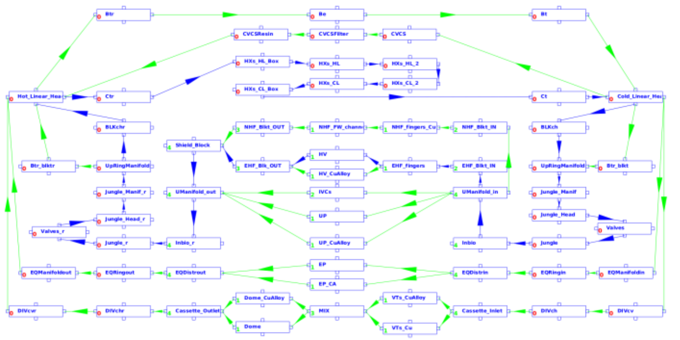
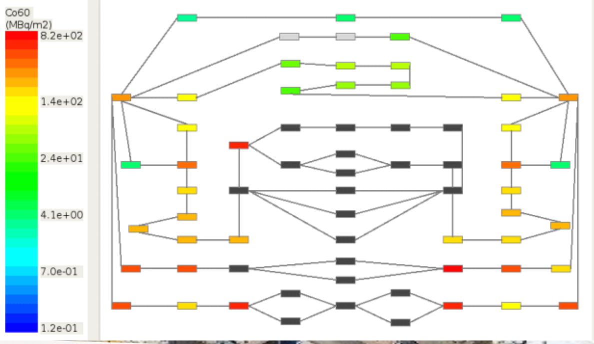




Parametric study of ITER main PHTS using OSCAR-Fusion v1.4.a code

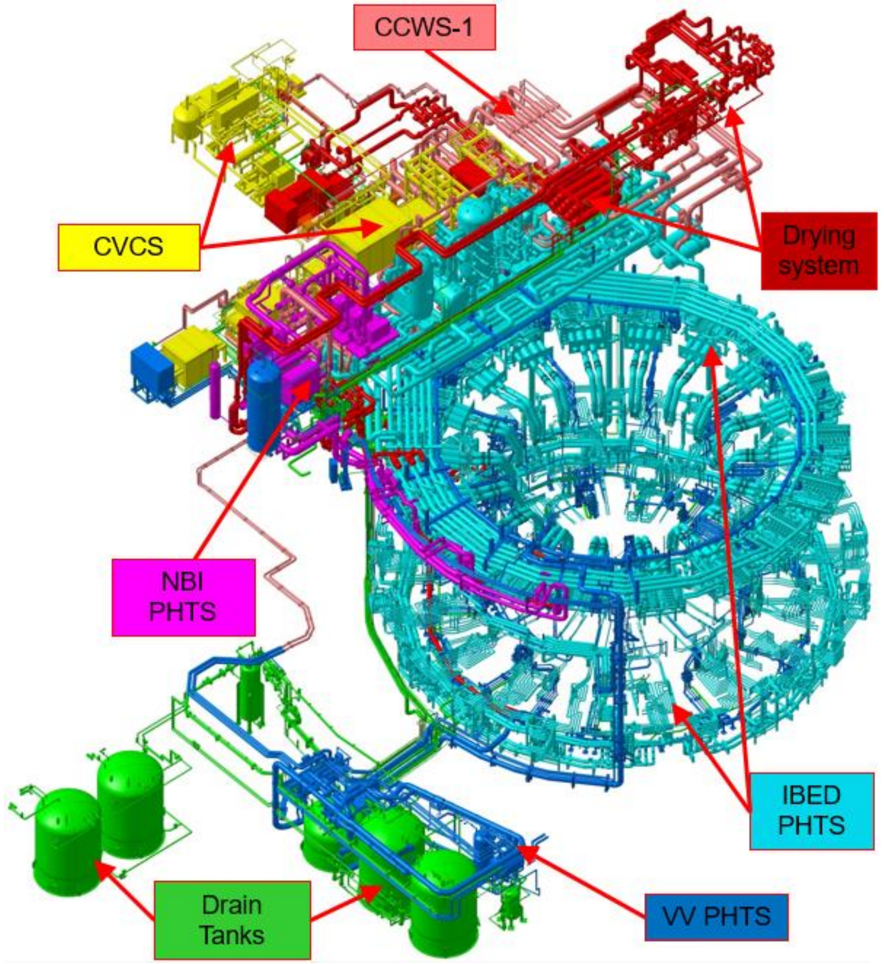
Dario Carloni on behalf of Radiation, Safety and Environment Group SQD/NS/RSE

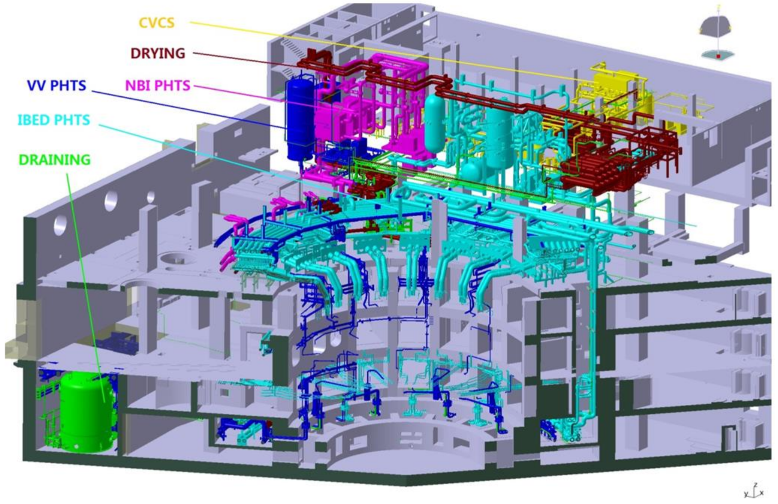
iter
china eu india japan korea russia usa

30 October-03 November 2023, Vienna
IAEA Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission reactors

ITER primary cooling loops

Tokamak Cooling Water System (TCWS) removes up to 1 GW of power





The main loop, IBED, cools down the in-vessel components during plasma operation

~ 5000 kg/s

70 °C (dwell) – 140 °C (burn)

4 MPa

IBED provides also high temperature water to purge the tritium retained during plasma

