VTT

FORTUM

February, 2020

APROS VALIDATION

SELECTED VALIDATION CASES RELATED TO NUCLEAR SAFETY ANALYSES
and
TRAINING SIMULATORS

Used during code development

1. THERMAL HYDRAULIC SEPARATE EFFECT TESTS **1.1 Homogeneous model**	MAIN PARAMETERS AND PHENOMENA
Hungarian PMK test facility (PWR): small break LOCA	Critical flow, primary/secondary pressure relationship during SBLOCA, two-phase natural circulation, core overheating
Edward's pipe: blowdown of horizontal pipe	Critical flow, fast depressurization during rapid blowdown with delayed flashing
Top blowdown test facility (Battelle Frankfurt), OECD ISP-6, steam blowdown	Depressurization of a vessel, phase separation below swell level, critical flow from single phase steam to two phase mixture
Marviken critical flow test MXC-17	Critical flow, pressure distribution in a large diameter blowdown pipe
FRIGG-loop, two-phase heat transfer	Two phase heat transfer during flow boiling
Christensen experiment, subcooled boiling	Boiling heat transfer with enthalpy non-equilibrium
1.2 Two-phase model (five equation model)	
Marviken critical flow test MXC-17	Critical flow, pressure distribution in a large diameter blowdown pipe
IVO large scale loop seal experiment	Loop seal effect in a full scale experimental facility, stratification in a horizontal pipe (air/water experiment)
FRIGG-loop, two-phase heat transfer	Two phase heat transfer during flow boiling
Christensen experiment, subcooled boiling	Boiling heat transfer with enthalpy non-equilibrium
1.3 Two-phase model (six equation model)	
Edward's pipe: blowdown of horizontal pipe	Critical flow, fast depressurization during rapid blowdown with delayed flashing
Top blowdown test facility (Battelle Frankfurt), OECD ISP-6, steam blowdown	Depressurization of a vessel, phase separation below swell level, critical flow from single phase steam to two phase mixture
IVO large scale loop seal experiment	Loop seal effect in a full scale experimental facility, stratification in a horizontal pipe (air/water experiment)
Becker's dryout test	Flow boiling, high quality dryout and enthalpy non-equilibrium in post dryout heat transfer regime

Ersec reflood test: OECD ISP-7	Reflooding, heat transfer in quenching, quenching front propagation, effect of axial heat conduction
Marviken critical flow test MXC-17	Critical flow, pressure distribution in a large diameter blowdown pipe
FRIGG-loop, two-phase heat transfer	Two phase heat transfer during flow boiling, Interfacial friction, Acceleration, hydrostatic and friction pressure drop distributions, void fraction distribution
Christensen experiment, subcooled boiling	Boiling heat transfer with enthalpy nonequilibrium
UPTF-loop seal experiment (integral experiments it1b and it2a)	Loop seal effect in a full scale reactor geometry, stratification in a horizontal pipe (four loop configuration, 1.5 MPa)
UPTF-loop seal experiment (separate effects tests 01a, 02a, 03a, 04b, 05a, 07a, 08b, 09d, 10e, 11d, 11e)	Loop seal effect in a full scale loop seal, stratification in a horizontal pipe (single loop configuration, 0.3 and 1.5 MPa)
IVO CCFL Experiment	Counter-current flow limitation, interface friction, perforated plate, fuel bundle
REWET-II, reflood test SGI/6, 19 rods	Reflooding, heat transfer in quenching, quench-front propagation, effect of axial heat conduction
LOTUS annular flow experiment	Pressure loss in vertical annular air/water flow
NOKO emergency condenser experiments	Condensation in horizontal tubes
PANDA isolation condenser experiments	Steam and steam/air mixture condensation in vertical tubes
PANTHERS full scale condencer experiment	Steam and steam/air mixture condensation in vertical tubes and heat transfer in a large pool (ICONE-8)
PACTEL pressurizer experiments ATWS 10-13, ATWS 20-21	Compression and expansion of steam, wall condensation and effect of spray.
MIT pressurizer	Compression and expansion of steam, wall condensation.
NEPTUNUS pressurizer experiments	Compression and expansion of steam, wall condensation and effect of spray.
LOVIISA turbine trip, only pressurizer modelled.	Compression and expansion of steam, wall condensation and effect of spray.
UPTF CCFL tests for downcomer and core upper tie plat	Limitation of counter current flow in large scale reactor pressure vessel downcomer and in core upper tie plate.
PACTEL CMT experiments GDE-41 and GDE-43	Thermal stratification in a tank
PACTEL NCG pressurizer experiments (run-1)	Release of dissolved nitrogen gas from liquid during depressurization

