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Source Term Reduction via Water Chemistry

April 10th, 2014

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ENSI

Source term reduction (I)

Good planing of a **new nuclear power plant** can help to reduce the source term drastically:

- Optimised material selection (e.g. Co has to be avoided)
- Reducing the number of welds (hence the number of periodical inspections is reduced)
- Geometry of the components should be suitable for time efficient NDT (non destructive testing)

Source term reduction (II)

For **running nuclear power plants** the reduction of the source term is by far more complex compared to new NPPs.

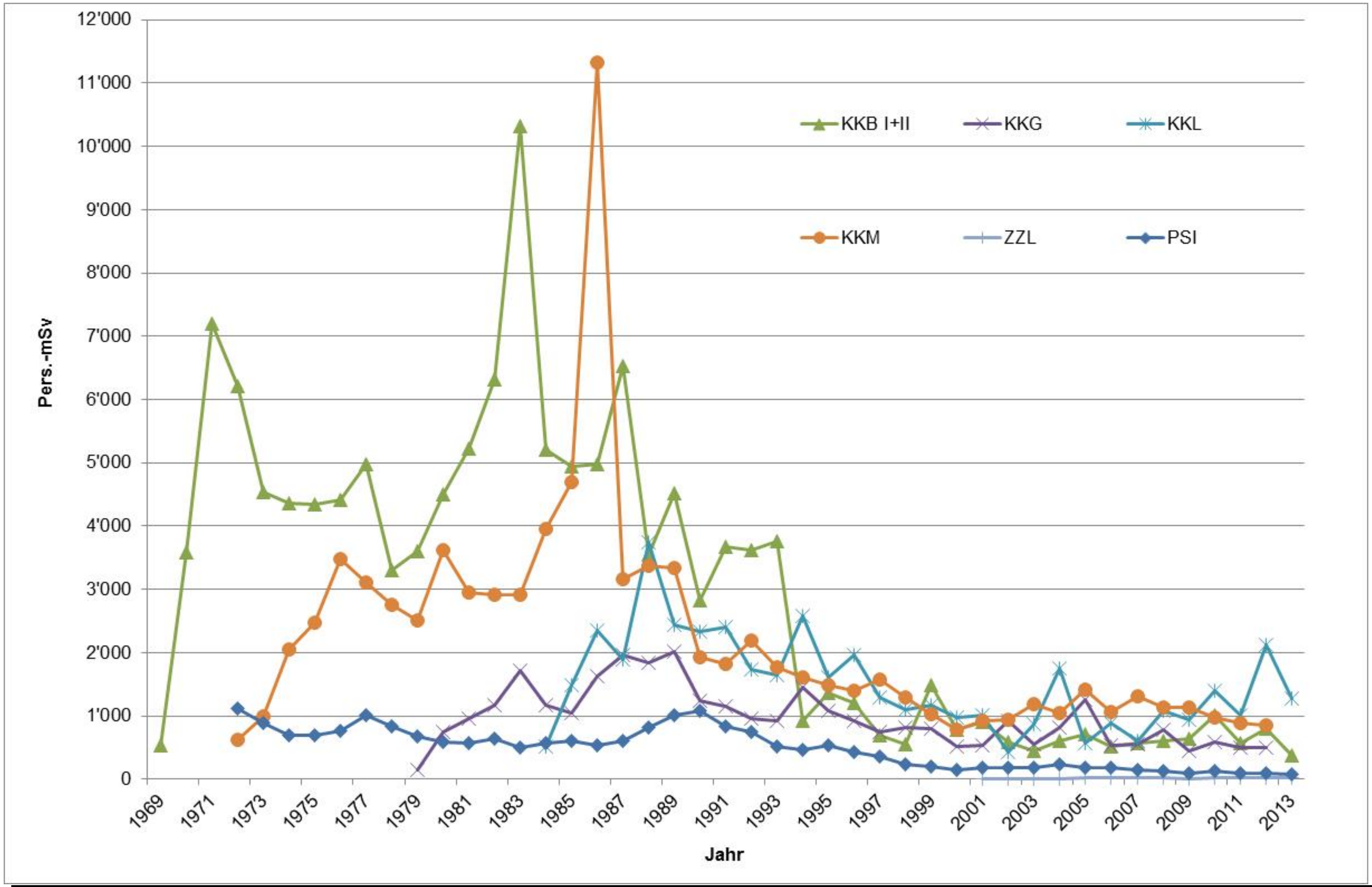
- Influence concerning material selection is impossible or at least little.
- The construction of the facility is finished and the geometry is given. Hence the NDT has to be performed partly under non-optimised conditions.

Source term reduction (III)

Although the reduction of the source term of **running nuclear power plants** is complex there are many possibilities to improve the situation for the personnel.

- Mock-up tests, improvement of shieldings, using Co-free or pure material when exchange of components is performed
- WATER CHEMISTRY
  - to mitigate corrosion effects
  - but also to reduce the dose rates in the NPPs

Annual collective doses for the personnel in Swiss NPPs, the Central Interim Storage Facility (ZZL) and the research institute PSI



Outline

Three examples to reduce the dose rate via water chemistry performed in Swiss NPPs including results and expectations

- Addition of DZO — Gösgen NPP
- Constant pH performance over the whole cycle — Beznau NPP
- Conditioning of the inner surface of the new circulation lines — Leibstadt NPP

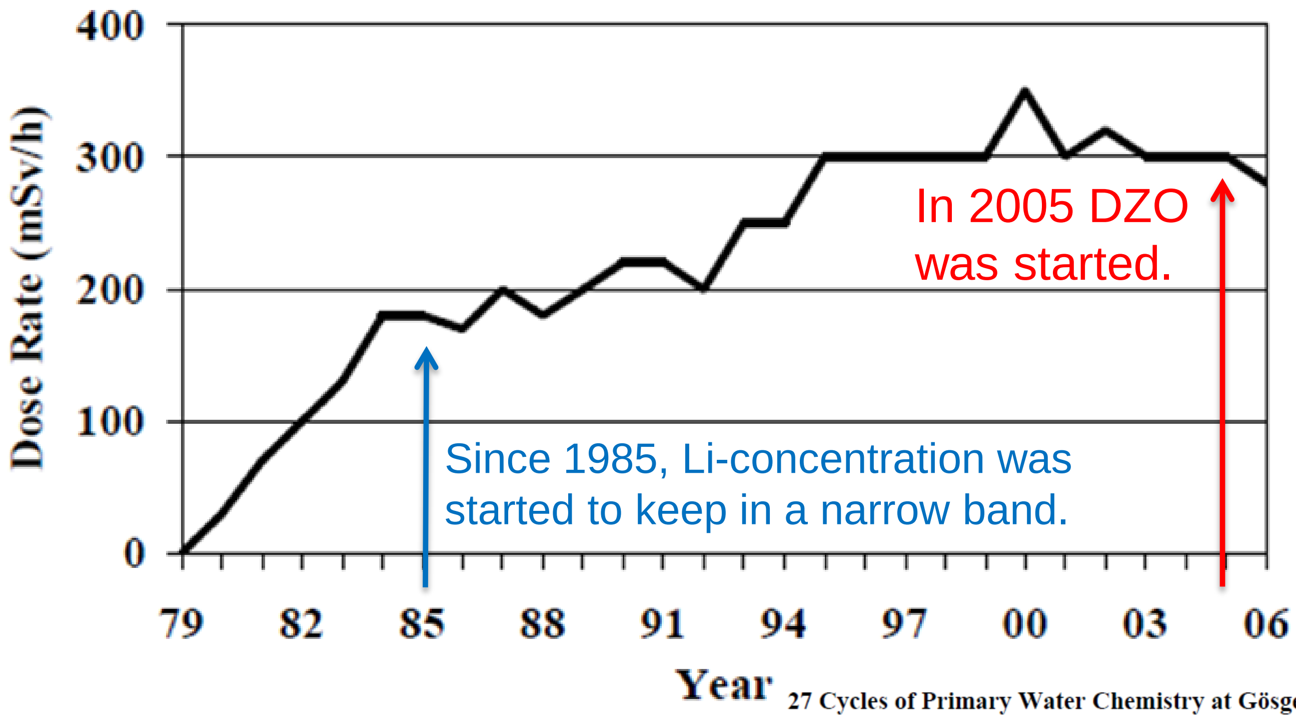
Gösgen NPP

PWR type (Siemens) 3-loop plant since 1979 in operation

in 2005 DZO injection started (high duty core index)

Dose rate build-up on the inner surface of the reactor vessel head

Main contributer to the dose rate is Co-60.
One measure was besides others to decrease the dose rate:
➡ The cobalt content of the spacer grids was reduced

