Artificial aging – problems and solutions

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Objective of Artificial Aging

To bring the equipment in a condition equivalent to its condition at the end of the desired qualified life

Qualified life is the period of time under normal operational conditions when aging does not prevent satisfactory performance of the equipment during a subsequent DBE condition

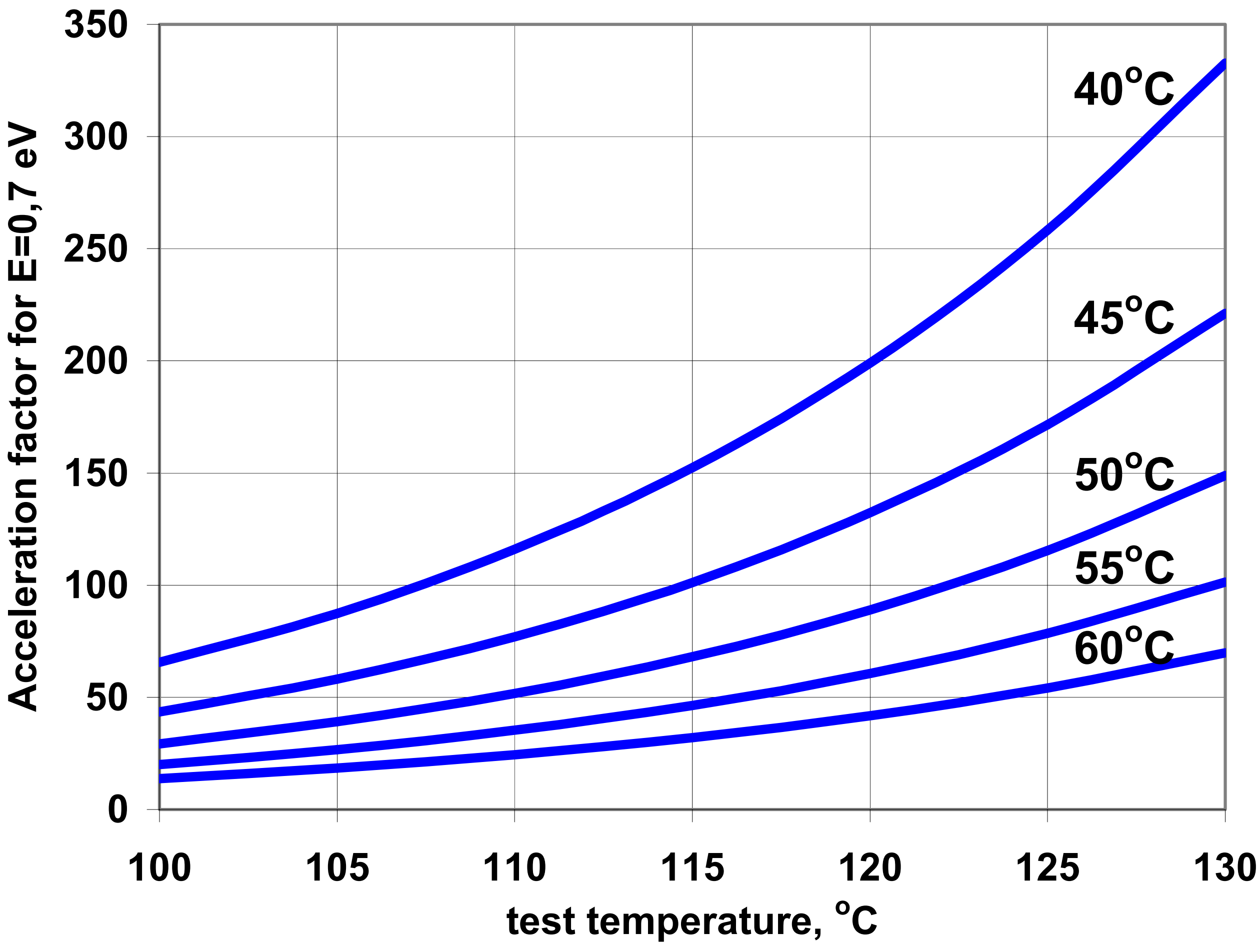
Acceleration factor

- Artificial aging is normally performed at elevated environmental conditions. The acceleration factor is the ratio between time to a certain degradation due to aging under operational conditions and the time to the same level of degradation due to aging under test conditions.