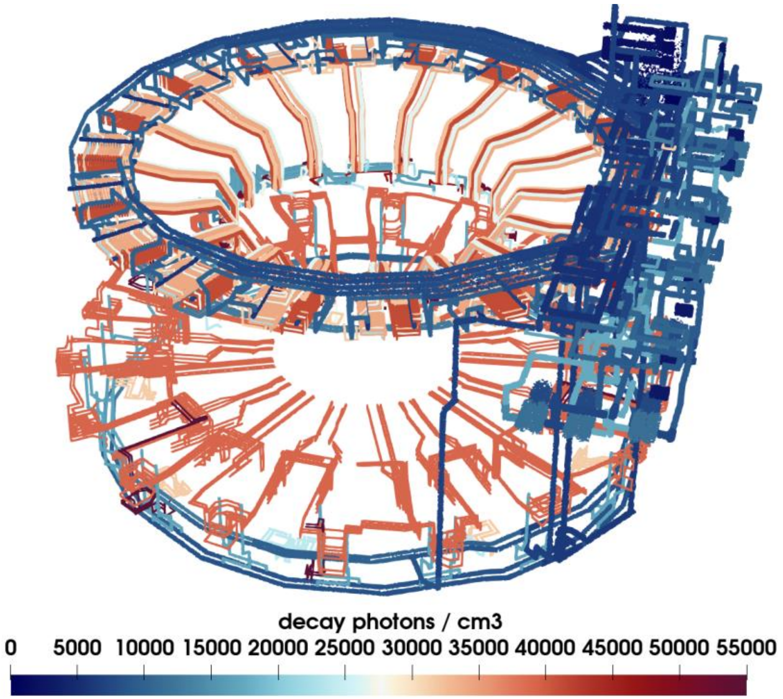
~ 500 kg/s

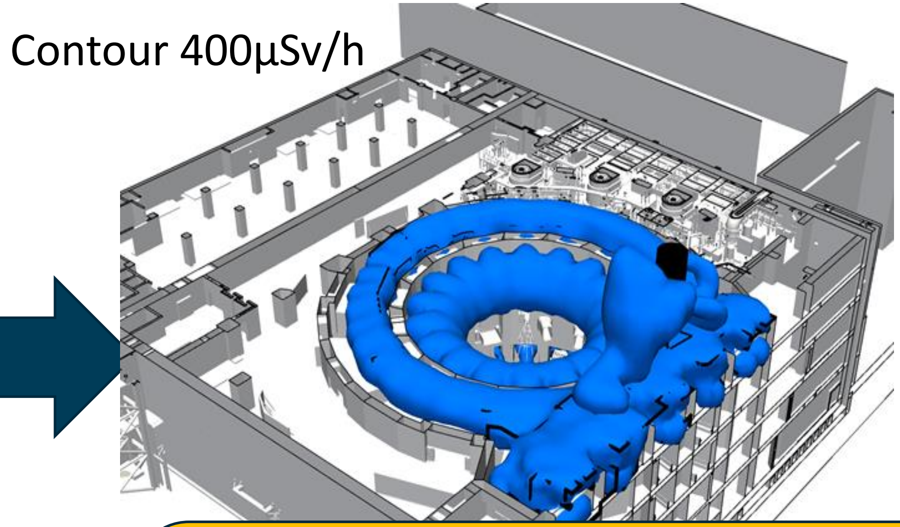
240 °C

4.4 MPa

IBED = Integrated Blanket ELMs and Divertor

ACPs contribution to the Occupational Radiological Exposure





Biological shutdown dose rate (SDDR) in the areas hosting cooling equipment is dominated by the decay of the ACPs

~ 70% of the ORE at 10^6 s of cooling time **due to ACPs**

Co60 is the driver

KEY for the neutrons budget definition in DT1

ACPs contributes also to the source term for accidental scenario (e.g. LOCA)

ACPs and ASN/IRSN

Validation of the ACPs source term required for ITER Safety demonstration:

1 – Safety Function “Limitation of exposure”: Rad zoning in mode 1 + ORE/ALARA

2 – Safety Function “confinement”: ACP is a contributor to some accidents (LOCA)

“We need to open the ACPs ***black box*** *used in the past”*

Validation of the ACPs source term requires also a staged approach due to lack of knowledge:
ACP will be part of “**Acquisition Knowledge program**” recently introduced in the new licensing roadmap

Materials for IBED loop

ex-vessel piping

AISI 304

in-vessel piping

AISI 316

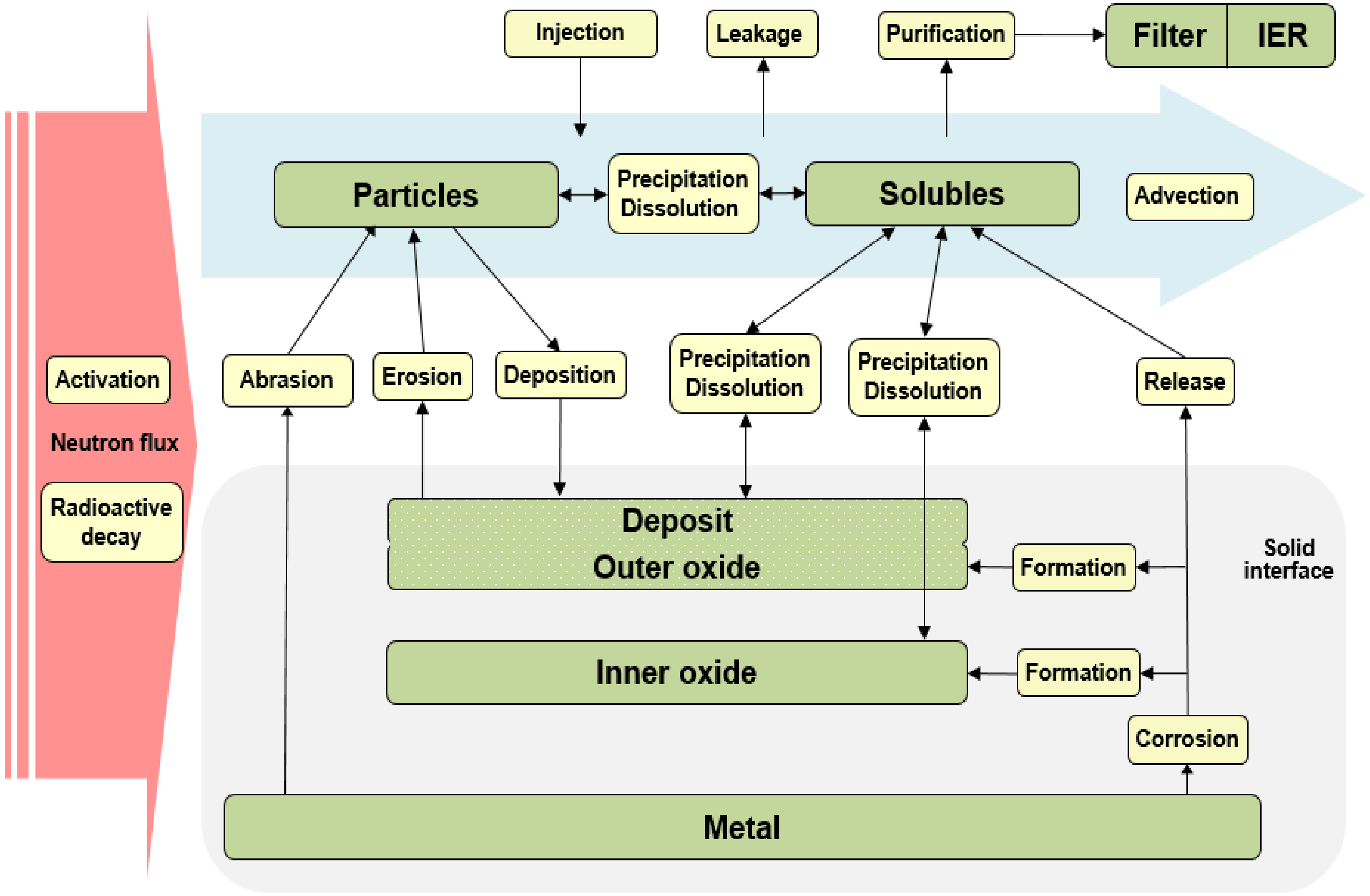
in-vessel components

AISI 316
Oxygen Free copper
CuCrZr IG

IBED Coolant Chemistry – status of art

	Mode	Plasma	Baking	
Parameter	Unit	IBED PHTS	IBED PHTS	Current consideration
Conductivity @25ºC	µS/ cm	<= 0.2	*	
pH @25ºC	-	7.0 - 9.0	*	
Sodium	ppb	<= 5	<= 5	No reason to increase/decrease during Baking
Chloride	ppb	<= 5	<= 5	No reason to increase/decrease during Baking
Hydrogen	ppb	<= 80	-	No injection expected during baking (no radiolysis)
Catalysed Hydrazine	ppb	<= 30	-	Injected for only initial filling
Ammonia	ppb	<= 1,000	-	No injection expected during baking, but could be injected to control pH
Oxygen	ppb	<= 10	<= 10	No reason to increase/decrease during Baking
ORP@25ºC	mV	(-400) - (-100)	*	

OSCAR Fusion code



OSCAR code (CEA)
Used for French PWR
(Major advantage: The only code who is consolidated with measurements campaigns)
ACPs assessments

Commercial license for the use of the code at IO till 2025

New OSCAR Fusion Version (1.4a) used for SA2 and DT1 studies in 2023

OSCAR input main upgrades made in 2023

Lithium Injection to control the pH > 7
During all phases

Update Geometries and Thermal hydraulics based on post Final Design Review of TCWS

Material Activation rates re-calculated for all the corrosion relevant elements in
4 different under flux regions