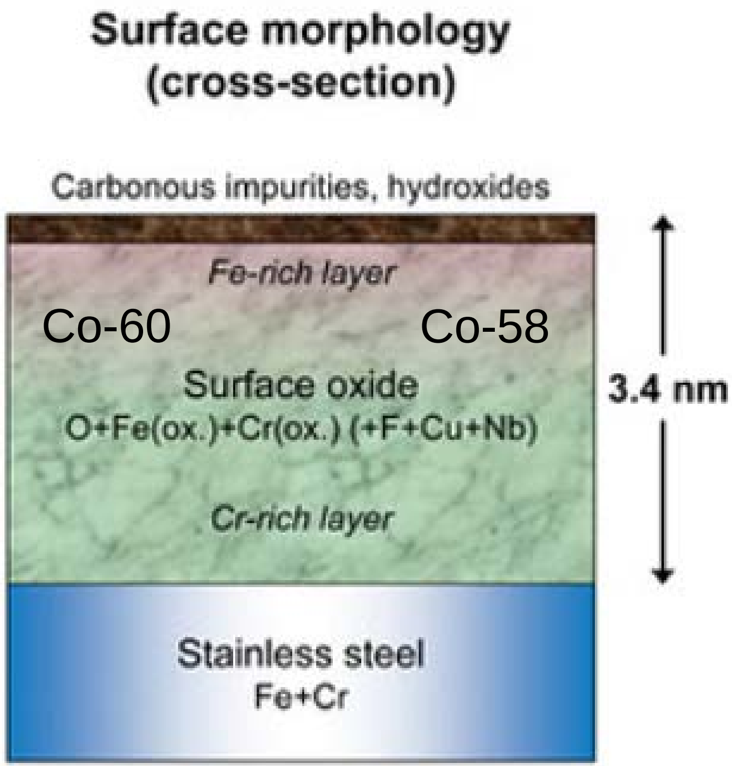


27 Cycles of Primary Water Chemistry at Gösgen Nuclear Power Plant
Rich et al. NPC Korea 2006

Addition of DZO to primary water circuit

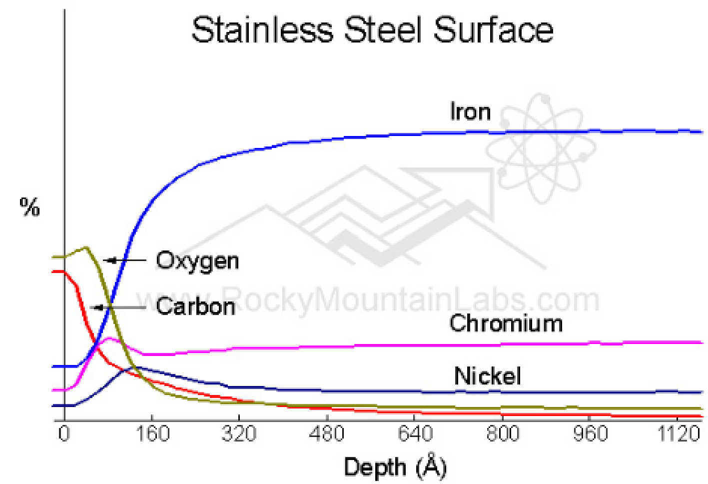
↳Dose rate reduction

WHY?

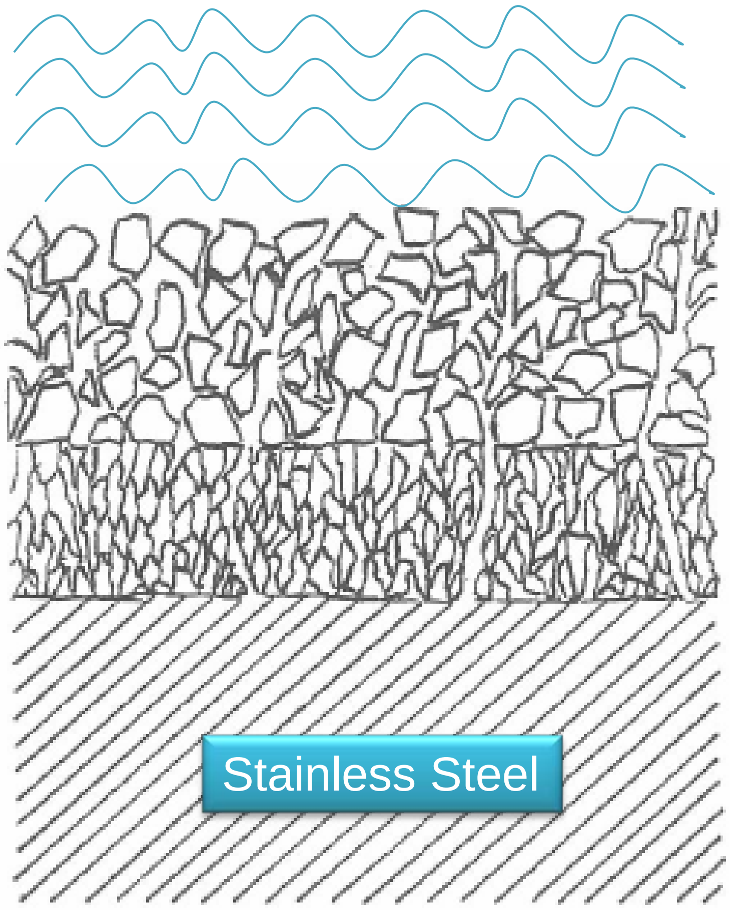


Bi-oxide layer

- Outer layer: Fe-rich, porous
- Inner layer: Cr-rich, very dense



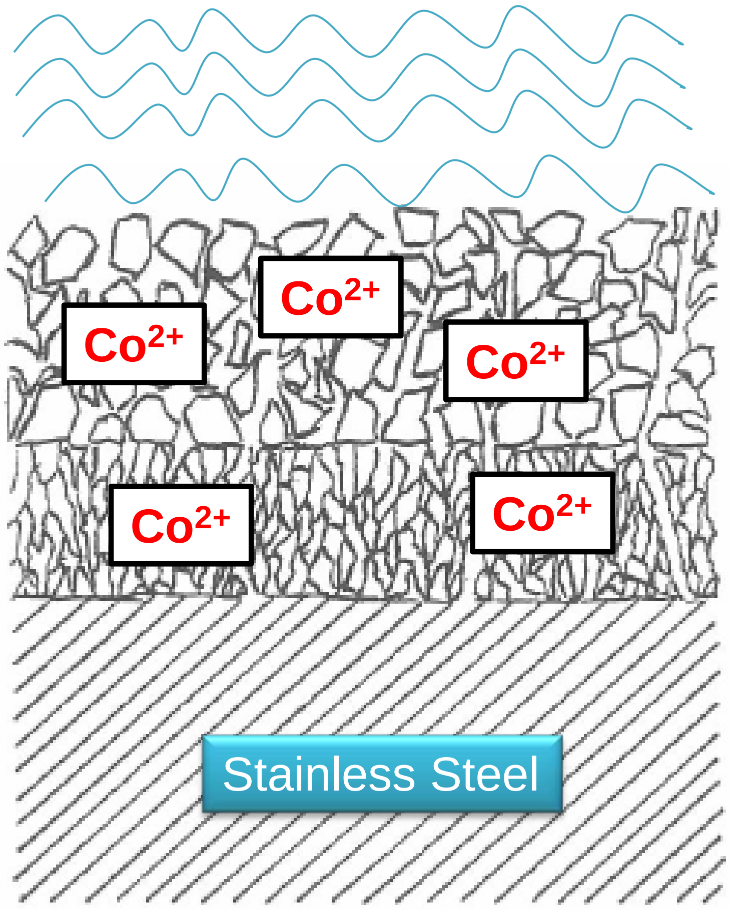
Addition of DZO to primary water circuit



Iron rich layer (porous)
$FeFe_2O_4$
$MnFe_2O_4$

Chromium rich layer (dense)
$FeCr_2O_4$

Addition of DZO to primary water circuit



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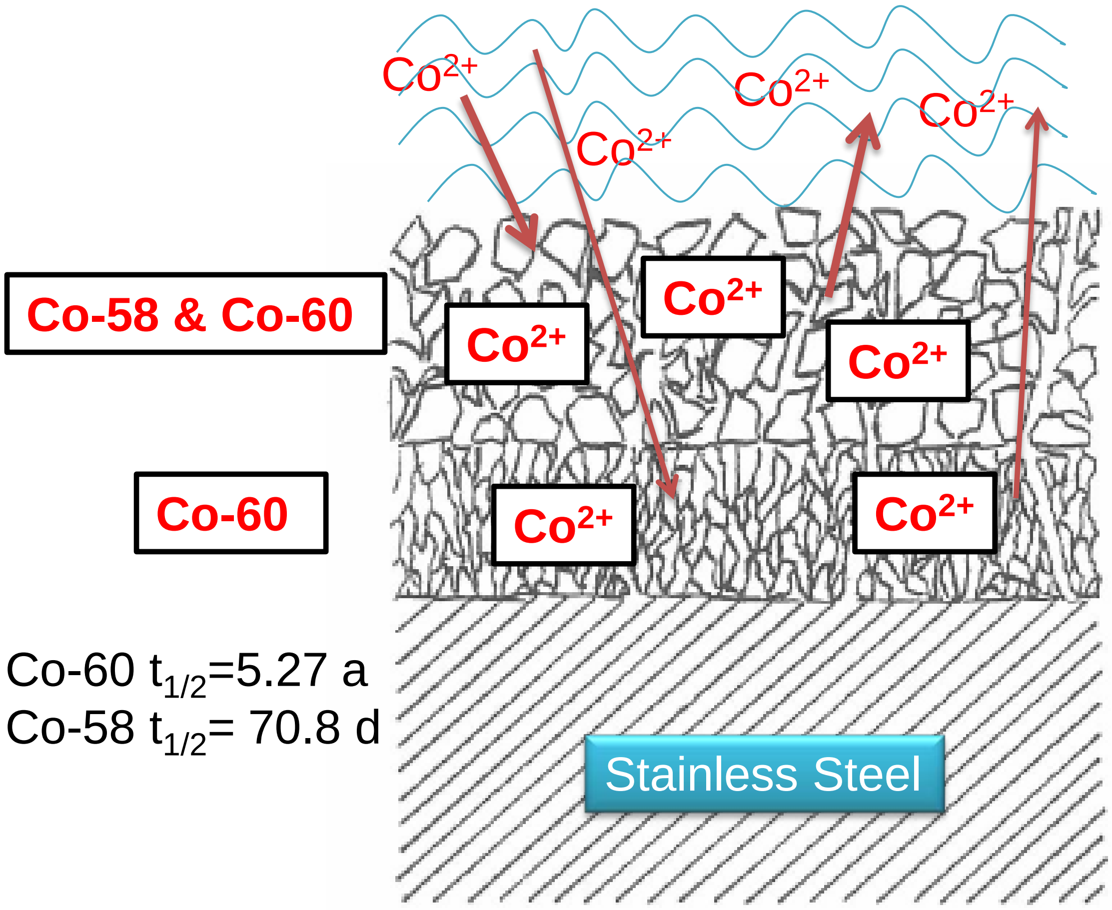
Co-60 $t_{1/2}$=5.27 a
Co-58 $t_{1/2}$= 70.8 d

Addition of DZO to primary water circuit



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Addition of DZO to primary water circuit

