Source Term Control by Optimized RHR Operations

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1. Radiological Situation
2. Soft Shutdown and RHR Operation in RFO 2014
3. Lessons Learned
4. Conclusions

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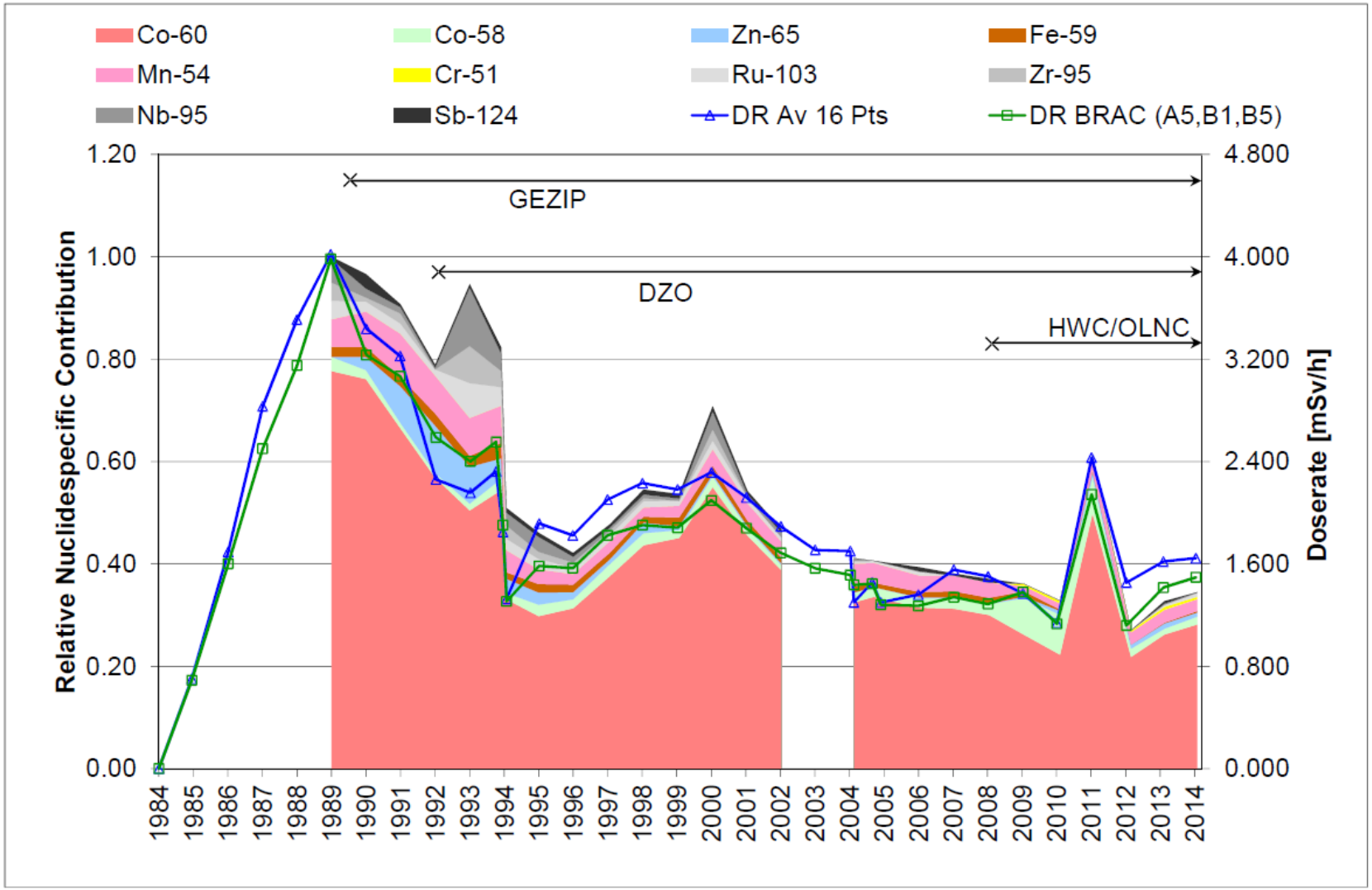
Dose Rates at RECIRC-Loops «BRAC»: no concern



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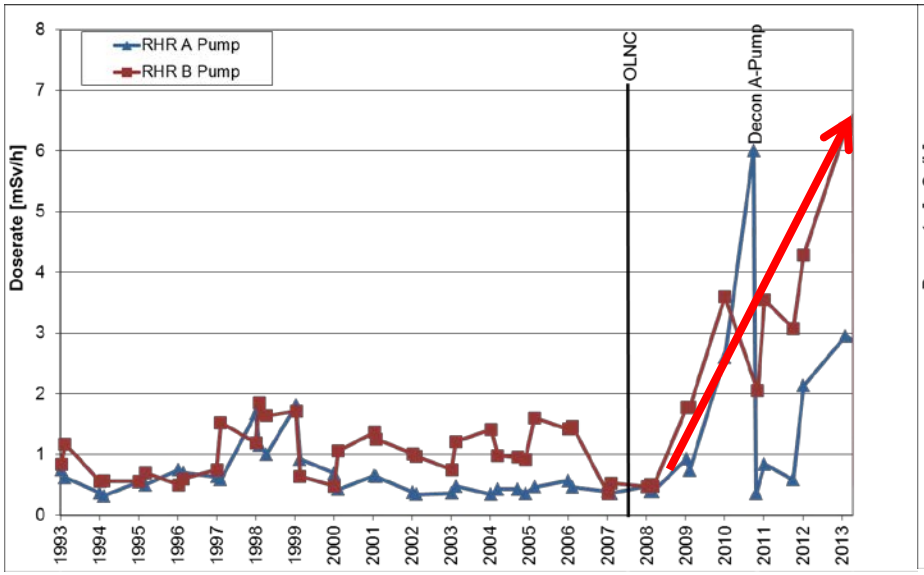
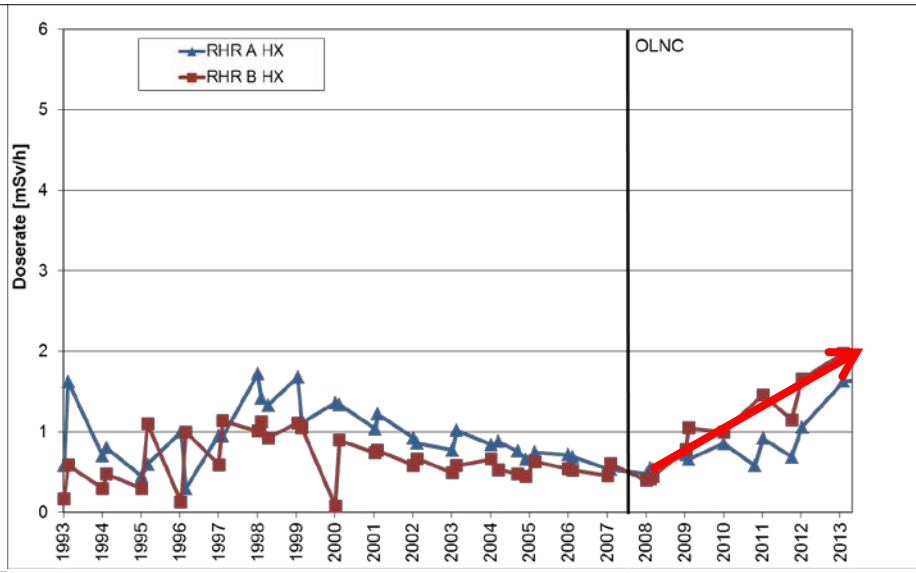
Dose Rates at RHR Pumps/Heat Exchangers: massive increase since implementation of OLNC





