Simulated Test Profile vs Service Condition Profile

Post Accident Operating Time (PAOT) Calculation

Total Integrated Dose

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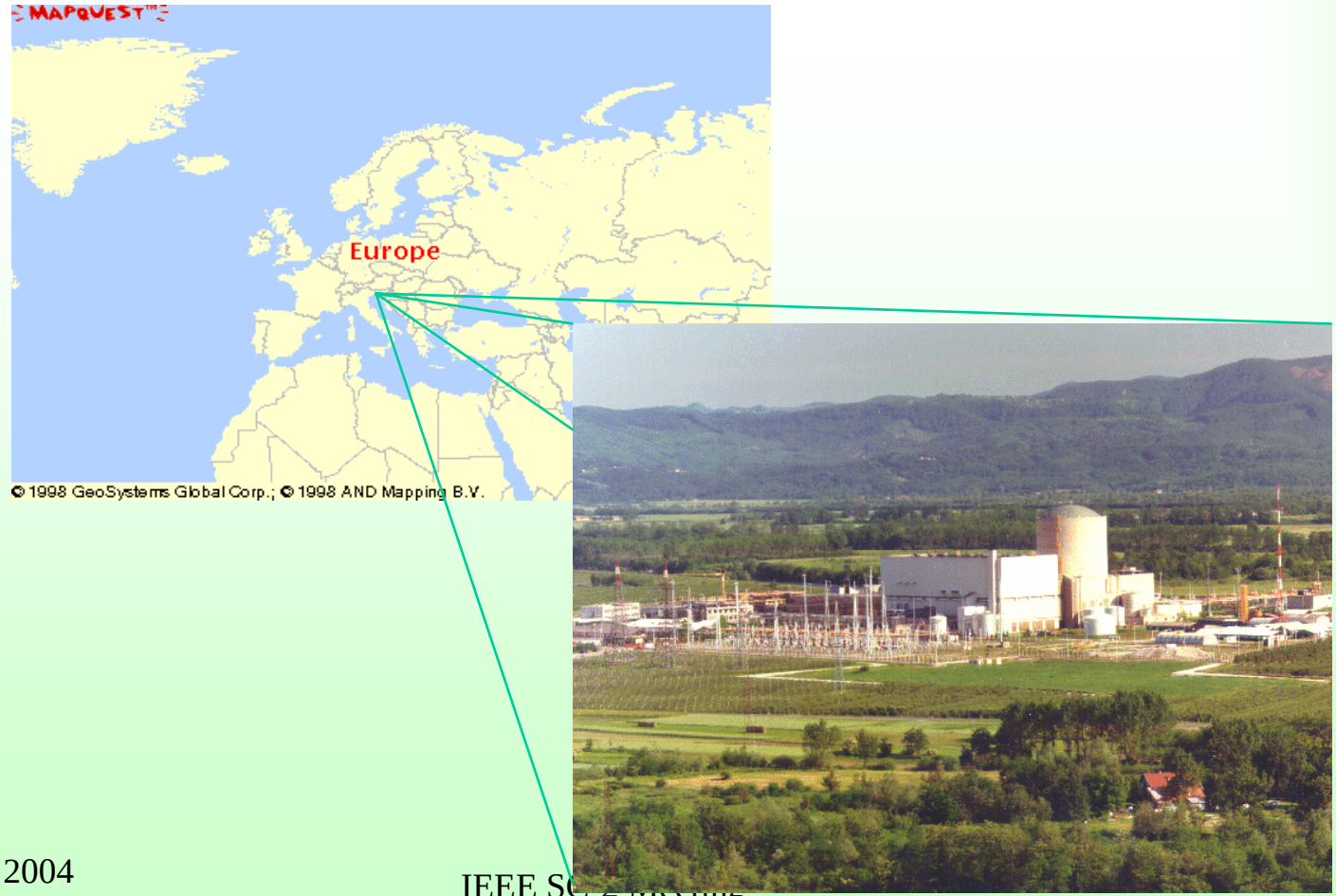
NEK - Krško NPP



Simulated Test Profile vs Service Condition Profile

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IEEE SC-2 Meeting
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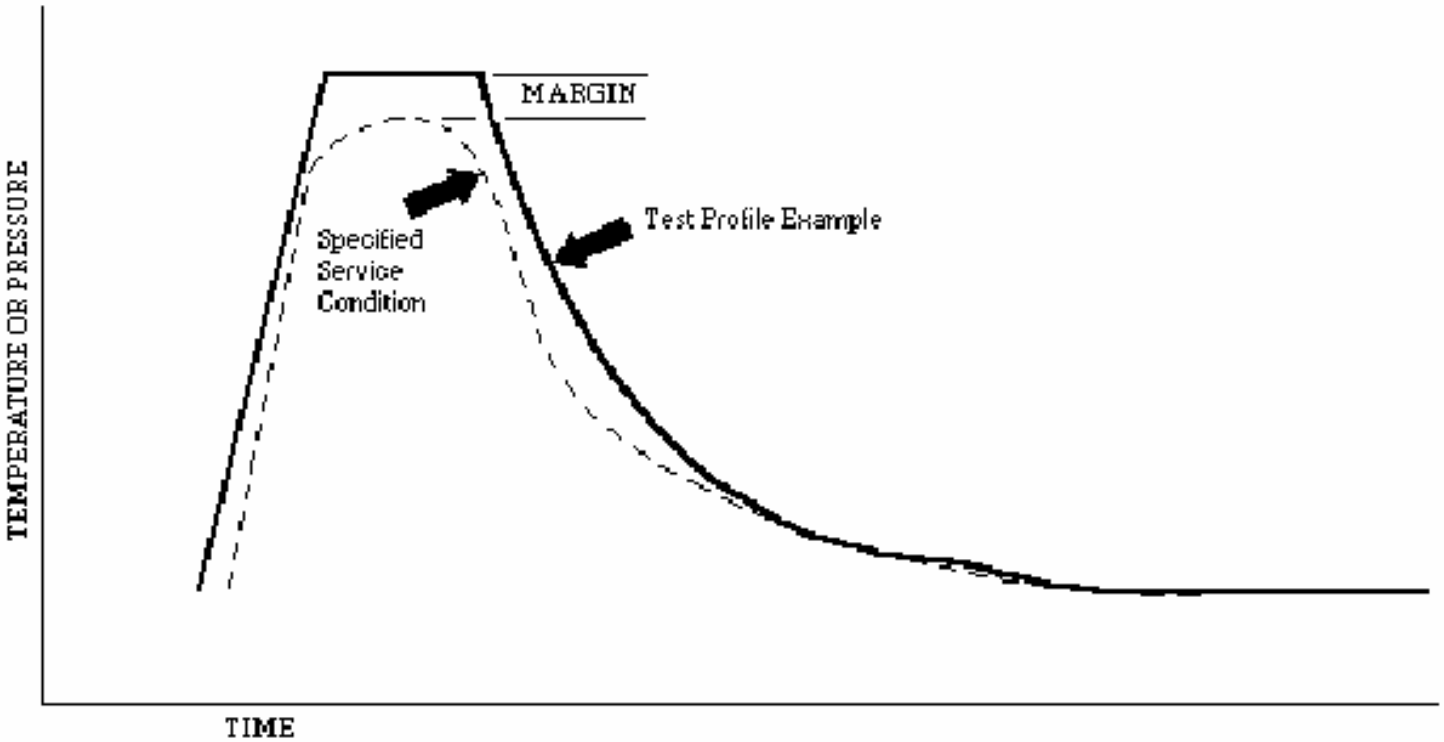
Inrtuduction

