EQSA

Equipment Qualification Services Alliance

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LOCA for I&C

Daniel Martín
Tecnatom

Road Map

- Tecnatom Introduction
- Brief Introduction to EQ (DBE)
- DBE post-DBE thermodynamic simulation tests
- Capabilities
- Experience and customers

About us

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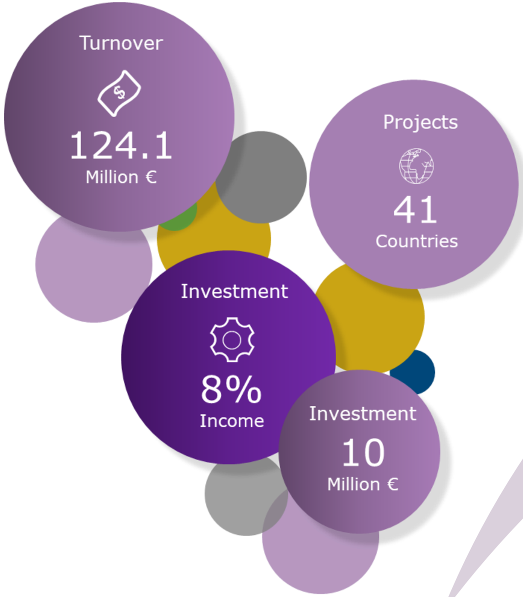

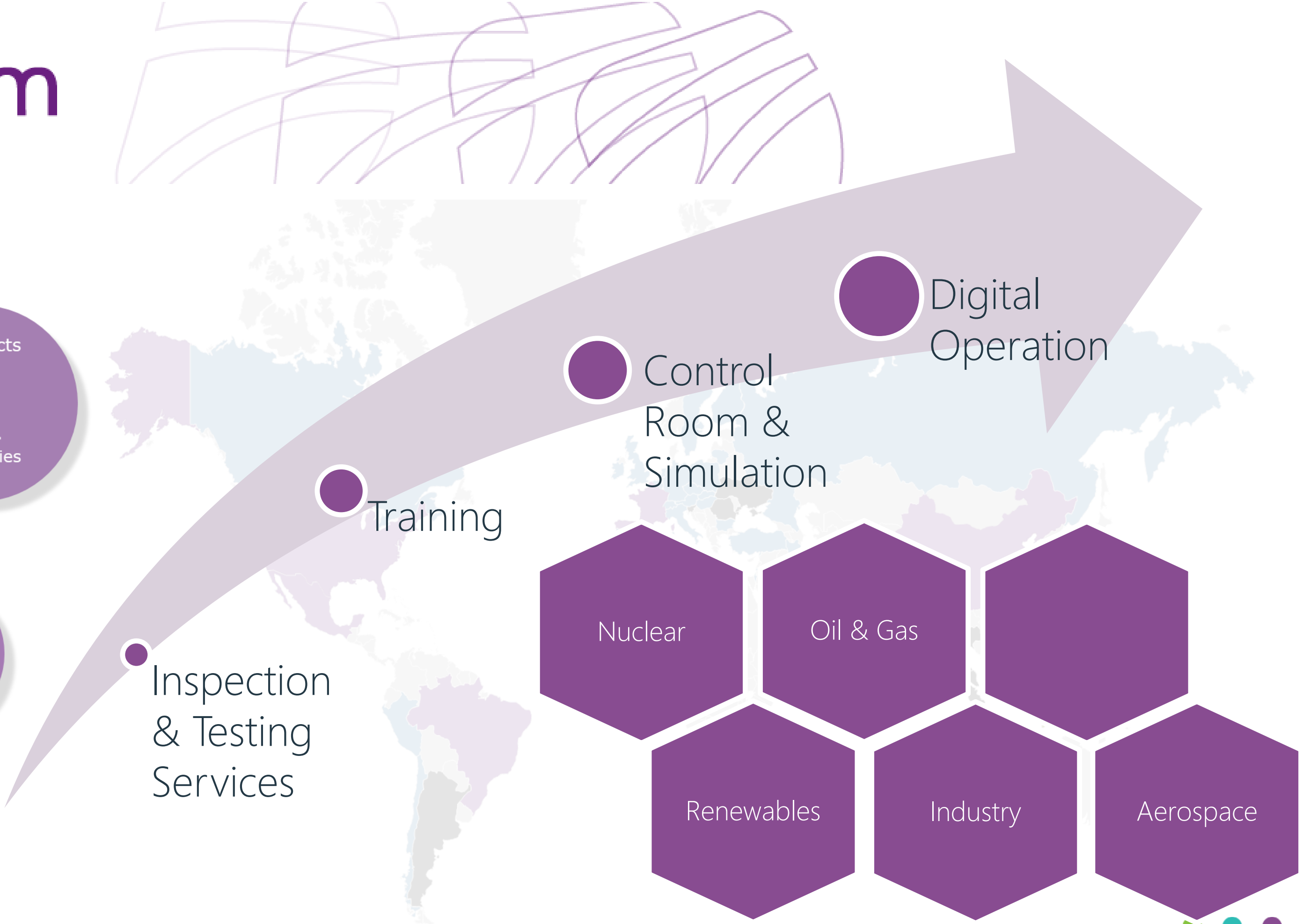

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Brief Introduction to EQ (DBE)

Brief Introduction to EQ (DBE)

Introduction

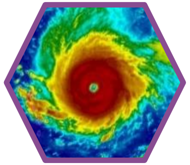
- The aim of the Equipment Qualification (EQ) is the generation and maintenance of a technical evidence to demonstrate, with reasonable assurance, that a safety-related equipment will operate properly on demand to meet the system performance requirements, maintaining its safety function(s) under the expected environmental conditions.

- Manufacturers and users of safety-related equipment are required to provide assurance that this equipment will meet its operating requirements throughout its qualified life.

Brief Introduction to EQ (DBE)

Definitions

- Design Basis Event (DBE): is a postulated event used in the design to establish the acceptable performance requirements of the structures, systems and components.
- Design Basis Accident (DBA): is a postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to ensure public health and safety (i.e., LOCA, MSLB…).
- Beyond Design Basis Accident (BDBA): this term is used as a technical way to discuss accident sequences that are possible but were not fully considered in the design process because they were judged to be too unlikely, they are considered beyond the scope of design-basis accidents that a nuclear facility must be designed and built to withstand (i.e., extended station black out, extreme natural hazards, severe accident).



i.e. tornado, fire, flood, explosion earthquake…

Three Mile Island and Chernobyl nuclear disaster

Fukushima nuclear disaster

DBE and post-DBE thermodynamic simulation tests

DBE and post-DBE thermodynamic simulation tests

During the EQ process, the Design Basis Events (DBE) in which the Class 1E equipment must perform its safety function(s) without experiencing common-cause failures before, during and after, must be established, i.e.,

- LOCA: loss-of-coolant accident
- HELB: high-energy line break
- MSLB: main steam line break

The equipment shall be tested for the duration of its operational performance requirement for each applicable DBE condition, including any required post design basis event operability period.

DBE and post-DBE thermodynamic simulation tests

DBE Thermodynamic simulation test

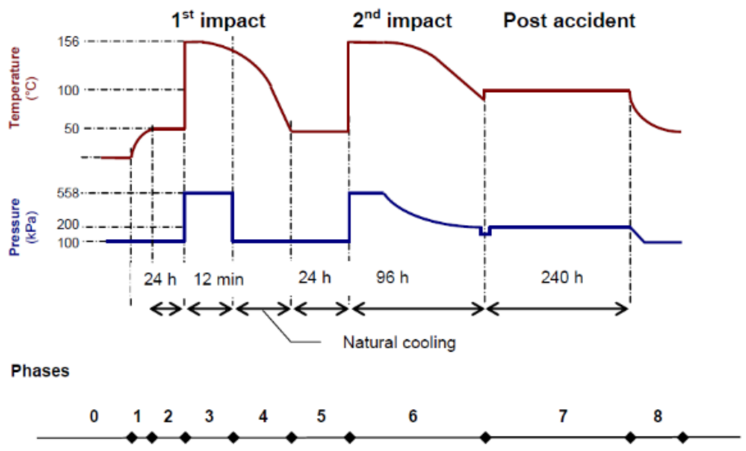
For each DBA, the accident profiles must be defined for the thermodynamic accident simulation test, including the following parameters and test times:

