Index

a	– catalytic recombiners 55			
aerosol behavior 59, 60	 CFX and REACFLOW, for simplified EPR 			
 application of DNS and LES methods 59 	geometry 58			
– CFD calculations 59	- characterized by damage to fuel rods 53			
 modeling of aerosol flows 59 	 coarse-mesh code GOTHIC 58 			
- PHEBUS test facility 60	– EUproject ECORA 56			
– RANS simulations 59	 formation of stable density stratification 			
– validation 60	– passive recombiners (PAR) 54, 55			
aleatory uncertainties 333	 post-test calculations of HYJET 			
ALE coupling, with multi-block grid 18	experiments 57			
ALE grid 20, 21	- production of hydrogen by zirconium-water			
Algol/Pascal force 360	reaction 54			
ANSYS-CFX version 10 320	BFRL's experiment, to test response of smoke			
APOLLO code 13, 14	detectors on 166. See also fire modeling			
APOLLO simulation 15, 16, 23	 benefits from CFD calculations 175 			
 surfaces of fireball, and leading shock 	 buoyant non-reacting flow over heated 			
wave 16	surface 168–170			
ASME Boiler 301, 369	- isothermal turbulent flow through 166–168			
atmospheric diffusion equation 245, 246	Smagorinsky factor 168			
atmospheric dispersion 337	 simulation of incipient fire 170–173 			
- eddy coefficient 337, 338	 simulation of smoke migration 174 			
- wind speed 337	 uncertainties, to be assessed for fire 			
automotive crash simulation 9	simulations 175			
	blast parameters, computed with APOLLO and			
b	AUTODYN 15			
balance equations	blow-down system 269			
 dynamic modeling of disturbances in 	boiler feed water (BFW) 292			
distillation columns 164	boundary conditions 2, 38, 39			
- for filtered quantities 248	 of CFD pool fire simulation 145 			
- integral form of 163	for CFD simulation 51			
- for mass, momentum, and heat	– geometrical 40			
transfer 162, 163	– influence of 207, 208			
 Navier–Stokes equations, in combination 	– periodic 55, 245			
with 234	 refining of mesh/changes of 115 			
 used in form of ordinary differential 	 significant uncertainty in 329 			
equations (ODEs) 162	 in treating consequences of accidents, 			
beyond-design-based accidents (BDBA)	relevance of 333			
analyses 53	Buncefield fuel depot, aerial view 315			

Buncefield incident, CFD for - boundary conditions, influence of 207, 208 reconstruction 313-328 - grid dependency, influence of 206, 207 - extent of mist 317, 318 - SMARTFIRE program, benchmark - final dispersion simulations 325-328 test 201 - fire after explosion, aerial photo of 314 - user's influence 200, 201 - validation 200 - ground topology 322, 323 - hedges and obstacles 323, 324 - verification 200 - sensitivity tests 320, 325 CFD simulations. See also direct numerical - vapor cloud dispersion, CFD modeling simulation (DNS); large eddy simulation (LES); RANS simulations of 318-328 - adaptive code 195 applied for safety engineering tasks 3 c case studies - commercial software 146 - future application of CFX 103-105 - 3D CFD simulations 11, 36 - to show, impact of different stochastic - to determine critical thermal distances 151 parameters 339 - in fire safety applications 198 cavitation hammer effects 95. See also water flow around catalyst plates 54 hammer, effects - initial and boundary conditions 51 C3/C4 rectification system 278 - of large pool fires 139 C3/C-separation system - quantification of area of uncertainty for 191 - dynamic UniSim model of 280, 281 - two-phase CFD simulation 49 - mass flows, on cooling water failure 286 - of vapor cloud dispersion at 322 - process flow diagram of 278, 284 CFD tools 1-3, 7 certification testing, of new valve family 369 license/quality labels
 4 CFD applications, on explosions and blast Chapman-Jouget model 14 chemical reactors, for high-temperature waves 12 reactions 251-256 APOLLO code 13 - conservation equations of continuum coarse-mesh code GOTHIC 58, 59 mechanics 12 column trays, damage 299 verification and validation 12 combustion modeling 141, 142 CFD codes. See also commercial codes combustion systems, characteristic properties categories, applications in explosive safety and 10 - ignition delay times 237-239 - model used as options for radiation models - ignition of flammable mixtures 234-237 - laminar flame velocities 239-242 - quality assessment procedures 200 - turbulent flame velocities 242-247 - risk analysis, categories 10 combustion zone, in symmetry plane 15 - validity of 20, 210 commercial codes CFD-FLO Module 113 - ANSYS AUTODYN 14 CFD in nuclear reactor safety - AUTOREAGAS 19 application, state-of-art of CFD - equipped with MpCCI interfaces 18 modeling 42-53 (See also CFD modeling) - FLACS 19 deboration transients in pressurized water composite model, for disturbances in distillation columns 263 reactors 42-47 CFD modeling 369-371 computational safety engineering 4 - for prediction computational structural dynamics (CSD) -- of final vapor cloud depth 327 code 17. 18 -- of gas dispersion, within urban canopy computer aided design (CAD) tools 370 layer 213-215 computer-aided engineering (CAE) — of progress of vapor cloud across 327 environment 9 - safety valves 369, 370 condensation-induced water hammer 97 software packages 370 conservation laws 139 containment systems, for carriage of weaknesses of 369 CFD program results, reliability of 200 LNG 123