- Profile comparison
- Peak value comparison & PAOT calculation

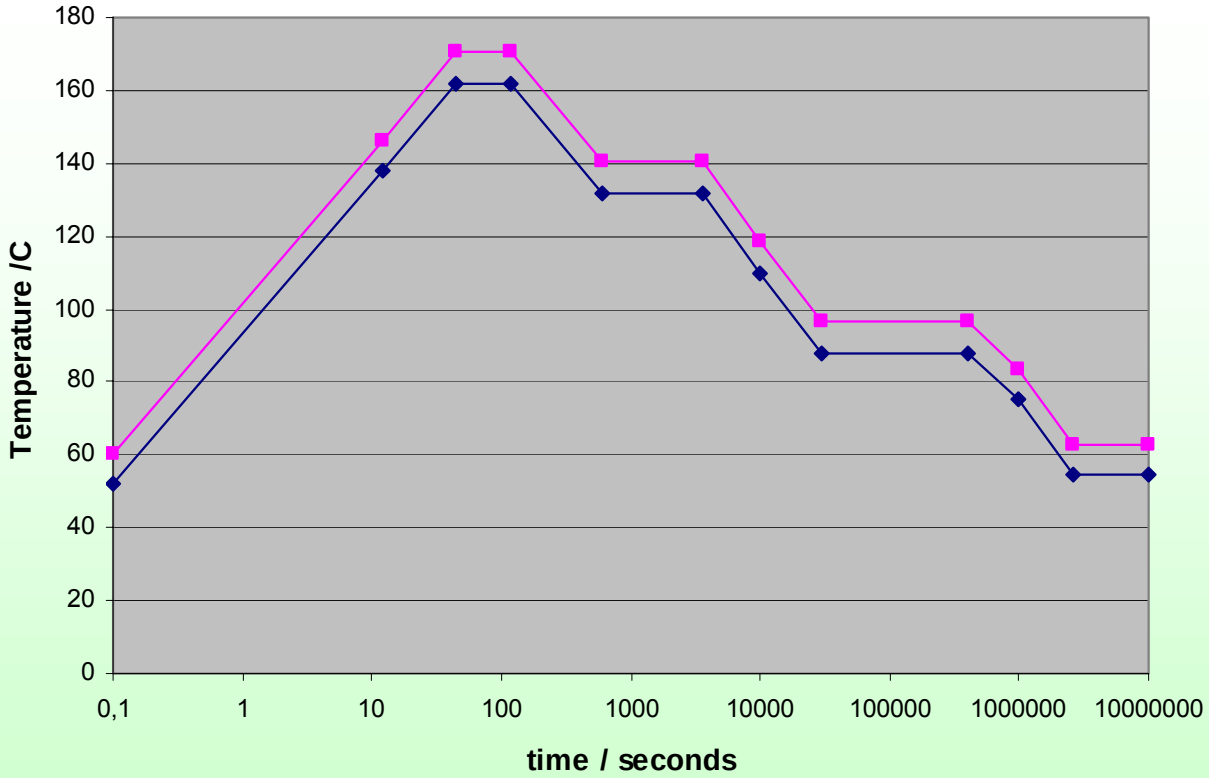
IEEE 323 - 2003



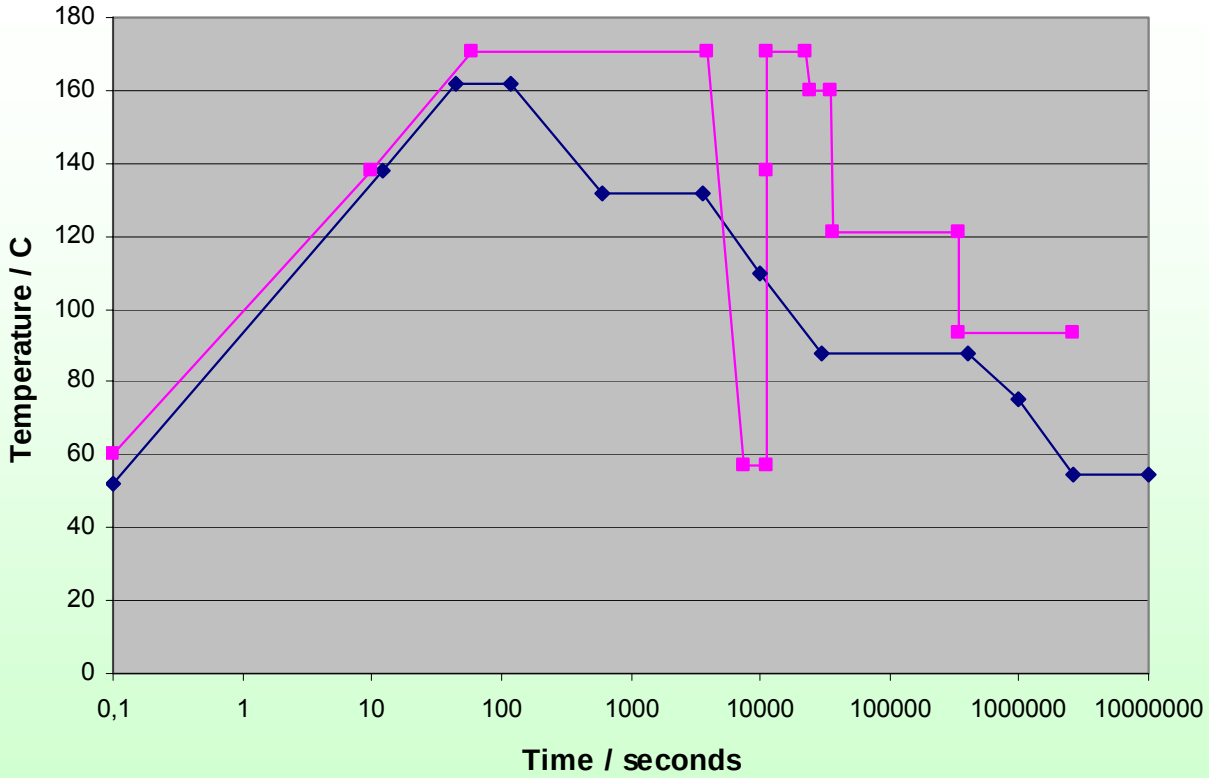
Comparison of profiles

1. Simulated test profile (STP) envelopes entire service condition profile (SCP) with required margin
2. STP envelopes SCP with amplitude margin
3. Shifted STP (Offset) envelopes the SCP

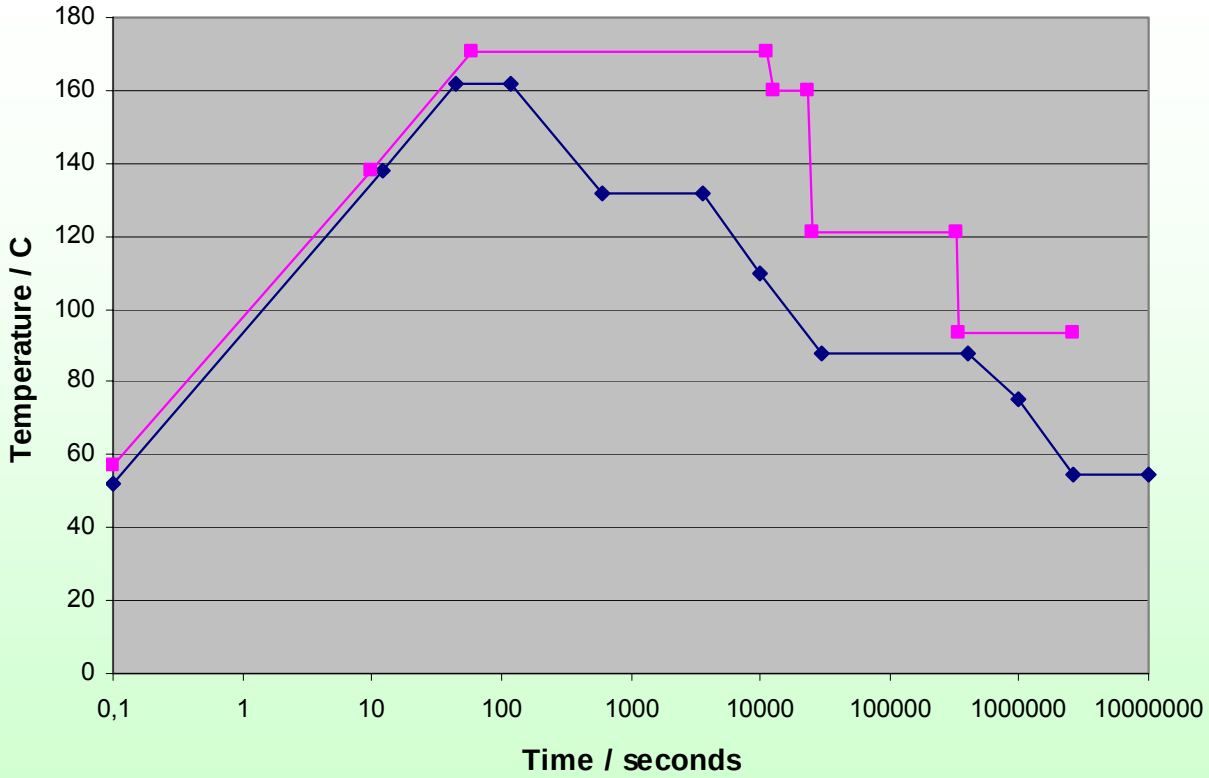
STP envelopes entire SCP with required margin



STP envelopes SCP with amplitude margin



Shifted STP (Offset) envelopes the SCP



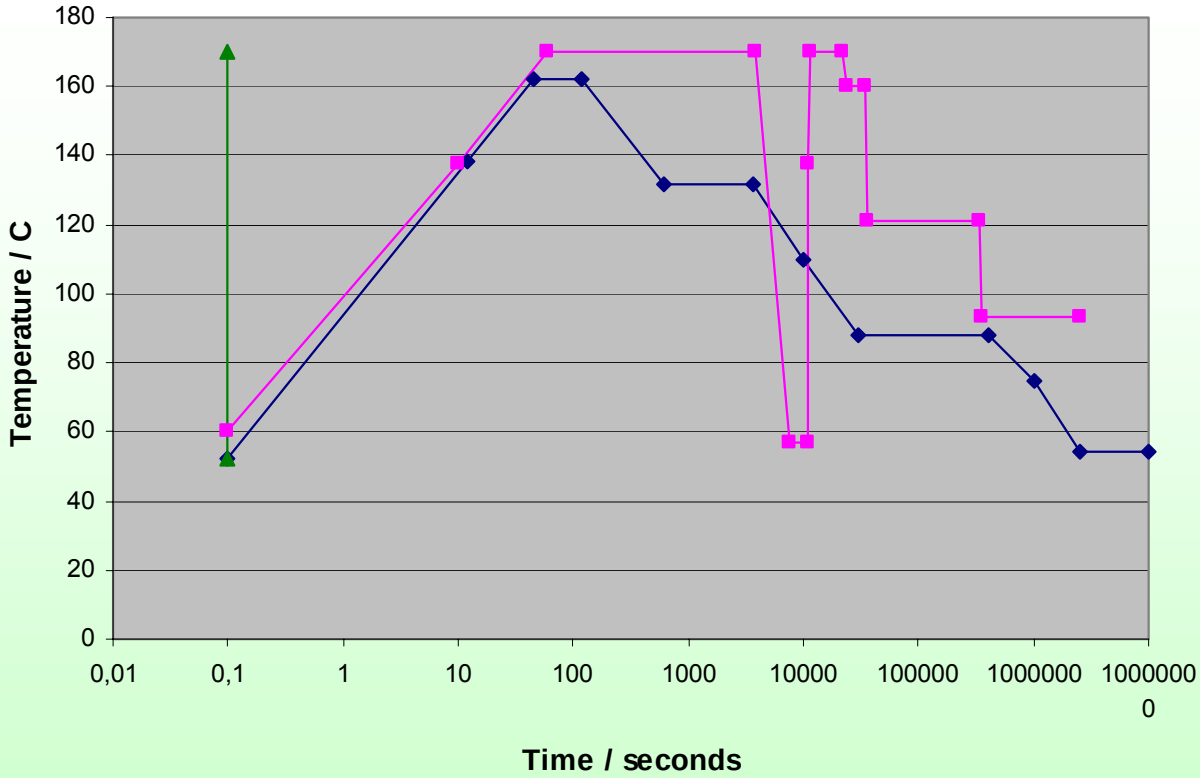
Peak value comparison & PAOT calculation