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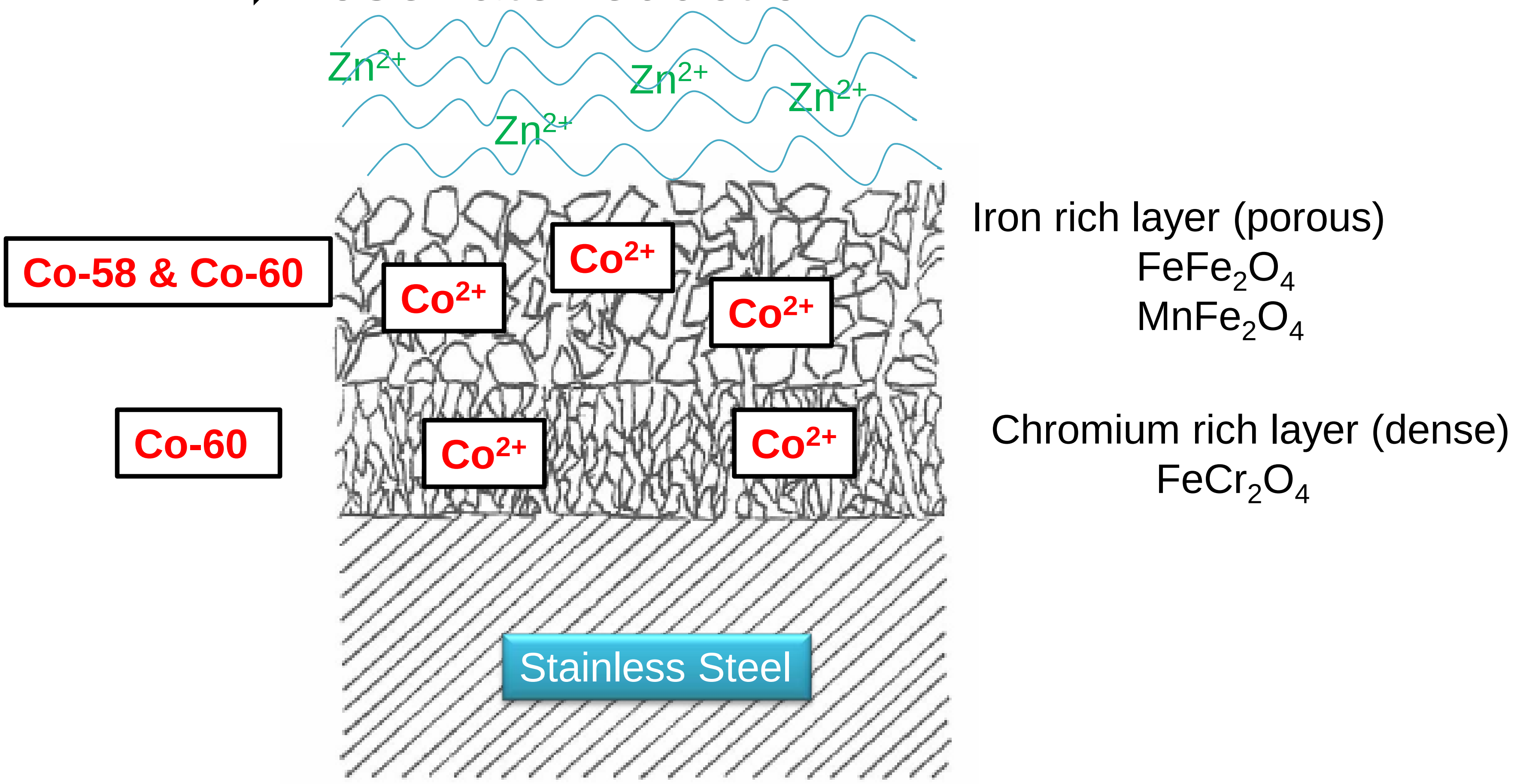

Addition of DZO to primary water circuit

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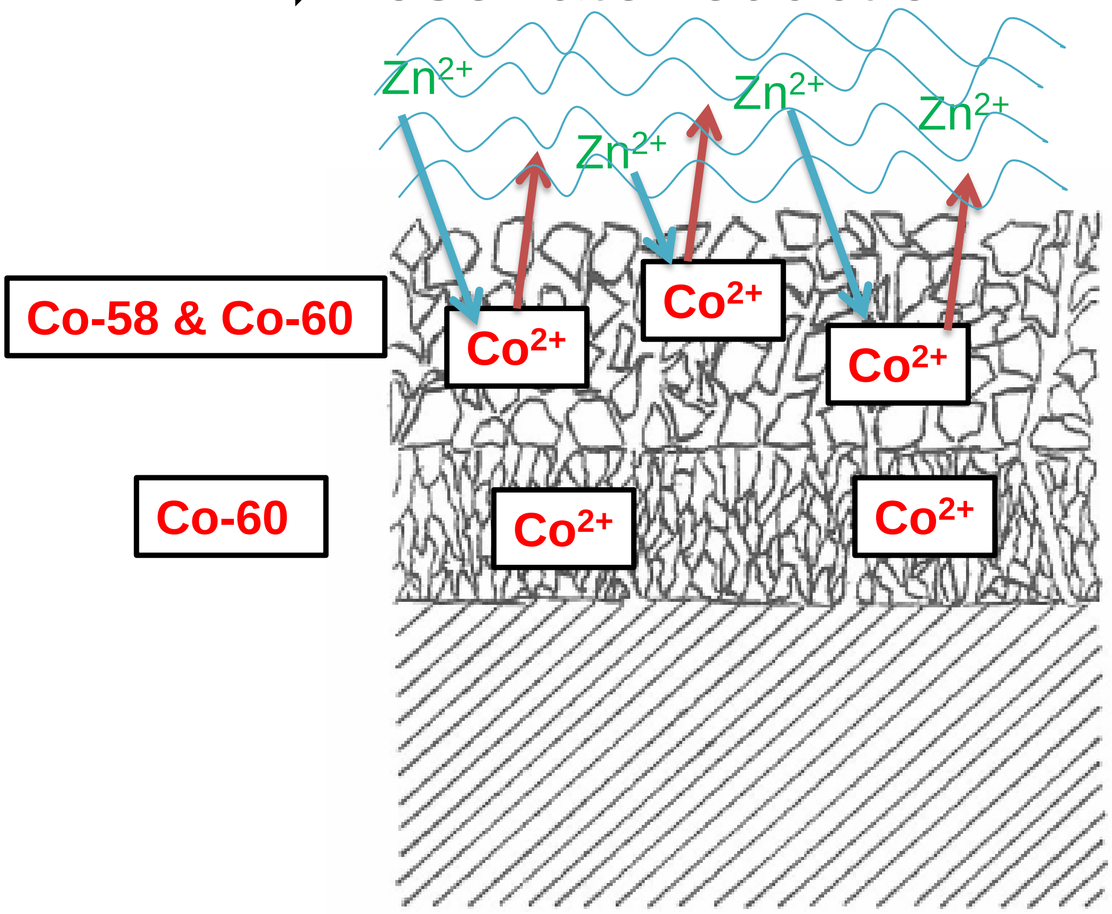
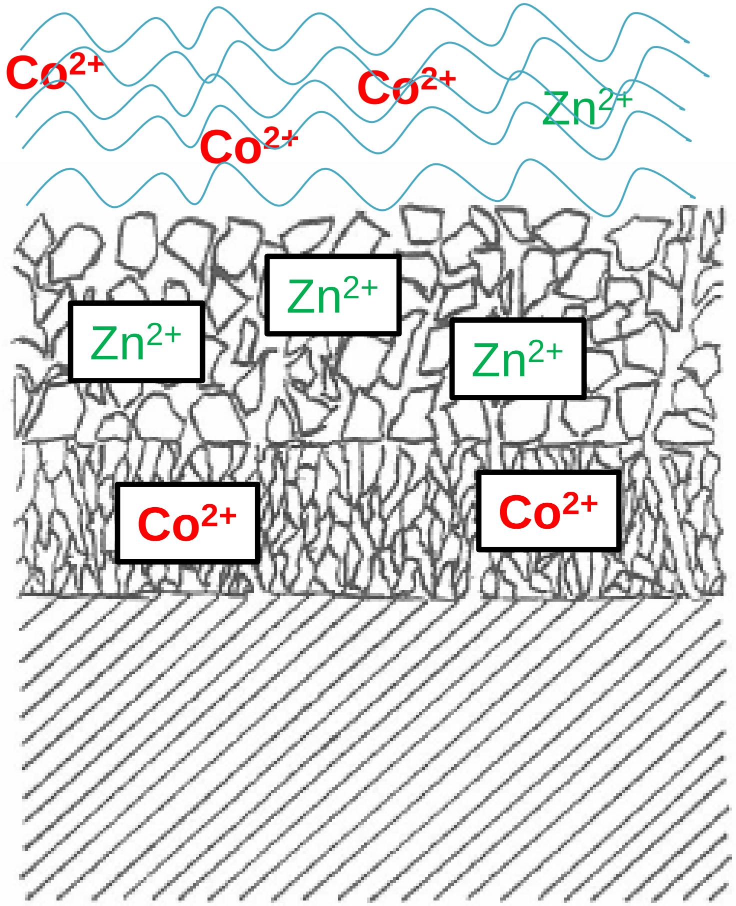


Zn builds most stable spinels. The SPE (Site Preference Energy) of Zn for tetrahedral sites is much higher than that of other divalent metal ions like Fe^{2+}, Ni^{2+} or Co^{2+}

Partial replacement of the Co-isotopes with Zn in the outer layer occurs !!!!!