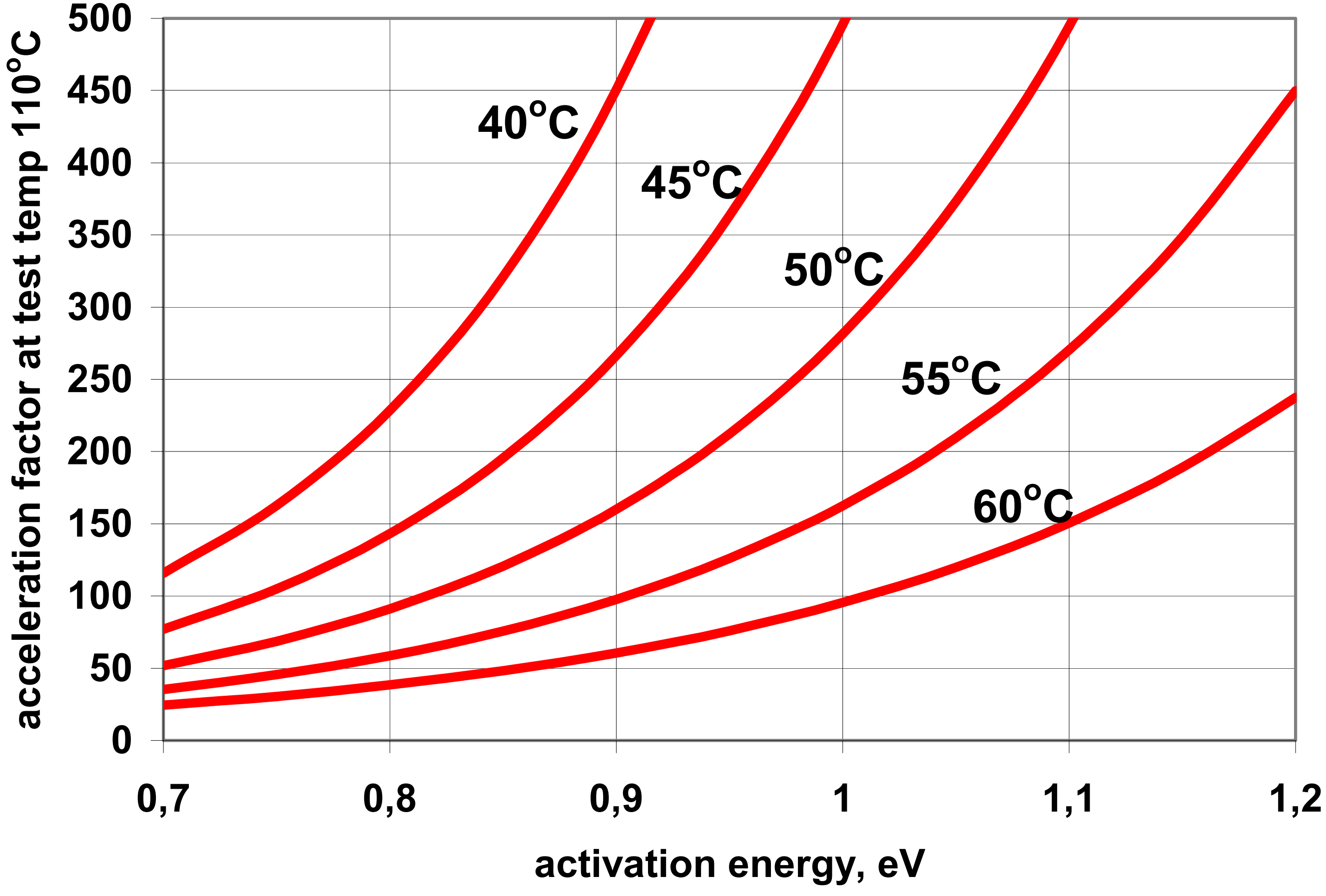
Uncertainties in qualified life determined from artificial aging

