PWSCC observations in Ringhals 3 and 4 safe ends

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Contents:

- Manufacture, repair, previous inspections
- Inspections and observations 2000
- Safety assessments
- Follow up inspections 2001
- Concerns and actions needed

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Design and manufacture

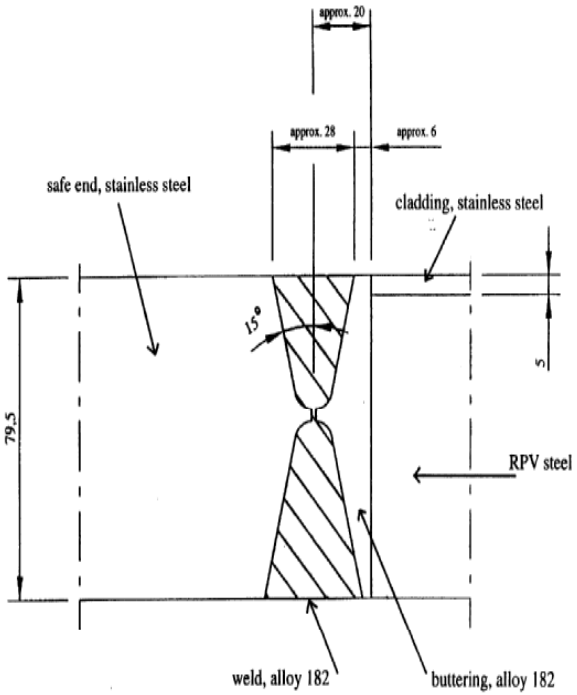
915 MW PWR W-design

Manufactured by Uddcomb Sweden AB

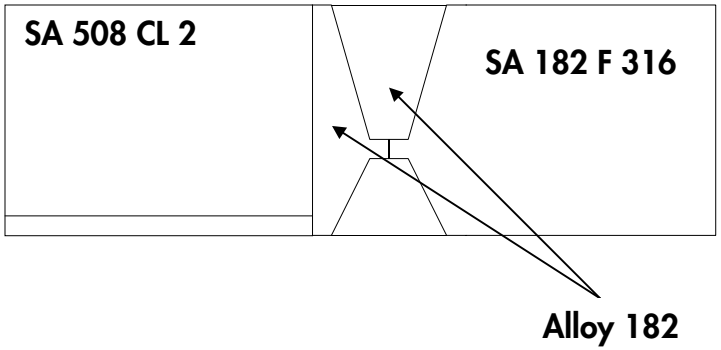
ASME Sec. III 1971 edition

Ringhals 3 in operation since 1981

Ringhals 4 in operation since 1983



Manufacture and repair

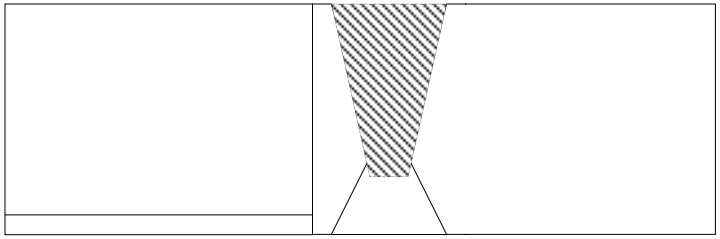


SMAW
Grinding of outer and inner surfaces
PT and RT

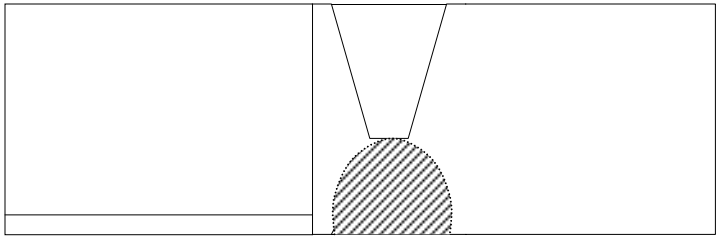
Slag inclusions and small weld cracks observed by RT of Ringhals 4 safe ends ⇨ Repair
No documented repair of safe ends in Ringhals 3

Repair of Ringhals 4 safe end pos. 25°

First and second repair:
Machining 360° around the circumference
⇨ SMAW ⇨ grinding ⇨ PT and RT



Third repair:
Grinding in local circumference positions
⇨ SMAW ⇨ grinding PT and RT



In-service inspections

Previous ISI 1993

- Inside inspection with techniques based on UT and ET
- Only inner 0,3 t
- No reported indications

New ISI programme acc. to SKIFS 1994:1

- Inspection with qualified NDE system planned for 1998 ⇨ problems to qualify the system ⇨ the inspection postponed to 2000.