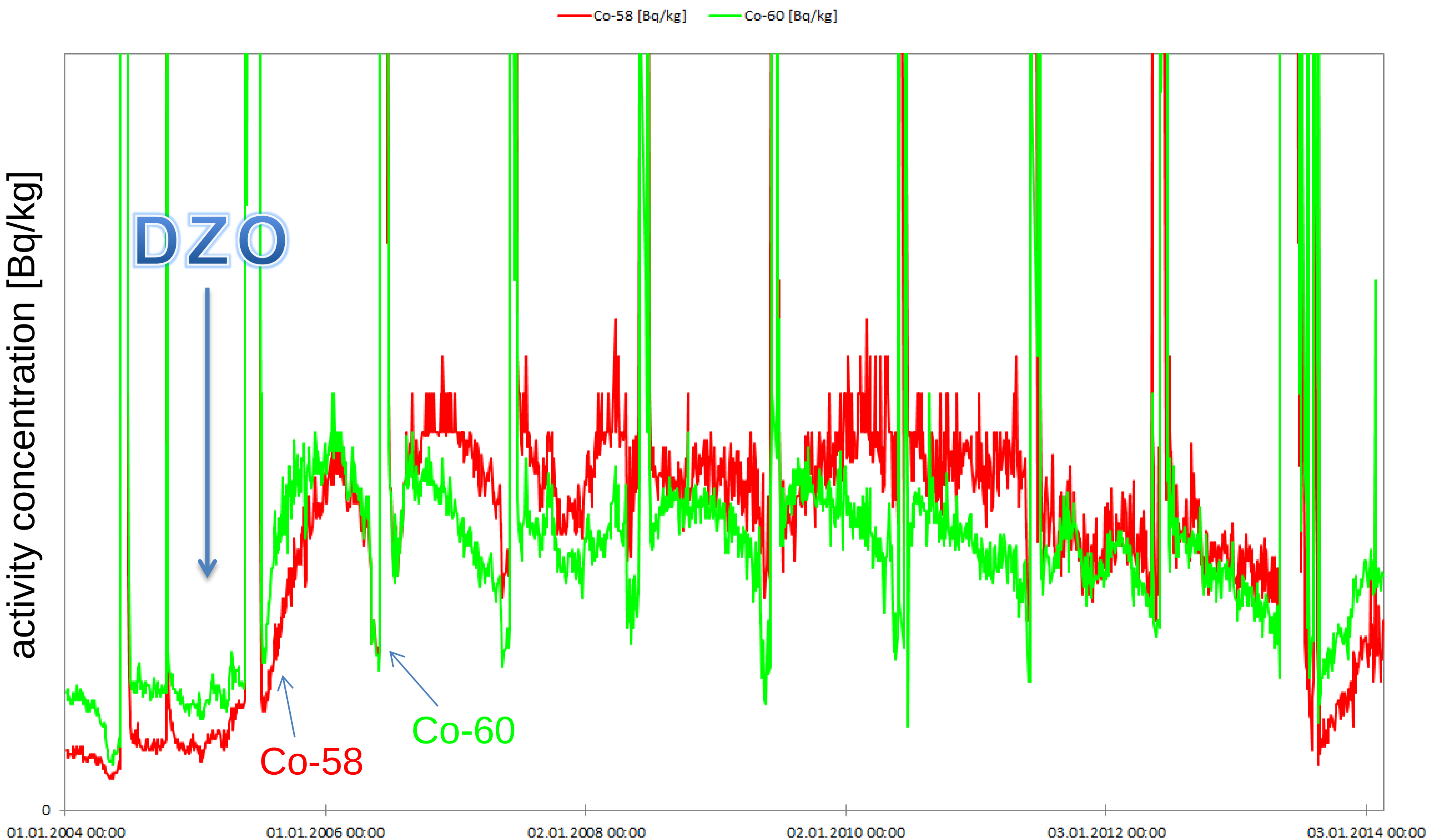
Addition of DZO to primary water circuit

↳Dose rate reduction



Increase of Co-58 and Co-60 in the primary water coolant is expected when the addition of DZO (depleted zinc oxide) is started!

Co-58 and Co-60 in the primary water via time



Technical Details

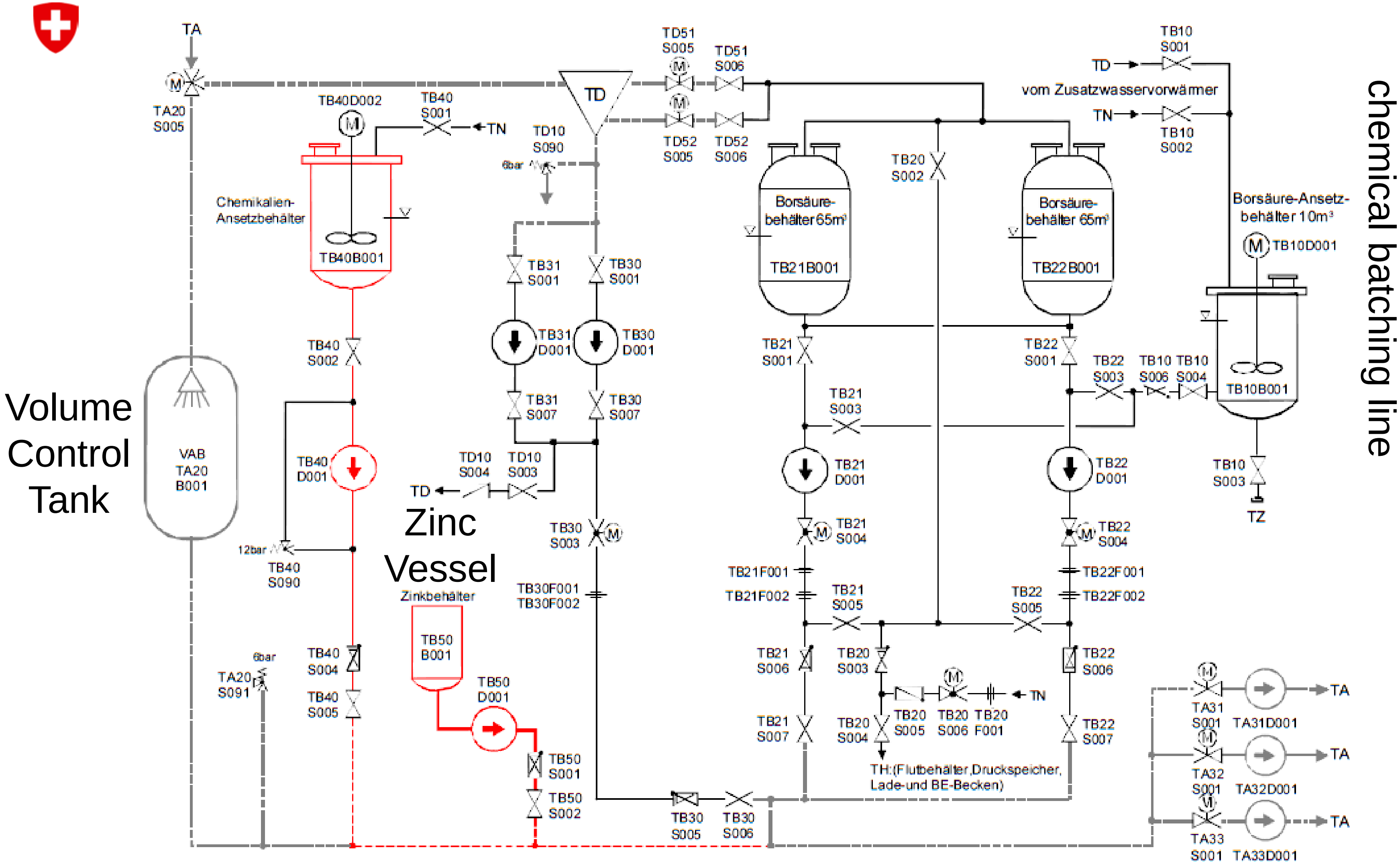
DZO + CH_3COOH + H_2O

↓

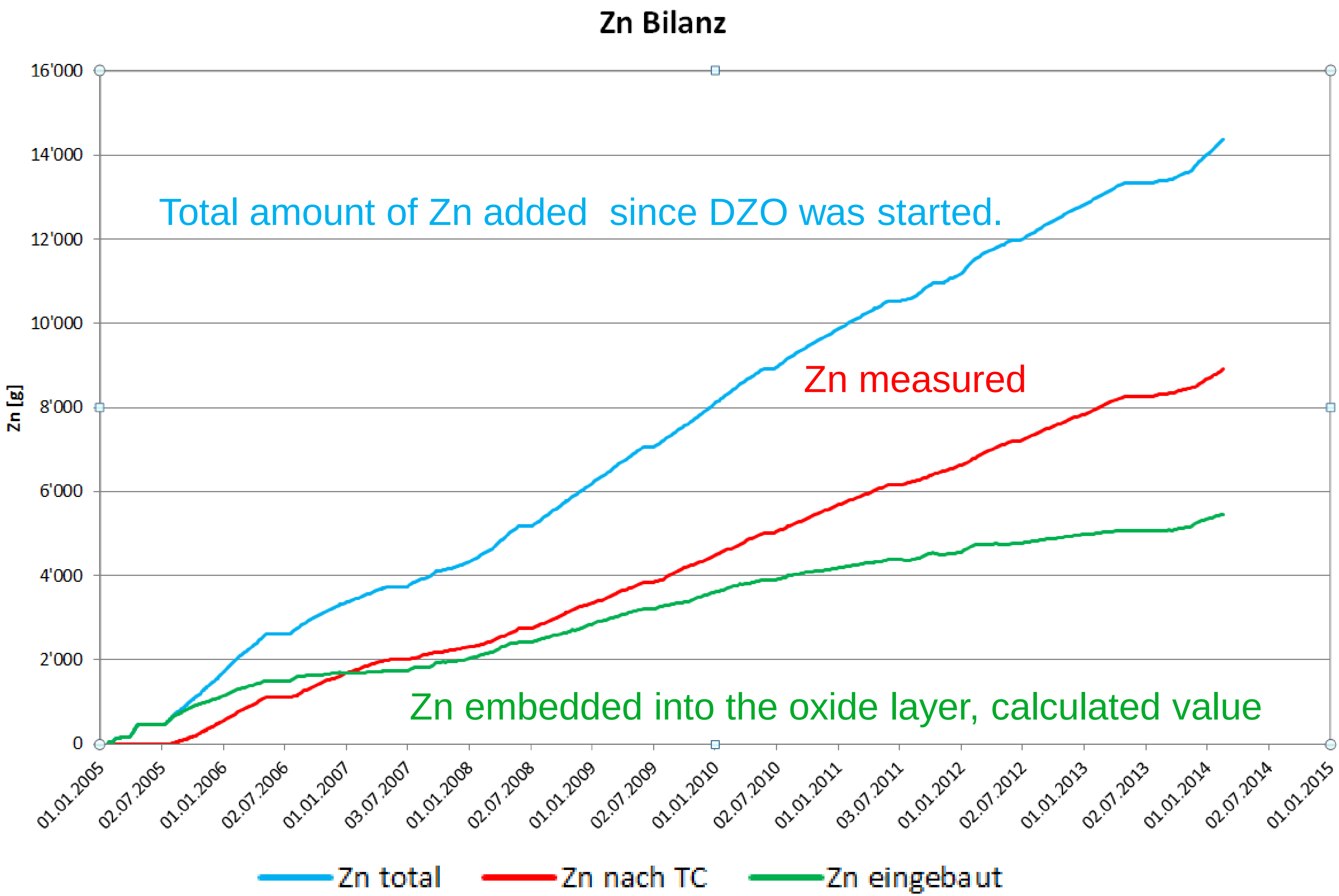
Zinc acetate

- in total up to 4 g/d zinc are added!

