United States Nuclear Regulatory Commission
Protecting People and the Environment

Back-up Slides

RES Slides for

ACRS Meeting 7/21-22/2020

SET / IET Overview

- Hibiki and Ishii
- Boesmans and Berghmans
- LINX
- CCTF
- SCTF
- PKL

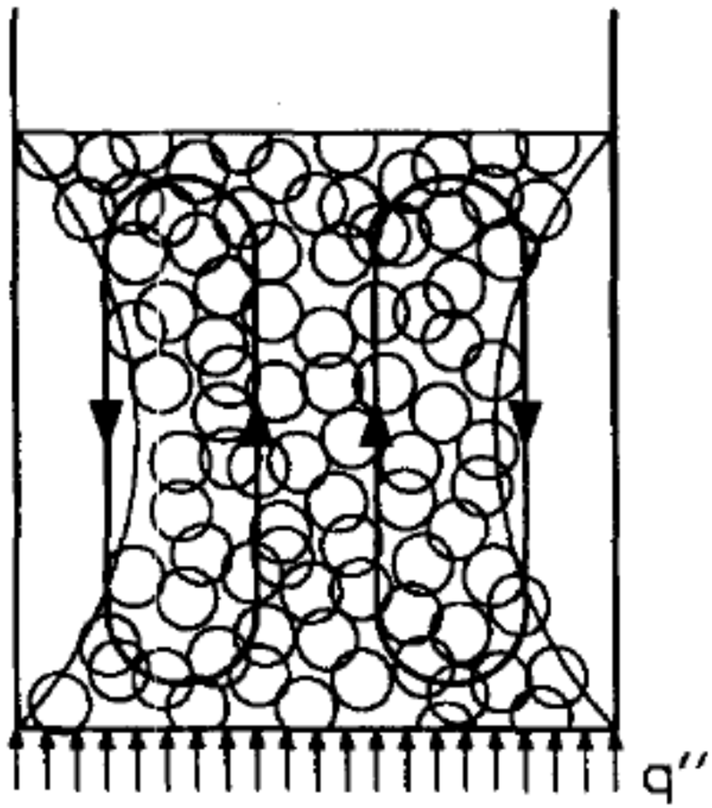
Literature Review

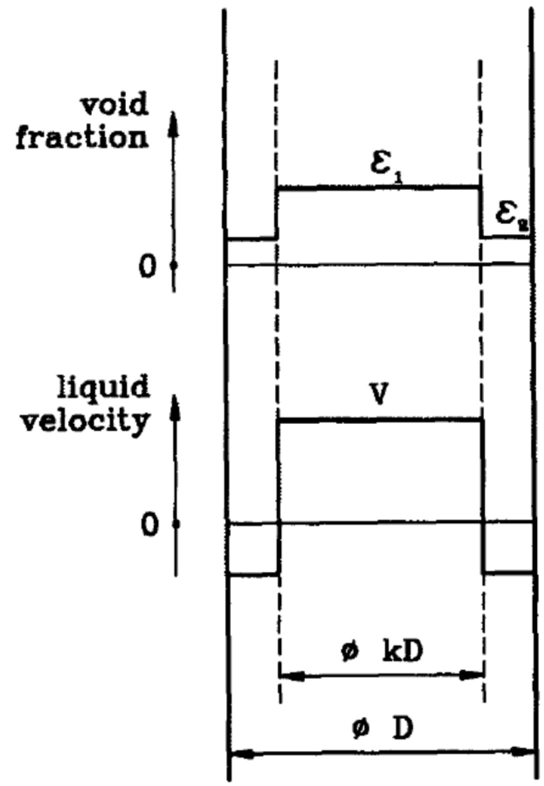
- Hibiki and Ishii summarized findings over many experimental campaigns that internal recirculation occurs near pool boiling conditions in large pipe geometries and bundle geometries
  - A key process that affects the 3D flow field is channeling of voids into a central column
- At LINX facility, voiding in adiabatic conditions drove internal recirculation
- At CCTF, radial power differences enhanced internal recirculation
- At PKL facility, internal recirculation homogenized the axial and radial boron distribution