- Peak value comparison

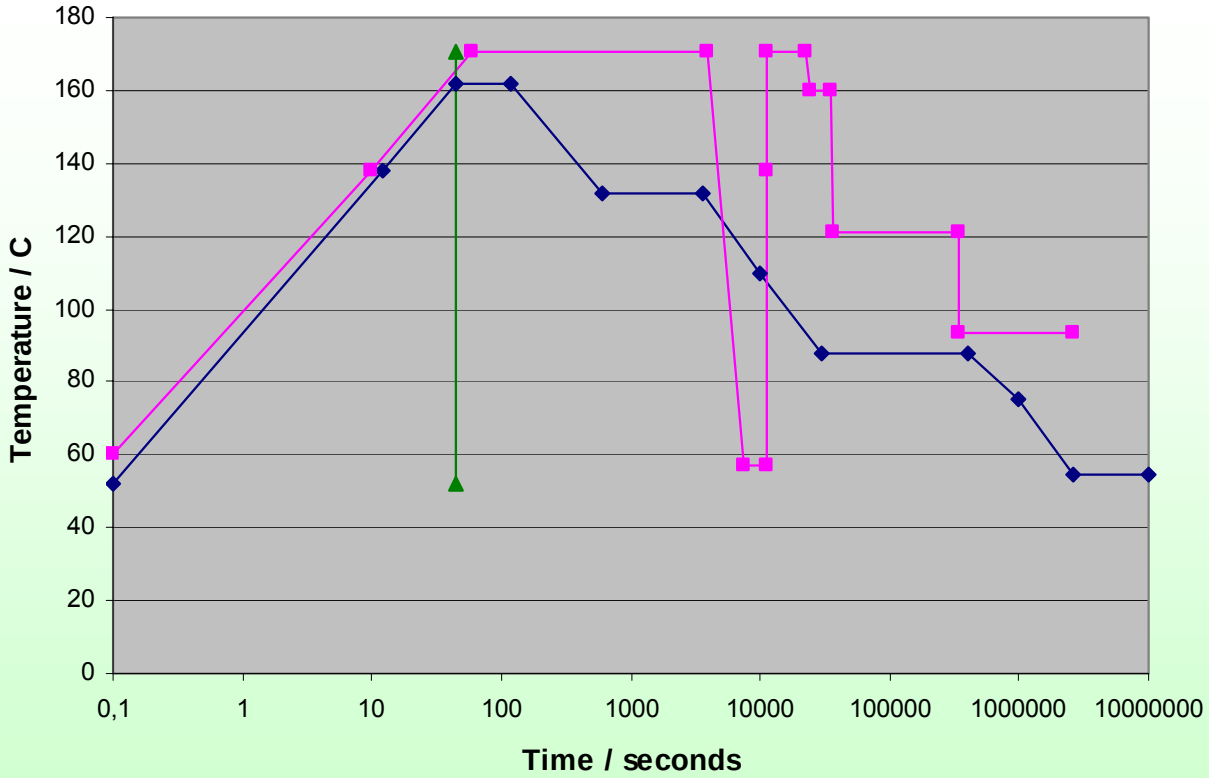
  Max of STP > Max of SCP + 15°F

- PAOT calculation
  1. PAOT calculation based on entire profiles
  2. PAOT calculation starts at PAOT Start Time
  3. After PAOT Start Time STP envelopes entire SCP (PAOT Start Time= 1 hour?)

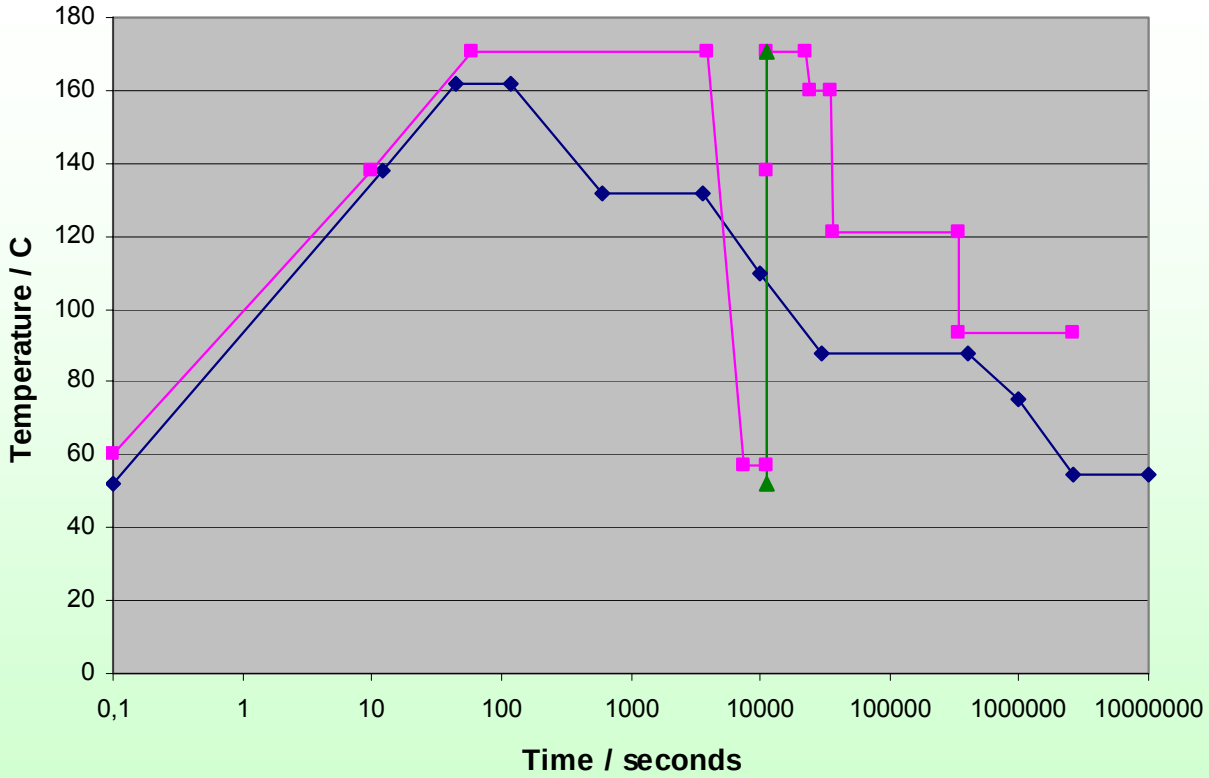
PAOT calculation based on entire profiles



