LOCA and Post-LOCA Qualification of PEEK insulated cables

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The success story about an EPA qualification

(EPA = Electrical Penetration Assemblies)
What happens?

Planning VS Real Life
Background

- The Swedish Radiation Safety Authority have a regulation SSM FS 2008:17 §17 that stipulate:

- Environmental tolerance and environmental impact

- Section 17

The barriers and equipment belonging to the safety systems of the nuclear power reactor shall be designed so that they withstand the environmental conditions that the barriers and equipment can be subjected to in the situations where their function is credited in the safety analysis of the reactor.

Equipment in the nuclear power reactor shall not have such an environmental impact that the performance of the reactor’s safety functions is reduced.
Background

- On the electrical and I&C area this lead to the requalification of about 70 different types of components.
- Also mechanical and civil structure component is handled under the §17 work.
- The requalification is done according to modern demands:
  - Low acceleration factors
  - Partly new environmental description (LOCA/Post-LOCA profiles)
  - New function demand time (longer Post-LOCA)
  - In some cases also submergence
  - Severe Accident
  - Traceability (Identity) between originally qualified component and component produced today
- A majority of components were not approved.
Background

• One of the component not approved was the EPA at Forsmark 3

• Main reasons are:
  - Accelerated LOCA profile
  - No submergence verification
  - No 30 day Post-LOCA
  - No severe accident/H5 verification
  - Only one test specimen

• After a design review it was decided to not perform a requalification of the original component
Location of penetrations at Forsmark Unit 3
Principal drawing of containment penetrations
Cubical in the lower DW
Original I&C module from Forsmark Unit 3
Cubical in the Mock-up
Demands at the new qualification

- **DBE**
  Demand of Electrical functionality and mechanical integrity.
  - DBE profile according to TBE 102:1 BWR 2. Post DBE 30 days.
  - Submergence profile later in the presentation.
  - Operation and Accident dose 30 days 7.4 kGy.

(TBE= Technical Requirements for Electrical Equipment)
Demands at the new qualification

• Severe Accident/H5
  - Only mechanical integrity.
  - Integrity verified >30 days.
  - Max temperature 185°C.
  - Max Pressure 8.3 Bar.
  - Accumulated dose during 30 days 1.7 MGy.

• Profile (including submergence) later in the presentation.
LOCA-profile

BWR 2/BWR generic, Inside Containment Accident Conditions

Note 1: Values for temperature and pressure given above shall be achieved or exceeded. 100% RH are valid for required profile and test profile. Rise and fall times shall be as short as possible.

2. Rise time: max 20 s up to 150°C and 5 min up to 173°C. Time t = 0 starts at 173°C.

3. Rise time: max 20 s up to 158°C and 5 min up to 181°C. Time t = 0 starts at 181°C.

4. Time for Post DBE shall be according to Technical Specification.

5. The pressure 0,5 Mpa abs shall be kept for at least 6h.

6. The pressure 0,55 Mpa abs shall be kept for at least 6h36m.
Temperature profile Severe Accident/H5

The graph represents the temperature profile over time for severe accident conditions (H5). The temperature values are as follows:

- **185 °C** at 10s
- **160 °C** at 10 min
- **100 °C** at 36 h
- **80 °C** at 72 h
- **80 °C** at 720 h

The graph shows the temperature changes over time, starting from 10 seconds and extending up to 720 hours.
Pressure profile (gas phase) Severe Accident/H5

![Graph showing pressure profile over time]

- 60 s: 7.5 bar
- 10 min: 4.5 bar
- 6 h: 2.5 bar
- 36 h: 1.5 bar
- 720 h: (Graph continues with lower pressure values)
Submergence profile Lower DW
Pressure profile (water phase) Severe Accident/H5

![Pressure profile graph](image)

- **Total pressure in LDW [bar]**
  - 8.3 bar at 60 s
  - 5.5 bar at 10 min
  - 3.8 bar at 6 h
  - 2.8 bar at 36 h
  - 0 bar at 720 h

**Time**
- 60 s
- 10 min
- 6 h
- 36 h
- 720 h

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Qualification of new EPA

- Contract in 2012
- Modification of the original design to reduce risk of corrosion
- Discussion about the choice of Pigtails
  - Zero Halogen
  - Possibility to withstand Severe Accident
- Possibility to envelope the LOCA and Severe Accident test
Choice of cable

- PEEK Cable. Qualified for LOCA and Post-LOCA 30 Day. 40 year of operation at 90 degree C.
- LOCA Curve exceeding the Forsmark 3 demand, Post-LOCA slightly below our requirement.
- Radiation: Total dose >2.5 MGy

- No indication of problem from qualification test or other applications.
Combined LOCA/Severe Accident profile

Verified by Post-LOCA test in accordance with Subsection 5.12
Combined Post-LOCA/Severe Accident profile

