

PROBABILISTIC MODELS TO ESTIMATE FIRE- INDUCED CABLE DAMAGE AT NUCLEAR POWER PLANTS

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- BACKGROUND.
- OBJECTIVE.
- PROPOSED MODELS.
 - KINETIC MODEL.
 - HEAT TRANSFER MODEL.
 - “K FACTOR” MODEL.
- DATA GATHERING AND ANALYSIS.
- DAMAGE-ENDURANCE MODEL DEVELOPMENT.
- RESULTS ANALYSIS.
- CONCLUSIONS AND RECOMMENDATIONS.

- FIRE IS A MAJOR CONTRIBUTOR TO NPP RISK.
- FIRE-INDUCED DAMAGE TO ELECTRICAL CABLES AND CIRCUITS.
- TYPES AND LIKELIHOOD OF FIRE-INDUCED FAILURES MODES.
- CONDUCTOR TO CONDUCTOR SHORTING FAILURE MODE.
- FIRE TESTING PROGRAMS (EPRI, NRC, ...)



- ✓ BETTER UNDERSTANDING OF FIRE-INDUCED CABLE FAILURE MODES.
- ✓ KNOWLEDGE OF CABLE FAILURE BEHAVIOR UNDER EXTERNAL THERMAL INSULT.
- ✓ IDENTIFICATION OF INFLUENCE FACTORS TO KEY CIRCUIT FAILURES MODES.



MODELS TO ESTIMATE THE LIKELIHOOD OF FIRE-INDUCED CABLE DAMAGE AND CIRCUIT FAILURE MODES THAT DO NOT CONSIDER THE UNDERLAYING CAUSALITIES AND MECHANISMS OF FAILURES.



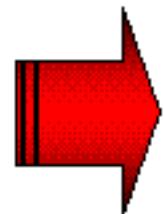
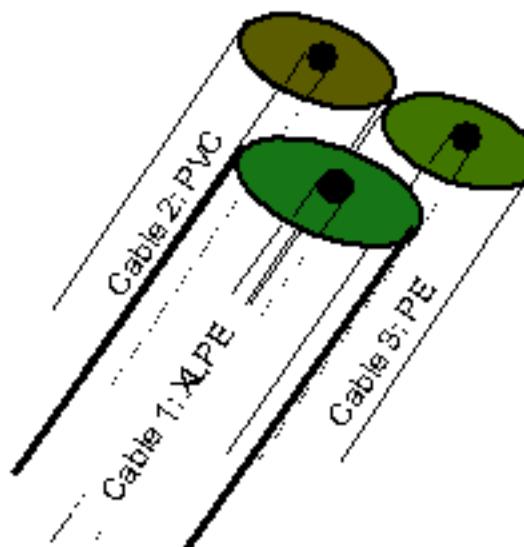
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THE OBJECTIVE OF THIS RESEARCH IS TO DEVELOP PROBABILISTIC MODELS TO PREDICT FIRE-INDUCED CABLE DAMAGE GIVEN A SPECIFIED FIRE PROFILE.

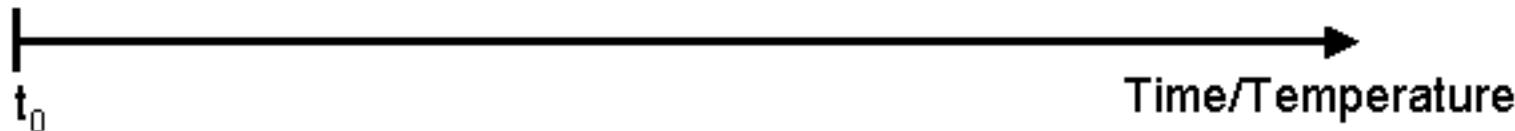
TO THE EXTENT POSSIBLE, THE MODELS MUST BE PHYSICS-BASED IN DESCRIBING THE UNDERLYING MECHANISMS OF FAILURE THAT TAKE PLACE WITHIN OR AMONG THE ELECTRICAL CABLES DURING THE FIRE ACCIDENT.

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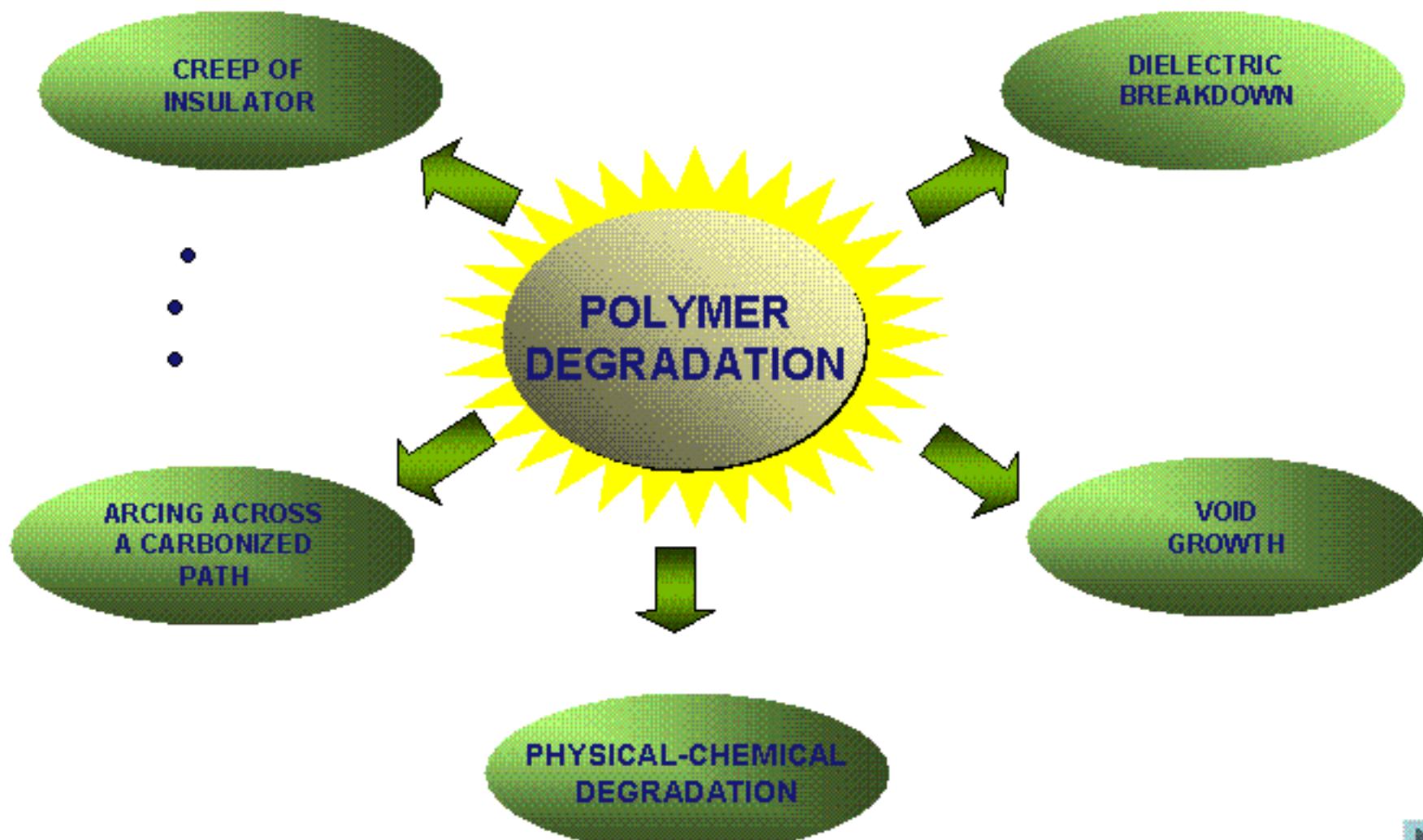
PHYSICS - BASED MODEL



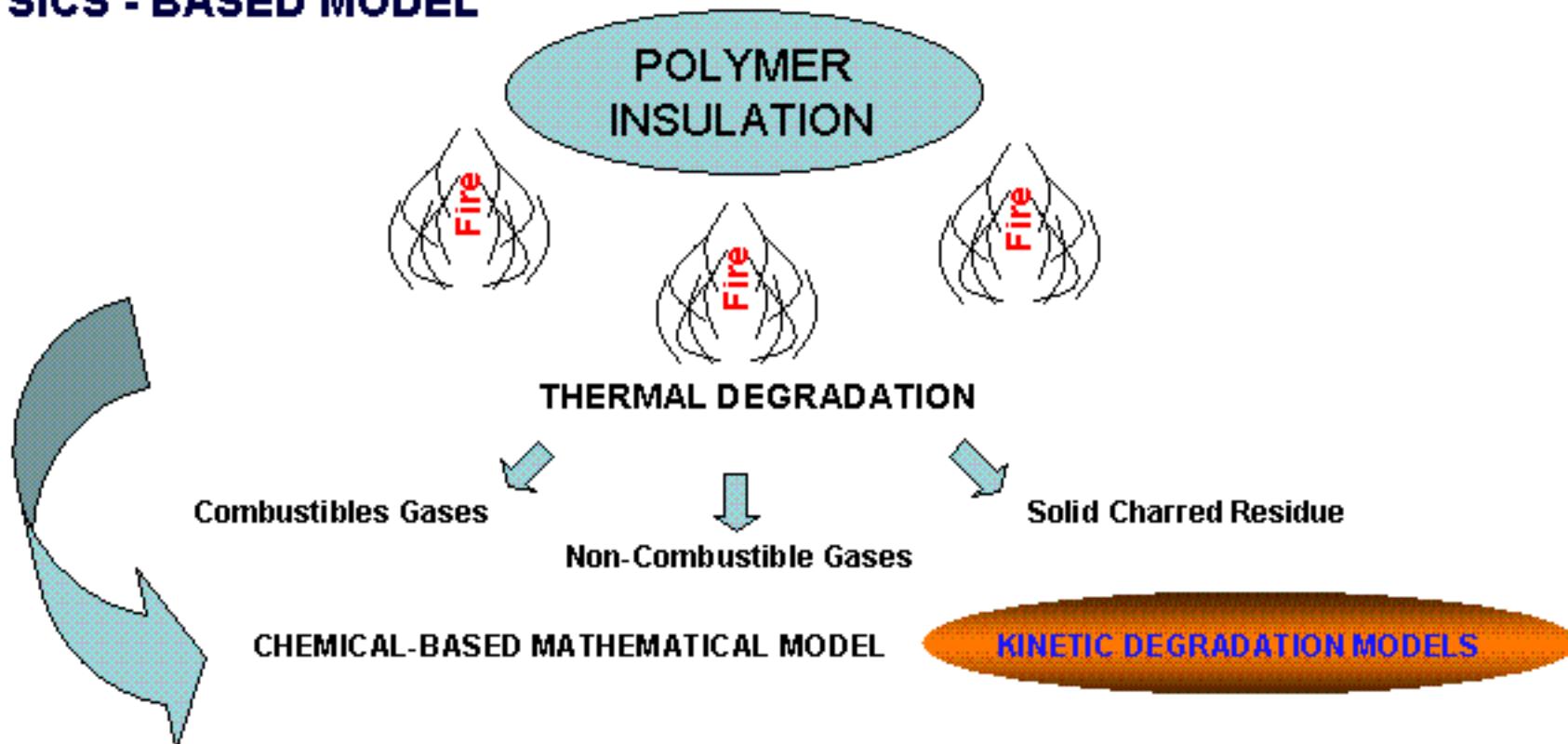
APPLICABLE
MECHANISMS
OF
DEGRADATION
AND
FAILURE



PHYSICS - BASED MODEL



PHYSICS - BASED MODEL



$$\frac{d\alpha}{dt} = -A\alpha e^{-\frac{E}{RT}}$$

$$\frac{d\alpha}{dt} = A e^{-\frac{E}{RT}} ((1-\alpha)^n \alpha^m [-\ln(1-\alpha)]^p)$$

$$\frac{d\alpha}{dt} = A_1(1-\alpha) e^{-\frac{E_1}{RT}} + A_2 \alpha e^{-\frac{E_2}{RT}}$$

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Where:

 $\alpha(t)$: degradation level

t: time

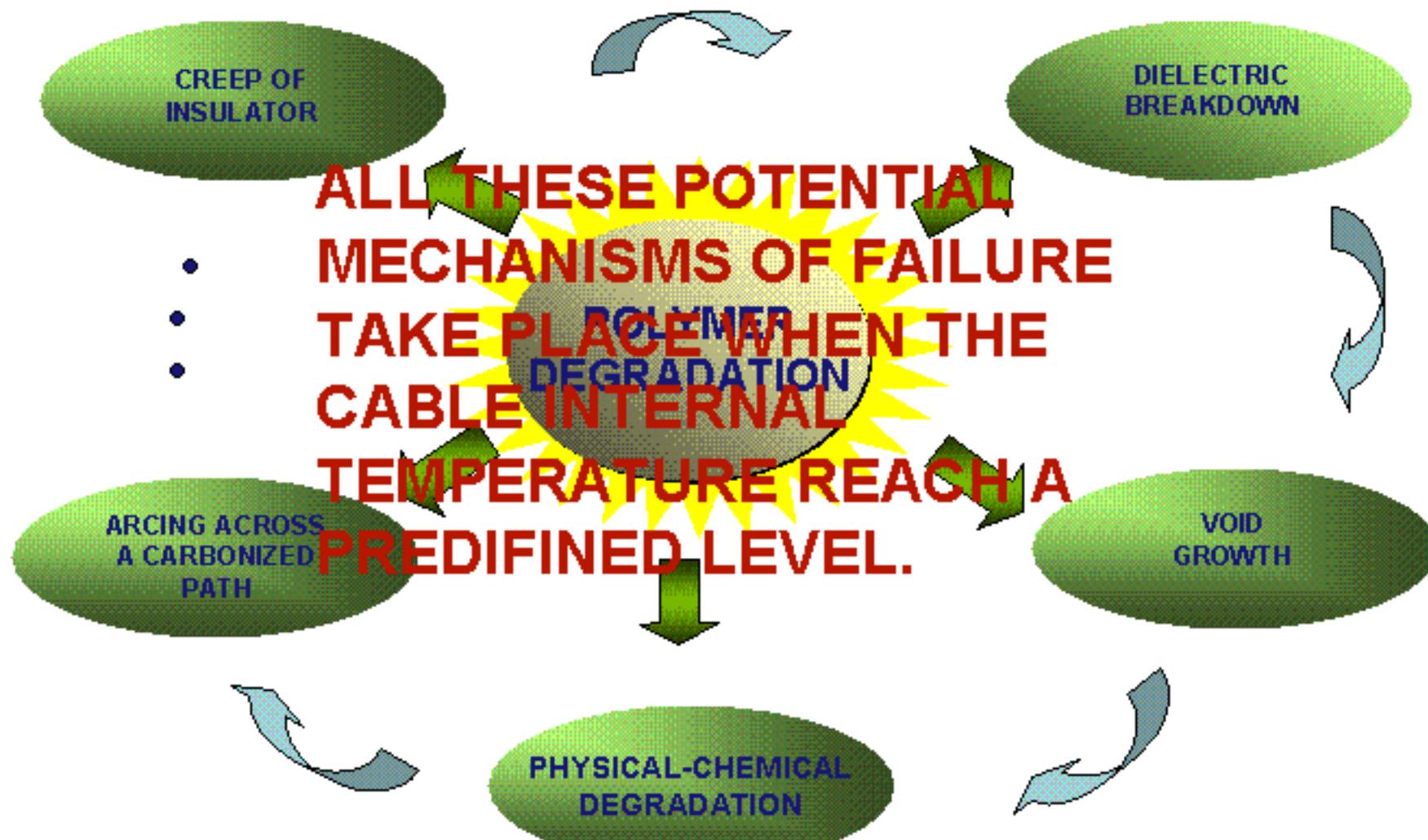
T: temperature

 A_i : pre-exponential factors

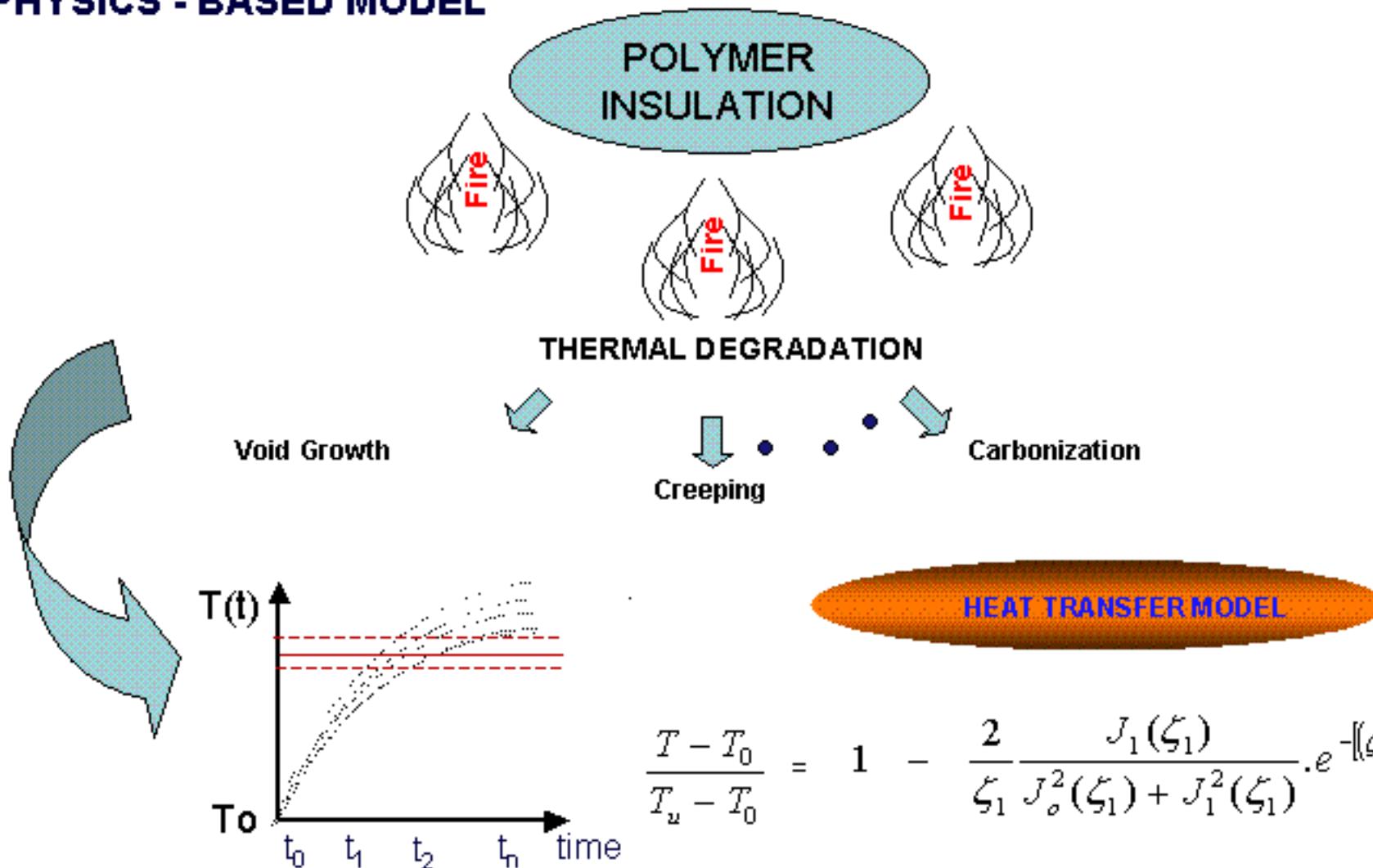
E: activation energy

R, m, n, p: constants

PHYSICS - BASED MODEL



PHYSICS - BASED MODEL

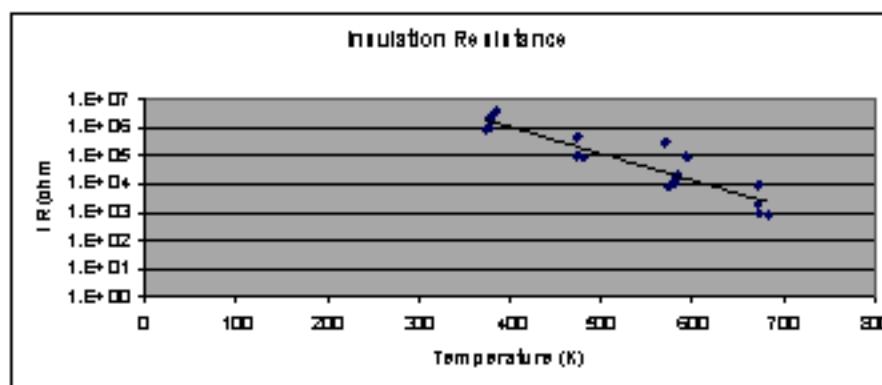
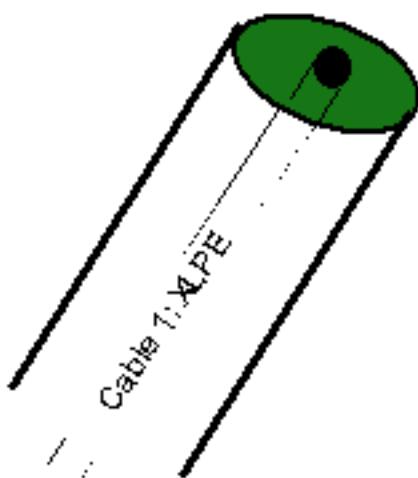


EMPIRICAL - BASED MODEL: "K Factor" Model

Insulation resistance drops exponentially with increasing temperature. One of the models proposed as an indirect approach to evaluate cable functionality upon external thermal insult is the "K factor" model.

$$IR = K(T_k) \cdot \ln\left(\frac{D_{out}}{D_{in}}\right)$$

$$K(T_k) = C_1 \cdot e^{-(C_2 T_k)}$$

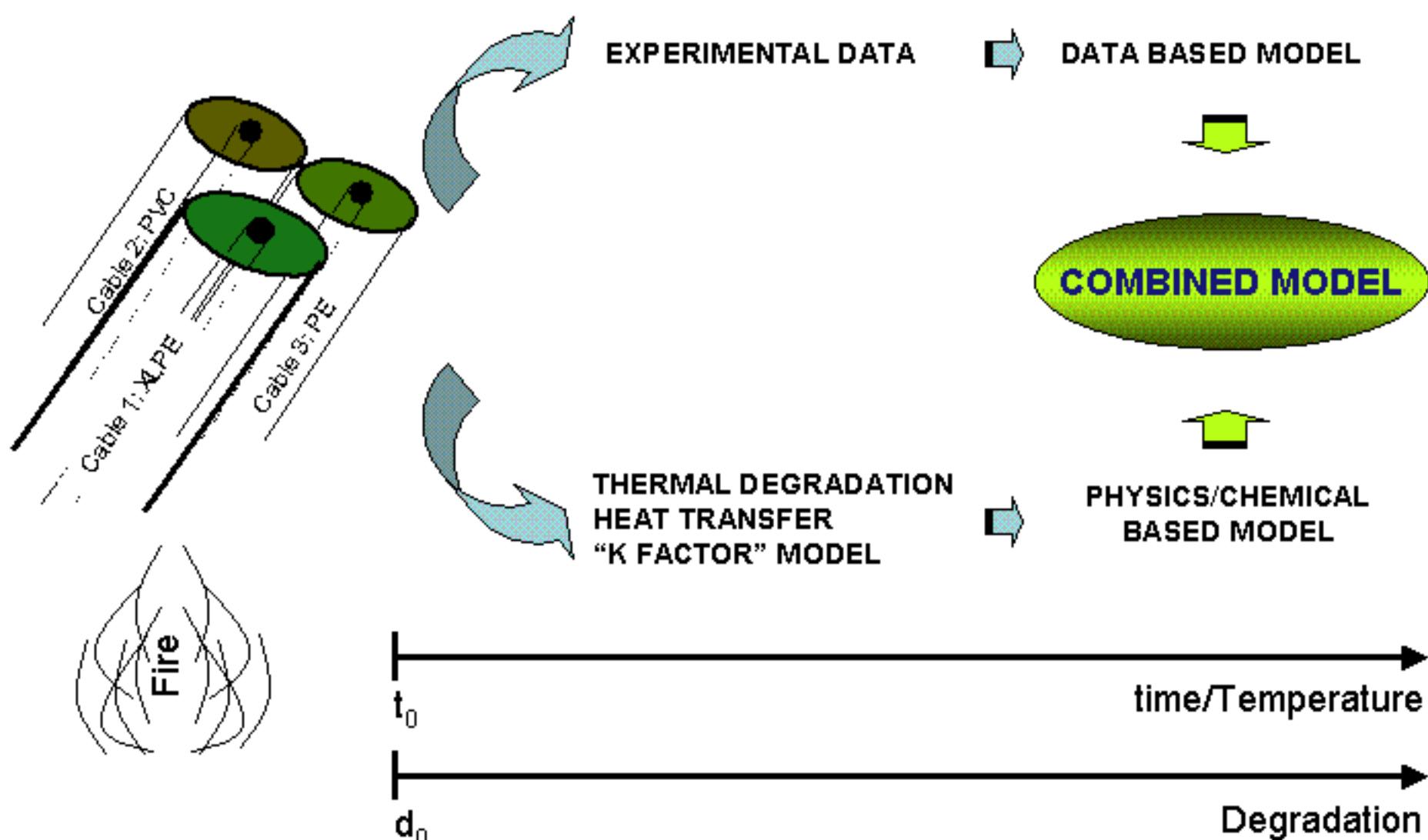


D_{out} = outer diameter of the insulation (m)

D_{in} = inside diameter of the insulation (m)

C_1 and C_2 constant for a given insulation material.

COMBINED MODEL



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DATA SOURCES

NUREG/CR-5546, SAND 90-0696.

Investigation of the effects of thermal aging on the fire damageability of electric cables.

NUREG/CR 6776, SAND 2002 - 0447P.

Cable Insulation Resistance Measurements made during cable fire tests.

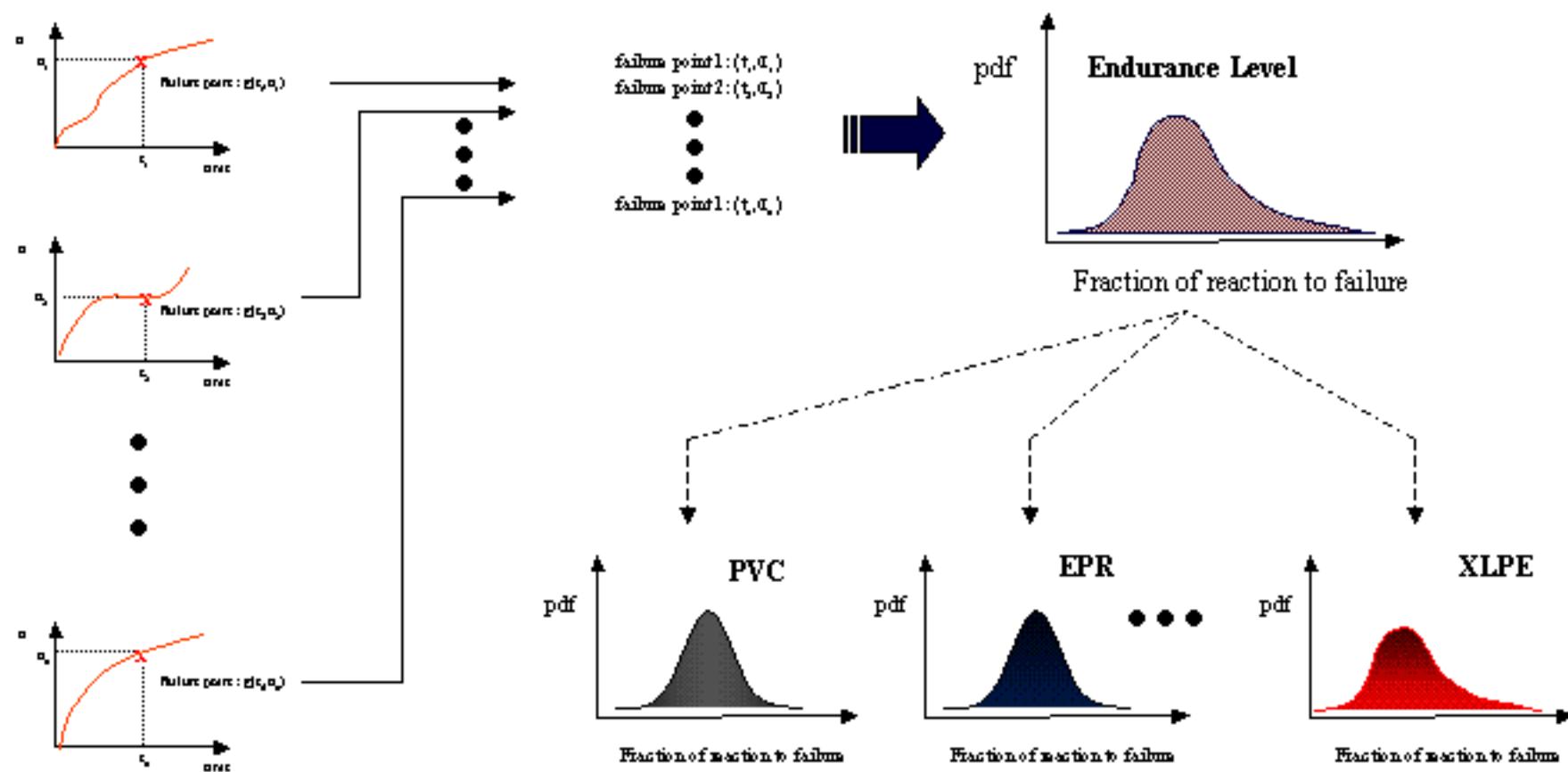
EPRI 1003326.

Characterization of Fire-Induced Circuit Faults.

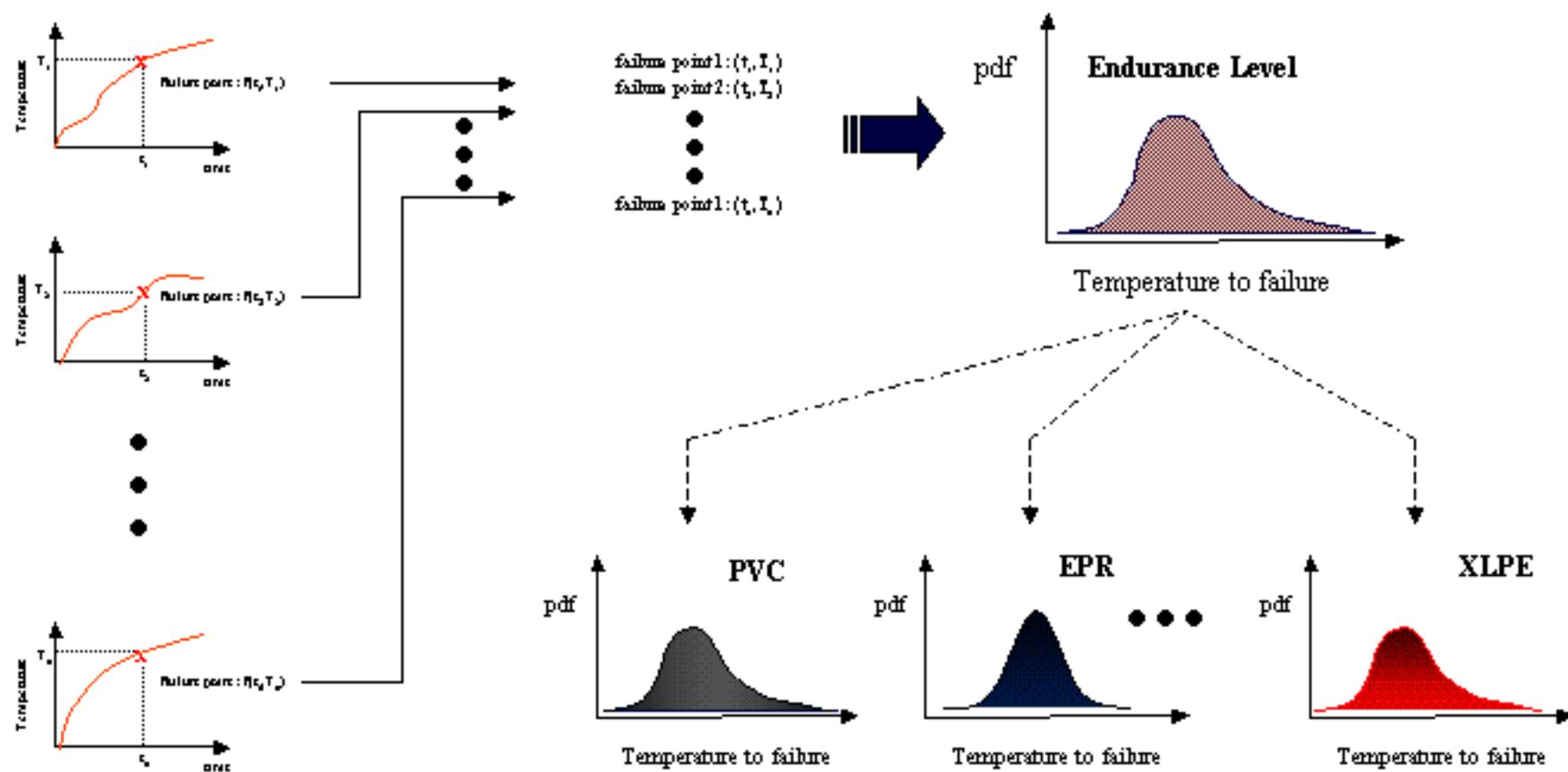
Cable Response to Live Fire (CAROLFIRE).

A combined test effort involving representatives of RES, SNL, NIST, and UMd (in progress).