- Temperature
- Pressure
- Humidity
- Chemical spray (if applies)

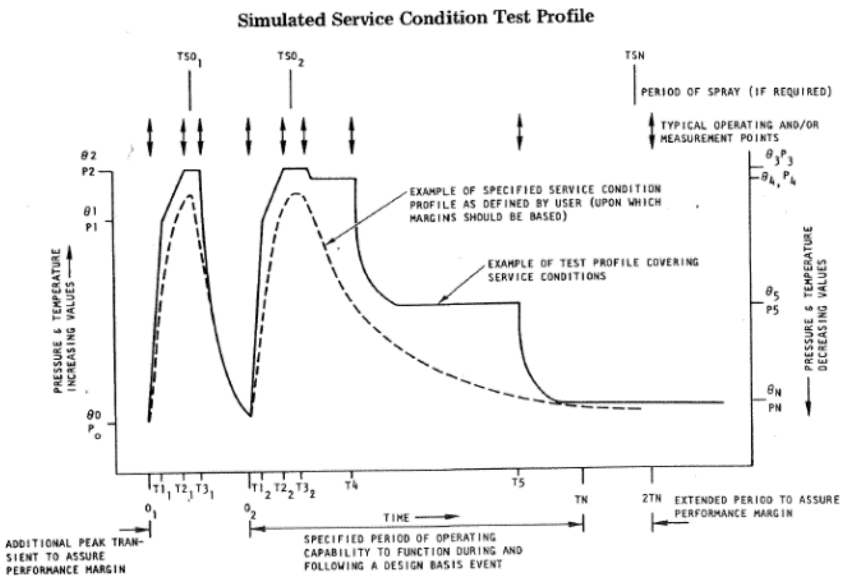
DBE and post-DBE thermodynamic simulation tests

DBE Thermodynamic simulation test

Examples of accident profiles are:



RCC-E (2016)



IEEE 323 (1974)

DBE and post-DBE thermodynamic simulation tests

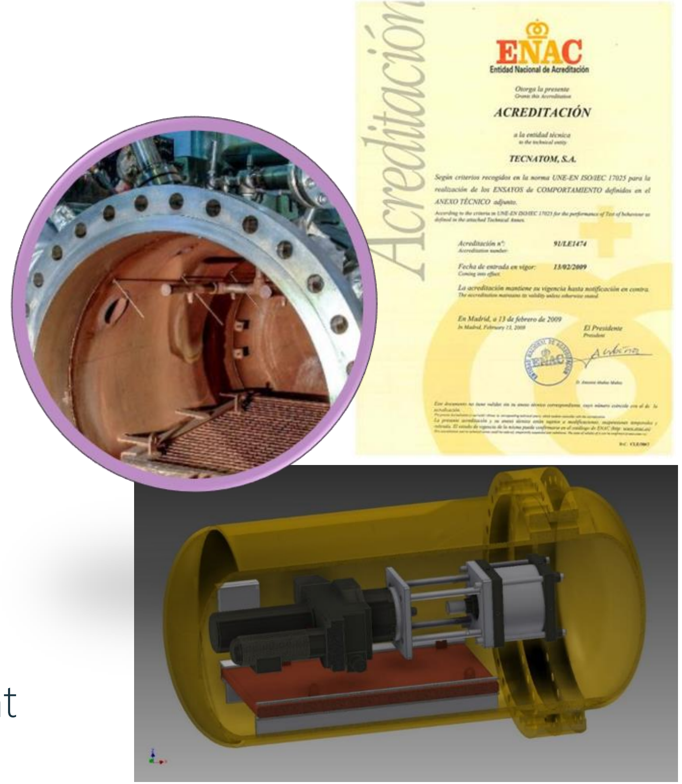
DBE Thermodynamic simulation test

- Safety function and operational requirements during and after the accident.
- Test margins
- Location in the plant
- Fixations
- Supply (electric power and pneumatic)
- Sealings
- Verifications to be performed

DBE and post-DBE thermodynamic simulation tests

LOCA test facility

- LOCA test facility sets up in 1989.
- LOCA test facility accredited by ENAC (91/LE1474) since 2009.
- Is capable of accurately reproducing temperature and pressure transients.
- Saturated or superheated steam with or without chemical spray.
- Automatic control (adaptive-predictive).
- Penetration for instrumentations.
- 30 years of experience in thermodynamic accident testing.



DBE and post-DBE thermodynamic simulation tests

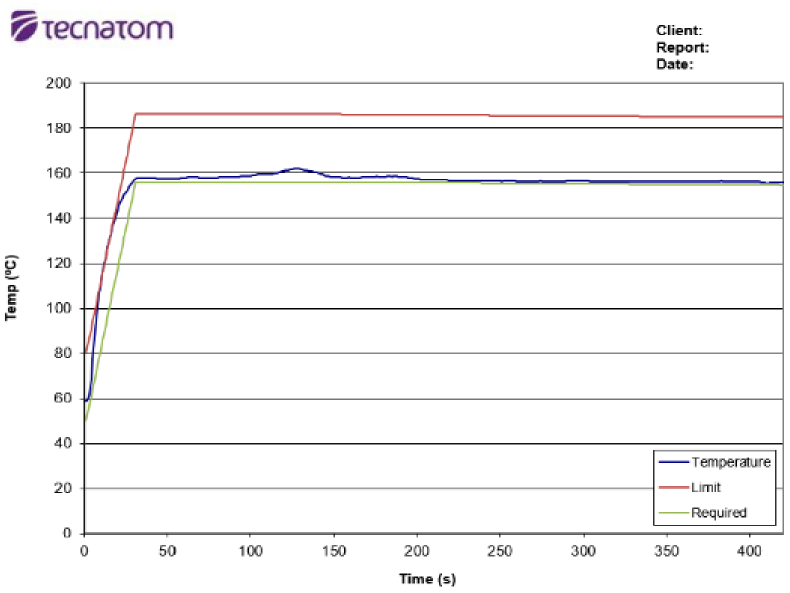
LOCA test facility

The most significant features are the following:

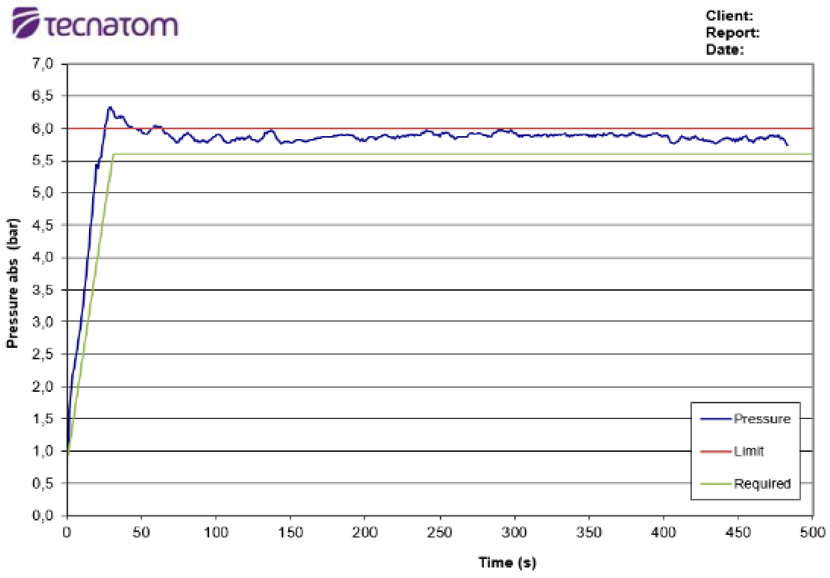
- Test volume: 1 m^3
- Chamber internal dimensions: 1 m of diameter x 1.75 m of length
- Maximum temperature: 250 °C (50 - 212 °C accredited)
- Maximum pressure: 10 bar
- Maximum temperature gradient: 15 °C/s
- Maximum pressure gradient: 0.5 bar/s
- Spray: solutions of BWR and PWR plants

