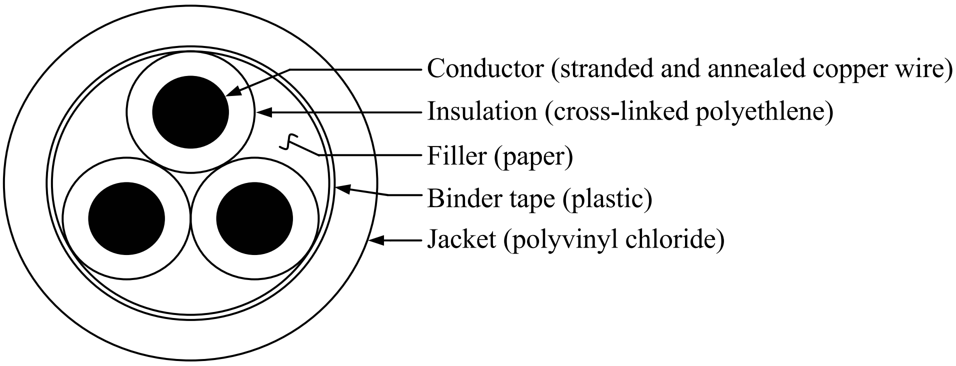
This project had been started in FY2002 and conducted planning, fabrication/preparation, test and assessment under the guidance of the Committee on the project of “Assessment of Cable Aging for Nuclear Power Plant” of the Japan Power Engineering and Inspection Corporation. After October, 2003, this project has been conducted by the Incorporated Administrative Agency Japan Nuclear Energy Safety Organization (JNES) with support of Materials Assessment Technical Review Committee (Cable Insulation Degradation Review Committee after November, 2006) and has performed planning, fabrication/preparation, test and assessment, and then has compiled the achievements. We, the staff engaged in this program are deeply grateful to the members in the above three committees.

We are also grateful to the many people who have implemented various works for preparations and tests relating to this project, and have provided beneficial advice for the compilation of this interim report

Appendix 1

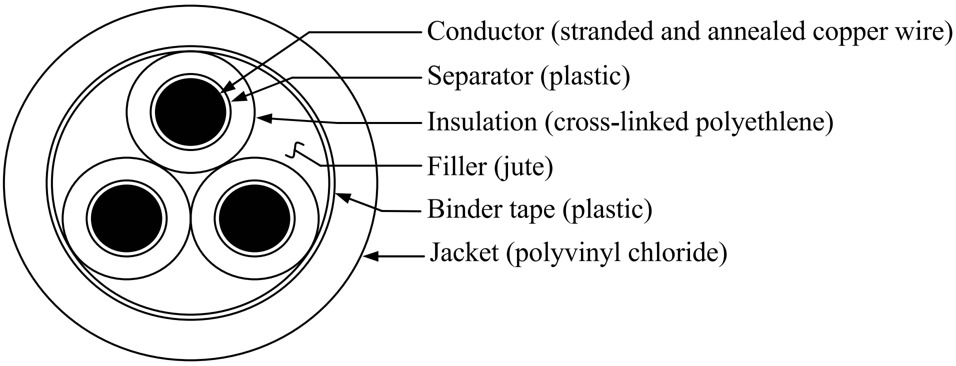
Construction of the Cable Specimens and Others

1. CV-2.0-A



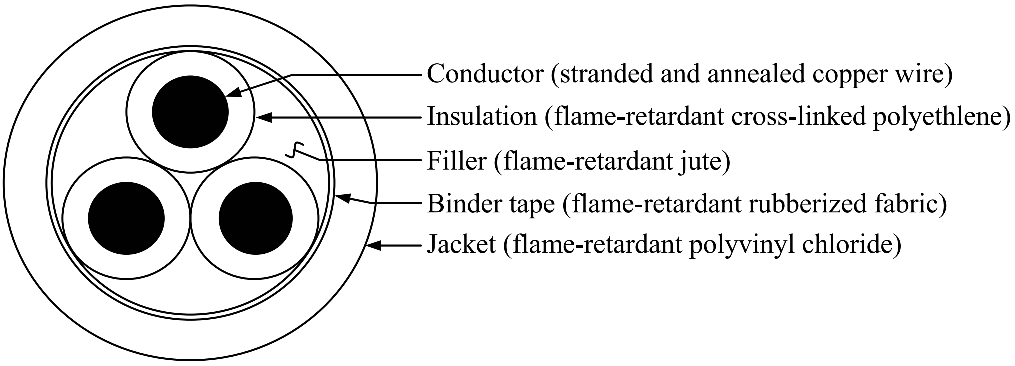
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	10.5	9.42	2500	1500	140

2. CV-2.0-B



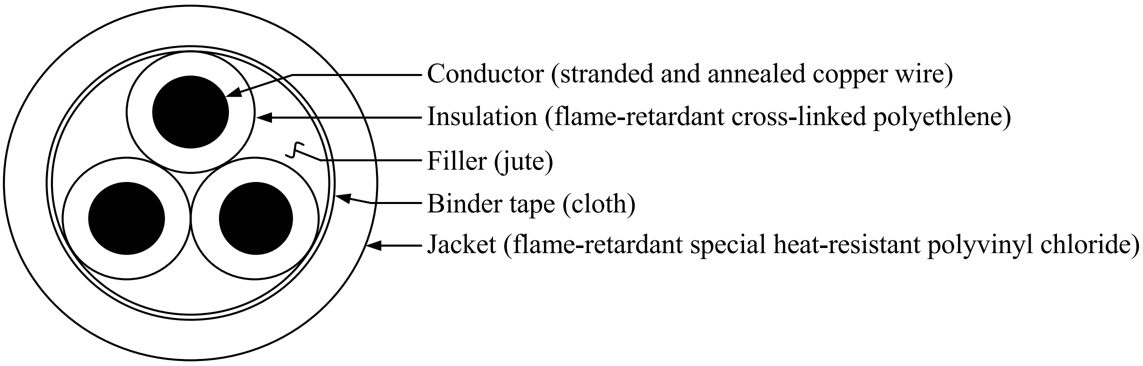
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. Of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	11.0	9.42	2500	1500	150