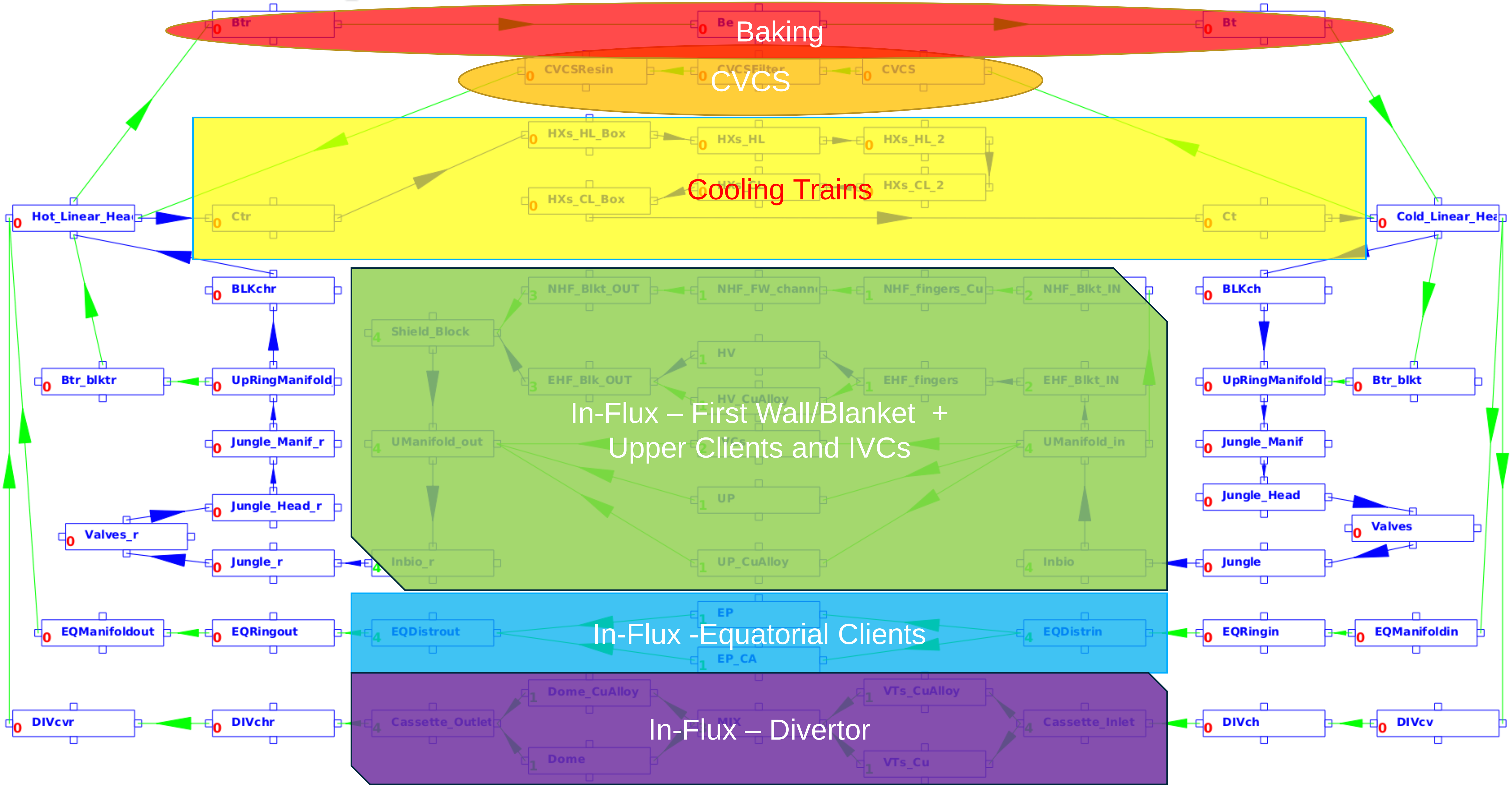
A better integration of the TCWS operation: 30 days of baking before and after each plasma campaign
(2 DD + 6 DT)

SA2 irradiation scenario
3E27 neutrons

New OSCAR Fusion Version (1.4a)

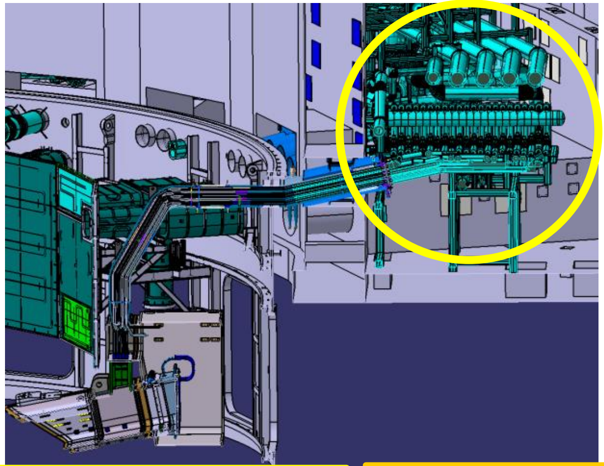
iter

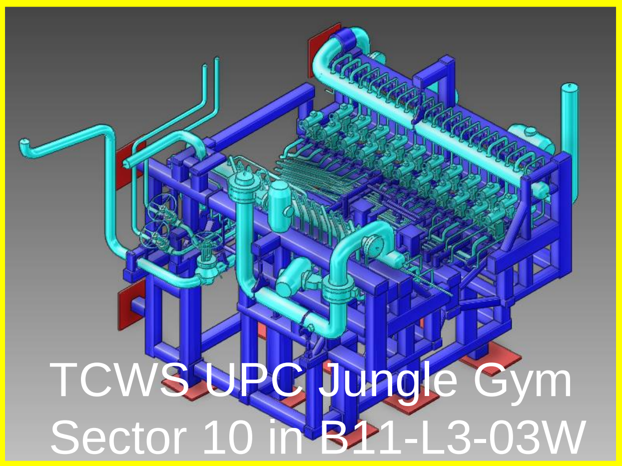
OSCAR input based on TCWS PI&D and PFDs

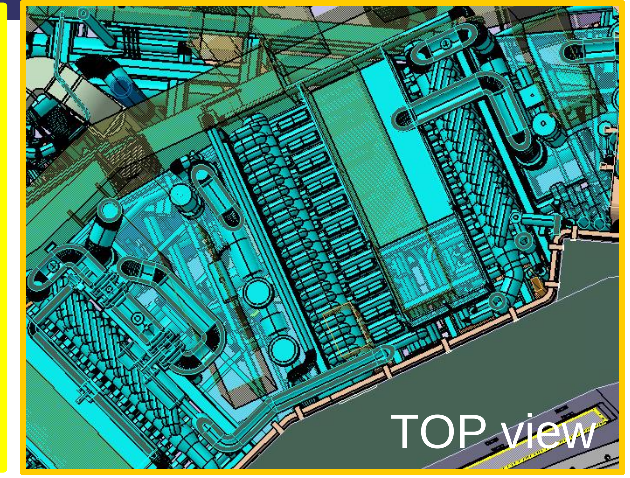


Focus on Jungle Gym

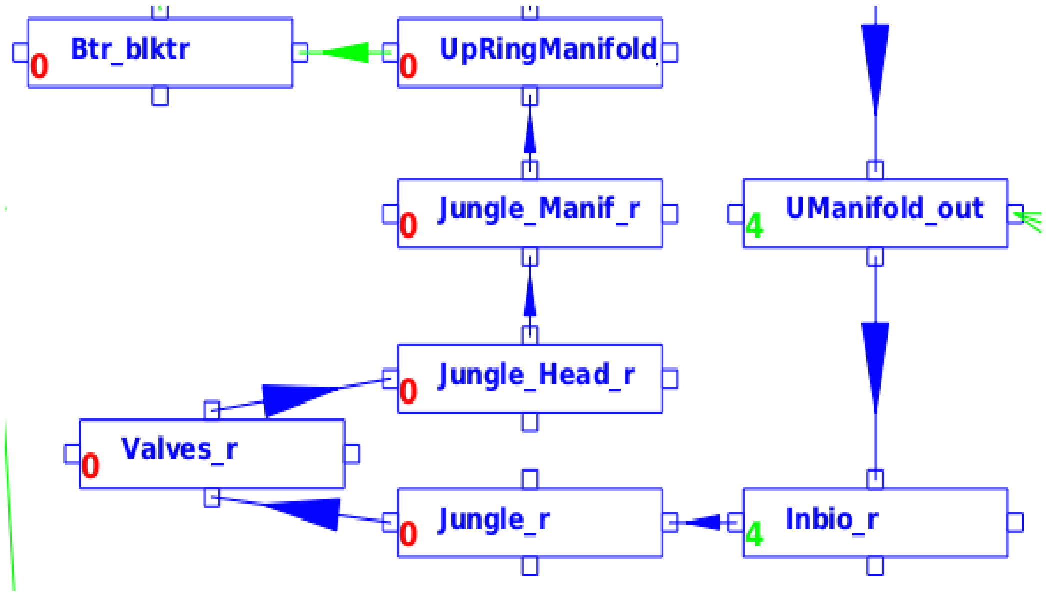
18
Jungle Gym
In L3







Jungle Gym
OSCAR MODEL 2023



New input data for both Geometry and Thermal hydraulics implemented in the model update