- Severities of environmental parameters during normal operation
- Material dependant characteristics of importance for design of artificial accelerated aging programmes, applied to equipment containing aging sensitive (organic) materials.
  - Activation energies (thermal aging). The equipment may also contain several organic materials with different activation energies.
  - The range of environmental severity for which the applied quantified aging laws are valid. For thermal aging, non-Arrhenius behaviour occurs if the temperature range extends above transition temperature (e.g. melting temperature).
  - Diffusion-limited oxidation if excessive dose rates and temperatures are used (the rate of oxygen diffusion is higher in amorphous materials – e.g. cross-linked polymers – than in crystalline materials – e.g. polyethylene with 90% crystalline degree)
  - Effects of simultaneous exposure to more than one environmental factor
- Number of test samples
- Test tolerances

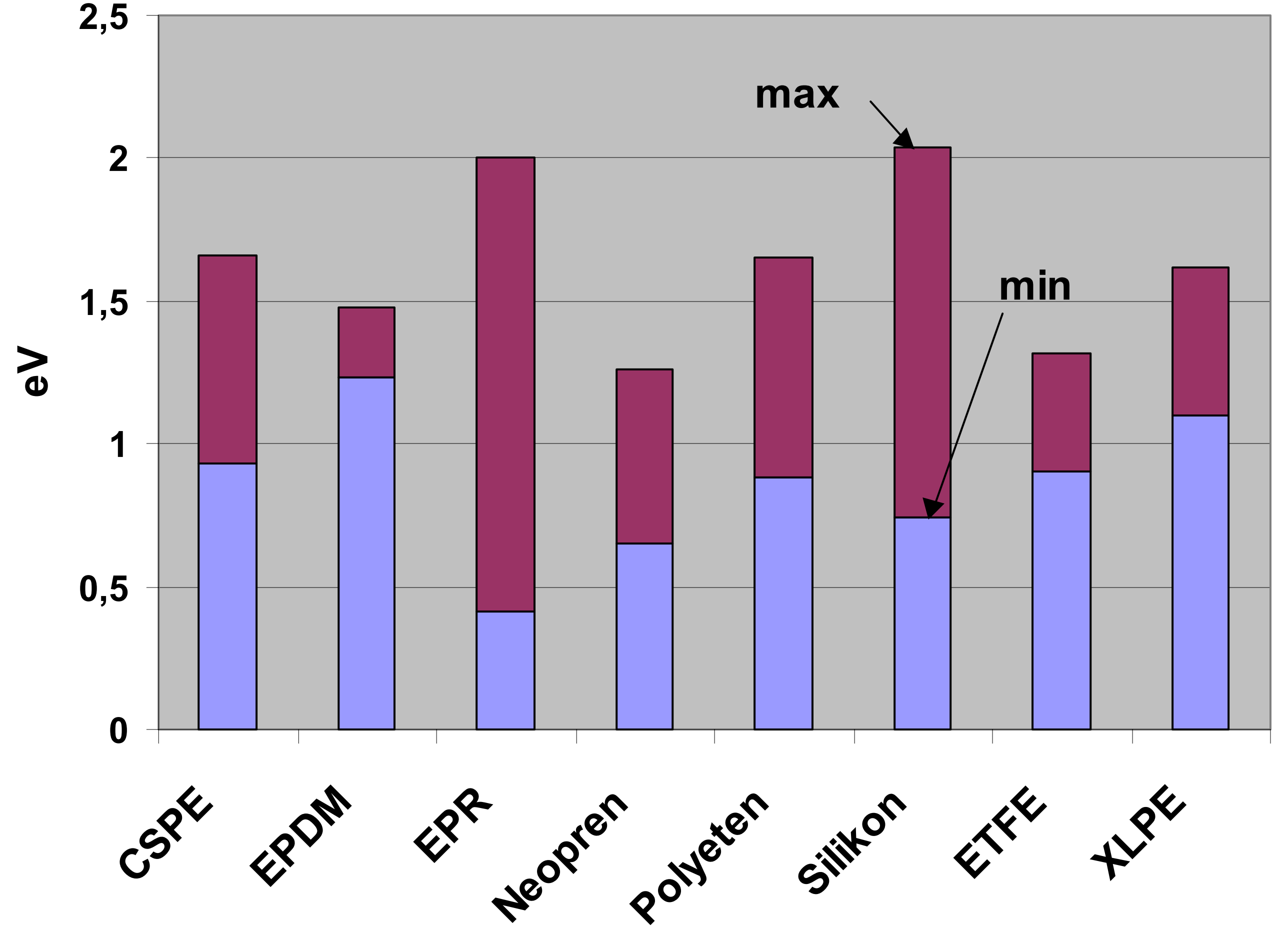
Artificial thermal aging. Acceleration factor, sensitivity to prediction of operational temperature



