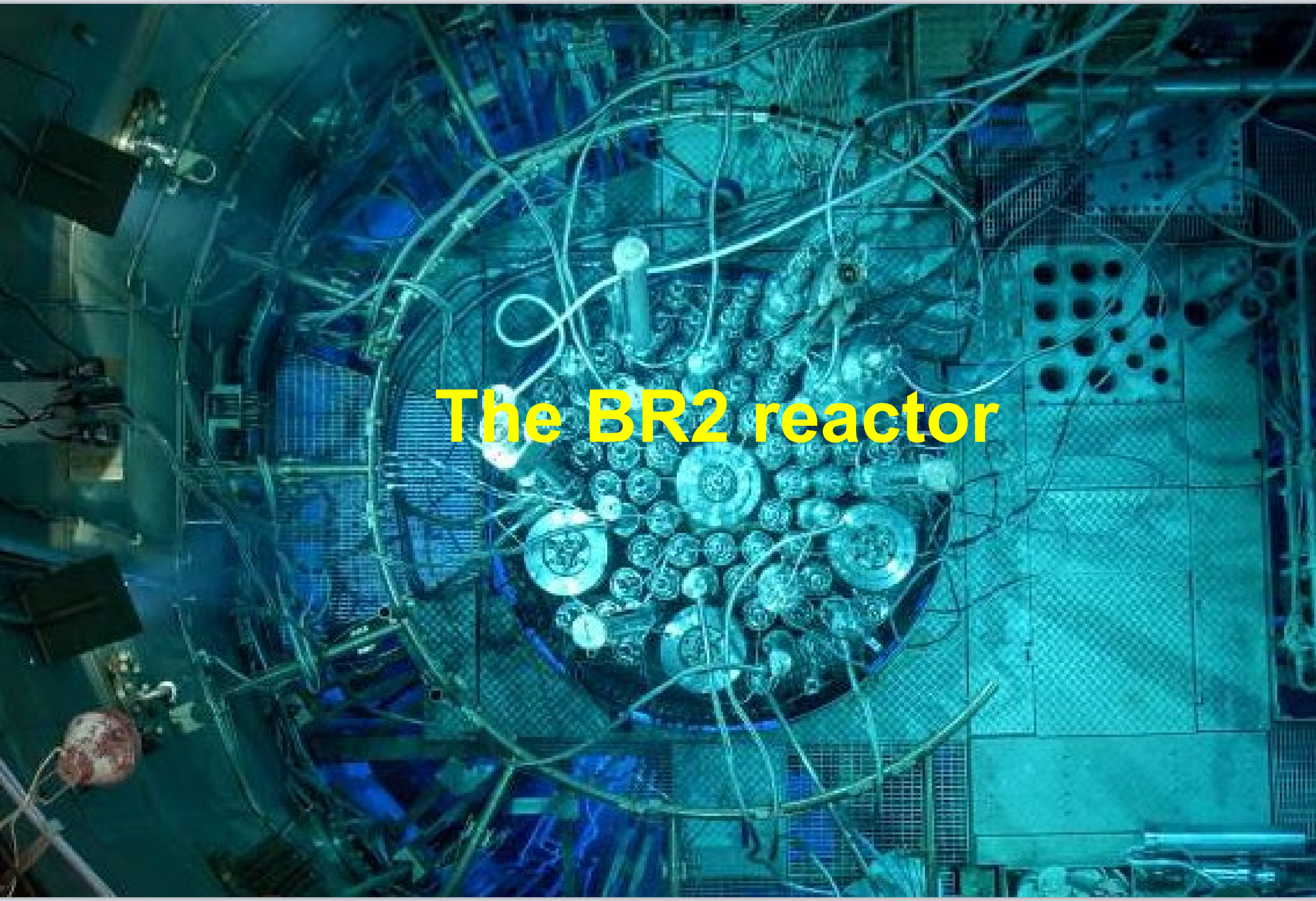
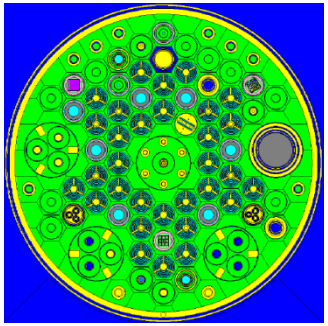
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

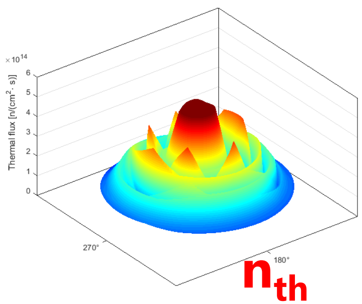
Country report Belgium
RROG 2019, Mainz

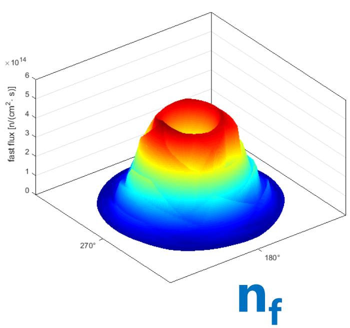
The BR2 reactor



Reactor core performance of BR2







- Design goal: thermal neutron flux up to 10^{15} n/cm^{2}s
  - Achievement by
    - Compact core arrangement with central flux trap
    - Material choice: Be moderator and metallic uranium fuel
    - High overall core power (upgraded from 50 to 100MW in 1968)
- Achievable flux levels (at mid plane in vessel)
  - Thermal flux: 7 10^{13} n/cm^{2}s to 10^{15} n/cm^{2}s
  - Fast flux (E>0.1MeV): 1 10^{13} n/cm^{2}s to 6 10^{14} n/cm^{2}s
- Allowable heat flux in primary coolant
  - 470W/cm^2 for the driver fuel plates
    - Demineralised 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

Reactor core geometry

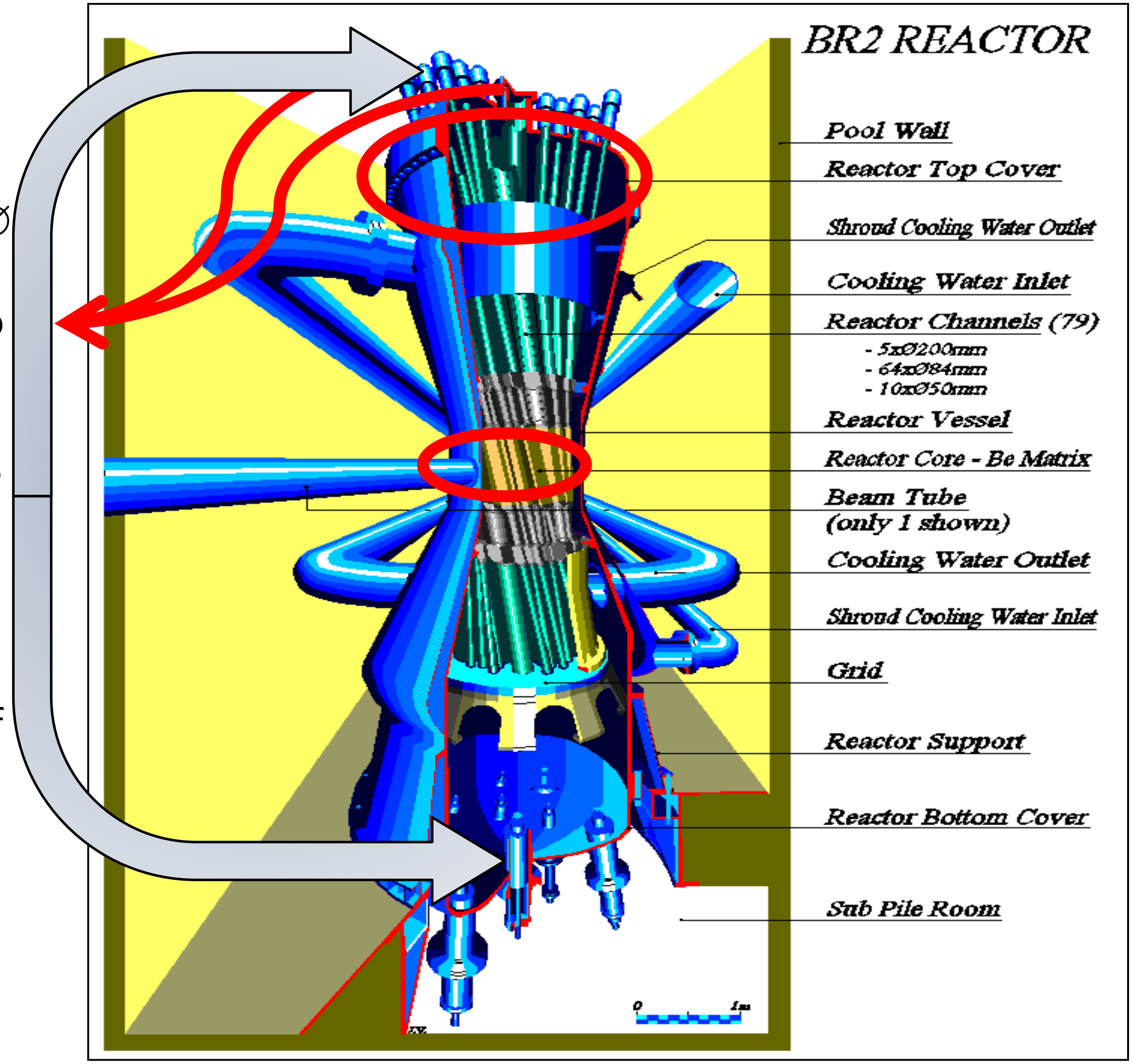
Diverging reactor channels for compact core and good access: core 1m, cover 2m ∅