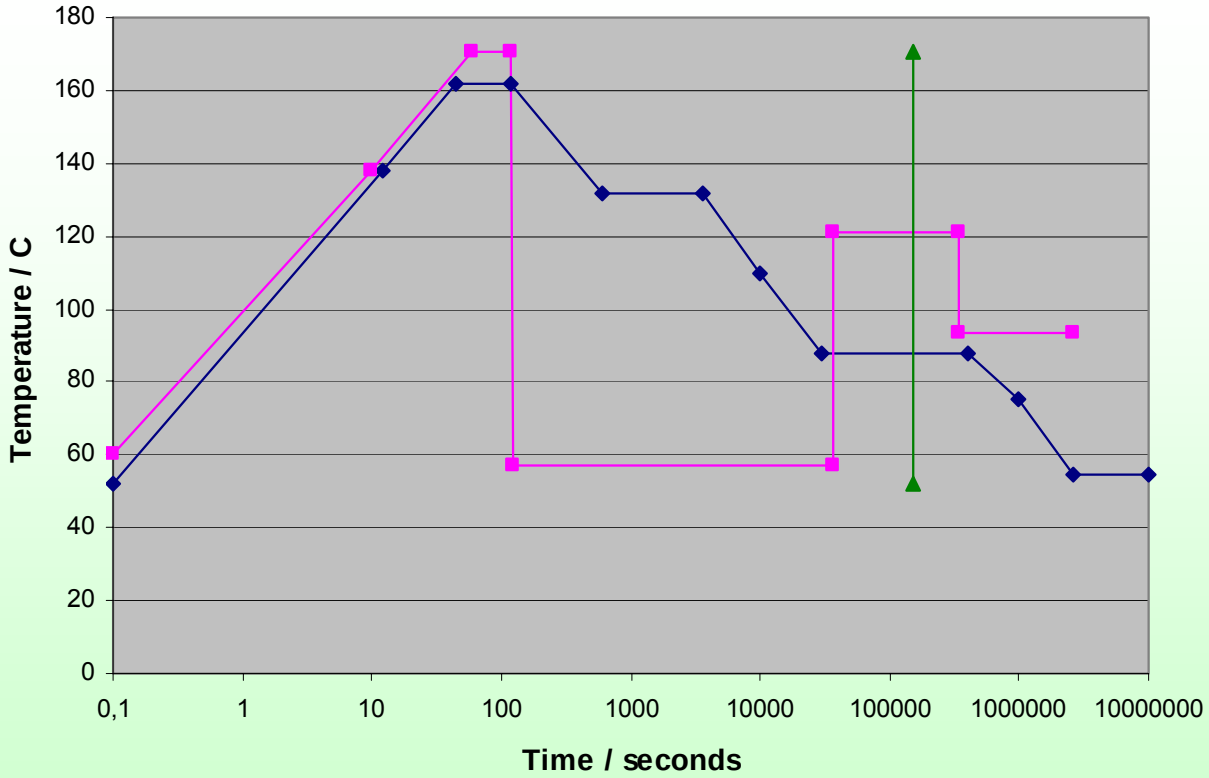
PAOT starts with PAOT Start Time



After PAOT Start Time STP envelopes entire SCP



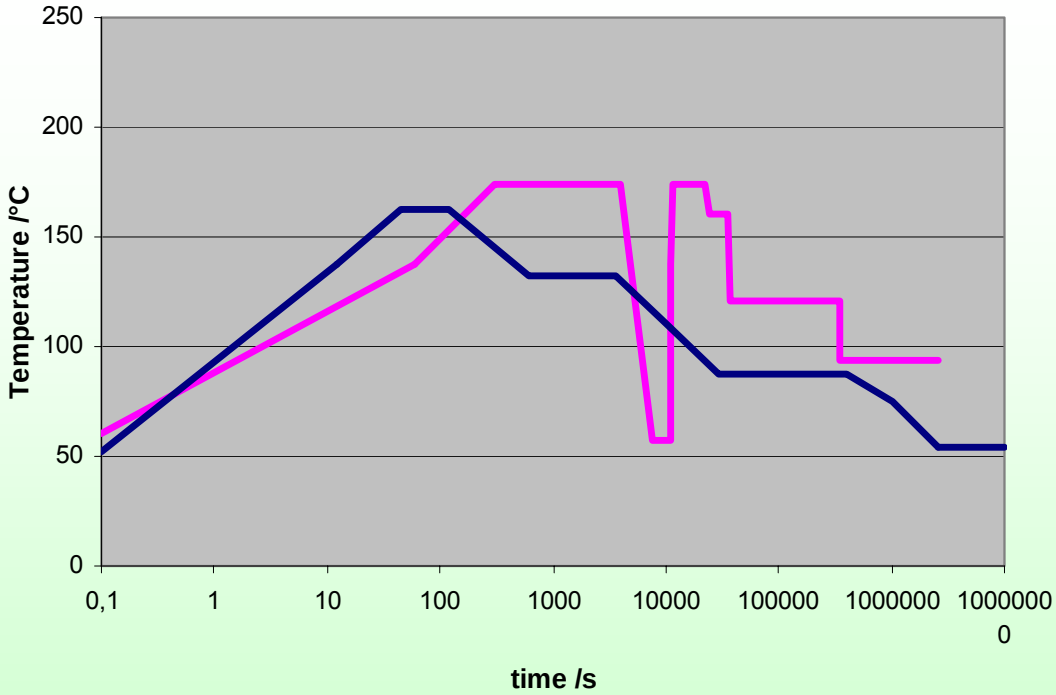
After PAOT Start Time STP envelopes entire SCP?!



Issues to be Addressed

- Rise Time (PAOT Start Time)
- Shifting of STP (Offset)
- Peak value comparison
- Profile Comparison
  - STP envelopes entire SCP
  - STP envelopes entire SCP with required margin at peak value
  - Shifted STP (Offset) envelopes entire SCP

Rise Time


250
200
150
100
50
0
Temperature /°C
0,1
1
10
100
1000
10000
100000
1000000
10000000
time /s

Post Accident Operating Time (PAOT) Calculation

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Post Accident Operating Time (PAOT) Calculation

- Calculation Methods
- Temperature Time Constant
- Transconfiguration of STP
  - Shifting of STP (Offset)
- Transconfiguration of SCP
  - Extrapolation of SCP
- Start Time
- Activation Energy
- Reference Temperature
- Heat-Rise-Temperature

Calculation Methods

- Comparison of degradation time equivalents (t_{eq}) of STP and SCP at referece temperature

$$(t_{EqTest} - t_{EqAcc}) / t_{EqAcc} > 10\ \%$$

  - Arrhenius Calculation

$$t_{eq} = A * \exp(- B / T))$$

  - 10-Degree-Rule Calculation

$$t_{eq} = A * 2 \wedge (B * T)$$

Arrhenius Equation

$$t_{eq} = A \cdot \sum_i \Delta t_i \cdot e^{-B/T_i}$$

$$t_{eq} = \sum_i \Delta t_i \cdot e^{-E_A / k_B \cdot (1/T_i - 1/T_{ref}}$$

$$t_{eq} = e^{-E_A/(k_B \cdot T_{ref})} \cdot \sum_i \Delta t_i \cdot e^{-E_A/(k_B \cdot T_i)}$$

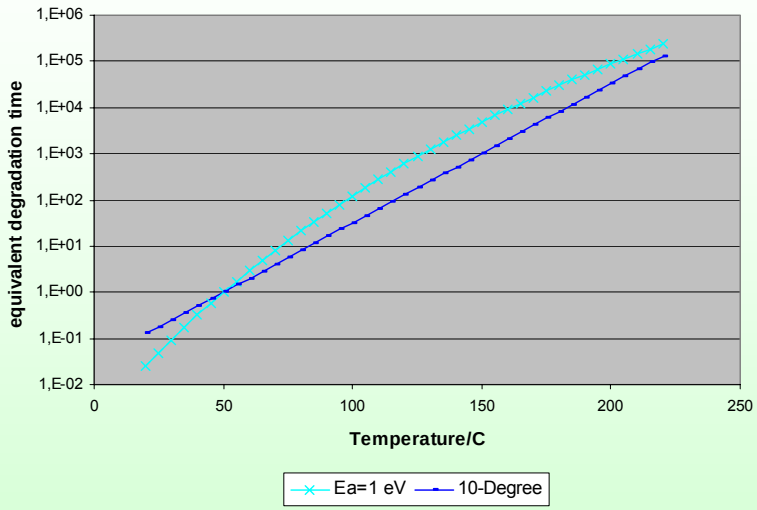
10-Degree-Rule Equation

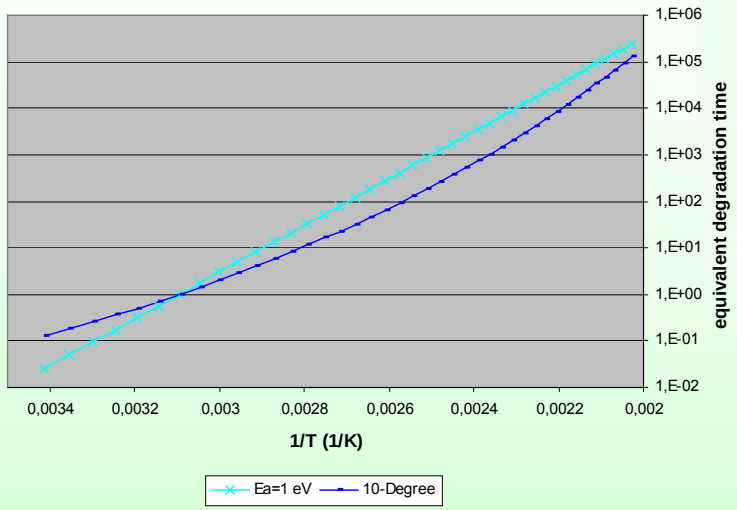
$$t_{eq} = A \cdot \sum_i \Delta t_i \cdot 2^{B \cdot T_i}$$

$$t_{eq} = \sum_i \Delta t_i \cdot 2^{(T_i - T_{ref})/10}$$

$$t_{eq} = 2^{T_{ref}/10} \cdot \sum_i \Delta t_i \cdot 2^{T_i/10}$$

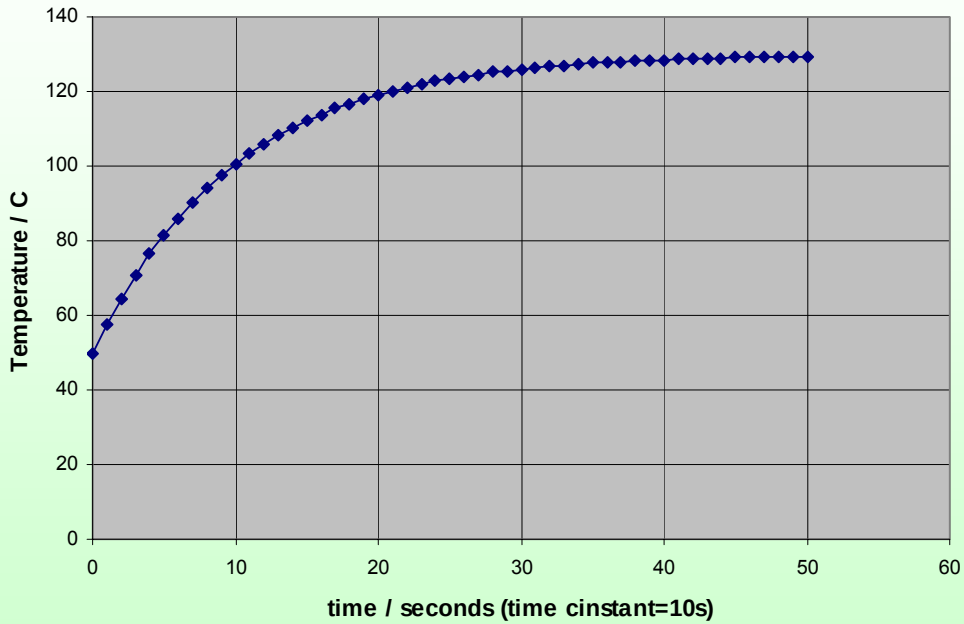
Arrhenius Calculation vs 10-Degree-Rule Calculation