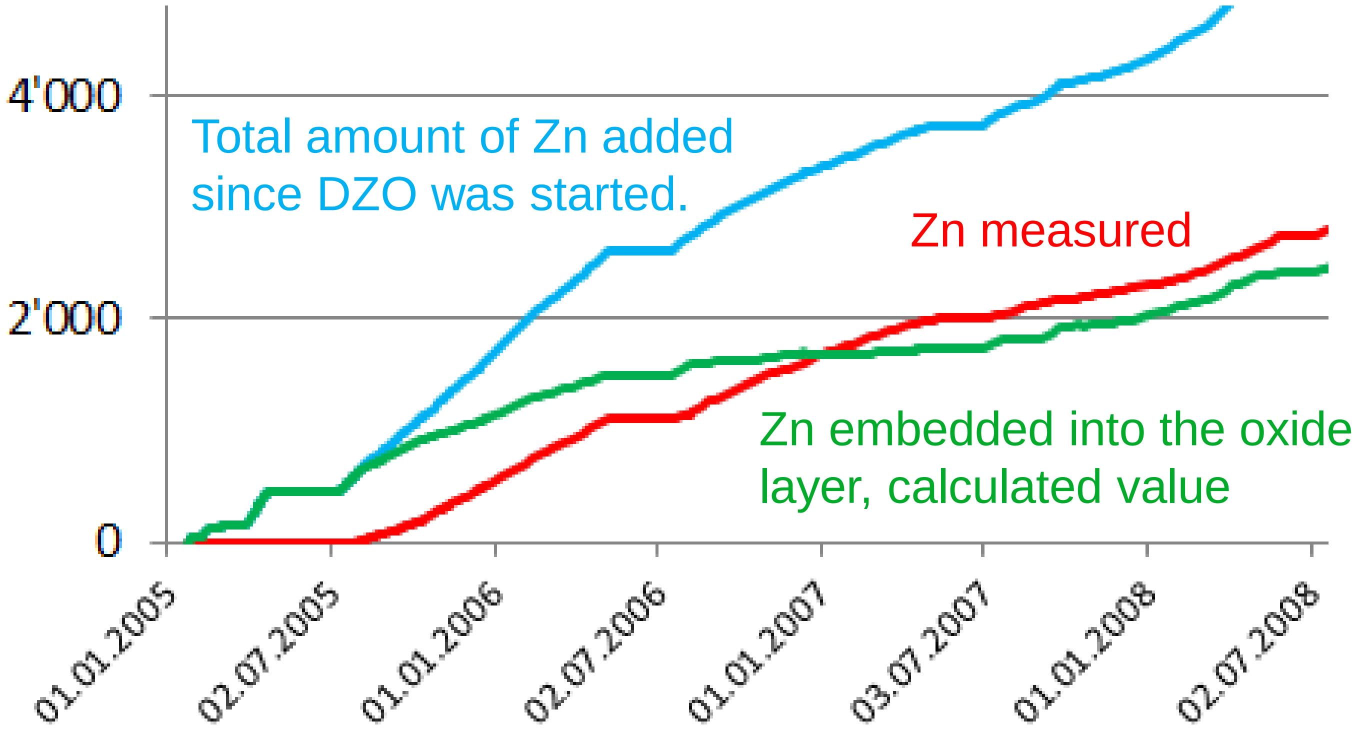
- concentration of about 5 µg/kg Zn (= 5 ppb) in the primary water are requested (EPRI)!



Zinc injection into the primary water circuit

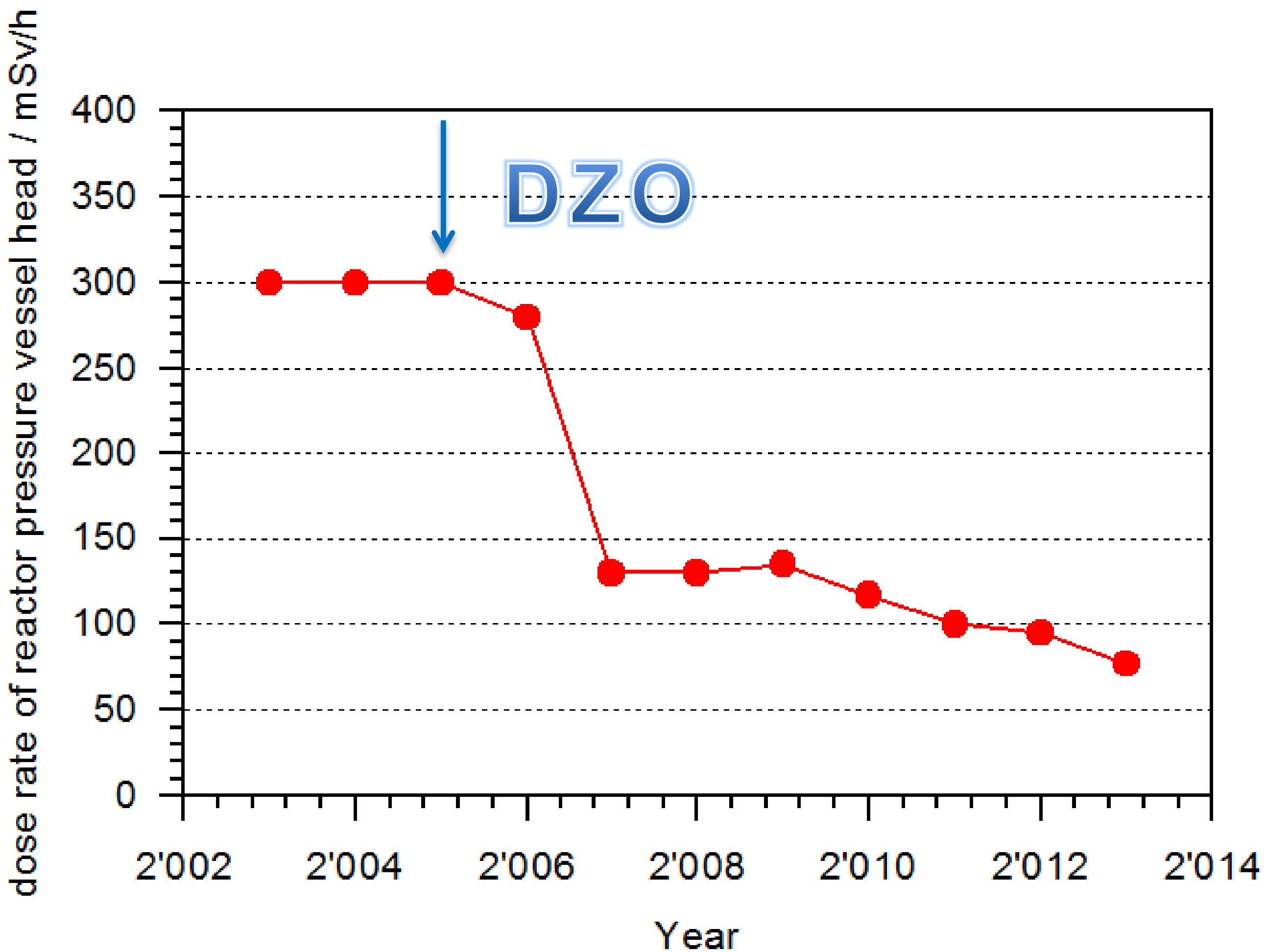

Zn Bilanz
16'000
14'000
12'000
10'000
8'000
6'000
4'000
2'000
0
Zn [g]
Total amount of Zn added since DZO was started.
Zn measured
Zn embedded into the oxide layer, calculated value
01.01.2005
02.07.2005
01.01.2006
02.07.2006
01.01.2007
03.07.2007
01.01.2008
02.07.2008
01.01.2009
02.07.2009
01.01.2010
02.07.2010
01.01.2011
03.07.2011
01.01.2012
02.07.2012
01.01.2013
02.07.2013
01.01.2014
02.07.2014
01.01.2015
Zn total
Zn nach TC
Zn eingebaut