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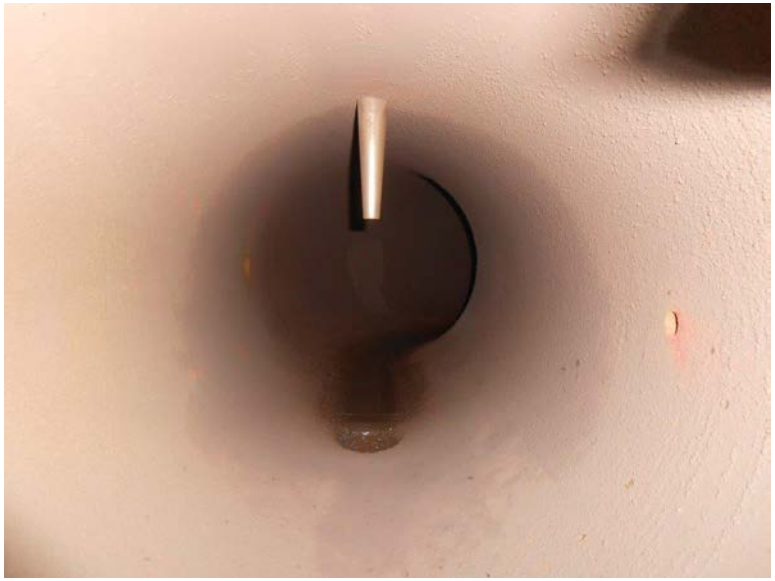
How did we proceed?

- Task Force: Fuel, RHR-Owner, Chemistry, Operations, Radiation Protection
- Goal: «Understanding and Stabilisation of RHR Source Term»
- Assessment of operational and radiological records back to 1992.
- Extended radiological surveys
- Chemical characterisation of RHR Deposits
- Evaluation of Industry Experience



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«Soft Shutdown» to RFO 2014

RHR-Flush before Shutdown

- Avoid elemental Cobalt-input into reactor

Power Reduction << 2%/min

- Avoid crud-spalling from fuel

Reduction to 20 % thermal Power during 24 hr before Shutdown

- Reduce residual heat generation

Keep Reactor Pressure stable until All-Rods-In

- Avoid crud-mobilisation

Shut Down Cooling <130 °C (266 °F)

- Keep crud-burst away from RHR

Temperature Change < 15 °C/hr (59 °F/h)

- Avoid crud-burst

Operate only RHR-A during initial cooldown

- Keep RHR-B clean

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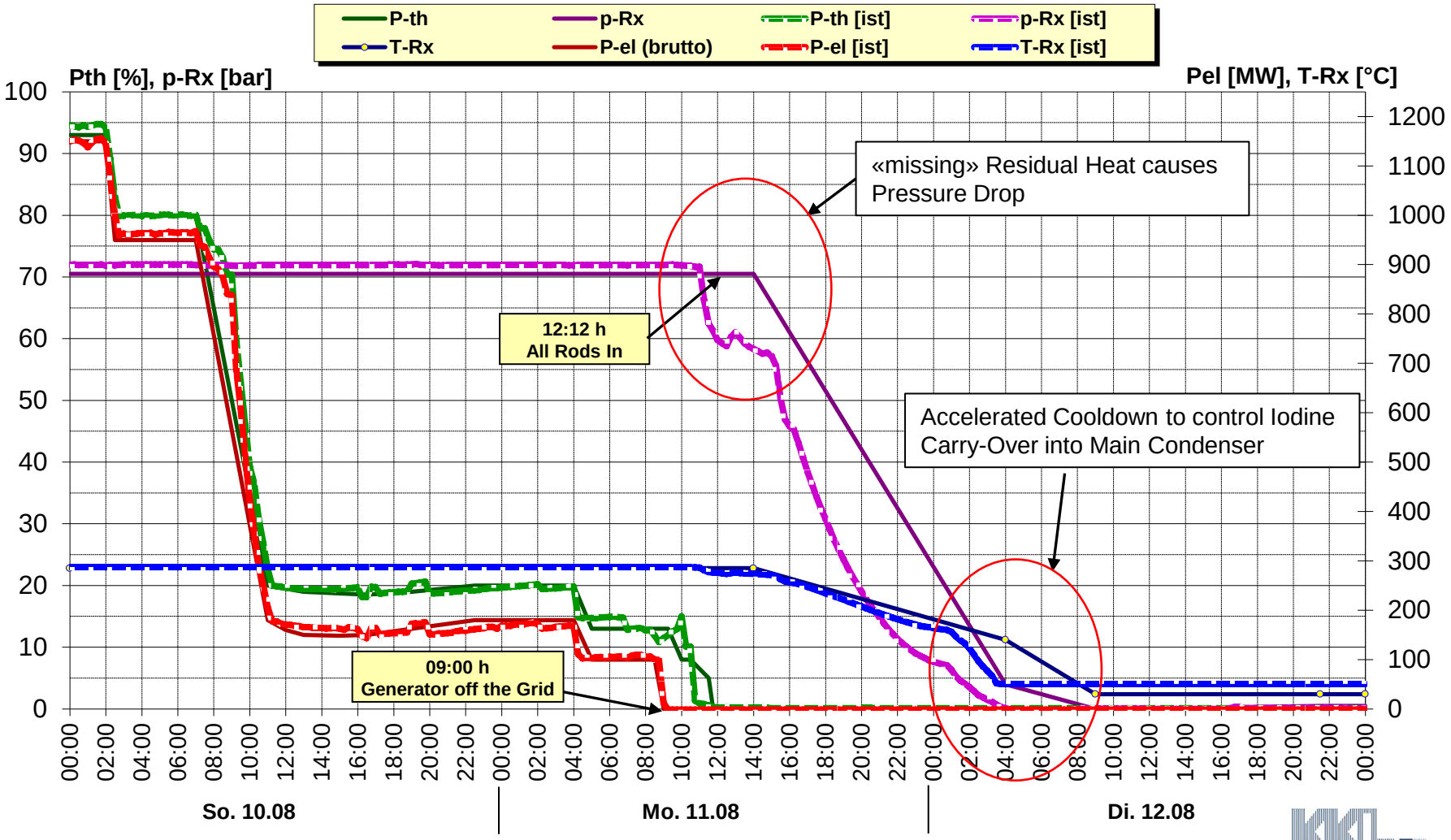
Soft Shutdown 2014