DBE and post-DBE thermodynamic simulation tests

Thermodynamic accident test examples – Test profiles



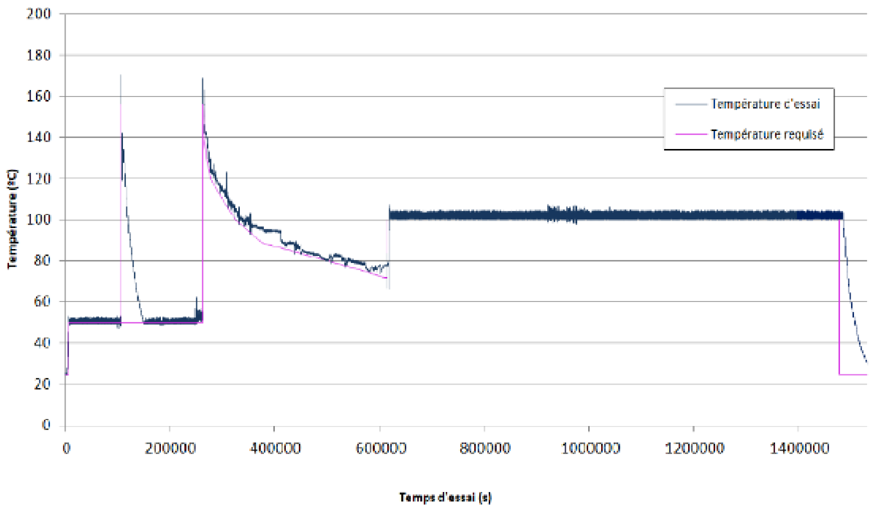
Temperature test profile



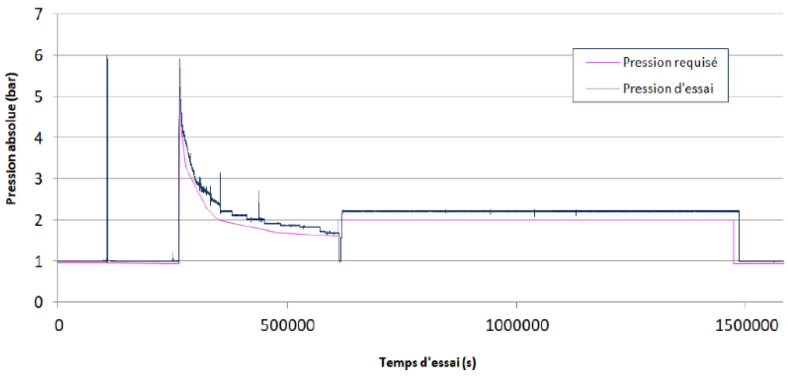
Pressure test profile

DBE and post-DBE thermodynamic simulation tests

Thermodynamic accident test examples – Test profiles



Temperature test profile



Pressure test profile

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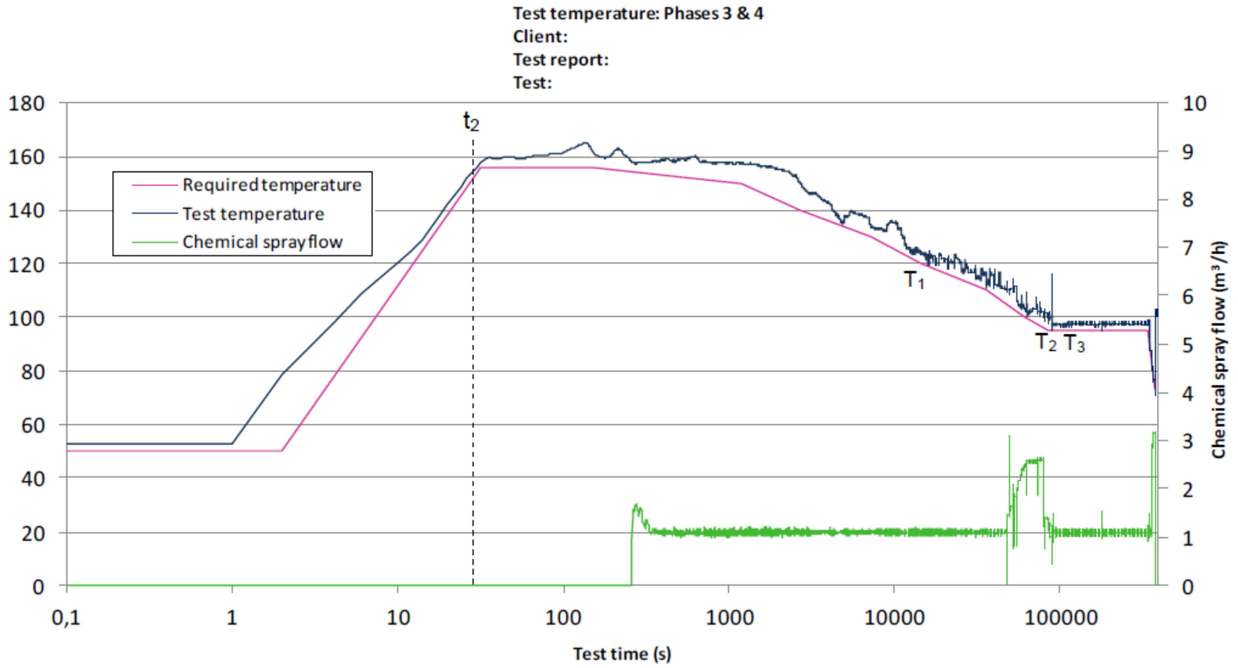
DBE and post-DBE thermodynamic simulation tests

Thermodynamic accident test examples – Test profiles



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Capabilities

Capabilities

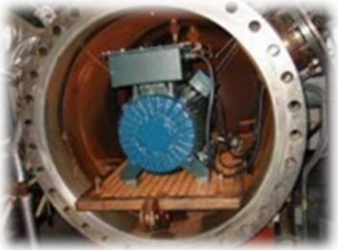
Background

- 1982 – Environmental and seismic equipment qualification (EQ) engineering.
- 1990 – Full scope EQ testing facilities.
- 1992 – EQ equipment design support to manufacturers.
- 1994 – Qualified life extension and alternative parts generation.
- 2000 – Initiation of in-house nuclear grade equipment development.
- 2002 – Partnerships with manufacturers for nuclear grade equipment development.
- 2007 – Five (5) years contract agreement for EQ engineering and testing with Electricité de France (EDF).
- 2009 – Accreditation by ENAC of LOCA facility (91/LE-1474).
- 2012 – Five (5) years contract agreement for EQ engineering and testing with Electricité de France (EDF).
- 2016 – New climatic chambers and autoclave.
- 2017 – Five (5) years contract agreement for EQ engineering and testing with Electricité de France (EDF).
- 2017 – EQSA alliance establishment with Wood, Element and TÜV.
- 2018 – Post-Fukushima accident tests.

Capabilities

Background

- Qualification according to all relevant international standards (IEEE, RCC, IEC,..).
- More than 35 years of active work to support NPP's (Spain and abroad) and equipment manufacturers.
- Fully recognized by international organizations such as IEEE, IAEA, NEA, etc.
- Establish the qualification program: safety function, qualification life, environmental and seismic requirements and required tests.
- Support to different manufacturers (motors, valves, cables, actuators, etc.) in the development of new nuclear grade series, including redesign and material enhancement activities to ensure EQ performance and to extend their qualified life.
- Our experience in the degradation of materials is of critical value which ensures the success of the qualification process.



Capabilities

Qualification

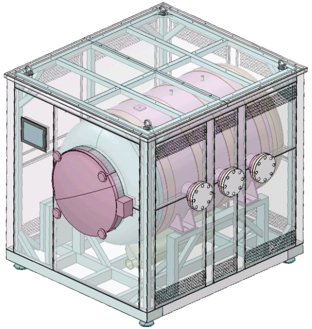
Complete facilities and associated engineering expertise to perform the total scope of an qualification campaign:

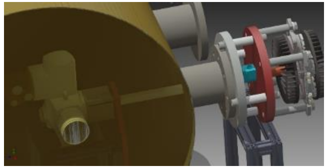
- In-house testing facilities:
  - Design basis thermodynamic accident testing (LOCA & HELB)
  - Environmental testing (cold test, damp heat test, humidity...)
  - Thermal ageing testing
  - Operational ageing testing
  - Functional testing
  - Seismic Qualification by Analysis (Finite Elements).
- External facilities (wide network of collaborating laboratories in Europe):
  - Irradiation testing
  - Vibration & Seismic testing
  - Electrical and EMC testing

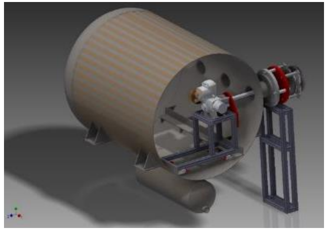
Capabilities

Autoclave

- Autoclave for post-LOCA, post-Fukushima and humidity tests.
- The most significant features are the following:
    - Capacity: 1600 L
    - Internal dimensions: Ø 1.2 m x 1.4 m length
    - Maximum humidity: 100 %RH
    - Maximum temperature: 120 °C
    - Maximum pressure: 2 bar
    - Three penetrations of 24 cm for instrumentation.
    - Remote control 24/7 by its embedded PLC system.
    - Several post-Fukushima and beyond post-Fukushima tests successfully performed.