cooling water failure 285 - time-averaged axial temperature core melting behavior 60-64 profiles 147 - CFD to calibrate models 63 Dufour effect 140 - coarse-mesh approach 63 dynamic process simulation, - concept of effective convectivity 62, 63 applications 277 - Generation III LightWater Reactor 63 - hydrogen plant 288-293 - KERENA, solution applied 63 - model building, and verification of - modeling of external RPV cooling 63 289-293 - SIMECO tests 61 process safety-related application of - temperature field in core melt 64 284-287 coupled fluid-structure simulations 18 - rectification systems 277 - verification of 278-284 d dynamic simulation model 262, 278 - additional equations 266 deflagration-to-detonation transition - balance equations 264 (DDT) 25 design-based accidents 37 - CFD calculations 262 design driven, by probabilistic approaches 11 CFD for safety technology 269–272 Design Institute for Emergency Relief Systems - column stages 263 - discharged mass during pressure (DIERS) 307 design of safe complex system, challenges 12 relief 271 diffusion coefficient 139, 240, 337 - as hybrid model 271 direct numerical simulation (DNS) 3, 41, 140, - incoming vapor flow 265 181, 192, 214, 244, 246, 248, 251, 256 - outgoing liquid flow 265, 266 discretized reactor, for synthesis of sulfur phase equilibrium 265 dioxide 251 - pilot plant flowsheet 270 - relief device 266-268 dispersion - CFD, application in 309, 310 - of heat and chemical substances 309 e. - of sprayed droplets, during application of a eddy diffusion coefficient 337 surface coating 308, 309 eddy viscosity turbulence models 3 of vapor cloud over time 326 energy conservation equation 140 displaced support grid, in packed engineering methods column 298 - evaluation 22 - TNT equivalence (See TNT equivalence) distillation column pressurization, nitrogen piping 296-301 equilibrium stage model. See dynamic - damage to column internals 297 simulation model - nitrogen flow rates, dynamic model of 297-301 ERCOFTAC knowledge base Wiki - steady-state assumptions 296, 297 181, 182 distillation columns 262, 268, 300 - application challenges (AC) 182, 183 - column head pressure during failure -- index 186 -- test cases for different application scenario 271 disturbances, dynamic modeling (See areas 182 dynamic simulation model) - content of knowledge base 184 - pilot plant flowsheet 270 - interaction with users 185 DNS. See direct numerical simulation (DNS) - navigation tree of Wiki 183 droplet evaporation, analysis of 318 - underlying flow regimes (UFR) 183, 184 DTBP (di-tert-butyl peroxide) pool fires 139 -- flow types 183 -- index 187 - block structured grid, for simulation 144 - CFD predicted instantaneous temperature Ergun correlation 323 fields 147 erroneous systems, general strategies to handle - ignition behavior of 235 in safe way 350-354 - measured and CFD-predicted SEP of 151 error-causing software module 362 - measured and CFD-predicted time-averaged errors avoidance, software development 355 irradiances E_{CFD} from 152 explosive safety, and risk analysis 13