ISI 2000 acc.to SKIFS 1994:1

- Qualified NDE system for inside inspection
  - UT for detection, characterisation, sizing
    - Qualification defect size 6x18 mm
    - Sizing accuracy depth ±3 mm, length ±13 mm
  - ET for discrimination between surface and non-surface breaking defects
    - Qualification defect size 1x18 mm

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Inspection results 2000

Ringhals 3

- Two indications recorded in one safe end, first evaluated as sub surface planar flaws (defects) < qualification targets
- Re-evaluation based on experience from Ringhals 4 ⇨ surface planar flaws (cracks) > qualification targets

Ringhals 4

- Several indications recorded in one safe end, evaluated as
  - volumetric defects
  - 3 sub surface planar flaws and 1 surface planar flaw > qualification targets
- Planar flaws removed by boat samples to
  - stop further growth
  - metallographic examination
- Comparison with inspection results showed that
  - two of the cracks were under sized
  - all cracks were surface breaking

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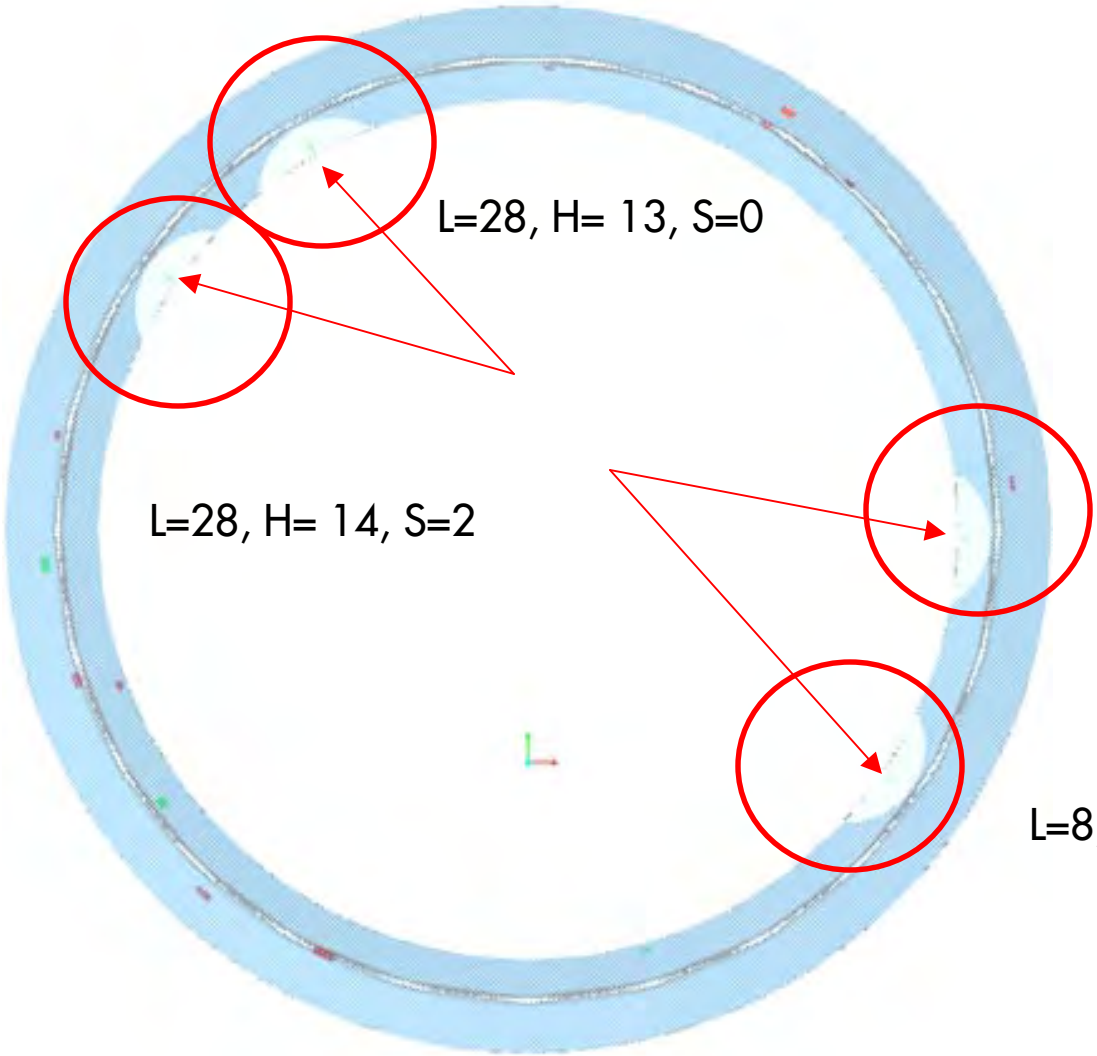
Ringhals 4 outage -00, 25° outlet nozzle to safe-end weld, UT indications.