KINETIC MODEL – ENDURANCE LEVEL



HEAT TRANSFER MODEL – ENDURANCE LEVEL



THRESHOLD LEVEL: HEAT TRANSFER MODEL

CAROLFIRE	PVC	XLPE	EPR	PE	TEFZEL ⁽¹⁾	EP ⁽¹⁾
Mean ($^{\circ}$ k)	4.93E+02	6.66E+02	6.92E+02	5.23E+02	NA	NA
Standard Deviation	1.97E+01	3.33E+01	1.44E+01	1.05E+01	NA	NA

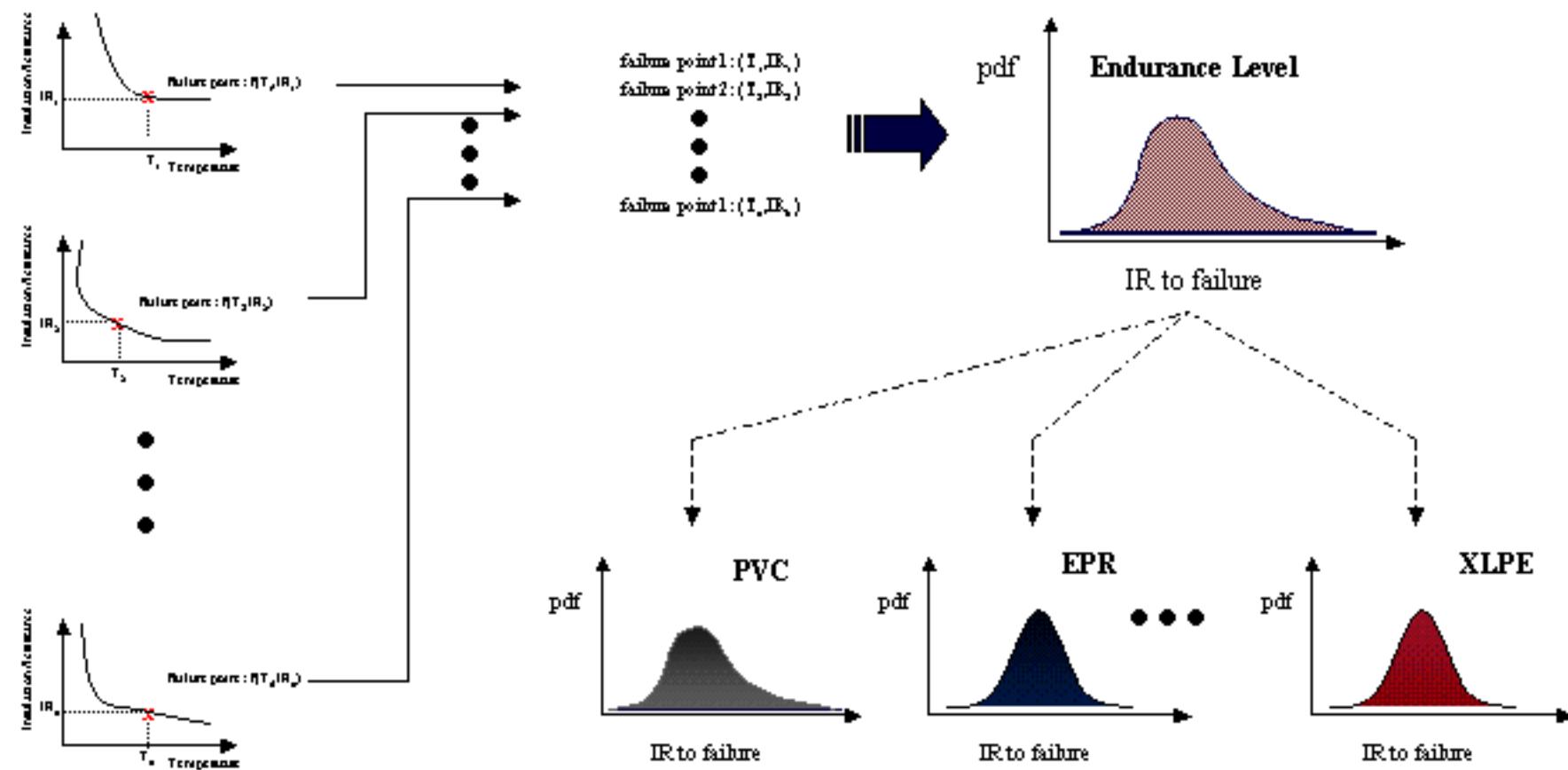
NUREG	PVC ⁽¹⁾	XLPE	EPR	PE ⁽¹⁾	TEFZEL	EP ⁽²⁾
Mean ($^{\circ}$ k)	NA	6.58E+02	7.23E+02	NA	4.59E+02	6.51E+02
Standard Deviation	NA	3.02E+01	3.84E+01	NA	2.48E+01	3.45E+00

EPRI	PVC	XLPE	EPR	PE	TEFZEL	EP ⁽¹⁾
Mean ($^{\circ}$ k)	4.56E+02	6.72E+02	7.04E+02	4.52E+02	5.00E+02	NA
Standard Deviation	3.18E+01	4.26E+01	5.50E+01	4.08E+01	4.61E+01	NA

(1) Not available

(2) Estimation based on one test.

IR "K FACTOR" MODEL – ENDURANCE LEVEL



THRESHOLD LEVEL: "K FACTOR" MODEL

NUREG		PVC ⁽¹⁾	XLPE	EPR ⁽²⁾	TEFZEL
IR - Threshold Level (Ω)	Mean	3.29E+04	6.11E+03	1.06E+04	1.34E+04
	Standard Deviation	1.70E+04	2.43E+03	1.82E+04	6.75E+03
IR - C ₁	Mean	5.53E+12	5.15E+11	7.61E+18	7.17E+10
	Standard Deviation	3.60E+14	3.99E+12	2.29E+20	2.50E+12
IR - C ₂	Mean	2.75E-02	2.08E-02	4.07E-02	2.19E-02
	Standard Deviation	6.58E-03	1.52E-03	4.68E-03	5.70E-03

CAROLFIRE		PVC	XLPE	EPR	TEFZEL ⁽¹⁾
IR - Threshold Level (Ω)	Mean	2.19E+04	1.05E+04	7.82E+03	NA
	Standard Deviation	2.55E+04	8.66E+03	4.79E+03	NA
IR - C ₁	Mean	1.00E+16	1.14E+15	3.03E+13	NA
	Standard Deviation	4.74E+18	9.02E+16	1.61E+14	NA
IR - C ₂	Mean	4.20E-02	2.83E-02	2.63E-02	NA
	Standard Deviation	1.01E-02	5.48E-03	3.97E-03	NA

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KINETIC MODEL



KINETIC DEGRADATION MODEL

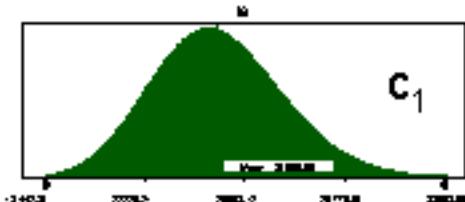


HEAT TRANSFER MODEL

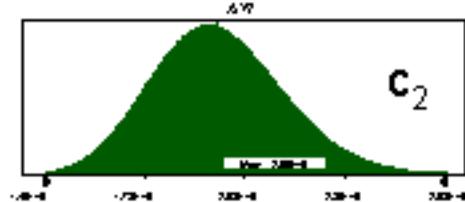


K FACTOR MODEL

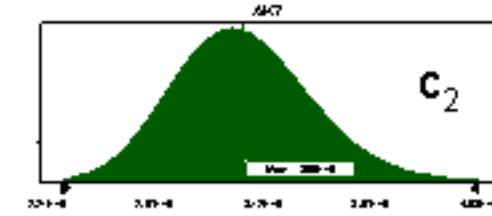
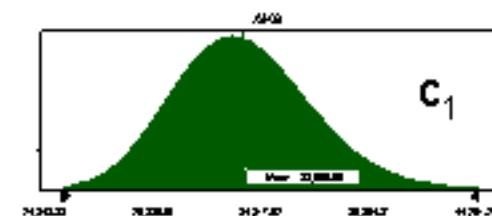
THERMOPLASTIC



The model should be able to cover a plausible range of temperature.

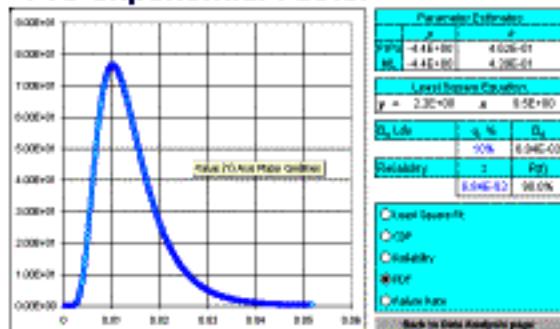


The thermoplastic material degrades faster than thermosets material.



KINETIC MODEL

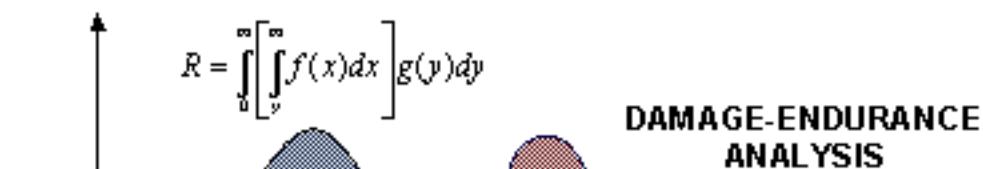
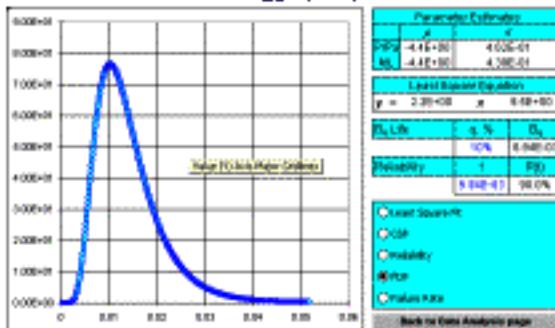
Pre-exponential Factor



$$\alpha(t) = [\alpha_0 - 1] e^{-A(e^{-\frac{E}{RT}})t} + 1$$



Activation Energy (Ea)

 $\alpha(t)$ $\alpha_{Failure}$ α α_0 α_n α_2

time

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 t_1 t_2 t_n

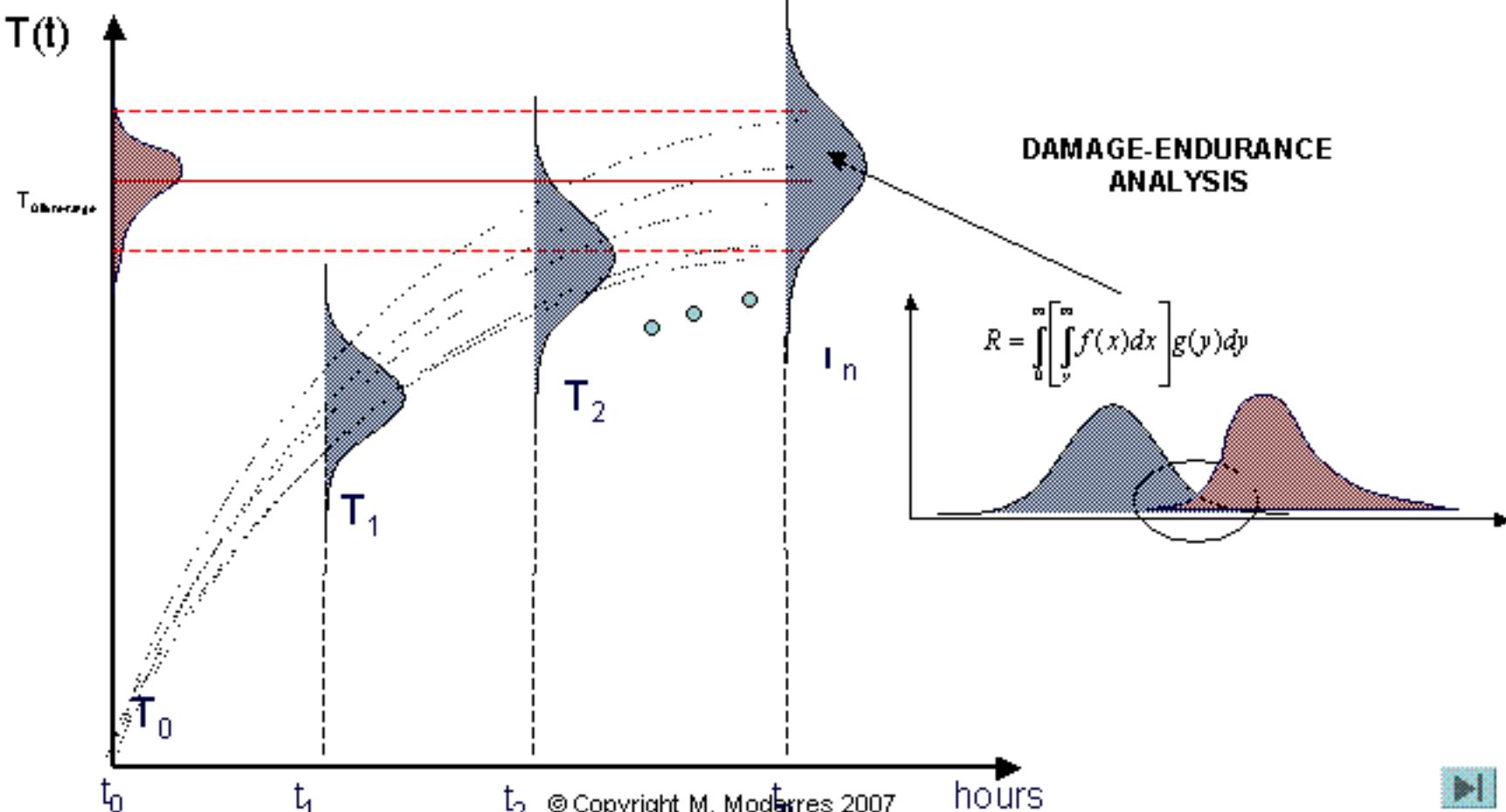
Prepared by: Ganesan Vaibhav

HEAT TRANSFER MODEL

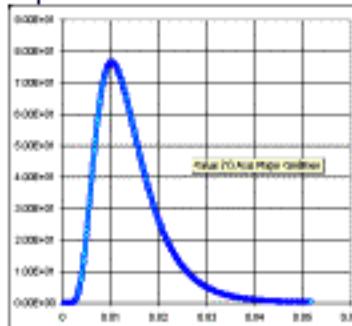
$$\frac{T - T_0}{T_u - T_0} = 1 - \frac{2}{\zeta_1} \frac{J_1(\zeta_1)}{J_o^2(\zeta_1) + J_1^2(\zeta_1)} e^{-[(\zeta_1^2 E_o) \nu_o(\zeta_1 r)]}$$



$$T = T_u + (T_o - T_u) \cdot C_1 e^{-\alpha t}$$

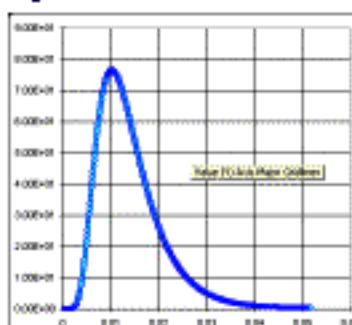


'K FACTOR' MODEL

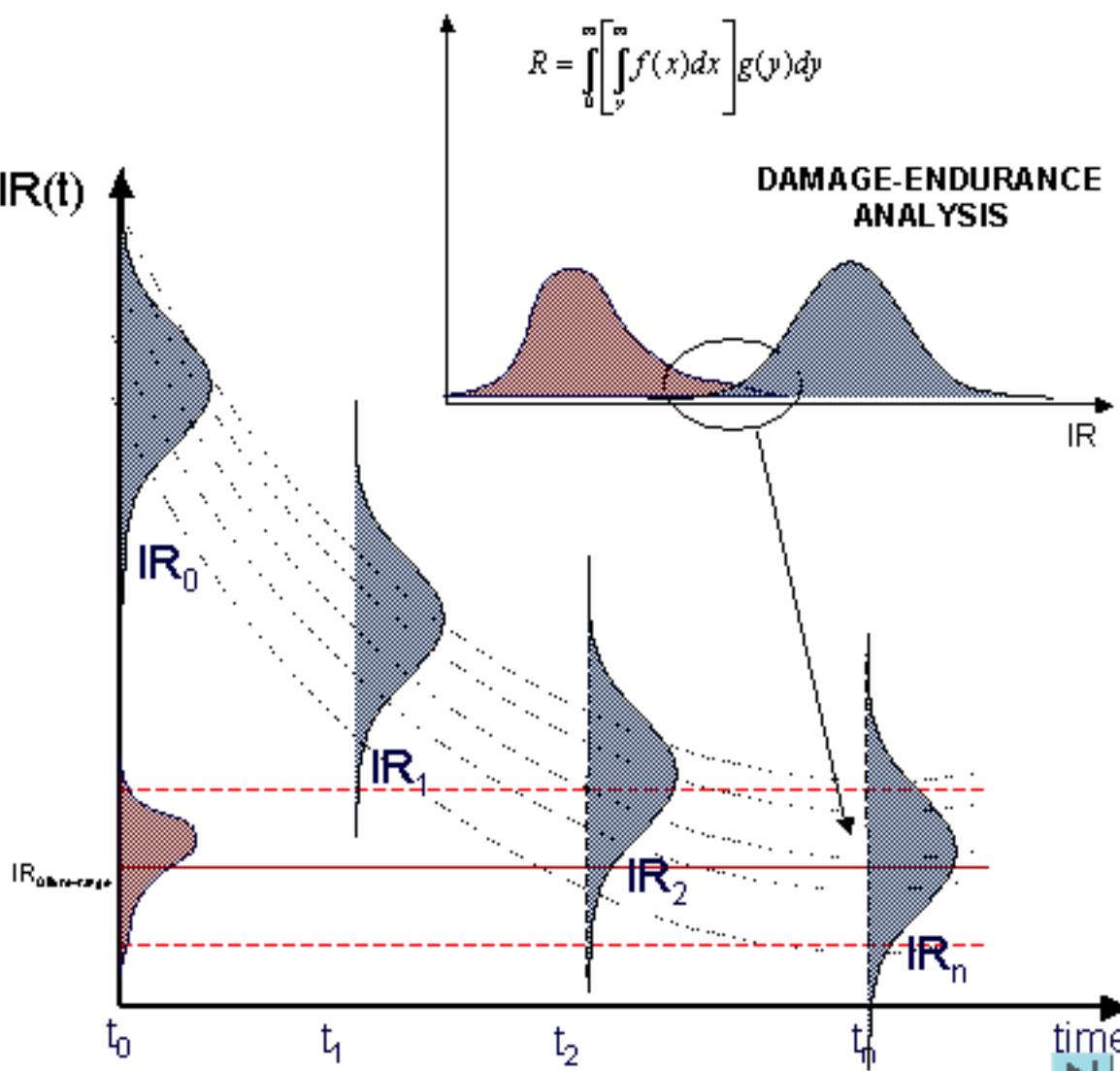
 C_1 Factor

Parameter Estimates	
μ	σ
-4.43e+00	4.62e-01
4.43e+00	4.20e-01
Least Squares Equations:	
$y = 2.39 \times 10^6$	$x = 9.58 \times 10^0$
D_{in}	d_{in}
90%	8.94e-03
Reliability	1
	8.94e-02 98.0%
<input type="checkbox"/> Least Squares Fit <input type="checkbox"/> CDF <input type="checkbox"/> Reliability <input type="checkbox"/> IR(t) <input type="checkbox"/> Failure Rate	
Back to Data Analysis page	

$$IR = C_1 \cdot e^{-(C_2 T_k)} \cdot \ln\left(\frac{D_{out}}{D_{in}}\right)$$

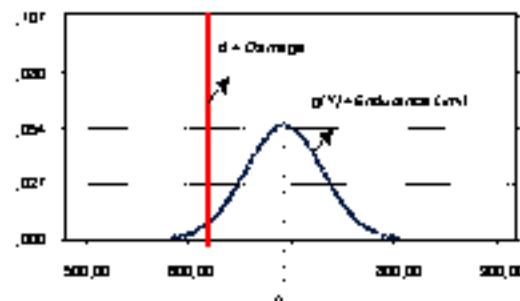
 C_2 Factor

Parameter Estimates	
μ	σ
-4.43e+00	4.62e-01
4.43e+00	4.20e-01
Least Squares Equations:	
$y = 2.39 \times 10^6$	$x = 9.58 \times 10^0$
D_{in}	d_{in}
90%	8.94e-03
Reliability	1
	8.94e-02 98.0%
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Back to Data Analysis page	