Angle of channels from 0 to 27°

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

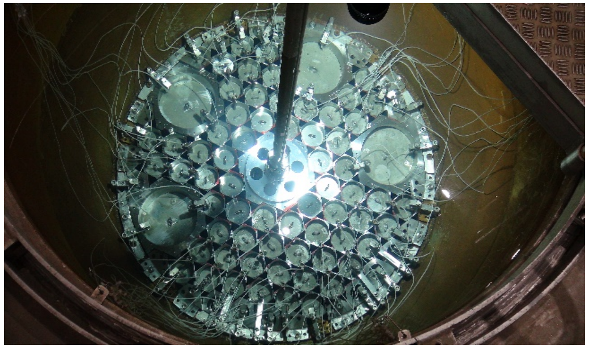
Irradiation inside rigs in reactor channel or in axis of fuel element

Loading elements hang on top cover

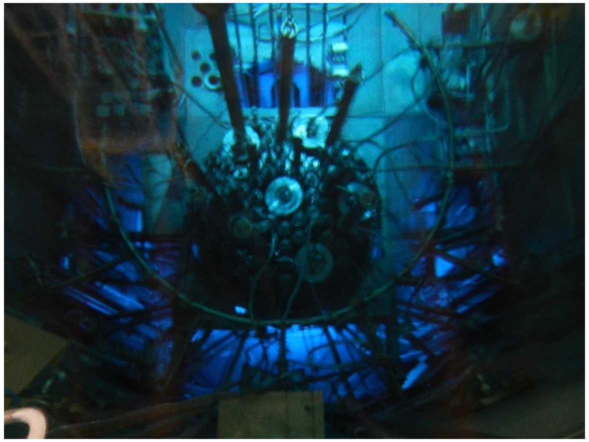


BR2 Overview

- Belgian Reactor 2 : in operation since 1963
  - Upgraded in 1968 to 100MW
  - Refurbishment in 1977-1980
  - Subject to decennial license review since 1986
  - Refurbished in 1995-1997
  - Refurbished 2015-2016



- Restarted on July 19, 2016
  - Requalification programme finalised
  - Periodic safety reassessment report delivered
  - 11 reactor cycles performed up to May 2019



Operational highlights

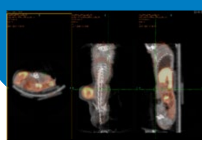
- 6 reactor cycles in 2018: 147 days of operation
- 5 reactor cycles in 2019 (scheduled): 163 days of operation
- Availability factor
  - 2018: 40%; actual 97% of planned realized
  - 2019: 44% planned (100% so far realized after 2 cycles)
  - 2020: aim to 200-210 days
- Utilisation
  - Large increase in demand for radio-isotopes and NTD-Si (capacity fully booked in 2019)
  - Material irradiations for fusion (W alloys) and RPV ageing
  - Fuel plate irradiations for MTR fuel qualification based on LEU
  - Requalification of LWR fuel pin irradiation capsule
- Large projects at SCK•CEN
  - Construction of MINERVA LINAC funded by Belgian government
  - NURA project integrating all activities on medical applications of nuclear technology

NURA

CLUSTERING KNOWHOW AND EXPERTISE WITHIN
THE FIELD OF RADIOPHARMACEUTICALS

Contract Research

Pre-clinical Development



C R O

Pre-clinical services to assist in the development of new therapeutic radiopharmaceuticals (i.e. proof-of-concept/impact assessment).

R&D

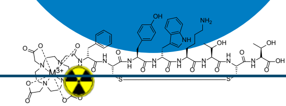
Radiobiology
Dosimetry
Radiochemistry

Research

Developing and strengthening SCK•CEN's **research** further within the Nuclear Medicine applications.

Contract Manufacturing

Production of Radioisotopes & Radio-pharmaceuticals



C M O

Sustainable supply *of relevant* ***therapeutic radio-isotopes*** *and* ***radiopharmaceuticals.***

GMP quality

Large Scale production

Continuous supply: partnerships – backup network

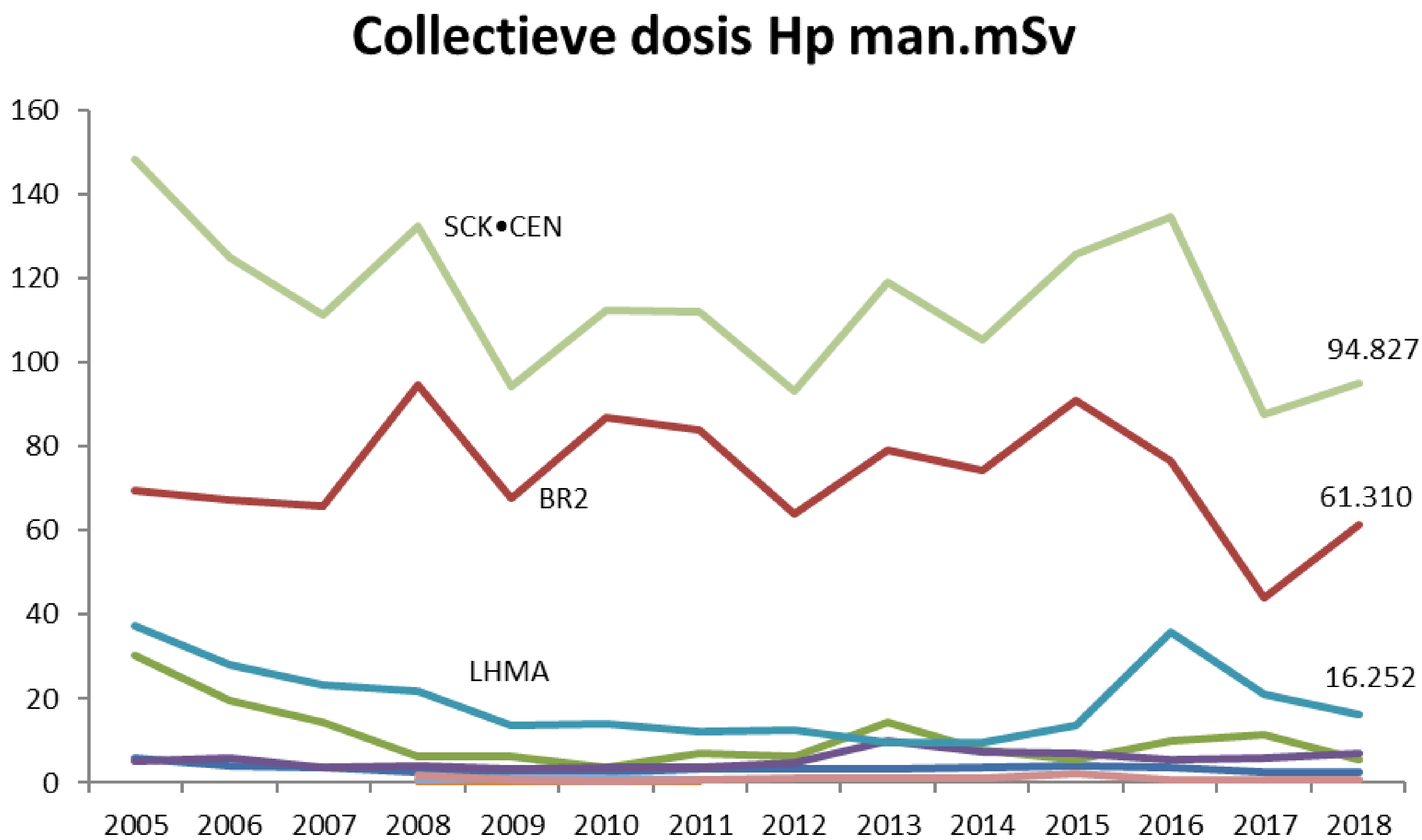
Safety indicators 2018

- Radiological exposure of staff:
  - Collective dose:
    - Reactor operation staff (33): 18mSv (6 reactor cycles)
    - All works: 61,3mSv
  - Average dose:
    - Reactor operation staff average: 0,12mSv – max individual 1,165mSv
    - Overall average: 0.5mSv – max individual 2.3mSv
- Emissions

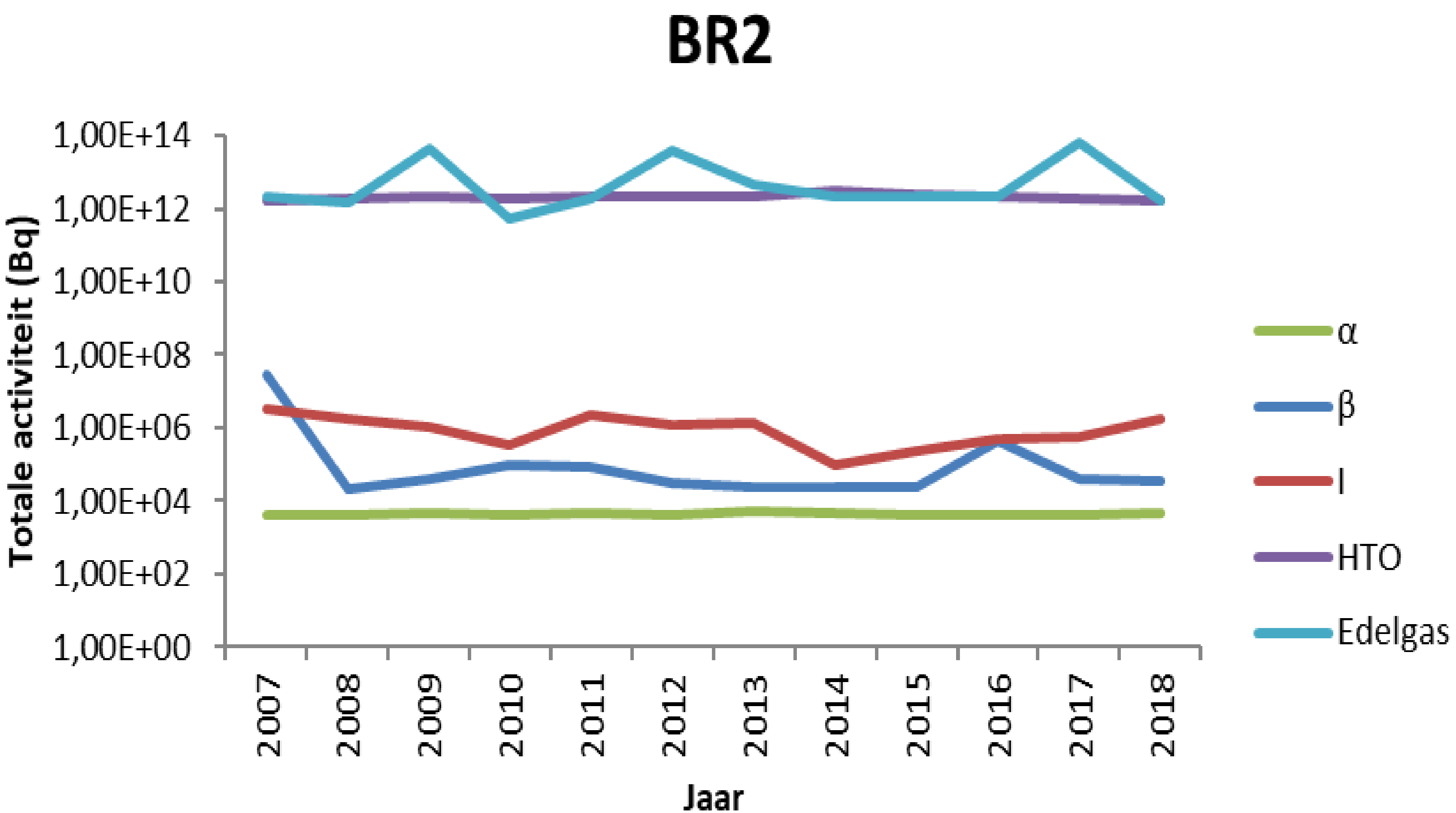
	α (Bq)	β (Bq)	I (Bq)	HT (Bq)	HTO (Bq)	Edelgas (Bq)
BR2	4,49E+03	3,48E+04	1,86E+06	-	1,76E+12	2,19E+12
Jaarlijkse limiet	*1,67E+08*	*1,54E+09*	*2,03E+09*		*1,19E+15*	*6,08E+14*