PACTEL NCg-1 and NCg-3 non-condensable experiments	Effects of non-condensable gases on heat transfer in horizontal steam generator
Choi’s DCC experiment	Direct contact condensation in a horizontal channel
FLECHT-SEASET reflooding test 32013	Reflooding and quench front propagation
LUT passive containment cooler experiment PCC-06	Condensation in horizontal tubes with presence of non-condensable gas
Typical BWR steam separator	Steam separator model was tested with different water levels and mass flows (confidential data)
Model Boiler 2 steam separator experiments	PWR Steam generator separator was tested with 25%, 50% and 100% power levels
PWR PACTEL tests RF-02, RF-03, RF-04	Flow reversing in SG u-tubes
PWR PACTEL CNC-01, CNC-02	Flow stagnation and reversal in SG u-tubes
Water hammer experiment by Fujii and Akagawa	Pressure wave propagation
Natural circulation loop SKÄLVAN	BWR flow instability
FEBA reflooding experiment number 216	Core reflooding
PERICLES 2D reflooding experiment RE0062	Core reflooding
ACHILLES ISP-25	Core reflooding and quench front propagation
RBHT experiments 937, 945, 1096, 1108, 1143, 1196, 1383	Core reflooding and quench front propagation
Super CANON blowdown test	Verification of critical flow model
UCL choked flow steady-state experiment	Verification of critical flow model

BNL nozzle test	Verification of critical flow model
Boivin nozzle test	Verification of critical flow model
CODEX CT1 experiment	Cladding oxidation
Twelve coil facility	Single phase wall friction in helically coiled tubes
SIET helical coil facility	Single and two phase wall friction in coiled tubes
POOLEX STB-08-05	Direct contact condensation and flow oscillations (chugging) in blowdown pipe outlet in a pressure suppression pool

2. INTEGRAL TESTS **2.1 Homogeneous, 5- and 6-equation thermal hydraulic models, 1-dimensional reactor model and the Loviisa plant model** **Loviisa nuclear power plant (compared to plant data):**	
Steady state (@ 1375, 1500, 1530 MWth)	Capability of reproducing normal operating conditions at different power levels
Natural circulation on various power levels (0.5,1.0,...4.0%)	Coolant flow and temperature distribution during natural circulation
Stepwise load change test (set point of turbine power is changed)	Response of the reactor power caused by coolant temperature induced reactivity change
Reactor trip	Coolant temperatures (hot, cold leg), primary pressure and pressurizer level response, effect of the upper head liquid temperature, secondary pressure and steam generator level in rapidly changing conditions
Turbine trip	Plant response to closing of turbine valve and opening of the turbine bypass line
Trip of one feed water pump	Start-up procedure of the auxiliary feed water pump, plant controller behaviour, if pump does not start
Trip of two primary coolant pumps	Automatic reactor power control with slow shutdown, loop temperatures, setup of reverse loop flow conditions in two loops
Feedwater line break	Partial loss of feedwater, dynamic response of plant safety systems, dynamic behaviour of the feedwater line system during blowdown
Several plant regulation tests	Plant control and protection system behaviour
Blackout test from primary circuit point of view	Transition to natural circulation
High pressure preheater system	Design of a high pressure preheater system, design and preconditioning of control system, dynamic tests
Primary circuit overcooling transient	Turbine bypass valve capacity for reactor system cooldown after reactor trip, primary circuit repressurization due to HPIS startup, pressurizer spray characteristics, pressurizer water level response to cooling, system pressure response to pressurizer level increase
Loviisa nuclear power plant, automation system (compared to Loviisa training simulator data):	
Movement of control rod group	Reactor power and power distribution response to control rod movement, primary circuit response to reactor power change