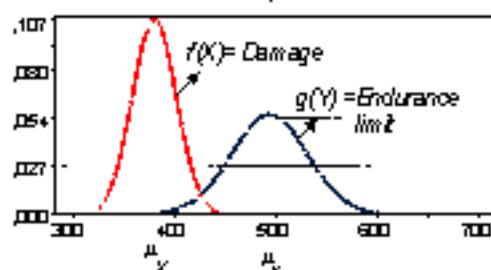
 $IR(t)$ 

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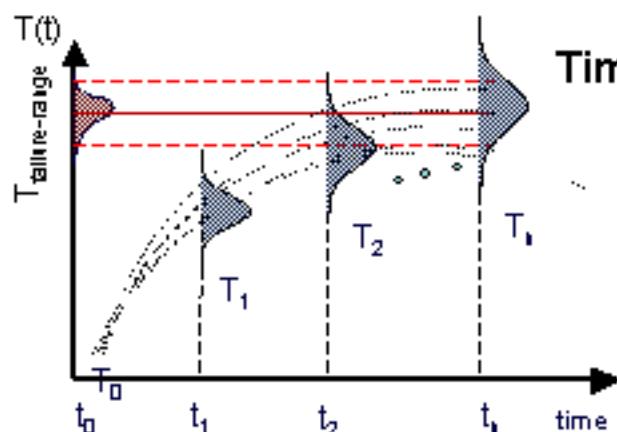
HEAT TRANSFER MODEL:

**Constant Damage:**

$$P_{\text{failure}} = P(\text{Endurance} \leq \text{Damage}) = \int_{-\infty}^{d^*} g(y) dy,$$

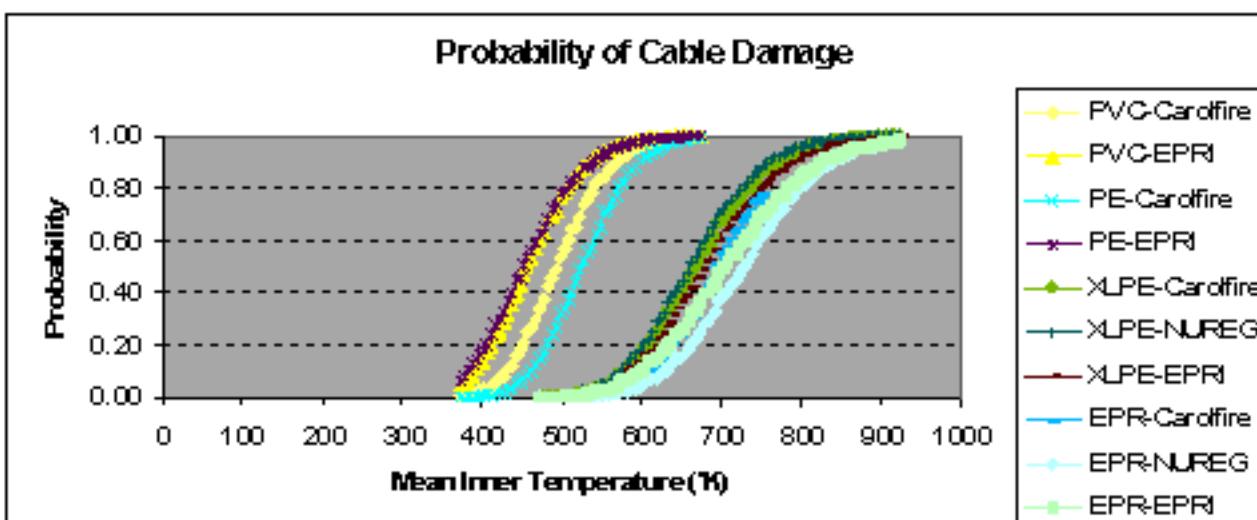
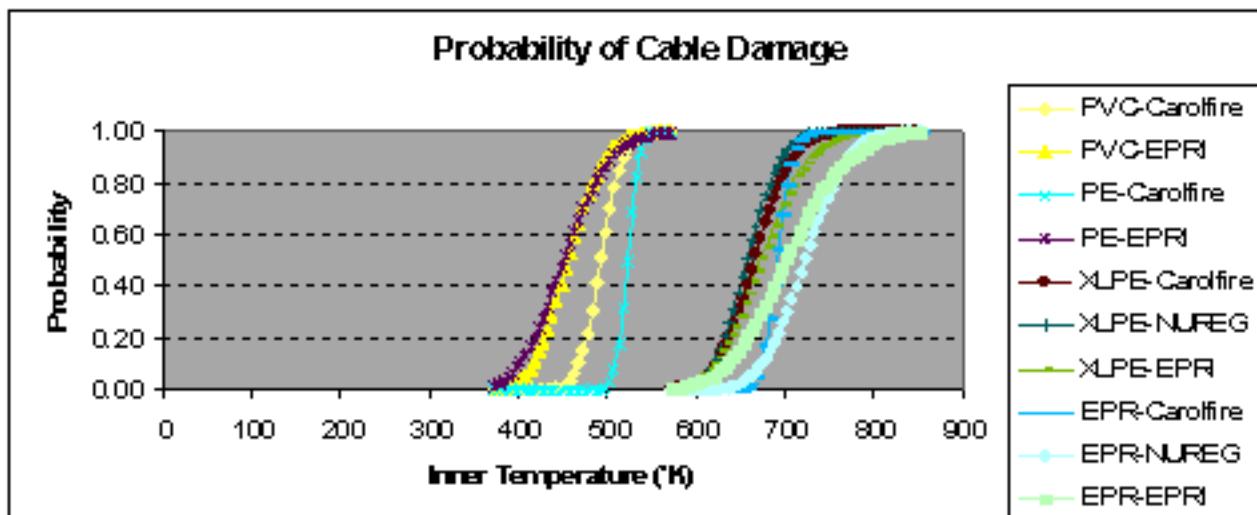
**Distributed Damage:**

$$P_{\text{failure}} = P(\text{Endurance} \leq \text{Damage}) = 1 - \int_0^{\infty} \left[\int_y^{\infty} f(x) dx \right] g(y) dy,$$

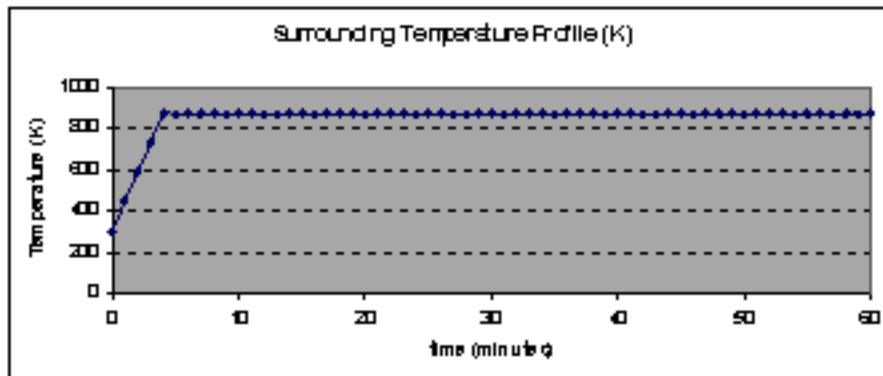
**Time-Temperature Pattern:**

$$P_{\text{failure}_{\text{average}}} = P_{f_a} = \frac{\sum_{k=1}^n P_{\text{failure}_i}}{\sum_{k=1}^n t_k}$$

HEAT TRANSFER MODEL:



HEAT TRANSFER MODEL: time-temperature pattern

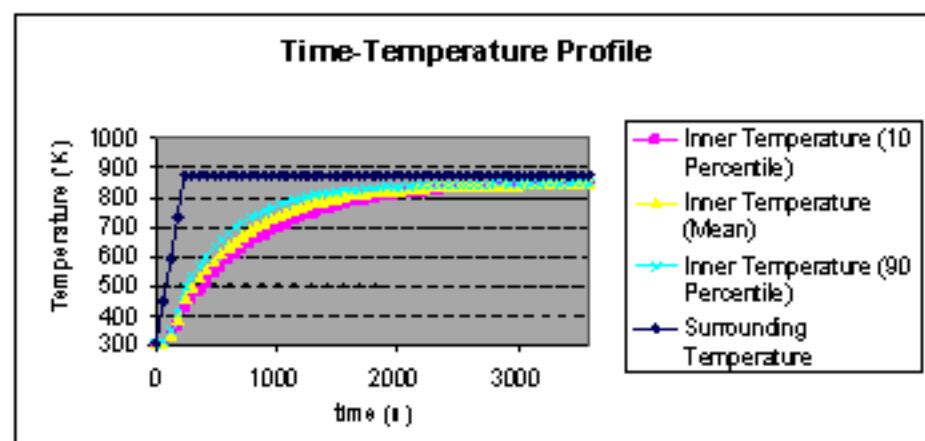


$$\frac{T - T_0}{T_u - T_0} = 1 - \frac{2}{\zeta_1} \frac{J_1(\zeta_1)}{J_o^2(\zeta_1) + J_1^2(\zeta_1)} e^{-[\zeta_1^2 F_o] \nu_o(\zeta_1 r)}$$

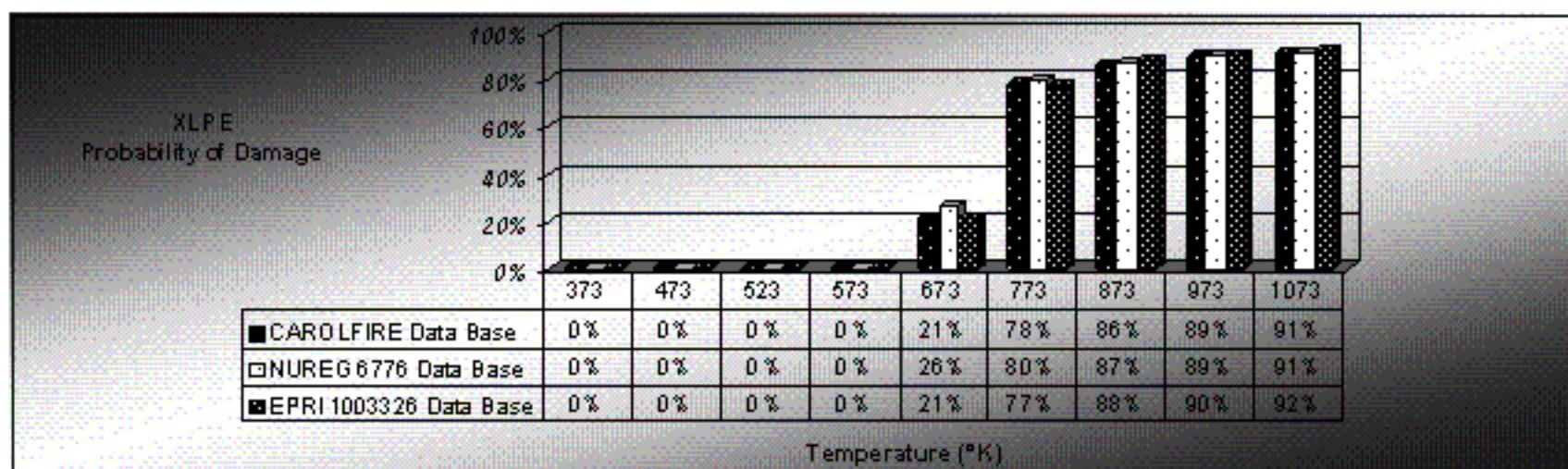
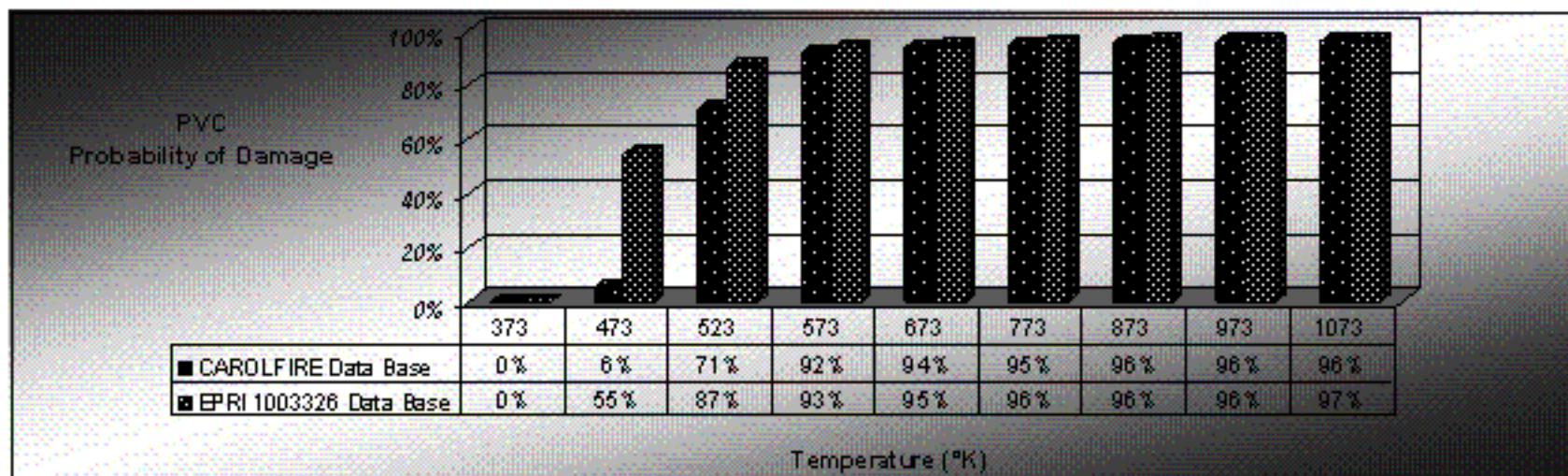
$$\frac{d(T)}{dt} = \frac{d(T_U)}{dt} + \frac{d[(T_O - T_U) \cdot C_1 \cdot e^{-\varphi t}]}{dt}$$

$$T_{(K+1)} = T_{(K)} + (T_{U(K+1)} - T_{U(K)}) - C_1 \cdot e^{-\varphi t} (T_{U(K+1)} - T_{U(K)}) + C_1 \Delta t \cdot \varphi e^{-\varphi t} (T_{U(K)} - T_O)$$