Reactor Parameters



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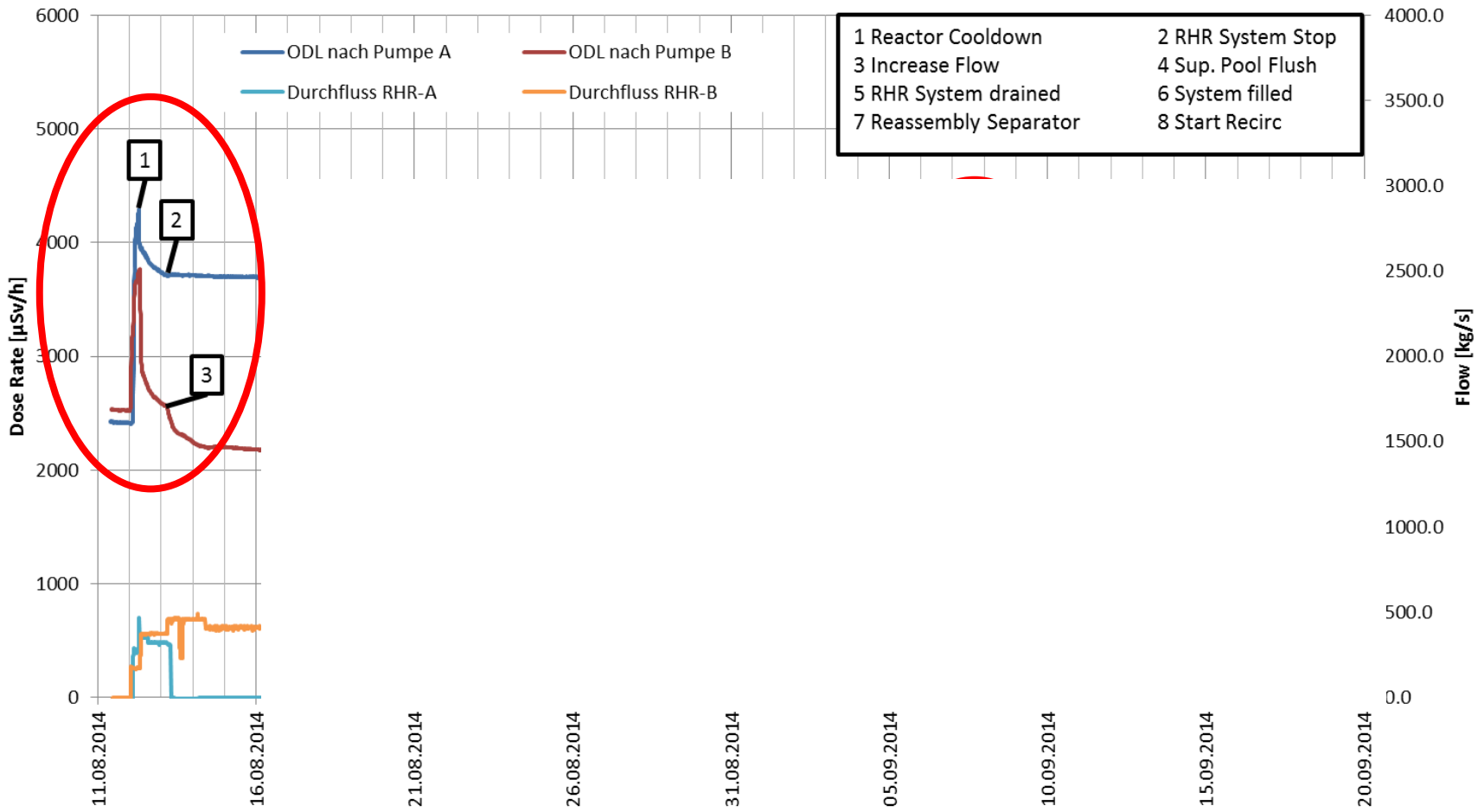
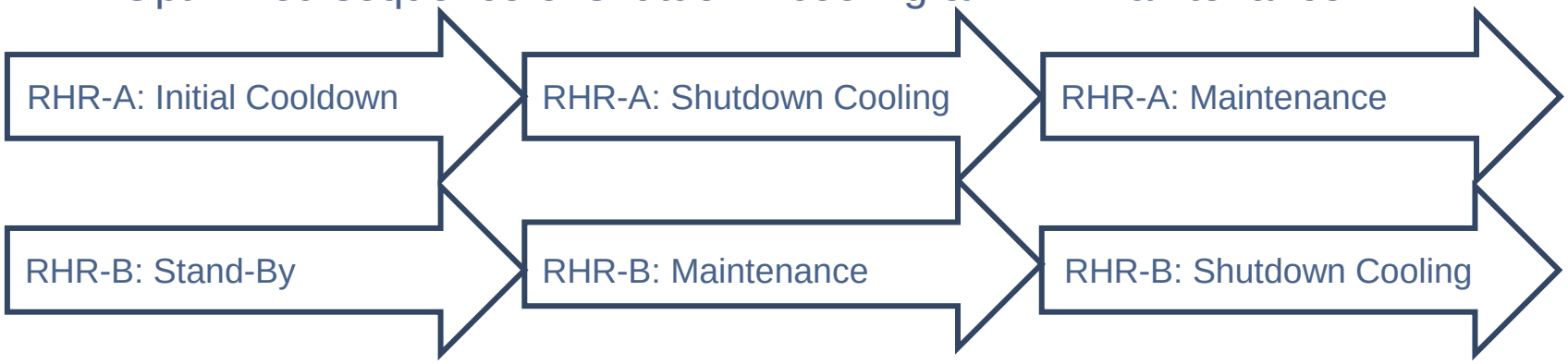
Dose Rate and Flow RHR-Pumps during RFO 2014