Small break LOCA	Single and two phase natural circulation characteristics, use of secondary side pressure control to accident management, gradual depletion of the secondary side water inventory, transition to loss-of-feed-water ATWS, primary system dynamics response to heat transfer decrease, energy removal through the break
Loss of feedwater transient (ATWS)	High pressure behaviour of the primary circuit after depletion of the secondary water mass and trip of reactor coolant pumps, two phase natural circulation and reflux cooling of the primary system
Turbine trip with steam dump to condenser	Plant response to turbine bypass opening, plant controller behaviour
Control rod withdrawal (ATWS)	Primary and secondary circuit response to overpower, gradual transition to a loss of feed water incident due to insufficient feed water injection rate, plant controller behaviour
Opening of one pressurizer safety valve	Primary and secondary circuit response to slow pressure decrease
2.2 Homogeneous and 5-equation thermal hydraulic models, TVO nuclear power plant (compared to accident analysis code results (GOBLIN, BISON)	
Steam line break	Steam flow out through the end of steam line, boiling water reactor vessel and steam line dynamics, pressure and water level behaviour in transients, response of reactor power to core inlet flow changes, feed-water and turbine flow controller dynamics
Simultaneous closure of all steam line isolation valves	Pressure and reactor power peaking due to the abrupt steam flow change
Loss of feed water	Plant system response to the delayed reactor scram
2.3 Homogeneous and 5-equation thermal hydraulic models, automation system, Forsmark 3 nuclear power plant model (compared to operational instructions, plant data and plant simulator data)	
Steady state (@ 65, 100, 109 % of nominal power)	Plant data from F3
Plant startup (cold shutdown > 109 %)	Operating procedures
Plant shutdown (109 % > cold shutdown)	Operating procedures
2.4 Homogeneous and 5-equation thermal hydraulic models, automation system, KOLA nuclear power plant	

Erroneous opening of pressurizer safety valve (KOLA 3)	Primary and secondary circuit response to slow pressure decrease
Trip of two main primary coolant pumps (KOLA 4)	Automatic reactor power control with slow shutdown, loop temperatures, setup of reverse loop flow conditions in two loops
2.5 Homogeneous, 5- and 6-equation thermal hydraulic models, LOFT test facility model	
Small break LOCA L3-6 (2.5%) with pumps running	Slow primary loop depressurisation, pump behaviour in two phase flow conditions, two phase heat transfer in steam generators
Small break LOCA LP-SB-03, cold leg break (5-6 kg/s)	Critical flow, two phase heat transfer in steam generator, pump behaviour in two phase flow, core uncovery and reflooding under high pressure, feed and bleed cooling
Medium size LOCA L5-1, cold leg break (110 kg/s)	Critical flow, coolant redistribution in primary circuit, core uncovery and reflooding
Large break LOCA L2-5, 200% double ended break in cold leg	Critical flow, coolant redistribution in primary circuit, core uncovery and reflooding under low pressure, accumulator and LPIS cooling
2.6 5- and 6-equation thermal hydraulic model, PACTEL test facility	
Natural circulation experiment (ISP-33)	Natural circulation as a function of primary coolant mass inventory in a horizontal steam generator, including single phase and two phase natural circulation and reflux boiling (SG scaled according to tube lengths)
SBLOCA experiment, hot leg loop seal behavior (SBL-22)	As above, SG scaled according to SG height, single loop, pressurizer isolated, opening of the loop seal with a pressure peak
SBLOCA experiment, hot leg loop seal behavior (SBL-30)	As above, three loops, pressurizer isolated, asymmetric behavior of the loops, opening of the loops seal(s) with a pressure peak
SBLOCA experiment, validation of the accumulator models (SBL-31)	As above, three loops, pressurizer included, ECC water from two accumulators
SBLOCA experiment, validation of the accumulator and HPI models (SBL-33)	As above, ECC from accumulators and HPIS, boron dilution during boiler-condenser natural circulation
Single phase flow instabilities (CMP-04)	Oscillations of single phase natural circulation during compensated leakage situation (single loop experiment, undamping oscillations)
Single phase flow instabilities (CMP-08)	As above, three loop experiment, damping oscillations
Single phase flow instabilities (CMP-09)	As above, three loop experiment, undamping oscillations