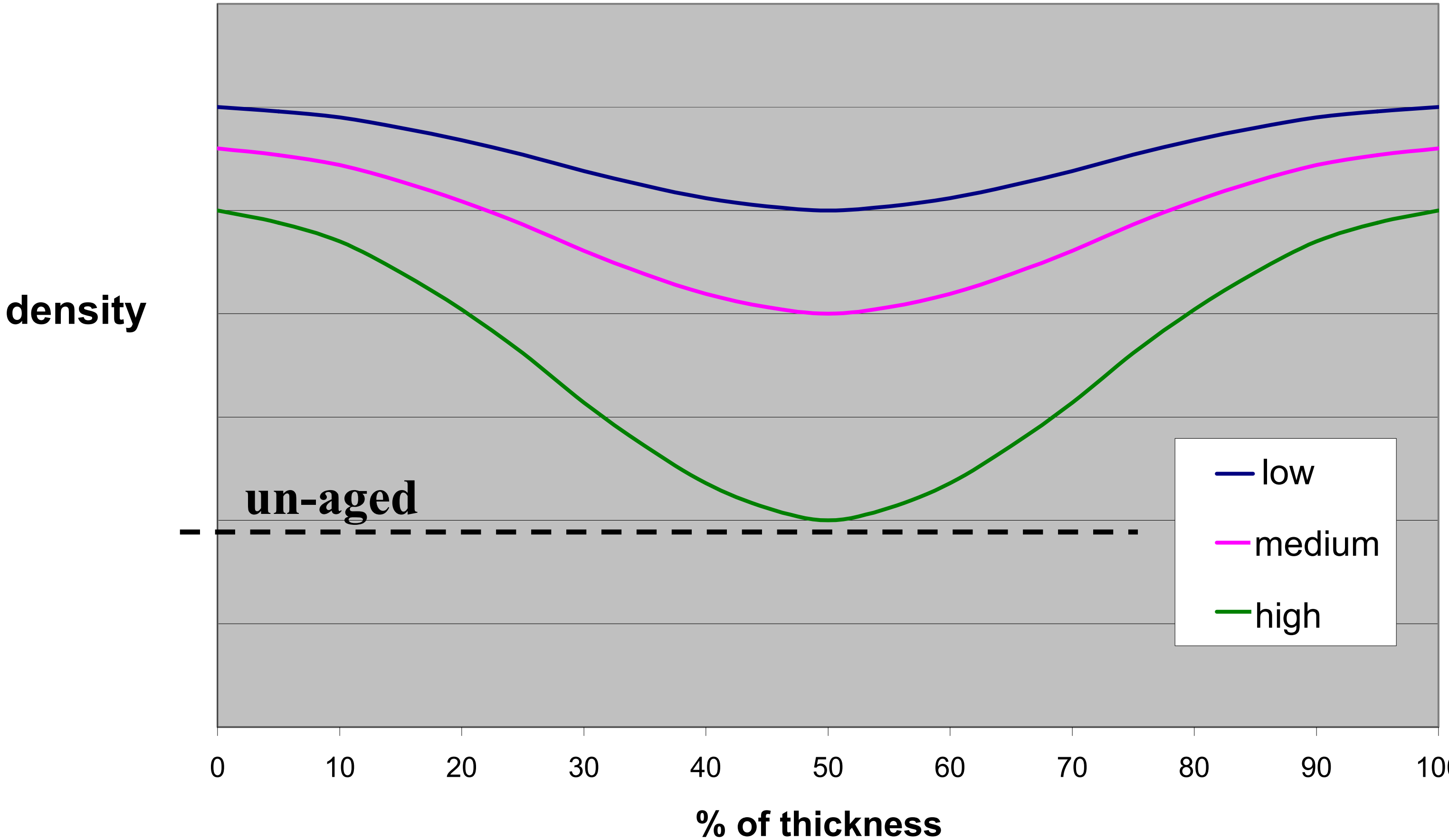
Artificial thermal aging. Acceleration factor, sensitivity to prediction of activation energy



