STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Loss of electrical feed to the vital network of the BR2 reactor

Safety impact and lessons learned

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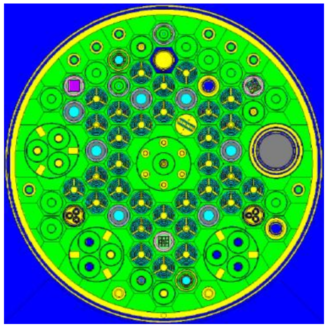
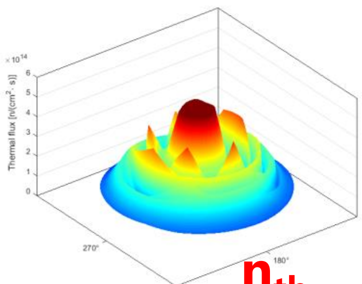
Presentation content

- General features of the BR2 reactor
- Safety functions overview
- “Vital” electrical grid loss
- Impact analysis
- Lessons learned and actions

General features of the BR2 reactor





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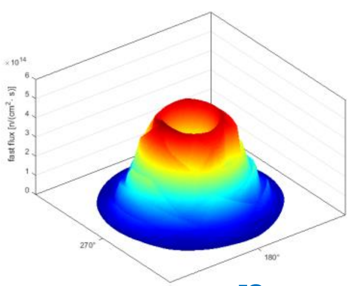

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- BR2 = high performance material test reactor
  - Achievable flux levels (at mid plane in vessel)
    - Thermal flux: 7 10^{13} n/cm^2s to 10^{15} n/cm^2s
    - Fast flux (E>0.1MeV): 1 10^{13} n/cm^2s to 6 10^{14} n/cm^2s
  - Maximum rated power: 125MW cooling capacity of primary cooling system
    - Allowable heat flux in primary coolant
      - 470W/cm^2 for the driver fuel plates
        - » Demineralised light water
        - » Pressure to 1.2MPa, temperature 35-50°C
        - » 10m/s flow velocity on fuel plate
      - Up to 600W/cm^2 can be allowed in experiments
  - Compact core design with good access
    - Be + water moderated
    - Diverging core channels

Reactor core geometry & access

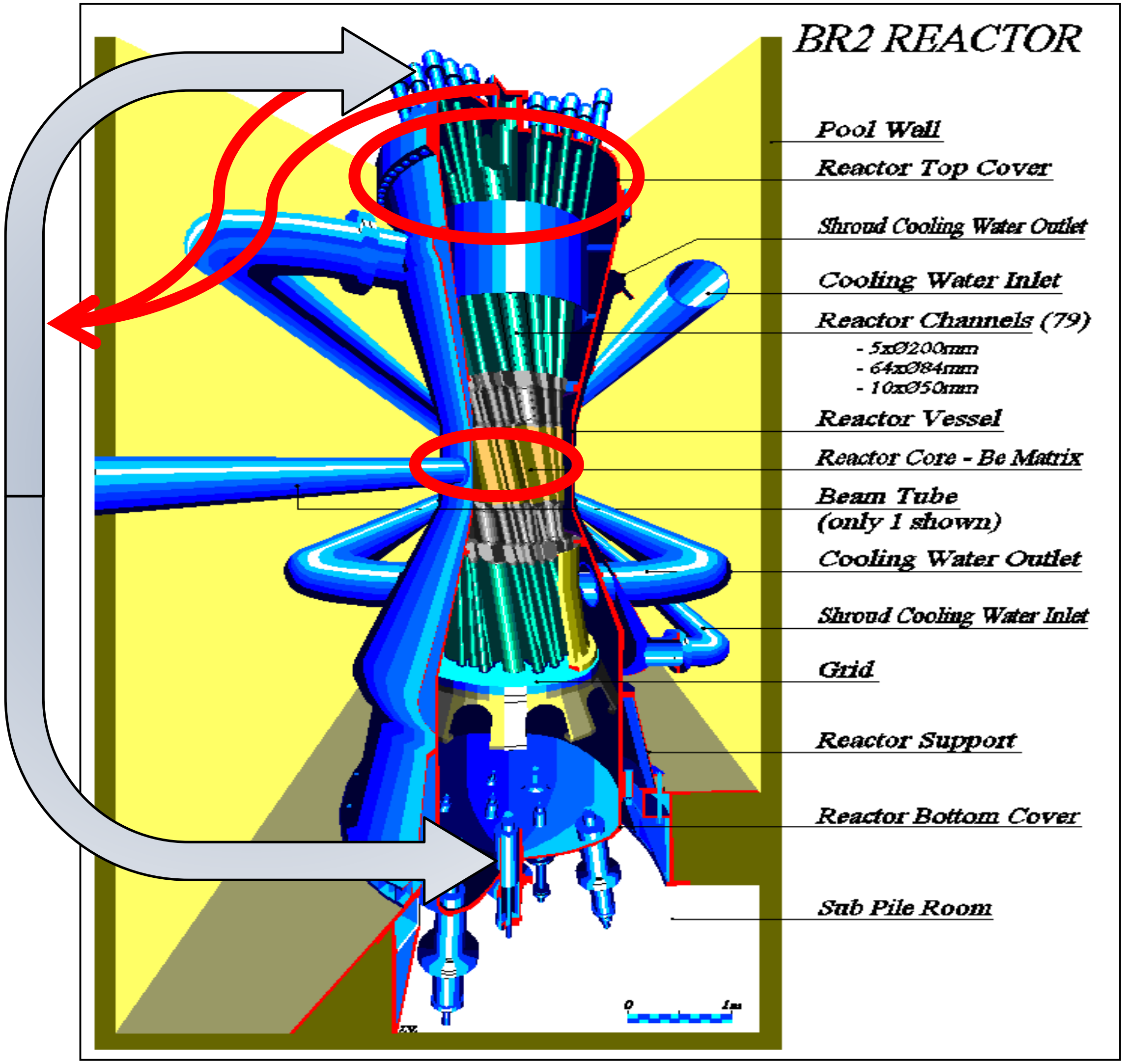
Diverging reactor channels for compact core and good access: core 1m, cover 2m ∅