3. FR-CV-2.0-A



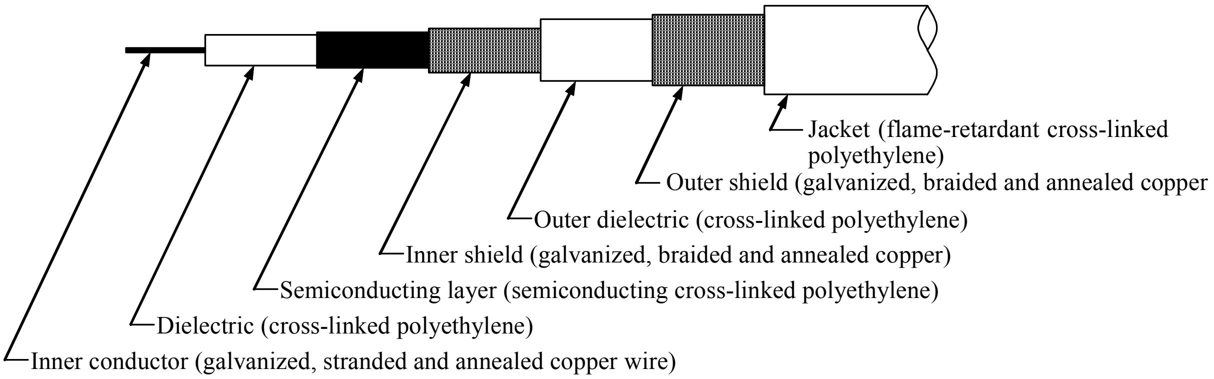
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. Of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	10.5	9.42	2500	1500	140

4. FR-CV-2.0-B



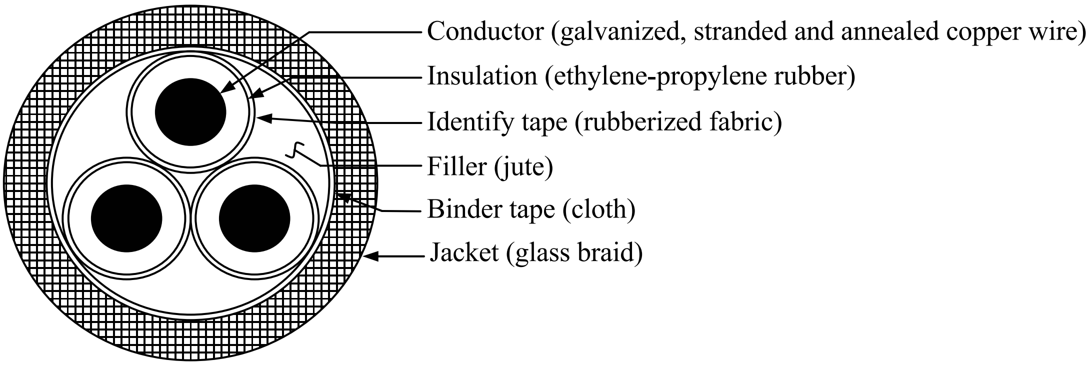
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. Of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	11.0	9.42	2500	1500	150

5. TRIAX



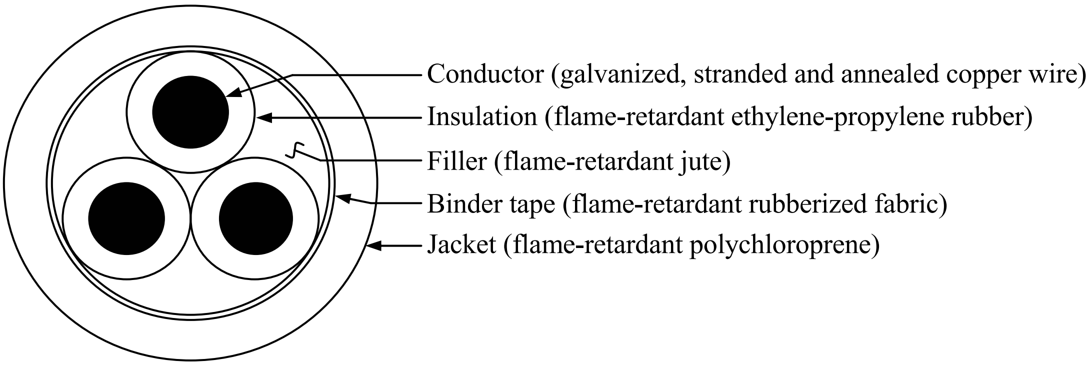
Outer dia. of inner conductor (approx.) mm	Outer dia. of dielectric (approx.) mm	Outer dia. of semiconduting layer (approx.) mm	Outer dia. of Inner shield (approx.) mm	Outer dia. of outer dirlectric (approx.) mm	Outer dia. of outer shield (approx.) mm	Overall dia. of cable (approx.) mm	Weight of completed cable (approx.) kg/km
1.14	6.94	7.24	8.14	9.4	10.3	11.7	190

6. PG-2.0



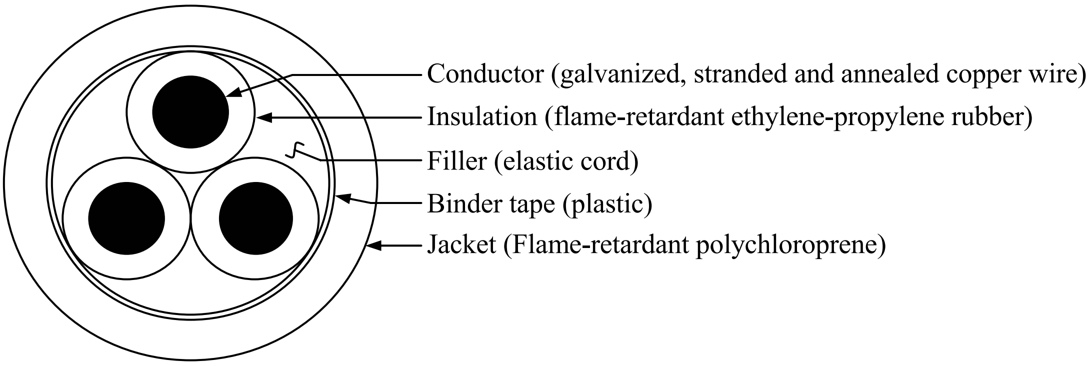
No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	1.8	0.8	1.0	11.0	9.82	500	1500	230

