URAN (2019-2022)

Uncertainty management in fire Risk ANalyses

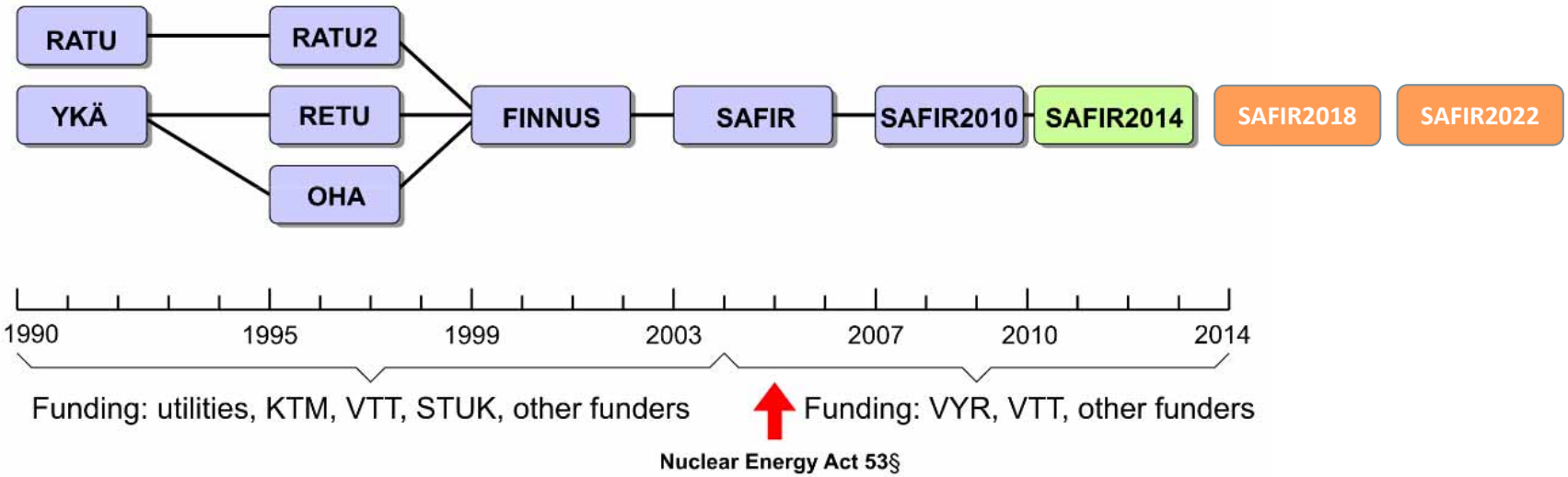
29/11/2019

VTT – beyond the obvious

SAFIR2010

The research is a continuum

Publicly funded NPP safety research programmes 1990 - 2014...



History of fire research projects

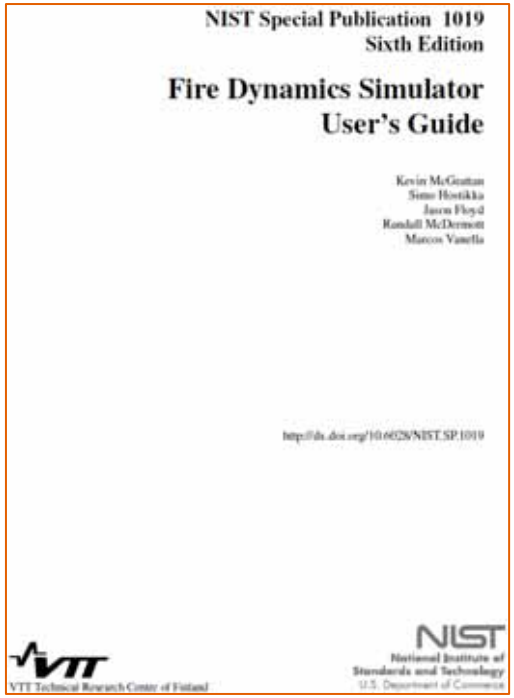
- RATU2: PALOTU 1995-1996
- RATU2: PALOTUB 1997-1998
- FINNUS: FISRE 1999-2002
- SAFIR: POTFIS 2003-2006
- SAFIR 2010: FIRAS 2007-2010
- SAFIR 2014: LARGO 2011-2014
- SAFIR 2018: FIRED 2015-2018
- SAFIR 2022: URAN 2019-2022

Scientific and societal impact:

- Advances in fire safety science
- Development of computational tools
- Experts for fire consultant companies
- Professor of Fire Safety Engineering at Aalto

Main topics

- Fires in electrical installations
  - Cable trays
  - Electronics cabinets
- Fire simulation
  - Fire Dynamics Simulator (FDS)
  - Probabilistic Fire Simulator (PFS)
  - Pyrolysis modelling (PyroPython)


NIST Special Publication 1019
Sixth Edition

Fire Dynamics Simulator
User's Guide

Kevin McGrattan
Simo Hostikka
Jason Floyd
Randall McDermott
Marcos Vanella

http://dx.doi.org/10.6028/NIST.SP.1019

VTT Technical Research Center of Finland

National Institute of Standards and Technology
U.S. Department of Commerce

Uncertainty management in fire Risk ANalysis - URAN

Background and objective

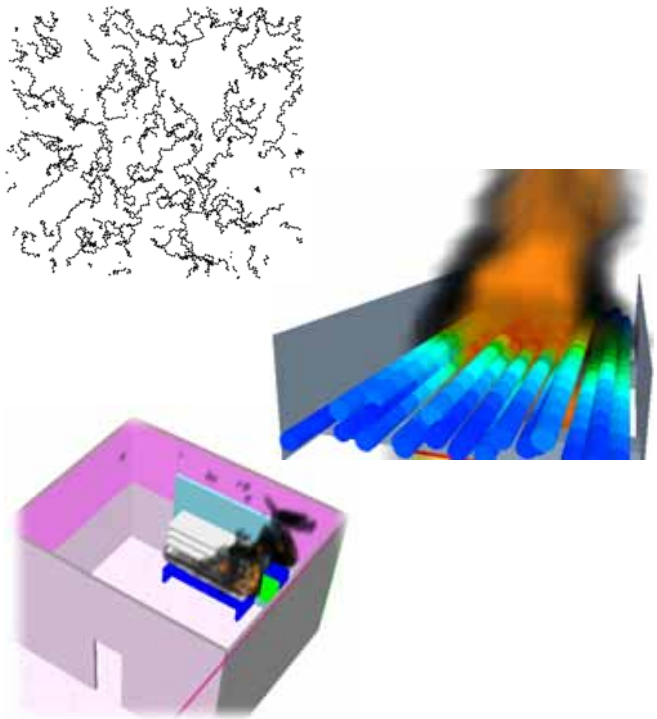
Computational tools are routinely used for fire hazard analyses. The overall goals of URAN are to quantify the uncertainties related to the fire growth predictions, and to manage them by developing better models that can serve the safety assessments of nuclear facilities and installations with different lifespans.