Angle of channels from 0 to 10°

Reactor channels accessible from top (all) and bottom (17)

Irradiation inside rigs in reactor channel or in axis of fuel element

Loading elements hang on top cover

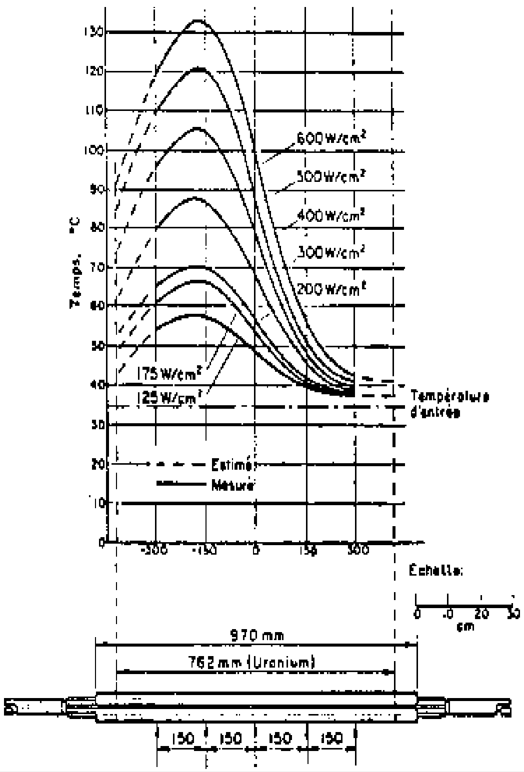


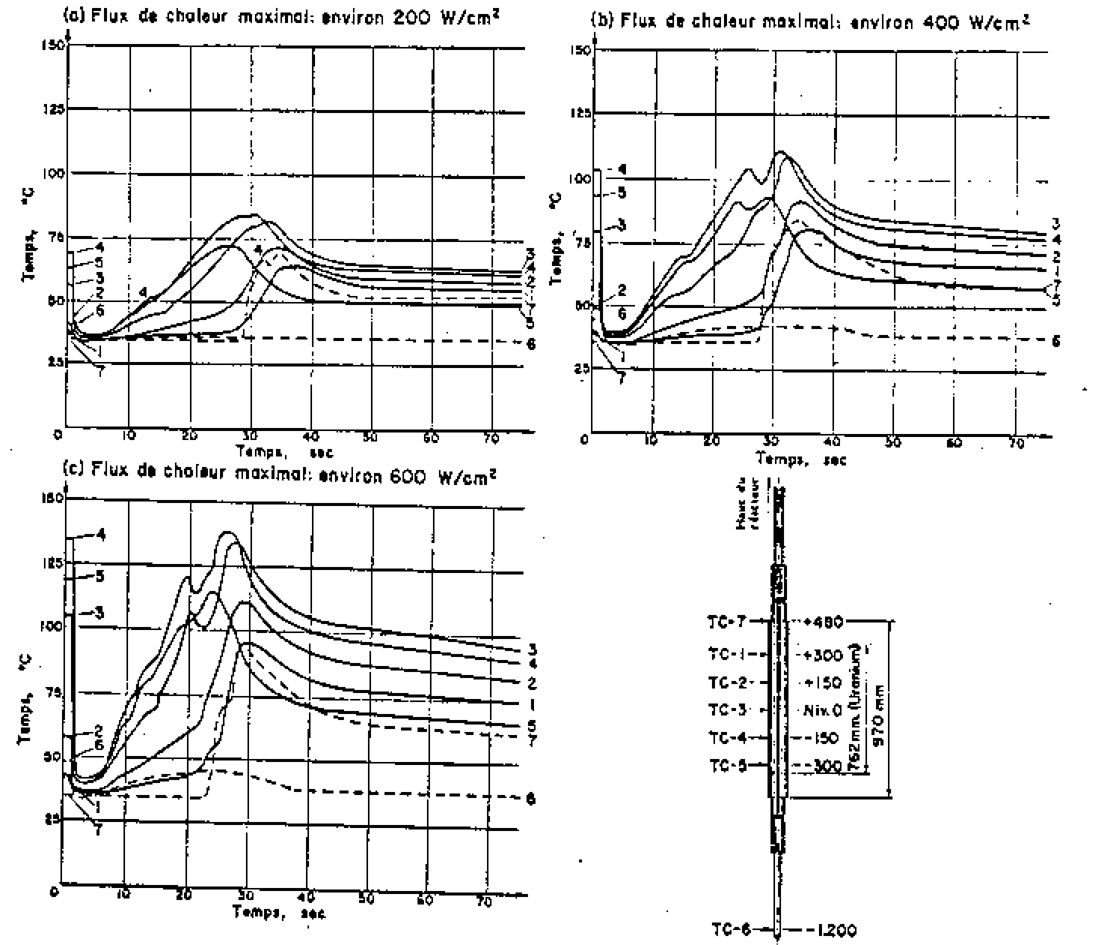
Safety functions of BR2

- Reactivity control
  - Shim/control rods and safety rods
    - Fail safe against loss of power
    - Powered by UPS
  - SCRAM initiating instrumentation
    - Fail safe against loss of power
    - Powered by UPS
- Removal of residual heat
  - Possible by natural convection
  - Automatic isolation and bypass valves driven by hydraulic batteries
  - Controlled by redundant and independent I&C
- Confinement
  - Isolation of containment building by hydraulic system
  - I&C with UPS back-up

Heat removal in accident conditions: historic tests

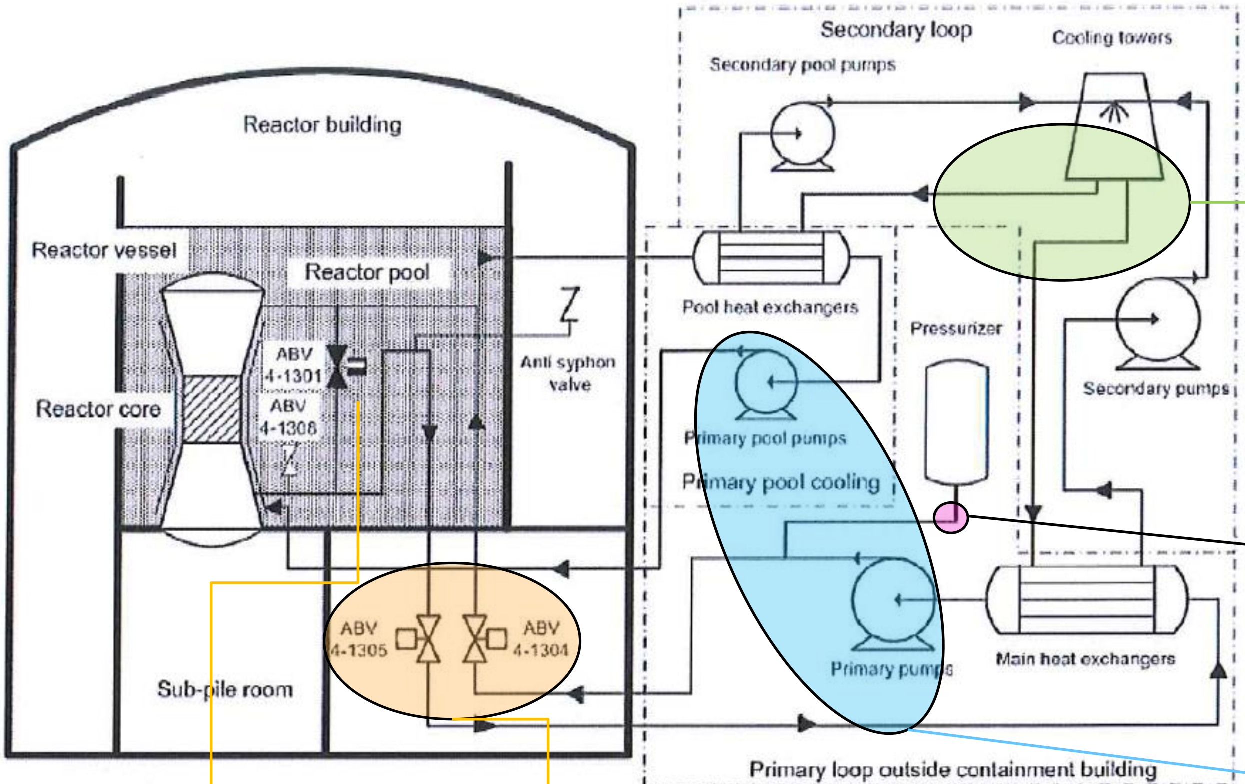
Cladding temperature in steady state conditions





Measured temperature evolution during simulated accident conditions

Schematic of BR2 cooling loops



Secondary loop: fail closed isolation valve

Pressuriser: fail closed isolation valve

Main pumps: normal electric feed
Shut down pumps: vital electric feed

Hydraulic driven bypass valve

Hydraulic driven isolation valves

Safety actions during reactor operation

- SCRAM reactor
  - Manual (2 control rooms)
  - Overpower (flux)
  - High/Low pressure drop over core
  - High/Low pressure in primary loop (high pressure: evacuation)
  - Low primary flow rate
  - Motion of isolation/by-pass valves
  - No external electrical feed (10kVAC, 220VAC)
  - No electrical feed for I&C (110VDC)
  - Evacuation signal for staff
- Reverse reactor
  - Overpower (flux, thermal balance, N-16)
  - Low pressure drop over reactor core
  - High inlet/outlet temperature
  - High temperature increase over core
  - High radio-activity in primary/secondary loop
  - Loss of automatic start up function of Diesel generators