- Utilisation factor: 40% in 2018
- Actual/planned operation in 2018: 97%

Dose evolution



Emission evolution



Incident reporting

- Operational feed from the RECALL material irradiation loop and incident reporting
  - Cycle 2/2018A (1 day commissioning test): feedback experience on accumulation and spreading of radio-activity in loop, mainly due to activation of Ar and Mn; electric heating quite weak to compensate for heat loss at nuclear heating of maximum 2W/g
  - Cycle 2/2018B: regular operation during 28 days
  - Cycle 03/2018: Reactor reverse due to low temperature in RECALL IPS – heating element broken
    - Root cause analysis:
      - Protection of heater in case of zero flow was wrongly programmed/not tested
      - Zero flow condition was triggered by high radiation in water return from IPS
      - High radiation due to stray resin particles and poor degassing of fresh water
      - Fresh water was needed due to leaking high pressure pumps

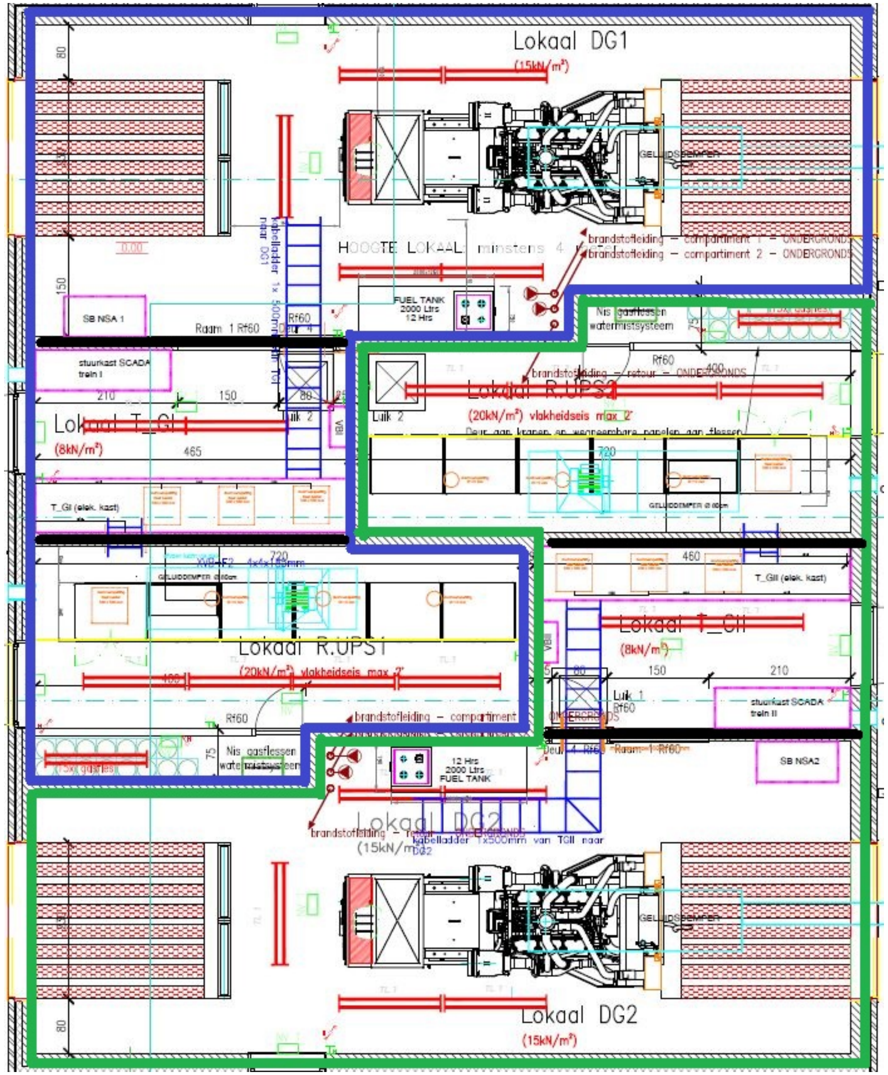
Ageing management

- Primary loop inspections
  - Indication of non acceptable defect in circumferential pipe to flange weld
    - Section at redundant primary pump taken out of service – no safety impact; operation with 3 primary pumps during cycle 03/2018
    - Pipe section replaced by stainless steel section during shut-down 04/2019
    - Designed according to ASME VIII code
    - New sealing material qualified with sufficient gamma dose margin
  - Post extraction analysis:
    - No defect present (X-ray), UT indication due to weld repair (not documented)

Ageing management (2)

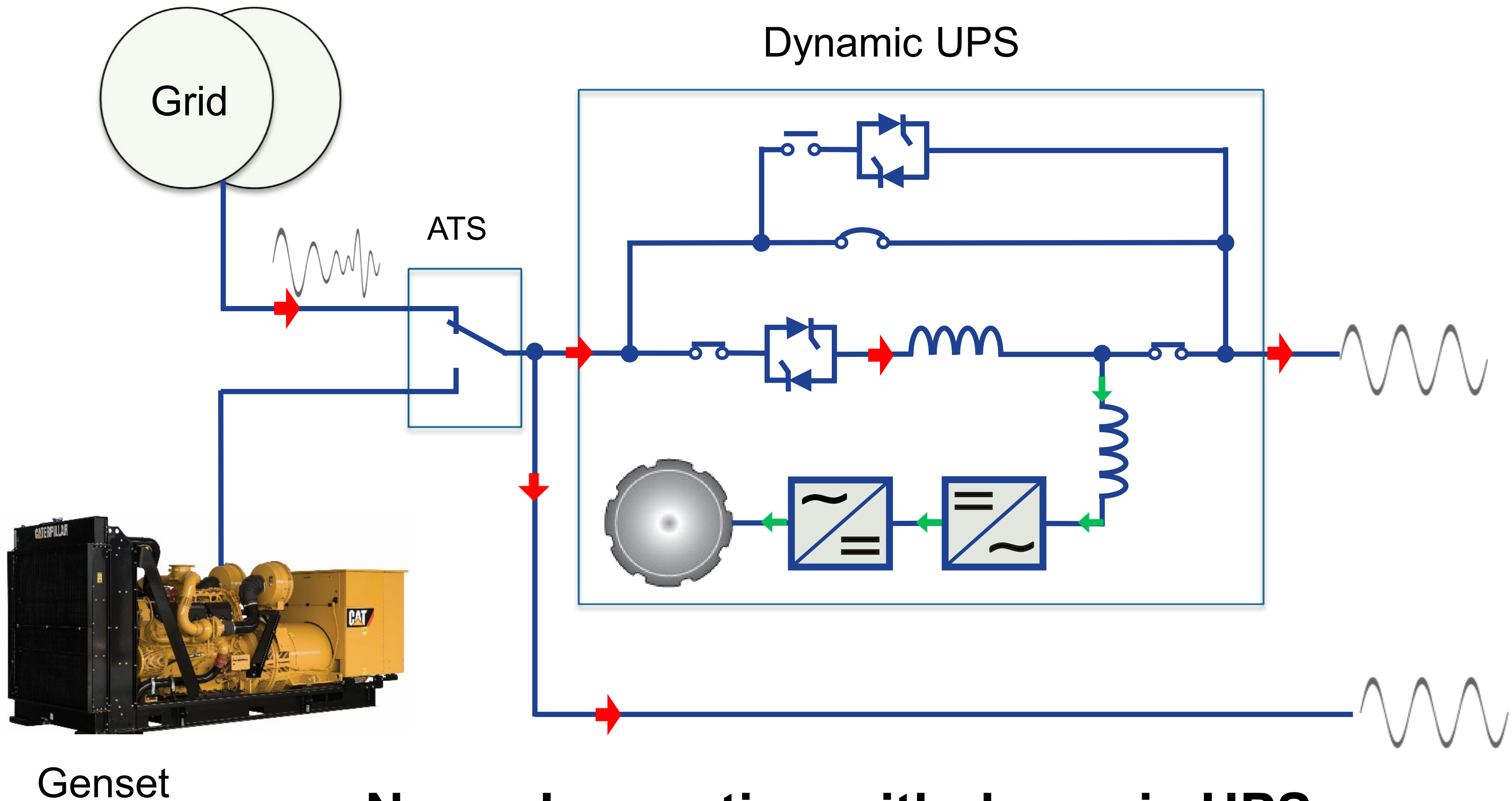
- Upgrade of emergency electrical feed
  - State of art technology rotating UPS + diesel generators
    - Obsolete technology of current generators difficult to maintain
  - Upgrade of resistance to hazards
    - Increased seismic resistance of building
    - Full separation of units with respect to fire hazard
  - Elimination of common cause failures
    - Redundant safety relevant components on common switchboards in old system
    - Full separation to independent and redundant lines in new system