Removed cracks in Ringhals 4, sizing results:

Crack position	Depth acc. to ultrasonic measurements	Depth acc. to destructive examination
91°	10 ± 3 mm	9 ± 1 mm
124°	9 ± 3 mm	6 ± 1 mm
305°	16 ± 3 mm	22 ± 3 mm
330°	13 ±3 mm	22 ± 3 mm

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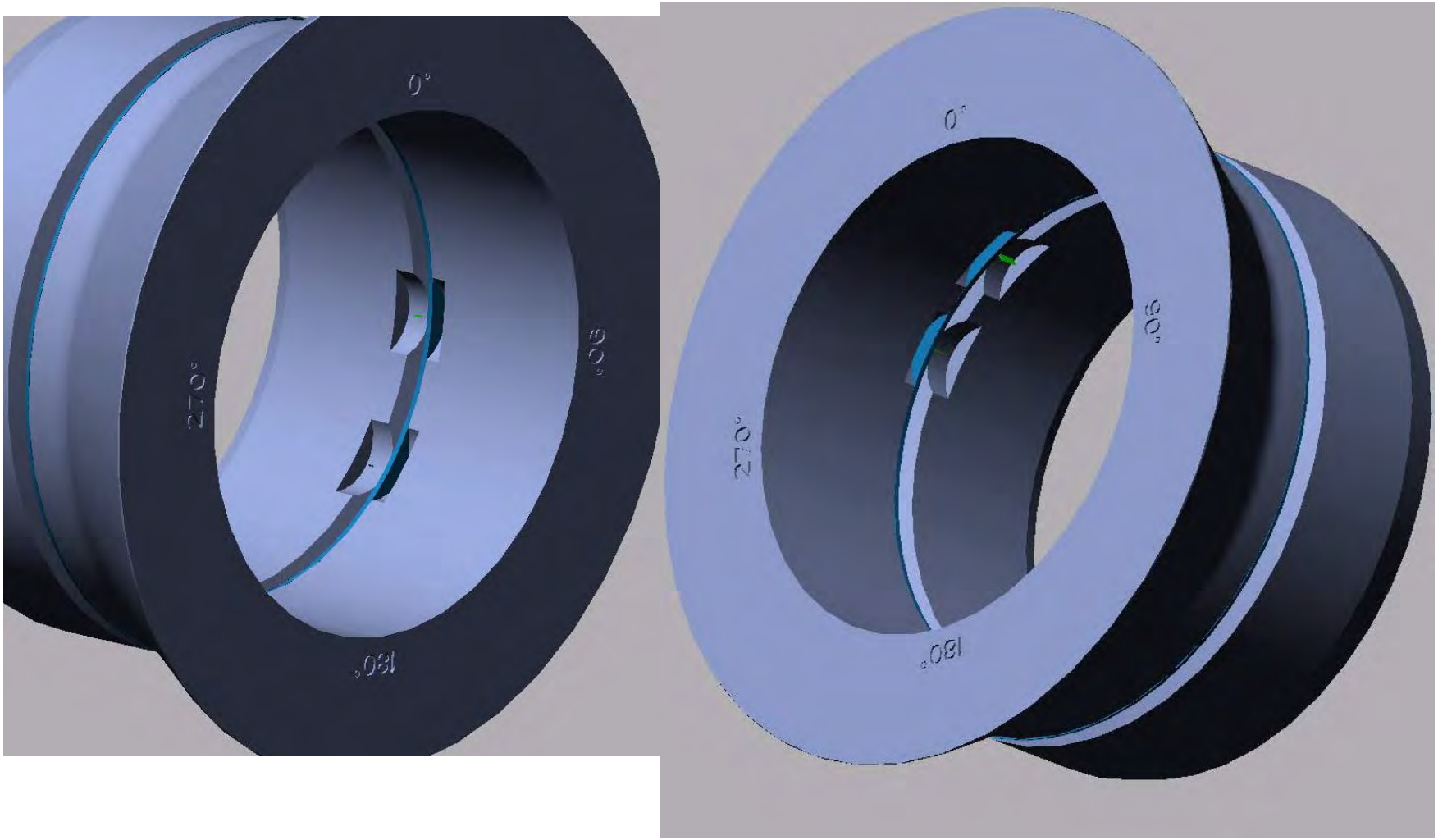
Removed boat/material samples