BR2 electrical feed networks

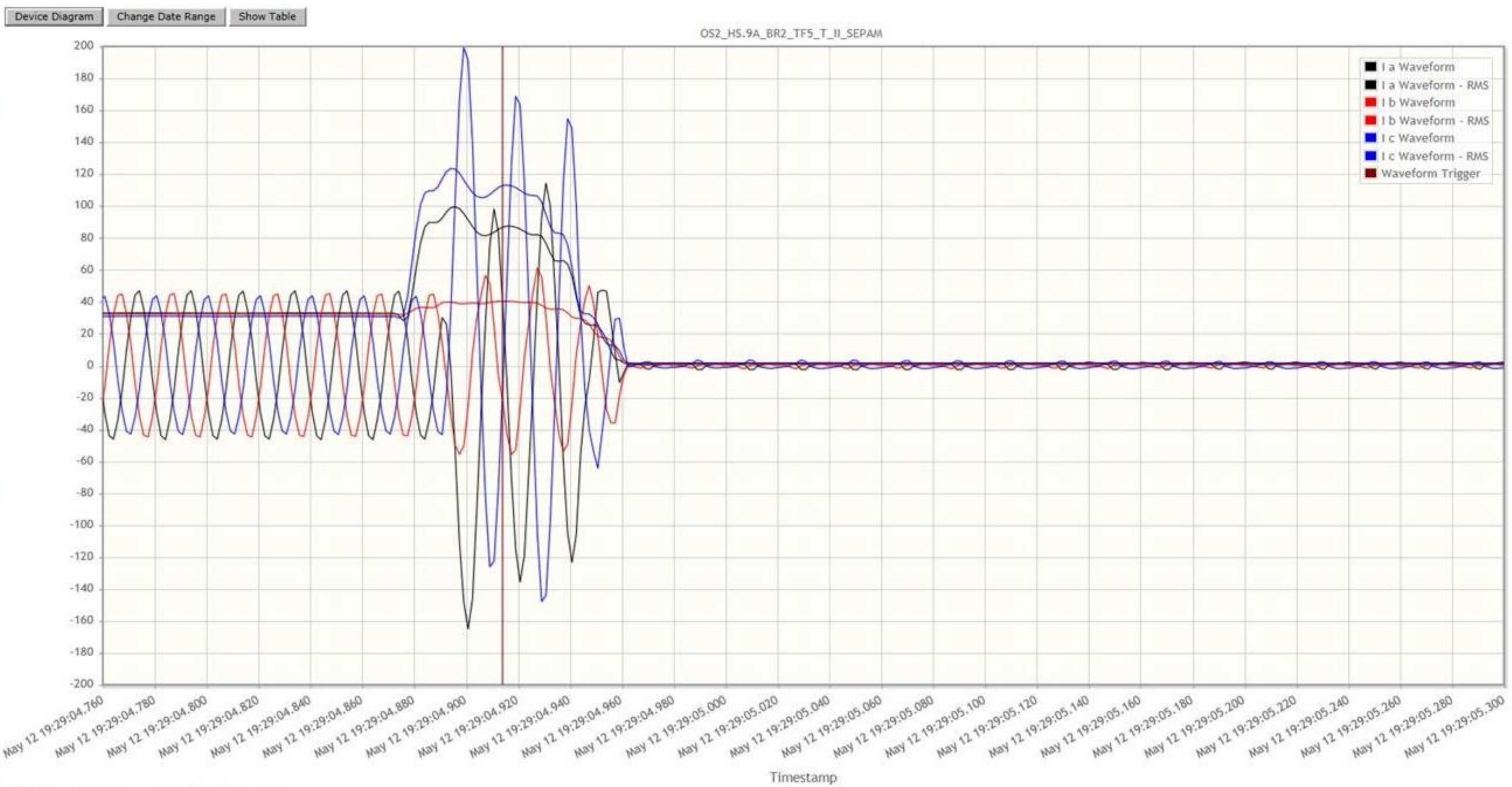
- External network (class 1)
  - Direct feed of non-safety related components (e.g. main primary pumps)
  - Normal feed of vital network $380V_{AC}$
  - Normal feed for battery units $110V_{DC}$
  - *Interruptions have no safety but operational impact*
- Vital network (class 2 and 3)
  - Safety relevant components
  - Alternative feed by external network or diesel generators (no break system)
  - *Not essential to safety*
- Battery units & UPS (class 4)
  - Feed for safety instruments and actions
  - *Multiple separated feeds available*

Vital electrical network feed loss events

- 2 events occurred during operating cycle in May 2017
  - May 12 and May 28: short electrical tension disruption
    - root cause: lightning impact on external network
  - Automatic decoupling between external network and vital network
  - Vital network is powered by inertia of flywheels
  - Frequency detection @49.5Hz trigger fails to start diesel engines
  - Power consumption level on vital network too low to trigger power detector to start diesel engines (normal network feeds main pumps)
  - Alternators are decoupled at @ 45Hz to protect vital network users against high currents
- Loss of automatic takeover of diesel generators trips reactor (reverse signal)