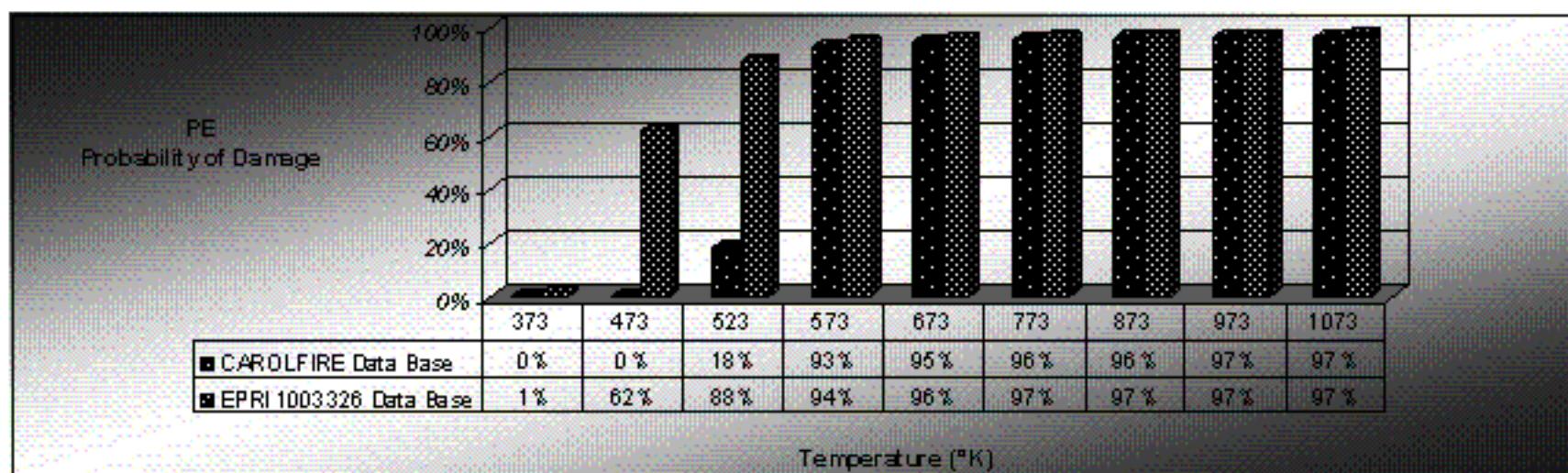
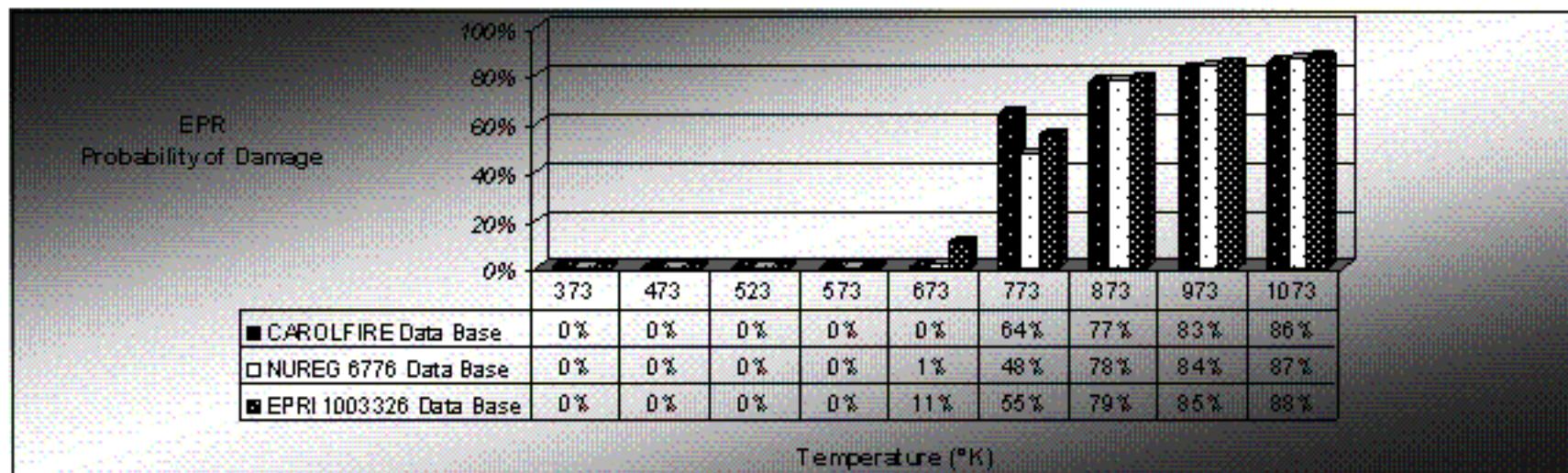
- $T(k+1)$: inner temp. cable at time $t(k+1)$.
- $T(k)$: inner temp. cable at time $t(k)$.
- T_0 : initial temp. cable ($t=0$).
- $T_{U(k+1)}$: surrounding temp. at time $t(k+1)$.
- $T_{U(k)}$: surrounding temp. at time $t(k)$.
- k : integrating step parameter

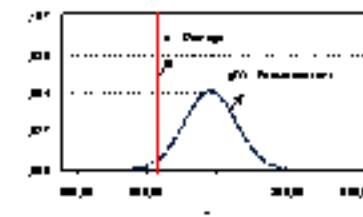
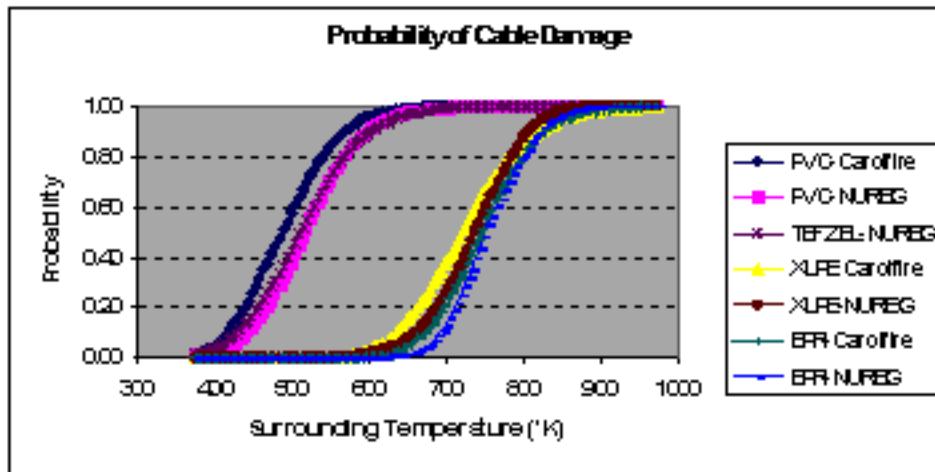


HEAT TRANSFER MODEL: time-temperature pattern

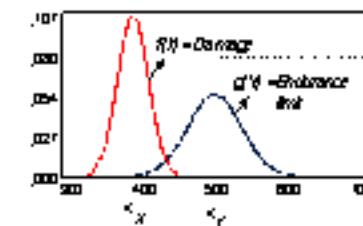
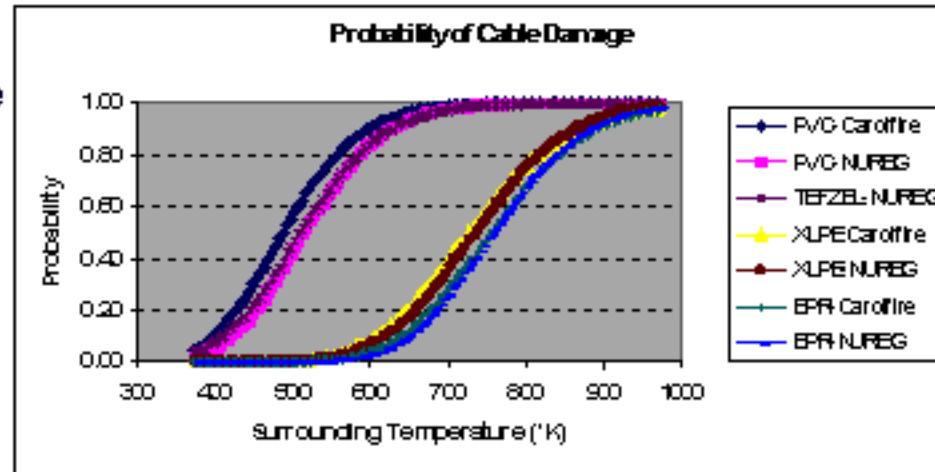


HEAT TRANSFER MODEL: time-temperature pattern

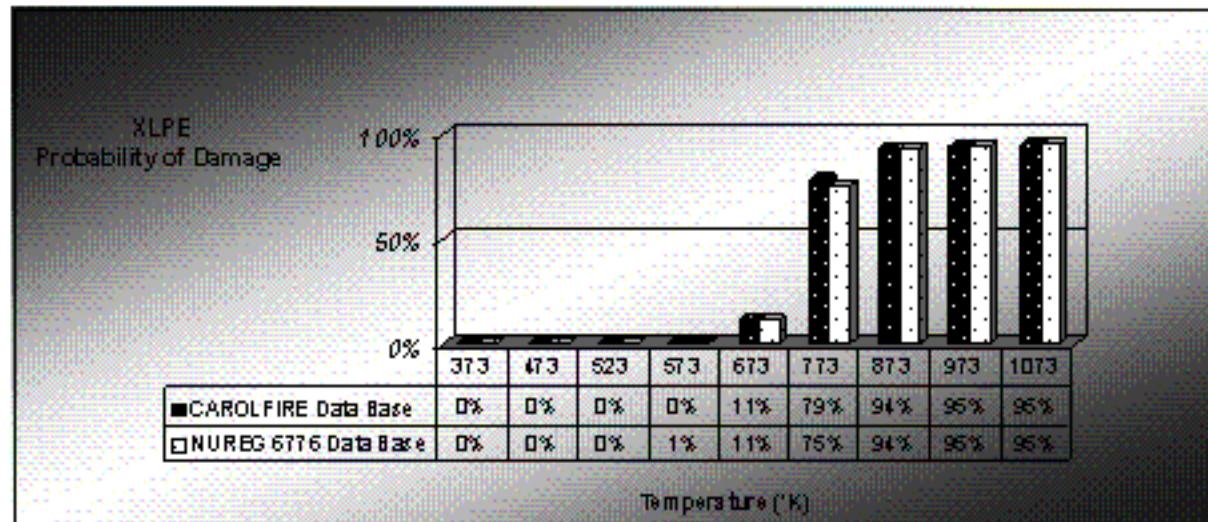
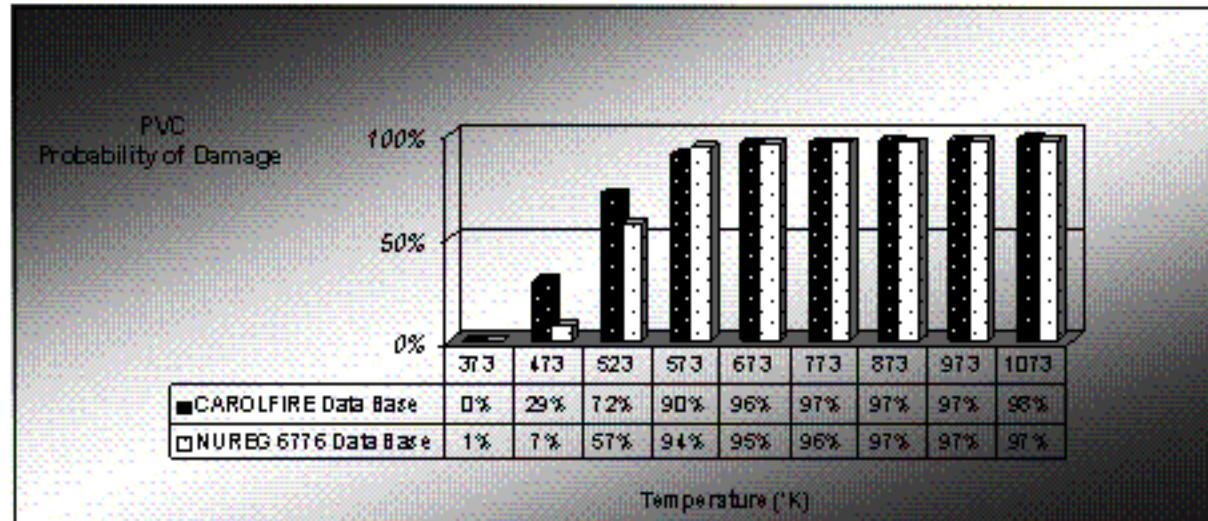


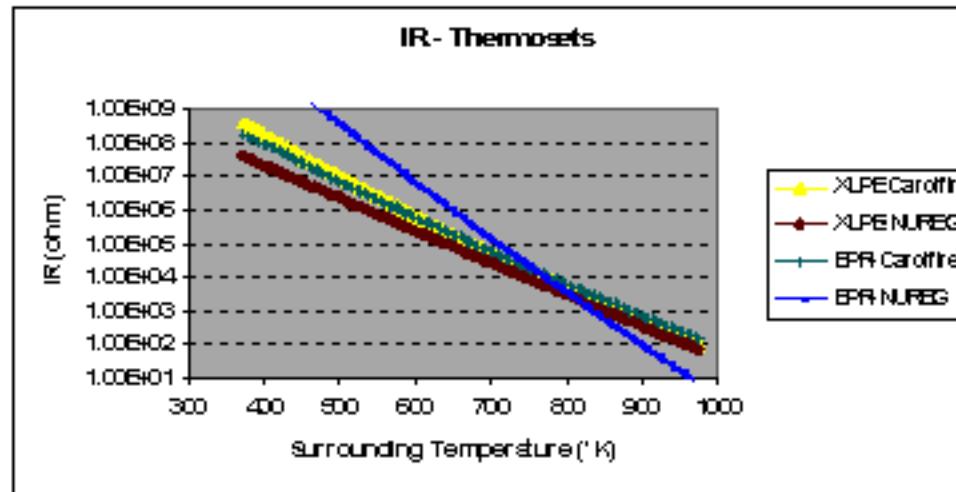
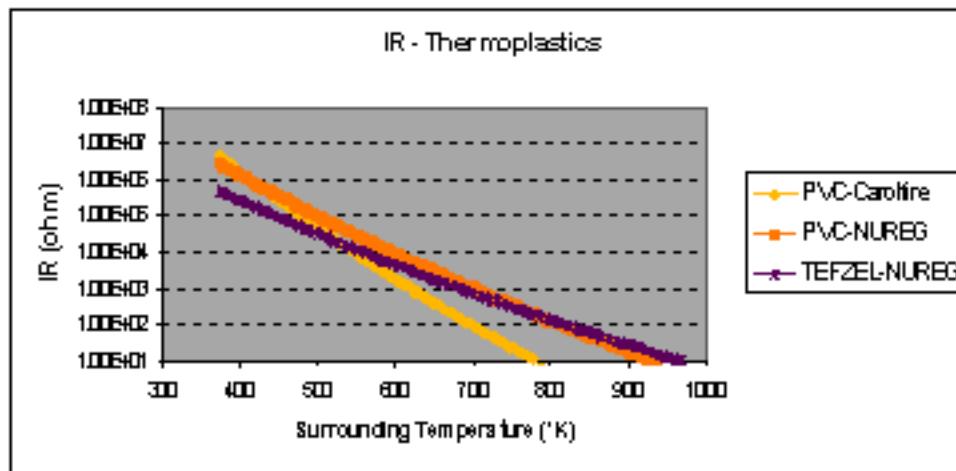
"K FACTOR" MODEL :**Constant Damage**

$$P_{\text{fall}} = P(\text{Endurance} \leq \text{Damage}) = \int_{-\infty}^{T_E} g(x) dx$$

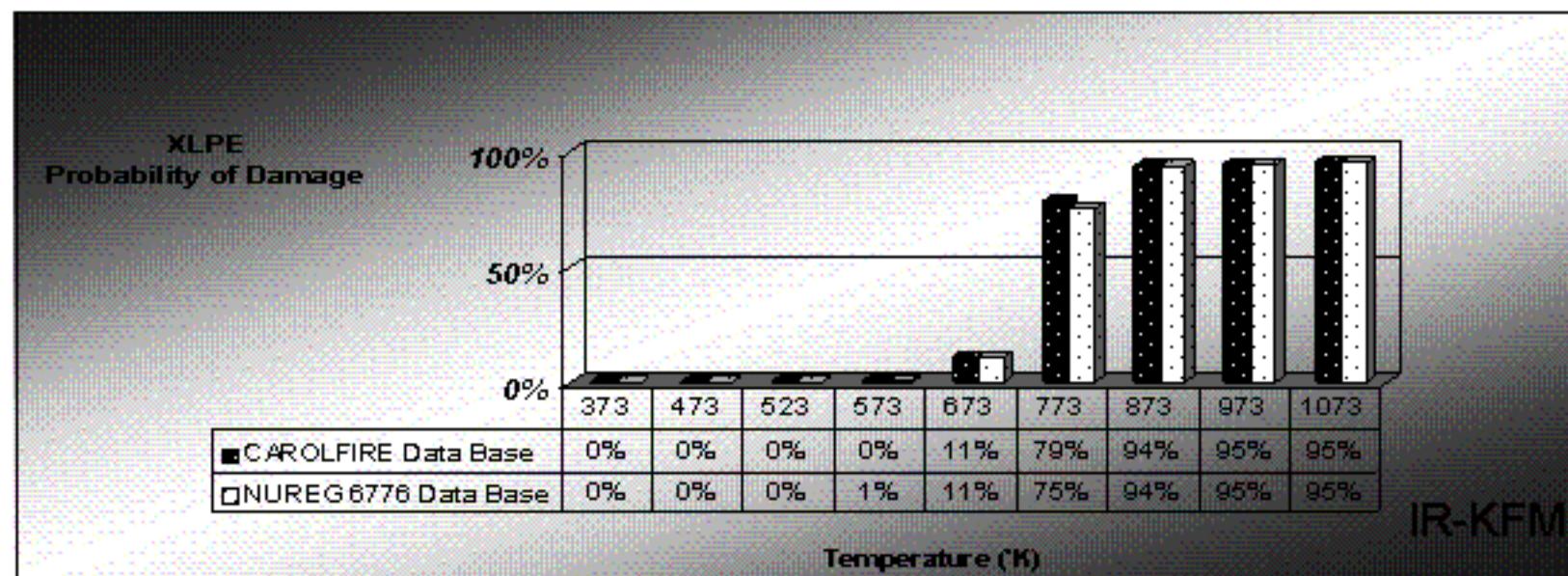
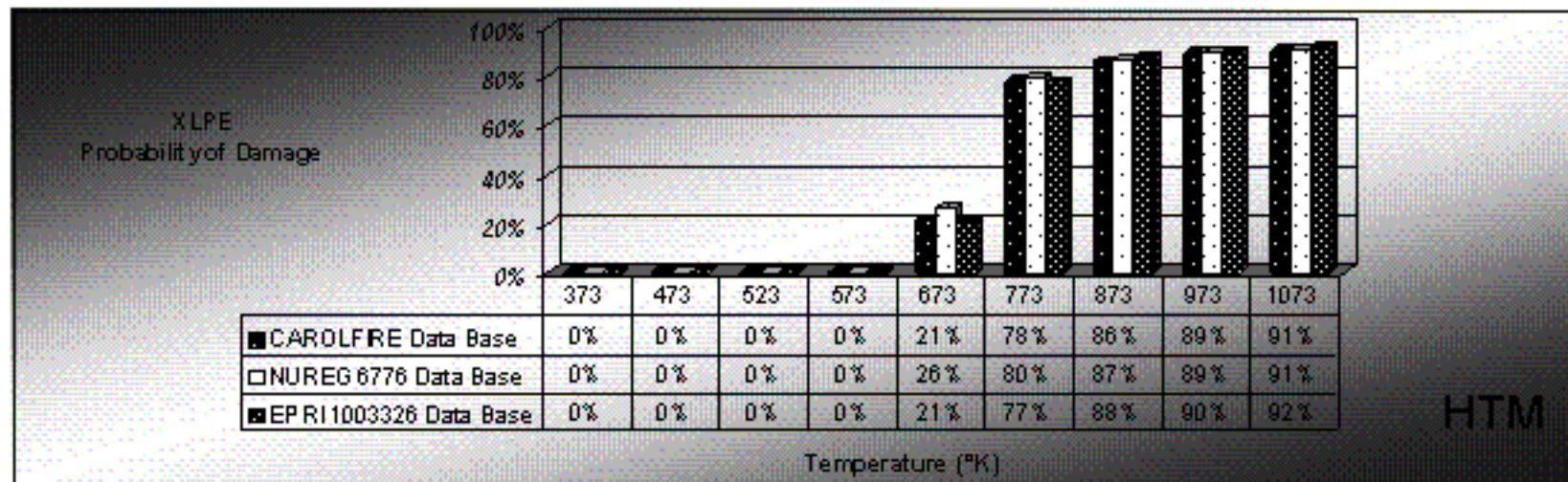
Distributed Damage

$$P_{\text{fall}} = P(\text{Endurance} \leq \text{Damage}) = \int \left[f(y) dy \right] g(y) dy$$