Hibiki-Ishii Review

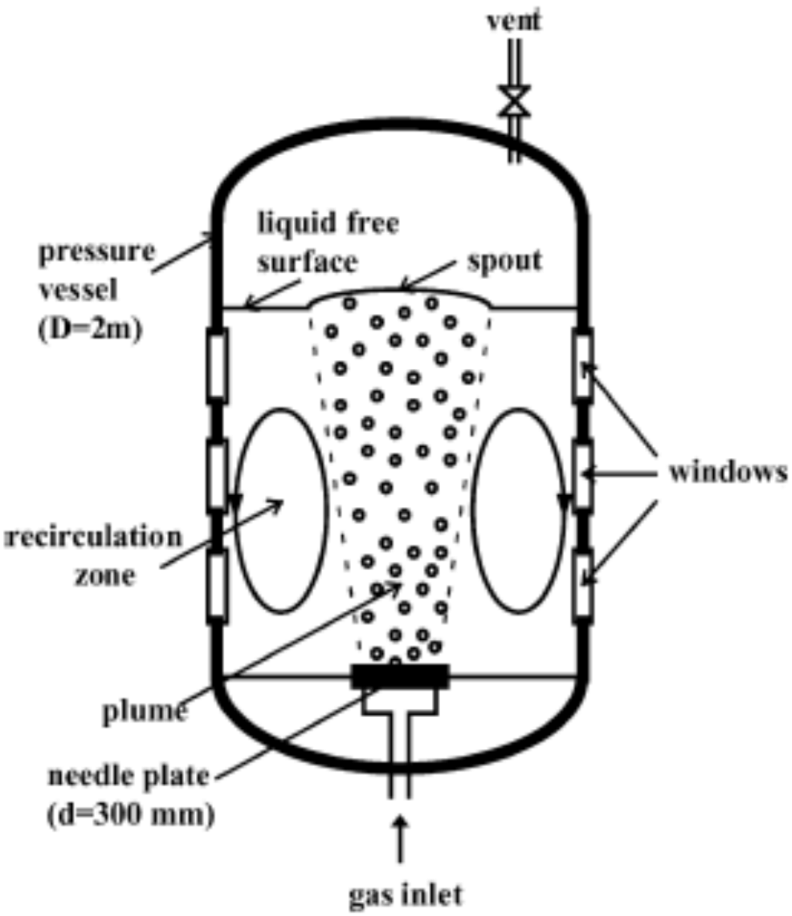
Investigator	Fluid system	Pipe diameter D (m)	Number of data	Superficial gas velocity $\langle j_g \rangle$ (m/s)	Superficial liquid velocity $\langle j_f \rangle$ (m/s)	Mixture volumetric flux $\langle j \rangle$ (m/s)	System pressure P (MPa)	Bubble injection method
Hibiki and Ishii [21,25]	Nitrogen–water	0.0508, $L/D = 108$	73	0.0320–0.484	0.00–0.596	0.0320–1.02	0.1	No horizontal section
Hibiki and Ishii [21]	Nitrogen–water	0.102, $L/D = 53.9$	59	0.0373–0.286	0.0109–0.387	0.0482–0.655	0.1	No horizontal section
Hibiki and Ishii [22]	Nitrogen–water	0.102, $L/D = 53.9$	12	0.0349–0.146	0.0389– 0.198	0.0754–0.336	0.1	Horizontal section
Hills [7]	Air–water	0.150, $L/D = 70.0$	301	0.040–0.62	0.0–0.50	0.040–0.85	0.1	Low flow data
Hills [7]	Air–water	0.150, $L/D = 70.0$	93	0.10–3.5	0.0–2.6	0.10–6.1	0.1	High flow data
Hashemi et al. [16]	Air–water	0.305, $L/D = 9.41$	16	0.0100–1.16	0.0–0.060	0.0300–1.22	0.1	No horizontal section
Hirao et al. [11,12]	Steam–water	0.102, $L/D = 55.3$	23	N/A	N/A	0.720–3.43	0.1, 0.5, 1.5	Vertical and L-shaped pipes
Ohnuki and Akimoto [18]	Air–water	0.480, $L/D = 4.2$	32	N/A	N/A	0.0284–1.01	0.1	Sinter inlet
Ohnuki and Akimoto [18]	Air–water	0.480, $L/D = 4.2$	73	N/A	N/A	0.0114–1.02	0.1	Nozzle inlet