Wet Surfaces corrected thanks to **check of the loop data with UNED**

Materials in OSCAR model

Material name	~~AISI304_12 mic~~ AISI316_12 mic	AISI316_ 6 mic	AISI316_ 2 mic	AISI316_ 12 mic20	Cu alloy	Cu
Composition	Co 0.0005 Cr 0.175 Cu 0.003 Fe 0.648 Mn 0.018 Ni 0.123	Co 0.0005 Cr 0.175 Cu 0.003 Fe 0.648 Mn 0.018 Ni 0.123	Co 0.0005 Cr 0.175 Cu 0.003 Fe 0.648 Mn 0.018 Ni 0.123	Co 0.002 Cr 0.175 Cu 0.003 Fe 0.648 Mn 0.018 Ni 0.123	Co 0.0005 Cr 0.0075 Cu 0.99148 Fe 0.0002 Mn 2e-05 Ni 0.0003 Zr 0.0007	Co 0.0005 Cr 0.0001 Cu 0.9991 Fe 0.0001 Mn 0.0001 Ni 0.0001
Roughness	12 µm	6 µm	2 µm	12 µm	1.3 µm	6.3 µm
Regions	Out-of-flux and in-flux regions	DIV stainless steel parts	HXs	Isolation Valves	In-flux regions	IVCs Divertor swirl tubes

[1] Zirconium concentration is not simulated in OSCAR runs due to its negligible impact in terms of both activity and contribution to the ORE

Early 2023 Results Comparison

WP-A-3: Validation of the OSCAR input and its results (Engineering support for TCWS ACPs assessment - 2nd Deliverable) (87D6BT v1.4)

Corrosion laws comparison

Moorea – Power Studsvik – Power Belus

Parametric study to justify the delta = > **factor 10 for OoF activity depending on the corrosion laws**

Cu alloy corrosion rates @ baking temperature

To be validated against experimental results to reduce Uncertainties

2023 Reference Case – SA2 – new corrosion law for Cu-alloy

TABLE 2: Erosion corrosion and release rates of CuCrZr.

Temperature [°C]	Erosion corrosion rate [μm ·year^{-1}]				Release rate [mg · cm^{-2} ·year^{-1}]			
	Oxidizing		Reducing		Oxidizing		Reducing	
Flow velocity [m/s]	*10*	*15*	*10*	*15*	*10*	*15*	*10*	*15*
110	25	27	1	1	22	24	2	2
150	37	43	/	/	33	39	/	/
250	1600*	3000*	8	24	1400*	2700*	15	45

* Calculated from data obtained for total exposure time of 170 h.

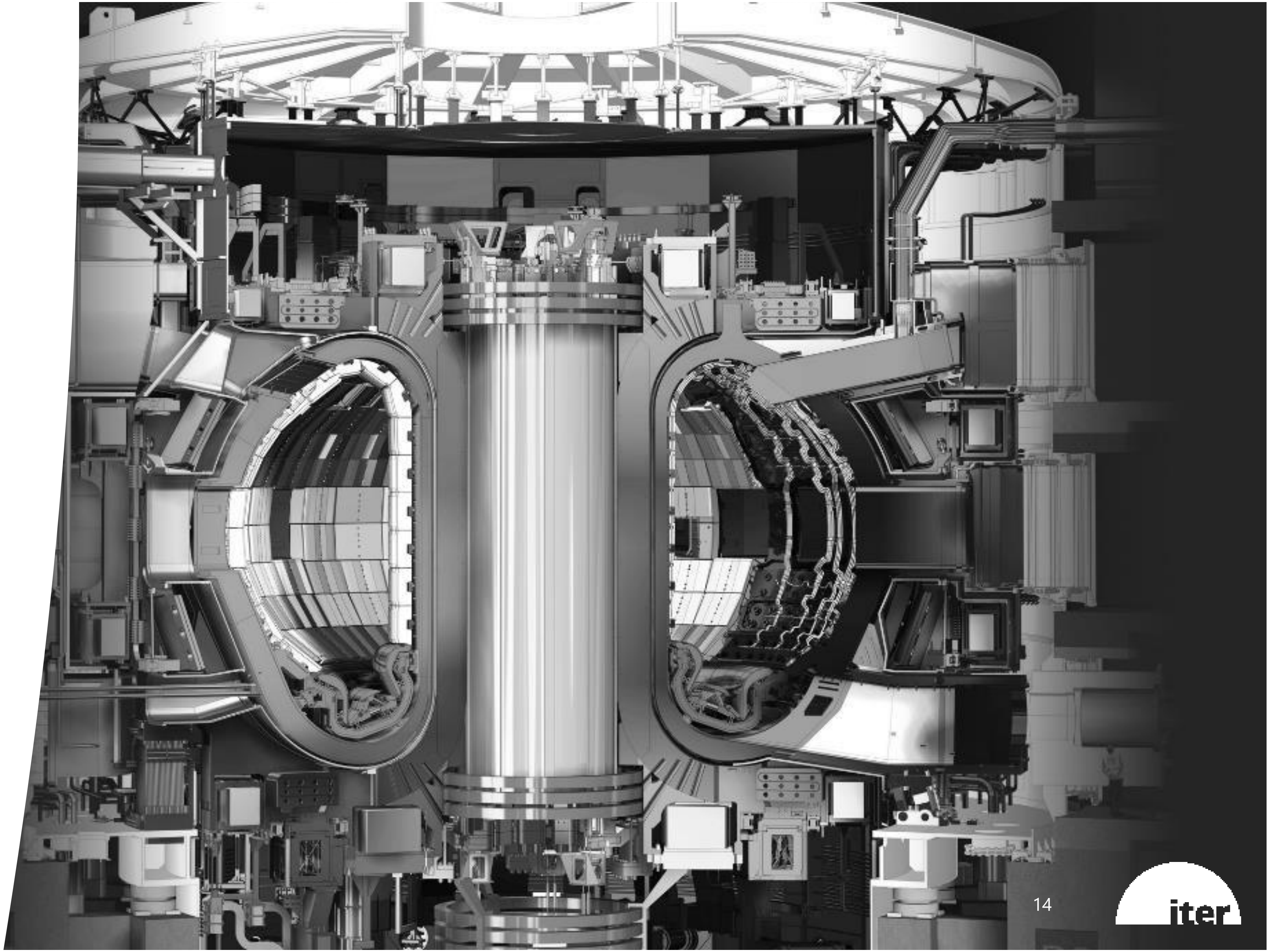
Structural Integrity of Cu-alloy components might be at risk during the real operation

Safety Review

Inventory Management

ACPs update

SA2 and DT1



Scenarios

SA2 (+ PFPOs)

Mode	Duration [s]	Comment	
1 day of D-T Plasma operation			
Burn	8000	500 MW plasma shot lasting 500 seconds 16 shots per day [41] [40]	
Dwell	78400	Including Night Shift	
1 DT session			
Dwell	9.98	14 days plasma session from [44] STM is simulated as dwell time	
Burn	1.02		
STM	3		
1 FPO			
Baking	30		
Dwell	319.4	1 FPO simulating 32 sessions, i.e. 16 months of operation	
Burn	32.6		
STM	96		
Baking	30		
Total 1 FPO	448+60= 508	At the end of each FPO an 8 months cold-shutdown phase, is considered	
TOTAL 6 FPO cycles [Days]			
Burn	Dwell	Baking	Shutdown
196 (4700 h)	1916+ 576 (STM)	360	1200+12 (only for FPOs)