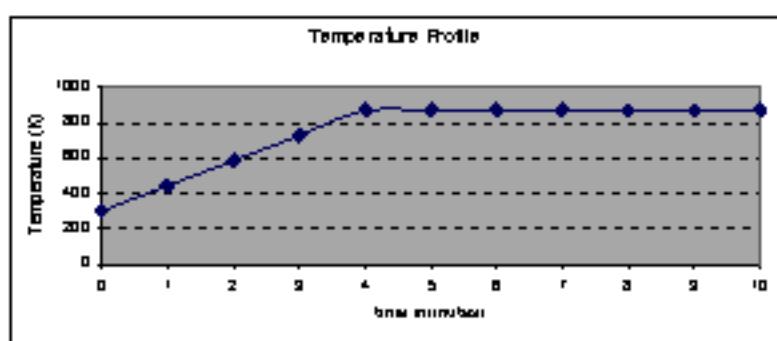
"K FACTOR" MODEL: time-temperature pattern

"K FACTOR" MODEL :

HEAT TRANSFER MODEL vs. "K FACTOR" MODEL



HEAT TRANSFER MODEL vs. "K FACTOR" MODEL



$Pe_a = 24\%$ (Carol fire)

HTM

$Pe_a = 26\%$ (NUREG)



$Pe_a = 69\%$ (Carol fire)

IR-KFM

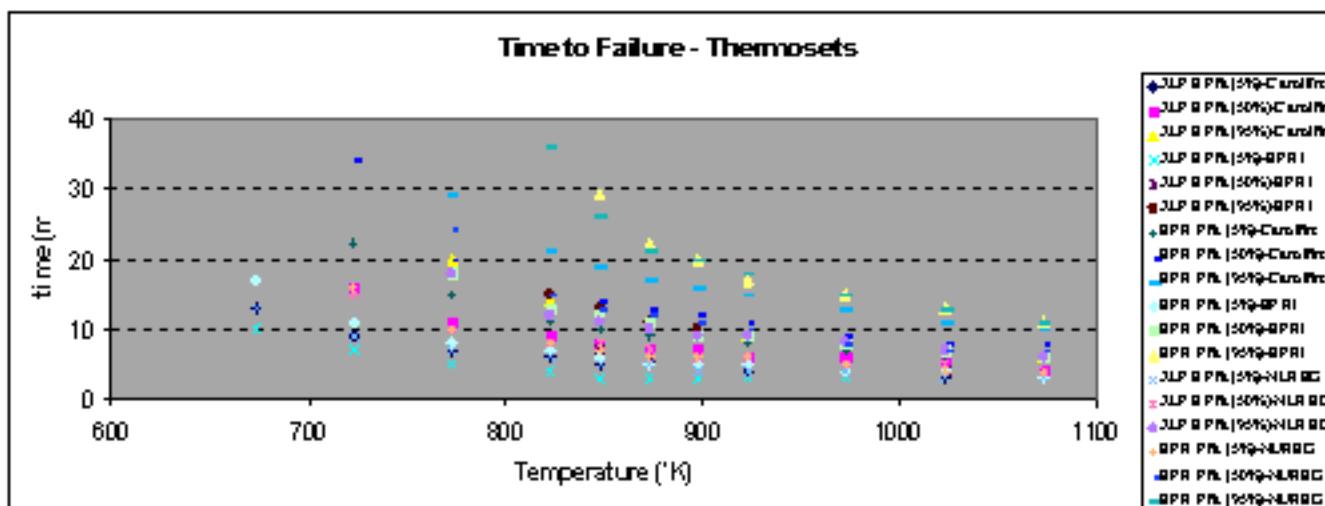
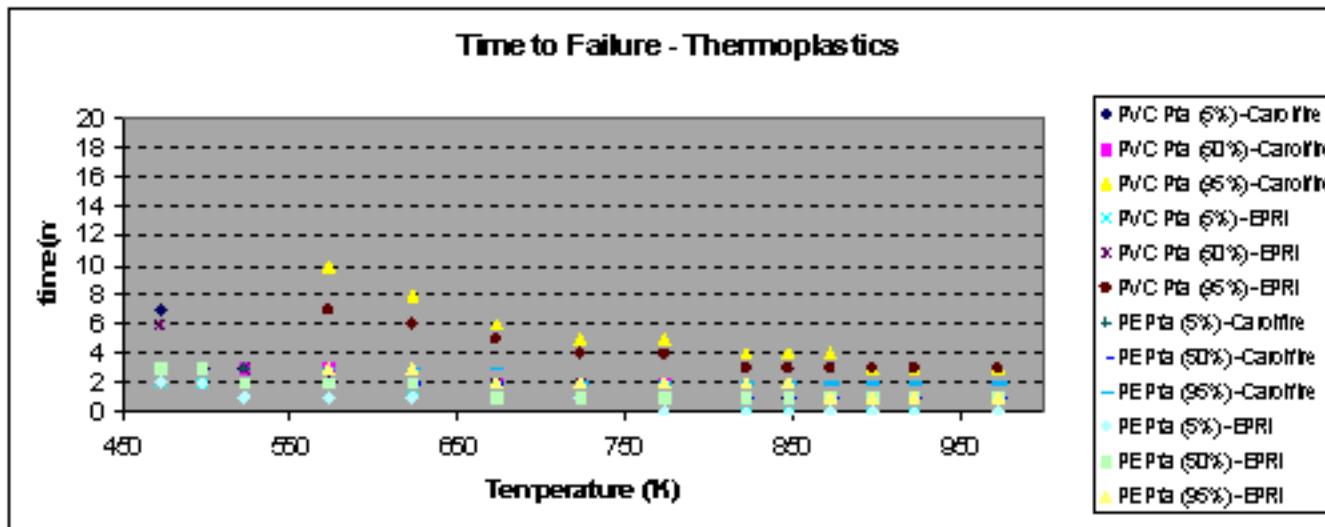


$Pe_a = 68\%$ (NUREG)

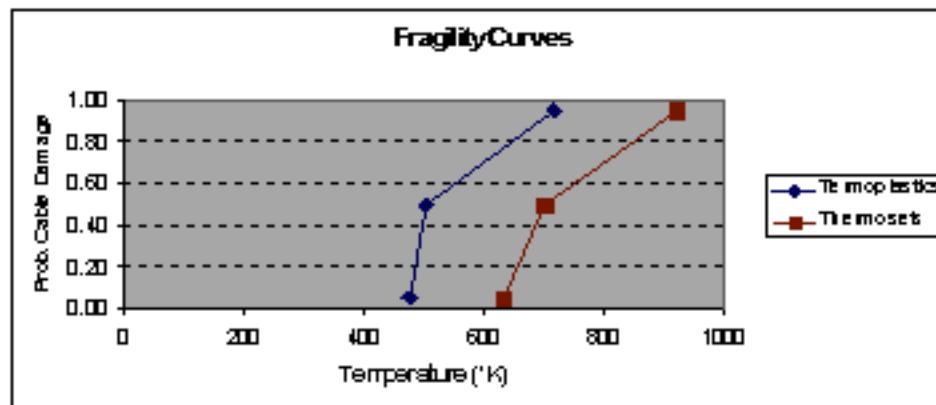
The heat transfer model considers the dynamic of the thermal insult and the thermal behavior of the cable material; therefore, even though a temperature of 873 °K (600 °C) is reached, it only lasts for few minutes..

The IR "K factor" model does not consider the "time", it just considers the "temperature"; therefore, even though the highest temperature of 873 °K (600 °C) was just reached for few minutes, the model predicts a high Pea..

TIME TO CABLE DAMAGE:



FRAGILITY CURVES:



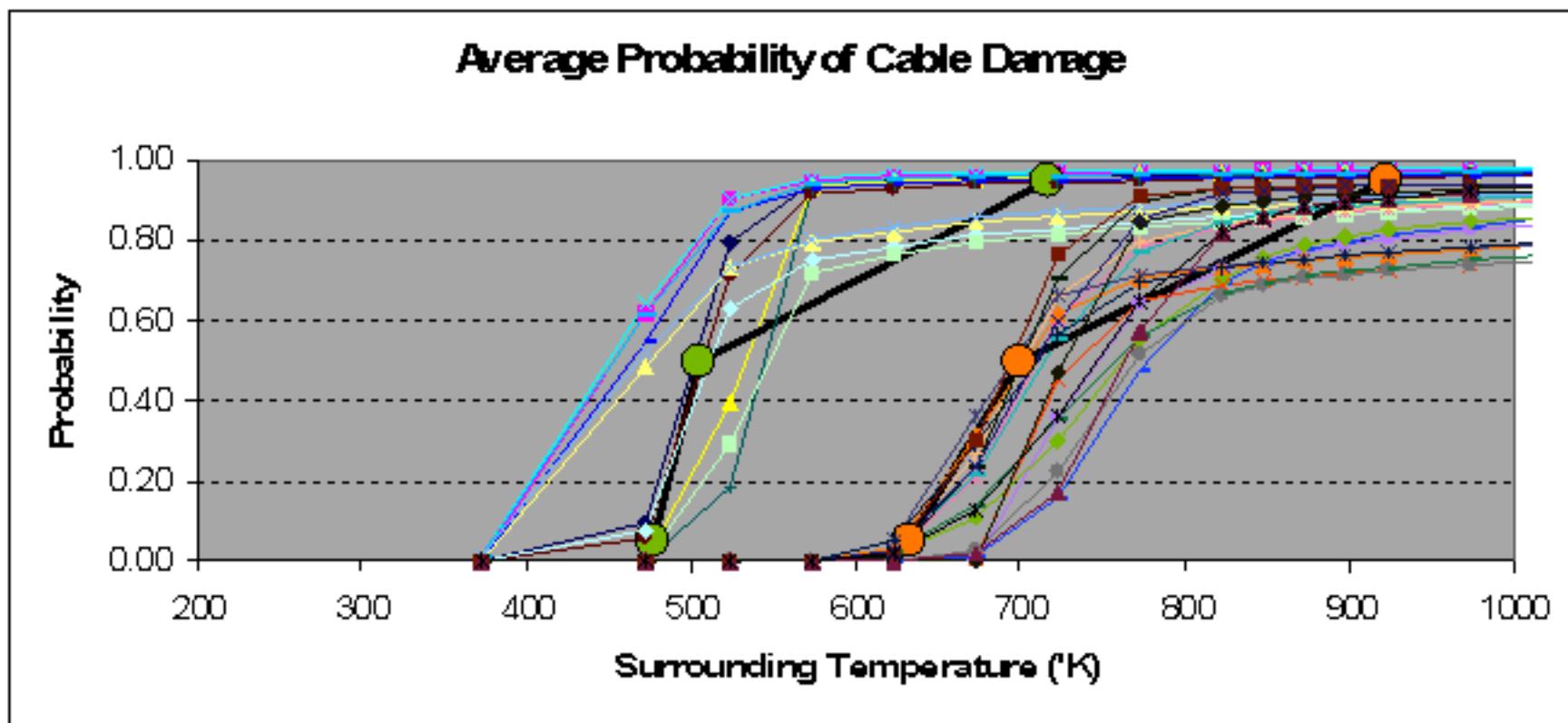
Thermoplastics:

Temperature below which essentially no failure occurs	477 °K (204 °C)
Median or best estimate point	505 °K (232 °C)
Temperature at which activity will almost surely occur	700 °K (427 °C)

Thermosets:

Temperature below which essentially no failure occurs	633 °K (360 °C)
Median or best estimate point	700 °K (427 °C)
Temperature at which activity will almost surely occur	922 °K (649 °C)

FRAGILITY CURVES vs. HEAT TRANSFER MODEL



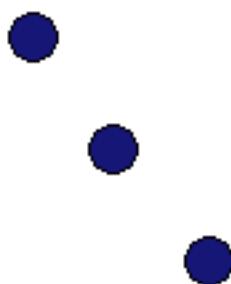
- BACKGROUND.
- OBJECTIVE.
- PROPOSED MODELS.
 - KINETIC MODEL.
 - HEAT TRANSFER MODEL.
 - “K FACTOR” MODEL.
- DATA GATHERING AND ANALYSIS.
- DAMAGE-ENDURANCE MODEL DEVELOPMENT.
- RESULTS ANALYSIS AND VALIDATION.
- CONCLUSIONS AND RECOMMENDATIONS.

KINETIC MODEL:

- In the light of the current knowledge and experimental evidence it is not possible to evaluate the feasibility of the kinetic model.
It is recommended to evaluate this model for a specific and well characterized polymeric material, preferably under controlled and well characterized thermal insults.
- The physics-based heat transfer model is a model capable of predicting the probability of cable damage under different thermal conditions.
To improve the robustness of this model it is recommended to enrich existing databases, to develop HTM for complex cable arrangements and develop thermal properties database for commercial cable polymeric materials.
- The IR “K factor” model is an empirical model that is simple to apply, but does not consider the dynamic of the thermal insult.
- Validate the models proposed for fire conditions out of the scenarios described in the fire testing programs utilized in this research.



QUESTIONS?



THANKS

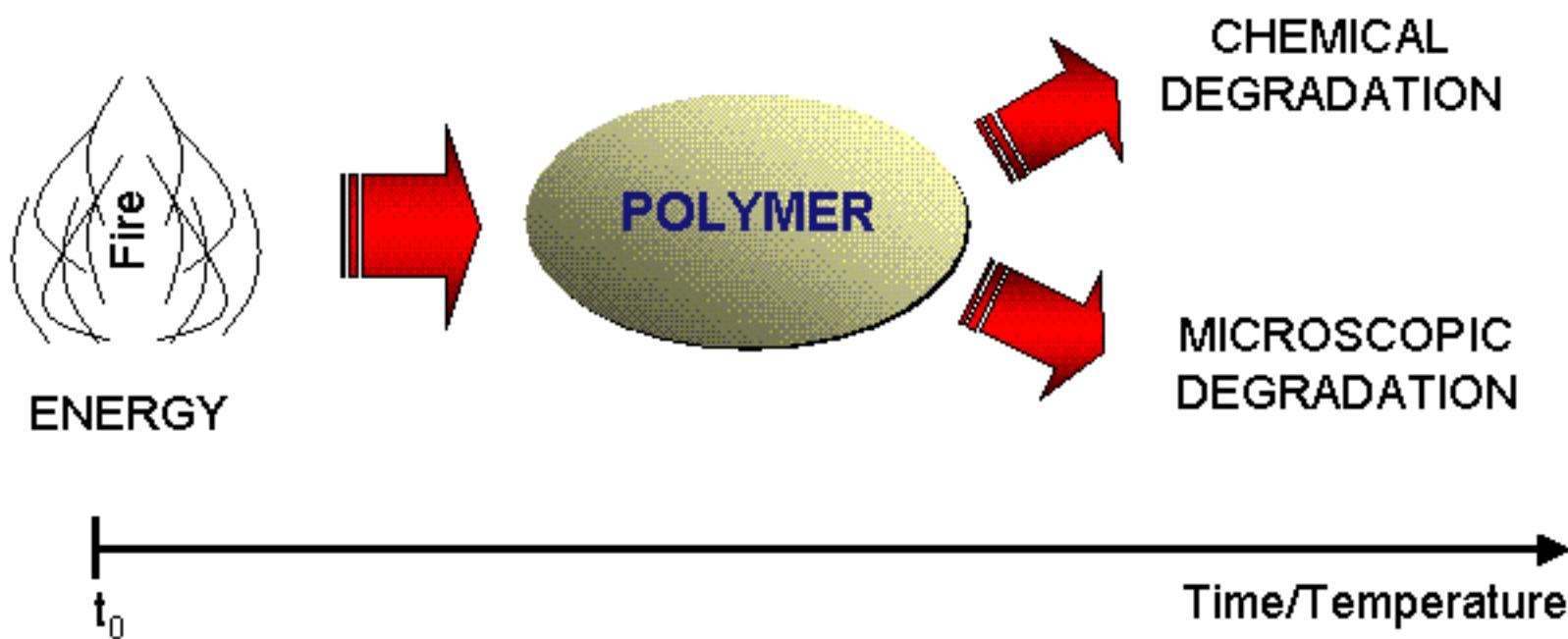
BACK-UP

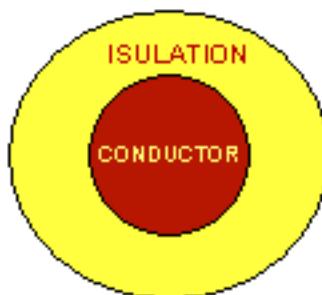
Recently a model was proposed to estimate the probability of some fire-induced circuit failure modes (EPRI 1008239, NUREG/CR-6850). This model is based on the classical concepts of probability and does not consider the underlying mechanisms of failure and the uncertainty and variability of the processes involve.*

Failure Mode Probability Estimates Given Cable Damage

Cable Type and Raceway	Description of Hot Short	Best Estimate	High Confidence Range
Thermoset Tray	M/C Intra-cable w/CPT	0.3	0.1 - 0.5
	M/C Intra-cable w/o CPT	0.6	0.2 - 1
	M/C Inter-cable	0.2	0.05 - 0.3
	M/C -1/C Inter-cable	0.1	0.05 - 0.2
	M/C -M/C Inter-cable	0.01 - 0.05	
Thermoset Conduit	M/C Intra-cable w/CPT	0.075	0.025 - 0.125
	M/C Inter-cable	0.05	0.0125 - 0.075
	M/C -1/C Inter-cable	0.025	0.0125 - 0.05
	M/C -M/C Inter-cable	0.005 - 0.01	
Thermoplastic Tray	M/C Intra-cable w/CPT	0.3	0.1 - 0.5
	M/C Inter-cable	0.2	0.05 - 0.3
	M/C -1/C Inter-cable	0.1	0.05 - 0.2
	M/C -M/C Inter-cable	0.01 - 0.05	
Armored Tray	M/C Intra-cable w/CPT	0.075	0.02 - 0.15

PHYSICS - BASED MODEL



PHYSICS - BASED MODEL: Heat Transfer Model**LUMPED CAPACITANCE METHOD**

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Conditions where temperature gradients within the solid are small. It assumes temperature of the solid spatially uniform during the transient phase.

$$B_i = \frac{h}{k} r_0 \quad B_i \ll 1$$

r_0 = radius of cable (m)
 h = heat transfer coefficient (kw/m²)
 k = thermal conductivity (w/m/k)

EXACT METHOD

Conditions where temperature gradients within the solid are not negligible.