The graph illustrates the temperature and total pressure profiles over time for a post-LOCA/severe accident scenario. The key points are:

- **Temperature**:
  - Initial temperature (20°C)
  - Increase to 128°C
  - Decrease to 100°C
  - Further decrease to 90°C

- **Total Pressure**:
  - Initial pressure (0.28 MPa or 2.8 bar absolute)
  - Decrease over time

- **Test Duration**:
  - 69.5 hours
  - 105.5 hours
  - 33 days

- **Legend**:
  - Red line: Required water temperature
  - Black line: Required total pressure on penetrations

The graph shows the critical parameters during the post-LOCA/severe accident scenario, indicating the necessary conditions for safety and operational integrity.
Combined Steam and Submergence test

- Electrical penetration module test specimen No. 3 (S/N 13-004): exposed to steam environment
- Inside submergence test chamber
- Outside submergence test chamber
- Header plate
- Required water level
- Electrical penetration module test specimen No. 2 (S/N 13-026): exposed to water submergence
- Electrical penetration module test specimen No. 1 (S/N 13-032): exposed to water submergence
Problem started to occur at submergence

- Fluctuating leakage current after submergence
- For 660 V the problem started immediately after submergence
- For 250 V the first problem occurs later
Test specimens after Post-LOCA
Test specimens after Post-LOCA
Test specimens after Post-LOCA
Trying to find the reason to failure

- Were carbon black the reason to the problem?

- Original qualification was on insulation without any pigment
Result of LOCA test with submergence on PEEK insulated wires.
PEEK with Carbon Black pigmentation
PEEK with Carbon Black pigmentation
PEEK with Carbon Black pigmentation
Test on insulation with and without different types of pigments

White, black and naturally coloured insulated wire

What will happen???
PEEK without any pigmentation
PEEK without any pigmentation
Test together with the cable manufacturer

- Samples was 10 single wires in each test
  Submerged in water

  - Different sizes 1, 2.5, 6 sqmm
  - Different voltage level 300-660 VAC
  - Different conductivity in the water
  - Different temperature in the water

  - Amorphous and Crystalline phase of the PEEK material
1 sqmm

- 660V, 90C, salt
- 500V, 90C, salt
- 300V, 90C, no salt
- 660V, 23C, no salt

No. of samples in operation vs. time [days]
2.5 sqmm

- 660V, 90C, salt
- 500V, 90C, salt
- 300V, 90C, no salt
- 660V, 90C, no salt
- 660V, 23C, no salt
Oven 1, 90°C, 660 VAC, salt

- No. of samples in operation vs. time [days]
- Comparison of 1.0 sqmm, 2.5 sqmm, and 6.0 sqmm cables

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Oven 2, 90°C, 500 VAC, salt

- No. of samples in operation
- time [days]

- 1.0 sqmm
- 2.5 sqmm
- 6.0 sqmm
Oven No. 3, 660 VAC, 90°C, no salt

- 2.5 sqmm, normal wall
- 2.5 sqmm, thick wall
- 6.0 sqmm
Oven 1, RT, 660 VAC, no salt

- 1.0 sqmm
- 2.5 sqmm
- 6.0 sqmm

No. of samples in operation vs. time [days]
Oven No. 2, 300V, 90C, no salt

- 1.0 sqmm, normal wall
- 1.0 sqmm, thick wall
- 2.5 sqmm
- AWG 28
Oven 3, ETFE, 660 VAC, 90C, no salt

- **1.0 sqmm**
- **1.0 sqmm, thick wall**
- **2.5 sqmm**
Oven No.1, 450 VAC, 90°C, salt

- No. of samples in operation
- time [days]
- 1.0 sqmm
- 2.5 sqmm
- AWG 28
Amorphous, 660V, 90°C, no salt

No. of samples in operation

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Competitor samples, 600V, 90°C, no salt

- OD 0.35 mm
- AWG 16
Conclusions

- I didn’t know enough about PEEK when starting this work
- I had a general assumption that steam atmosphere is tougher for electrical component than submergence
- Focus on Carbon Black made the project lose time and money
Status today

- The problem is highly voltage dependent
  - Safe level below 250 VAC??

- The thickness of the insulation is an important factor
  - There will be future tests, too thick insulation gives too stiff wire

- Amorphous PEEK handle the submergence better than crystalline PEEK
  - PEEK will be crystalline during an LOCA event

- PEEK is no alternative for power application?
  PEEK could be an alternative for I&C application?
Future questions

• Similar problem with thin insulation material (PEEK, ETFE, xxx)?

• Do we have “submergence” condition in other applications inside containment?

• Same damage regardless 660 VAC and 660 VDC?

• Overpressure during LOCA simulation?
It's very interesting
to work with

Environmental Qualification

(Real Life supersede planning)