3E27 neutrons
5550 days

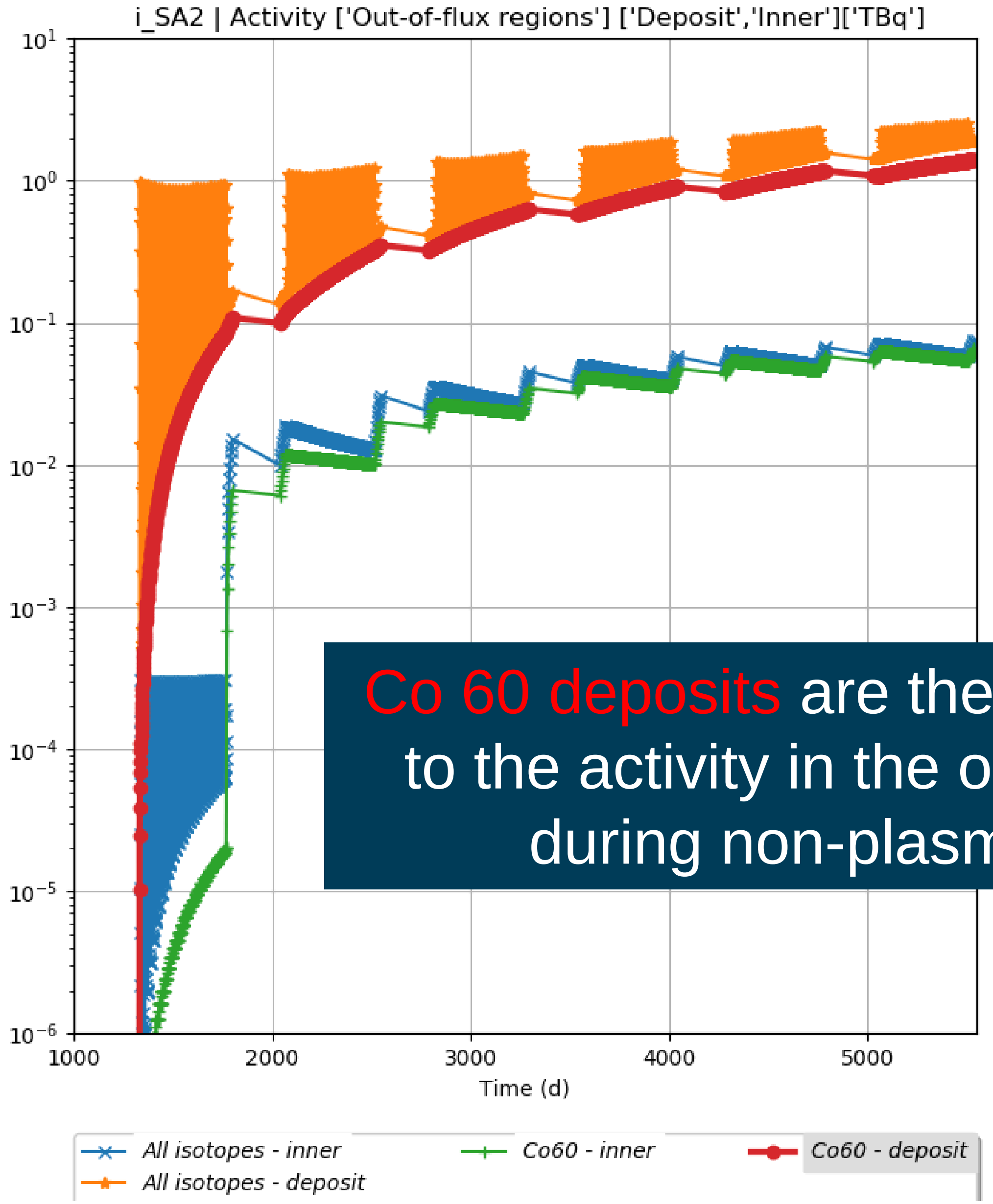
DT1 (+ AFP)

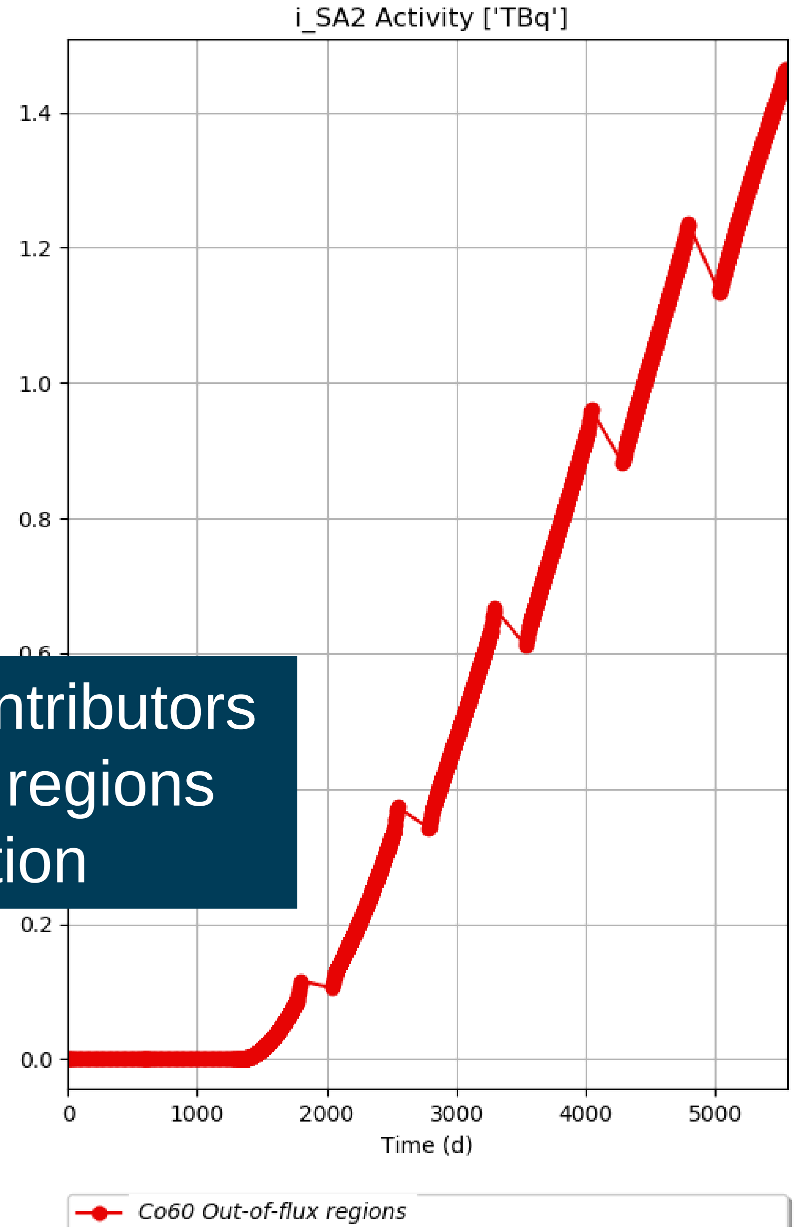
Mode	Duration [days]	Comment
Circuit Initialization		
Burn	1[s]	"Zero Power" to initialize the calculation (no activation)
AFP		
Baking	30	(30 days minus 1s to initialize the calculation with the reference period)
Dwell	640	
Cold-shutdown	240	
FPO1		
Baking	60	A longer baking operation is simulated for the first FPO1, since VV opening occurring between AFP and FPO1
Dwell	371	
Baking	30	

FPO campaign	Duration, [y]	Plasma species	Neutron yield ($x10^{24}$)	Duration of the DT pulse in (days)	Duration of the DT pulse in OSCAR (days)
FPO-1	2	DD	0.0191	0.0014	0.0014
FPO-2	2	DT	1.31585	0.08	0.1
FPO-3	2	DT	4.3447	0.29	0.3
FPO-4	2	DT	11.1617	0.73	0.72
FPO-5	2	DT	17.7972	1.17	1.17
				Total : **2.2714**	Total : **2.29014**

