Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Evaluation of Insulation Properties of Cables Used in Nuclear Power Plants

Background and Objective

In order to establish safe and stable operation of nuclear power plants, integrity evaluation methods are important for materials aged during their service operation under heat and radiation environments. In regards to the aging of polymeric insulating materials used for instrumental and control cables installed in containments, discrepancies between actual aging during the service operation and aging predicted using a conventional manner are reported[*1, 2]. The objective of the present study is to improve this conventional prediction method by considering several effects under normal plant operation conditions. Knowledge and information obtained in this study is anticipated to improve the lifetime evaluation, thus contributing to safe operation of nuclear power plants.

Main results

1 Aging trend of cable insulating materials during normal service operation and possible mechanism of material degradation

A statistical analysis was conducted for the data of elongation at break[*2] obtained for the service-used cable insulations. As a result, the aging trend in service is found to be approximately slower by half than that expected from acceleration aging test results (Fig. 1)[*3]. Such service-used cables were subjected to additional thermal aging[*4], which was induced by the wear-out approach[*5] (H14002). Obtained results were compared with the degradation behavior of corresponding control material subjected to acceleration aging (Fig. 2). The rate of degradation is three times slower than that predicted on the basis of an acceleration aging test in control samples. Instrumental analyses show that the unique slow dynamics in the service cables is considered to be due to oxidation control and cross-linking reaction[*5], which may be affected during the service duration. It follows that usage history such as low concentration environment in boiling water reactor containment is necessary to improve the aging prediction method.

2 Study on acceleration factor of acceleration aging tests

Acceleration aging tests for safety cables are implemented by combinations of heat and radiation. Therefore, it is important to accurately estimate the acceleration factors. Simultaneous applications of the two factors with high dose rates up to 1000 Gy/h were conducted against flame-retardant ethylene-propylene rubbers; where low dose rate acceleration tests of the corresponding material were already reported[*1]. Analytical parameters for the acceleration factor found only under low dose rate conditions were optimized to be explainable also for degradation behaviors under high dose rate radiations (Fig. 3). From such investigations, more conditions of accelerated aging tests become applicable to material aging estimation.

*1 Japan Nuclear Energy Safety Organization, JNES-SS-0903, 2009 (Assessment of Cable Aging for Nuclear Power Plant, ACA project).
*2 Y. Eguchi, presented at 2012 Equipment Qualification Technical Meeting, San Antonio, TX, 2012.
*3 N. Fuse et al., IEEE Trans. Dielectr. Electr. Insul., 21(5), 2012-2019, 2014.
*4 Additional thermal aging conditions were determined by considering the degradation level, which is equivalent to radiation aging.
*5 K.T. Gillen and M. Celina, Polym. Degrad. Stab., 71(1), 15-30, 2001.
*6 A chemical reaction that links one polymer chain to another. Generally, elasticity is lost due to the brittleness of rubber materials.

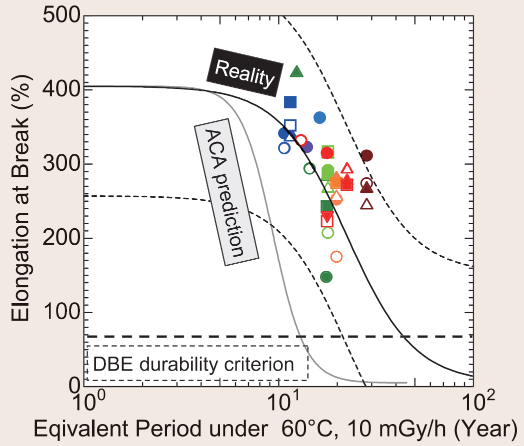

Fig. 1: Comparison of aging trend statistically analyzed for service-used cables (colored plots) and prediction (gray curve)

Data shift was conducted for statistical analysis using the superposition of time-dependent data procedure with activation energy of 19 kJ/mol. The black solid curve and the two broken curves represent fitted logistic curves and its 95.4% prediction band, respectively. The gray curve is a prediction from an acceleration aging test*1. DBE durability criterion is represented by the horizontal line.