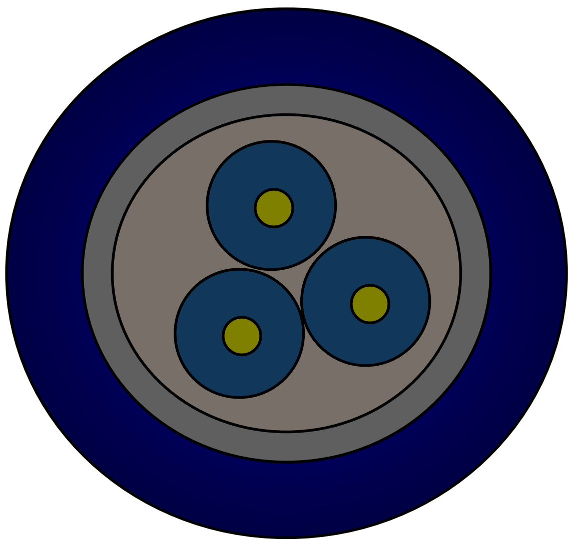
Areas of measured activation energies (EPRI report)



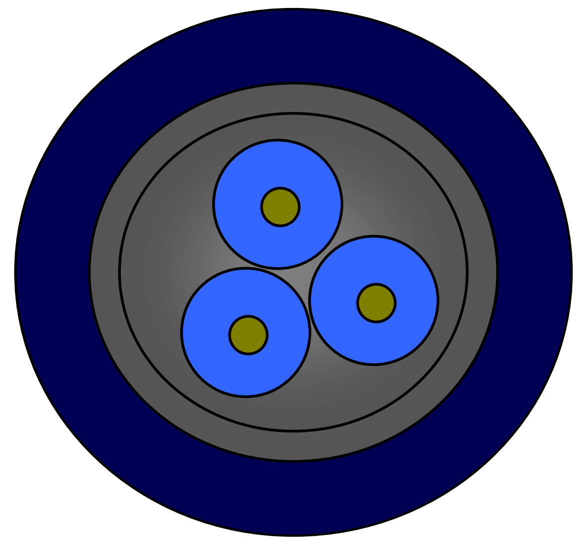
Influence of temperature or dose rate on oxidation



Possible effects of use of excessive temperatures or dose rates in accelerated ageing