New Powerhouse



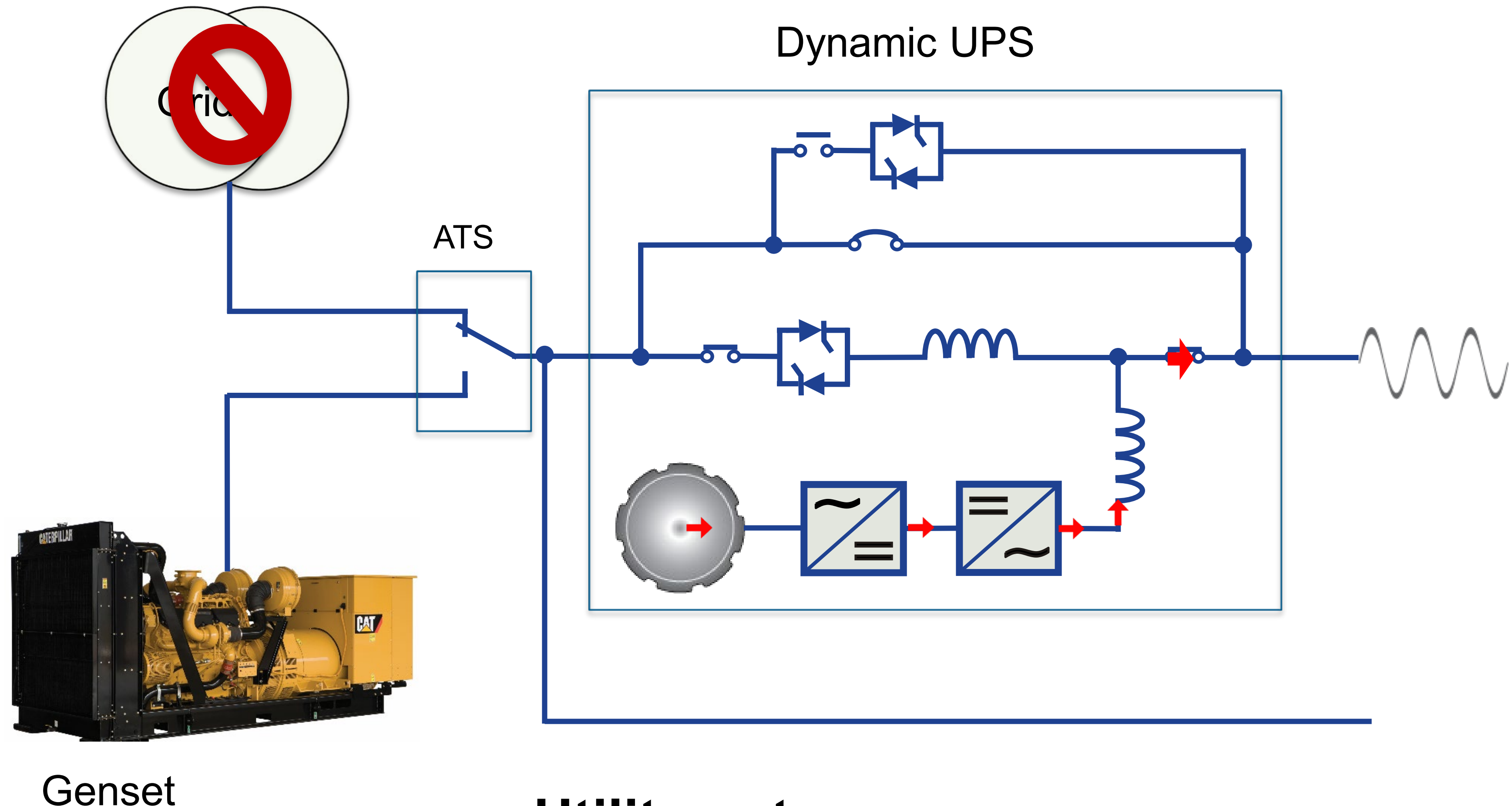
- 6 fire compartments
  - 2 independent fire extinguishing systems
    - Genset: water + nitrogen
    - DUPS: inert gas
- 2 separated gensets and DUPS
- Compliant to modern environmental standards
- Secured building