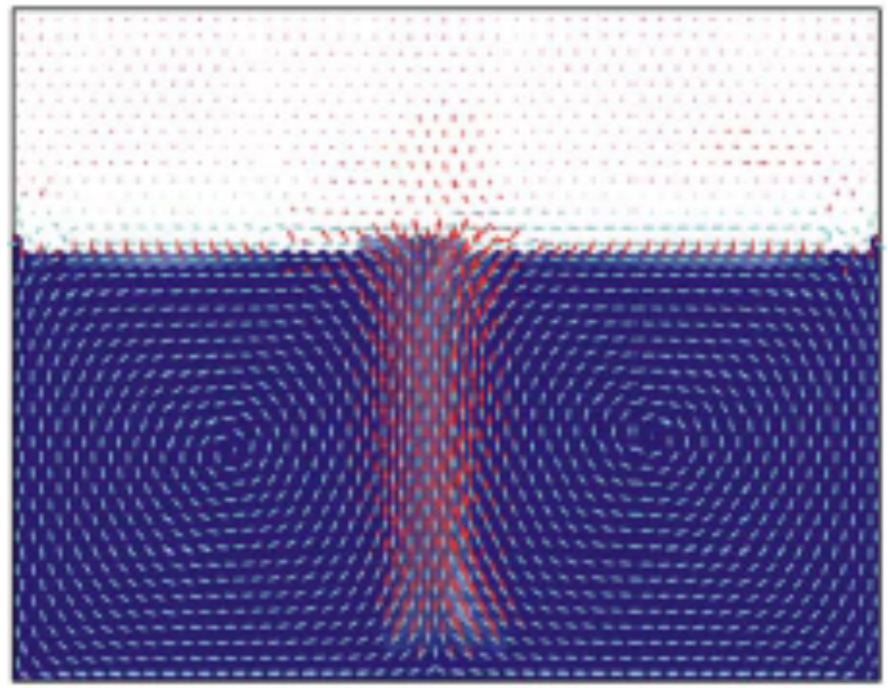
Boesmans and Berghmans



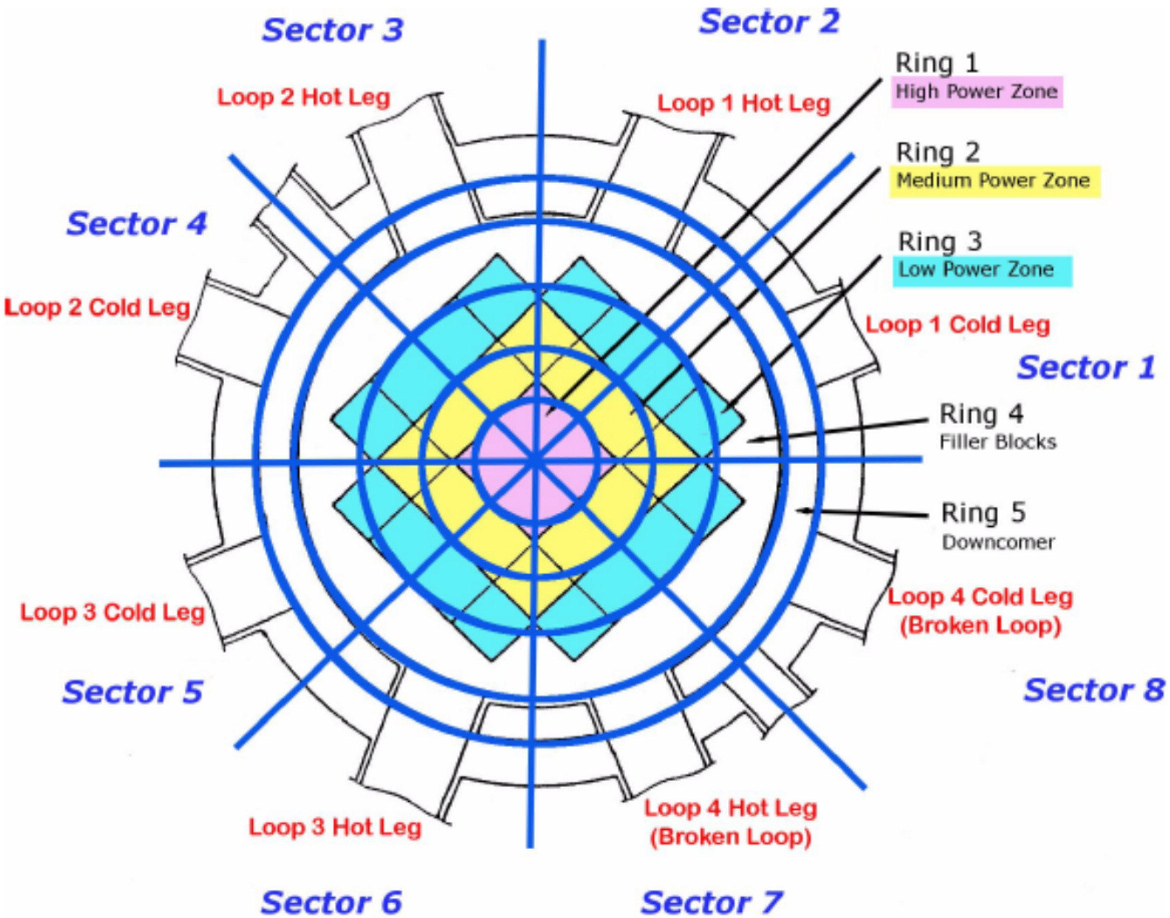


LINX

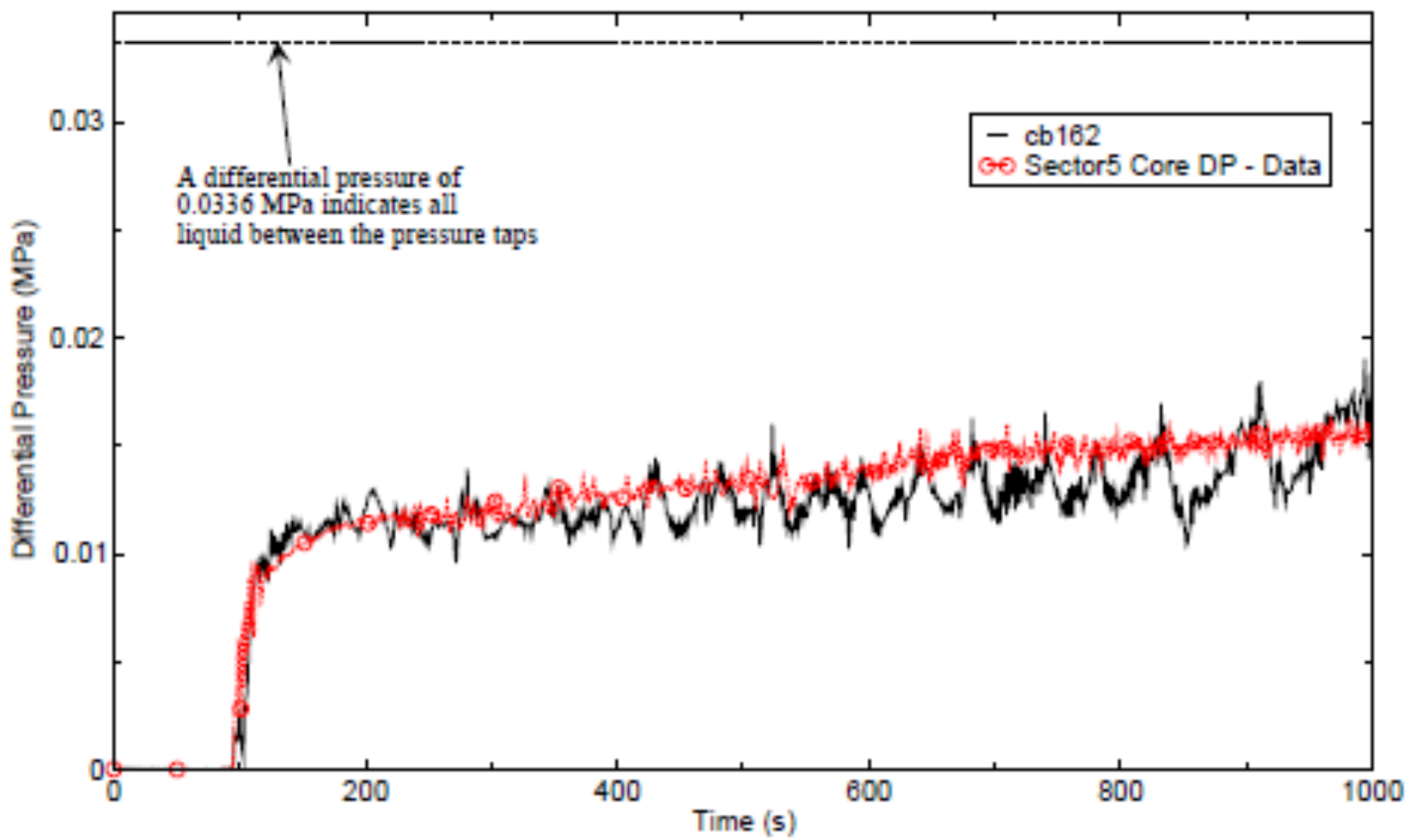

vent
pressure vessel (D=2m)
liquid free surface
spout
windows
recirculation zone
plume
needle plate (d=300 mm)
gas inlet



CCTF

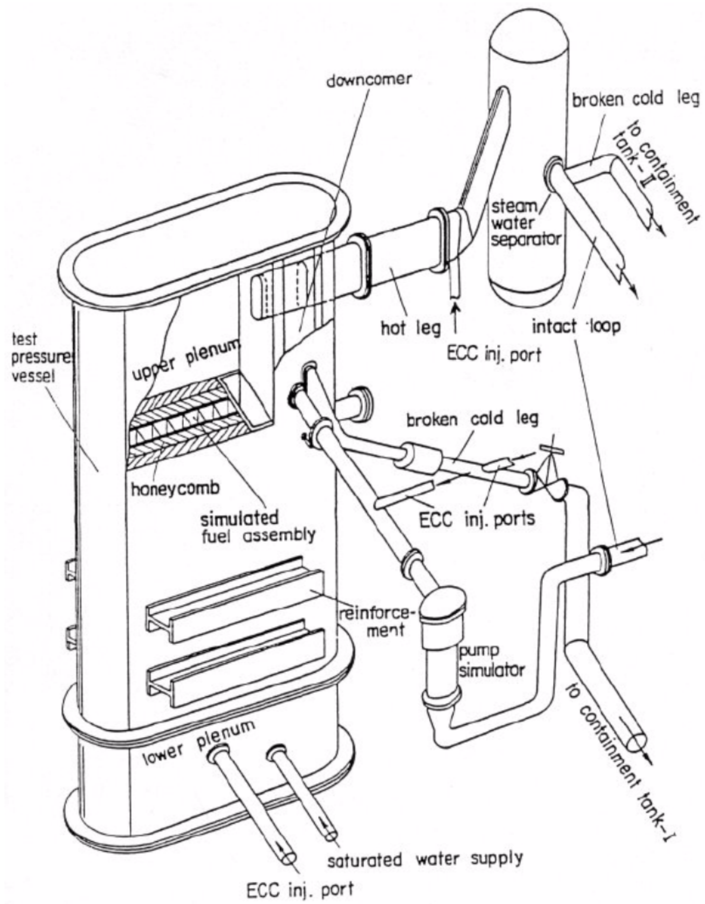

Sector 3
Sector 2
Ring 1
High Power Zone
Loop 2 Hot Leg
Loop 1 Hot Leg
Ring 2
Medium Power Zone
Sector 4
Ring 3
Low Power Zone
Loop 2 Cold Leg
Loop 1 Cold Leg
Sector 1
Ring 4
Filler Blocks
Ring 5
Downcomer
Loop 3 Cold Leg
Loop 4 Cold Leg
(Broken Loop)
Sector 5
Sector 8
Loop 3 Hot Leg
Loop 4 Hot Leg
(Broken Loop)
Sector 6
Sector 7