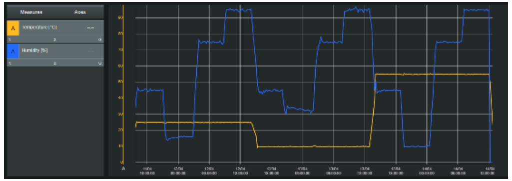




Capabilities

Climatic chambers

- Climatic chambers available for humidity, cold, dry heat, hot, cycling and fast variations of temperature tests.
- The most significant features are the following:
  - Test volume: 1 m^3
  - Temperature range: -75 to +180 °C
  - Humidity range: up to 98 %RH
  - Maximum weight of testing samples: 350 kg
  - Two penetrations.
  - Remote control 24/7.
  - Several climatic tests for nuclear successfully performed.



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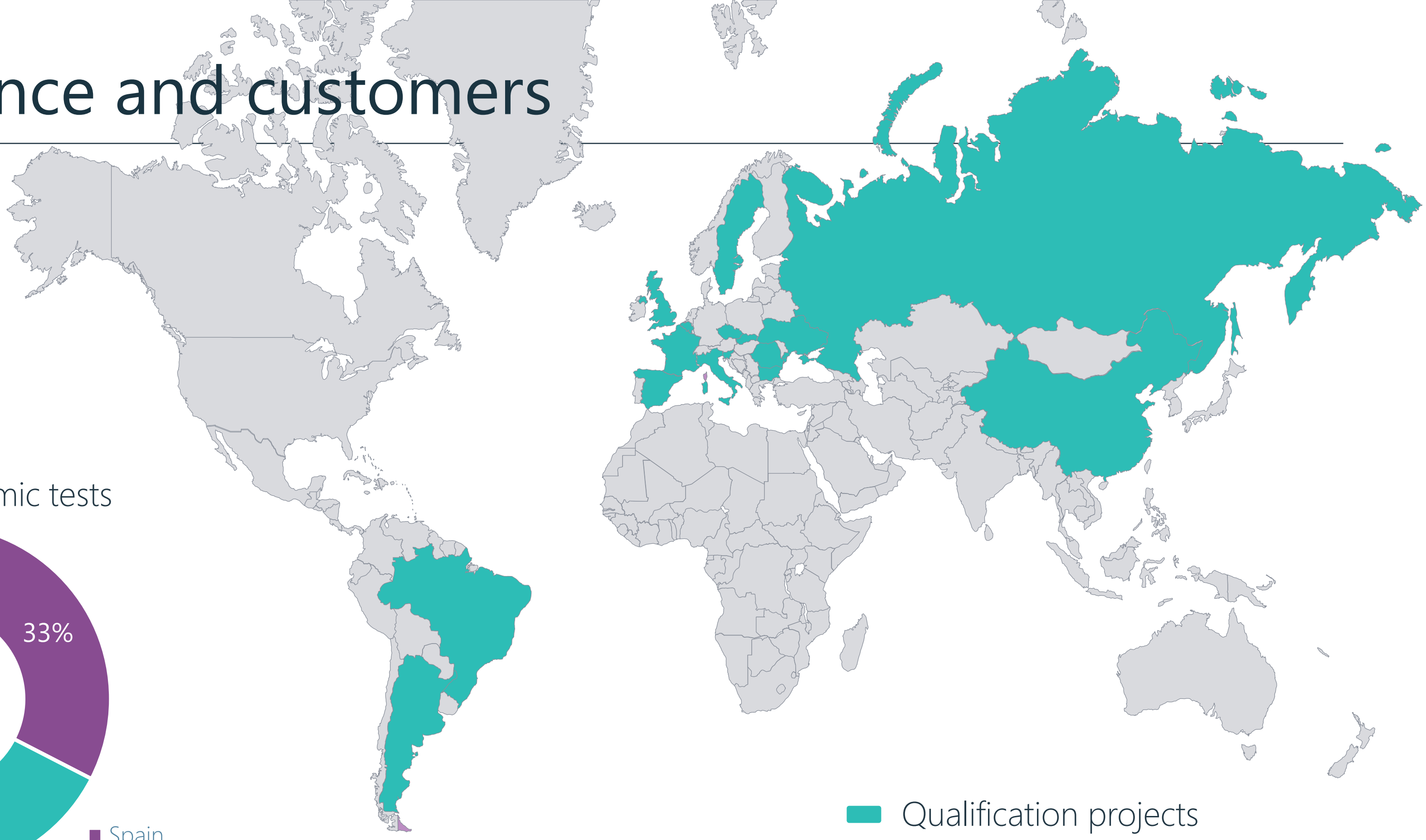
Experience & Customers

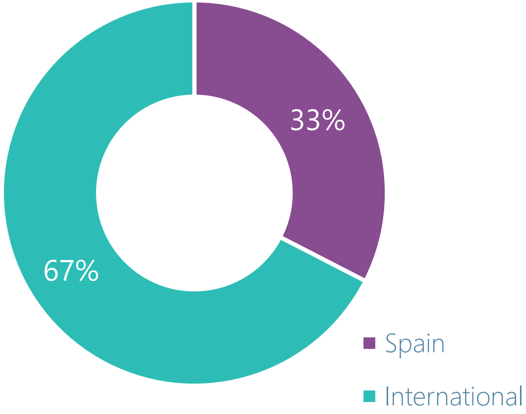
Experience and customers

- Significant safety equipment engineering related work for the Spanish NPP´s:
  - For all the plants (PWR & BWR).
  - For all kind of equipment (mechanical, electrical, I&C).
  - Environmental, seismic qualification.
  - Qualified life extension for no longer available original equipment.
- Large range of qualification work for relevant foreign clients:
  - EDF (France)
  - Alstom Power (France & UK)
  - NIDEC-Leroy Somer (France)
  - Rotork (UK)
  - Tractebel (Belgium)
  - Litton Veam (Italy and Sweden).
- Qualification work for VVERs under EEC PHARE and TACIS projects:
  - Bulgaria, Czech Republic, Slovak Republic, Ukraine.

Experience and customers



DBE thermodynamic tests



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EQSA

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Accelerated radiation and thermal ageing to underpin EQ

Dr Victoria Smith
Wood

18th September 2019

Introduction

- Why EQ?
  - Providing as much confidence as we can that safety related components will remain functional for their qualified life
- Overview of key ageing parameters that are fundamental to carrying out representative EQ tests
- How does accelerated ageing affect polymers and radiation sensitive components, how effective are the common test approaches?

Where do you begin?

Background

- Radiation sensitive components such as polymers are used in many different areas across plant
  - Seals and gaskets in valves and actuators
  - Electrical cables providing power, control for many safety related systems
  - Polymer coatings and paints
  - Lubricants (oils and greases)

- Unlike metals and ceramics, polymers are susceptible to the effects of radiation and temperature.