HEAT TRANSFER MODEL

RADIAL SYSTEM WITH CONVECTION: INFINITE CYLINDER

$$\theta^* = 1 - \sum_{n=1}^{\infty} C_n e^{-[(\zeta_n^2 F_o) J_o(\zeta_n r)]} = \frac{T - T_0}{T_u - T_0}$$

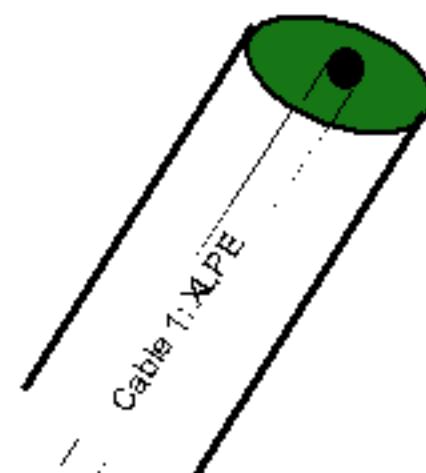
$$C_n = \frac{2}{\zeta_n} \frac{J_1(\zeta_n)}{J_o^2(\zeta_n) + J_1^2(\zeta_n)}$$

Using the one term approximation:

$$\theta^* = 1 - C_1 \cdot e^{-[(\zeta_1^2 F_o) J_o(\zeta_1 r)]} = \frac{T - T_0}{T_u - T_0}$$

ASSUMPTIONS:

- Simple configuration.
- One dimensional conduction.
- No internal generation.



Where:

$$C_1 = \frac{2}{\zeta_1} \frac{J_1(\zeta_1)}{J_o^2(\zeta_1) + J_1^2(\zeta_1)} \quad \zeta_1 \frac{J_1(\zeta_1)}{J_o^2(\zeta_1)} = B_i$$

Values of the coefficients C_1 and ζ_1 have been determined and are available in open literature.

HEAT TRANSFER MODEL

$$\frac{T - T_0}{T_u - T_0} = 1 - \frac{2}{\zeta_1} \frac{J_1(\zeta_1)}{J_o^2(\zeta_1) + J_1^2(\zeta_1)} \cdot e^{-[(\zeta_1^2 F_o) V_o(\zeta_1)]}$$

$$\frac{d(T)}{dt} = \frac{d(T_v)}{dt} + \frac{d[(T_o - T_v) \cdot C_1 \cdot e^{-\varphi t}]}{dt}$$

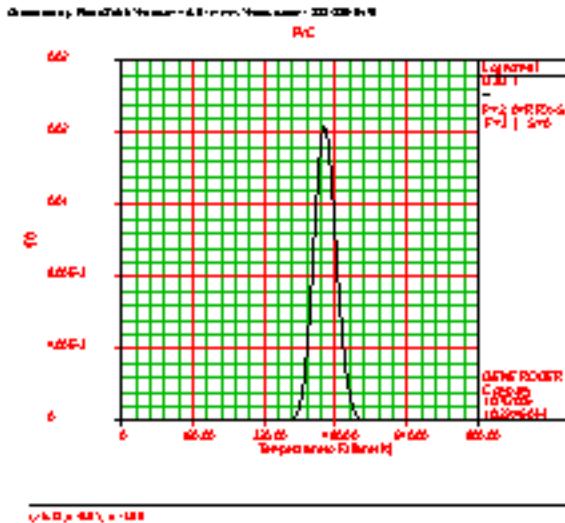
$$T_{(K+1)} = T_{(K)} + (T_{U(K+1)} - T_{U(K)}) - C_1 \cdot e^{-\varphi t_K} (T_{U(K+1)} - T_{U(K)}) + C_1 \cdot \Delta t \cdot \varphi e^{-\varphi t_K} (T_{U(K)} - T_o)$$

- $T(k+1)$: inner temperature of the cable (polymeric cylinder) at time $t(k+1)$.
 $T(YK)$: inner temperature of the cable (polymeric cylinder) at time $take$.
 T_0 : initial temperature of the cable ($t=0$).
 $T_{U(k+1)}$: temperature in the surrounding area of the cable at time $t(k+1)$.
 $T_{U(k)}$: temperature in the surrounding area of the cable at time $take$.
 k : integrating step parameter

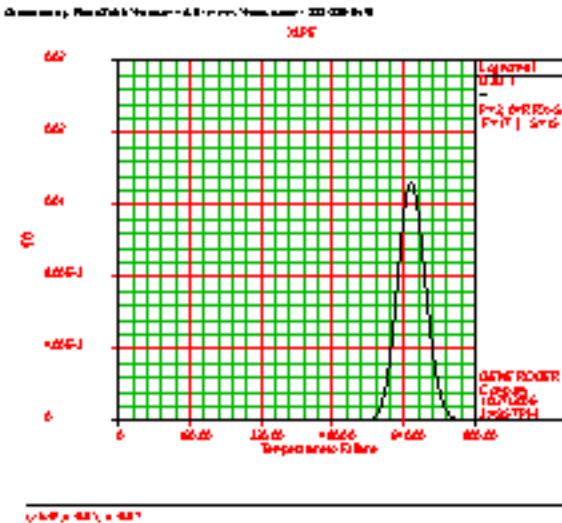


HEAT THERMAL MODEL: Endurance Limit

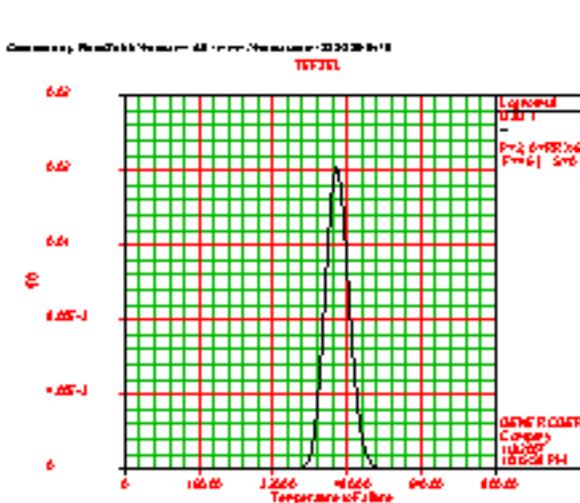
PVC



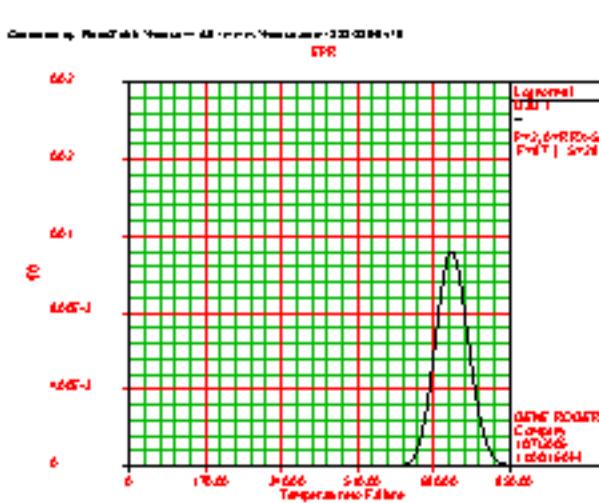
XLPE



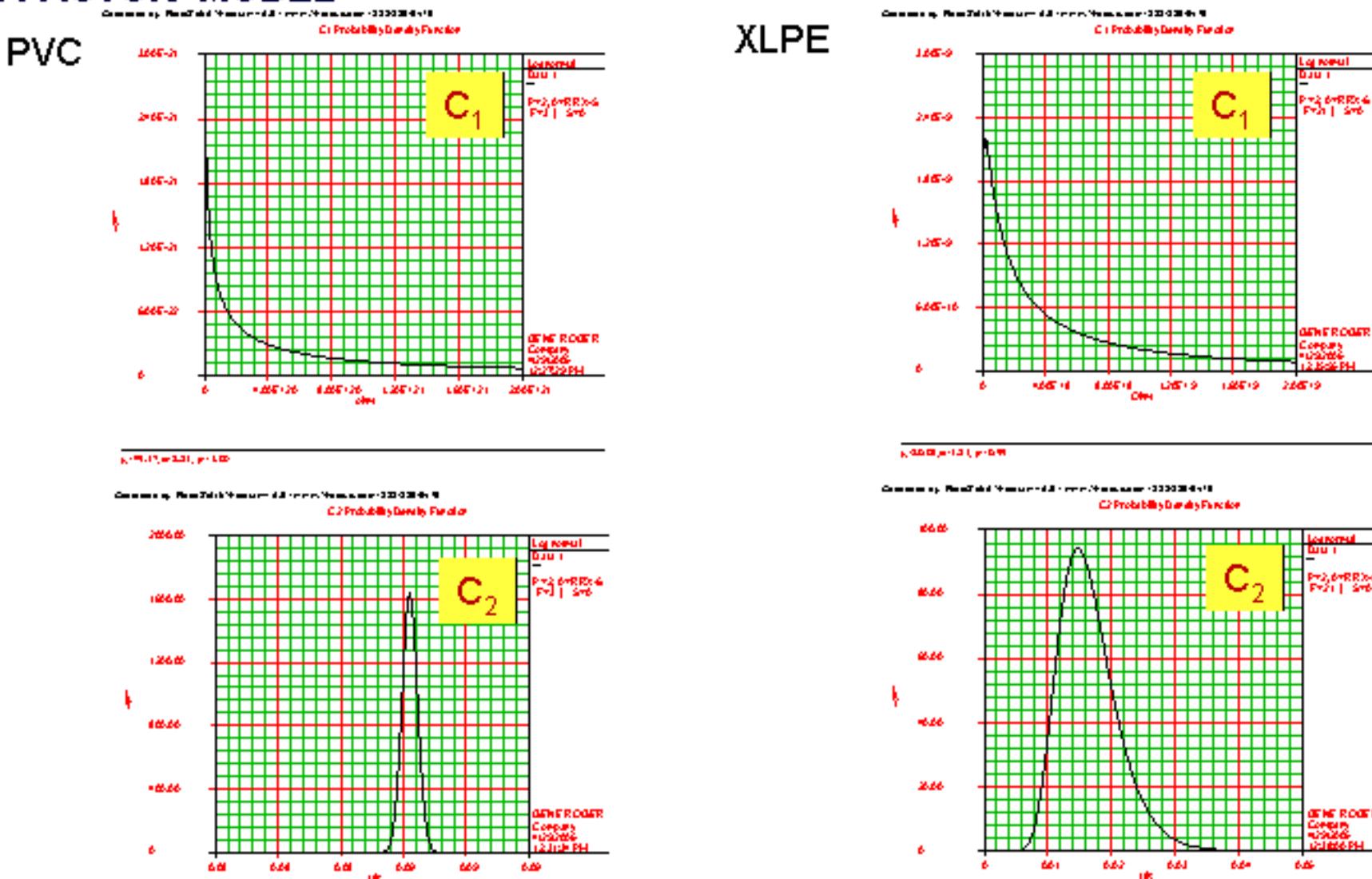
TEFZEL



EPR



'K FACTOR' MODEL

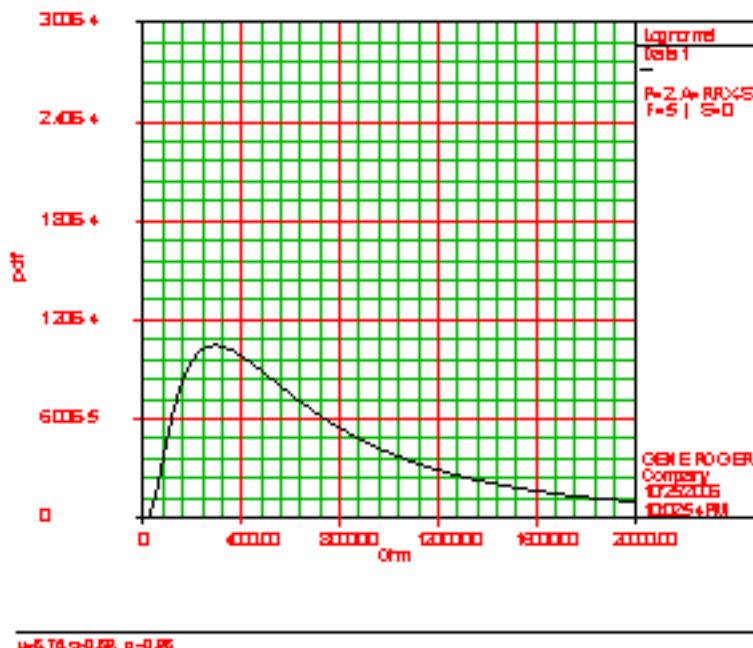


'K FACTOR' MODEL: Endurance Limit

PVC

Generated by ReliaSoft's Weibull++ 3.0 - www.Weibull.com - ddd-ddd-d-1d

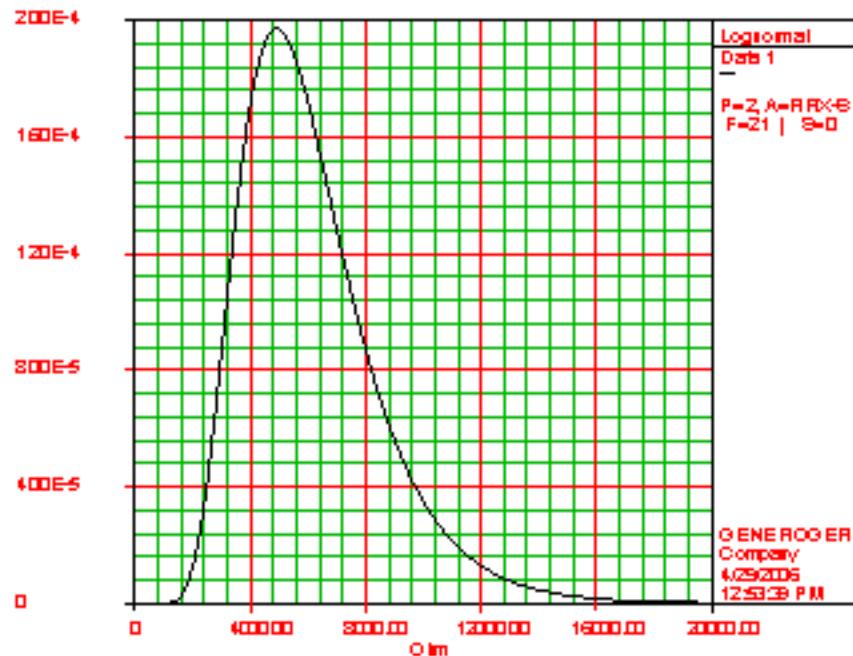
Probability Density Function (PVC)

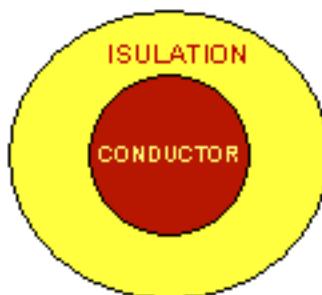


XLPE

Generated by ReliaSoft's Weibull++ 3.0 - www.Weibull.com - ddd-ddd-d-1d

Failure Definition (pdf)



PHYSICS - BASED MODEL: Heat Transfer Model**LUMPED CAPACITANCE METHOD**

-
-
-

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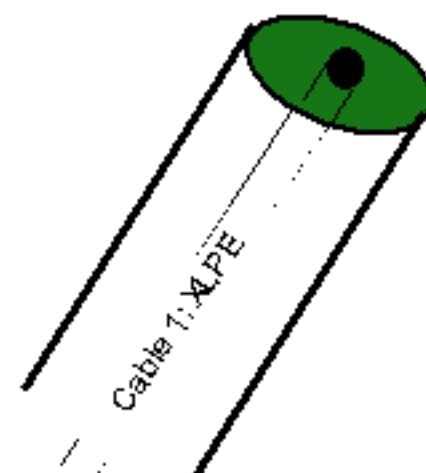
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$$\theta^* = 1 - C_1 \cdot e^{-[(\zeta_1^2 F_o) J_o(\zeta_1 r)]} = \frac{T - T_0}{T_u - T_0}$$

ASSUMPTIONS:

- Simple configuration.
- One dimensional conduction.
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Where:

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Values of the coefficients C_1 and ζ_1 have been determined and are available in open literature.