Metallographic examinations

- IDSCC in weld repaired Alloy 182 material
- significant branching of some cracks
- very tight crack tips and also tight crack parts connected to inner surfaces
- some hot cracking and small lack of fusion
- no IDSCC propagation into RPV CS and SS

Safety assessments based on the inspection results 2000

Ringhals 3:

Fracture mechanics calculations with SACC (a "R6-method") based on

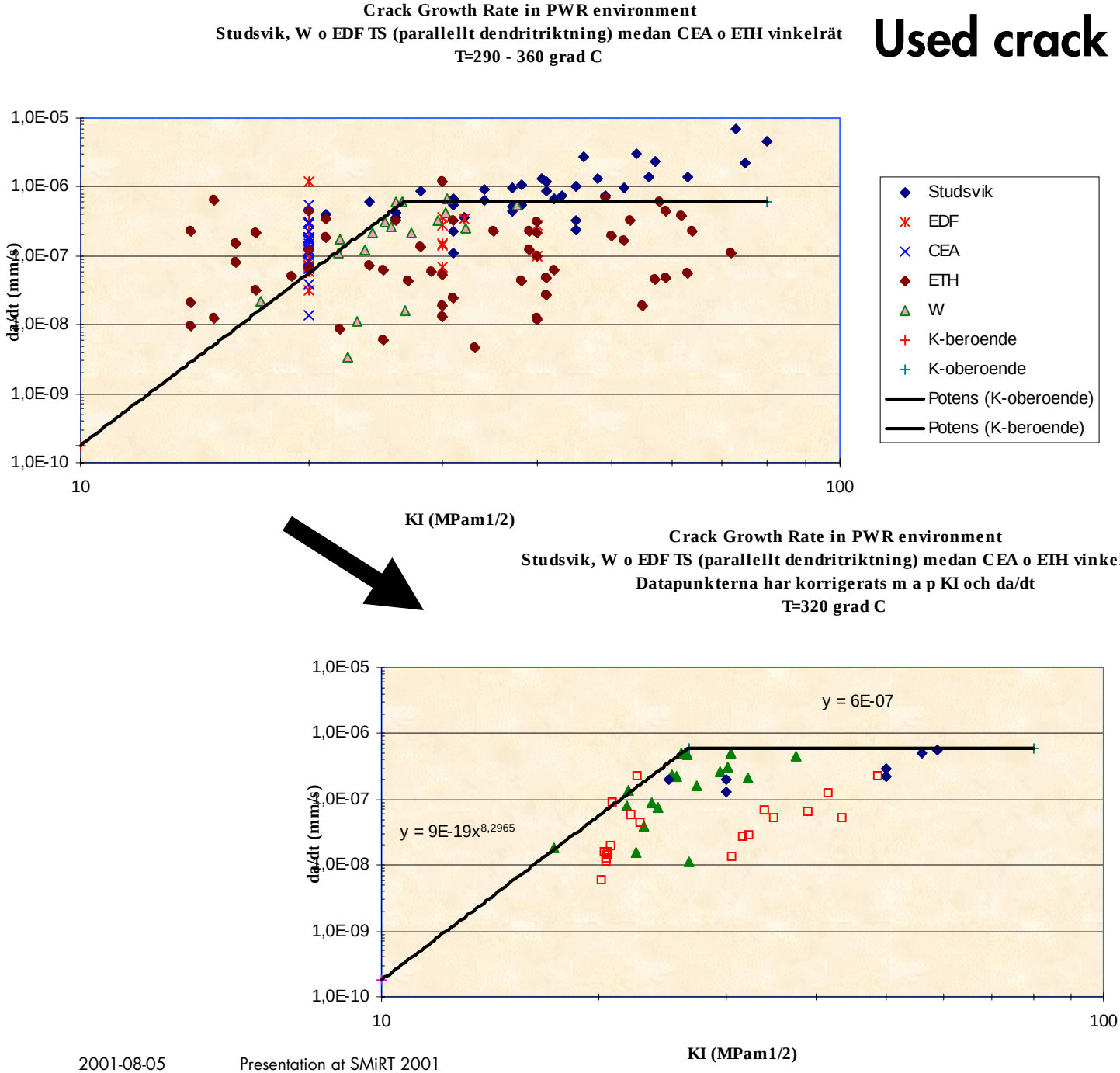
- assumed maximum size of a the cracks 9x29 mm
- material fracture toughness of 284 MPa√m
- IDSCC crack growth of da/dt=
  $9x10^{-19}$ $K_I^{8,3}$ mm/s for K_I< 26, 6 MPa√m
  $9x10^{-7}$ mm/s for K_I> 26, 6 MPa√m
- ⇨8000 h operation approved by SKI

Ringhals 4:

Fracture mechanics calculations with SACC based on

- assumed maximum size of a remaining crack 14,5x29 mm
- a postulated 1 mm deep crack in a boat sample cavity
- material fracture toughness of 284 MPa√m
- IDSCC crack growth of da/dt=
  $9x10^{-19}$ $K_I^{8,3}$ mm/s for K_I< 26, 6 MPa√m
  $9x10^{-7}$ mm/s for K_I> 26, 6 MPa√m
- ⇨ 8000 h operation approved by SKI

Used crack growth data



Follow up inspection 2001 in Ringhals 3

- All safe ends inspected
  - out and inlet nozzles
- Same UT part of the NDE system as was used 2000
  - for detection and characterisation plus sizing, but only for of defects <14 mm
- Improved and more sensitive ET part of the system

- Indications of crack growth plus new cracks

Nozzle/Defect position (circumferential position)	ISI 2000 (depthxlength)	ISI 2001 (depthxlength)
Outlet 265°/299°	9x13	13x18
Outlet 265°/323°	9x16	16x20
Outlet 25°/323°	-	8x8

- Indications of cracks removed by boat samples to
  - stop further growth
  - further NDE developments
  - metallographic examination

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Concerns

- Occurrence and behaviour of PWSCC in Alloy 182 →
  - Long incubation time followed by relatively fast growth?
  - Only transverse (axial) or also longitudinal (circumferential) cracks?
  - All Alloy 182 welds susceptible?
- Complex crack morphologies in complex inhomogeneous and anisotropic weld structures →
  - Difficult to inspect
  - Difficult to produce
    - crack simulations for NDE qualifications
    - reliable crack growth data

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R&D actions needed

- to get more understanding of the mechanism and root causes, and thereby
  - how to identify susceptible safety important components for ISI, replacements or other measures
- to get more reliable crack growth data
- to develop reliable NDE systems and how to demonstrate their performance

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