Zinc balance during the first years

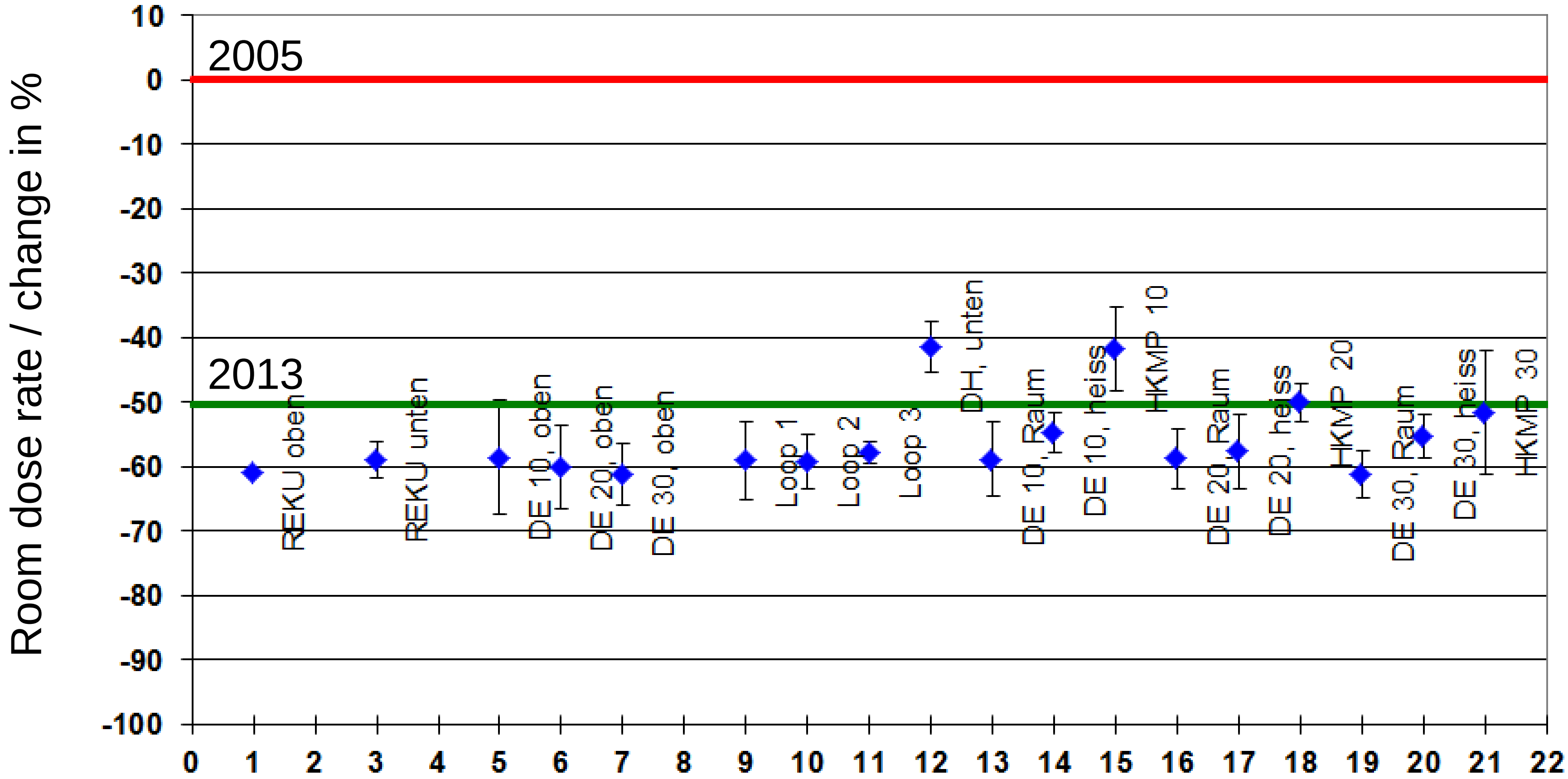


- There was no Zn in the primary water detectable in the beginning of DZO operation mode
- All added Zn was embedded into the oxide layer

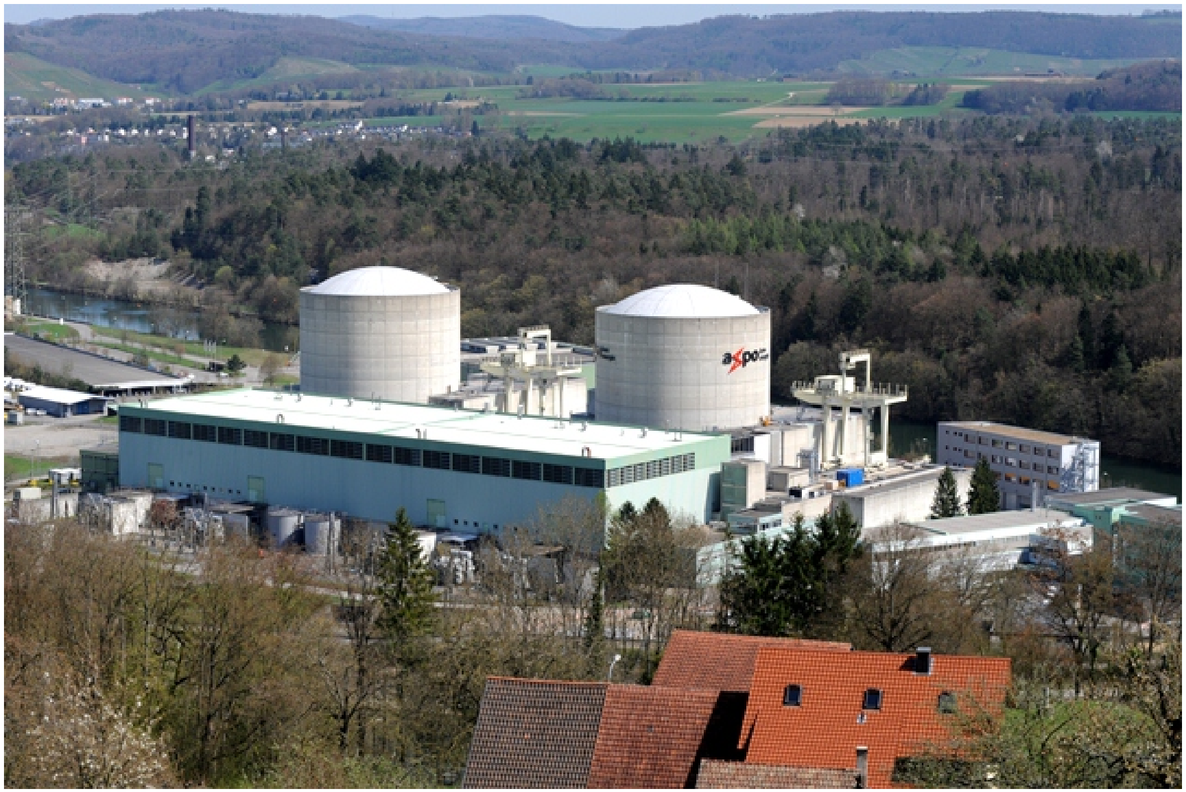
Dose rate of the reactor vessel head



Comparison of the dose rates 2005 and 2013: a reduction of 55,9 % has occured



Beznau NPP1 and NPP2



PWR type

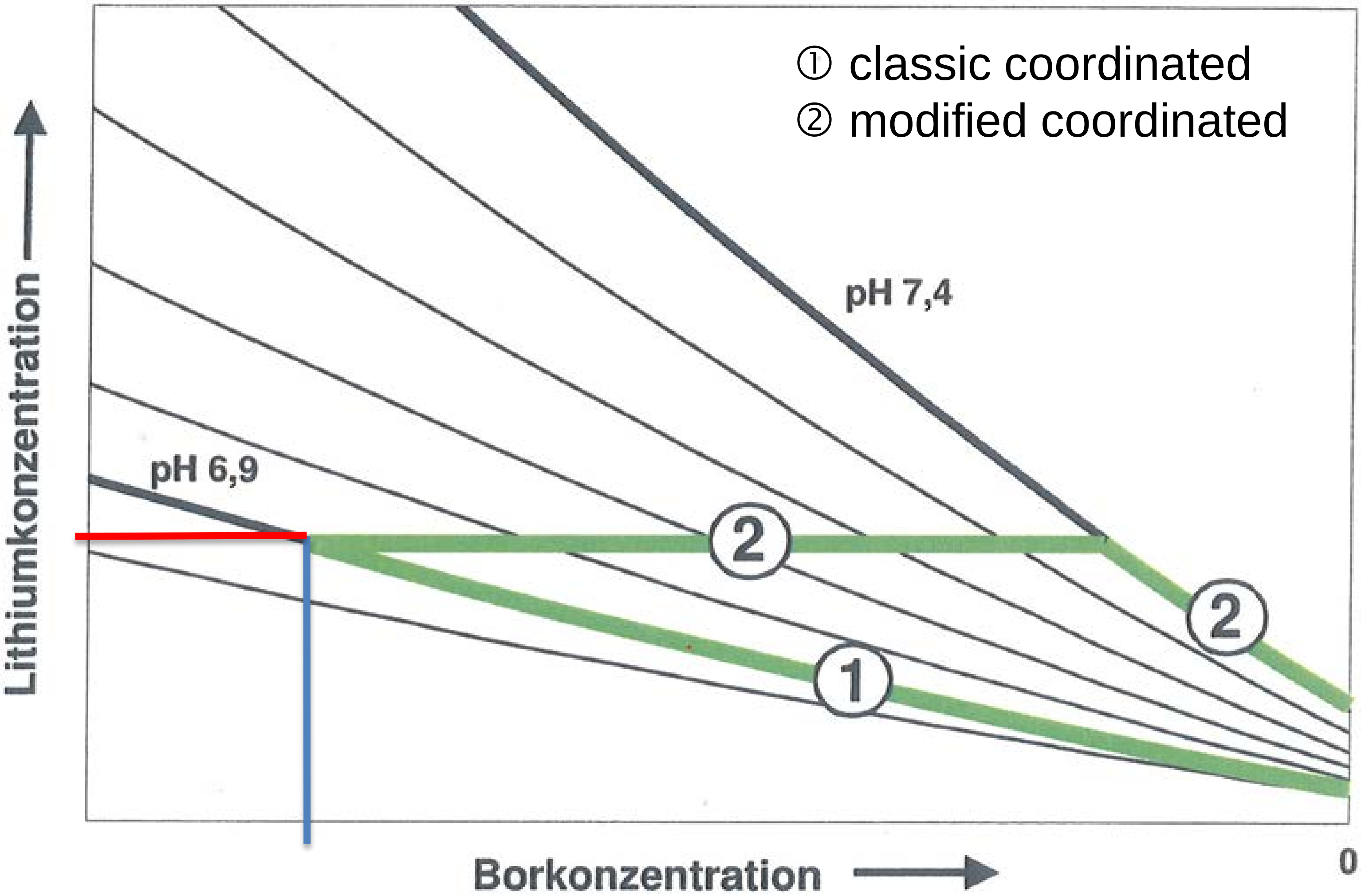
(Westinghouse)