7. FR-PN-2.0-A



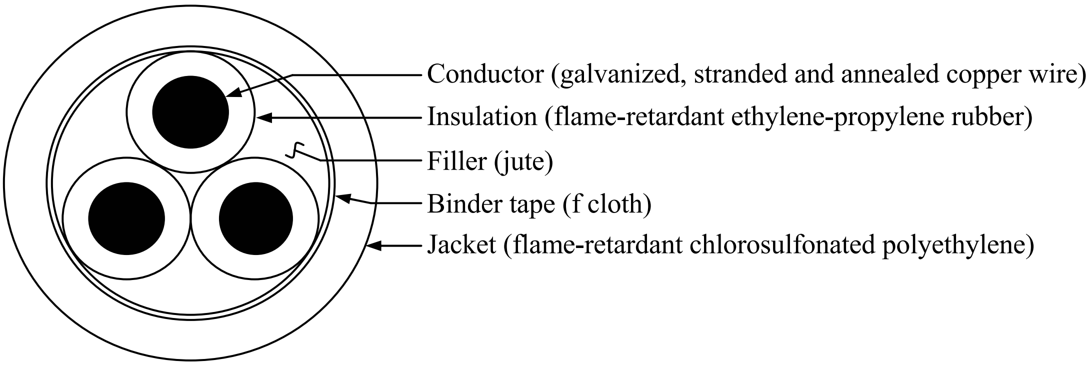
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. Of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm²	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	11.0	9.82	500	1500	175

8. FR-PN-2.0-B



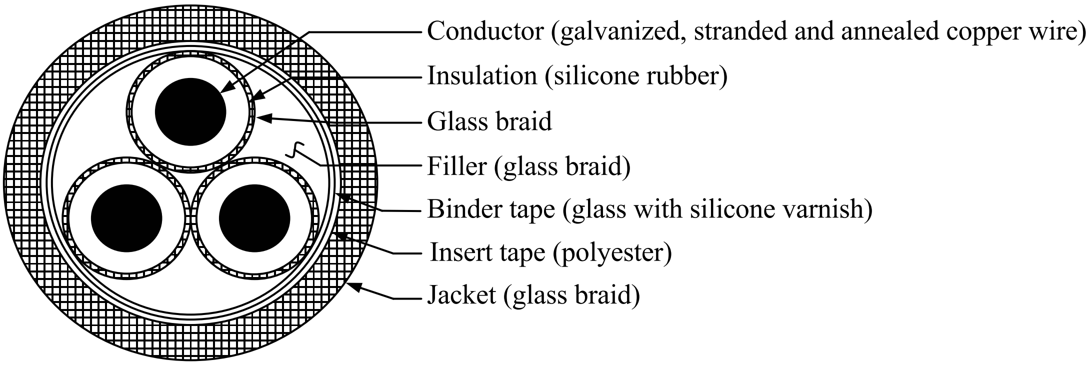
No. of core	Conductor			Thickness of insulation mm	Thickness of jacket mm	Overall dia. Of cable (approx.) mm	DC conductor resistance at 20 °C (max.) Ω/km	Insulation resistance at 20 °C (min.) MΩkm	AC test voltage V-1min.	Weight of completed cable (approx.) kg/km
	Size mm²	No. & dia. of each wire No./mm	Outer dia. (approx.) mm							
3	2.0	7/0.6	1.8	0.8	1.5	11.5	9.82	500	2000	180

9. FR-PH-2.0



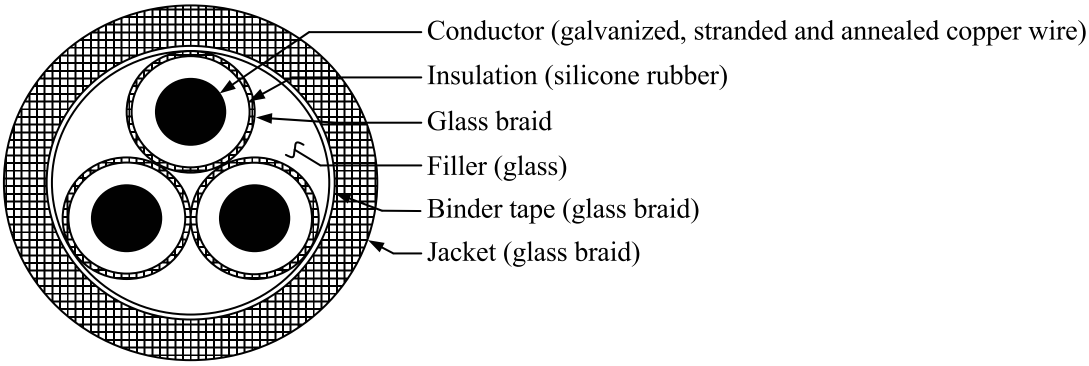
No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	2.4	0.8	1.5	11.5	9.82	500	1500	180

10. KBG-2.0-A



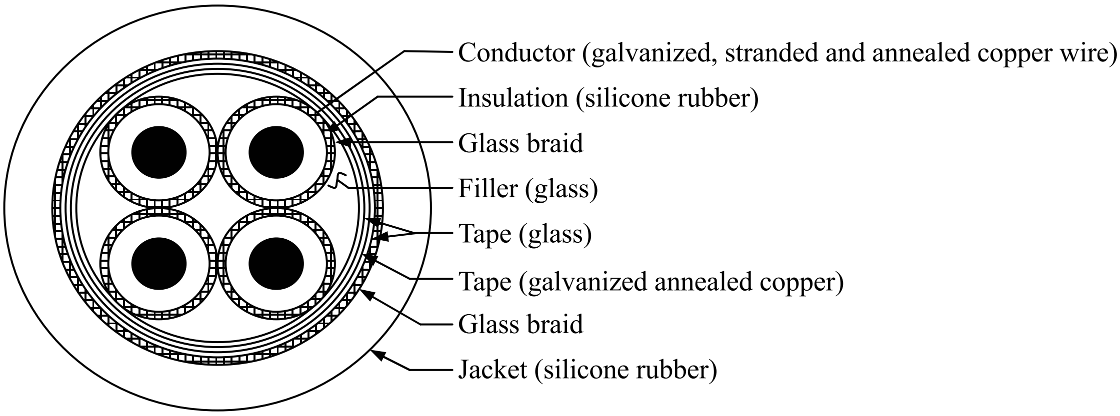
No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	1.8	1.1	0.7	11.5	9.82	100	1500	200