Lessons Learned (1)

- Initial cooldown causes RHR contamination
- System needs sufficient time (couple of days) to recover
- Initial cooldown with RHR-A is mandatory for technical reasons
- RHR-A contaminated heavily after cooldown
  - No maintenance work right after cooldown!
  - Optimized sequence of shutdown cooling & RHR maintenance:



- High RHR-Flow removes contamination
  - Coolant temperature may drop below 30 °C (86 °F)

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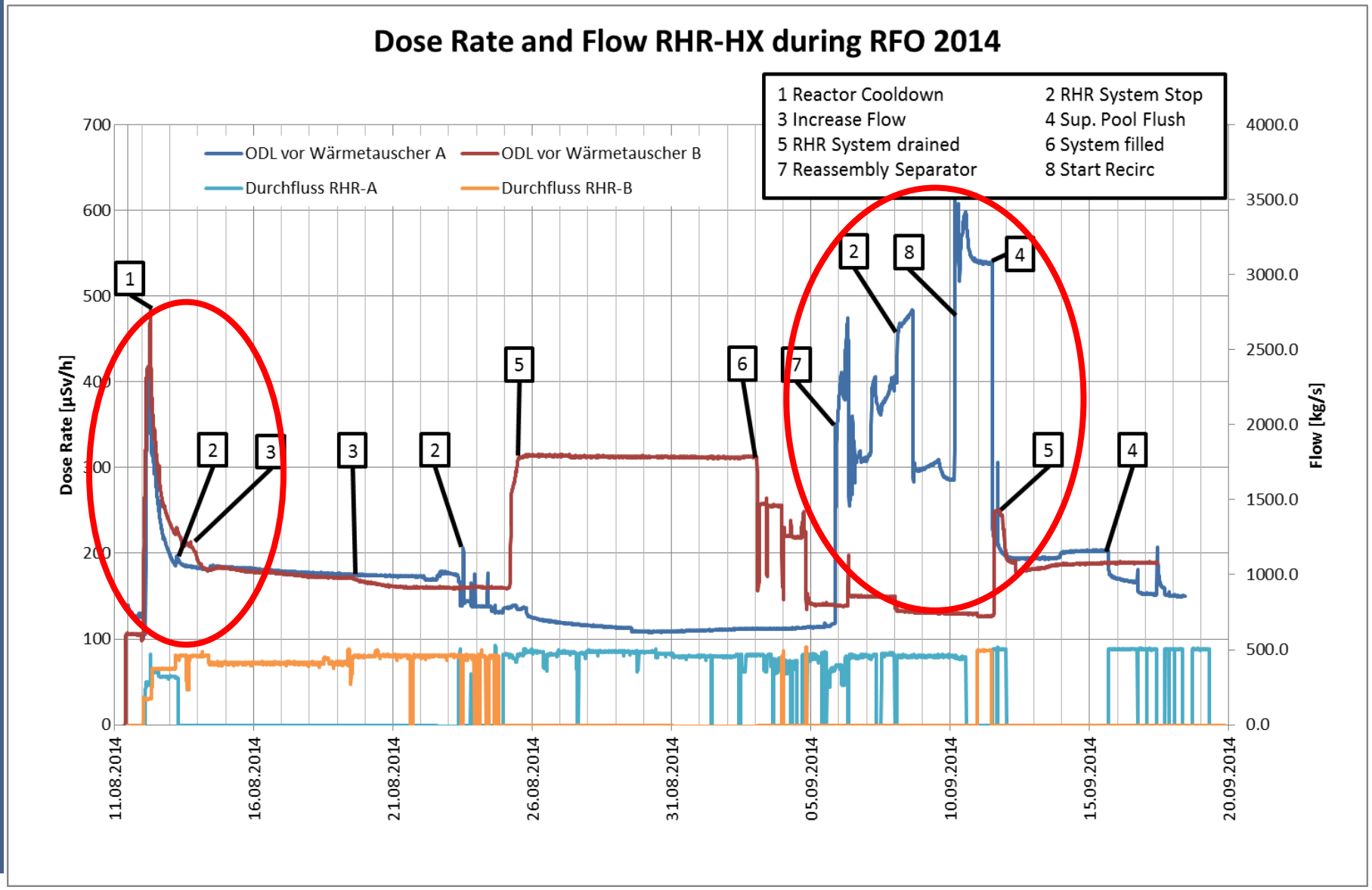
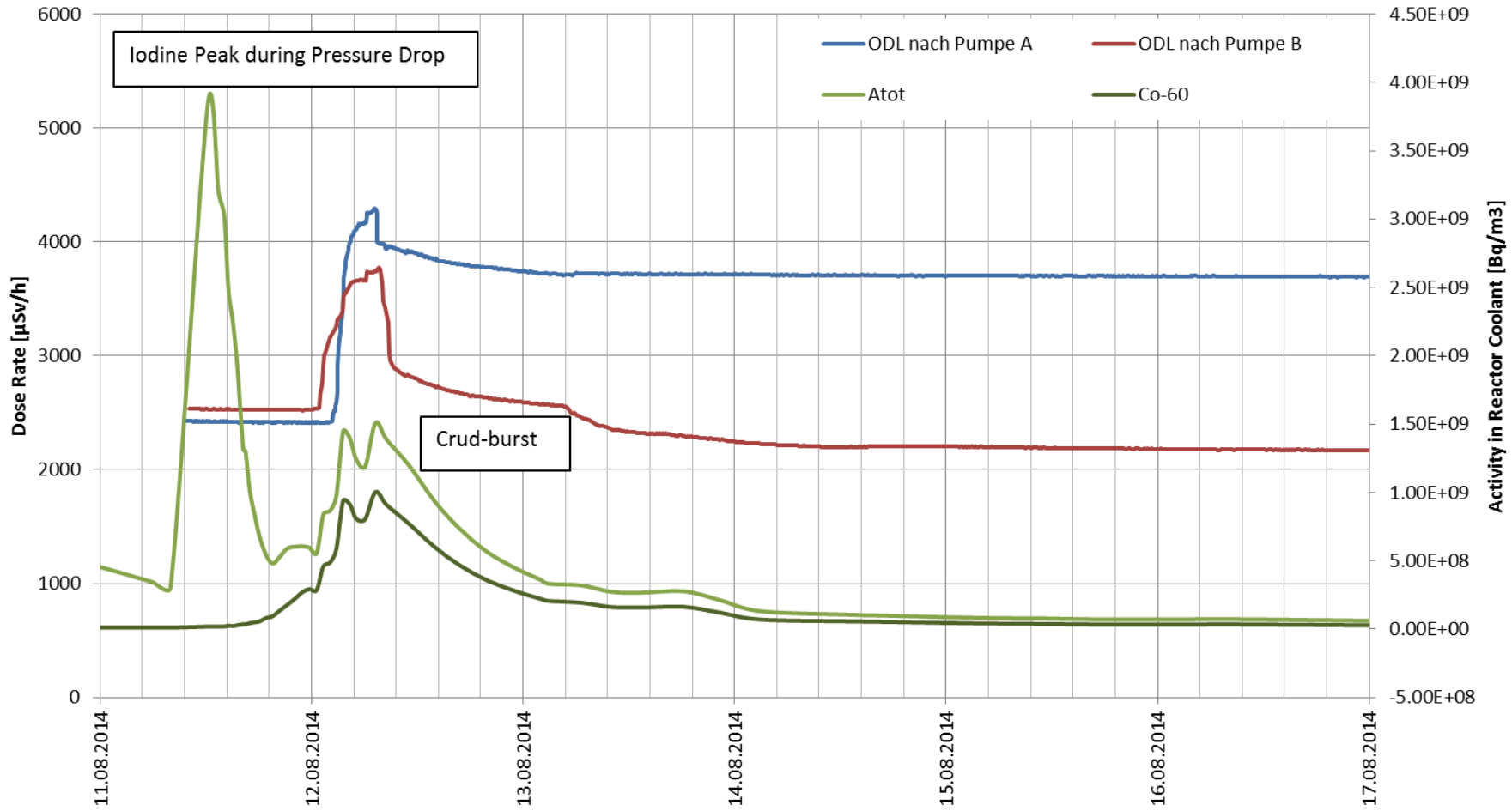
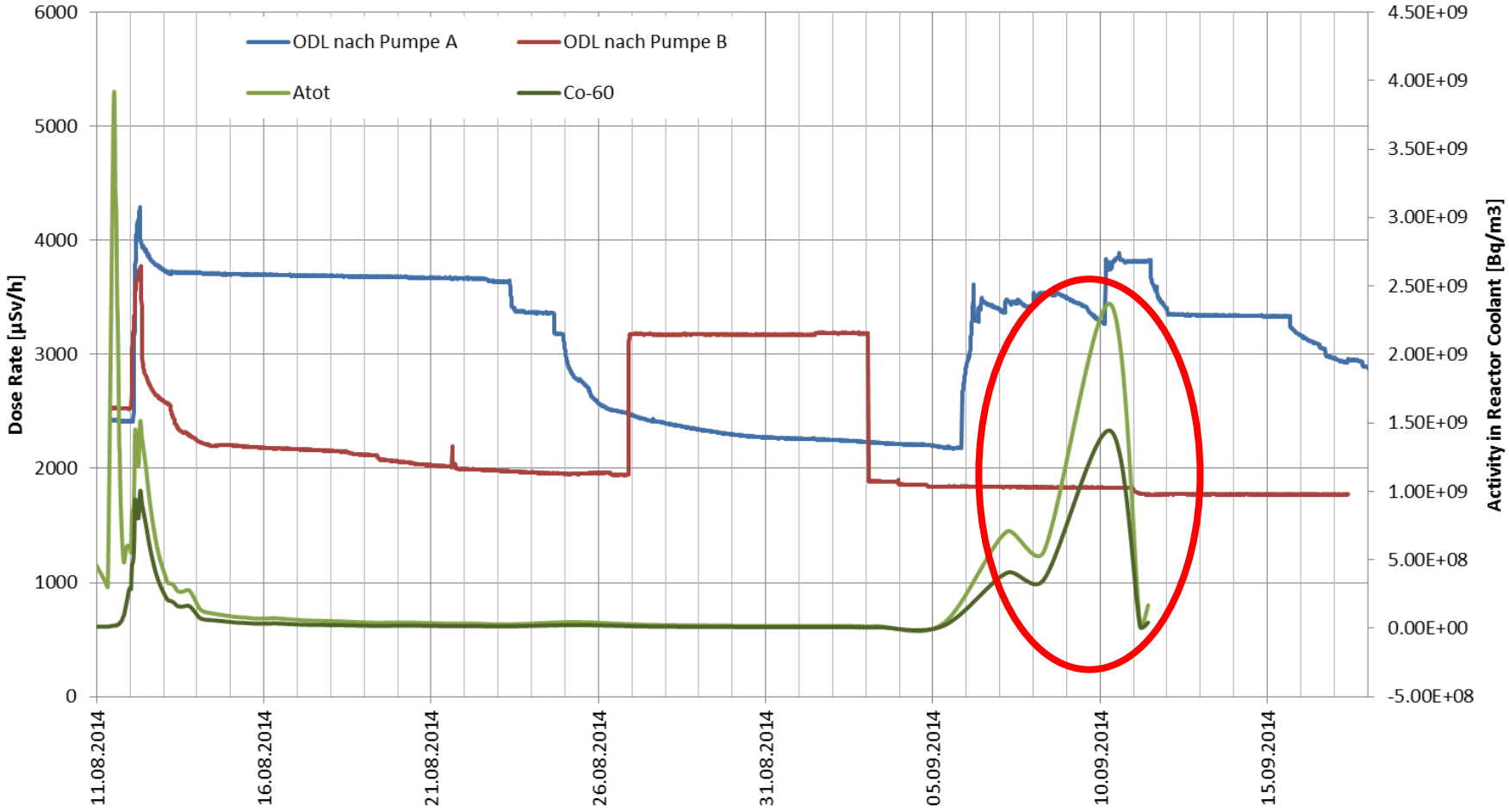