- Typical key stressors include –
  - Temperature
  - Radiation dose rate and total dose
  - Presence of oxygen
  - Mechanical stress
  - Moisture
  - Chemical contamination

Typical changes in properties as polymers are aged

- Tensile elongation and strength tend to decrease
- Hardness increases (usually)
- Compression set (seals) increases
- Density increases
- Changes in colour and surface texture often visible
  - e.g. cracking and flaking
- Standard electrical properties (e.g IR) show little change until material is significantly degraded (usually)

Accelerated Thermal Ageing

- Simulation of operational temperature is carried out at elevated temperatures
- Usually based on Arrhenius relationship, using the following equation

$$t_1 = t_2 \exp [Ea/R (1/T_1 - 1/T_2)]$$

  - Where t_1 is ageing time required at a temperature T_1 to simulate a service life of t_2 at a temperature T_2, Ea is the activation energy for thermal ageing and R is the gas constant

- *However, this assumes*
  - A single degradation mechanism- oxidative degradation and radical induced reactions are complex and usually involve several different chemical reactions, each with its own reaction rate and Ea
  - Degradation mechanisms are the same at both operational conditions and at the higher temperatures used during accelerated ageing
  - Activation energy is constant, and an accurate value is known for the specific polymer formulation being tested

Accelerated Thermal Ageing

Changes in degradation mechanisms

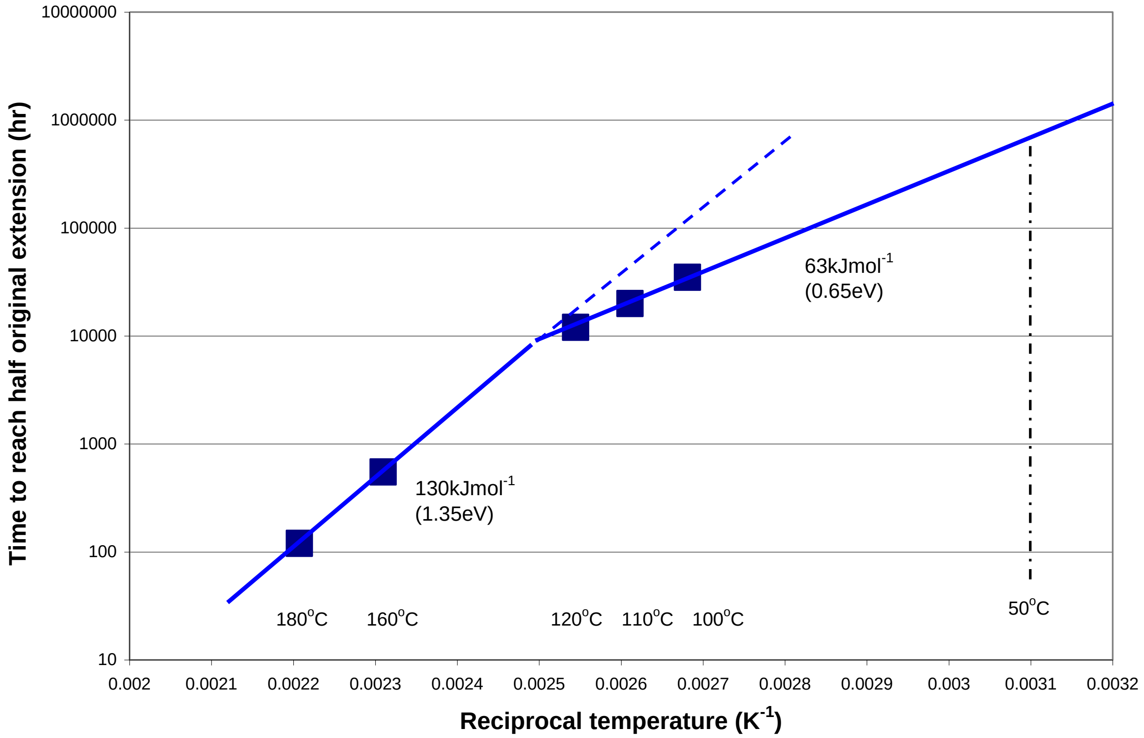
- Important factors that can change degradation kinetics:
  - Thermal transitions such as melting points, glass transition and crystalline melting points in semi-crystalline polymers.

    Note: if a crystallite melting peak is ~120°C, melting could start at lower temperatures
  - Loss of plasticiser (a key degradation process during service)
  - Environment (presence of oxidation)
  - Surface oxidation or skin effects
  - Degradation products from the polymers as they are heated

    e.g HCl from PVC

Accelerated Thermal Ageing

Activation energy remains constant



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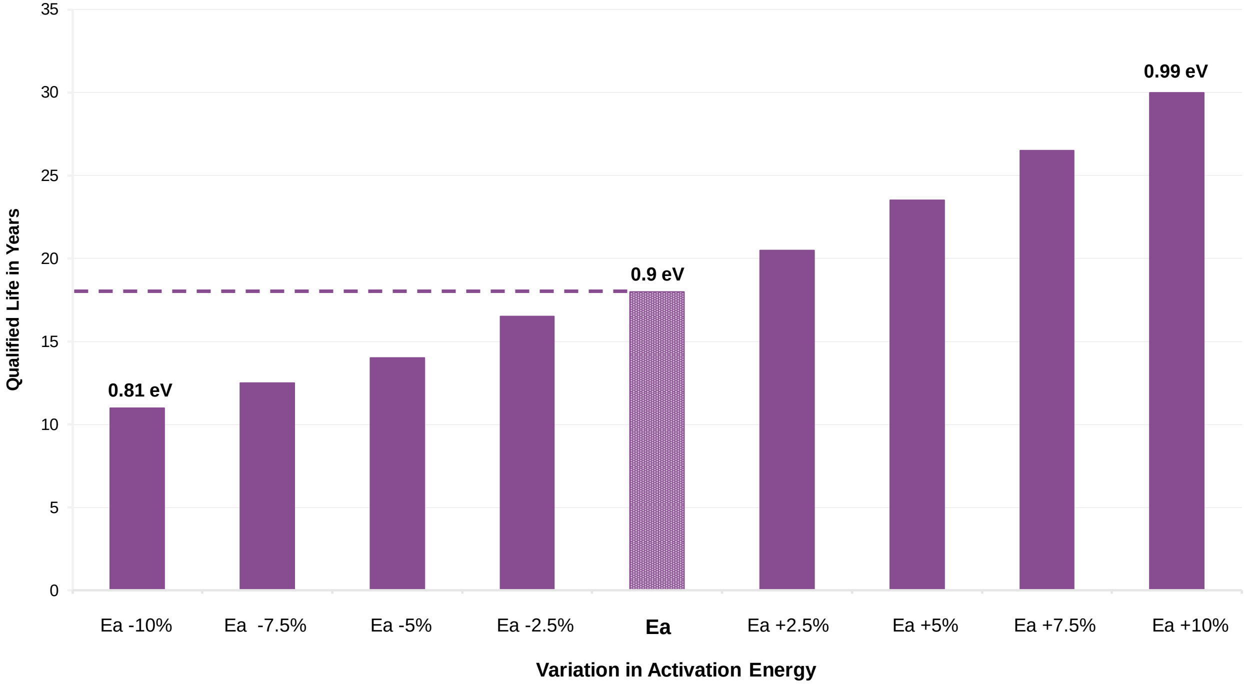
Accelerated Thermal Ageing

Potential impact of variations in the value of Ea on qualified life



Influence of activation energy on qualified life, determined from artificial thermal ageing for 42 days at 110° C, followed by simulated design basis event. The normal service temperature is 50° C. E = 0.9 eV

Accelerated Thermal Ageing

Selecting a suitable Ea?