Results exploitation and effect on safety

Result	End-user	Timescale
Quantification of uncertainty	Utilities, regulators, all users of fire-PRA	1-4 years
Prediction of ageing effects on the fire behaviour of polymeric materials	Utilities, regulators, all users of fire-PRA, manufacturers of polymeric components	5-10 years
Continuous maintenance of fire modelling tools	Technical support organizations, fire engineering companies subcontracting to utilities	immediate

Resources

- Project manager: Jukka Vaari, VTT
- VTT, Aalto
- 2019: 14 pm and 220 k€



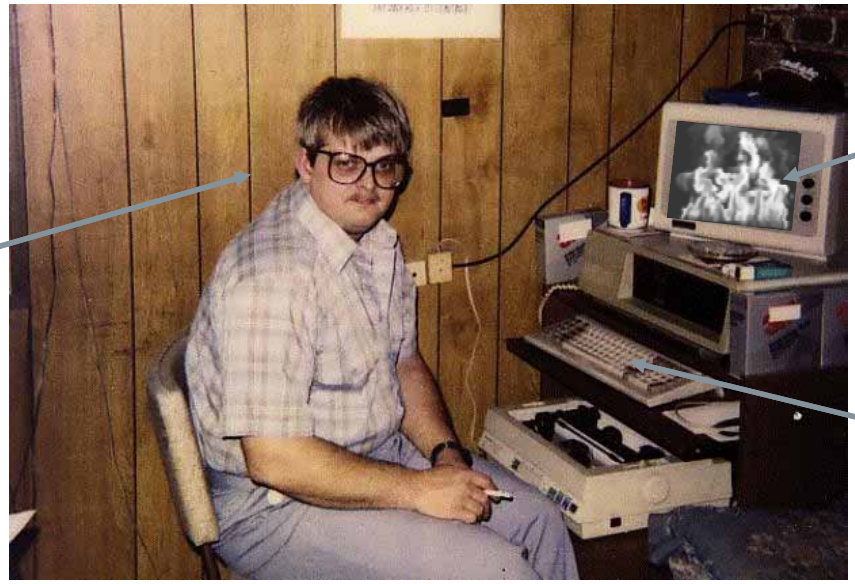
URAN involves fire modelling in molecular, component, and plant scales.

Work plan

	2019	2020	2021	2022
WP1 - Fire spread	**14**	**13.5**	**12**	**16**
T1.1 Fire spread model uncertainty	5	3	3	0
T1.2 User effect analysis by benchmarking	1	0.5	1	0
T1.3 Input uncertainty in real NPP event	0	0	0	4
T1.4 Next generation of cable fire models	3	9	7	11
T1.5 OECD/NEA PRISME3 participation	2	1	1	1
T1.6 Uncertainty propagation through surrogate models	3	0	0	0
WP2 – Fire behaviour of ageing materials	**3**	**4**	**4**	**4**
T2.1 Ageing effects of fire retardant materials	2	1	1	1
T2.2 Thermal decomposition of aged materials	1	2	3	3
T2.3 Supporting experimental studies.	0	1	0	0
Total	17	17.5	16	20

Blue – VTT
Red – AALTO
Green – Both

Sources of uncertainty in fire simulations



Verification and validation

- Verification: Are we solving equations correctly?
  - Is our mathematics right?
  - Are numerical and analytical solutions the same?
- Validation: Are we solving correct equations?
  - Is our physics right?
  - Are model and experimental results in agreement?

Types of validation

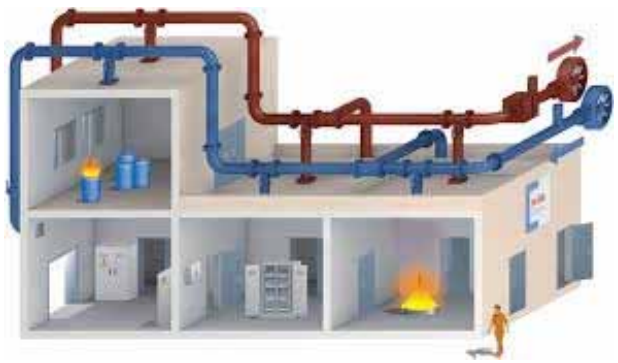
- ASTM E 1355
  1. Blind (a priori): user is provided with a basic description of the scenario to be modeled. The problem description is not exact; the model user is responsible for developing appropriate model inputs. No experimental results available.
  2. Specified ('semi-blind'): user is provided with a complete detailed description of model inputs, including geometry, material properties, and fire description. No experimental results available.
  3. Open (a posteriori): user is provided with a complete description of the scenario to be modeled, including experimental data.