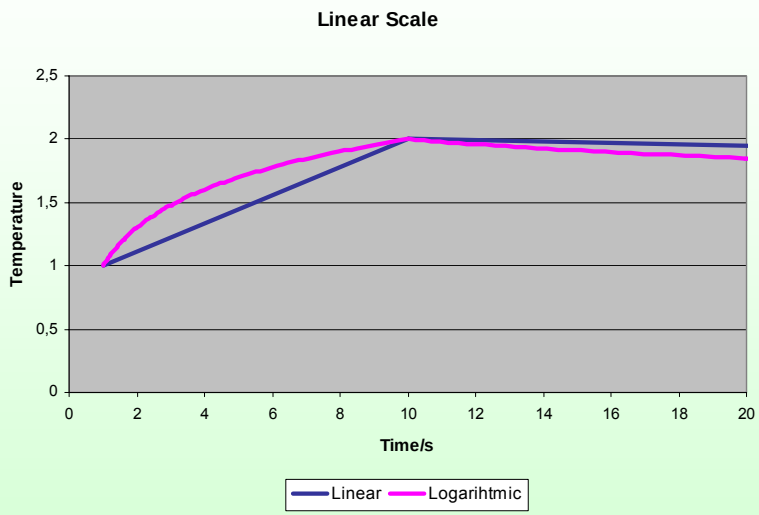


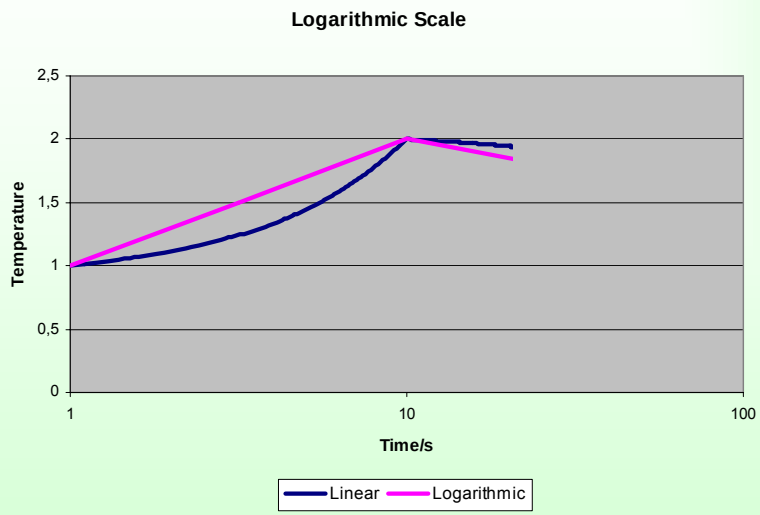
Temperature Time Constant

$$T(t)=T(t=0)+\Delta T^{*}(1-\exp(-t/\tau))$$

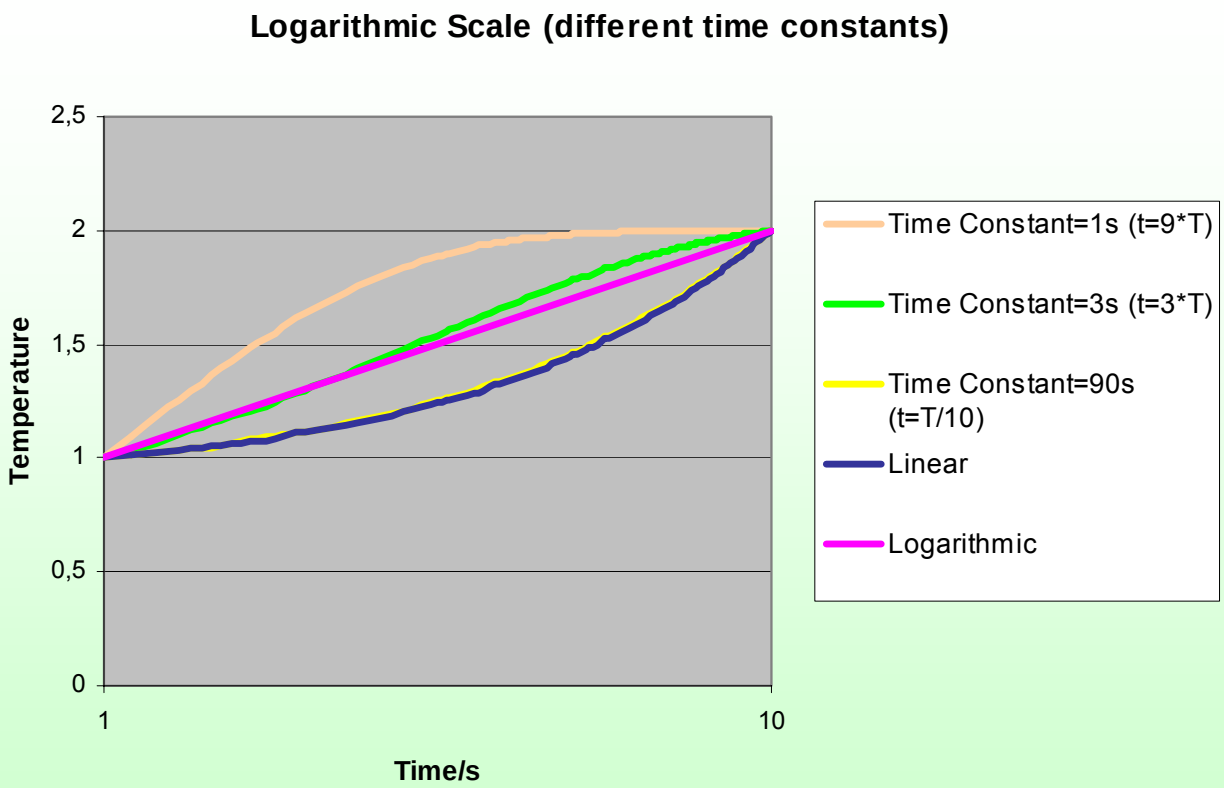


Linear vs Logarithmic Time Scale





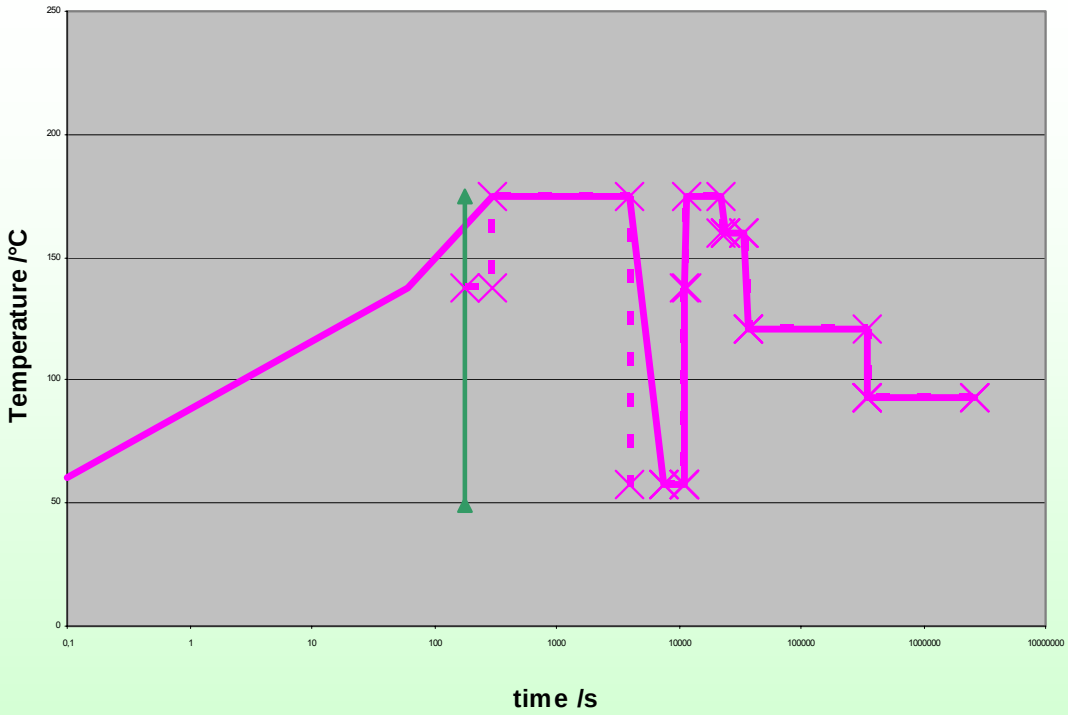
Different Time Constants



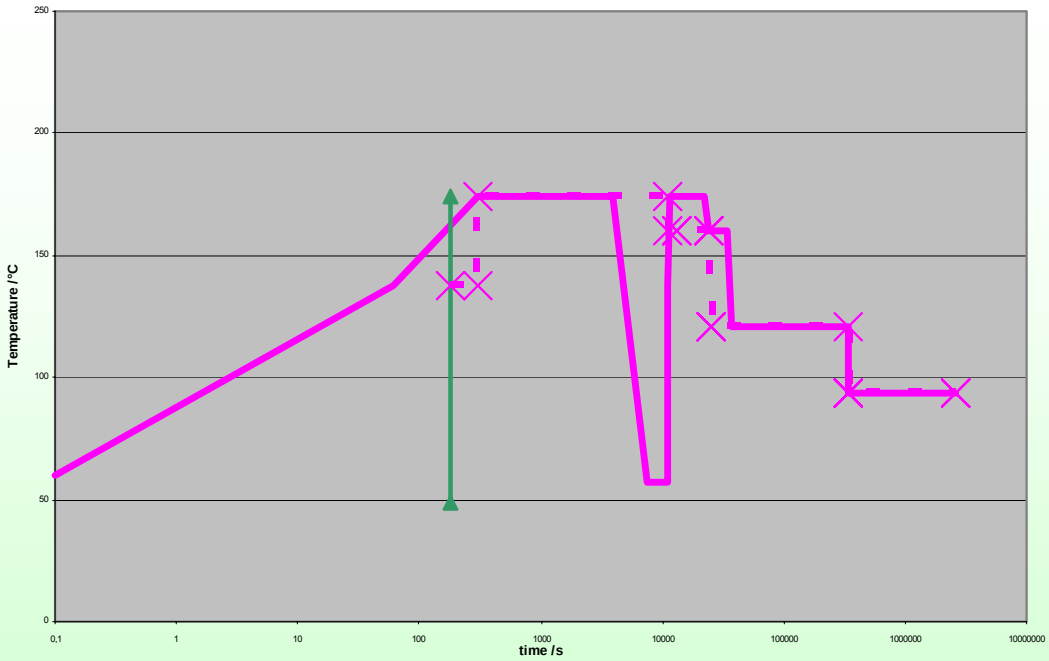
Transconfiguration of STP

- First data point
- Lower temperature value of two neighbouring points
- Shifting of profile (Offset)