Tension disruption on external feed network

Decoupling between external network and vital network



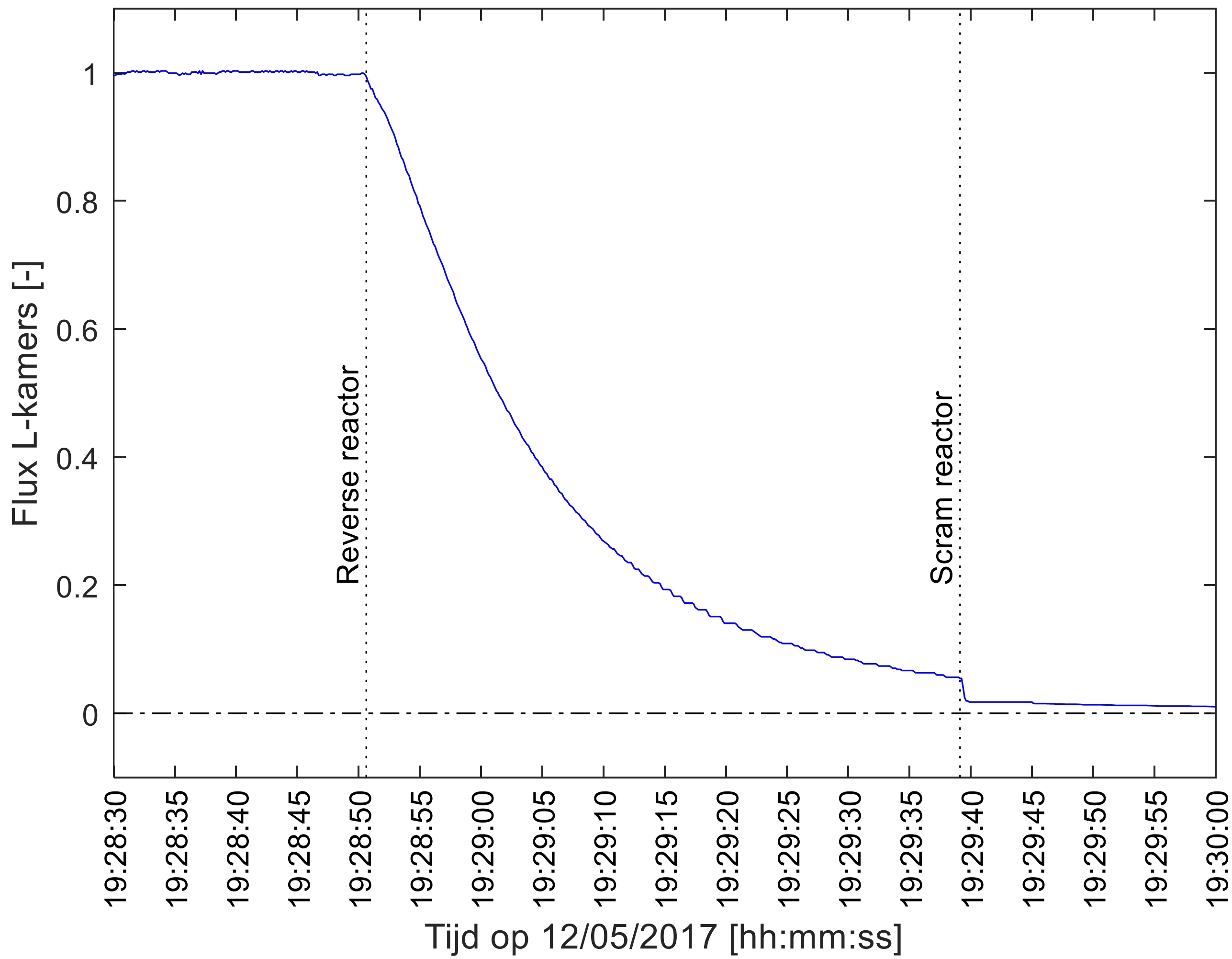
Impact of loss of vital network 12/05

- Reactivity control of reactor
  - No impact: instruments and I&C are fed by UPS
  - Reverse signal results in lowering of control rods
  - SCRAM (manual)

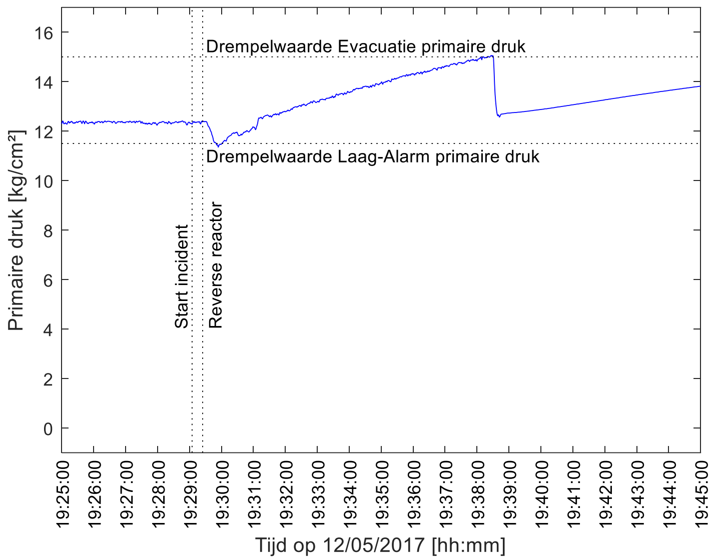
- Heat removal
  - Upon reverse, secondary flow is reduced by pilot to maintain primary pressure
  - After 1 minute, secondary flow stops due to closing of isolation valve on secondary side (fail close)
  - Primary pressure increases due to low heat removal
  - Evacuation due to high primary pressure
    - Closing of automatic isolation valves and opening of bypass valve