OECD/NEA PRISME

- *PRopagation d'un Incendie pour des Scénarios Multilocaux Élémentaires*
- Propagation of fire for elementary multi-room scenarios
- Carried out by IRSN, France (Cadarache facility)
- Active participation by several OECD member countries
- PRISME 1: 2006-2011, 7 M€
- PRISME 2: 2011-2016, 7 M€
- PRISME 3: 2017-2021, 7 M€

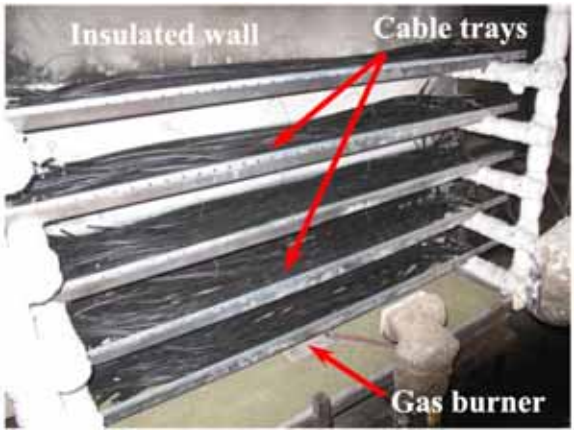
PRISME 3 research topics

Smoke spread



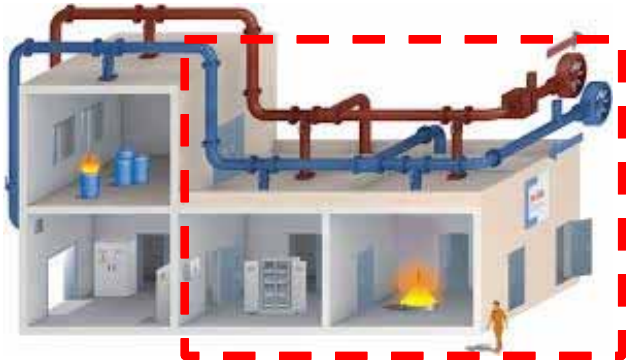
Fire spread:
electronics cabinets

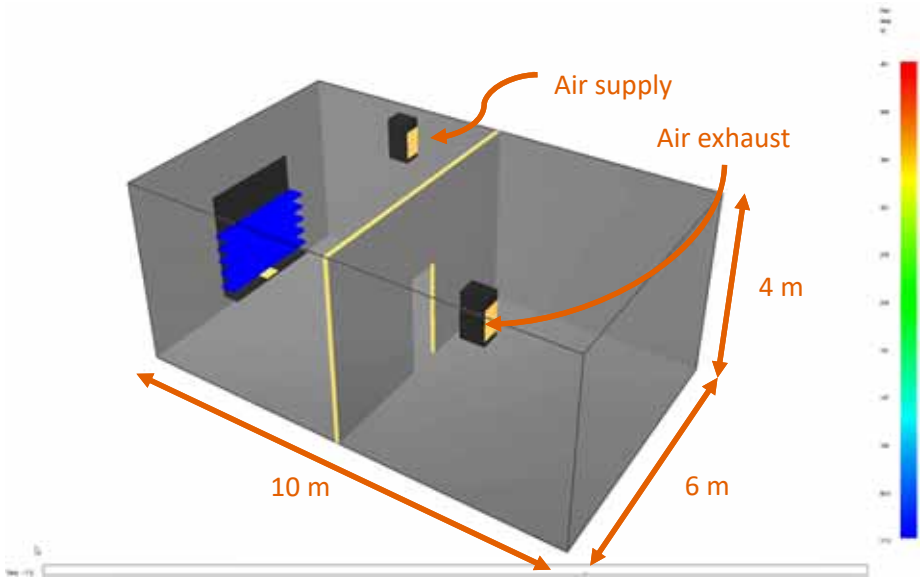
Fire spread:
cable trays



PRISME 3 modelling benchmark, step 1

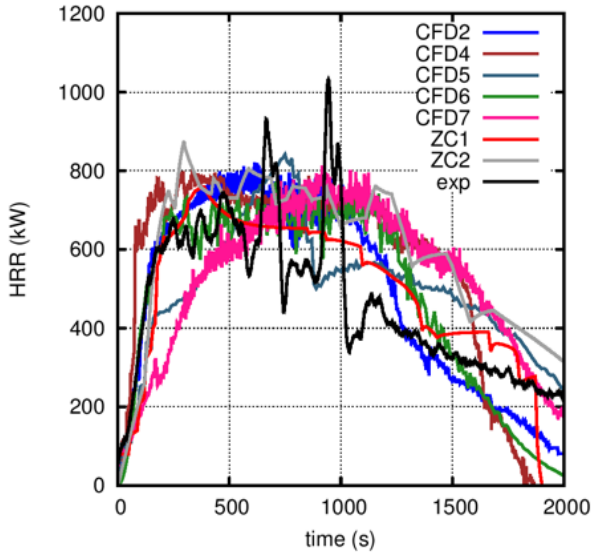
- Fire spread in cable tray, underventilated conditions
- Open simulation

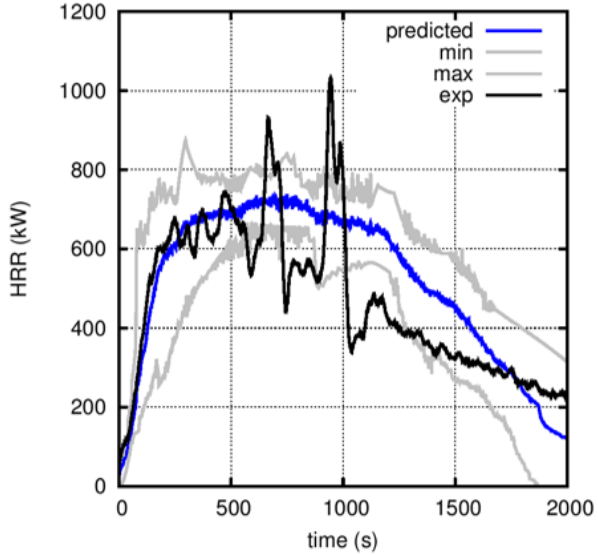




PRISME 3 modelling benchmark, step 1

Simulation	Fire Simulation Software	Institution
CFD 2	ISIS	IRSN
CFD 4	COCOSYS[2]	GRS
CFD 5	FDS	NRC
CFD 6	FDS	IBMB
CFD 7	FDS	VTT
ZC 1	SYLVIA	IRSN
ZC 2	BRI2002	CRIEPI