Transconfiguration of STP



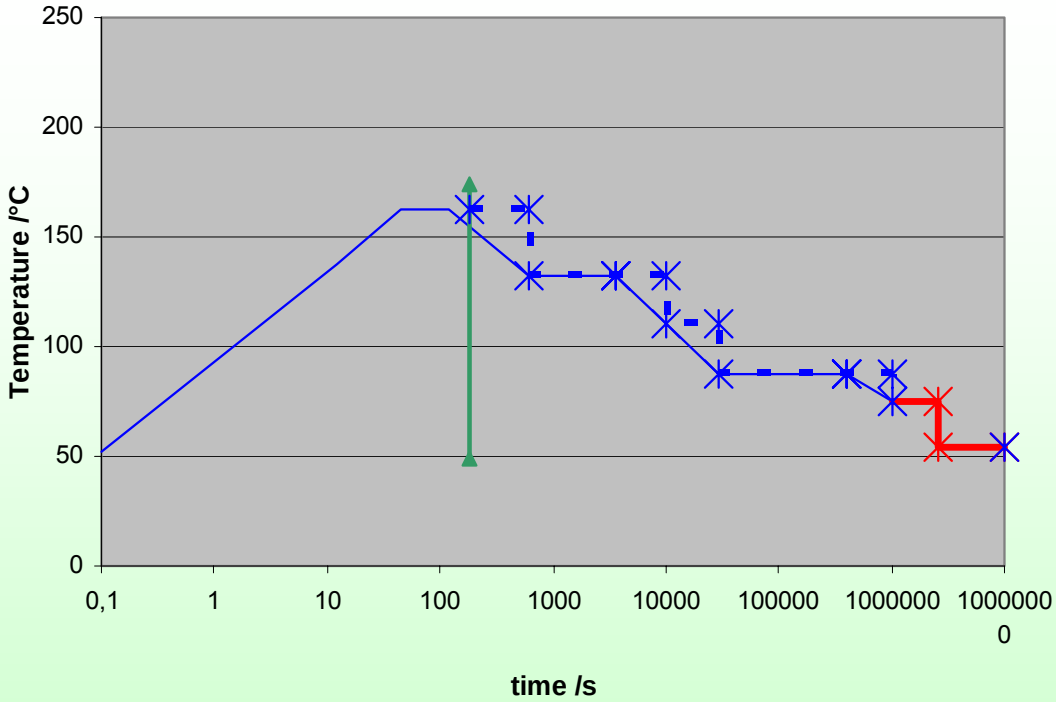
Transconfiguration of STP Shifting of STP (Offset)



Transconfiguration of SCP

- First data point
- Higher temperature value of two neighbouring points
- Duration of profile
- Last data point
- Extrapolation of profile when duration is longer than the last data point and temp. of last datapoint is above normal temp.

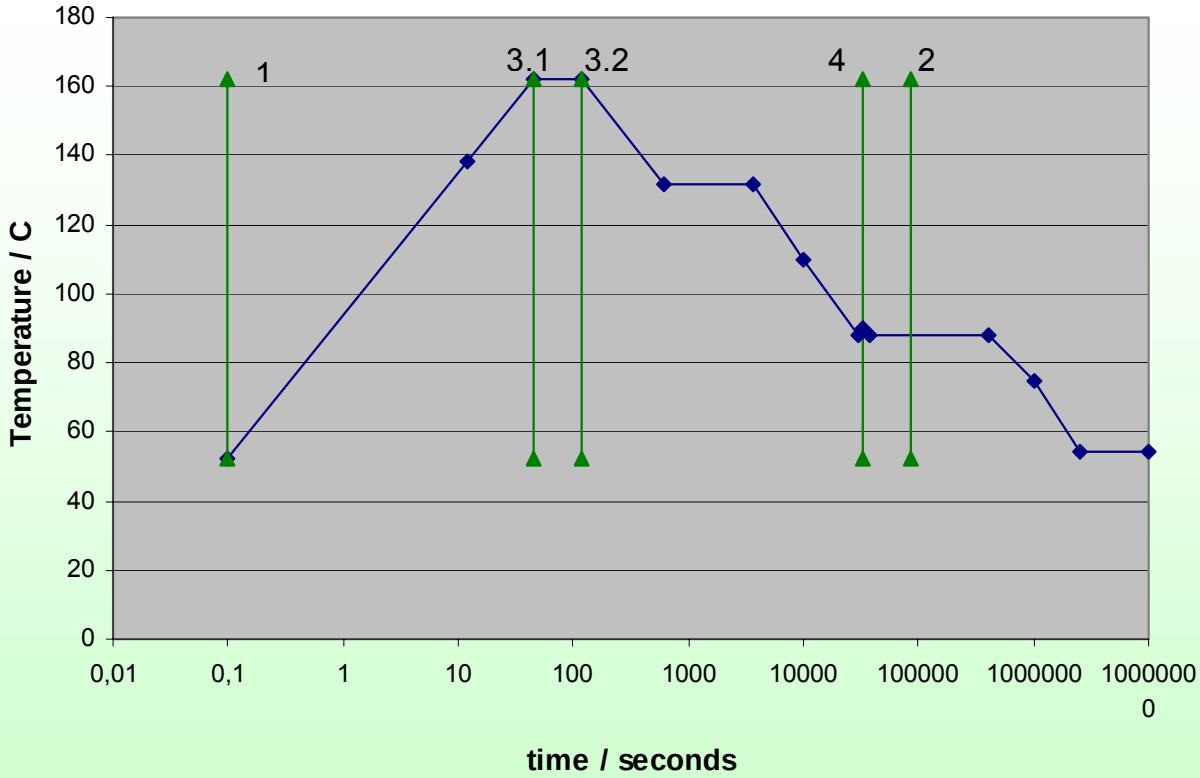
Transconfiguration of SCP
Extrapolation of SCP



Start Time

1. At first data point
2. At fixed time value (e.g. 24 hours)
3. After the peak value of SCP
4. After the last temperature rise

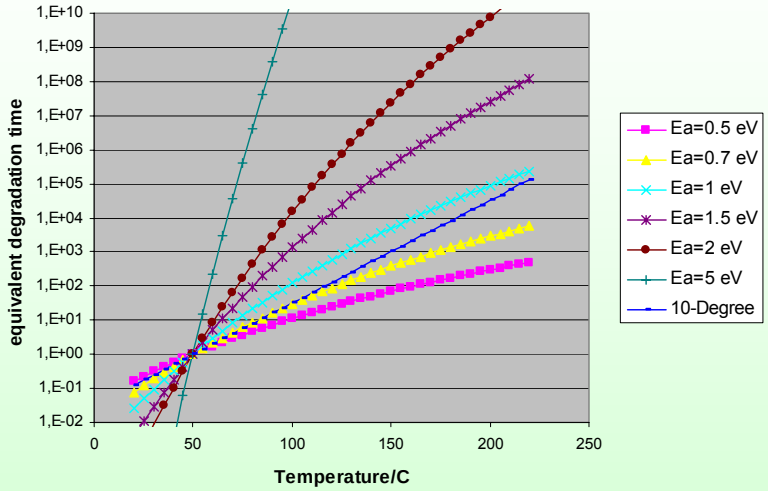
Start Time

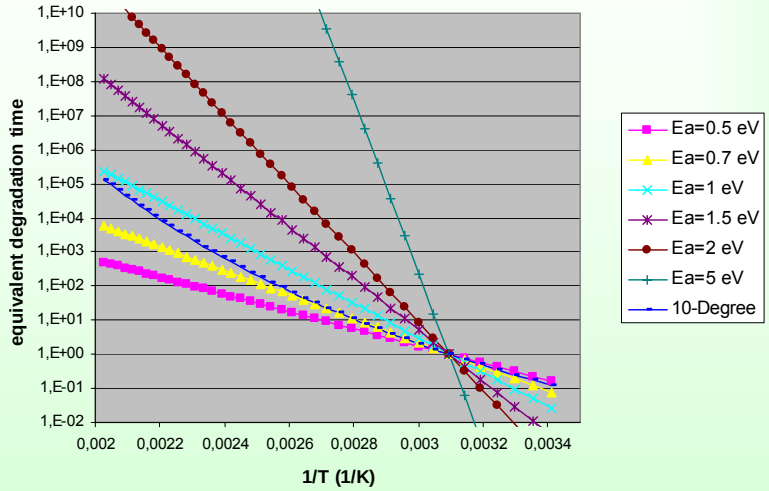

180
160
140
120
100
80
60
40
20
0
Temperature / C
1
3.1
3.2
4
2
0,01
0,1
1
10
100
1000
10000
100000
1000000
10000000
time / seconds

Activation Energy & Reference Temperature

- Activation Energy – the lowest value of activation energy of all component parts
- Reference Temperature does not impact on the calculation
  - Normal temperature
  - Normal temperature + process-heat-rise temperature
  - Fixed temperature (e.g. 50C)