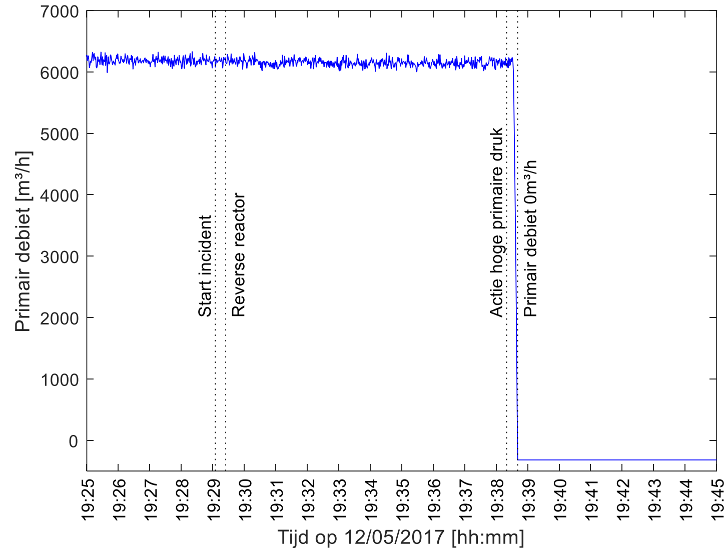
- Confinement function
  - Evacuation signal automatically isolates reactor building