11. KGB-2.0-B



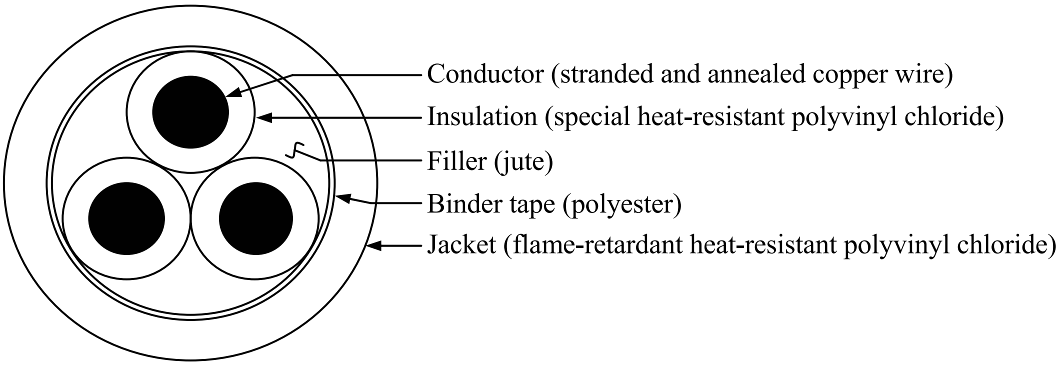
No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	1.8	1.1	0.7	10.5	9.82	100	1500	180

12. KK-1.25



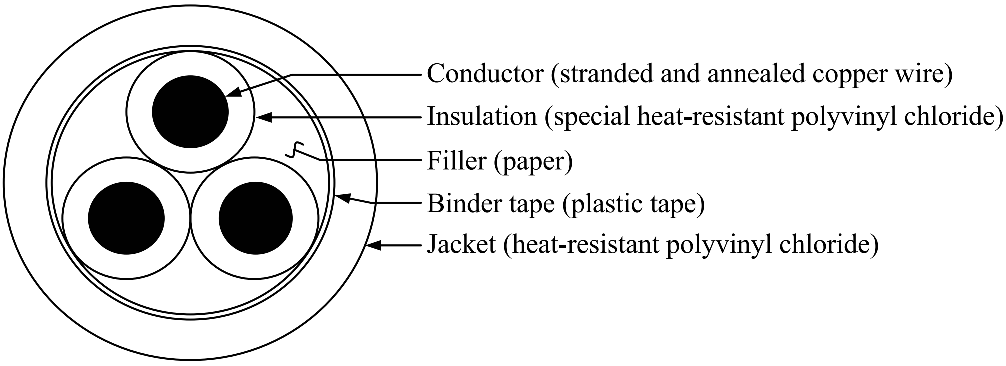
No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 15.6 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩ1000ft	V-5min.	kg/km
4	1.25	7/0.45	1.35	0.76	1.5	13.6	17.9	1500	1000	240

13. SHVV-2.0-A



No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	1.8	0.8	1.5	11.0	9.42	50	1500	160

8. FR-PN-2.0-B



No. of core	Conductor			Thickness of insulation	Thickness of jacket	Overall dia. Of cable (approx.)	DC conductor resistance at 20 °C (max.)	Insulation resistance at 20 °C (min.)	AC test voltage	Weight of completed cable (approx.)
	Size mm^2	No. & dia. of each wire No./mm	Outer dia. (approx.) mm	mm	mm	mm	Ω/km	MΩkm	V-1min.	kg/km
3	2.0	7/0.6	1.8	0.8	1.5	11.0	9.42	50	2000	160

Appendix 2

Specifications of the Thermostatic Oven to be Used for Fabrication of Thermal Aging Specimens

For the fabrication of thermal aging specimens to be used in the cable aging evaluation test, three kinds of ovens owned by the Mitsubishi Cable Industries, Ltd. which are shown in Attached Table 2-1.

Specifications of these ovens are shown in Attached Table 2-2 through 4.

Attached Table 2-1 Specifications of ovens to be used for fabrication of thermal aging specimens

Oven No.	Test Temp.	Manufacturer	Model	Remark
No.1	100°C	ESPEC Corp.	PVH-221	
No.2	110°C	ESPEC Corp.	PVH-221	
No.3	120°C	ESPEC Corp.	PVH-221M	on wheels
No.4	100°C	ESPEC Corp.	PVH-211	
No.5	110°C	ESPEC Corp.	PVH-211	
No.6	120°C	ESPEC Corp.	GPHH-200	
No.7	135°C	ESPEC Corp.	PVH-211	
No.8	155°C	ESPEC Corp.	PVH-211	
No.9	175°C	ESPEC Corp.	GPHH-200	
No.10	100°C	ESPEC Corp.	PVH-211	
No.11	110°C	ESPEC Corp.	GPHH-200	
No.12	120°C	ESPEC Corp.	GPHH-200	

Attached Table 2-2 Specifications of the model PVH-211

Item	Specification
1. Supply voltage	AC 200 V, 1 ph, 50/60 Hz
2. Power consumption	4.0 KVA
3. Inner dimension	600 W x 600 H x 600 D
4. Outside dimension	770 W x 1200 H x 925 D
5. Weight	165 kg
6. Ventilation	Forced internal air circulation
7. Performance	(Ambient temp.: 20°C, No lord, Circulative operation)
a. Temp. range	Ambient temp. + 20 to 300°C
b. Temp. span of adjustable range	± 0.2°C at +100°C to 200°C, ± 0.3°C at +300°C
c. Temp. distribution	± 1.0°C at +100°C, ± 2.0°C at +200°C, ± 3.0°C at +300°C
d. Time of temp. raise	Within 60 min. to ambient temp. + 300°C
8. Heater	Sheathed heater
9. Blower	Sirrocco fan of iron finished in heat-proof coating
10. Damper	Circulation/ Ventilation manual switching
11. Material of outer shell	Preserving cold-rolled steel melamine resin baking finish
12. Material of inward	Stainless steel sheet
13. Heat insulator	Glass wool