- Ea data can be found in literature for generic families of materials i.e. EPDM
- It can not be assumed that 2 nominally similar materials will respond the same way when thermally aged. Methods of manufacture and material composition such as quantity and types of fillers, stabilisers and other additives all affect degradation mechanisms.
- Care should be taken when selecting Ea from literature data
  - Different Ea values generated depending on ageing temperature
  - Some values of Ea are derived from thermal decomposition rather than thermal degradation and are not representative of thermal ageing in service.
- Best way to eliminate the potential for significant error is to measure Ea precisely for the applicable ageing parameters
- However, if the Ea is unknown, always select a conservative value.
  - If the value of Ea is too high then the predicted lifetime is likely to be greater than it actually is

Accelerated Radiation Ageing

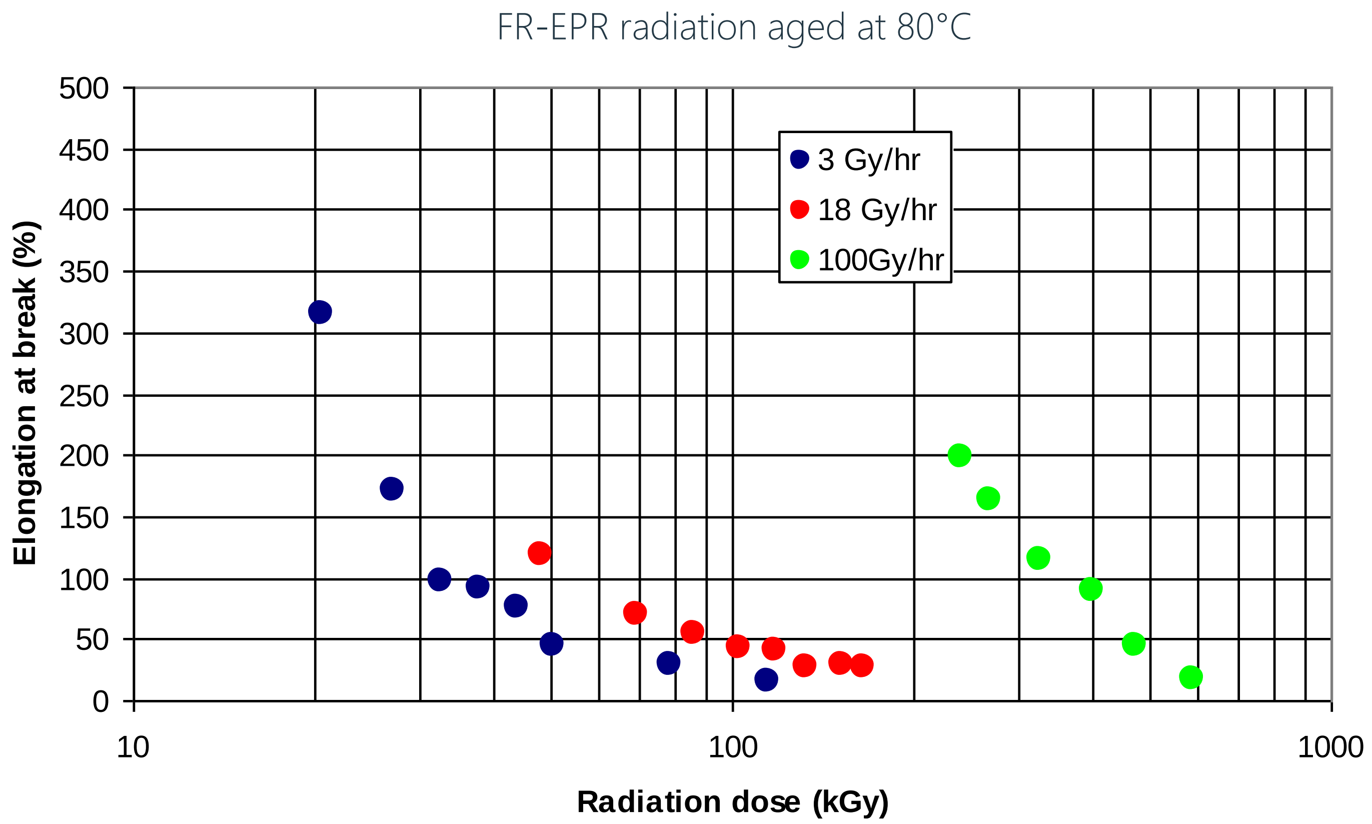
Believed for many years: "*equal dose means equal damage*"

- Polymers are susceptible to radiation damage, however the type and levels of damage can be dose rate dependent
  - Dose rate effects
    - Diffusion limited oxidation
  - Synergy between radiation and temperature
  - Reverse temperature effect
  - Formulation

What is a dose rate effect?

The total dose required to reach a specific level of ageing decreases with decreasing dose rate

Accelerated Radiation Ageing



Accelerated Radiation Ageing

Diffusion Limited Oxidation (DLO)

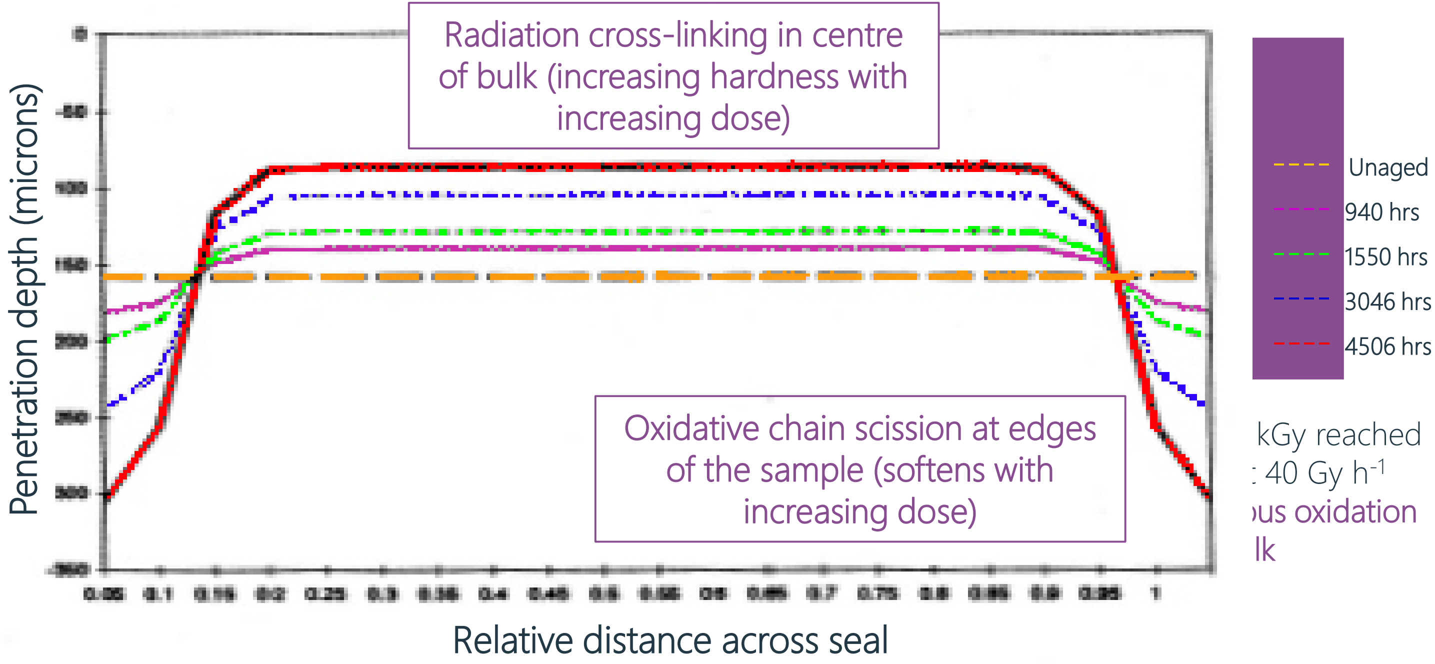
- Oxidative degradation is a key degradation mechanism in polymers
- The degree of oxidative degradation as a function of depth is limited by diffusion of oxygen into material
- Under operational conditions (low dose rates and long ageing times) oxidation is observed to be homogeneous
- During accelerated testing (higher dose rates, shorter ageing times) oxidation is often observed to be heterogeneous
  - High levels of oxidation at the surfaces, but the interior effectively ages under anaerobic conditions

Why is this so important?