CCTF

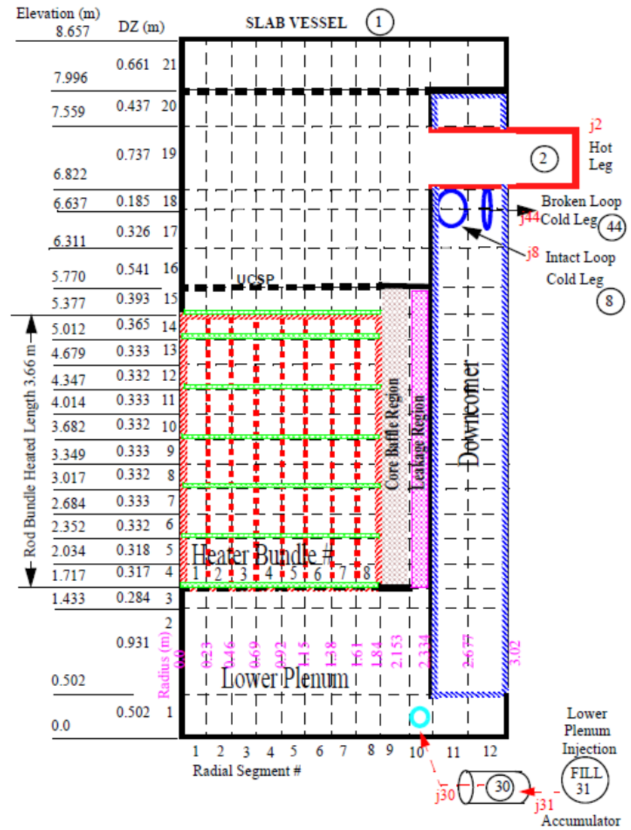


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SCTF

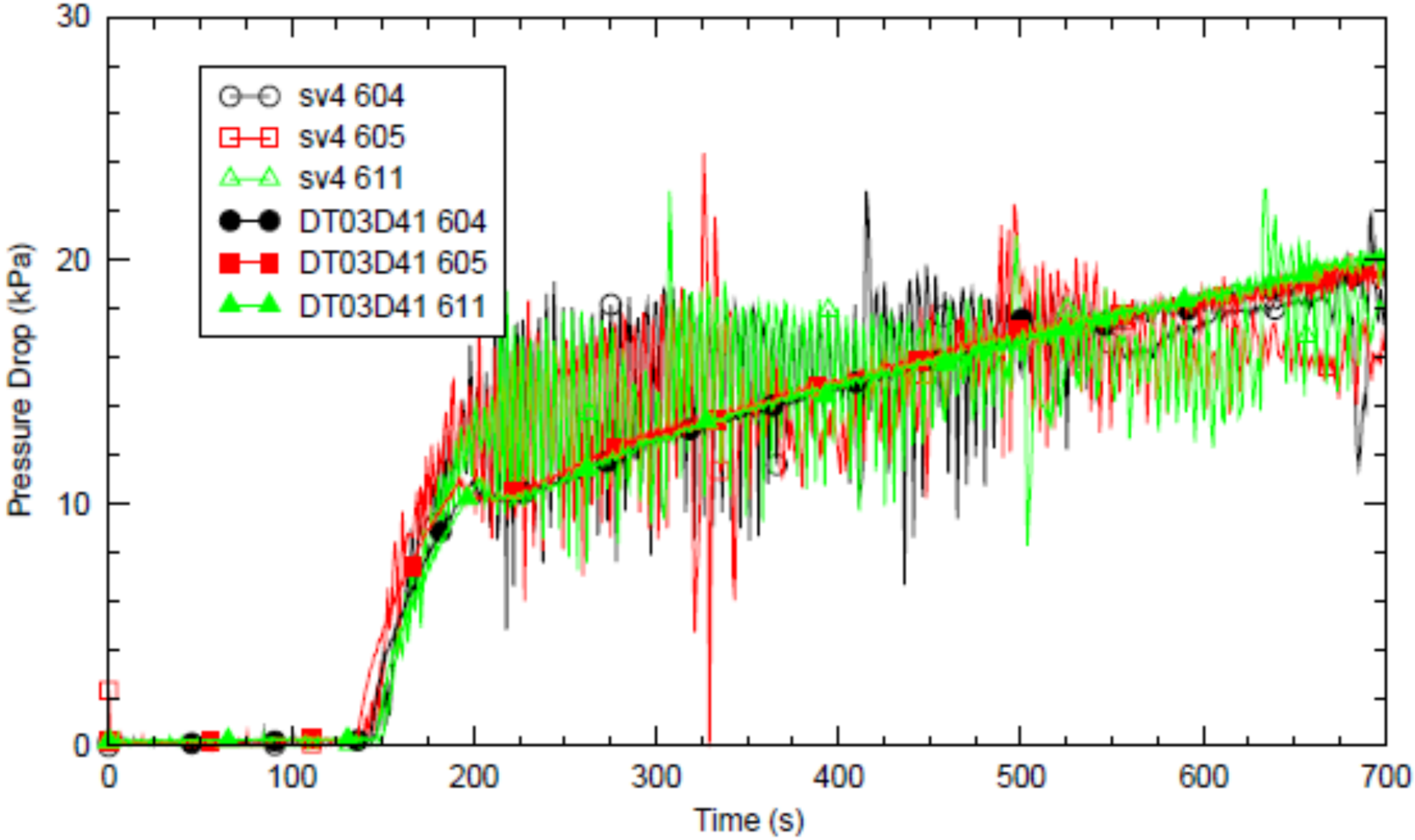


downcomer
broken cold leg
to containment tank-II
steam water separator
test pressure vessel
upper plenum
hot leg
ECC inj. port
intact loop
honeycomb
simulated fuel assembly
broken cold leg
ECC inj. ports
reinforce-ment
pump simulator
lower plenum
to containment tank-I
saturated water supply
ECC inj. port



Elevation (m)
DZ (m)
SLAB VESSEL
1
Hot Leg
2
j2
Broken Loop Cold Leg
44
j44
j8
Intact Loop Cold Leg
8
UCSP
Rod Bundle Heated Length 3.66 m
Heater Bundle #
Core Baffle Region
Leakage Region
Downcomer
Lower Plenum
Radius (m)
Radial Segment #
Lower Plenum Injection