Dose Rate and Flow RHR-HX during RFO 2014
1 Reactor Cooldown
2 RHR System Stop
3 Increase Flow
4 Sup. Pool Flush
5 RHR System drained
6 System filled
7 Reassembly Separator
8 Start Recirc
ODL vor Wärmetauscher A
ODL vor Wärmetauscher B
Durchfluss RHR-A
Durchfluss RHR-B
Dose Rate [µSv/h]
Flow [kg/s]
700
600
500
400
300
200
100
0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
11.08.2014
16.08.2014
21.08.2014
26.08.2014
31.08.2014
05.09.2014
10.09.2014
15.09.2014
20.09.2014

Dose Rate at RHR-Pumps and Reactor Coolant Activity during Soft Shutdown



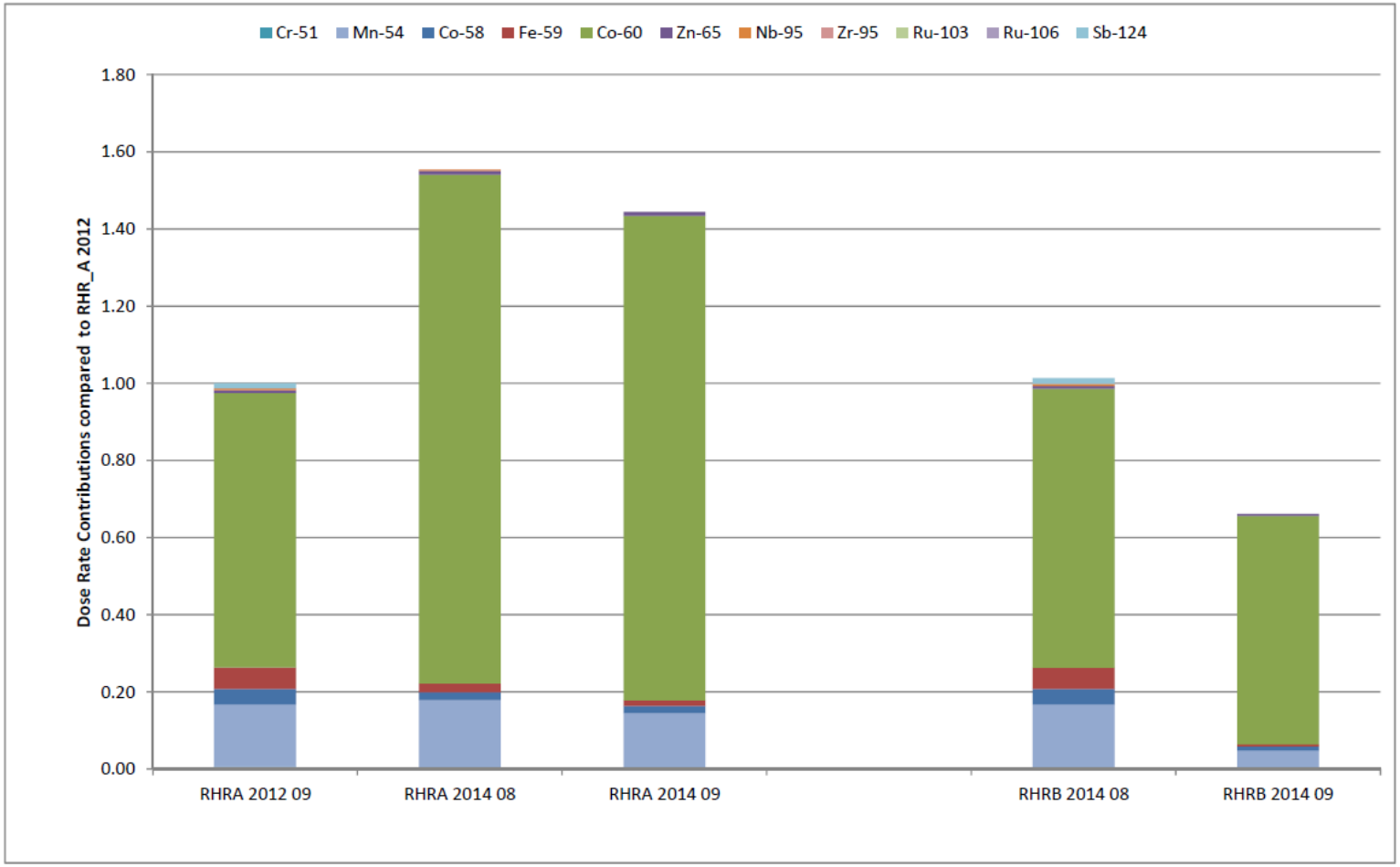
Dose Rate at RHR-Pumps and Reactor Coolant Activity during RFO 2014



Lessons Learned (2)

- Pressure drop triggers Iodine release to reactor coolant
- Iodine was kept away from RHR
- Crud-burst was moved into RHR-System and plates out as soon as system is stopped
- Reassembly of moisture separator causes crud-burst, intake into RHR.
- Start of recirc pumps causes crud-burst, intake into RHR.
- Long term operation in suppression pool cooling mode removes contamination from RHR
- Suppression pool contamination is increased
- RHR heat exchangers are generally on a lower level than pumps
- Reactor reassembly and plant start up are critical to source term during on-line maintenance of RHR