Accelerated Radiation Ageing

Diffusion Limited Oxidation (2)

- Benchmark tests for material properties such as compression set or elongation at break are likely to be non-representative



Se

kGy reached
: 40 Gy h^{-1}
›us oxidation
lk

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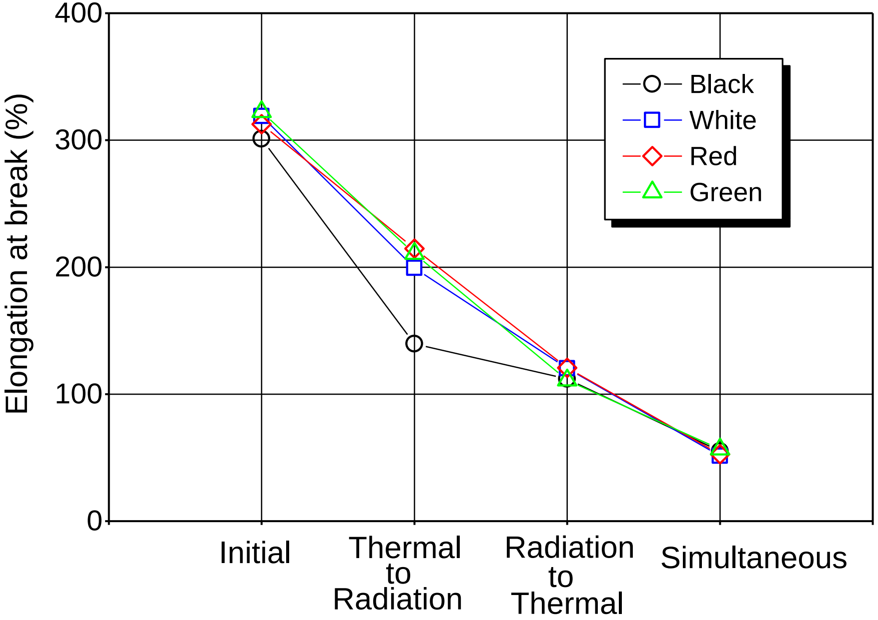
Accelerated Radiation Ageing

Radiation and thermal synergy

- EQ tests follow a sequential ageing profile
- Radiation ageing at elevated temperatures can act synergistically

SiR insulation ageing from the Japanese National Programme



Does RCC-E ageing at 1 kGy h^{-1} at 70°C address synergy effects?

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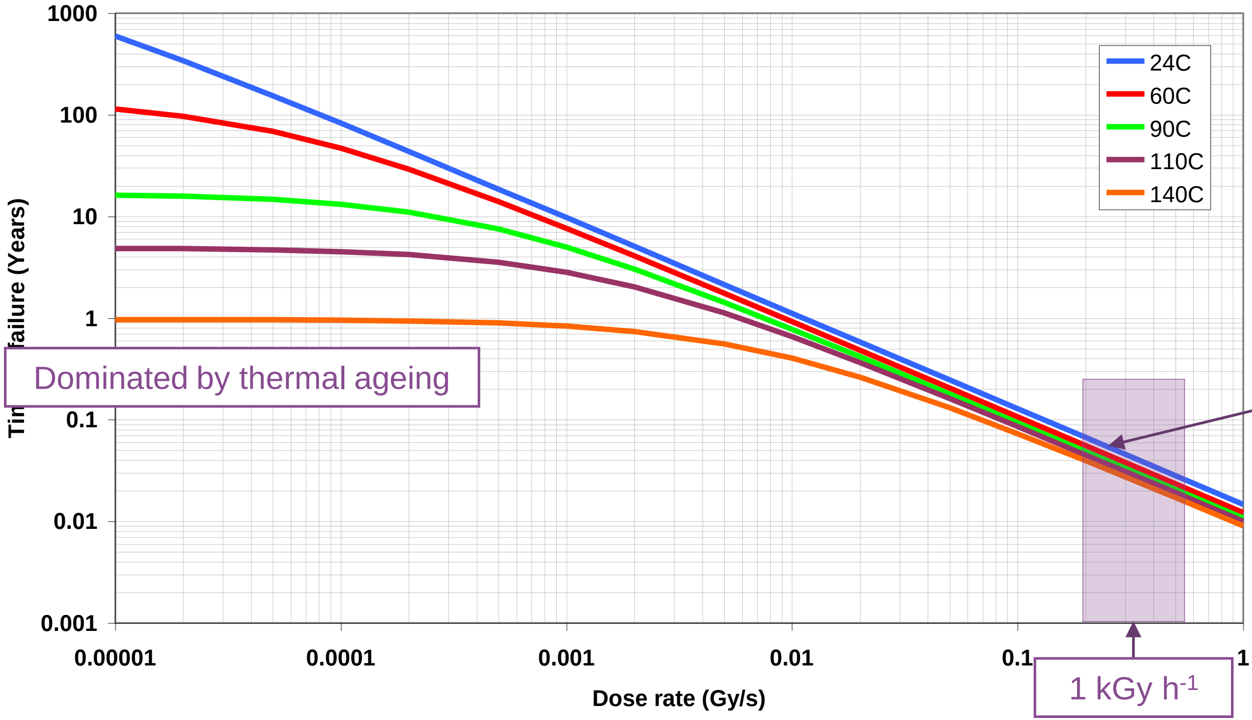
Accelerated Radiation Ageing

Radiation and thermal synergy (2)

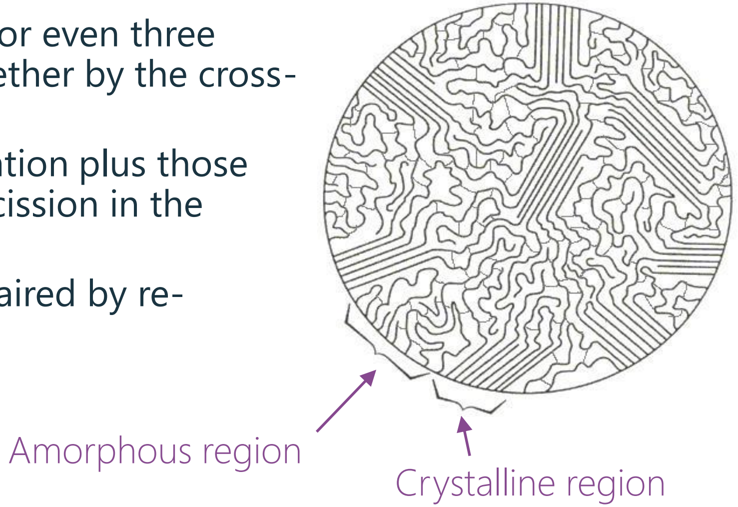


Dominated by radiation ageing
- Temperature has little effect in this region

Reverse Temperature Effect

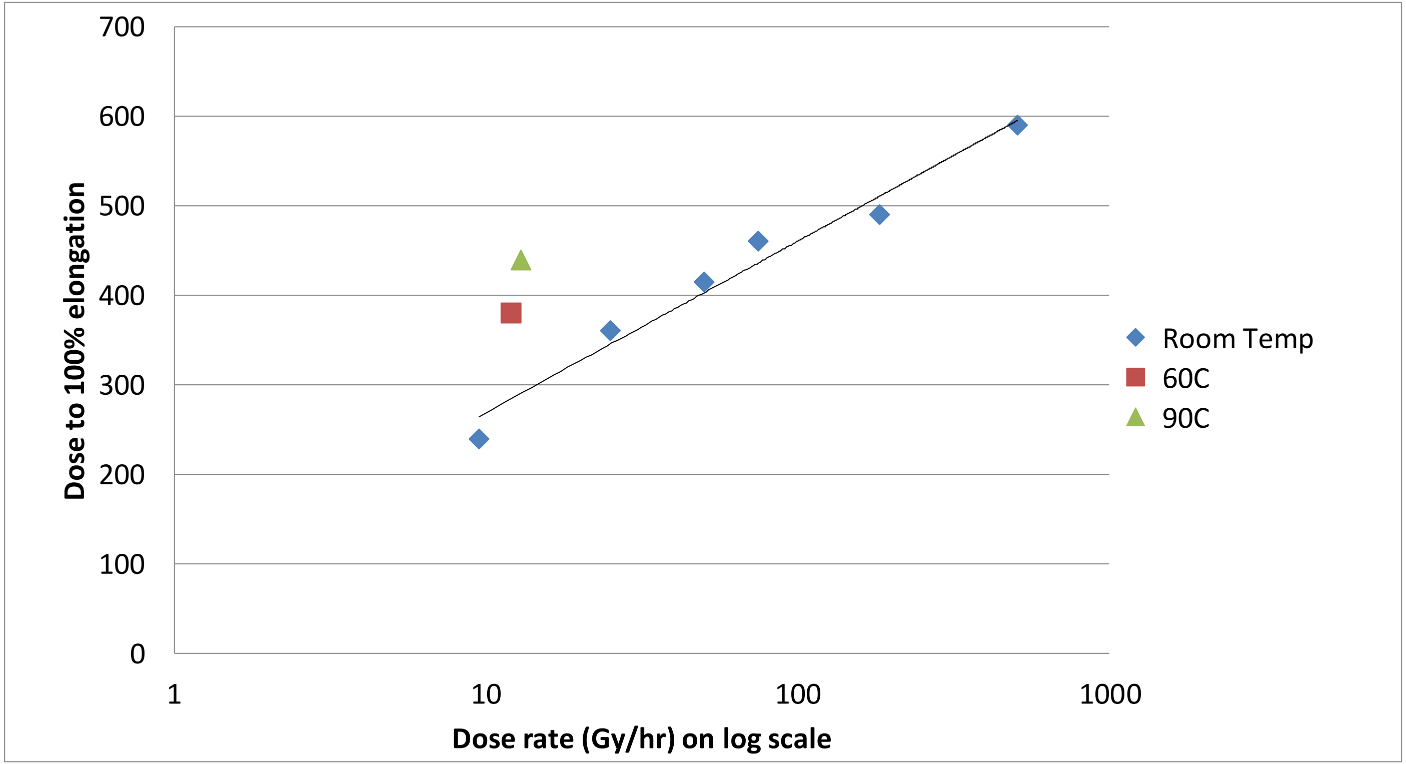
Degradation is higher at lower temperatures than the higher temperatures in the presence of radiation