Activation Energy

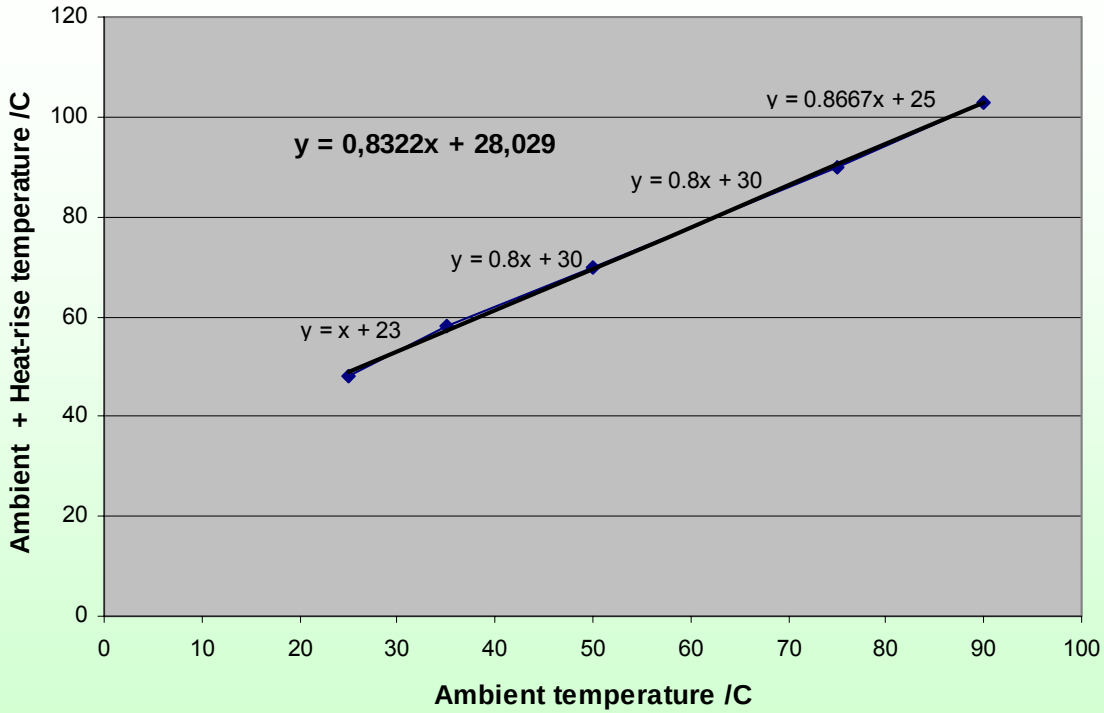




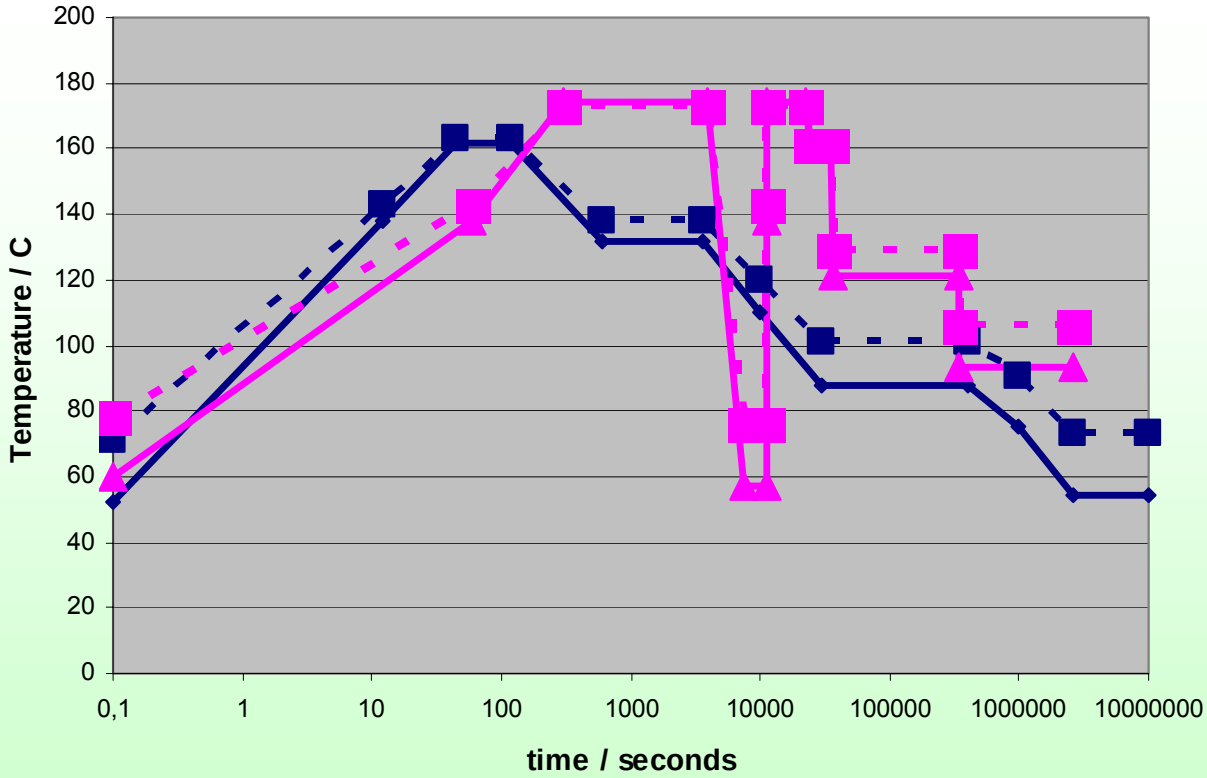
Heat-Rise-Temperature

- Linear extrapolation
  - Define slope and intercept for each segment
  - Define slope and intercept for entire profile
- Influence of temperature time constant
  - Add heat-rise to entire profiles
  - Add heat-rise to SCP only
  - Add heat-rise after fixed time (e.g. 1 hour)
  - Add heat-rise to entire SCP and to STP after fixed time

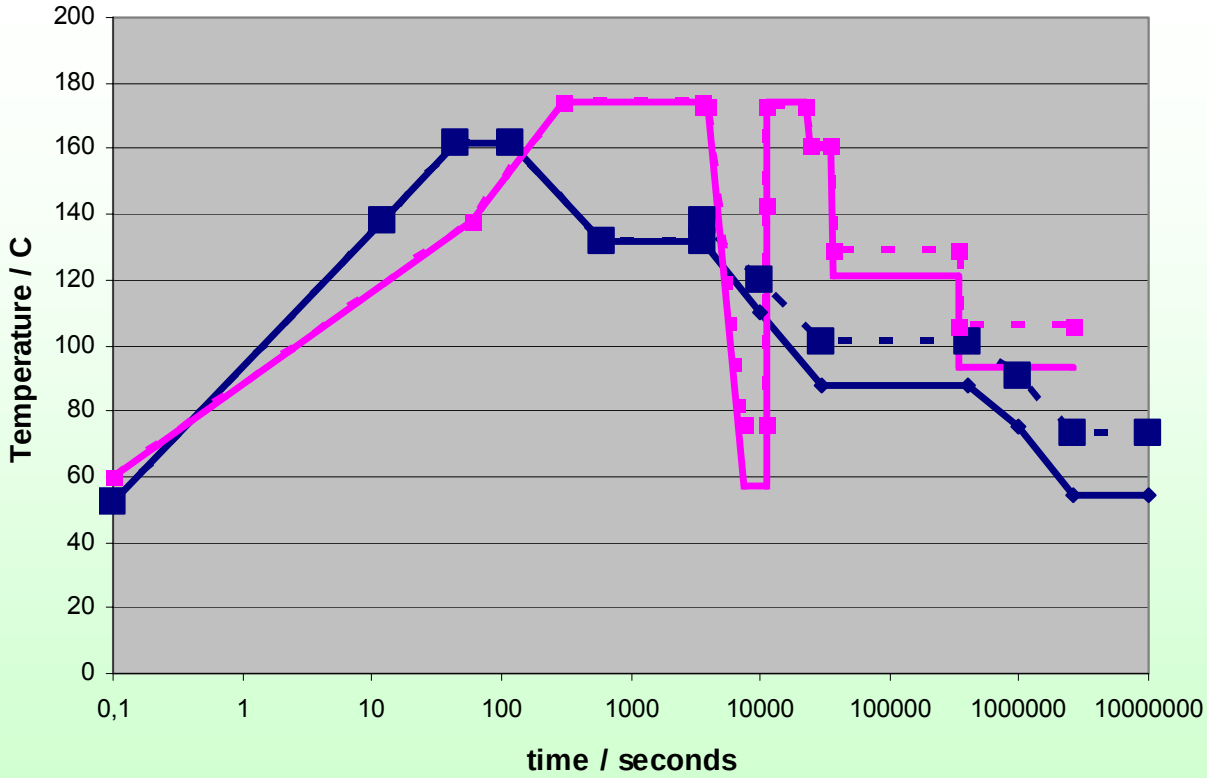
Slope and Intercept



Heat-rise Apply to Entire Profile



Heat-rise Apply after Fixed Time



Total Integrated Dose Calculation

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Total Integrated Dose Calculation

- Aging dose & Accident doses
- HARSH criteria
- Operating time
- Beta dose reduction
- Using tested aging dose in accident dose comparison
- Using tested accident dose for qualified life calculation

Aging dose & Accident doses

- 40 - year dose gamma - $\gamma_{40\text{-year}}$
- Accident dose gamma - γ_{acc}
- Accident dose beta - β_{acc}
- Reduced accident dose beta (E>0,5 MeV) - β_{50}
- Bremsstrahlung dose - x_{brems}
- TID - total integrated dose (gamma equivalent)