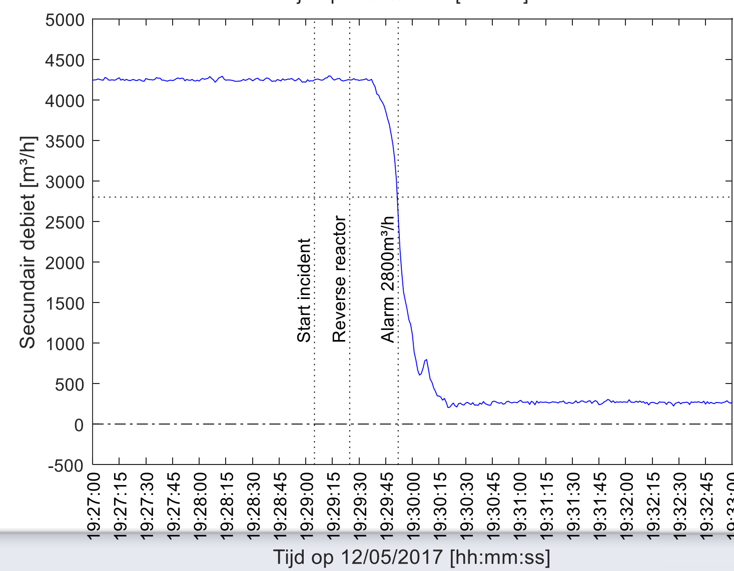
Neutron flux observation



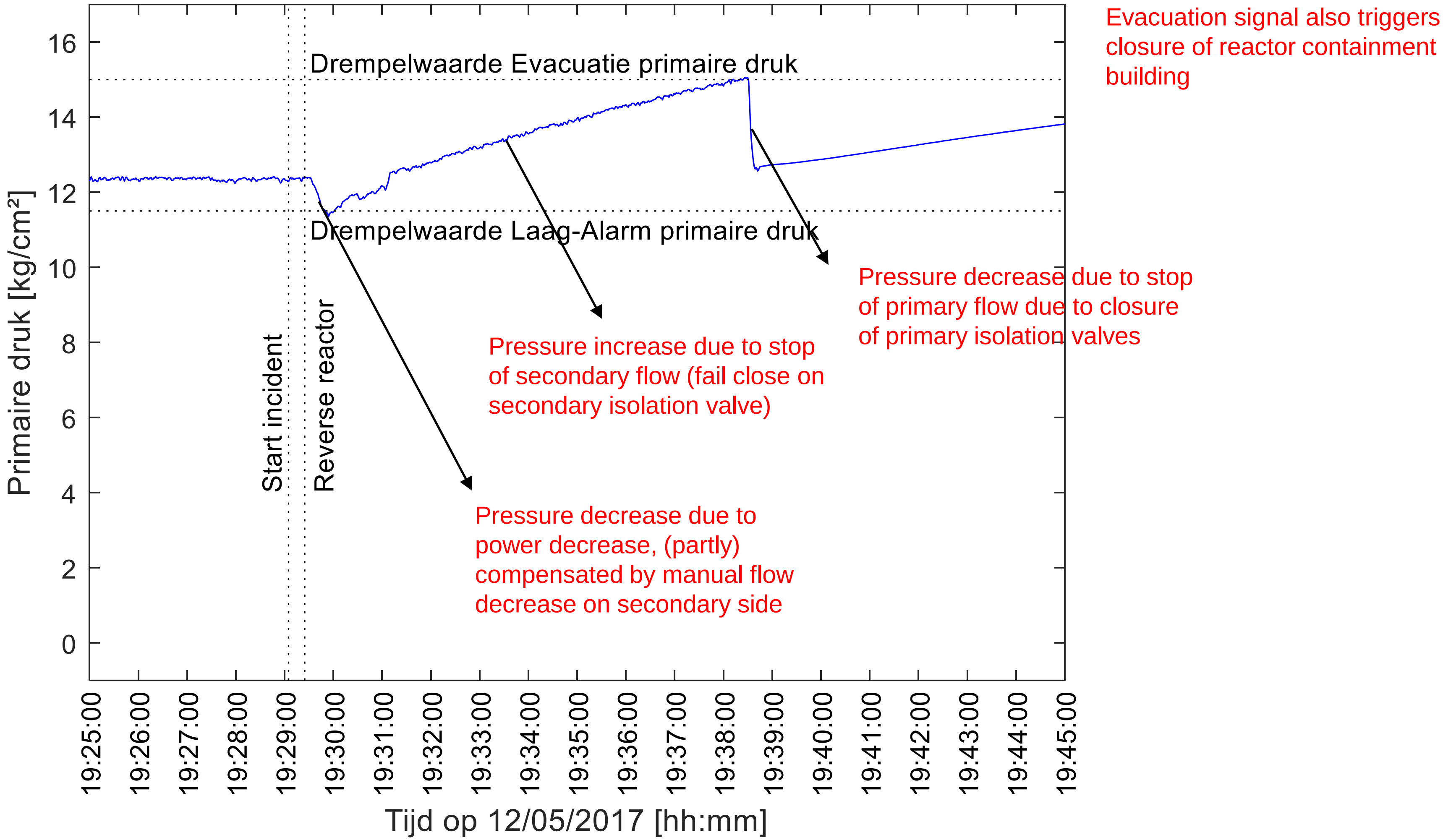
Hydraulic conditions







Primary pressure evolution



Impact on operations and data acquisition

- Radiation monitoring equipment
  - Connected to vital network, most sensitive to electrical feed disruption
  - Measurement of radio-activity in primary water non-functional during isolation of primary loop inside reactor pool (ABV closed)
  - Radiation monitoring equipment triggers REVERSE action: non-fail safe architecture (>< SCRAM triggers)
- Illumination
  - Machine control room: connected to vital network – black out
  - Reactor building: 50% vital network, 50% normal network
  - Reactor control room: connected to UPS
- Control rooms
  - Reactor control room: minor impact, but evacuated
  - Machine control room
    - Synoptic panel black-out
    - Alarms & recorders powered by UPS
- DAQ: computer recording and visualization of data lost (partially)
  - No safety function

Recovery actions

- Verification of safe condition of auxiliary systems/buildings: check by fire brigade
- Coupling of vital and normal network
  - First attempt unsuccessful: short restart of secondary flow and pressure drop in primary system
  - Restart of illumination and signalization on synoptic panel in machine control room
- Manual restart of radiation monitoring devices, check of absence of contamination/increased radiation levels
- Coupling of diesel unit to vital network in stand-by mode (21h00)
- Start of shut-down pumps and opening of isolation valves to verify absence of fission products in primary water (22h30)
- Restart ventilation (23h25)
- Shut-down and cool-down according to standard procedures