PRISME 3 modelling benchmark, step 1

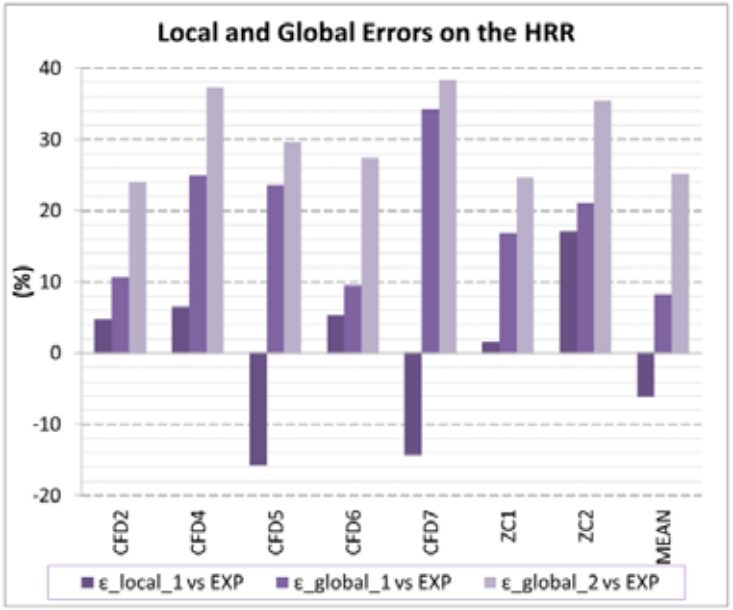
Data points: y_i = sim, x_i = exp.

Normalized single-point error:

$$\epsilon_{local} = \frac{(y-y_0)-(x-x_0)}{x-x_0}$$

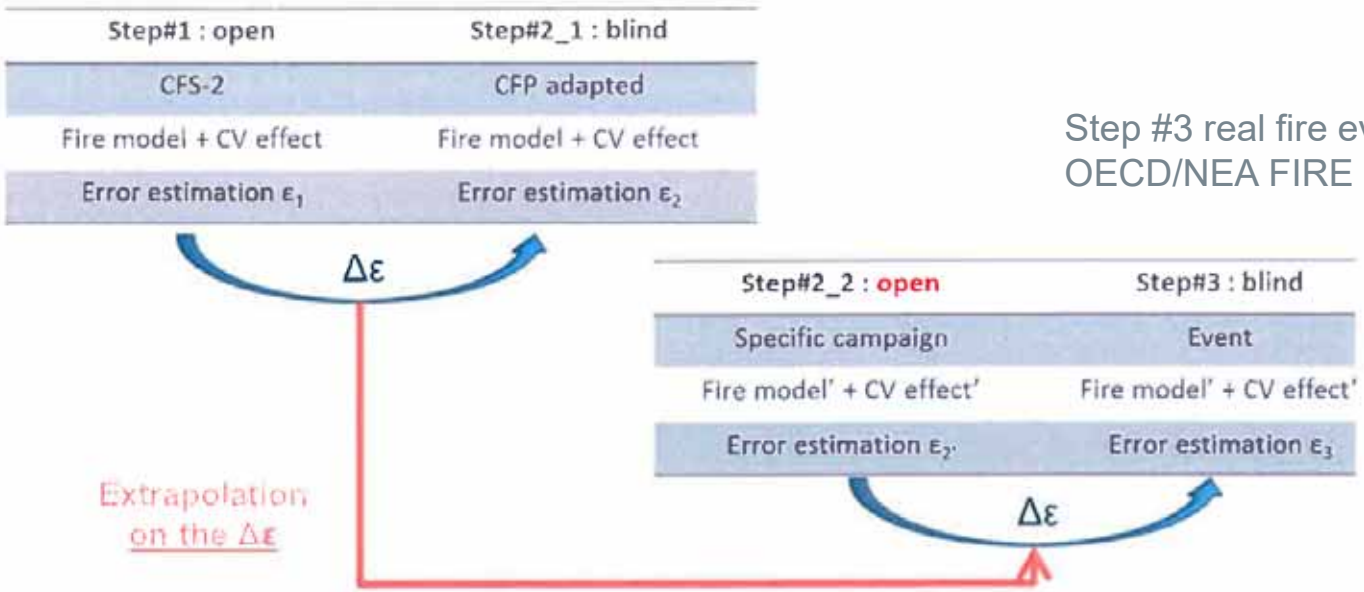
Normalized global error:

$$\epsilon_{global} = \frac{\|\vec{y}-\vec{x}\|}{\|\vec{x}\|} = \sqrt{\frac{\sum_{i=1}^{n}(y_i-x_i)^2}{\sum_{i=1}^{n}(x_i)^2}}$$



t=0-500s, peak t=0-500s t=0-2000s

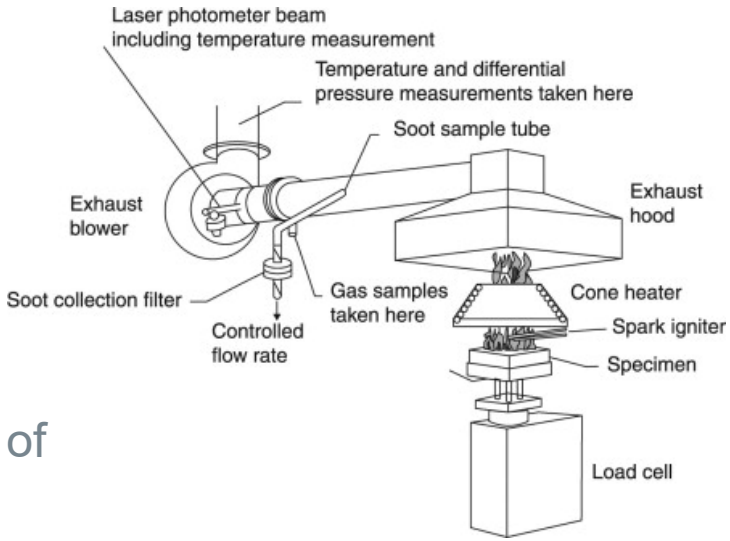
PRISME 3 modelling benchmark, steps 2&3



Step #3 real fire event from OECD/NEA FIRE database

Fire behaviour of ageing materials

- LARGO 2014: Literature review & some experiments
  - General impression: ageing reduces fire risk
- FIRED 2015: Thermal ageing experiments
  - No significant changes in fire behaviour
- FIRED 2016: Radiation ageing experiments
  - TGA & DSC: no significant effects
  - Cone calorimeter: decreased time to ignition, increased peak HRR, increased effective heat of combustion
  - “Topic should be studied further”