Operational conditions



Test conditions

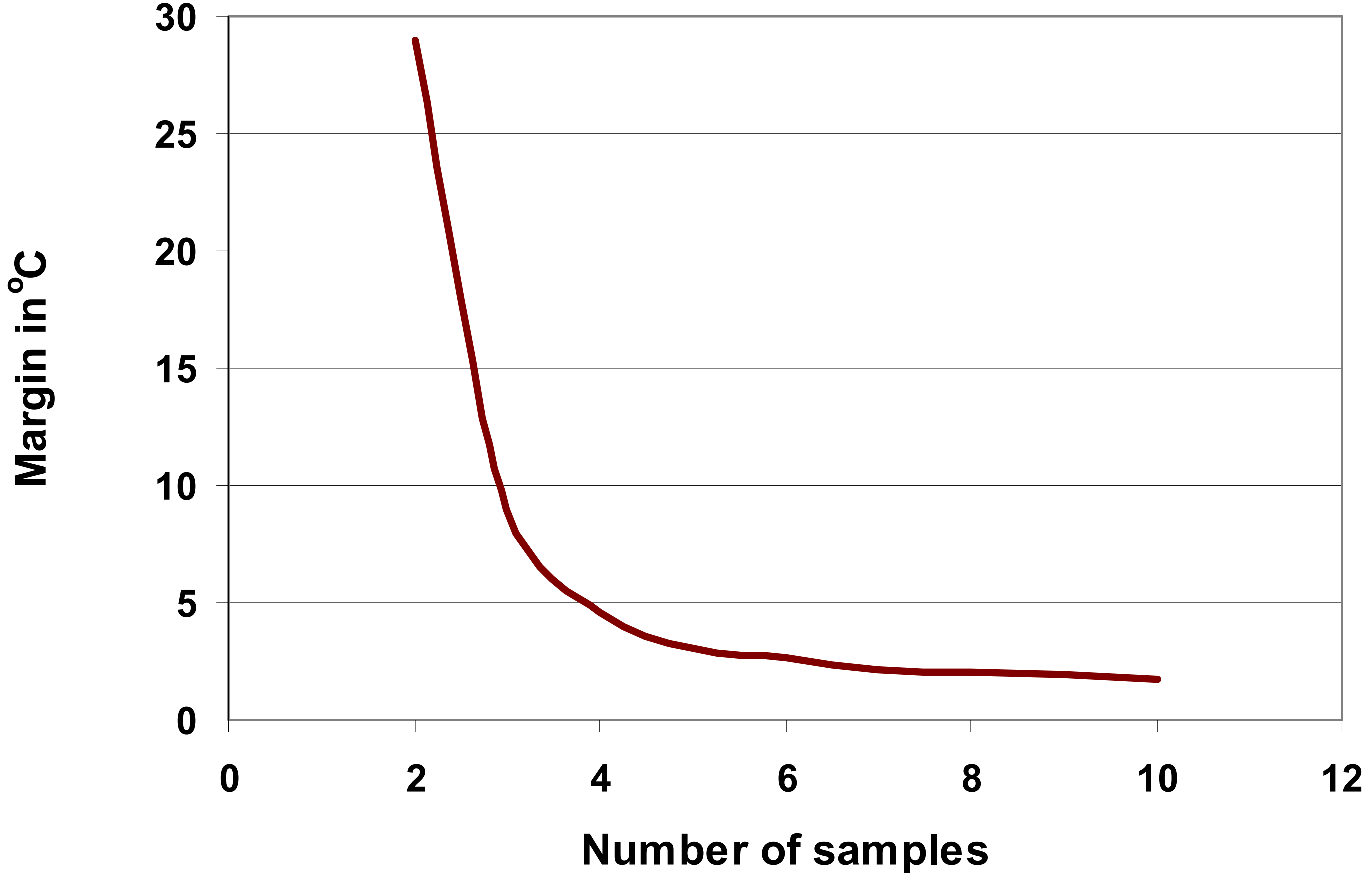
Aging in ionising radiation. Dose-rate effects Examples (should not be generalised!)

Material	*Dose-rate effect high/medium dose-rate*	*Dose-rate effect high/low dose-rate*
EPR/EPDM	small	Medium-large (3-8)
EVA	rather small	Very large (30)
XLPE	small	Medium-large (3-10)
SiR	medium (3)	Large (12)
Viton		Large
PEEK	small	Small

High dose-rate: 1-10 kGy/h
Medium dose-rate: 50-100 Gy/h
Low dose-rate: 0.3-2 Gy/h

Influence of number of test samples on needs for margin.

(From measurement of indenter modulus on CSPE cables aged at 120 °C during 48 days. 90% confidence)



Synergism (combination and sequences of environmental stresses)

Examples of possible synergism

- Ionising radiation - temperature
- Humidity - temperature
- Vibration-thermal ageing and/or ageing in ionising radiation

Synergism between thermal and humidity aging. Cable CSPE

			IR, Mohm for 1 m.	
Temp oC	Humidity %	Duration days	Before LOCA	During LOCA
95	low	48	99000	0,3564
95	low	96	119700	0,2700
95	low	192	103500	0,1107
95	low	384	105300	0,0558
95	>95	24	110700	0,0252
95	>95	48	99000	0,0234

IEC 60780 (1998) Nuclear power plants – Electrical equipment of the safety system – Qualification

- Describes the qualification process, methods for qualification and documentation. Includes methods for initial qualification (type testing) and methods for maintaining qualified status.
- Includes a comprehensive section (7 pages) on "Assessment of accelerated ageing"

IAEA TECDOC-1188 (2000) Assessment and management of ageing of major nuclear power plant components important to safety: In-containment instrumentation and control cables

- Very detailed description of the concept of management of the aging of components in NPP's, with special emphasis on cables. Discusses in detail methods for condition monitoring and ongoing qualification and evaluates their applicability, pros and cons.