HARSH criteria

- Treshold value
  - 10kRads to 100kRads
  - 1000 Rads for electronics
- Criteria
  - Aging dose + Accident doses > Treshold value
  - Accident doses > Treshold value

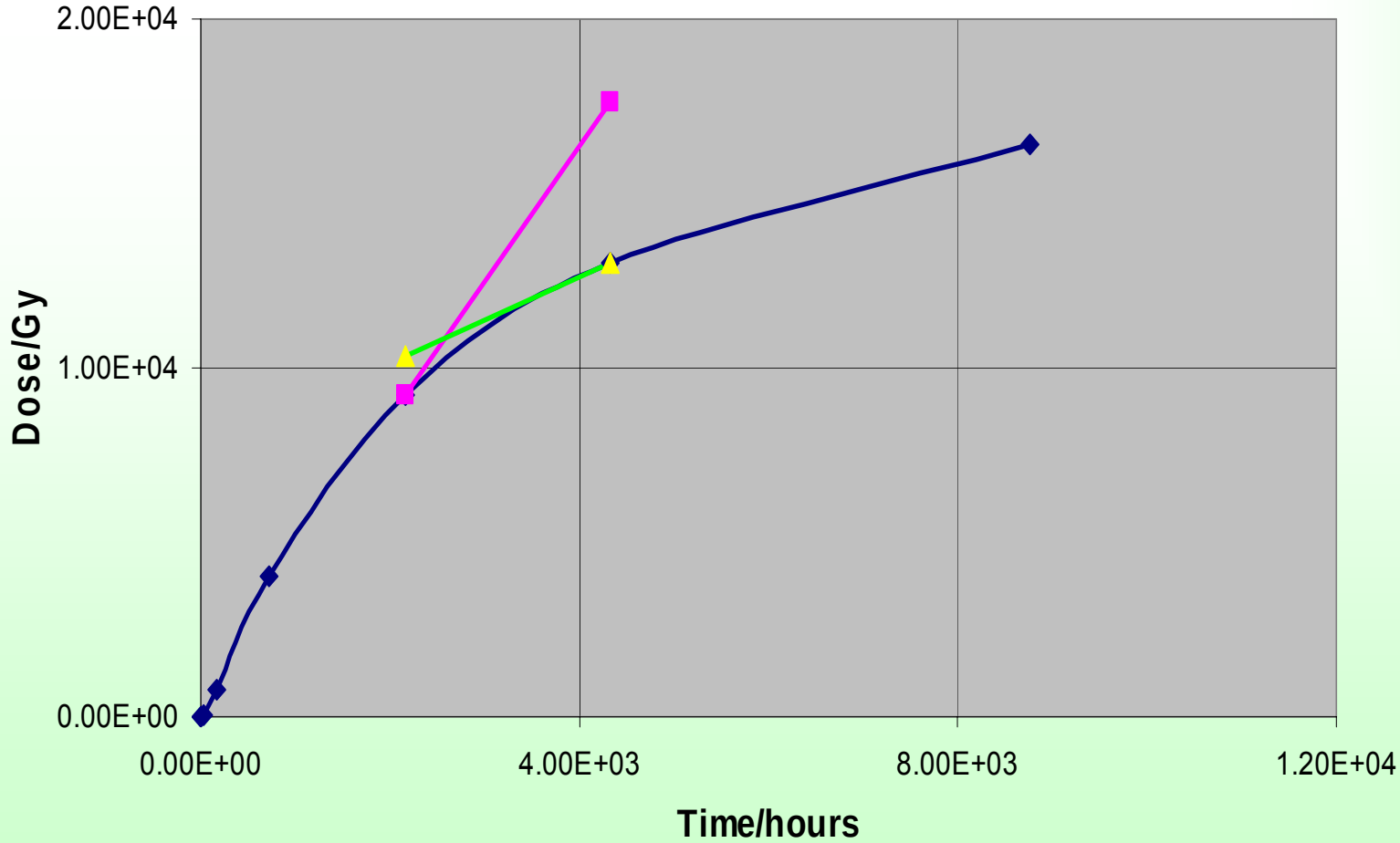
TID Calculation
Operating time

$$TID_{acc} = \gamma_{acc} + x_{brems} + \gamma_{e\beta}$$

$$TID = \int_0^t (\gamma_{accRate} + x_{bRate} + \gamma_{e\beta Rate})dt$$

$$TID_{tx}=min[TID_{tn}+rate_{tn}(t_x-t_n),TID_{tn1}-rate_{tn}(t_x-t_{n1})]$$

Cumulative Dose



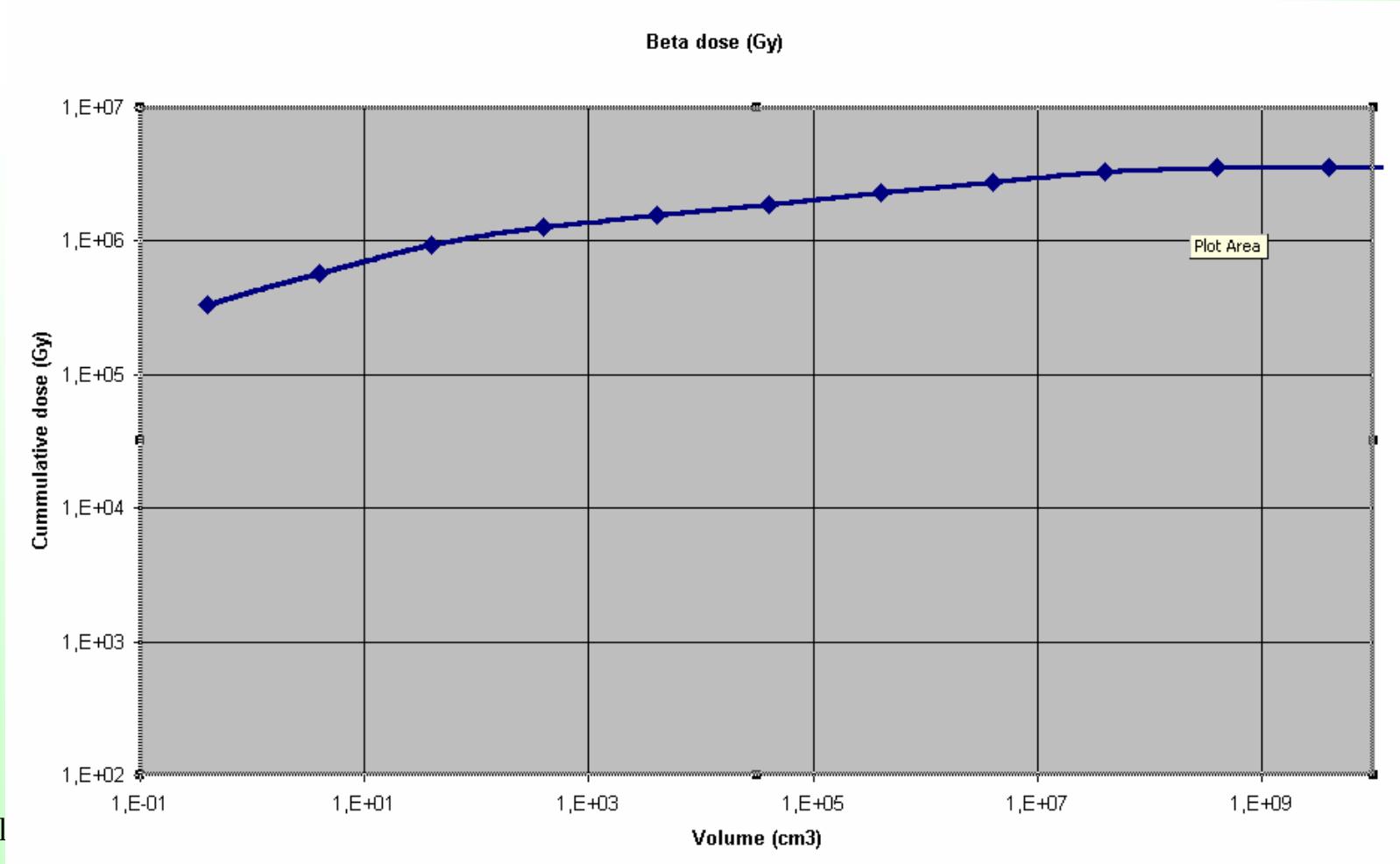
Gamma Equivalent of Beta Dose Calculation ($\gamma_{E\beta}$)

$$\gamma_{E\beta} = \beta VRF \; x \; \beta$$

- β - *Beta dose* β_{acc} *or* β_{50}
- βVRF - *beta dose reduction factor* $(0 < \beta vrf < 1)$

$$\beta(x) = \beta(N) \cdot \left(\frac{V(x)}{V(N)} \right)^{\frac{\log(\beta(N+1)/\beta(N))}{\log(V(N+1)/V(N))}}$$

Beta Dose Volume Reduction Factor (βVRF)



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Using tested aging dose in accident dose comparison

- *Peak value comparison:*

$$(TID_{TestAcc} - TID_{Acc})/(TID_{Acc}) > 10\%$$

or

$$(TID_{TestAcc} + k*\gamma_{TestAging} - TID_{Acc})/(TID_{Acc}) > 10\%$$

where

$$0 <= k <= 1$$

Using tested accident dose for qualified life calculation

$$QL_R = \gamma_{TestAging} / \gamma_{40rate}$$

Or

$$QL_R = (\gamma_{TestAging} + TID_{TestAcc} - 1{,}1 \times TID_{Acc}) / \gamma_{40rate}$$

When aging and accident radiation were performed at the same time (before seismic testing) and

$$TID_{TestAcc} > 1{,}1 \times TID_{Acc}$$

Questions?

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