f fail-operational systems 353 fail-safe systems 354	 validation data requirements, of model 215–218 validation of mathematical flow, and
fail-safe systems 354 fast-acting valves 95. <i>See also</i> water hammer – benchmark test, for numerical	dispersion models 215 Gaussian dispersion models 295
diffusion 107–109	Gaussian dispersion models 275
 boundaries, characteristics of material and 	h
medium 108	hazards prevention, approaches for software
- case studies, future application of	systems 351, 352
CFX 103–105	HAZOP (hazard and operability study) 10 heat flux 124, 127, 134–136
 development of pressure, over time with linear closing of control surface 	heat transfer, evaluation of 125
breakup of 1st cavitational hammer 107	- burning insulation 128
within 10 s 105, 106	- deterioration, different phases of 126,
- experimental results 100–103	127
– experimental set-up 99, 100	– film boiling, possibility of 127, 128
 Kaplan turbine failure, 1D modeling of 105 	– simplified steady-state model 125, 126
– multi-phase flow test facility 97, 98	Hertfordshire Oil Storage Limited
– PPP extension, for software validation 99	(HOSL) 314, 320, 322, 325, 326
 use of CFX for calculations, difficulties 	Heskestad model. See plume models
in 106, 107	hydrocarbonl fires, large
faults avoidance, general measures 351	– CFD simulations 144, 145
fault-tolerant systems 352, 353	– boundary conditions 145
feed pipe damage 298	– radiation modeling 142–144
Fick's law 139	- turbulence modeling 140, 141
fireball surface	hydrocarbon rectification, dynamic simulation
cauliflower shape caused by instabilities 15comparison, of simulation results 17	of 277
- effects of combustion 16	hydrogen plants 288 – dynamic UniSim model of 290
- and shock front in simulated detonation 16	- process flow diagram of 288
fire dynamics simulator (FDS) 167, 199, 201,	HYJET experiments 57
202, 206	,,
fire modeling	i
– analytical models 161	ideal gas, isentropic expansion 335
– empirical model 161	industrial turbulent flows 321
– zone models 161, 162	Interactive Development Environments
flow force 113	(IDEs) 359
flow simulations on uncertain parameters,	
dependency of 196–198	J
flow testing 114	jet-in-cross-flow set-ups, mixing of fuels with
fluid dynamics modeling	air in 247–251
coupled to chemical reaction kinetics 35fluid–structure coupling 9, 18, 20	– filtered momentum equations 248– turbulent flame velocity 247
fluid–structure interaction (FSI) 97	- turbulent name velocity 247
Fourier's law 140	k
Francis weir formula 265	Kaplan turbine failure. See fast-acting valves
Friedlander function	Karman's constant 338
	Kolmogoroff dissipation scale 189
g	
gas discharge 335	1
gas dispersion, within urban canopy layer	Laplace transform, inversion of 346
- analysis of data from urban monitoring	large eddy simulation (LES) 3, 39, 47, 48, 64,
station 218–227	140, 166, 168, 181, 191, 194, 195, 214, 248,
– CFDs model for 214, 215	251, 256