HEAT TRANSFER MODEL

$$\frac{T - T_0}{T_u - T_0} = 1 - \frac{2}{\zeta_1} \frac{J_1(\zeta_1)}{J_o^2(\zeta_1) + J_1^2(\zeta_1)} \cdot e^{-[(\zeta_1^2 F_o) V_o(\zeta_1)]}$$

$$\frac{d(T)}{dt} = \frac{d(T_v)}{dt} + \frac{d[(T_o - T_v) \cdot C_1 \cdot e^{-\varphi t}]}{dt}$$

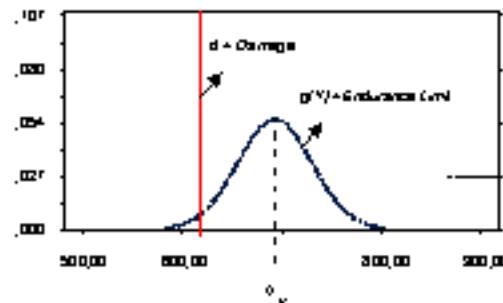
$$T_{(K+1)} = T_{(K)} + (T_{U(K+1)} - T_{U(K)}) - C_1 \cdot e^{-\varphi t_K} (T_{U(K+1)} - T_{U(K)}) + C_1 \cdot \Delta t \cdot \varphi e^{-\varphi t_K} (T_{U(K)} - T_o)$$

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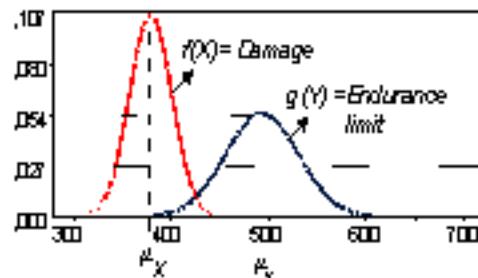


"K FACTOR" MODEL:

$$IR = C_1 \cdot e^{-(C_2 I_a)} \cdot \ln\left(\frac{D_{out}}{D_{in}}\right)$$



$$P_{falla} = P(Endurance \leq Damage) = \int_{-\infty}^d g(y) dy,$$



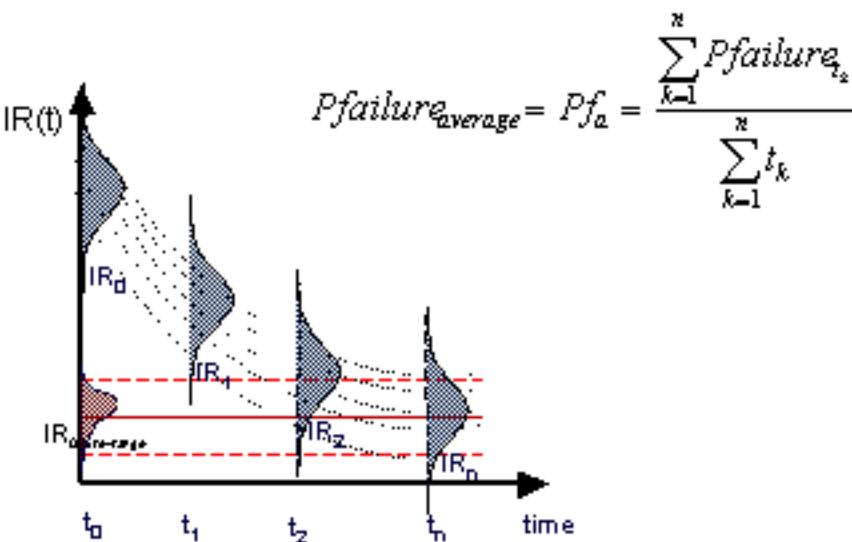
$$P_{falla} = P(Endurance \leq Damage) = 1 - \left[\int_y^{\infty} f(x) dx \right] g(y) dy,$$

$$P_{falla} = P(Endurance \leq Damage) = \int_{-\infty}^R g(y) dy,$$

where:

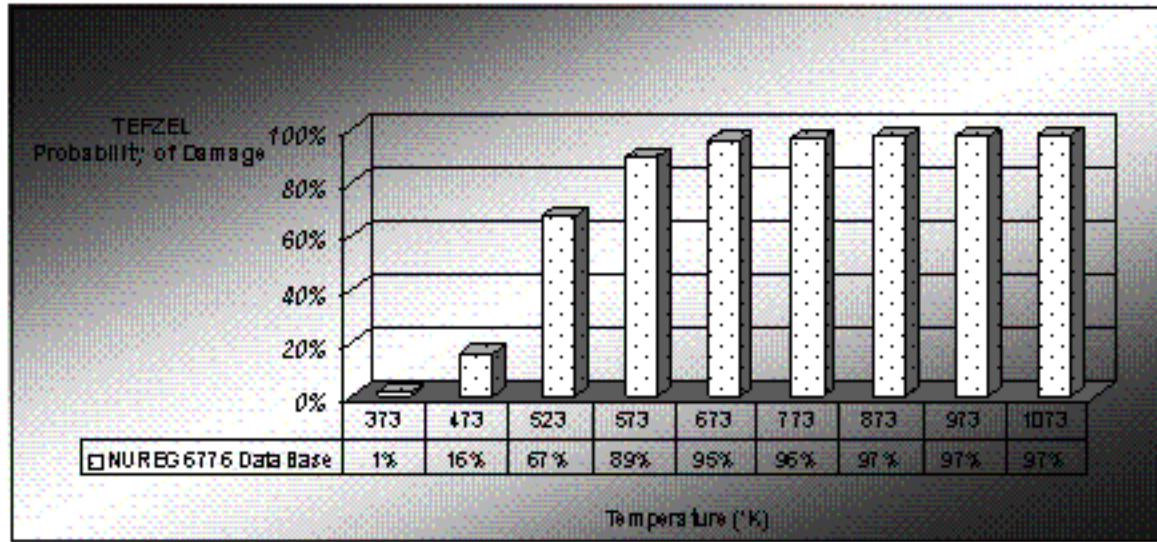
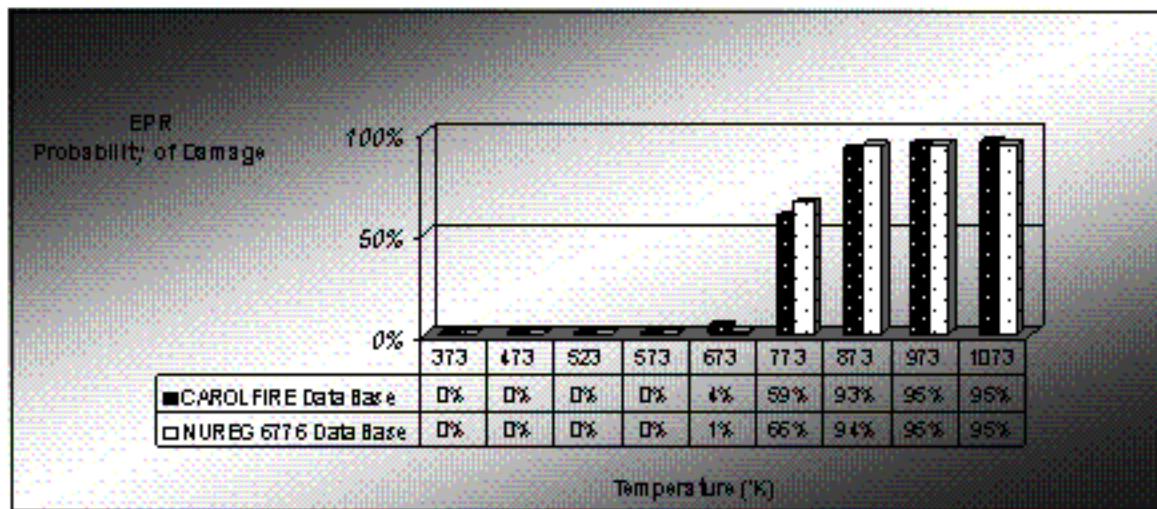
R_i : Instantaneous IR at temperature T_a (ohm).

$g(y)$: endurance-damage probability density function

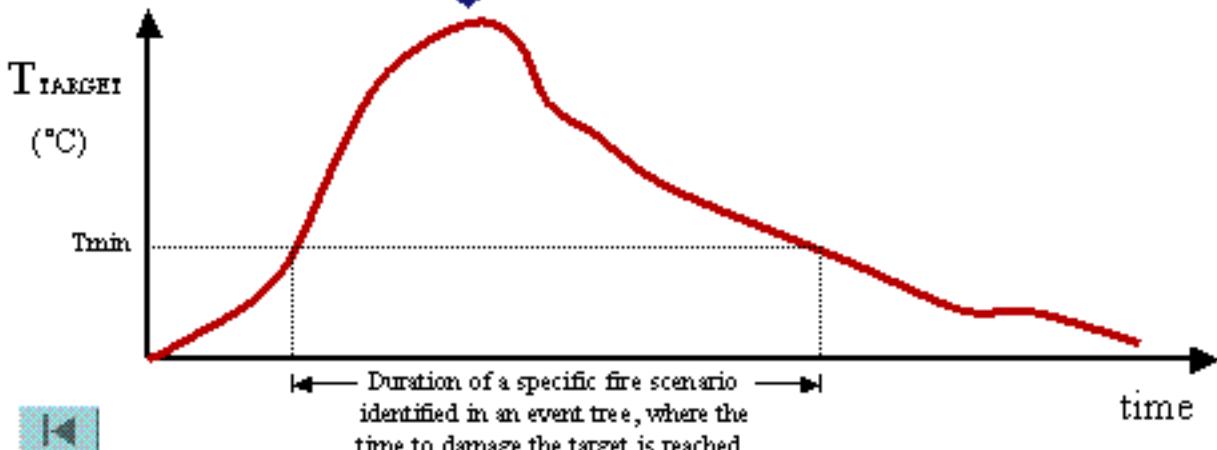
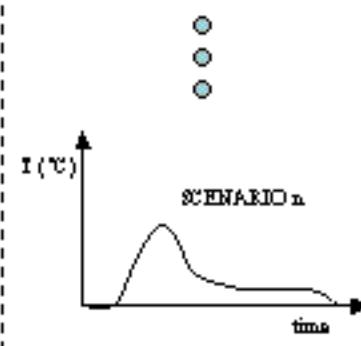
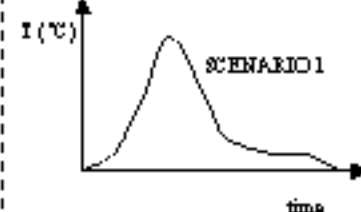
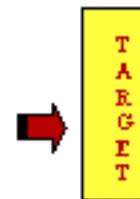
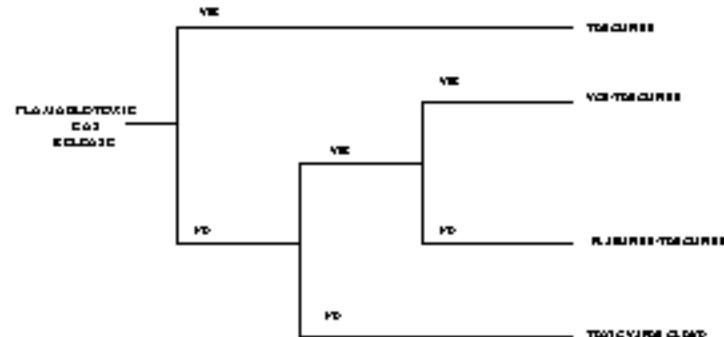


$$P_{failure_average} = Pf_a = \frac{\sum_{k=1}^n P_{failure_{t_k}}}{\sum_{k=1}^n t_k}$$

“K FACTOR” MODEL: time-temperature pattern



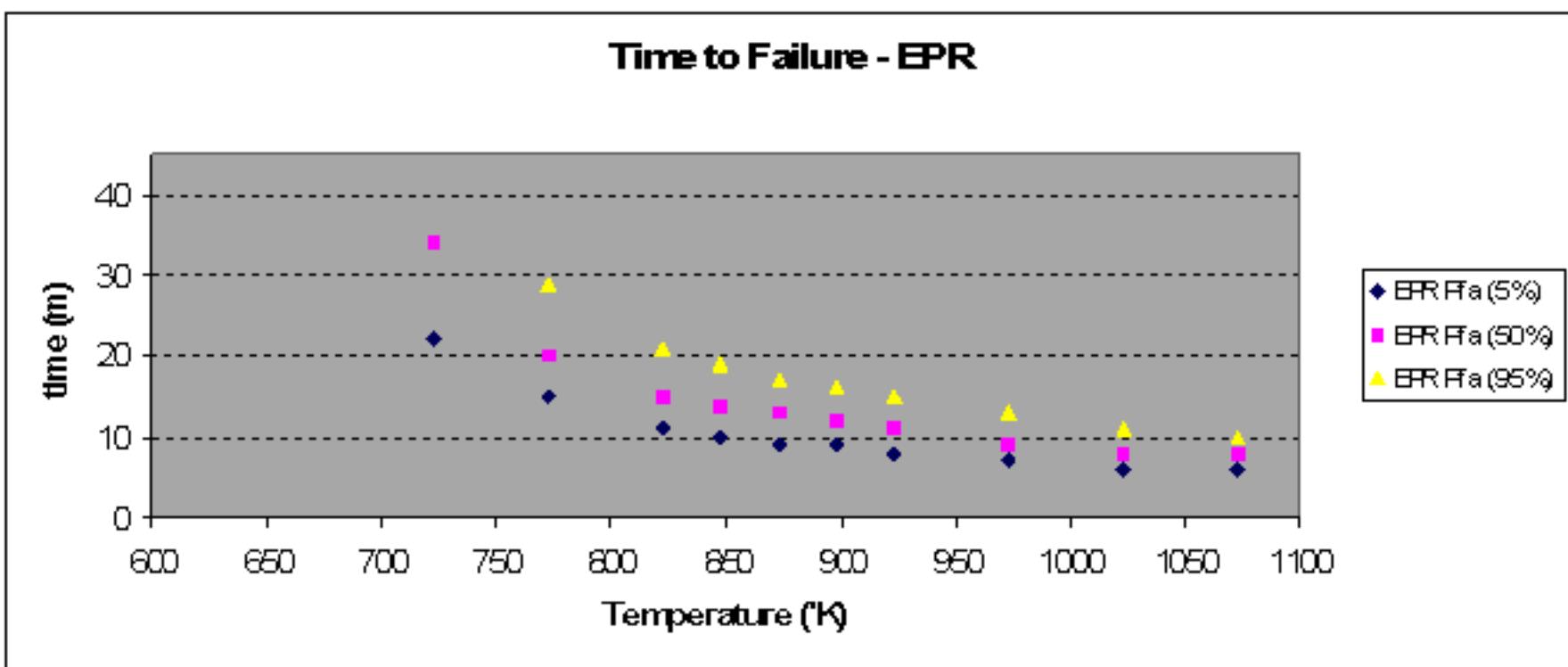
INITIATING EVENT	IMMEDIATE IGNITION	BURST IGNITION	BLAST VIBR.	PROTECTED
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The target damage time (t_{damage}) is compared to the duration of a specific fire scenario.

The conditional probability of damage to the "critical cable" is equal to the probability of that fire scenario if the damage time is less than the duration of the fire scenario.

TIME TO CABLE DAMAGE:



KINETIC MODEL:

In the light of the current knowledge and experimental evidence it is not possible to evaluate the feasibility of the kinetic model. Uncertainty associated with the characterization of kinetic parameters in addition to a lack of a universally accepted kinetic model, capable of modeling the thermal degradation process in a wide range of conditions, unable the development of this model at this time.

It is recommended to evaluate this model for a specific and well characterized polymeric material, preferably under controlled and well characterized thermal insults. Depending of the results obtained, evaluate the feasibility to extend this physics-based model to real fire scenarios.

HEAT TRANSFER MODEL:

The physics-based heat transfer model is a model capable of predicting the probability of cable damage under different thermal conditions. It takes into account the properties and characteristics of the cables and cable materials, and the characteristics of the thermal insult.

In order to improve the robustness of this model it is recommended:

- To enrich the existing databases for PVC, PE, XLPE, and EPR, and develop new databases for other common polymeric cable materials encountered in nuclear power plants (Tefzel, Silicone, XLPO, etc).
- To develop heat transfer models through which the cable inner temperature of complex cable arrangements and configurations can be estimated.
- To develop a database for thermal properties of polymeric cable materials of interest

IR “K FACTOR” MODEL:

The IR “K factor” model is an empirical model that is simple to apply, and it only requires the conductor-insulation radius ratio once the characterization of the parameters C1 and C2 has been done. However, it does not consider the dynamic of the thermal insult.

In order to improve the robustness of this model it is recommended:

- To enrich the existing databases for PVC, Tefzel, XLPE, and EPR and develop new databases for other common polymeric cable materials encountered in nuclear power plants (PE, Silicone, XLPO, etc).
- To evaluate the feasibility of this model for complex cable arrangements and configurations (multi-conductors with different insulation and jacket materials, armored cables, etc).

The models proposed were developed and validated with experimental evidence from different fire testing programs. However, most of the experimental tests represent fire scenarios where:

- The rate of temperature rise ($^{\circ}\text{K}/\text{minute}$) varies in the range from 40 to 120.
- The heat release rate (for large scale fire) varies from 70 KW to 350 KW.
- The heat flux (for small scale fire) varies from 6.1 to 30 KW/m².
- The maximum surrounding temperature achieved was about 900°K (627°C)

Therefore, the validity of these models should be evaluated for scenarios out of the limits defined above.