2-loop plant

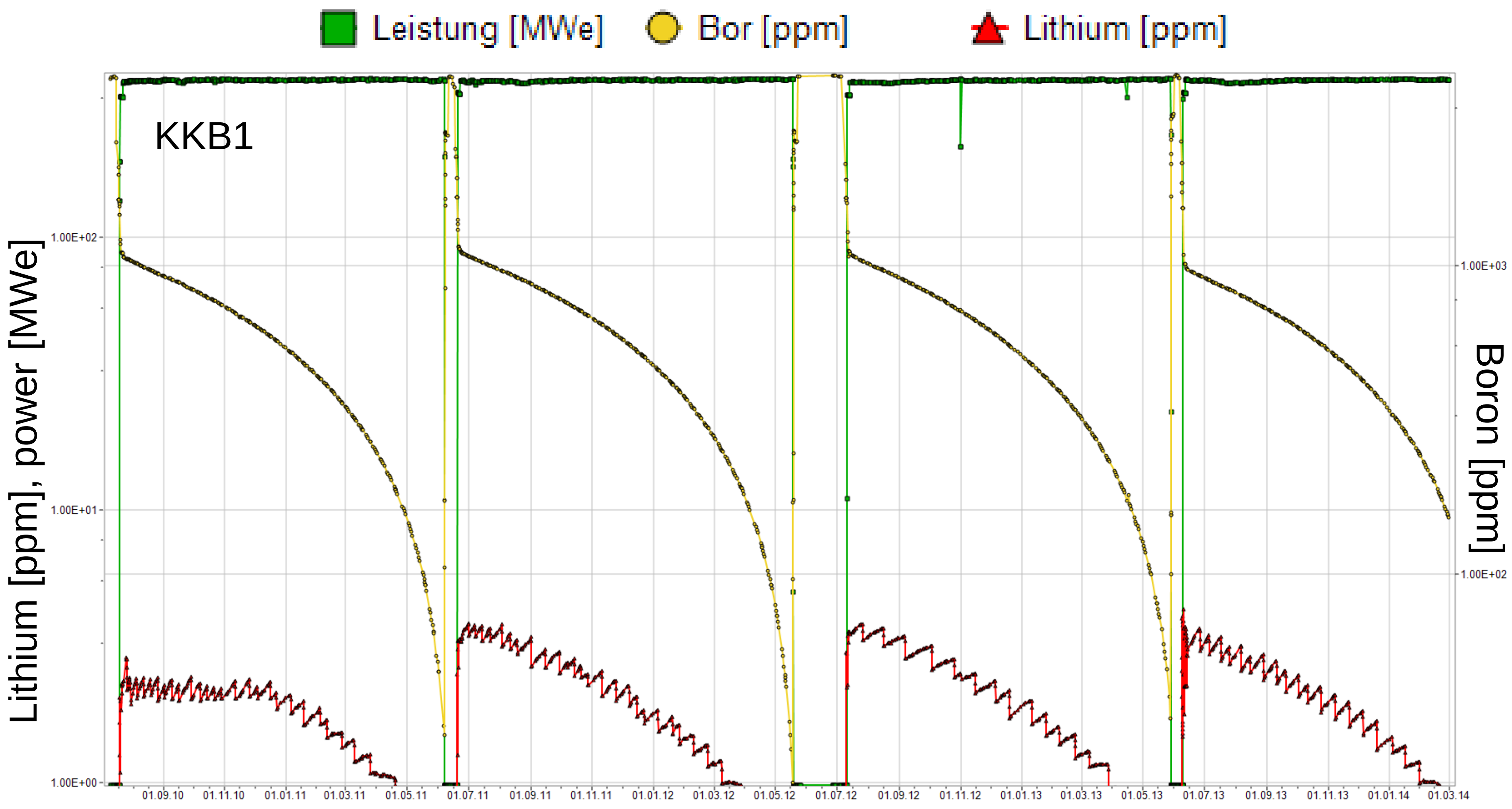
KKB1 since 1969 in operation

KKB2 since 1971 in operation

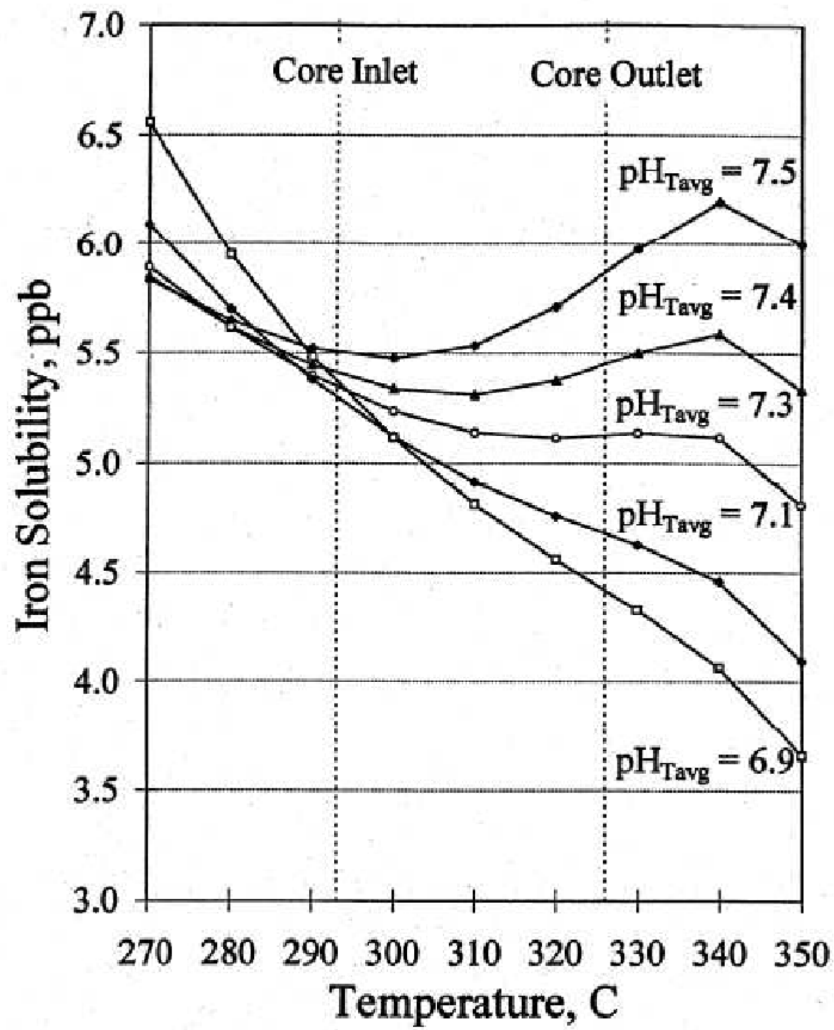
Operation modes of B-Li



Trend of Li and B within a cycle



Solubility of iron of nickel ferrite

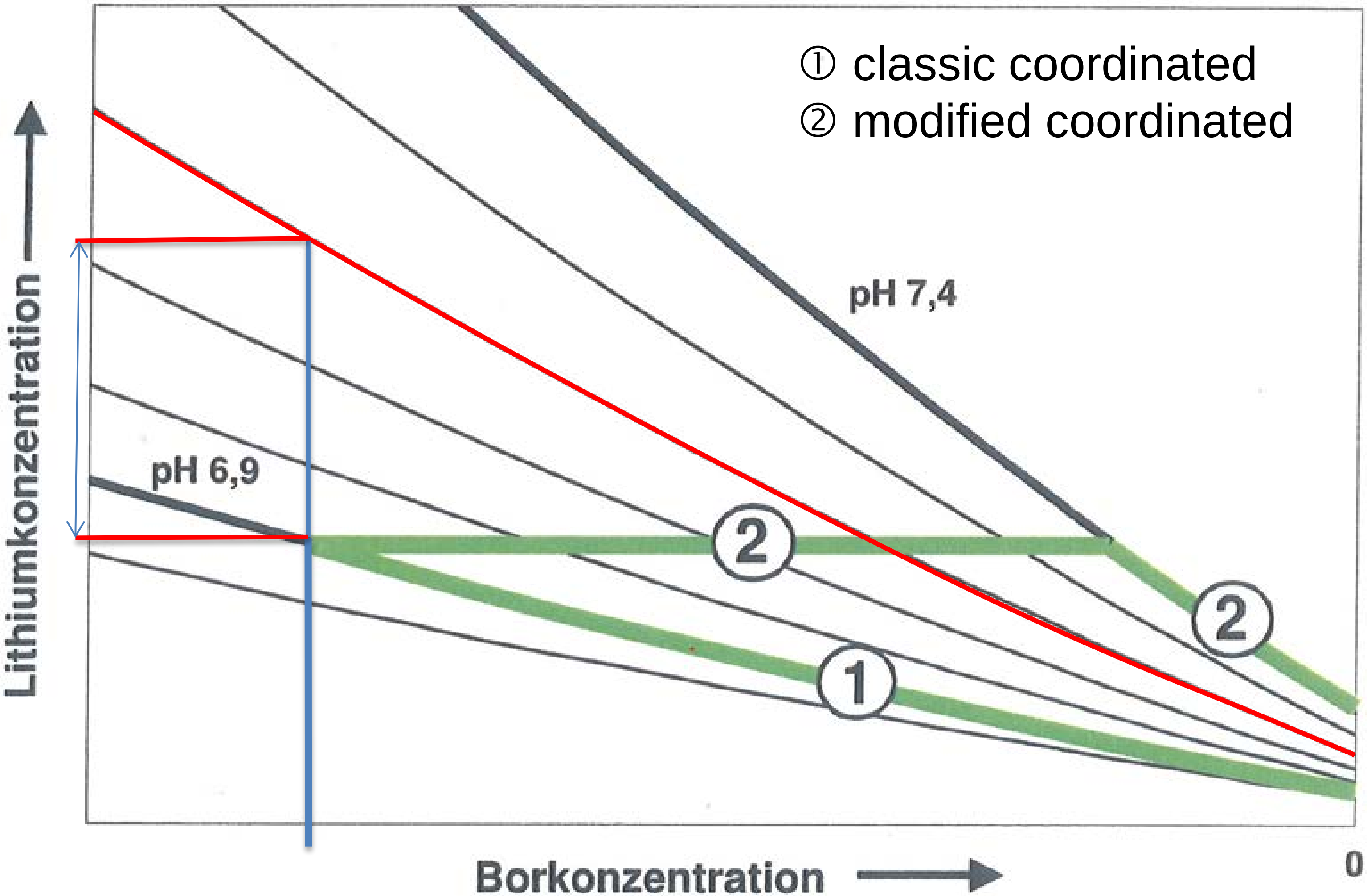


M. Bolz et al.
VGB Chemie im Kraftwerk 2012

Composition and solubility of an oxide layer on the structural material is dependend on T and pH.