Diesel replacement - main principle



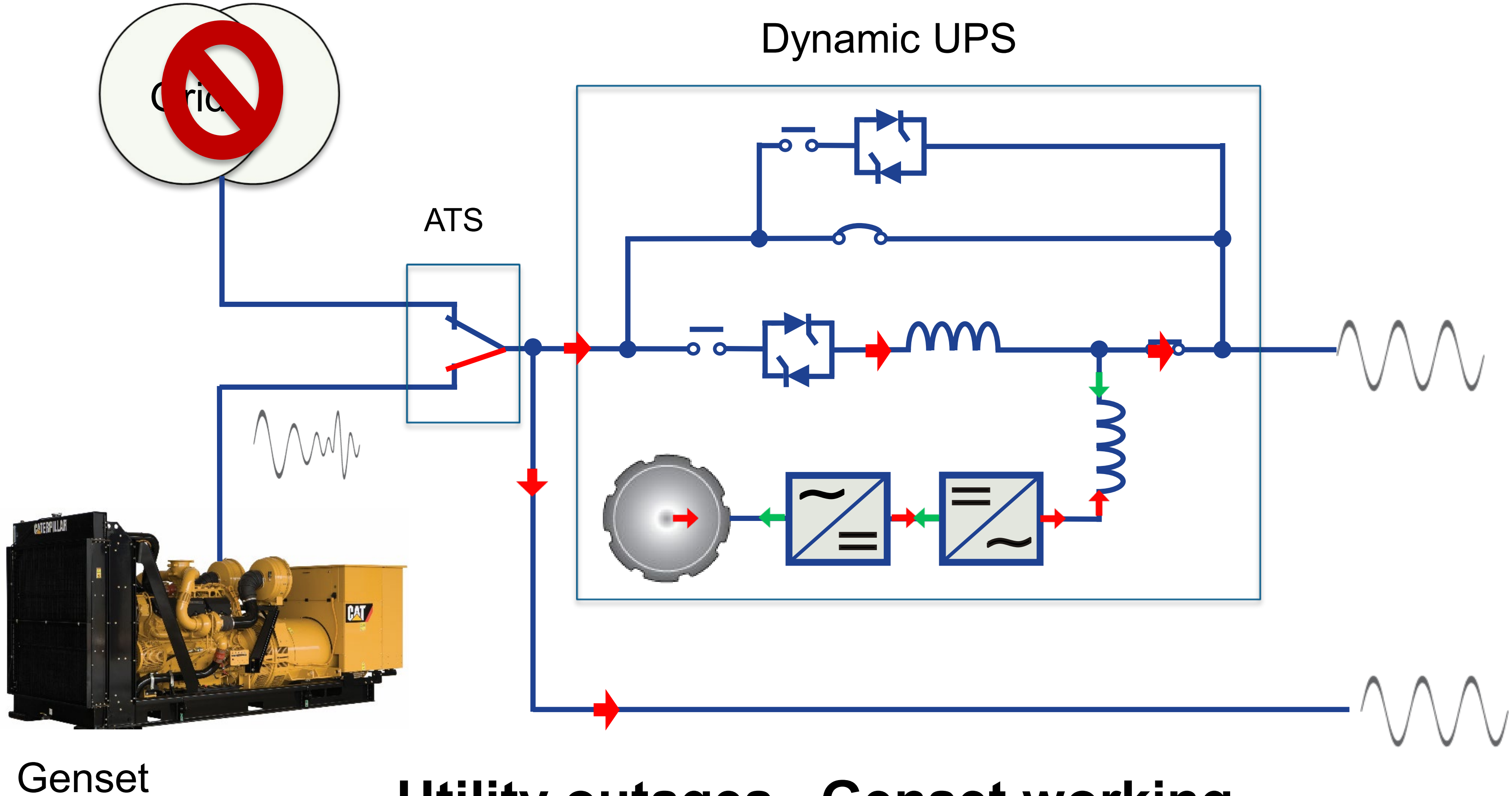
Normal operation with dynamic UPS

Diesel replacement - main principle



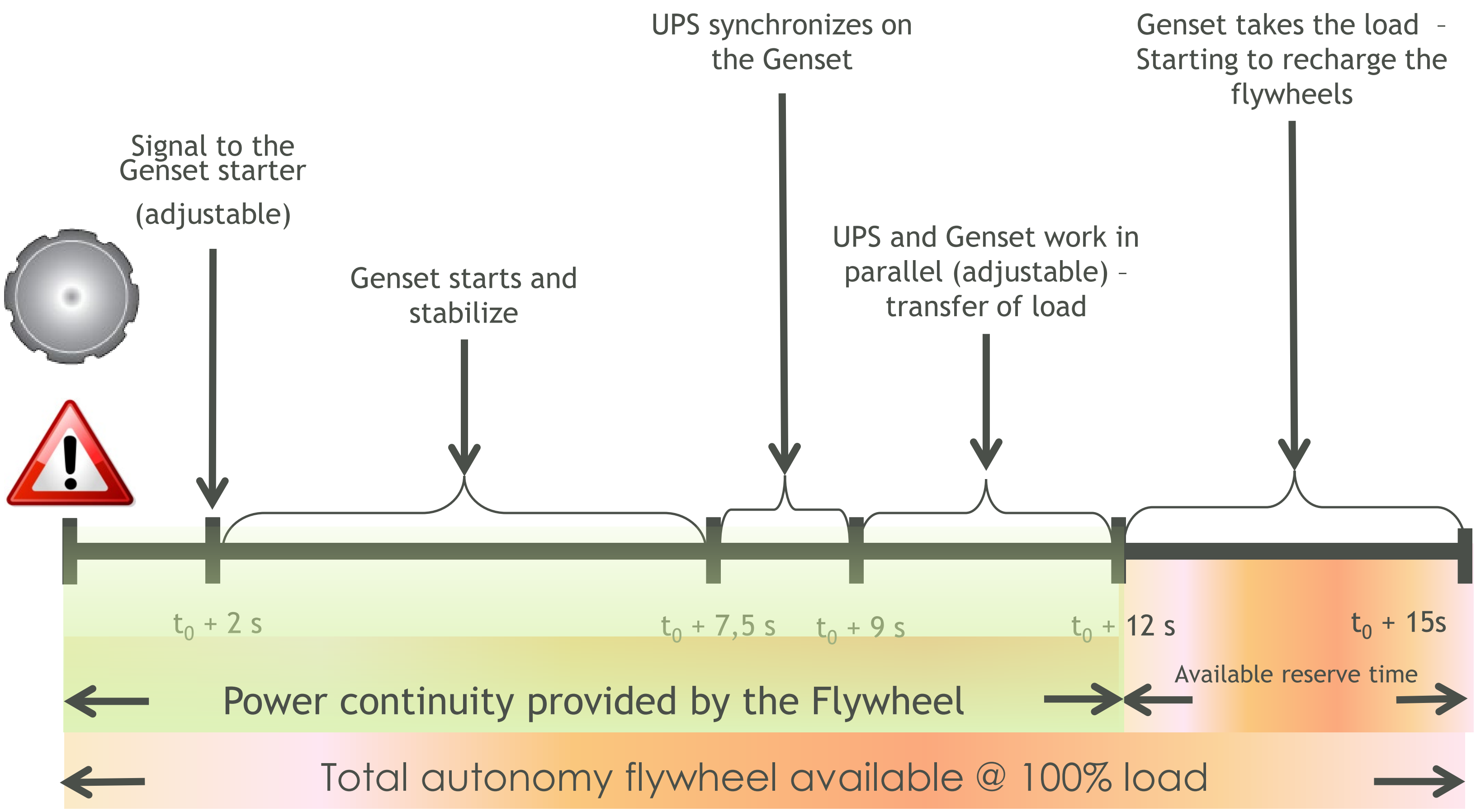
Utility outage

Diesel replacement - main principle



Utility outages– Genset working

Start kinetics



Upgrade of electrical feed of vital network – old situation

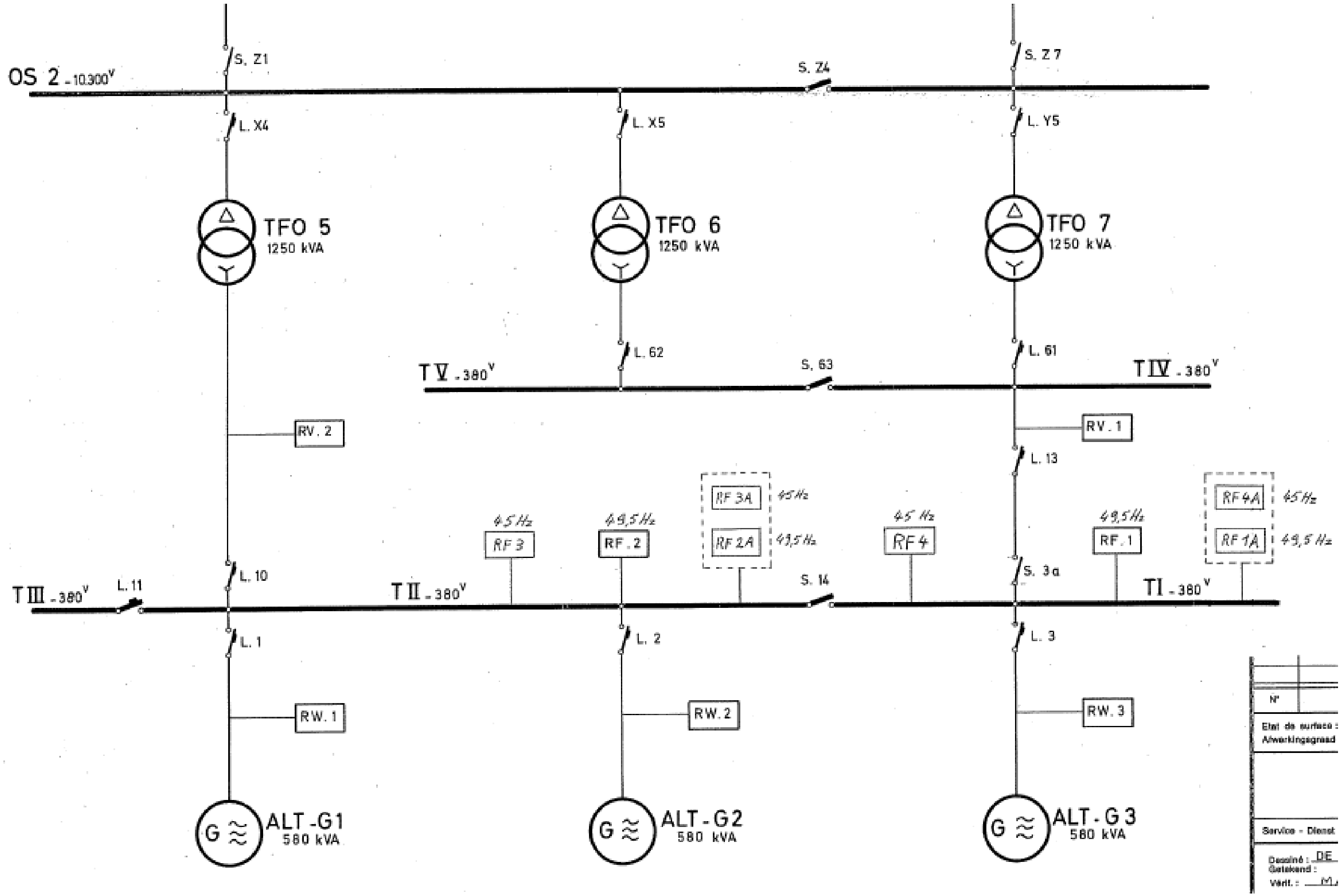


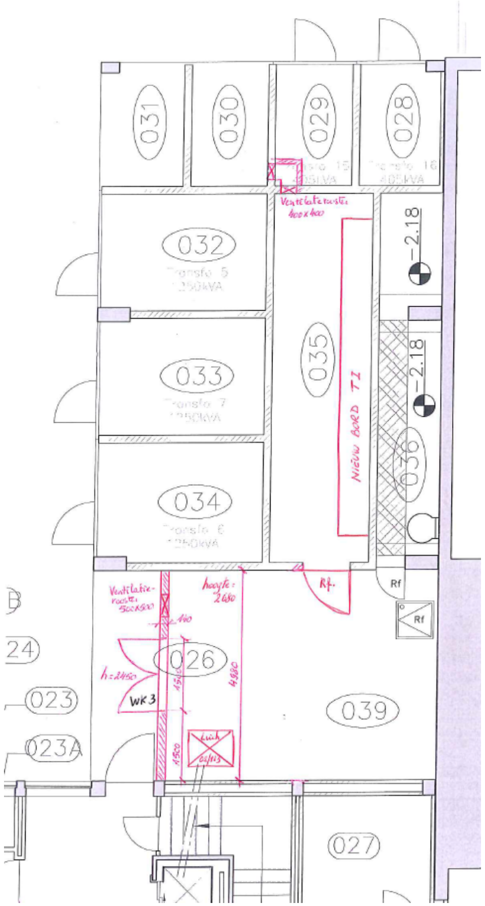
Illustration of redistribution of redundant systems

Current feed	New Feed TGI (TI)	New Feed TGII (TII/TIII)	Current feed
TIII	E1	E2	TIII
TIII	J18-304	J18-303	TIII
TIII	J28-5-304	J28-5-303	TI
TIII	T52 (net2)	T52 (net1)	TIII
TII	J5-402	J5-401	TII
TII	J5-412	J5-411	TII
TII	J4-406	J4-405	TII
TII	J28-5-404	J28-5-403	TII
TII	Tfo21 (UPS-KZR)	UPS-KZR	TI
TI	J28-5-412	J28-5-411	TI
TI	Tfo30 (info-net)	Tfo29 (info-net)	TIII
TII-EX	TVB2	TVB1	TII
TII-EX	TXI (via TC1/17)	TXI	TII
TII-EX	CB20 (via CB118)	CB20	TII