~ 3E25 neutrons
4347 days

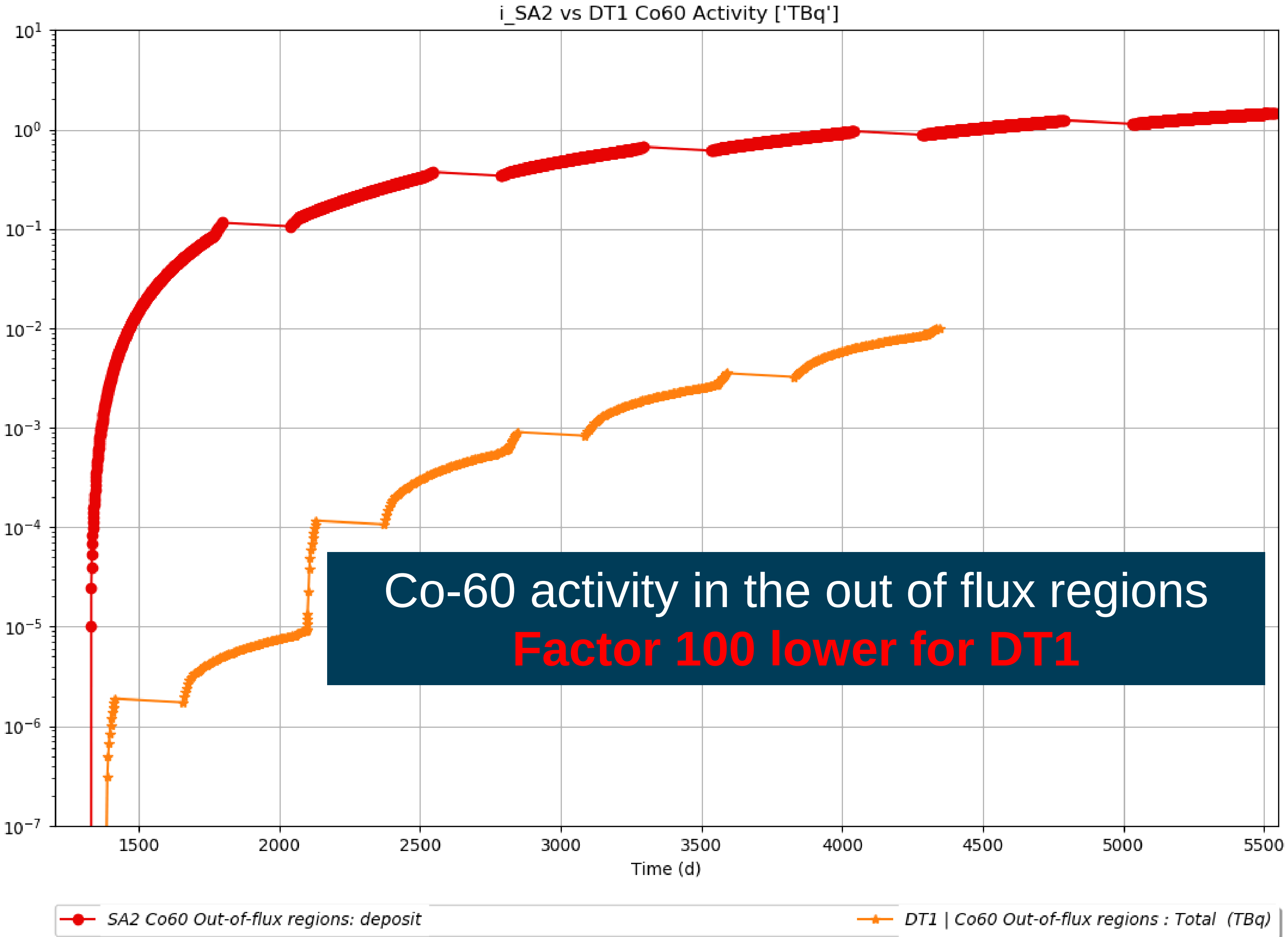
SA2 – Activity





Co 60 deposits are the main contributors to the activity in the out of flux regions during non-plasma operation

SA2 vs DT1 Co-60 Activity

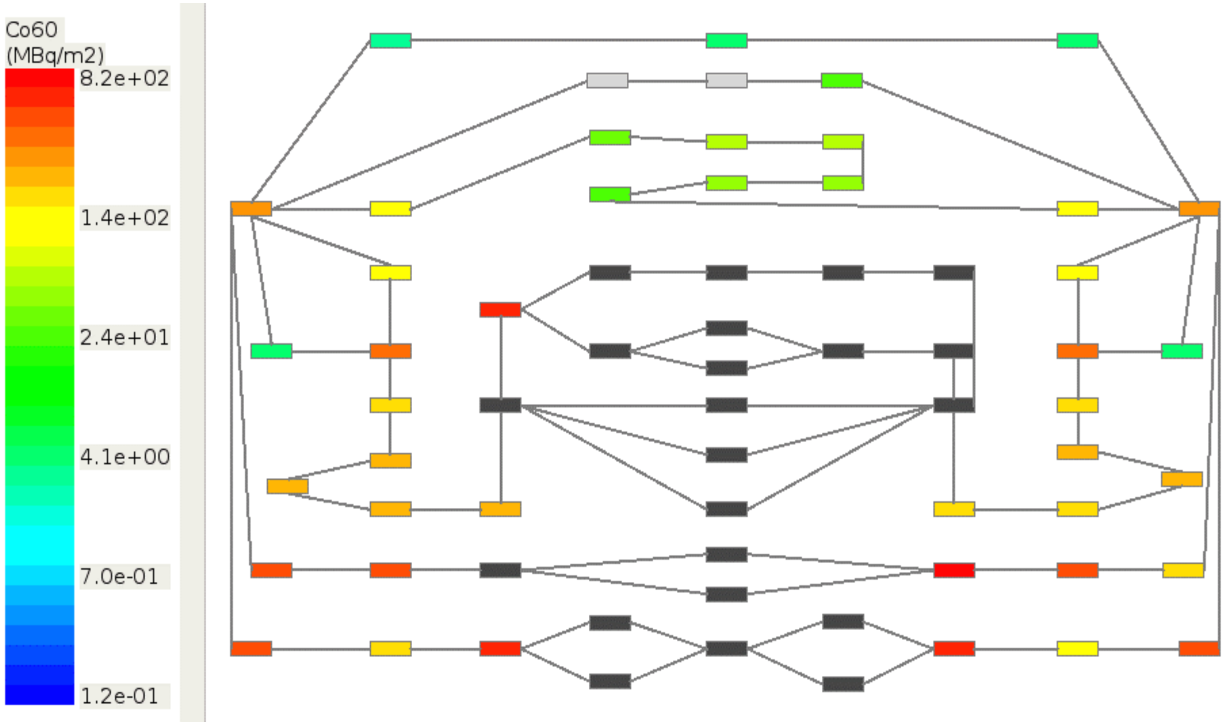


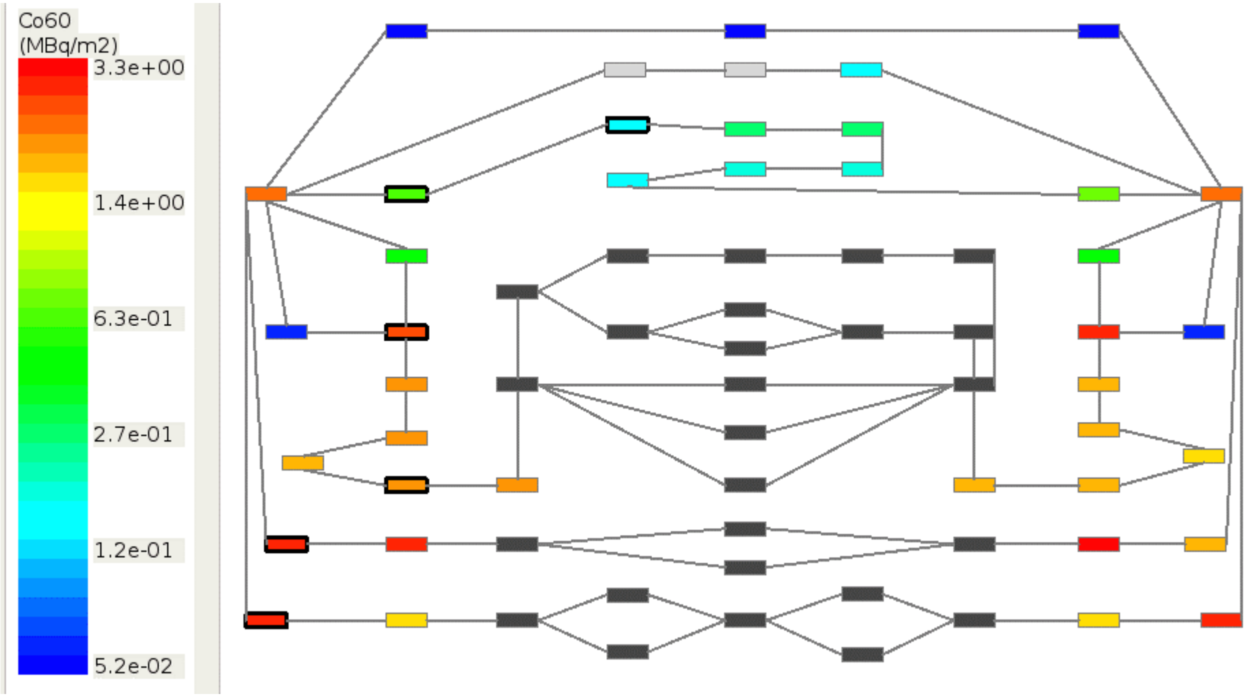
Co-60 activity in the out of flux regions