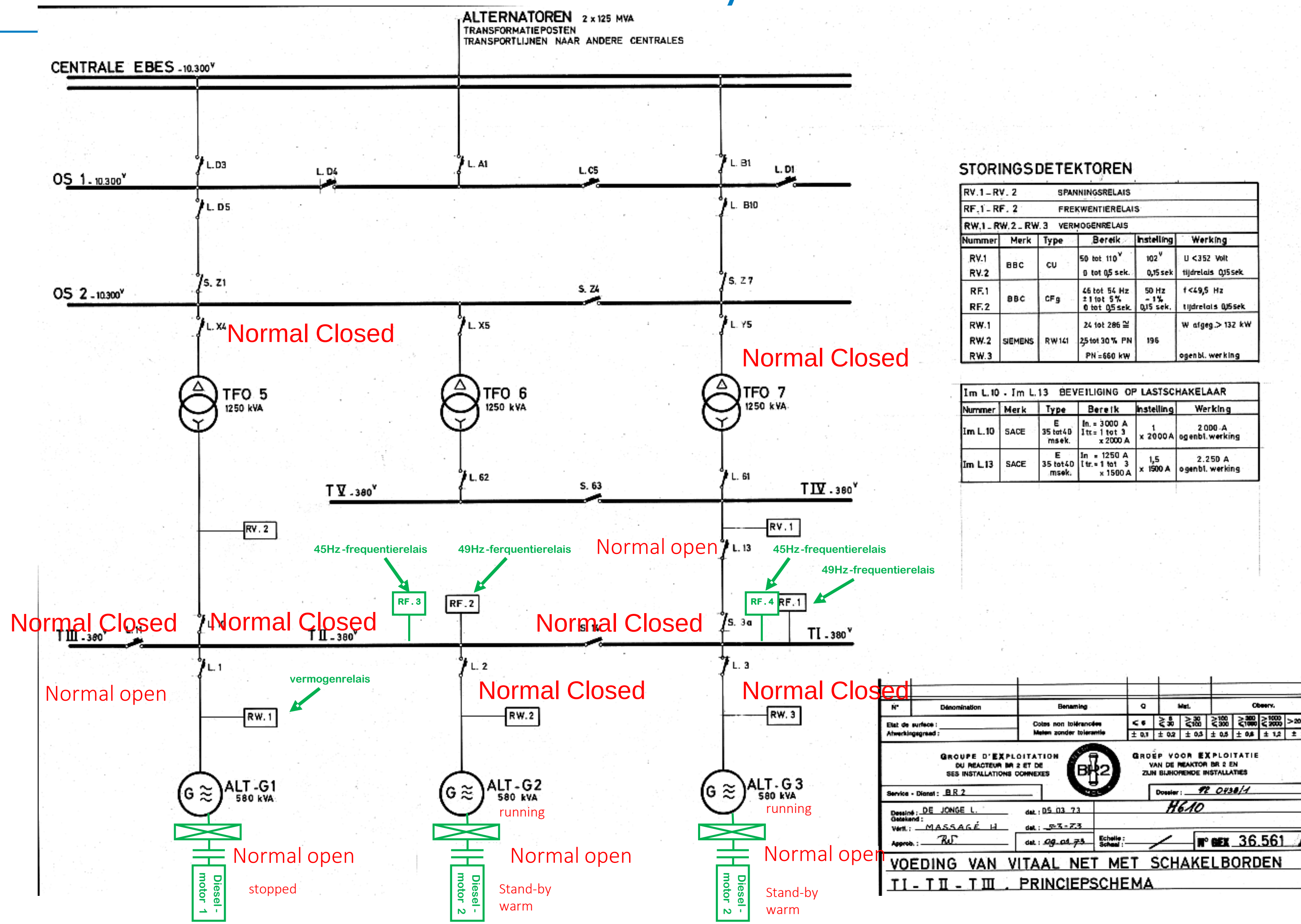
Lessons learned & actions

- Black out of "vital" electrical feed is no initiating event for safety issue
  - Basic safety functions remain intact due to passive nature & redundant feeds
  - Sufficient layers of defense-in-depth
  - Basic INES evaluation = 0; +1 due to common cause loss of external feed and internal feed by diesel generators
- Failure of diesel generator start was due to 2 causes
  - Ageing issues with detection and switching devices to couple diesel generators to alternators
  - Threshold of power consumption higher than actual level during operation with external network feed available
- Test procedure and maintenance schedule revised
  - System functional test unable to identify hidden failures in parallel systems
  - Lab maintenance and test procedures for individual components
- System upgrades
  - Installation of additional switches
  - Replacement of aged components
  - Adjustment of power threshold and systematic verification of power consumption on vital network

Testing issues

- Initial field test method: simulation of external feed loss by opening connector between external and vital network
  - Only RF and RW switches are tested, RV switch is not tested
  - Test is passed when 1 switch reacts: hidden failure of switch can remain undetected
  - Test is always performed under shut-down conditions: favorable (higher) level of consumption on vital network
- Improved field test method: simulation of external feed disruption by opening connector AND trigger on low voltage
  - All types of switches are solicited; two possible configurations are tested
  - Evaluation of operation of all switches
  - Recording of system and component response
    - Frequency and tension level at switching moment
    - Time to restore nominal values
    - Power consumption

Lay out of vital network 380V



Lab tests and maintenance

- Lab tests allow for individual component characterization
  - All individual components are tested (10 repetitions)
  - Effect of maintenance can be evaluated
  - Full system test after every modification

- Electro-mechanical switches are cleaned and lubricated
- Drift on settings is corrected
- Periodic maintenance scheme for components is defined

Maintenance effect on voltage switch

	Trip Voltage before maintenance (V)									
	1	2	3	4	5	6	7	8	9	10
ON	101,1	110,7	109,6	110,2	102,7	106,8	107,9	107,6	107,8	106,7
OFF	113,8	113,1	112,4	112,8	114,4	109	109.3	109	109	109,4

	Trip voltage after maintenance (V)									
	1	2	3	4	5	6	7	8	9	10
ON	110,4	110,4	110,5	110,2	110,5	110,4	110,4	110,5	111,3	110,5
OFF	112,1	112,3	112,4	111,9	112,4	111,9	112,1	112,4	112,4	112,3

	Trip voltage after recalibration (V)									
	1	2	3	4	5	6	7	8	9	10
ON	102,1	102,5	102,9	102,1	102,3	102,4	102,2	102,6	102,3	102,2
OFF	103,1	103,3	103,6	103	103	103,4	103,4	103,1	103,1	103

General conclusions

- Generic lessons learned
  - Testing for reliability of parallel systems
    - Observation of functioning of individual components
    - Statistics for acceptance of result: how many positive to accept one negative?
    - Frequency of tests of individual components versus test to failure
  - Evaluation of settings versus evolution of installation
    - Challenge to nominal thresholds with evolution in installation

- Safety evaluation
  - Passive nature of safety systems confirmed
  - Diverse feed for I&C robust against malfunction of one system
  - Incident management needs support from power on minimal set of instruments