FILL 31
30
j30
j31
Accumulator

SCTF

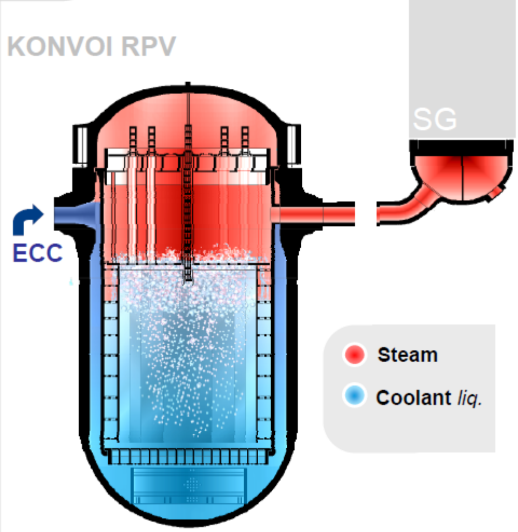


sv4 604
sv4 605
sv4 611
DT03D41 604
DT03D41 605
DT03D41 611
Pressure Drop (kPa)
Time (s)
0
10
20
30
0
100
200
300
400
500
600
700

Primärkreislauf Primary Circuit Reactor Coolant System (PKL) Information Follows

PKL

A Postulated Scenario

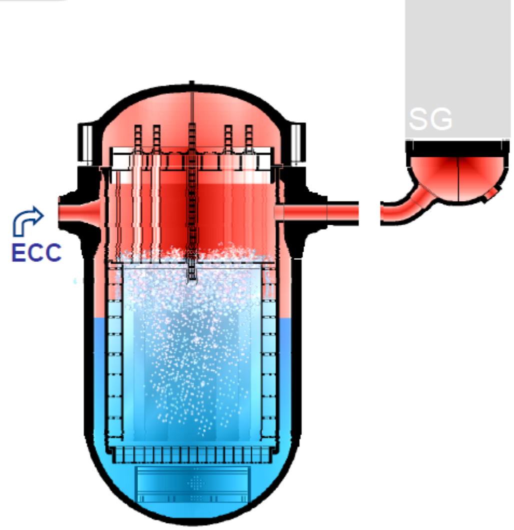


- High flow resistance in COL (partially filled)
- High pressure in upper plenum

  → High pressure in UP effectuates low swell level in core

  → Small mixing volume in RPV

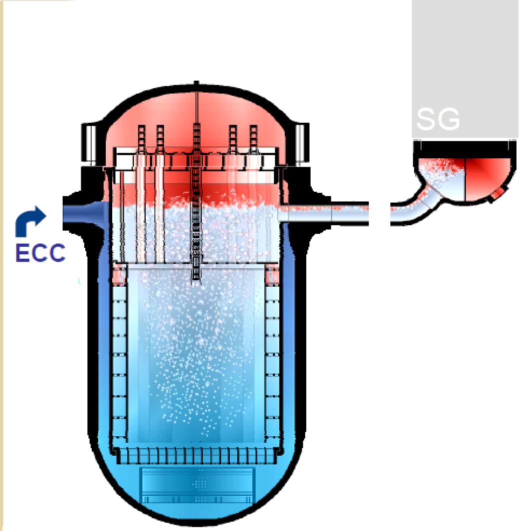
B PKL at SOT



- ECC just compensates for evaporation in core
  → very low ECC flow rates
- Hot side swell levels just covers core