Attached Table 2-3 Specifications of the model PVH-221

Item	Specification
1. Supply voltage	AC 200 V, 3 ph, 50/60 Hz
2. Power consumption	5.8 KVA
3. Inner dimension	600 W x 900 H x 600 D
4. Outside dimension	770 W x 1500 H x 925 D
5. Weight	190 kg
6. Ventilation	Forced internal air circulation
7. Performance	(Ambient temp.: 20°C, No lord, Circulative operation)
a. Temp. range	Ambient temp. + 20 to 300°C
b. Temp. span of adjustable range	± 0.2°C at +100°C to 200°C, ± 0.3°C at +300°C
c. Temp. distribution	± 1.0°C at +100°C, ± 2.0°C at +200°C, ± 3.0°C at +300°C
d. Time of temp. raise	Within 60 min. to ambient temp. + 300°C
8. Heater	Sheathed heater
9. Blower	Sirrocco fan of iron finished in heat-proof coating
10. Damper	Circulation/ Ventilation manual switching
11. Material of outer shell	Preserving cold-rolled steel melamine resin baking finish
12. Material of inward	Stainless steel sheet
13. Heat insulator	Glass wool

Attached Table 2-1 Specifications of the model GPHH-200

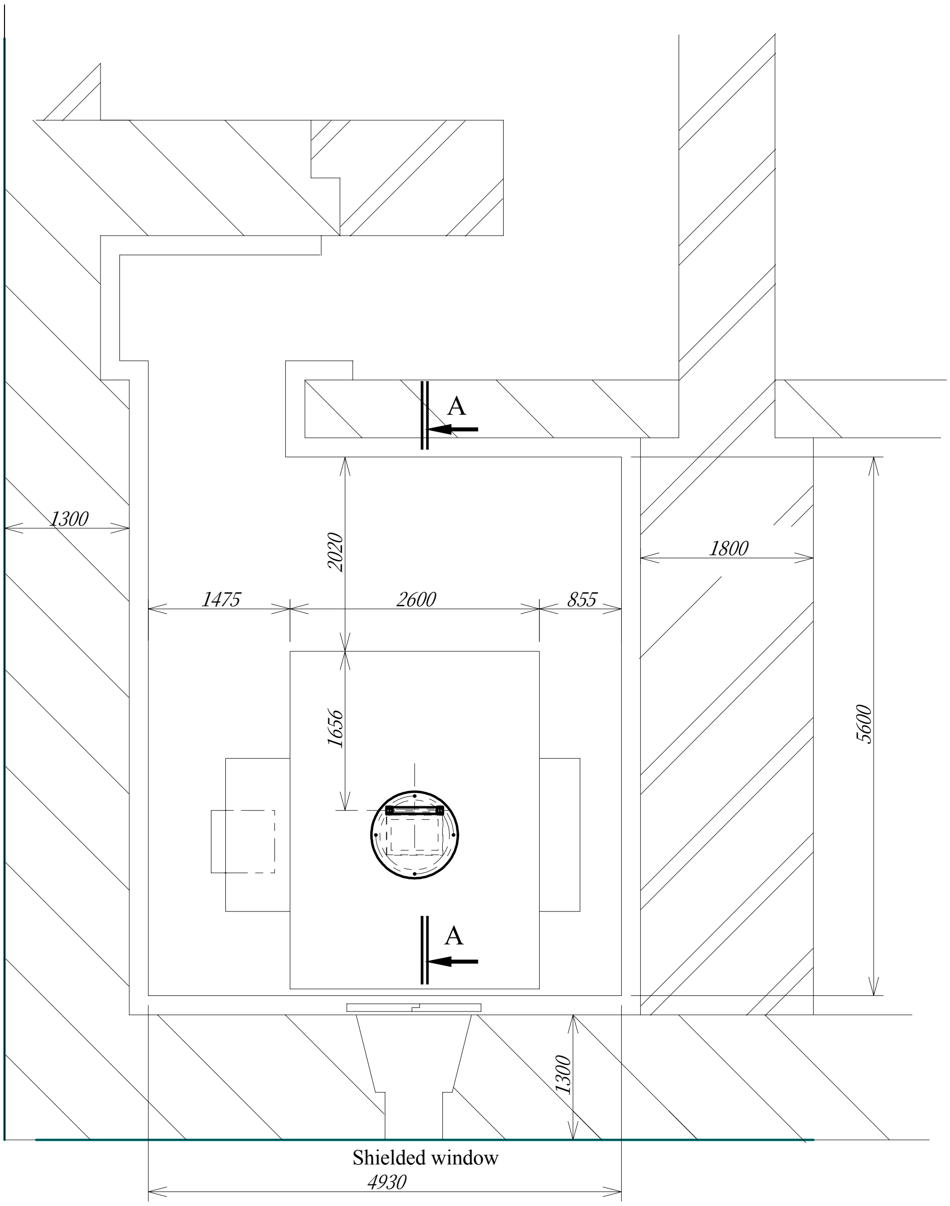
Item	Specification
1. Supply voltage	AC 200 V, 1ph, 50/60 Hz
2. Power consumption	3.8 KVA
3. Inner dimension	600 W x 600 H x 600 D
4. Outside dimension	1190 W x 970 H x 785 D
5. Weight	130 kg
6. Ventilation	Forced internal air circulation
7. Performance	(Ambient temp.: 20°C, No lord, Circulative operation)
a. Temp. range	Ambient temp. + 20 to 300°C
b. Temp. span of adjustable range	± 0.05°C at +100°C, ± 0.1°C at 200°C, ± 0.2°C at +300°C
c. Temp. distribution	± 0.5°C at +100°C, ± 1.5°C at +200°C, ± 2.5°C at +300°C
d. Time of temp. raise	Within 60 min. to ambient temp. + 300°C
8. Heater	Iron-chrome strip wire heater 3.6 kW
9. Blower	Stainless propeller fan 20W
10. Damper	Circulation/ Ventilation manual switching
11. Material of outer shell	Preserving cold-rolled steel melamine resin baking finish
12. Material of inward	Stainless steel sheet
13. Heat insulator	Glass wool