Horizontal steam generator behavior (SG-2, SG-3, SG-4)	One loop operation, heat transfer in primary and secondary side with different secondary side water levels, mixture level behavior in the secondary side pool
Loss of feedwater, horizontal steam generator behaviour (LOF-10)	One loop operation, heat transfer in primary and secondary sides with different secondary water levels, water circulation in primary side tubes (low level)
Gravity Driven Core Cooling test (GDE-11)	Passive safety injection system behaviour, CMT with two pressure balancing lines, rapid condensation in CMT, thermal stratification in CMT
Gravity Driven Core Cooling test (GDE-24)	Passive safety injection system behaviour, CMT with pressure balancing line to cold leg only, condensation and thermal stratification in CMT
Gravity Driven Core Cooling test (GDE-34)	As GDE-24 , CMT initially full of hot water, start up of natural circulation through passive safety injection system with small driving force
Gravity Driven Core Cooling test (GDE-41)	As GDE-24 , 1.5 % break in cold leg
Gravity Driven Core Cooling test (GDE-43)	As GDE-24 , 0.1 % break in cold leg
ATWS-10	Compressibility of steam in the top of pressuriser, pressuriser heating
Dissolved gas behaviour in Pactel facility during LOCA	Comparison of tank and node based models for dissolved gas release during LOCA
PACTEL NCG-1, NCG-3, NCg2-04 and NCg2-05	Test were performed with ~50% primary mass inventories and only one loop in operation to study air and helium effects on heat transfer in the steam generator.
PWR PACTEL Benchmark (SBL-50)	Blind benchmark with post-test open calculation phase to study modified SBLOCA scenario.
PWR PACTEL CNC-01, CNC-02	Cool down with natural circulation with isolated steam generator
PWR PACTEL Station black-out experiment SBO-02	Steam generator boil off, core uncover, heat up and accumulator injection.
2.7 5- and 6-equation thermal hydraulic model, BETHSY test facility	
Loss of Residual Heat removal during mid-loop operation (BETHSY test 6-9C)	• Low pressure range in primary loop • Phase separation by large velocity differences (0-20 m/s) in vertical, inclined and horizontal pipes • Stratification in horizontal hot leg and cold leg pipes • Counter current flow in vertical steam generator

	- Phase separation in core in low pressures - Liquid holdup in pressurizer during counter-current flow
2 inch cold leg break in a PWR with vertical steam generators and with high pressure safety injection assumed to be unavailable. Low pressure safety injection actuated assisted by the secondary pressure reduction (BETHSY test 9.1b)	- Small break LOCA chain in a Western commercial PWR - Critical break flow in the orifice with subcooled liquid, saturated liquid, two-phase mixture and single phase steam upstream the break - Core uncover - Core quenching by level swell after pressure drop - Final core quenching by low pressure injection - Vertical steam generator (process component) in accident and transient conditions - Stratified flow in hot and cold leg - Clearance of hot leg and cold leg loop seals - Counter-current flow in steam generator tubing
2.8 6-equation thermal hydraulic model, PSB-VVER test facility	
OECD PSB-VVER analytical exercise	Primary to secondary leakage (PRISE), SG collector cover lift up
2.9 6-equation thermal hydraulic model, PKL III test facility	
E2.2	SBLOCA, Boron dilution
E3.1	Mid loop operation, Boron dilution
G7.1	Hot leg SBLOCA
H2.1	Station black-out (SBO) experiment
NC-flowmap experiment	Natural circulation with stepwise decreased primary system water inventory
2.10 6-equation thermal hydraulic model, ROSA test facility	
OECD/ROSA research program test 6.1	SBLOCA in pressure vessel upper head
OECD/ROSA research program test 6.2	SBLOCA in pressure vessel bottom
OECD/ROSA-2 test 3	Hot leg SBLOCA (1.5%)
OECD/ROSA-2 test 2 and 7	Cold leg intermediate size LOCA
2.11 6-equation thermal hydraulic connected to containment model	

PANDA PCC T1-1	Heat transfer and condensation in passive containment cooling (PCC) system. The tube side was modelled with the 6-equation thermal hydraulic model, the drywell and the wetwell with the Apros containment.