  → Small mixing volume in RPV

C PKL Test Result



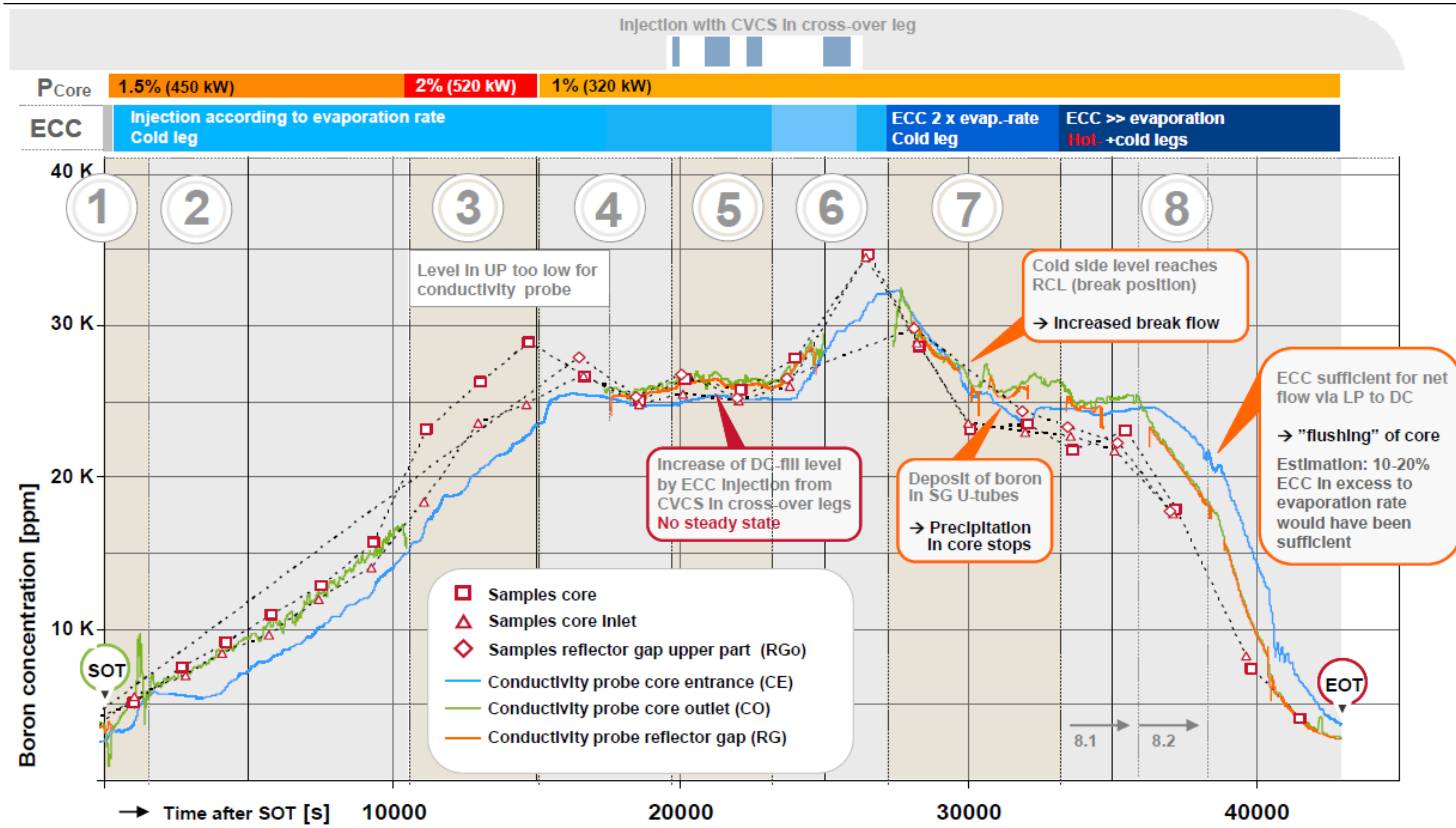
Realistic power and ECC flow rates:

→ DC completely filled, hot side swell level reaches SG inlet chambers

→ Deposit of boron into SG U-tubes
  → boron precipitation in core stagnates

→ Large mixing volumes

PKL



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SET/IET References

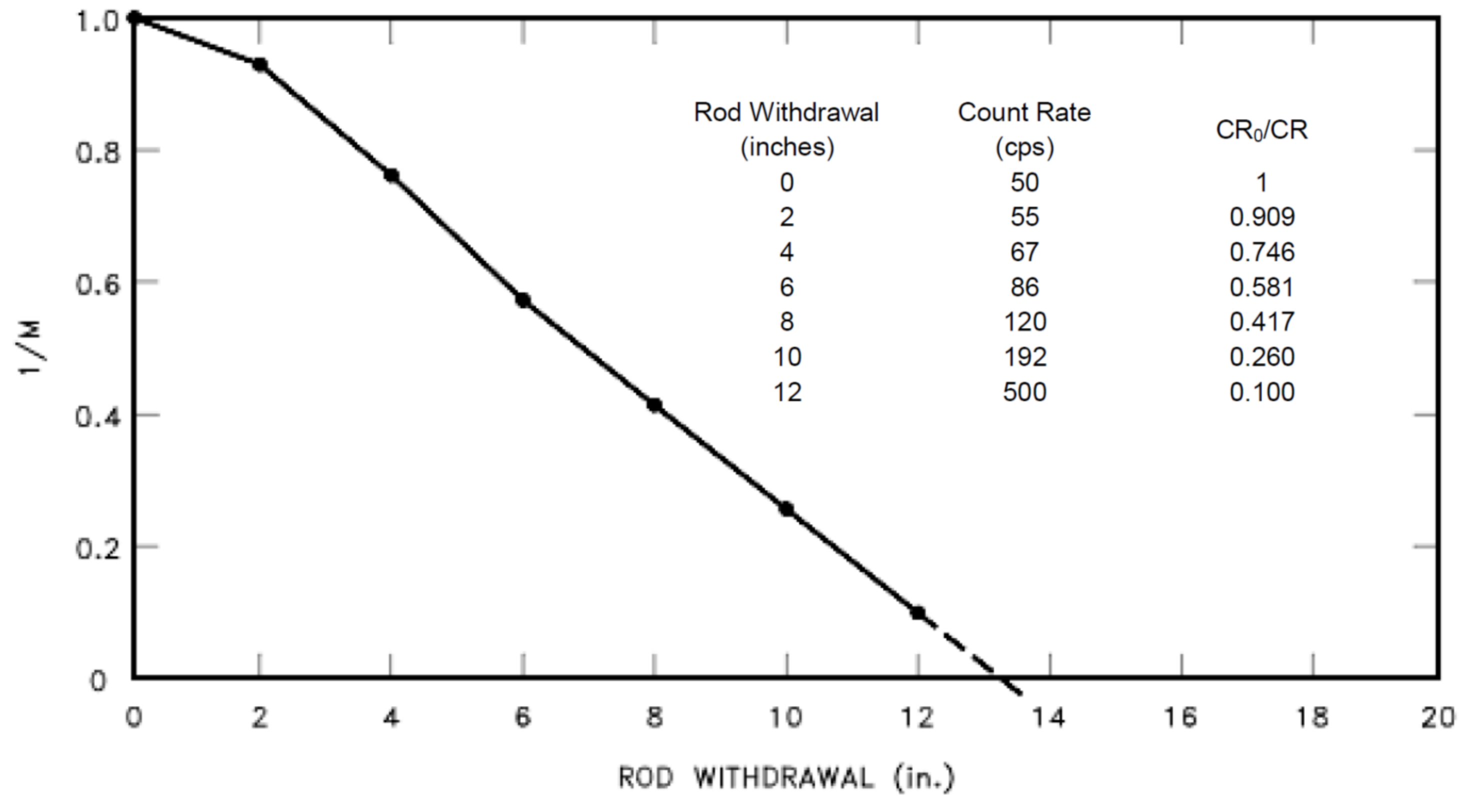
- Hibiki, T. and Ishii, M., “One-dimensional Drift Flux model for Two-phase Flow in a Large Diameter Pipe,” *Intl. Journal of Heat and Mass Transfer* **46** (2003) pp.1773–1790.
- Staedke, H., Franchello, G., Worth, B., Graf, U., Romsedt, P., Kumbaro, A., et al., “Advanced Three-dimensional Two-phase Flow Simulation Tools for Application to Reactor Safety (ASTAR),” *Nucl. Engr. And Design*, **235** (2005) pp. 379-400.
- Bosemans, B and Berghmans, J., “Level swell in pool boiling with liquid circulation,” *Intl. Journal of Heat and Mass Transfer* **38** (1995) pp.989-998.
- NUREG/IA-0127, “Reactor Safety Issues Resolved by the 2D/3D Program,” July 1993 (ADAMS Accession No. ML062560279)
- "Analysis Report on SCTF Core-I and II Reflood Test," prepared by Japan Atomic Energy Research Institute, JAERI-Memo-01-348.
- TRACE V5.0 Assessment Manual Appendix C: Integral Effects Tests
- PKL III G5.1 Test Report PTCTP-G/2011/en/0004 Rev. B, “Investigation on Boron Precipitation following a Large Break LOCA,” March 2011 (ADAMS Accession No. ML14099A208).

Monitoring Subcritical Margin

- Similar to startup procedures, ex-core nuclear instrumentation can be used to monitor subcritical margin.
- Subcritical multiplication monitoring is used with 1/M plots typically to predict critical rod position.

1/M Plot

(from DOE Fundamentals Handbook)



Timing of Downcomer Dilution

Time of ECCS Actuation	Approximate DC Concentration post-ECCS	Reactor Power	Steaming Rate	Time to reach 100 ppm	Time to reach 10 ppm
seconds	ppm	%RTP	kg/sec	days	days
1700	1000	1.0	0.74	0.96	10.3
2800	900	1.0	0.74	0.86	9.3
3300	800	1.0	0.74	0.77	8.3
1700	1000	0.5	0.37	1.89	20.6
2800	900	0.5	0.37	1.70	18.5
3300	800	0.5	0.37	1.49	16.5
1700	1000	0.2	0.15	4.70	51.5
2800	900	0.2	0.15	4.19	46.3
3300	800	0.2	0.15	3.68	41.1