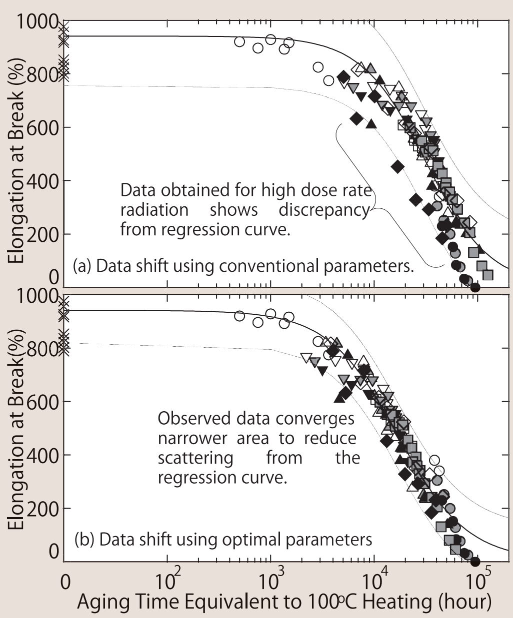

Fig. 3: Aging trend of elongation at break in frame retardant ethylene propylene rubbers

Data shift of aging time was conducted using analytical parameters of a conventional set (a) and those optimized in the present study (b). ×: before degradation. Other plots are obtained from acceleration aging test varying with dose rates, temperatures and degradation time (0-1050 Gy/h, 80-120°C, 0-42481 hours).

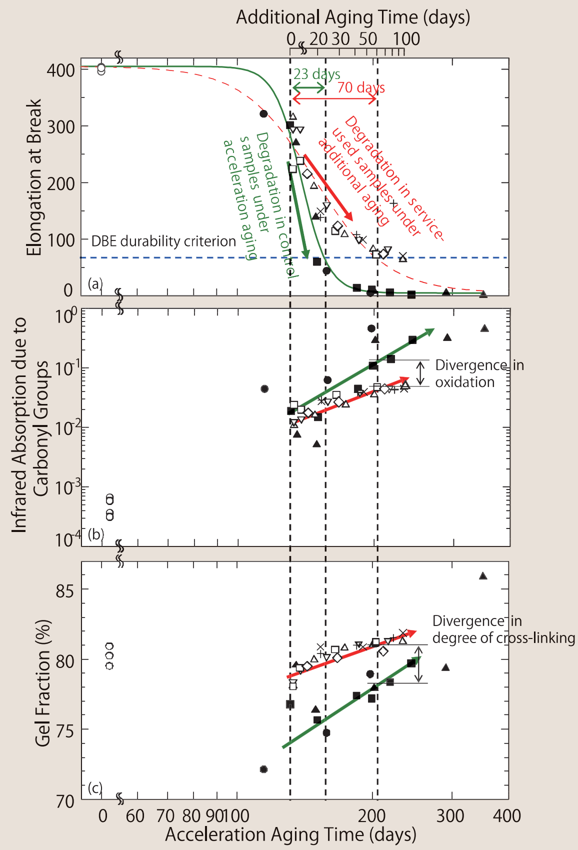

Fig. 2: Comparison of aging trend for control samples (solid symbols) and for the corresponding materials used for 16 years of service operation under BWR containment (open symbols)

Comparisons are shown for aging trends of elongation at break (a), carbonyl index (b), and gel fraction (c). Both acceleration aging for control samples and additional aging for service-used samples were conducted under the 110°C-thermal condition without radiation. Open circles represent initial value. Two curves in (a) are regression results using the logistic formula. Carbonyl index in (b) is absorbance at 1720 cm^{-1} normalized by that of 2920 cm^{-1}, measured by Fourier transform infrared spectroscopy.