leak cross sections 335 m leak diameter 334 mass balance 83, 85, 162, 176, 237, 244, 264, 266, 304 leaks - atmospheric diffusion equation 345, 346 mass flux density 139 - atmospheric dispersion 337, 338 mathematical modeling, of physical - deterministic calculations 339 phenomena 159 distance-dependent conditional probability - balance equations for 159, 160, 176 of death for 340 - principles 159 - gas discharge 335, 336 - verification and validation 159 geometry of aperture 335 membrane tanks 123 location risk of death 345 - advantages 124 - mass flow rates for 339 memory leaks 365 - probabilistic calculations 342, 345 message passing interface (MPI) 18 - sensitivity studies 339, 342 model's limits of applicability, influence - size 334, 335 of 202-204. See also grid dependency - fire in closed room 204 LES. See large eddy simulation (LES) light water reactors, safety and safety - fire in leaky room 205, 206 analysis 33-36 - fire in open room 204, 205 - barriers against release of radioactive momentum conservation equation 140 substances 34 Monte-Carlo calculations 344 - beyond-design based accidents 35 Moss type LNG carrier 124 - design-based accidents 34 - boundary conditions 129 - emergency core cooling (ECC) system 34 - CFD-calculations, of response to fire - loss-of-coolant accidents 34 exposure 128 - probabilistic safety analysis (PSA) 35 - checking CFD model 129-131 - reactivity-induced accidents (RIA) 36 - melting of insulation caused by heat - severe accident management guidelines 35 flux 134 liquefied natural gas (LNG) 123, 124 - model of solution domain 129 - transportation 124 - results of CFD calculation 133-136 liquid distributor damage 298 - weather cover, evaluation 129 liquid layer, hydrostatic pressure of 265 -- ABS FEA prediction 129 liquid petrol cascaded 318 Motor Industry Software Reliability liquid-vapor distribution 262 Association (MISRA) guidelines 363 lower explosive limit (LEL) 318 multiphysics 162 low-pressure valves. See low-pressure venting Murphree efficiency 263, 265 low-pressure venting 113 - CFD modeling 113 n - design of vent 114 natural gas 123 - different orientation of geometries 117 Navier-Stokes equations 9, 63, 194, 214, 234, - effect of rotated T-pipe part 116 244, 246, 252 - end-of-line vent 115 nitrogen flow rate flow force calculation 113, 114 - additional restriction orifice, effect of 301 - flow testing 114 nitrogen piping, for distillation column pressurization 297. See also process safety - lift as function of force and alpha value 116 non-linear behavior, of devices 12 - measured mass flow 113 - mesh and prism layer 114 nuclear power plants (NPPs) 35, 48, 54, 99 - optimized geometry 115 nuclear safety 33, 35, 37, 38 - piping structure, influencing vent's flow numerics, and under-resolved simulations and 115 - large eddy simulation (LES) models volume flow tank pressure diagram 118 194-196

- numerical discretizations, and under-

resolution 190, 191

low-Reynolds-number turbulence

models 370

 Reynolds-averaged Navier–Stokes (RANS) models 192, 193 	 initial and boundary conditions, taken from 51
- turbulence modeling 191, 192	– instantaneous surface deformations 52
_	- interfacial heat transfer and
0	condensation 52
oxides 35, 54	- NEPTUNE-CFD 50, 51
coefficients of probit equation 338mechanically stability 54	steam condensation rate contours 52temperature distribution as result of mixing in liquid 52
p	- thermal hydraulic phenomena, to reactor
packed column internals, damage 298, 299	pressure vessel wall 50
pair programming 363	– TOPFLOW-PTS experimental setup 53
PANDA drywell vessel 57	– turbulence modeled by 51
Peng-Robinson equations 279	ProcessNet Safety Engineering Section 5–7
perfect systems approach 352	process safety toolbox 295-311
peroxide pool fires. See also hydrocarbonl fires,	
large	9
 CFD predicted temperature fields, of DTBP pool fires 147 	quantitative risk analysis (QRA), for explosive safety 10, 25–27
- CFD simulations 144, 145	- CFD tools, role in QRA 26
block structured grid for 144	- consecutive events following some original
boundary conditions 145	cause 26
– combustion modeling 141, 142	- effects of single event 25
 JP-4 pool fire dynamics, quantitative 	event probability, expression 25
description of 145, 146	– modeling of event require 26
critical thermal distances 150–154	– models, currently being developed 27
flame temperature 146	– process of 25, 26
irradiance <i>E</i> 149, 150	– quantitative measure of risk 25
surface emissive power 147–149	
– radiation modeling 142–144	r
– turbulence modeling 140, 141	radiation modeling 142–144
petrochemical plants 277	RANS simulations 39, 41, 48, 59, 252, 256
petrol vapor concentrations, above ground level 322, 323, 324	Rayleigh–Taylor instabilities 15 REACFLOW, combustion code 58
petrol vapor source conditions 319	reactor, for producing sulfur dioxide 252–256
phenol-formaldehyde reaction 307	boundary conditions 253
phenol-formaldehyde uncontrolled exothermic	droplet trajectories 255
reaction 306–308	- equation for movement of droplets in 254
- disengagement behavior, effect of 307, 308	mass fraction field 254
 single-phase venting, assumptions 306 	 mass transfer coefficient 255
– two-phase venting 306, 307	– probability of wall hitting in dependence of
plume models 164. See also fire modeling	droplet sizes 256
– equations 165	- simulation of turbulent reacting flows 256
Pointing correction 265	– temperature field 253
polystyrene 123	– velocity fields 253
pressure relief valves (PRVs) 261	reboiler
pressure swing adsorption unit (PSA) 288	– heat transfer 287
pressure vessel code 301	– steam supply to 282
pressurized thermal shock (PTS) 49–53	relief device model 266, 267
- CATHARE code 51	- closing characteristic 268
– free surface flow, and stratification in cold	- opening characteristic 268
legs 51	Richtmyer–Meshkov instabilities 15
 high-end two-phase flow simulations 51 	RNG k-eps model 58