General Description of the Irradiation Facility to be Used for Fabrication of Simultaneous Aging Specimens

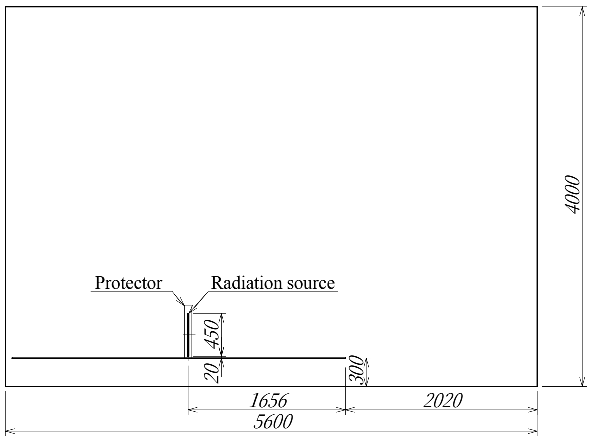
The No.3 irradiation facility of Takasaki Branch, Advanced Science Research Center of Incorporated Administrative Agency Japan Atomic Energy Agency was used for fabrication of simultaneous aging specimens for the cable aging evaluation test.

Specifications for the irradiation room are shown as follows:

(1) Geometry of the irradiation room: Refer Attached Figure 3-1
(2) Radiation source and its geometry: Rod shaped Cobalt 60 (1 cm diameter, 45 cm long)
(3) Source intensity: 5 x 105 Ci max.
(4) Management method of irradiation period: Irradiation time is integrated in the unit of minute by "Irradiation operational management system operation logger" currently installed in the control room.



Plan View



A-A Section

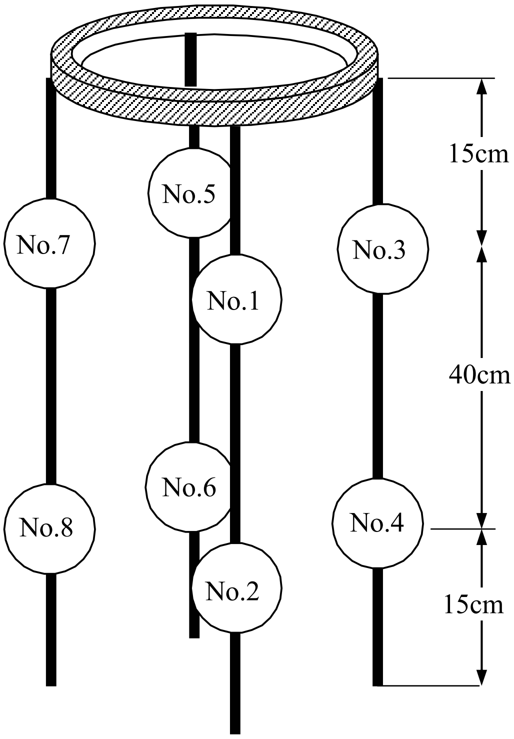
Attached Figure 3-1 No.3 Irradiation room, Quantum Beam Science Directorate, Takasaki of Japan Atomic Energy Agency

Appendix 4

Results of Dose Rate Adjustment

Attached Figure 4-1 shows the installed positions of Alanine dosimeters to be used for dose rate adjustment in the thermostatic oven.

The result of dose rate adjustment at the start of fabrication of specimens (November 6, 2003) is shown in Attached Table 4-1, result of the periodic dose rate adjustment on May 13, 2004 in Attached Table 4-2, result of the periodic dose rate adjustment on November 12, 2004 in Attached Table 4-3, result of dose rate adjustment associated with the dose rate change on March 25, 2005 in Attached Table 4-4, result of periodic dose rate adjustment on September 25, 2005 in Attached Table 4-5, result of dose rate adjustment associated with the dose rate change on December 15, 2005 in Attached Table 4-6 and result of periodic dose rate adjustment on August 10, 2006 in Attached Table 4-7 respectively.



Attached Figure 4-1 Position of dosimeters in the thermostatic oven at the dose rate adjustment

Attached Table 4-1 Result of adjustment of dose rate on November 6, 2003 at the start of fabrication

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	3.10	3.44	2.90	3.26	2.85	3.14	2.97	3.36	3.13
No.2	2.91	3.36	2.88	3.15	2.65	2.93	2.81	3.18	2.98
No.3	2.95	3.36	2.82	3.17	2.57	3.02	2.77	3.17	2.98
No.4	3.02	3.36	2.76	3.22	2.72	3.08	2.86	3.25	3.03
No.5	2.96	3.39	2.81	3.19	2.74	3.06	2.78	3.29	3.03
No.6	3.09	3.41	3.02	3.40	2.74	3.14	2.73	3.09	3.08
No.7	3.27	3.28	3.08	3.05	2.88	2.95	3.14	3.14	3.10
No.8	3.23	3.36	3.05	3.11	2.87	2.92	3.08	3.18	3.10
No.9	3.23	3.32	3.06	3.13	2.83	2.83	2.99	3.15	3.07
No.10	3.21	3.37	3.10	3.12	2.91	2.89	3.13	3.14	3.11
No.11	3.32	3.33	3.08	3.21	2.92	2.95	3.01	3.18	3.13
No.12	3.44	3.44	3.38	3.38	3.12	3.05	3.19	3.26	3.28
No.13-1	17.24	20.02	17.13	19.88	15.46	17.98	15.86	18.73	17.79
No.14-1	17.53	19.99	16.59	19.82	15.37	18.14	15.43	19.74	17.83
No.15-1	17.80	19.73	16.21	19.73	15.78	19.01	16.73	20.51	18.19
No.16-1	18.99	19.94	18.16	18.64	16.44	16.86	17.08	17.72	17.98
No.17-1	20.07	19.74	19.00	19.34	17.28	17.78	18.62	19.38	18.90
No.18-1	20.65	19.60	18.76	19.56	17.85	18.11	19.31	19.85	19.21