IEEE 323 (2003) Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations

- The methods and procedures described are intended to be used for qualifying equipment (initial qualification or type testing), maintaining and extending qualification, and updating qualification.
- Qualified Condition is given as an alternative (or complement) to Qualified Life.

Qualified condition

- the level of degradation due to aging at which the equipment has been demonstrated to perform satisfactorily during a subsequent DBE test
- given as a CM indicator value, e.g. elongation-at-break

Attitudes to high acceleration factors in artificial thermal aging

IEC 60780

- ...attempts to achieve large accelerations contain significant risks of error.
- Accelerated ageing…cannot completely replace qualification by experience.

TECDOC-1188

- The formula for acceleration factor is only valid within a limited range of environmental severity.
- Diffusion-limited oxidation may result in overestimation of the acceleration factor calculated from artificial ageing in high temperature or at high dose rates
- The uncertainty in application of accelerated laboratory ageing rises with the deviation between actual and test conditions. It is generally recommended to use moderate acceleration factors in artificial ageing.

IEEE 323 (2003)

- Does not discuss possible risks of errors at use of high acceleration factors in thermal aging. Indicates that the duration of a thermal aging conditioning before DBE testing may be down to 4 days. Gives an option to substitute or complement qualified life by qualified condition.

SKI

- In case it is not convincingly shown that high acceleration factors can be used with high degree of confidence, the maximum acceleration factor that can be credited at thermal is 250.

Attitudes to high acceleration factors in artificial aging in ionizing radiation

IEC 60780

- When determining the whole radiation dose and dose rate, oxidation and gaseous diffusion effects should be taken into account. However, a high dose rate may be necessary, in order to perform the test in a reasonable time. It is always better to apply a total dose higher than the dose corresponding to the useful life, so as to obtain a margin taking all these elements into account.

TECDOC-1188

- For many insulation materials, the degradation due to a specific total radiation dose depends on the dose rate. Unless it has been proven by tests that the dose rate effect is negligible, it is recommended that the dose rate be limited in the artificial ageing test. Very low dose rates (20-30 Gy/h) have been found necessary for testing certain materials particularly sensitive to the dose rate.

IEEE 323 (2003)

- The dose rate for radiation aging should be as low as can be accommodated within reasonable cost and schedule.

SKI

- The dose rate shall not exceed 5 kGy/h and the total duration of conditioning in ionizing radiation shall be at least 10 days.

General trends in standards and guides

- Uncertainties in established qualified life from initial testing has traditionally been compensated primarily by a high degree of conservatism in selection of environmental severities and material characteristics (e.g. activation energies). The general trend in newly developed standards and guides is to promote follow-up activities (on-going qualification, condition monitoring, …). Development, standardization and validation of condition monitoring methods are subject to intensified studies.

- NEA/CSNI/R(2004)12 Research Efforts Related to Wire System Ageing in NEA Member Countries (OECD report) identifies environmental qualification as one of first priority near-time needs for collaborative research. It states that emphasis needs to be placed on condition-based demonstration of ongoing qualification.

”New” equipment, strategies for management of ageing

Initial qualification for desired qualified life, using extrapolation from artificial accelerated aging followed by DBE. For thermal aging, use measured or conservative activation energies. Preferably use moderate acceleration factors. High acceleration factors can be accepted if

- It is shown that the organic material parts of the equipment are not (or insignificantly) affected by diffusion-limited oxidation (example: PEEK).
- or
- The qualification is successively validated by introduction of a follow-up program, including condition monitoring for comparison with the condition for which the equipment has been shown to fulfil its functional requirements in DBE (qualified condition). If this is the case, also less conservative values on activation energies may be used in the initial qualification.
- The condition monitoring must be capable of measuring the condition of the organic material parts of importance to the safe function during Design Basis Event of the equipment, e.g. the conductor insulation of a cable, not only the cable jacket.