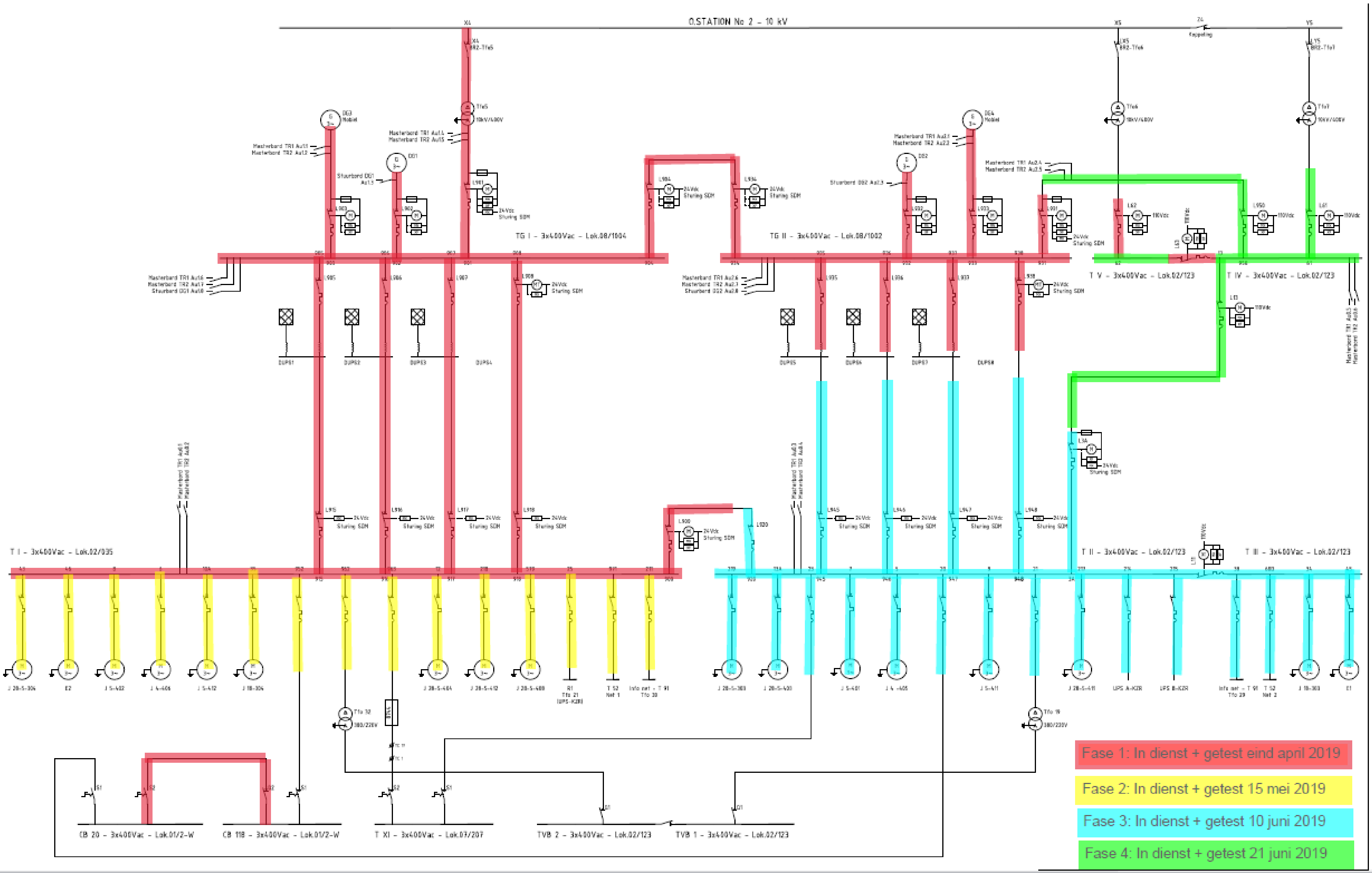
New situation

- Old switchboard lay out → single point of failure

  Loss of switchboard T II
    - Loss of all users on TII and TIII
    - Loss of connection to 2 of 3 diesel generators
- Upgrade to 2 separated feeds (with option of coupling
  - Electrical common cause failure prevention
    - T I → new T I
    - T II + T III → new T II
  - Prevention of common cause failure by fire
    - New T I in separate room

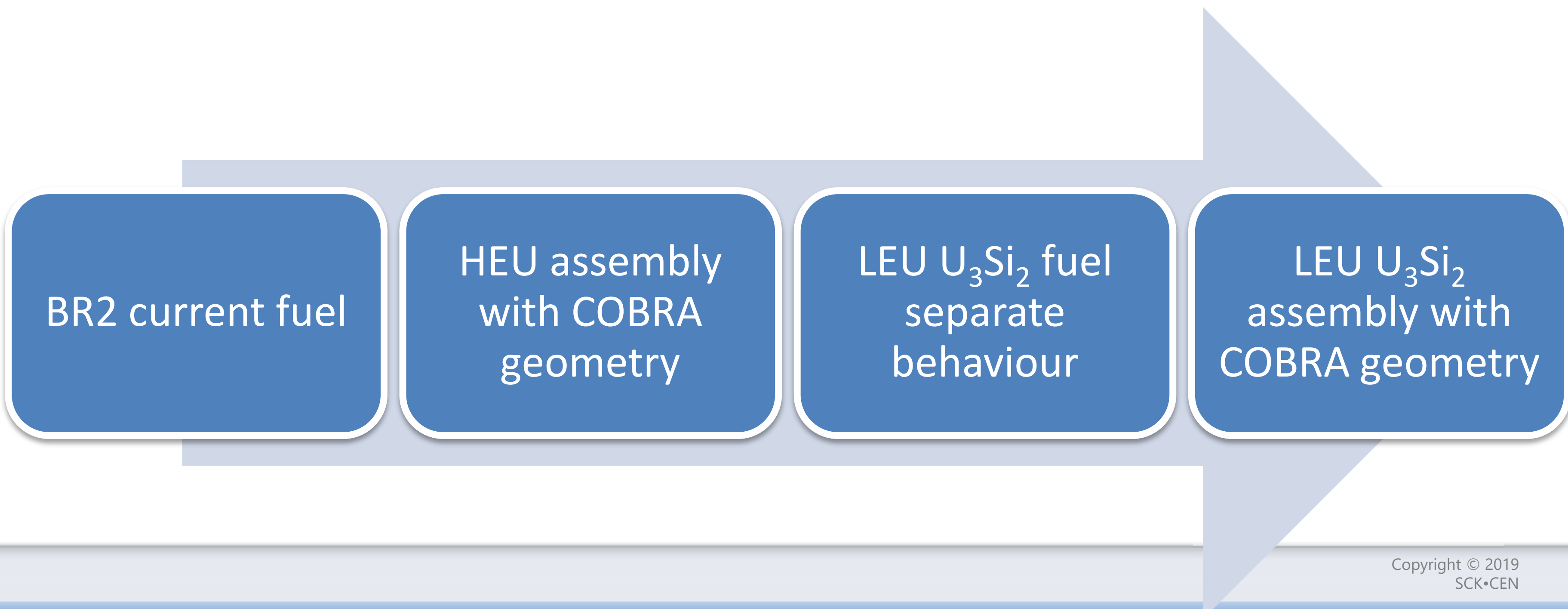


Implementation plan



Driver fuel conversion HEU-LEU

- 3 step approach
  - Modify geometry of HEU element
    - Increased meat thickness
  - Qualification of LEU based system with evolutionary properties: 5,2g/cc silicide: flat plate irradiation
  - Qualification of LEU lead test assemblies