Factor 100 lower for DT1

Co-60 Surface Activity

SA2 vs DT1



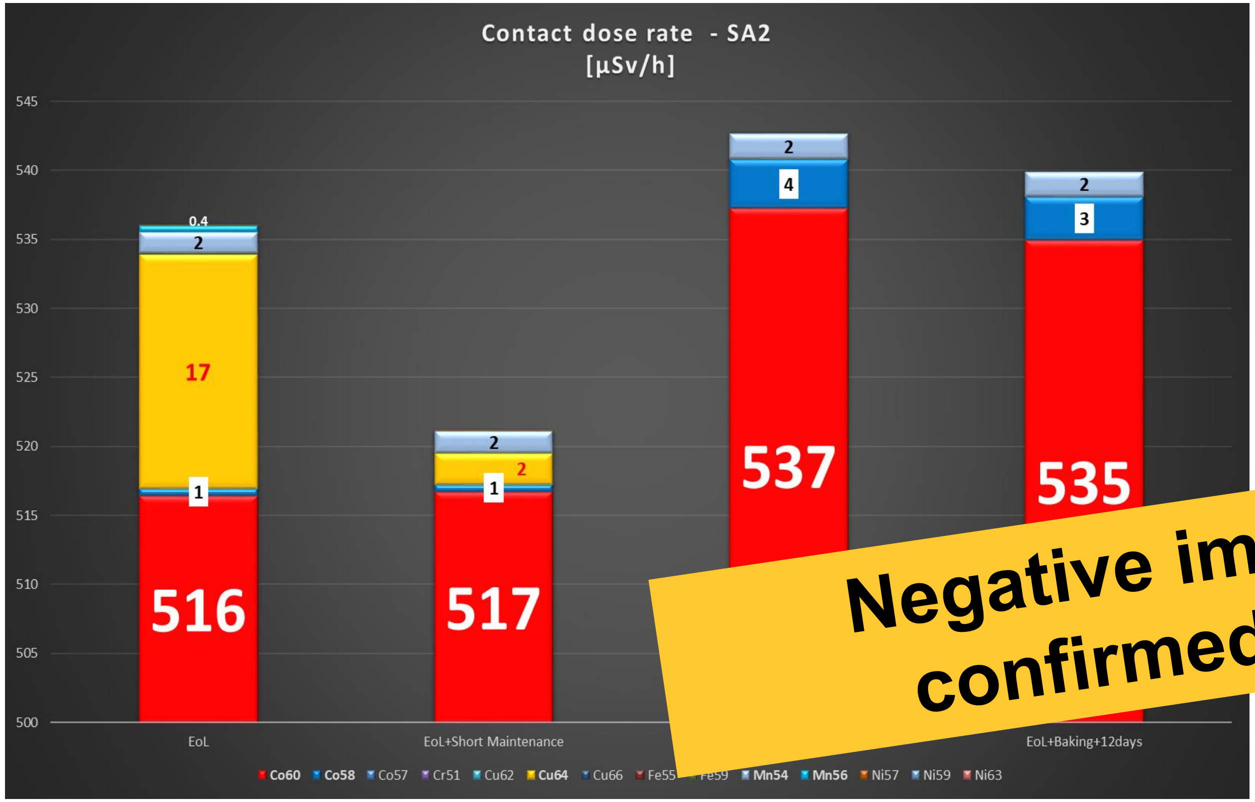


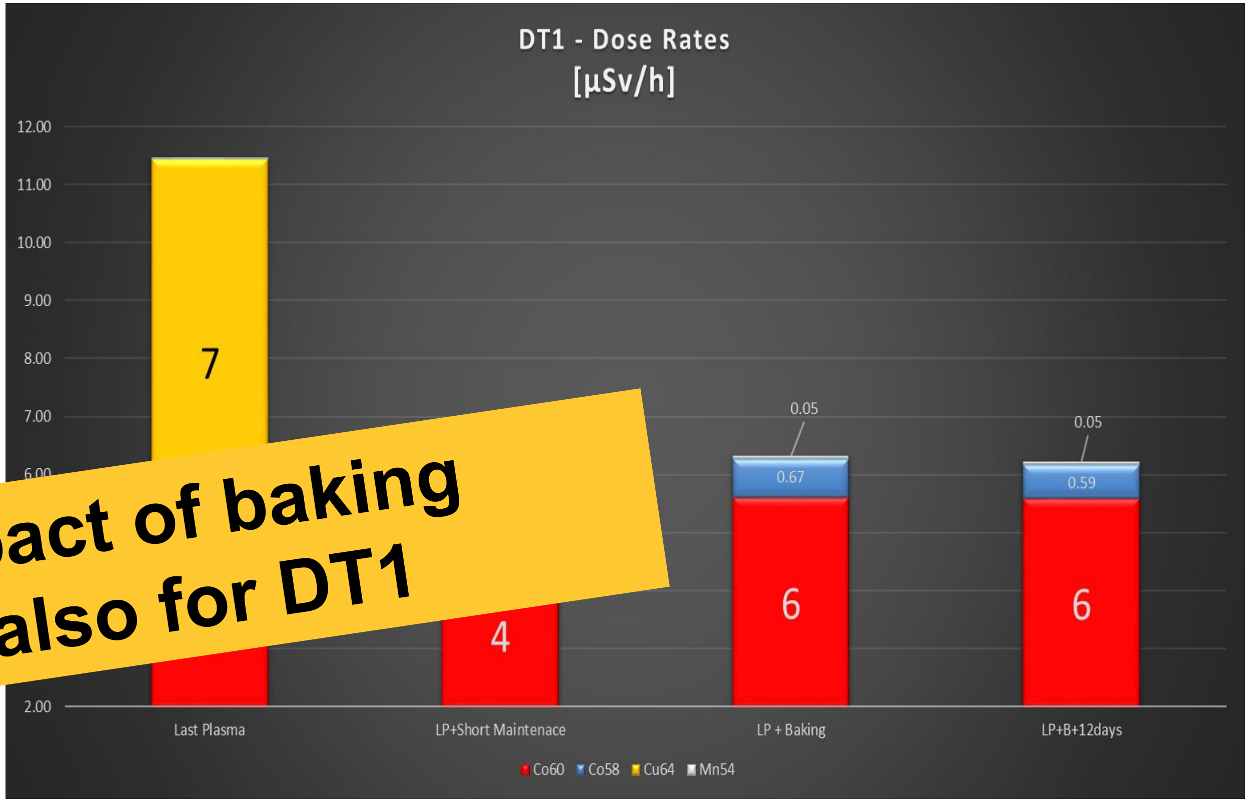
Co-60 Surface activity in the out of flux regions

~ Factor 100 lower for DT1

Dose rate

SA2 vs DT1





Negative impact of baking confirmed also for DT1

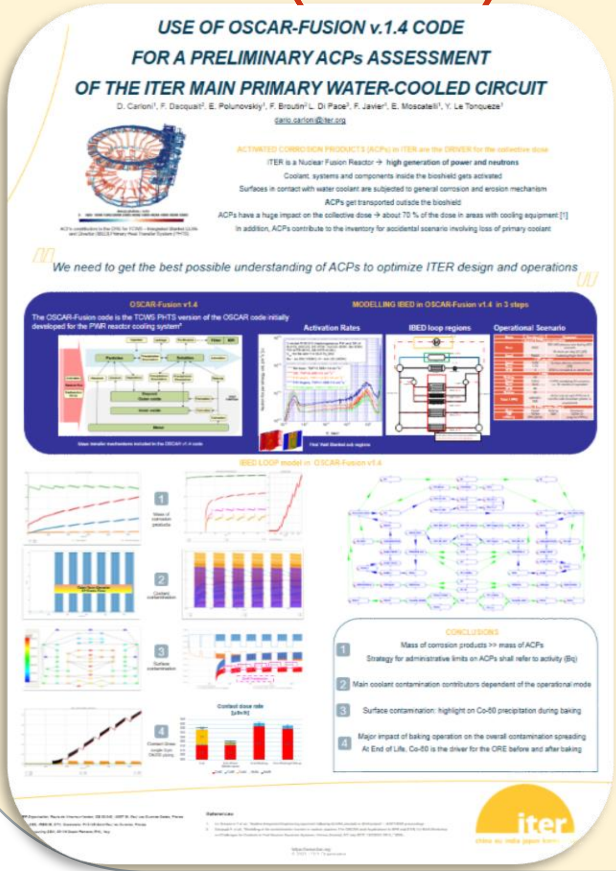
Dose rate

~ Factor 80 lower for DT1 after baking

On IDM

SA2

WP-A-3: Validation of the OSCAR input and its results (87D6BT) V1.6 under review



Paper for FEC2023 [9GS6FN]