“New” equipment. Actions for enabling follow-up activities

- *At initial qualification*: Condition monitoring during and (especially) at the end of the ageing conditioning before DBE testing. The condition at the end of the ageing is <u>the qualified condition</u>.

The qualified condition can also be established afterwards by repeating the conditioning on new samples (<u>no need for DBE testing</u> since this has already been done)

Storage: store new samples in environmental controlled stores (should always be done)

Installation: Deposit samples for future use for condition monitoring or on-going qualification (if non-destructive CM can be used or installed equipment can be removed and substituted by stored equipment, this is optional)

Extension of qualified life by on-going qualification

– Assumes that spare samples were deposited at the time of installation in areas with environmental conditions equally or more severe than those for the installed equipment.

– In case the deposits are placed in areas with environmental conditions equally severe as those for the installed equipment, deposits are taken out when approaching the end of qualified life, and subjected to artificial aging for extension of qualified life, followed by DBE testing.

– In case the deposits are placed in areas with environmental conditions more severe than those for the installed equipment, the deposits can be submitted to DBE tests without accelerated artificial ageing. In this case the extension of the qualified life is determined from the difference in exposure between the locations of the deposits and the location of the installed equipment.

“Old” equipment. Updating or extending qualification.

- In the initial qualification a high degree of conservatism has normally been applied in order to take into account limitations in knowledge of parameters important for the establishment of qualified life as well as limitations in the applicability of formulas used for calculation of qualified life from accelerated aging. The conservatism applied may
- be overconservative, meaning that the real qualified life is much longer than the qualified life. This is probably the most common case.
- not be enough conservative. For some materials, dose-rate effects and similar effects of excessive heat is very large and a very high degree of conservatism is needed for compensating risks inherited in application of high acceleration factors.
- It can be very difficult to define what is a “safe” degree of conservatism in artificial aging and establishment of qualified life.
- A follow up program after installation is the safest way of reducing the uncertainties and will in most cases justify an installed life longer than the originally established qualified life.

Follow up of qualified life: Updating of environmental conditions.

- Measurement of environmental conditions for the equipment during normal operation

Follow up of qualified life: Updating and validation of activation energies used

- If spare equipment are available: perform measurements of activation energies on the organic materials forming part of the equipment that are important for the functional capabilities.
- Use sensitive degradation measurement parameters so that the activation energies can be measured at moderate temperatures, preferably below the temperatures used for aging conditioning.

Follow up of qualified life: Acceleration factors

- Investigate the importance of diffusion-limited oxidation and other possible effects of use of excessive acceleration of thermal aging and/or conditions of aging in ionising radiation for organic parts of the equipment that are important for the functional capabilities.

Alternative: Follow up of qualified condition

- If qualified condition is used instead of qualified life for verification there is no dependence in qualification on uncertain parameters such as activation energies, dose-rate effects, applicability of formulas for determining qualified life from accelerated aging, etc.
- In this case, qualified life is possibly still calculated in order to have an estimate of the time the equipment can be expected (but not ascertained) to remain in a qualified condition.

Updating of qualified condition

– If new (or insignificantly aged) equipment is available, the development of the condition in the initial test can be reproduced by repeating the aging made in the initial qualification test and measuring the condition. The condition at the end of the aging is the qualified condition.

Conclusions (or remarks)

- It is important to close the gaps between different international and national standards and guidelines on management of aging of safety related equipment. This will reduce needs for additional testing in order to adapt to a certain country's specific demands and reduce the costs for purchase and installation of equipment.

  A triple standard IEC-IEEE-CENELEC covering the subjects and scopes of IEEE 323/IEC 60780 would be a good solution!

- Always store spare samples of equipment, identical to installed safety related equipment, in environmentally controlled stores. They will be very useful sooner or later in follow up activities!

- Condition monitoring is of great value as a tool for management of aging of equipment containing materials sensitive to aging and where the sensitive materials are accessible. Existing methods need to be further developed and standardized.