3. CONTAINMENT **3.1 Validation against experiments**	
AECL hydrogen recombiner test	Recombination rate of AECL type recombiner in Large-Scale Vented Combustion Test Chamber.
AREVA type recombiner	Validation of recombiner efficiency correlations against the data provided by manufacturer.
Marviken full scale suppression pool containment experiment BD 18	LBLOCA in BWR suppression pool containment. Comparison to Contempt results
Battelle ice condenser tests 6 and 11	Validation of the Single node Ice Condenser (SIC) model.
Victoria 13	General behaviour of containment and ice condenser. Normal operation of IC doors. Both IC block are full of ice.
Victoria 29	General behaviour of containment and ice condenser. Behaviour of formation of the natural circulation loop inside the containment. IC doors are forced open. Other IC block is empty of ice.
Victoria 42	General behaviour of containment and ice condenser. Start of the natural circulation loop inside the containment. IC doors are forced open. Asymmetric ice loading i.e. other IC block is full of ice and other empty of ice.
Victoria 50 (multiple node IC)	General behaviour of containment and ice condenser. Helium distribution. Timing of start of the natural circulation loop inside the containment. Both IC blocks are loaded with half of the normal amount of ice.
Victoria 50 (single node IC)	General behaviour of containment and ice condensers. Helium distribution. Timing of start of the natural circulation loop inside the containment. Both IC blocks are loaded with half of the normal amount of ice.
ISP-42 at Panda facility, Phase F	General behaviour of BWR suppression pool containment during the steam and helium injection.
Battelle ice condenser tests	Thermal hydraulics and the aerosol behaviour in the ice condenser.
ISP-35 at NUPEC facility	Effect of containment internal spray system on pressure, gas temperatures, and hydrogen (helium) behaviour.
ISP-47 at MISTRA facility	Steam condensation on structures during the injection of pure steam, and a mixture of steam and helium. Pressure, gas temperatures, helium behaviour.
Spray tests MASP1 and MASP2 at Mistra facility	Effect of inner spray on vessel pressure and temperature in conditions where initial temperature was stratified.
PACOS x1.2 internal spray test in Battelle model containment (test by GRS)	Effect of containment internal spray system on pressure and gas temperature behaviour. initial temperature was stratified.
ISP-42 at Panda facility, Phase F	General behaviour of BWR suppression pool containment during the steam and helium injection.

PPOOLEX STR-1	Natural cooling of wetwell suppression pool
PPOOLEX STR-4	Long-tern thermalhydraulic behaviour of suppression pool containment and thermal stratification of suppression pool.
PPOOLEX WLL-5-2	Steam condensation on drywell wall.
POOLEX STB-20	Thermal stratification of suppression pool
POOLEX STB-21	Thermal stratification of suppression pool
PPOOLEX STR-9	Thermal stratification of suppression pool
PPOOLEX STR-9	Thermal stratification of suppression pool
Panda test T1.1	Behaviour of PCC heat exchanger during steam and helium injection to facility
Panda test ST4.1	Thermalhydraulic behaviour and steam and helium stratification in containment including a tube bundler cooler.
HYMERES Panda test HP6_1	Gas transport and relating natural circulation flow with consequent homogenization of hydrogen stratification
IRSN CARAIDAS single droplet spray test.	Spray droplet effects in a very simple uniform geometry under well controlled conditions.
GEKO building condenser experiments series GEKO-E and GEKO-F	Heat transfer in condenser using Dittus-Bölter Nusselt and Grimison correlations.
PPOOLEX test MIX-04	Effects of horizontal passive containment cooling system (PCCS)
PPOOLEX test PCC-06	Effects of horizontal passive containment cooling system (PCCS)
THAI test TH24	Steam stratification and dissolution of stratification by natural convection
CONAN facility in Pisa.	Wall heat and mass transfer inside a channel during forced convection.
THAI test HM-2	Hydrogen stratification and mixing.
HYMERES MISTRA experiment HM2-1	Thermal stratification and stratification of hydrogen with heat source from PARs.
HYMERES MISTRA experiment HM3-2	Thermal stratification and stratification of hydrogen with heat source from PARs.
TOSQAN test T201	Sump evaporation and wall condensation.
TOSQAN spray test 101	Effect of multi-sized spray droplet.
PASI characterizing experiment HL-01	Heat losses from the water loop of the PASI test facility