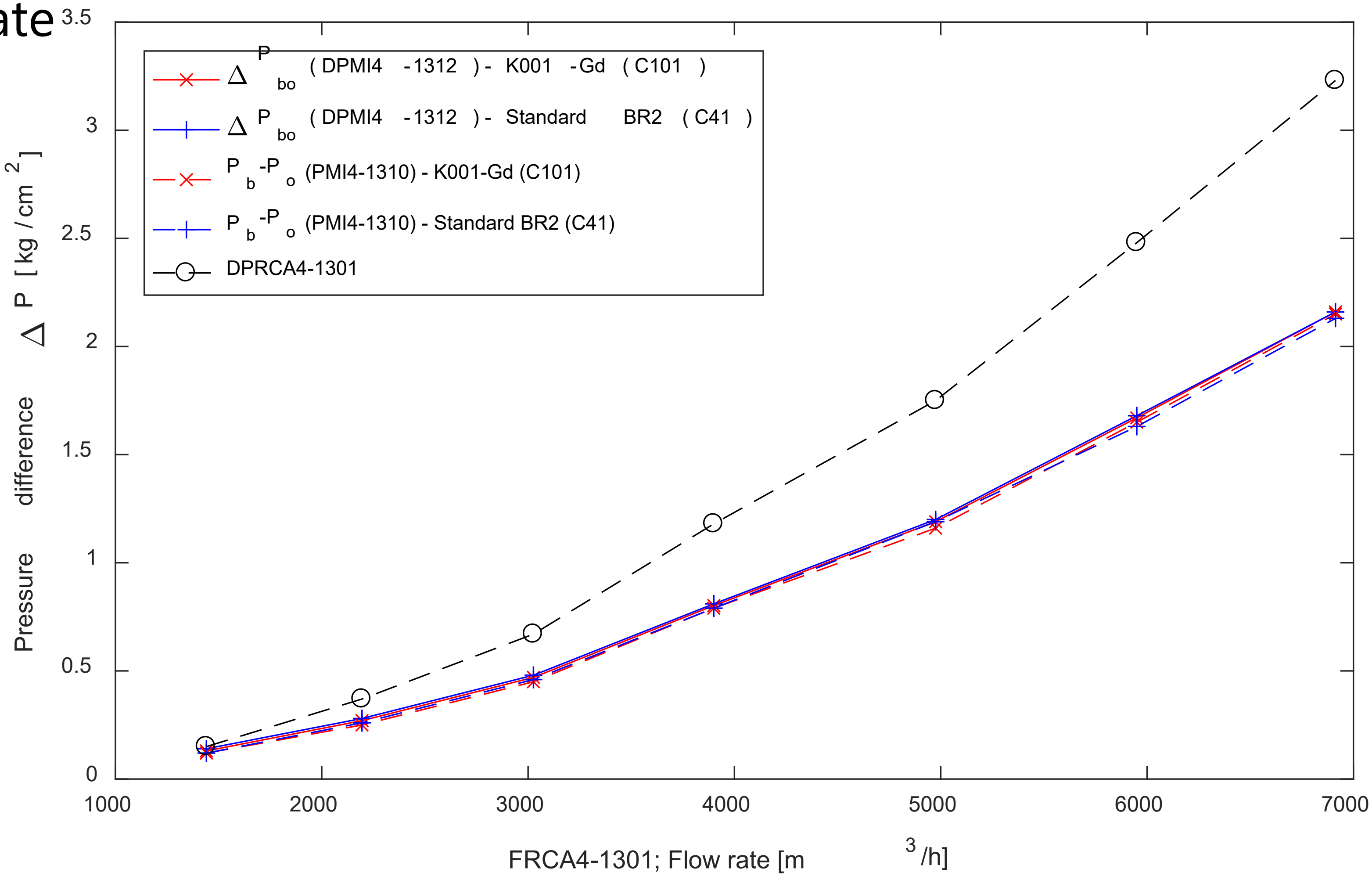


COBRA HEU LTA description

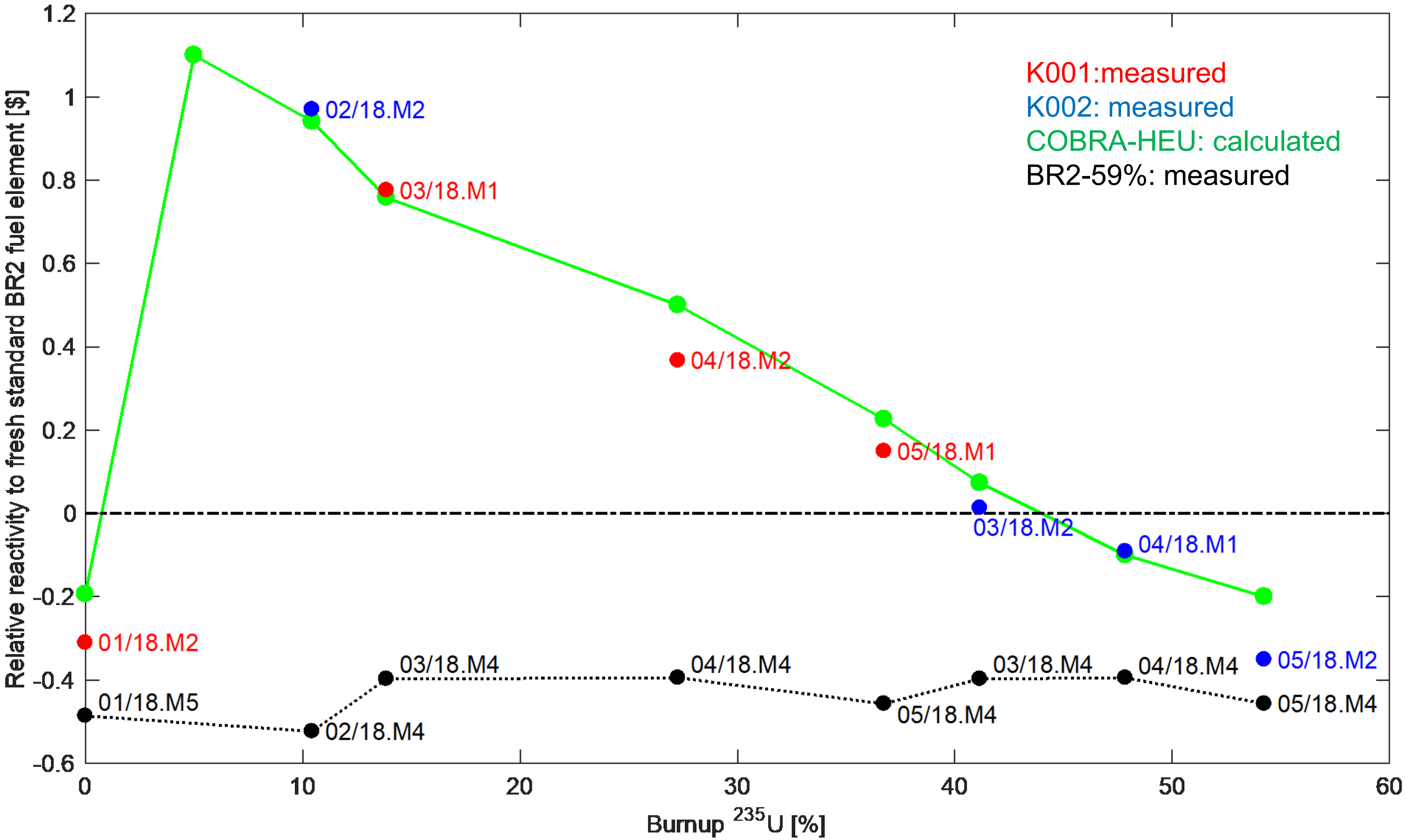
	COBRA-HEU-Gd	COBRA-HEU-BSm		Standard FE
Enrichment ^{235}U [%]	93.0	93.0		93.0
Density [gU/cm^3]	1.04	1.04		1.3
^{235}U [g/FE]	400	400		400
Plate thickness [mm]	**1.33**	**1.33**	**>**	**1.27**
Thickness fuel meat [mm]	**0.63**	**0.63**	**>**	**0.51**
Cladding average/minimum [mm]	**0.35/0.25**	**0.35/0.25**	**</=**	**0.38/0.25**
Inter-plate water gap [mm]	**3.0**	**3.0**	**=**	**3.0**
Outer FE diameter [mm]	**38.94**	**38.94**	**<**	**38.58**
Outer water gap	**3.16**	**3.16**	**<**	**3.52**
B (B_4C) [g/FE]	**–**	**3.8**		**3.8**
Sm (Sm_2O_3) [g/FE]	**–**	**1.4**		**1.4**
Gd (Gd_2O_3) [g/FE]	**2.5**	**–**		**–**

Hydraulic measurements

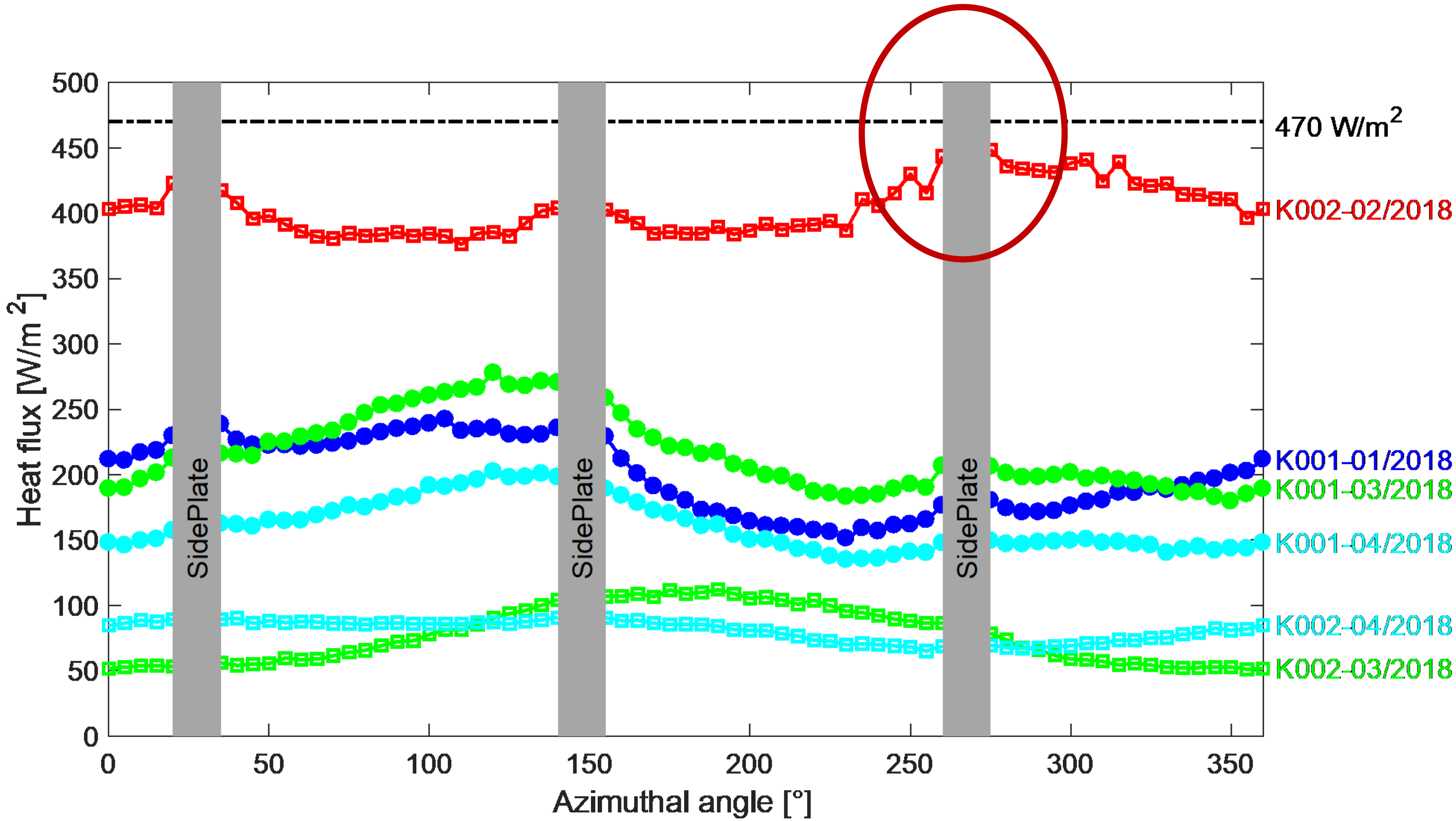
- At start irradiation campaign: pressure drop as a function of flow rate