Gamma-Scan Results of RHR Surface Contamination



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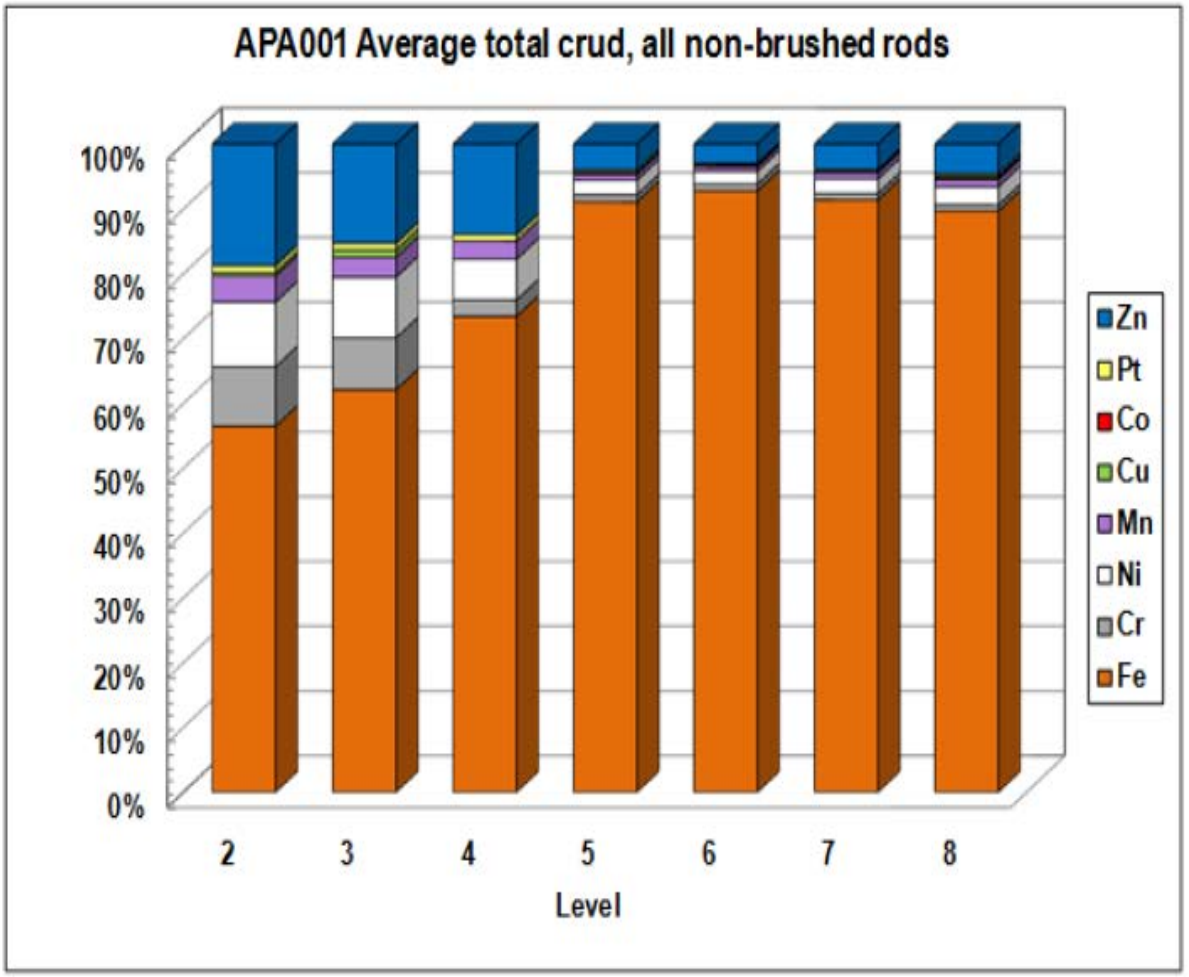
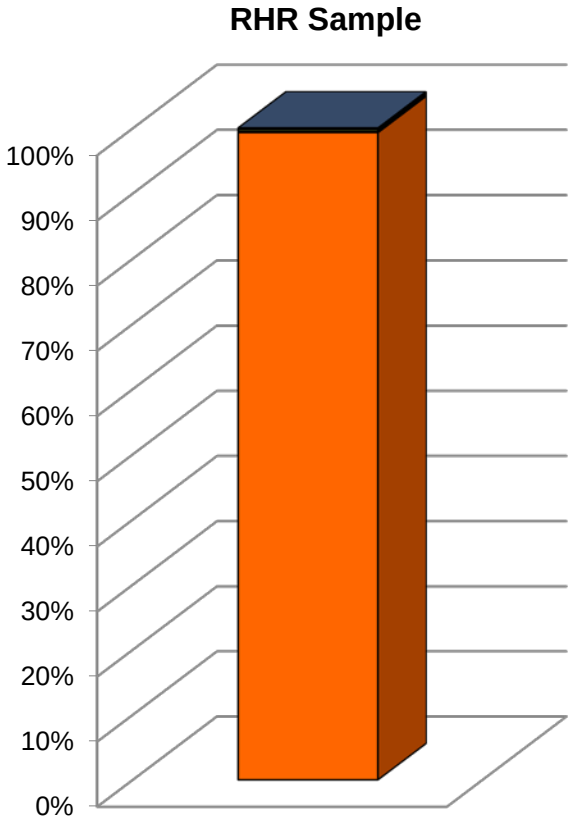
Elemental Composition on Fuel Rod and RHR Surfaces





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Lessons learned (3)

- Contamination mainly consist of Co-60. Fission products from failed fuel are of minor impact.
- Radioactive decay of Mn-54 ($T_{1/2}$ = 312 days) will lower dose rate by 10 %
- Contamination on RHR surfaces does not match the characteristics of crud on fuel cladding. Apparently RHR contamination does not originate from fuel rods. Where does it come from?

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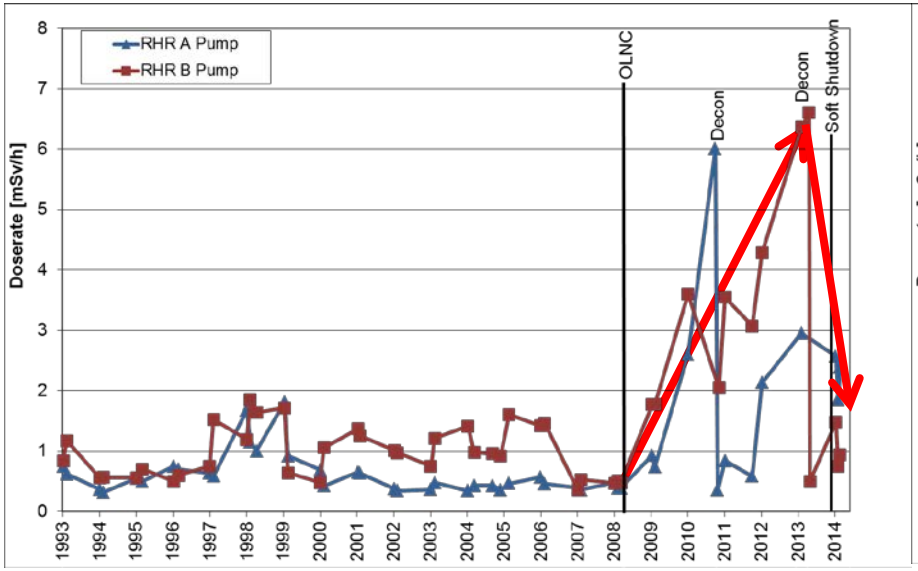
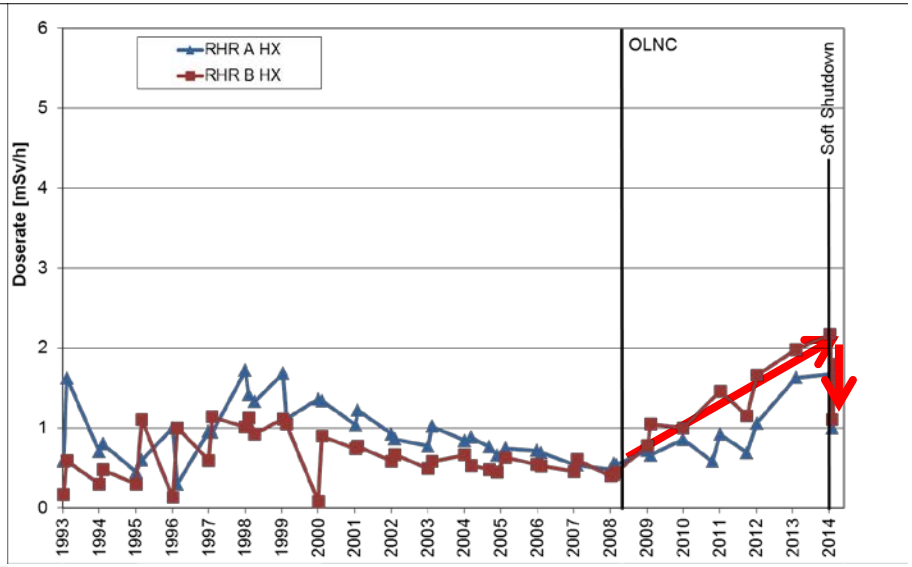
Conclusions:
Dose Rates at RHR Pumps/Heat Exchangers are significantly decreased by Soft Shutdown and optimized RHR Operations