PASI characterizing experiment HL-02	Heat losses from the gas space of the PASI test facility
PASI characterizing experiment NC-01	Behaviour of natural circulation flow and cooling capability of heat exchanger.
3.2 Code-to-code benchmarks	
Ice condenser containment	Behaviour of pressure, gas temperature, humidity, condensation rate, sump temperature, gas flows, natural circulation, heat transfer to structures, ice condenser doors, containment spray, and ice melting.. Comparison to COCOSYS code results.
Blowdown	Containment thermodynamics during the water and steam blowdown. Effect of the mist droplets. Comparison to SUPLES and Apros TH calculation results.
Bubble condenser	Suppression of pressure in the bubble condenser containment by steam condensation in water pools, and by passive internal spray from the pools. Comparison to CONTAIN and MELCOR code results.
LLOCA and MSLB in Loviisa ice condenser containment	Behaviour of Loviisa containment during LLOCA and MSLB sequences. Comparison to COCOSYS code results.
MSLB in Olkiluoto NPPLLOCA and MSLB in Loviisa ice condenser containment	Behaviour of Olkiluoto 1&2 primary coolant and containment systems during MSLB sequences. Comparison of containment behaviour to COPTA results. Comparison of behaviour of primary coolant system to COBLIN code results.
SARNET-2 Generic Containment Benchmark	General containment thermahydraulics behaviour and effects of PARs in German pressurized water reactor (PWR 1300 MWe) during a severe accident. Comparison to most common lumped parameter codes used worldwide.
External spray cooling.	Effects of external spray system cooling. Comparison to COCOSYS code results.

4. NUCLEAR REACTOR **4.1 Comparison with Loviisa Plant Core Measurement Data (3-D Model)**	
Assemblywise power at BOC and EOC	Bundle inlet and outlet temperatures
4.2 OECD/NEA 3-D LWR Core Transient Benchmarks (3-D Model)	No measurement data, code results were required for the following items
PWR core	• Control assembly ejections at full power • Control assembly ejections at hot zero power • Uncontrolled withdrawal of control rods at zero power
PWR in steady state	• Critical boron concentration • Radial power distributions at various axial levels • Maximum power peaking factor • Position of maximum power peaking factor • Axial power distribution
PWR in transient	• Core power versus time • Core averaged fuel temperature versus time • Maximum fuel temperature versus time • Coolant outlet temperature versus time • Radial distribution of power at time of power maximum (at various axial levels) • Radial distribution of power at final time 5 s (at various axial levels)
BWR core	• Cold water injection • Fast and slow core pressurisation
BWR in steady state	• k-eff • Radial power distribution at middle core • Coolant outlet density distribution • Maximum power peaking factor • Position of maximum power peaking factor • Axial power distribution

BWR in transient	• Core power versus time • Core averaged fuel temperature versus time • Maximum fuel temperature versus time • Coolant outlet temperature versus time • Radial distribution of power at time of power maximum (at middle core) • Radial distribution of power at final time 20 s (at middle core) • Coolant outlet density distribution at time of power maximum • Coolant outlet density distribution at final time 20 s
4.3 First AER 3-D Hexagonal Kinetic Benchmark (3-D Model)	No measurement data, code results were required for the following items
VVER-type Core control rod ejection	• Core power versus time • Core power distribution at various axial levels (at steady state and at five time points during the transient)
4.4 Second AER 3-D Hexagonal Kinetic Benchmark (3-D Model)	No measurement data, code results were required for the following items
VVER-type Core control rod ejection with adiabatic feedback	• k-eff of initial state • Core power versus time • Total time integrated power of reactor • Maximum fuel temperature • Reactivity • Core power distributions at various axial levels (at steady state and at five time points during the transient) • Fast flux distributions at various axial levels (at steady state and at four time points during the transient) • Thermal flux distributions at various axial levels (at steady state and at four time points during the transient)
4.5 Third AER 3-D Hexagonal Kinetic Benchmark (3-D Model)	No measurement data, code results were required for the following items
VVER-type Core control rod ejection, whole core dynamics and thermal hydraulics	• Spatial power distributions at 5 specified times • Axial distributions of average coolant density • Time functions: (14 items, including power, temperatuers, mass flows, enthalpies) • Hot channel axial distributions • Hot channel time functions (11 items, including DNB, maximum temperatures, mass flux, void fraction, steam quality, oxide layer thickness)
4.6 Fifth AER 3-D Hexagonal Kinetic Benchmark (3-D Model)	No measurement data, code results were required for the following items