Reactivity evolution as a function of burnup



Azimuthal heat flux distribution COBRA-HEU-LTAs



Feedback new type driver fuel

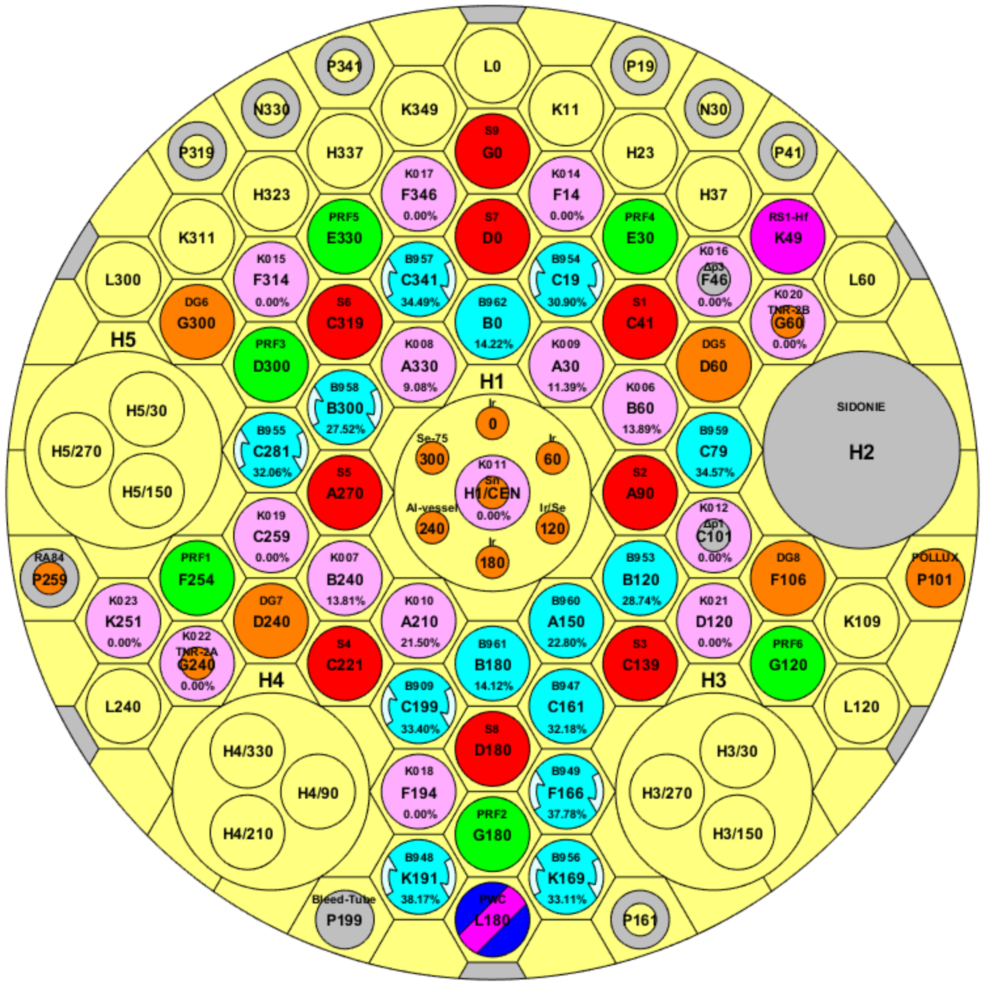
- Cycle 01/2019: 5 type K fresh elements
  - Burn up end of cycle 9 to 21%
  - Heat flux 130-220 W/cm^2
- Cyclus 02/2019: 12 fresh elements type K, 5 elements in second cycle
  - Maximum heat flux 410W/cm^2 (fresh element in H1c) and 406W/cm^2 (2nd cycle element in A30)

No failures detected up to now

- Addition of Gd as burnable absorber allows for longer reactor cycle
  - First 5 week cycle of BR2 was performed from March 26 until April 30

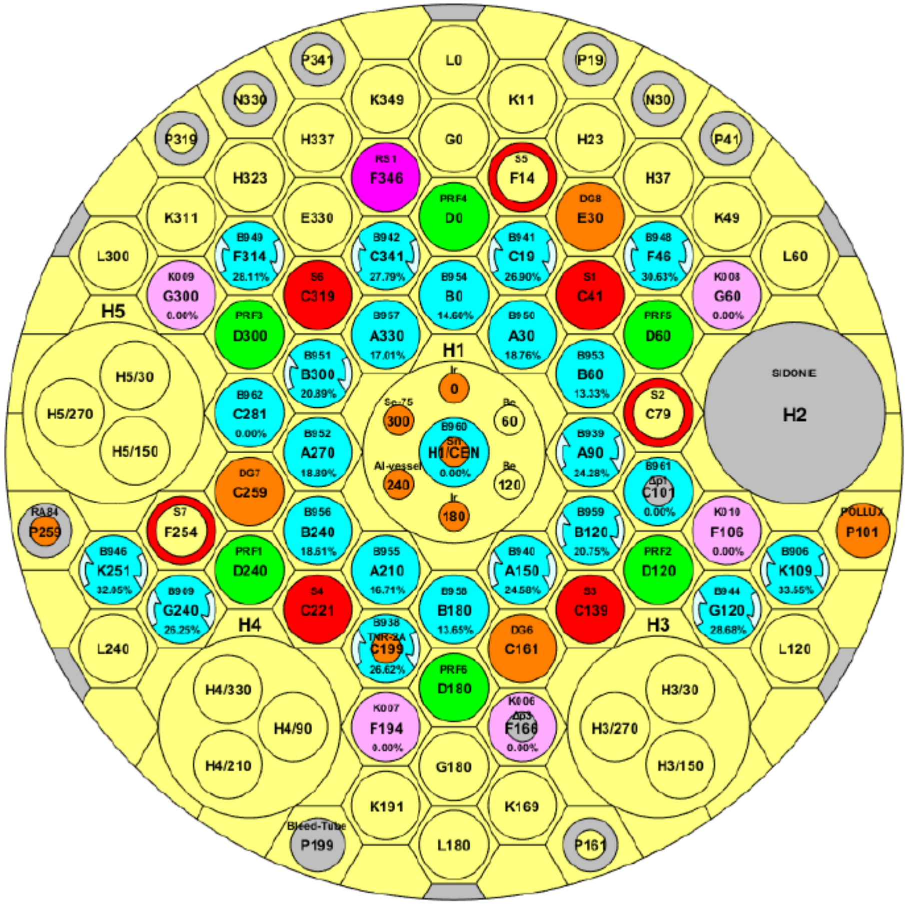
Configuration of cycle 02/2019

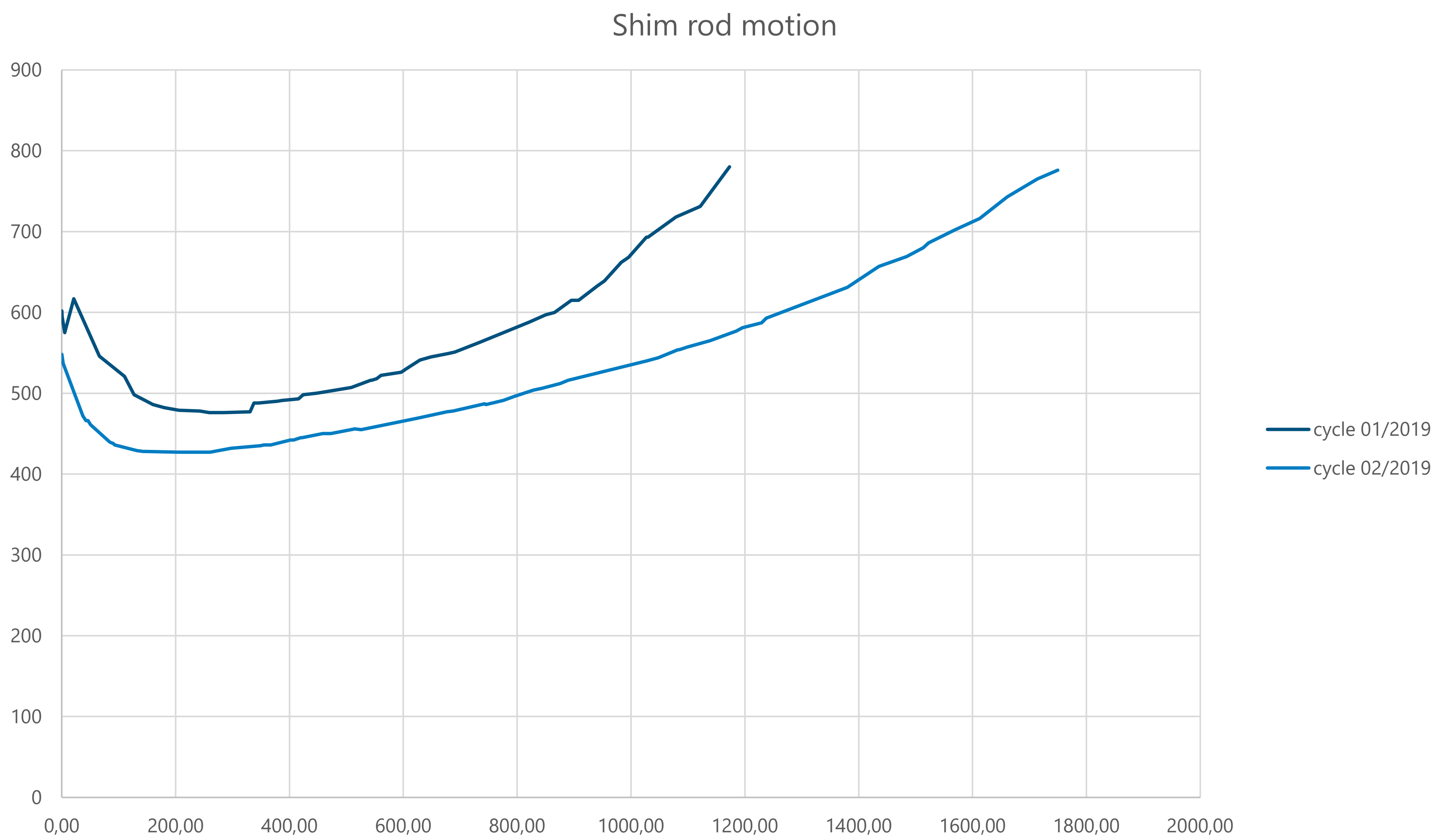
02/2019.A6
(Confirmed & Approved)



Configuration of cycle 01/2019

01/2019.A5
(Confirmed & Approved)




Shim rod motion
900
800
700
600
500
400
300
200
100
0
0,00
200,00
400,00
600,00
800,00
1000,00
1200,00
1400,00
1600,00
1800,00
2000,00
cycle 01/2019
cycle 02/2019

Impact of longer cycle

- More operation days possible with same manipulation effort (1 cycle loading/unloading = +/- 12 days)
- Need for more control / shim rods: less available positions for irradiation devices
  - Compensation by utilization of positions in 200mm channels
- Somewhat larger shift in axial hot spot
  - Lower minimum position of rods due to large amount of burnable absorbers