Attached Table 4-2 Result of the periodic dose rate adjustment on May 13, 2004

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.90	3.32	2.77	3.08	2.62	2.92	2.78	3.14	2.94
No.2	2.89	3.27	2.78	3.05	2.57	2.91	2.56	3.10	2.89
No.3	2.87	3.30	2.75	3.11	2.57	2.91	2.66	3.08	2.91
No.4	2.88	3.34	2.75	3.08	2.58	2.93	2.73	3.13	2.93
No.5	2.89	3.32	2.76	3.09	2.61	2.95	2.78	3.16	2.95
No.6	2.96	3.36	2.93	3.28	2.69	3.00	2.76	3.07	3.01
No.7	3.16	3.20	2.99	3.03	2.85	2.84	2.99	3.08	3.02
No.8	3.13	3.26	2.86	2.99	2.78	2.87	2.96	3.04	2.99
No.9	3.12	3.21	2.96	2.99	2.72	2.76	2.88	2.99	2.95
No.10	3.18	3.29	2.94	3.08	2.77	2.87	2.95	2.99	3.01
No.11	3.18	3.27	2.94	3.08	2.81	2.80	3.00	3.05	3.02
No.12	3.32	3.40	3.23	3.28	2.92	3.01	3.04	3.10	3.16
No.13-1	17.36	19.45	16.56	18.18	15.64	16.97	15.78	17.43	17.17
No.14-1	17.29	19.23	16.47	18.09	15.53	16.83	16.60	18.03	17.26
No.15-1	17.73	19.65	16.58	18.02	15.82	17.12	16.92	18.67	17.56
No.16-1	18.34	18.98	17.38	17.99	15.89	15.90	16.48	17.08	17.26
No.17-1	19.52	20.59	18.23	18.91	16.93	17.39	18.08	18.86	18.56
No.18-1	19.78	20.40	17.94	18.12	16.87	17.05	18.28	18.78	18.40

Attached Table 4-3 Result of the periodic dose rate adjustment on November 12, 2004

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.84	3.15	2.71	2.92	2.55	2.76	2.75	2.94	2.83
No.2	2.83	3.14	2.64	2.94	2.63	2.76	2.68	2.96	2.82
No.3	2.81	3.19	2.71	2.97	2.65	2.73	2.68	2.90	2.83
No.4	2.90	3.18	2.74	2.96	2.58	2.85	2.71	3.01	2.87
No.5	2.93	3.23	2.81	3.10	2.56	2.84	2.80	3.03	2.91
No.6	3.08	3.35	3.04	3.23	2.77	2.99	2.86	3.15	3.06
No.7	3.20	3.23	2.96	3.02	2.85	2.93	3.08	3.15	3.05
No.8	3.22	3.33	3.03	3.07	2.85	2.90	3.01	3.10	3.06
No.9	3.27	3.31	3.01	3.13	2.69	2.73	3.02	3.04	3.03
No.10	3.25	3.31	3.05	3.13	2.84	2.81	3.07	3.06	3.07
No.11	3.33	3.41	3.13	3.21	2.81	2.94	3.08	3.17	3.14
No.12	3.41	3.41	3.30	3.27	3.02	2.93	3.18	3.11	3.20
No.13-1	19.18	19.46	17.52	17.92	16.79	16.73	17.58	17.44	17.83
No.14-1	19.61	18.75	18.43	17.45	17.28	16.33	18.95	17.24	18.01
No.15-1	17.86	18.74	16.63	18.61	15.87	18.05	17.27	19.68	17.84
No.16-1	19.26	19.57	18.33	18.69	16.56	16.71	17.24	17.64	18.00
No.17-1	19.73	20.25	18.23	18.86	16.81	17.14	18.10	18.37	18.44
No.18-1	18.98	19.29	17.13	17.20	16.05	16.20	17.57	18.21	17.58

Attached Table 4-4 Result of dose rate adjustment associated with the dose rate change on March 25, 2005

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.84	3.16	2.64	2.90	2.76	3.08	3.22	3.39	3.00
No.2	2.93	3.03	2.78	2.89	2.72	2.86	2.87	3.09	2.90
No.3	3.33	3.44	3.14	3.19	2.96	2.95	3.00	3.07	3.14
No.4	3.32	3.39	3.05	3.04	2.92	2.88	3.15	3.19	3.12
No.5	3.08	3.20	3.09	3.20	2.80	2.98	2.85	2.97	3.02
No.6	2.97	2.93	3.18	3.13	3.07	3.09	3.13	3.16	3.08
No.7	3.23	2.96	2.92	2.83	2.66	2.75	3.32	2.95	2.95
No.8	3.08	3.08	2.77	2.81	2.67	2.68	2.92	2.92	2.87
No.9	3.36	3.41	3.07	3.10	2.85	2.91	3.08	3.04	3.10
No.10	3.36	3.35	3.04	2.94	2.79	2.85	3.09	3.10	3.07
No.11	3.38	3.32	3.25	3.20	2.83	2.76	2.98	2.95	3.08
No.12	3.01	2.67	2.90	2.76	2.86	2.76	3.15	3.03	2.89
No.13-2	102.86	113.84	99.77	108.80	91.03	99.16	94.37	103.68	101.69
No.14-2	101.90	113.58	95.15	106.59	87.92	99.09	94.44	105.13	100.47
No.15-2	105.33	113.59	98.03	104.56	87.71	98.85	86.99	96.02	98.89
No.16-2	110.25	113.47	105.70	107.24	95.55	95.87	99.58	107.05	104.34
No.17-2	110.77	112.57	101.24	102.38	91.30	92.39	102.49	103.22	102.05
No.18-2	108.55	112.93	98.63	99.71	90.60	92.73	85.78	90.47	97.42
No.19-1	100.59	114.79	93.40	105.24	89.77	102.44	96.81	109.39	101.55
No.20-1	113.04	104.44	109.57	95.46	100.09	85.03	111.71	97.97	102.16

Attached Table 4-5 Result of the periodic dose rate adjustment on September 15, 2005