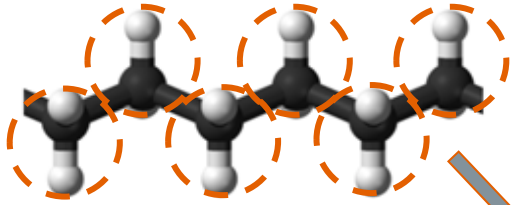
Fire behaviour of ageing materials

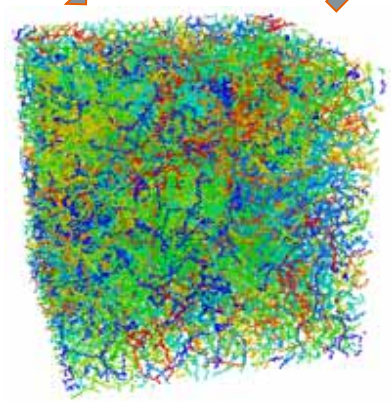
- Recent review by Vahabi et al, Polym. Int. 64 (2015) 313-328
  - According to the wide range of ageing conditions, polymers and FRs, ageing can lead to a decrease, no change or even an increase in flame retardancy.
  - Irradiation generally increases the peak HRR in cone calorimeter tests
    - Effects suggested but not proven: chain scission, crosslinking, filler degradation, filler migration, interactions between crosslinking agent and fire retardant

Modelling background

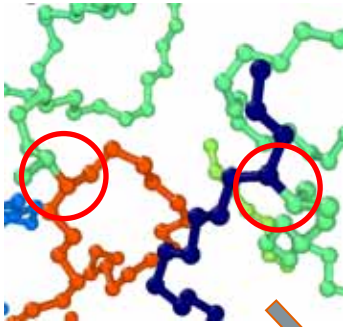
SA-DIGPOL
EU-TeaMCables
SAFIR2018-COMRADE

United-atom PE description

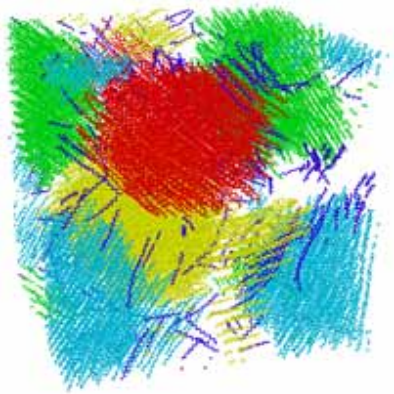




Equilibrium melt generation



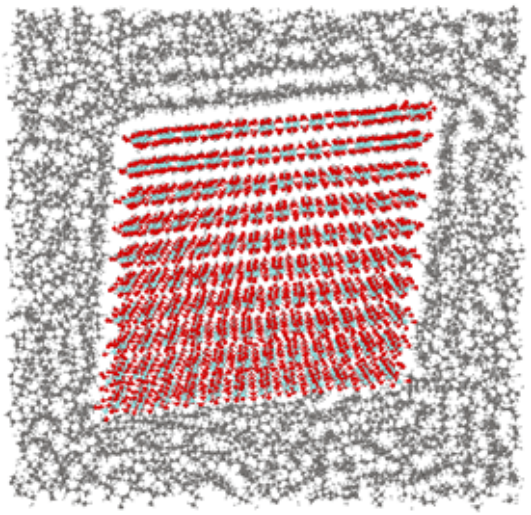
Building cross-links

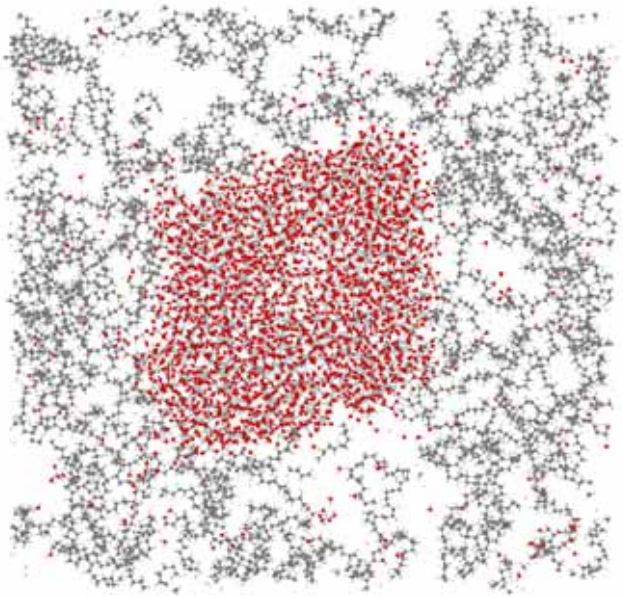


Crystallisation

Modelling background

SAFIR2018-FIRED





URAN WP2 main idea

SA-DIGPOL
EU-TeaMCables
SAFIR2018-COMRADE

- *United-atom description*
- *Ageing effects*

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SAFIR2018-FIRED

- *pyrolysis*

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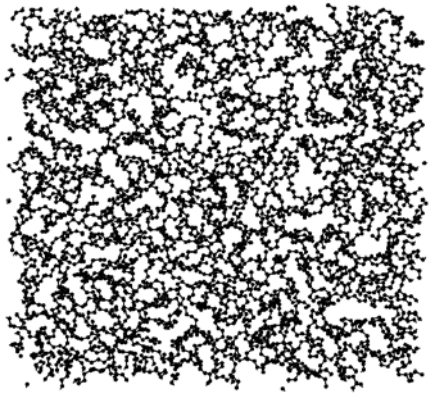
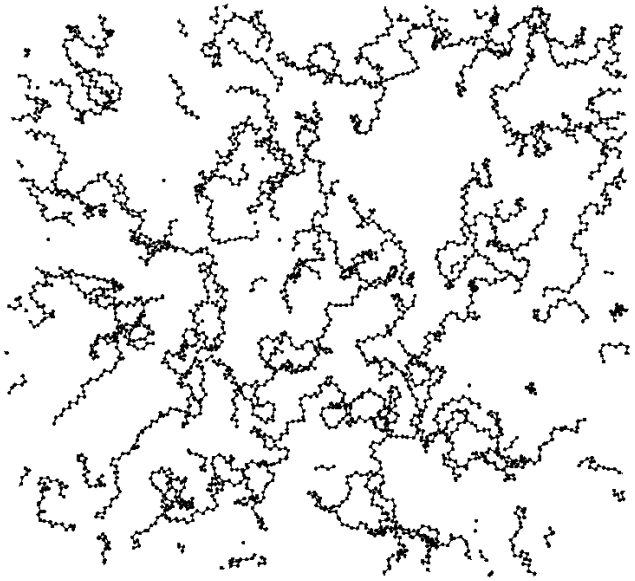