VVER-type Core
Steam line break transient
	• Results of tuning:
	    ○ Subcriticality of the initial state
	    ○ Time of reaching recriticality
	    ○ Time of maximum fission power + value
	• Spatial nuclear power distributions (3 specified situations)
	• Core power versus time
	• Time funtions of global plant parameters: 14 items (pressures, temperaturs, flow rates etc.)
	• Time functions for broken loop: 12 items (pressures, levels, powers, mass flows)
	• Time functions for intact loops: 12 items (pressures, levels, powers, mass flows)

4.7 OECD PWR MSLB Benchmark	Reference solution with TRAC-PF1/NEM code results required for following items
TMI-1 NPP Main steam line break transient Three stages: a) Point kinetics and circuit model b) 3-D core with boundary conditions c) 3-D core and circuit model APROS-model: Point kinetics /3-D core model + 6-equation circuit model.	**Steady state** • k-eff • Radial power distribution • Axial power distribution • Scram and stuck rod worth • Primary system pressure, temperatures and flows **Transient** • Sequence of events • Reactor power • Steamline pressure (broken/intact loop) • RCS pressures • Hot and cold leg temperatures • Break flow rates • Steam generator mass • Reactivity edits • Snapshot at 3 specified situations
4.8 VVER-1000 main coolant pump trip transient	
Kozloduy NPP, unit 6 Coast-down of one of three working main coolant pumps Validation of 3D nodal model and 3D finite-difference model against measured data and corresponding results calculated by HEXTRAN	• Power distribution in steady state • Reactor power evolution during the transient • Control rod instertion • Assembly-wise coolant temperatures • Various plant parameters during the transient (coolant mass flows, steamline pressure, RCS pressure, coolant temperatures)

Validation cases used regularly at each APROS version change

Separate effects tests	Integral tests with power plant models
EDWARDS PIPE **BATTELLE TOP BLOWDOWN EXPERIMENT** **BECKER'S EXPERIMENTS** **ERSEC REFLOODING TEST** **MARVIKEN CRITICAL FLOW TESTS** **LIQUID BLOWDOWN TO CONTAINMENT** **BLOWDOWN EXPERIMENT MX-II AT MARVIKEN CONTAINMENT FACILITY** **SPRAY EXPERIMENT (ISP-35) AT NUPEC CONTAINMENT FACILITY** **STEAM CONDENSATION EXPERIMENT (ISP-47) AT MISTRA CONTAINMENT FACILITY** **WATER LEVEL RISE TRANSIENT IN PACTEL PRESSURIZER**	**LOVIISA NUCLEAR POWER PLANT (2 versions)** • Stopping of main recirculation pump • Reactor scram • Small break LOCA • Large break LOCA • Stopping of three main recirculation pumps with modified end: 3D-neutronics test **VVER-440 NUCLEAR POWER PLANT** • Stopping of main recirculation pump • Reactor scram **OLKILUOTO 1 NUCLEAR POWER PLANT** • Steam line break • Reactor scram **FORSMARK 3 NUCLEAR POWER PLANT (HAMBO)** • Electric load rejection • Turbine trip, turbine bypass fails • Loss of condenser vacuum • Trip of all recirculation pumps • Feed water line break, ATWS • Steam line break **LOVIISA ICE CONDENSER CONTAINMENT** • Results of Large Break LOCA **CCGT POWER PLANT MODEL WITH DISTRICT HEATING CIRCUIT** • Power set point change