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Corrective Actions for next Refueling Outage

- Slightly reduce Zinc and Platinum injection rate to avoid possible crud-spalling
- Reduce workload in upcoming RHR-A on-line maintenance
- Repeat Soft Shutdown for RFO 2015
- No RHR-B operation during inital cooldown
- Sequence of maintenance work: first RHR-B, then RHR-A
- Operate RHR at maximum flow
- Modify Ops procedures to allow coolant temperature below 30 °C (86 °F)
- Reactor Water Cleanup in operation during installation of Moisture Separator
- Stop RHR during installation of moisture separator and start of recirc pumps
- Evaluate decon of moisture separator
- Increase frequency of reactor coolant sampling during reactor reassembly

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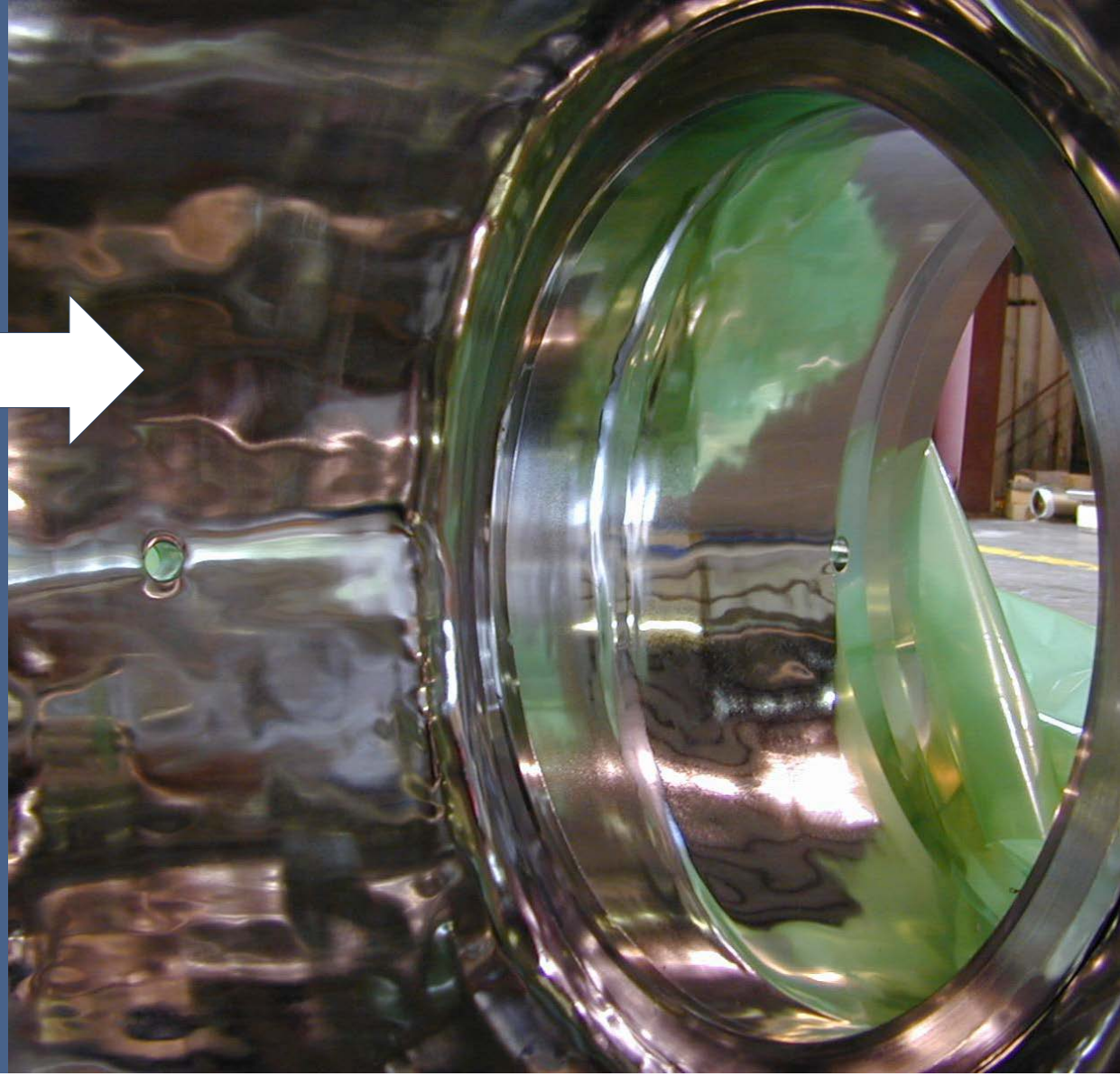
Our Vision:

Top:

RHR-Piping at KKL

Right:

RHR-Piping at Browns Ferry



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