ROCOM reactor pressure vessel model, -- linear displacement sensor 84 nodalization of 44 - high pressure test facility 82-86 Society of International Gas Tankers and Terminal Operators (SIGTTO) 123 safe software systems. See also software, safety software, developed for code coupling 18 software development methods 350 system safety analysis 10 software errors, and error handling safety engineering 1 354-366 safety functions, software for 350 software quality, classification of methods to safety-related simulations, limitations of assure 363 CFDs 208-210 software, safety system safety valves 71 - advantages of 349 - black box testing 365 - computational domain, for flow simulation 87 - CFD 367 - contour of flow 72 - coding guidelines 362, 363 -- coefficients of 79 - definitions 350, 351 - 3D numerical simulation (CFD) 85, 91 development errors 355 - nozzle discharge coefficient models 80-82 - development methods 350 - nozzle/discharge coefficient sizing - dynamic analysis 365 - errors preventing methods 362 procedure 72 -- throat vs. reduced inlet stagnation - errors within source code 358 pressure 82 - error-tolerant systems 353, 354 - fail-safe systems 354 - nozzle flow models, for sizing coefficient Cg 80-82 - fault-tolerant systems 352, 353 - numerical model, and discretization 86, 87 - memory leak analysis 365 - numerical results 87-90 - numerical errors 361, 362 acceleration of spindle with disk - N-Version programming 364 during 89 - pair programming 363, 364 -- fluid-structure interaction (FSI) 89 - perfect systems 351, 352 - numerical sizing, for real gas flow 77, 78 - performance measurements 365, 366 - phenomenological description, of flow - portability errors 362 through 71, 72 - process models for 355, 356 - prototypes of 369 - safety-critical applications 350 - valve sizing (See also sizing of safety valves, - sawtooth model 357 applying CFD) - semantic errors 360, 361 -- according to ISO 4126-1 73, 74 - spiral model 357, 358 -- limits of standard valve sizing static code analysis 364 procedure 74 - static testing 362 -- method, for real gas applications 74-77 - syntax errors 358-360 sawtooth model, for software errors - user's needs 364 handling 357 - validation and verification 364, 365 - V-Model 356, 357 self-supporting tanks 123, 124 vs. membrane systems 124 - waterfall model 355, 356 - white box testing 365 semantic errors 360 sensitivity tests 320, 321 Soret effect 139 - CFD model geometry 321 spiral model, for software errors shear stress transport (SST) model 86 handling 357, 358 short-path evaporator spontaneous condensation hammer 97 - design, typical 302 steady-state simulation, use of 287 - dynamic simulation of 304 steam reformer 288 sizing of safety valves, applying CFD 82 - electric power failure - BASF high pressure safety valve 83 -- simulation results of 292 disk lift measurement 84 - emergency shutdown 291