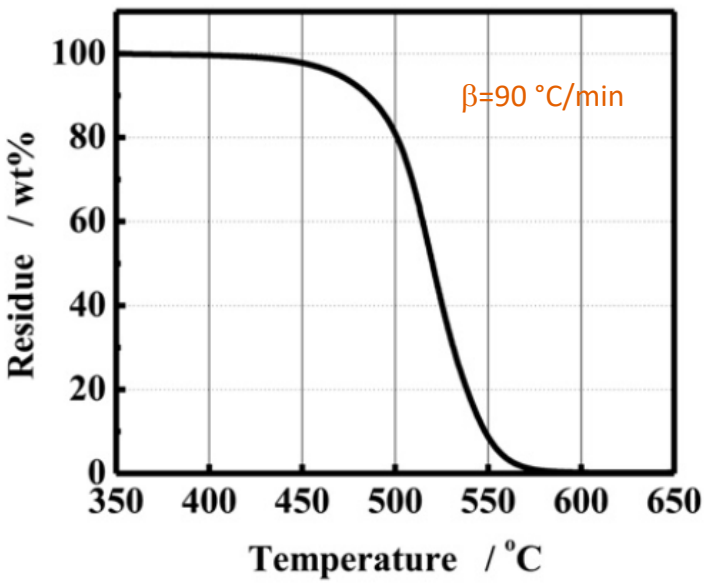
Polyethylene pyrolysis

- Free-radical chain mechanism

$\underset{P}{\sim CH_2CH_2\text{-}CH_2CH_2\sim} \xrightarrow{k_i} \underset{R_p\bullet}{\sim CH_2CH_2\bullet} + \underset{R_p\bullet}{\bullet CH_2CH_2\sim}$	Initiation
$\underset{R_p\bullet}{\sim CH_2CH_2CH_2\bullet} \xrightarrow{k_\beta} \underset{R_p\bullet}{\sim CH_2\bullet} + CH_2{=}CH_2$	Unzipping (UZ)
$\underset{R_p\bullet}{\sim CH_2CH_2\bullet} + \underset{P}{\sim CH_2CH_2CH_2CH_2CH_2\sim} \xrightarrow{k_H} \sim CH_2CH_3 + \underset{R_s\bullet}{\sim CH_2CH_2CH_2CH(\bullet)CH_2\sim}$ $\underset{R_s\bullet}{\sim CH_2CH_2CH_2CH(\bullet)CH_2\sim} \xrightarrow{k_\beta'} \underset{R_p\bullet}{\sim CH_2CH_2\bullet} + CH_2{=}CHCH_2\sim$	Random Scission (RS)
$\underset{R_p\bullet}{\sim CH_2CH_2CH_2CH_2CH_2(CH_2)_{x\text{-}4}CH_2\bullet} \xrightarrow{k_{1,x}} \underset{R_s\bullet'}{\sim CH_2CH_2CH(\bullet)CH_2CH_2(CH_2)_{x\text{-}4}CH_3}$ $\xrightarrow{k_\beta''} \underset{R_p\bullet}{\sim CH_2\bullet} + CH_2{=}CHCH_2CH_2(CH_2)_{x\text{-}4}CH_3$	Back-Biting (BB)