- This effect means that irradiation testing of some polymers at high temperatures can be non-conservative
- Polymer morphology plays an important role - usually the semi-crystalline polymers where the ageing temperatures span the crystalline melting point
- At temperatures of about 90-100°C we have almost a two or even three phase material with partially molten crystallites linked together by the cross-linked amorphous regions – high chain mobility
- We would expect the free radicals generated by the irradiation plus those from the thermal process to cause degradation by chain scission in the amorphous regions
- But - any degradation caused by chain scission can be repaired by re-crystallisation processes due to the high chain mobility



Reverse Temperature Effect

Radiation test data for a typical XLPE cable material from the UK



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Polymer formulation

- Commercial polymer formulations include a number of additional components
    - Fillers, plasticisers and flame retardants
    - Anti-oxidants, colour pigments, extenders
    - Curing system i.e. peroxide vs sulphur cured formulations
    - Where morphology is important, chain structure can be important e.g. PE
  - Polymer content can be small with more than 50wt% comprised of a mixture of additives
  - Specific properties of a polymer can be varied by adjusting the relative proportions of the additives

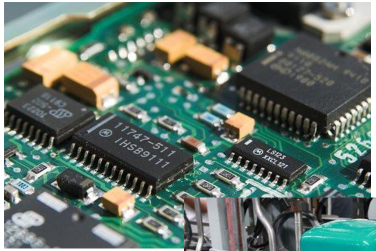
Degradation mechanisms and changes in material properties are strongly dependent on a materials specific formulation.

Polymers of nominally the same material can show significant variations in ageing behaviour

- Formulations are commercially sensitive and the exact details of the composition may be unknown
  - Some functional properties i.e. electrical, can be maintained even when additives are replaced with newer or cheaper alternatives. However, radiation tolerance can be severely affected
  - Where possible, use manufacturers that will guarantee consistency in the composition and production methods

Radiation Ageing of Electronics

- Ionising radiation can result in inaccurate/misleading outputs from electronic devices
- Depending on the device and ageing conditions, different effects may be observed, both irreversible or reversible (partially or totally)
  - Single event effects
  - Cumulative build up of ionising dose (TID) over time
  - Displacement damage



- Typical parameters affected by ionising radiation include:
  - Resistance
  - Capacitance
  - Inductance
  - Semiconductors (linear bipolar devices)
  - 'Bit flip' in memory devices
- Electronics have also demonstrated dose rate effects or enhanced degradation at low dose rates (ELDRS). Differences in device outputs were observed after irradiation ageing at high and low dose rates
- It is recommended to carry out representative accelerated ageing of the device under service conditions (electrically powered, duty cycles, loads etc).

Accelerated Radiation & Thermal Ageing

Things to consider when undertaking accelerated radiation and thermal ageing

- Have you selected the most appropriate materials for the job?
- Is the material under test exactly the same as that to be used in plant?
- Are you using an appropriate value for Ea?
- Are the degradation mechanisms the same at the accelerated ageing temperature and in service?
- Does your material suffer from dose rate effects?
- As a consequence have dose rate effects such as diffusion limited oxidation (both radiation and thermal ageing) been factored in?
- Has any synergy between radiation and temperature been considered when establishing accelerated test conditions?

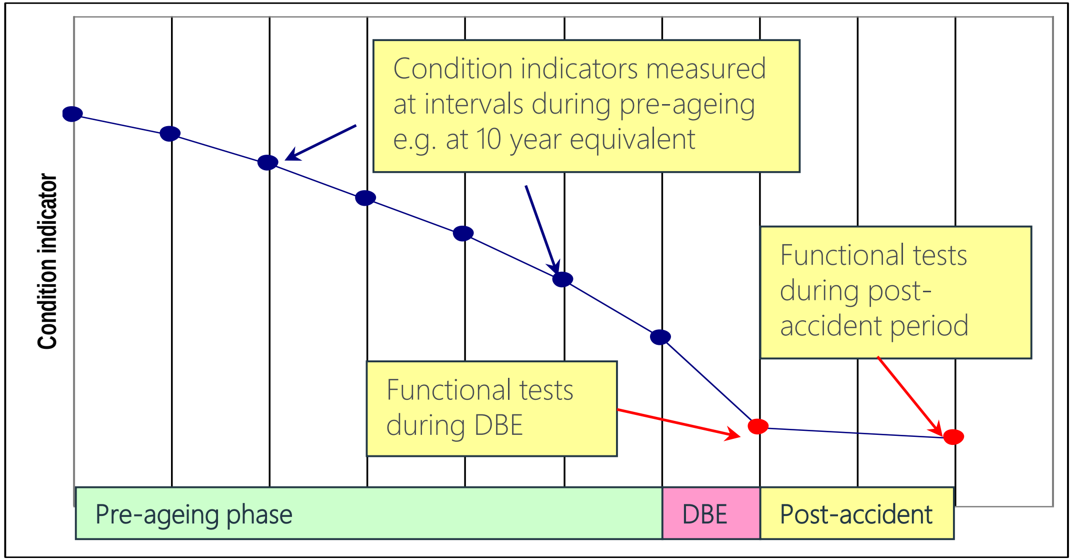
On a more practical note….

Things to consider when undertaking accelerated radiation ageing (2)

- High dose rate space is a premium as the available volume is smaller than at lower dose rates
- Testing might be more cost effective at lower dose rates, and provide a more representative ageing environment
- Consider how to make best use of the space – scaling down or testing only the radiation sensitive components
  - Smaller sample sizes/geometries/weights
  - During the test consider whether other parts of a component could shield the materials of interest
  - Are there specific regions within the geometry where radiation sensitive components are housed?
  - Use appropriate samples for functional/mechanical testing i.e. dumbbells of cable sheaths instead of whole sections
- Batch testing of materials or electronic devices to demonstrate reproducibility
- When testing electrical/electronic components, irradiate whilst powered and where possible, monitor functional outputs as a function dose and dose rate
- Do not overlook cabling and peripherals when ageing electronic components

Qualified Life

- The focus has been to establish a qualified life or an end of life condition for a material or component
- An alternative approach based on Condition-Based Qualification can overcome many of the uncertainties and can be particularly useful for materials operating in the harsher environments or are safety related
- Based on knowing the condition of a component that would survive an accident condition i.e. qualified condition
- With periodic monitoring the condition of the component in plant can then be compared to the qualified condition to determine whether it is still acceptable



Qualified Life

- How?
- Requires a different approach to EQ, particularly during the pre-ageing sequence
  - Need to understand how the condition of the component changes with ageing
  - The pre-ageing should be carried out using as low acceleration factors as possible
  - A condition indicator must be measured and needs to be a property that trends with ageing, but does not have to be a functional property (e.g. mechanical, electrical or chemical property)
- Modelling techniques can be used to determine how long it will take to reach the end of life condition under actual environmental conditions
- Benefits:
  - Costs can be reduced as an awareness of a material/component performance can enable maintenance schedules can be planned
  - With the additional understanding of a materials ageing characteristics it is easier to underpin plant life extension safety cases
  - This methodology has been used to great effect for the cables in SZB

Any questions?