pressure in cooling train and steam	turbulent burning velocities 242, 245, 246
drum 292	 of hydrogen mixtures with air 244
steam and air flows 291	TUV-certified flow test facility 113
temperature profile of cooling train 291	
stochastic input parameters 339	и
stochastic uncertainties 333	uncertainties data, for CFD simulations in fire
storage tank's design, for thermally sensitive	safety applications 196
liquids 308	UniSim steady-state model 279
Strohmeier leak 343	,
surface emissive power (SEP) 139	ν
surface roughness 370	vapor cloud dispersion, CFD modeling of
surface-to-air missile (SAM) system 361	- description of 320
syntax error 358	- final dispersion simulations 325–328
Syllian Cirol 330	- initial model tests 318, 319
t	- sensitivity tests 320
	•
tank design 124	grid resolution 321
thermal energy 303	ground surface roughness 324, 325
thermal fatigue, due to turbulent mixing	ground topology 322, 323
47, 48	hedges and obstacles 323, 324
thermal–hydraulic system codes 36	turbulence 321, 322
thermal radiation 34, 62, 139, 145	- vapor source term 319, 320
thermo-physical interaction 262	VDI-GVC (the German society of engineers
TNT equivalence 22	and society for chemical and process
- blast parameters of spherical detonation 23	engineering) 5
 deflagration-to-detonation transition (DDT), 	vessel dimensions 11
influencing factors 25	viscous bubbly behavior 307
 for gas explosions, APOLLO simulation 23, 	V-model, software errors handling 357
24	
 Graham–Kinney correlations for 24 	W
 hydrocarbon–air mixtures, rules for 25 	wash water flow 285, 286
– methane–air mixtures 24	 temperature profile in reboiler 287
 normalizing distance with 23 	waterfall model, modifications of 355, 356
 peak overpressures and positive 	water hammer
durations 24	 difficulties in use of CFX for
– pressure–time curves 24	calculations 106–109
 scaled distance, defined 22 	– effects 95
scaling property 23	- impact of increased temperature on 98
TOPFLOW-PTS test 54	- improvement, case studies 103–105
Torricelli equation 265	– induced by fast-acting valves 95
total electric power failure 285, 292	 and modeling of fluid dynamics
toxic substances	processes 97
- health effects of 338	– modeling, use of CFX in 109, 110
– probability of death 340, 341, 342	
1	
transient cavitating flow, in piping	– wave propagation 96
transient cavitating flow, in piping	– wave propagation 96Weibull distribution 337
systems 95	– wave propagation 96Weibull distribution 337wind tunnel experiments 227–229
systems 95 transient gaseous cavitation 95	 – wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 – generation of wind tunnel boundary
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity,
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during – mass balance for 304	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity, measurement 227
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during – mass balance for 304 – quality of mixture in 306	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity, measurement 227 validation data for RANS CFD-models
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during – mass balance for 304 – quality of mixture in 306 – temperature and pressure 305	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity, measurement 227 validation data for RANS CFD-models 228
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during – mass balance for 304 – quality of mixture in 306 – temperature and pressure 305 tunnel grid 20	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity, measurement 227 validation data for RANS CFD-models 228 vortex generators and roughness
systems 95 transient gaseous cavitation 95 transient vaporous cavitation 96, 97 tube failure, wiped-film evaporator during – mass balance for 304 – quality of mixture in 306 – temperature and pressure 305	 wave propagation 96 Weibull distribution 337 wind tunnel experiments 227–229 generation of wind tunnel boundary layer 227 time series of wind velocity, measurement 227 validation data for RANS CFD-models 228

wiped-film evaporator, tube failure 301–306. See also process safety toolbox

- dynamic simulation of 304-306
- potentially dangerous overpressurization scenario 301-303
- required relieving rate
- -- based on steam flow 303
- -- based on water flow 303

z

zone models, as simplified form of fire models 164

- CFAST, computer code 164
- ordinary differential equations (ODEs)
- thermodynamic properties 164