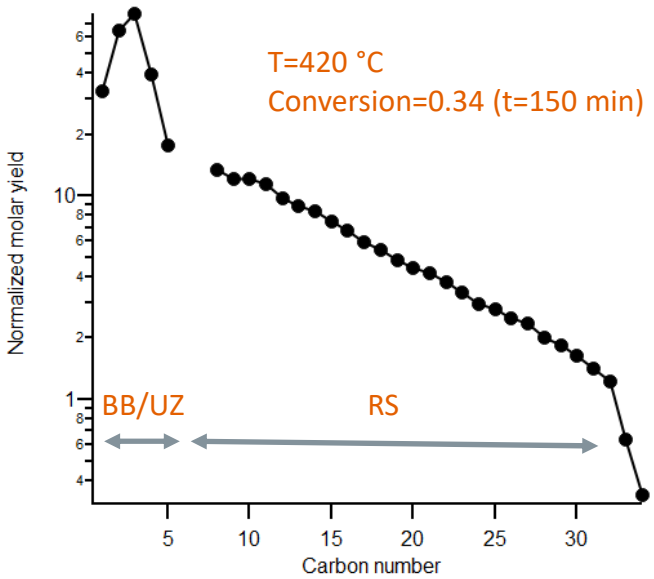
Polyethylene pyrolysis

TGA curve



Ueno et al. 2010

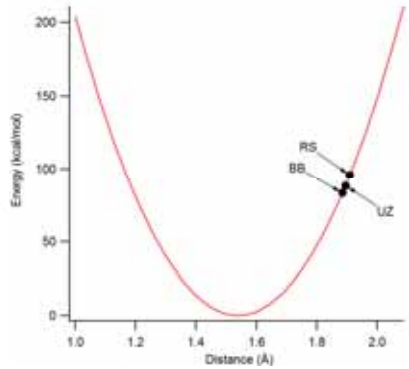
Product distribution

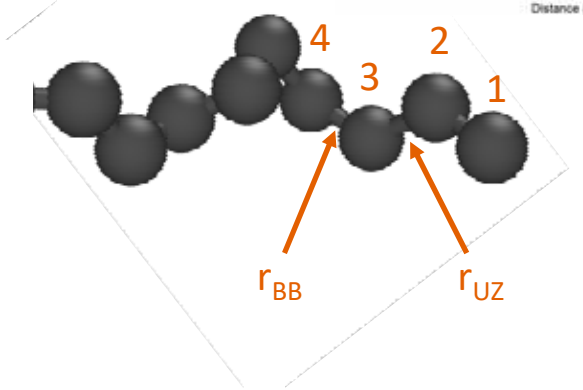


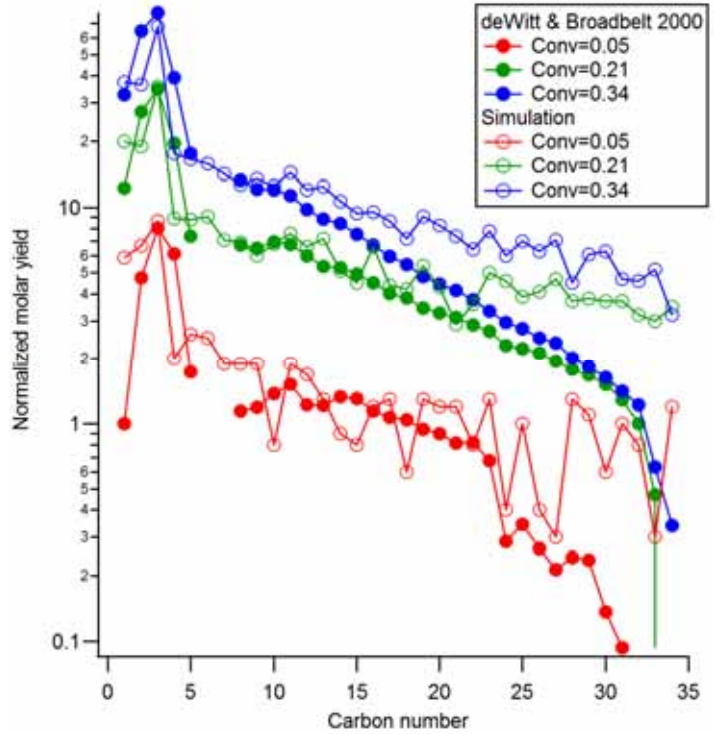
deWitt & Broadbelt 2000

Polyethylene pyrolysis

$$E = K(r - r_0)^2$$



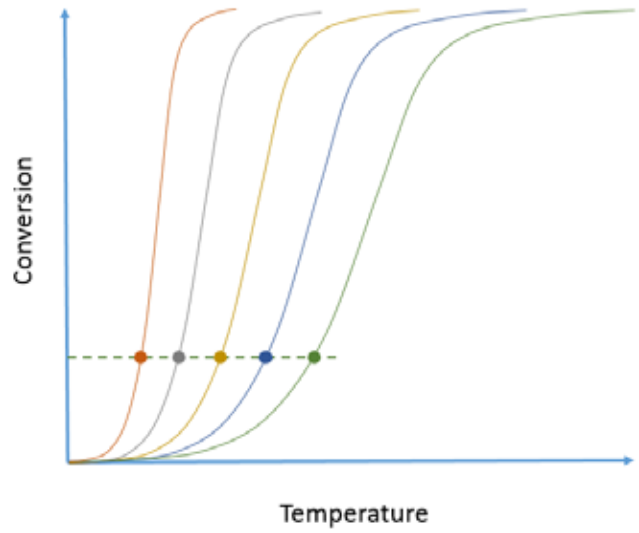


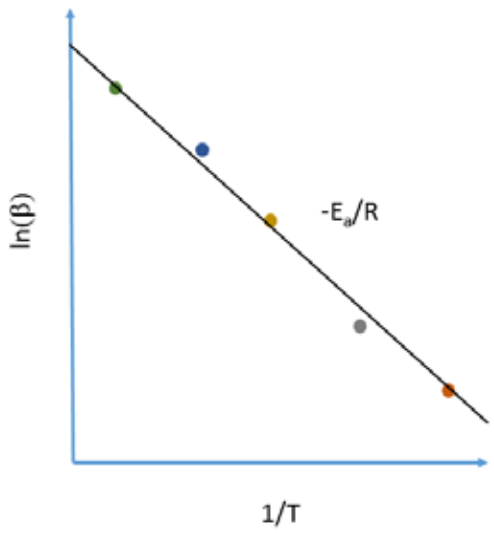


Simulated system: 10 x 9000

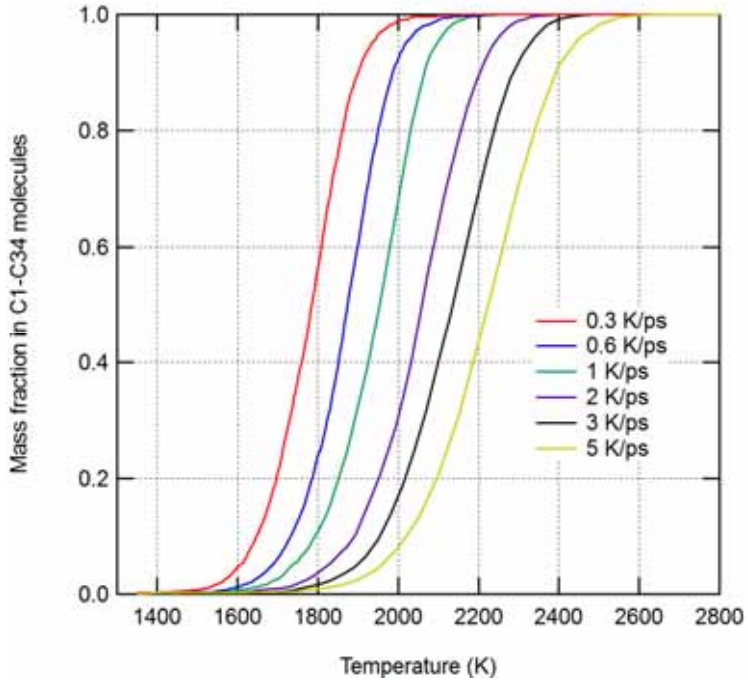
Isoconversional methods

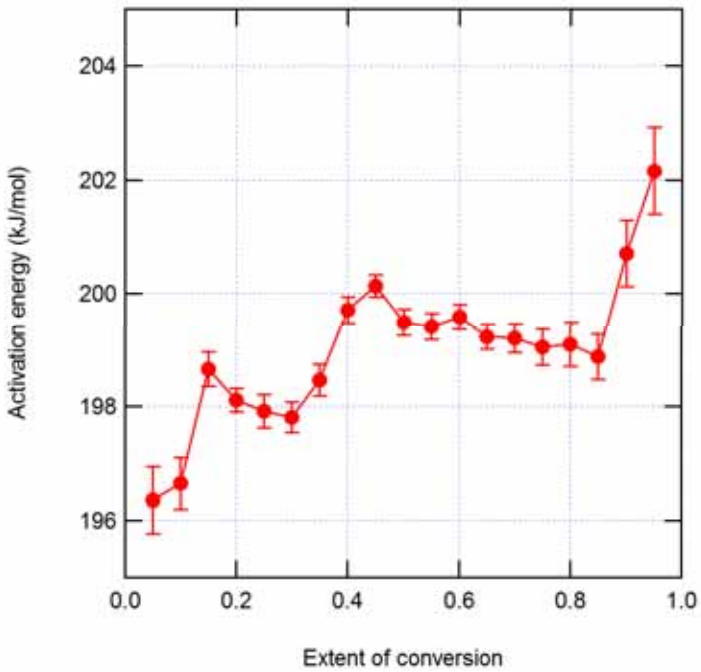
- Reaction rate at a constant extent of conversion is only a function of the temperature



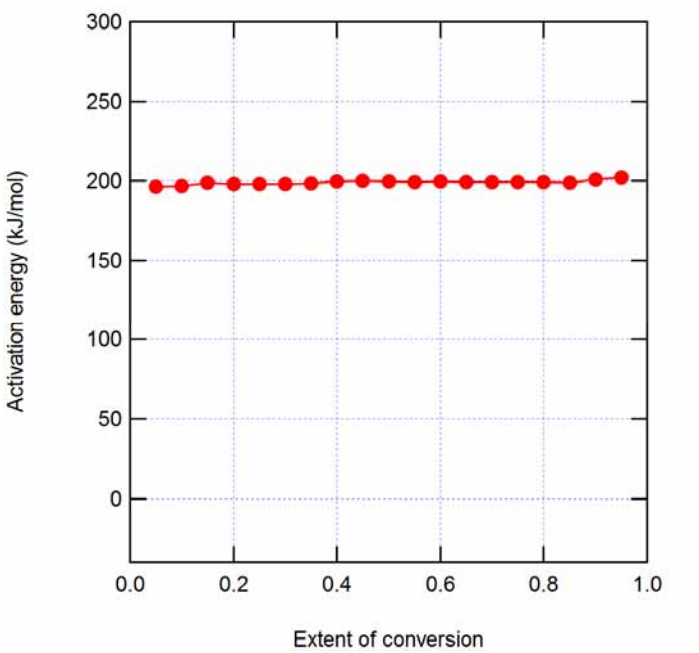


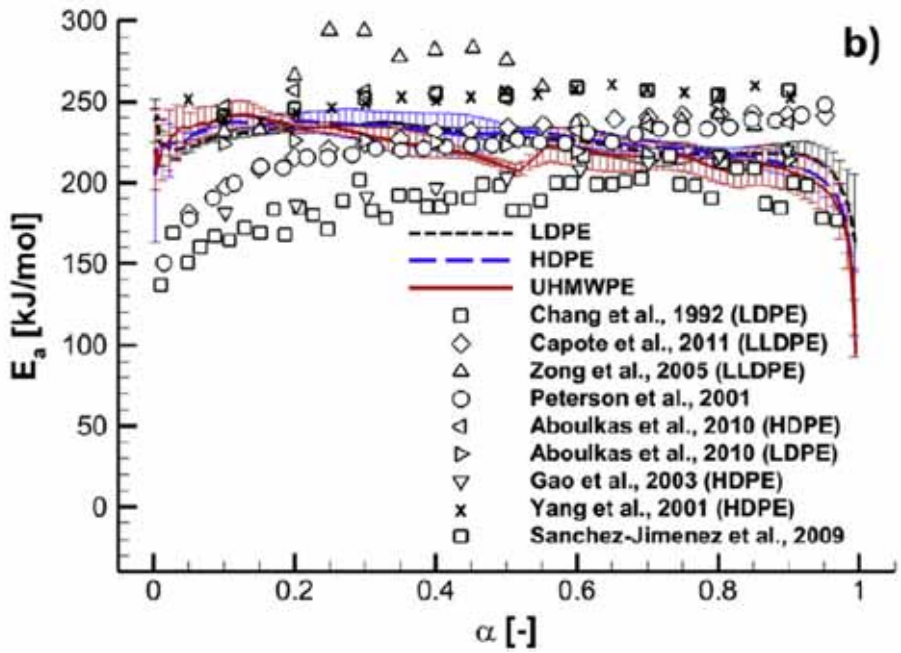
Isoconversional analysis





Isoconversional analysis





Snegirev et al. 2017

Oxidative degradation mechanism

Initiation:

- $RH \rightarrow R\cdot + H\cdot$ — Radiative initiation
- $\delta ROOH \rightarrow \alpha R\cdot + \beta ROO\cdot$ — Oxidative initiation, with chain scission

Propagation:

- $R\cdot + O_2 \rightarrow ROO\cdot$
- $ROO\cdot + RH \rightarrow ROOH + R\cdot$

Termination:

- $R_1\cdot + R_2\cdot \rightarrow R_1\text{-}R_2$ — Cross-linking
- $R_1\cdot + R_2OO\cdot \rightarrow R_1\text{-}O\text{-}O\text{-}R_2$
- $R_1OO\cdot + R_2OO\cdot \rightarrow R_1\text{-}O\text{-}O\text{-}R_2 + O_2$

VTT

beyond

the obvious

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29/11/2019