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.76	2.85	2.62	2.70	2.65	2.75	3.09	3.12	2.82
No.2	3.19	3.23	2.88	2.92	2.83	2.84	2.95	3.02	2.98
No.3	3.39	3.19	3.03	3.08	2.84	2.79	2.90	3.02	3.03
No.4	3.19	3.22	2.78	2.81	2.78	2.90	3.08	3.08	2.98
No.5	3.11	3.20	2.99	3.03	2.76	2.78	2.84	2.93	2.95
No.6	2.96	2.90	3.30	3.19	2.98	2.91	2.83	2.95	3.00
No.7	2.79	3.00	2.78	2.78	2.82	2.66	3.30	2.95	2.89
No.8	3.39	3.35	2.95	2.94	2.76	2.80	3.15	3.13	3.06
No.9	3.23	3.21	2.95	3.04	2.62	2.73	2.87	2.94	2.95
No.10	3.11	3.14	2.85	2.81	2.60	2.71	2.91	3.00	2.89
No.11	3.39	3.37	3.33	3.23	2.88	2.83	3.00	2.89	3.11
No.12	3.07	2.76	3.09	2.68	2.88	2.62	3.06	2.85	2.88
No.13-2	100.55	114.53	91.61	103.40	87.92	99.64	93.00	103.44	99.26
No.14-2	100.90	114.93	94.30	109.40	88.91	101.99	93.40	110.19	101.75
No.15-2	104.13	114.26	92.42	103.01	89.82	99.41	93.54	100.29	99.61
No.16-2	112.91	114.18	102.70	104.97	94.62	96.40	103.01	106.11	104.36
No.17-2	111.51	114.56	102.83	100.49	94.54	96.36	101.71	102.49	103.06
No.18-2	108.58	114.18	100.92	103.69	92.16	92.98	88.12	90.23	98.86
No.19-1	100.55	114.83	92.81	103.30	89.47	101.55	96.74	109.28	101.07
No.20-1	112.18	113.67	103.01	102.07	92.90	94.00	104.77	103.08	103.21

Attached Table 4-6 Result of dose rate adjustment associated with the dose rate change on December 15, 2005

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.70	3.10	2.59	2.93	2.59	2.90	2.85	3.22	2.86
No.2	3.09	3.27	2.76	2.94	2.94	2.87	2.95	3.07	2.99
No.3	2.97	3.26	2.95	3.08	2.69	2.84	2.72	2.90	2.93
No.4	3.07	3.29	2.85	3.05	2.81	2.95	3.00	3.13	3.02
No.5	3.11	3.21	3.23	3.29	2.78	3.03	2.80	3.00	3.06
No.6	3.00	3.43	2.65	2.66	2.82	2.92	3.25	3.33	3.01
No.7	3.35	3.22	3.09	3.01	2.80	2.81	3.30	3.22	3.10
No.8	3.11	3.13	2.79	2.70	2.85	2.80	3.05	3.08	2.94
No.9	3.17	3.18	3.12	3.08	2.78	2.83	2.83	2.89	2.99
No.10	3.20	3.25	2.92	2.94	2.80	2.87	3.24	3.14	3.05
No.11	3.36	3.21	3.16	3.12	2.82	2.69	2.83	2.79	3.00
No.12	3.42	3.24	2.74	2.74	2.86	2.63	3.38	3.15	3.02
No.13-3	18.84	20.49	18.18	19.19	17.33	17.53	16.20	16.57	18.04
No.14-3	18.77	20.53	17.25	18.91	16.08	17.63	18.23	19.67	18.38
No.15-3	19.38	20.49	18.85	19.74	17.40	18.98	17.86	19.21	18.99
No.16-3	19.52	19.26	20.59	19.99	17.00	16.94	18.15	17.92	18.67
No.17-3	20.51	20.63	18.63	19.33	16.67	16.32	20.36	20.64	19.14
No.18-3	20.52	20.34	18.55	18.66	16.91	16.09	17.75	18.25	18.38
No.19-2	91.35	104.31	86.03	97.06	85.30	90.79	85.38	99.54	92.47
No.20-1	103.75	103.77	93.30	90.87	89.26	86.38	98.65	96.25	95.28

Attached Table 4-7 Result of the periodic dose rate adjustment on August 10, 2006

No. of oven	Dose rate at each measured position (Gy/h)								Average dose rate (Gy/h)
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	
No.1	2.88	3.31	2.70	3.00	2.62	2.96	3.04	3.38	2.99
No.2	3.24	3.45	2.84	2.96	2.79	2.98	2.83	3.16	3.03
No.3	2.97	3.21	2.90	3.20	2.67	2.86	2.68	2.96	2.93
No.4	3.13	3.32	2.84	2.97	2.75	2.91	2.92	3.18	3.00
No.5	3.13	3.32	3.13	3.28	2.84	2.92	2.83	2.96	3.05
No.6	2.97	3.40	2.56	2.86	2.78	3.21	3.06	3.44	3.03
No.7	3.43	3.18	3.17	3.07	2.97	2.87	3.45	3.30	3.18
No.8	3.24	3.20	2.85	2.85	2.75	2.75	3.05	3.02	2.96
No.9	3.21	3.25	3.09	3.07	2.78	2.79	2.88	2.95	3.00
No.10	3.18	3.28	3.05	3.00	2.82	2.85	3.19	3.20	3.07
No.11	3.19	3.02	3.06	3.02	2.61	2.70	2.78	2.76	2.89
No.12	3.39	3.27	3.40	3.26	2.86	2.76	2.84	2.59	3.04
No.13-3	18.90	20.47	18.42	20.70	16.76	18.45	16.98	18.72	18.67
No.14-3	20.13	20.41	17.77	18.98	17.20	18.42	18.91	20.61	19.05
No.15-3	17.71	20.50	18.66	20.54	17.35	19.27	17.44	19.69	18.90
No.16-3	20.08	20.30	19.41	19.77	17.78	17.79	17.66	17.63	18.80
No.17-3	20.61	20.70	18.24	18.49	16.80	17.23	18.40	18.91	18.67
No.18-3	20.62	20.15	19.50	19.56	17.84	17.59	18.12	18.55	18.00
No.19-3	100.88	107.82	97.25	104.11	91.00	93.59	91.15	94.47	97.53
No.20-2	100.86	98.65	102.90	97.35	97.00	87.68	104.01	93.80	97.78