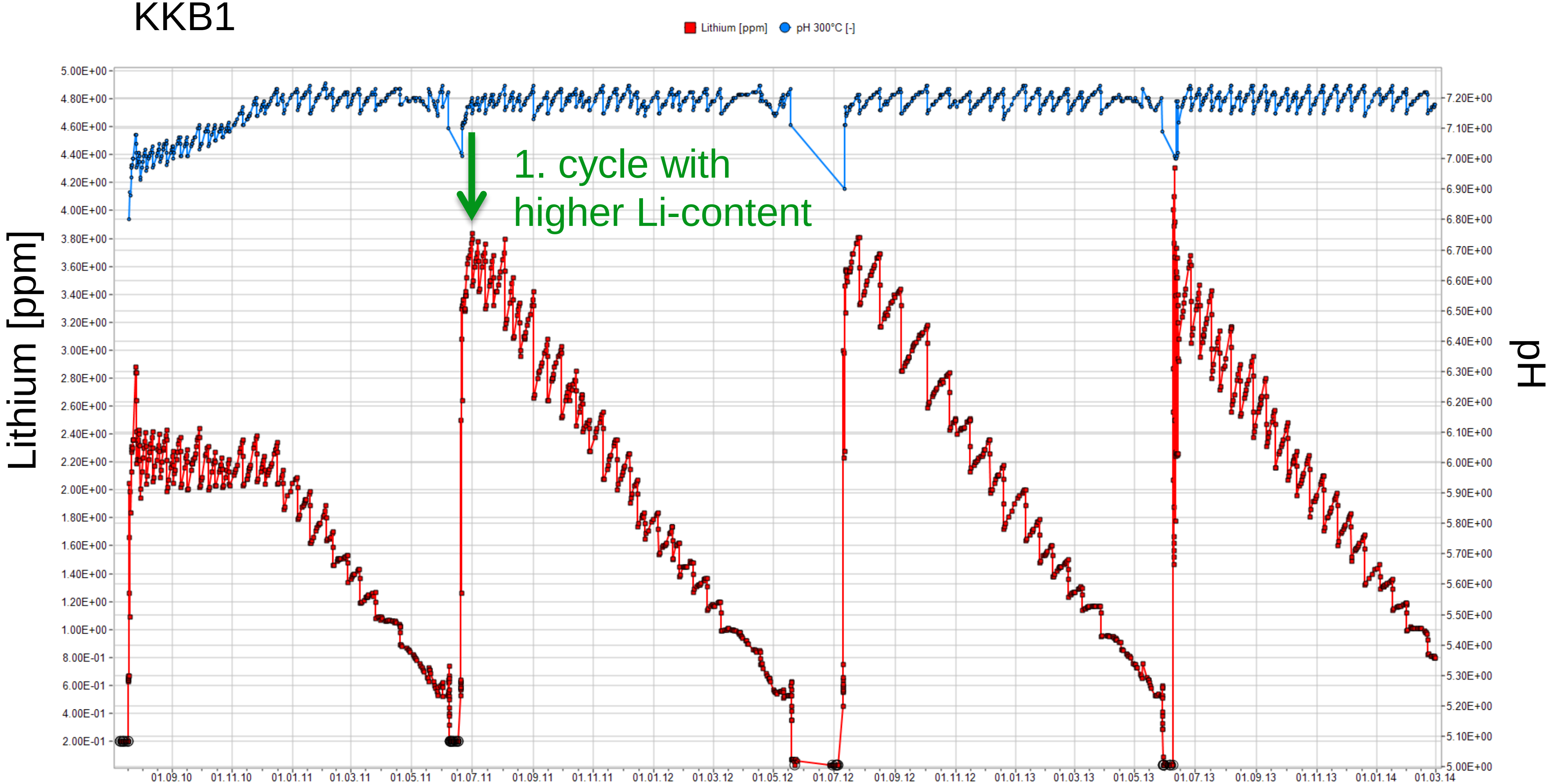
- A stable environment (T, pH = const.) reveals no changes on the structure of the oxide layer.
- Corrosion effects have to be mitigated mainly by avoiding environmental changes.

Operation mode



Influence of Lithium-content on pH

KKB1



Leibstadt NPP

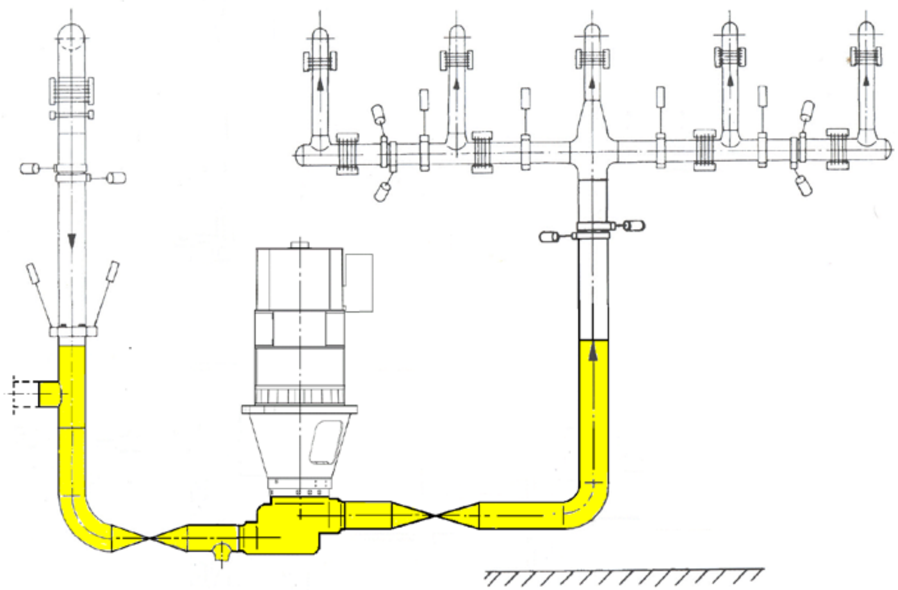
BWR/6 type
(General Electric)
since 1984
in operation

YUMOD

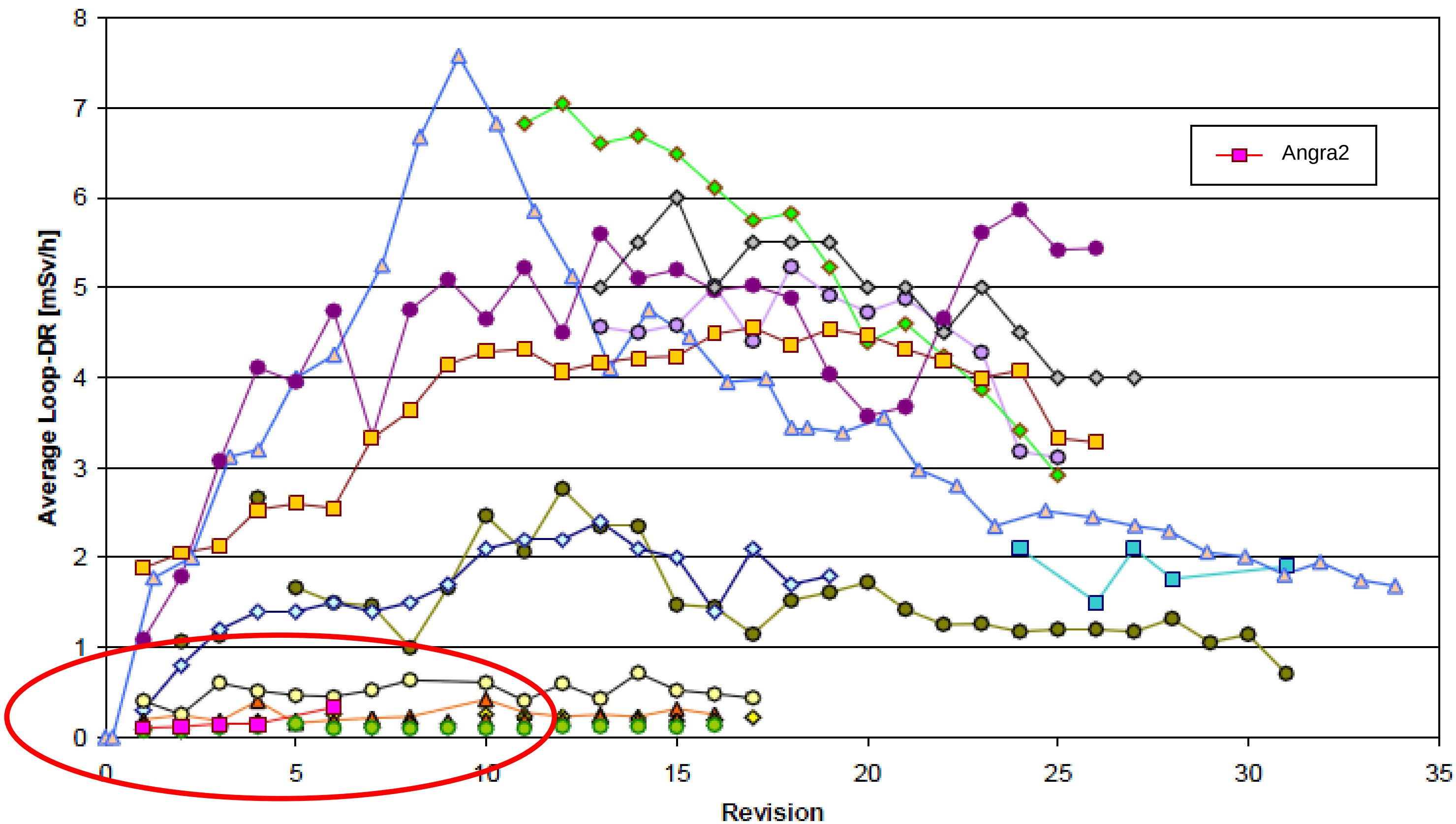
It is well known, that a special surface treatment can have a positive influence for the operation concerning corrosion and dose rate build up in the primary circuit.

Best examples are Angra-2 (Brazil) and Tomari-3 (Japan)

Exchange of the recirculation line



Average loop dose rate of Siemens PWRs



Angra 2 dose rates are at least three times lower than that of sister plants with similar stellite inventory

B. Stellwag et al.

International Symposium on Water Chemistry and Corrosion in Nuclear Power Plants in Asia 2009, Nagoya, Japan 28. – 30. Oct. 2009

Conclusion

The selection of suitable water chemistry parameters can reduce the dose rate in NPPs and mitigate the corrosion effects.

The changes have to be individually adapted to each NPP.

One has to keep in mind that it could take some time until a dose rate reduction is visible.

Acknowledgement

H. W. Rich KKG

KKB

KKL

Thank you

for your

attention

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