Poster for FEC2023 [9PS98U]

DT1

ACPs inventory for DT-1 scenario (9GLRFZ v1.1)

Attached:

DT1_ACPs_Inventory.ods
For Generic Safety Analyses

DT1s_Surface Activity.ods
For ORE studies

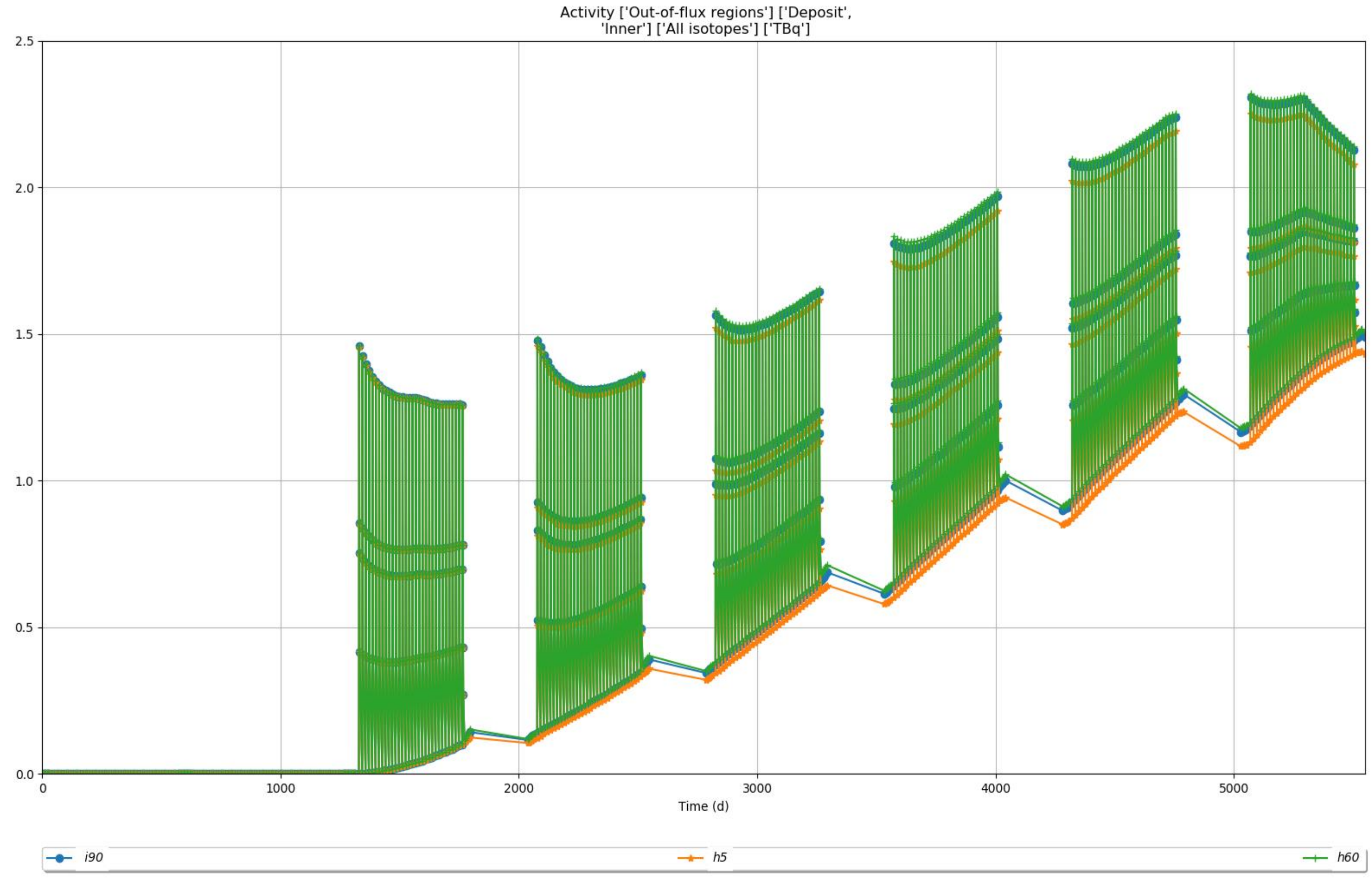
2023
Parametric Studies
on coolant and material properties

(ITER_D_8FZ6DW v1.1)

Analyses Domains

Coolant Chemistry	Operation	Material properties
pH **[H2]**	**CVCS flow rate** **Baking**	**Roughness** **Co content**

H2 Concentration



Five H2 concentrations [ml/kgw]

5

15

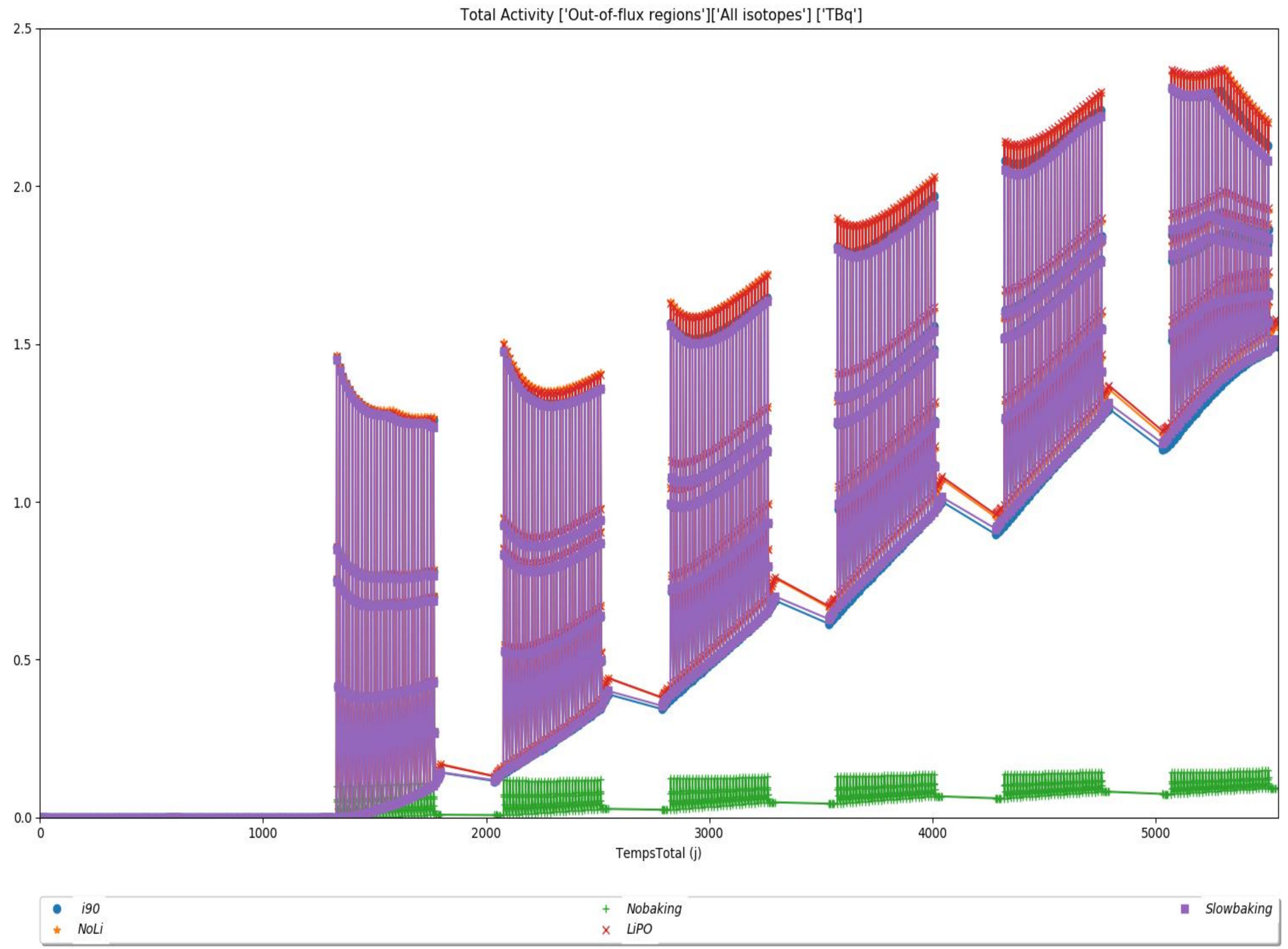
25 (reference)

45

60

Low H2 concentration is preferable

pH Control & Baking operation



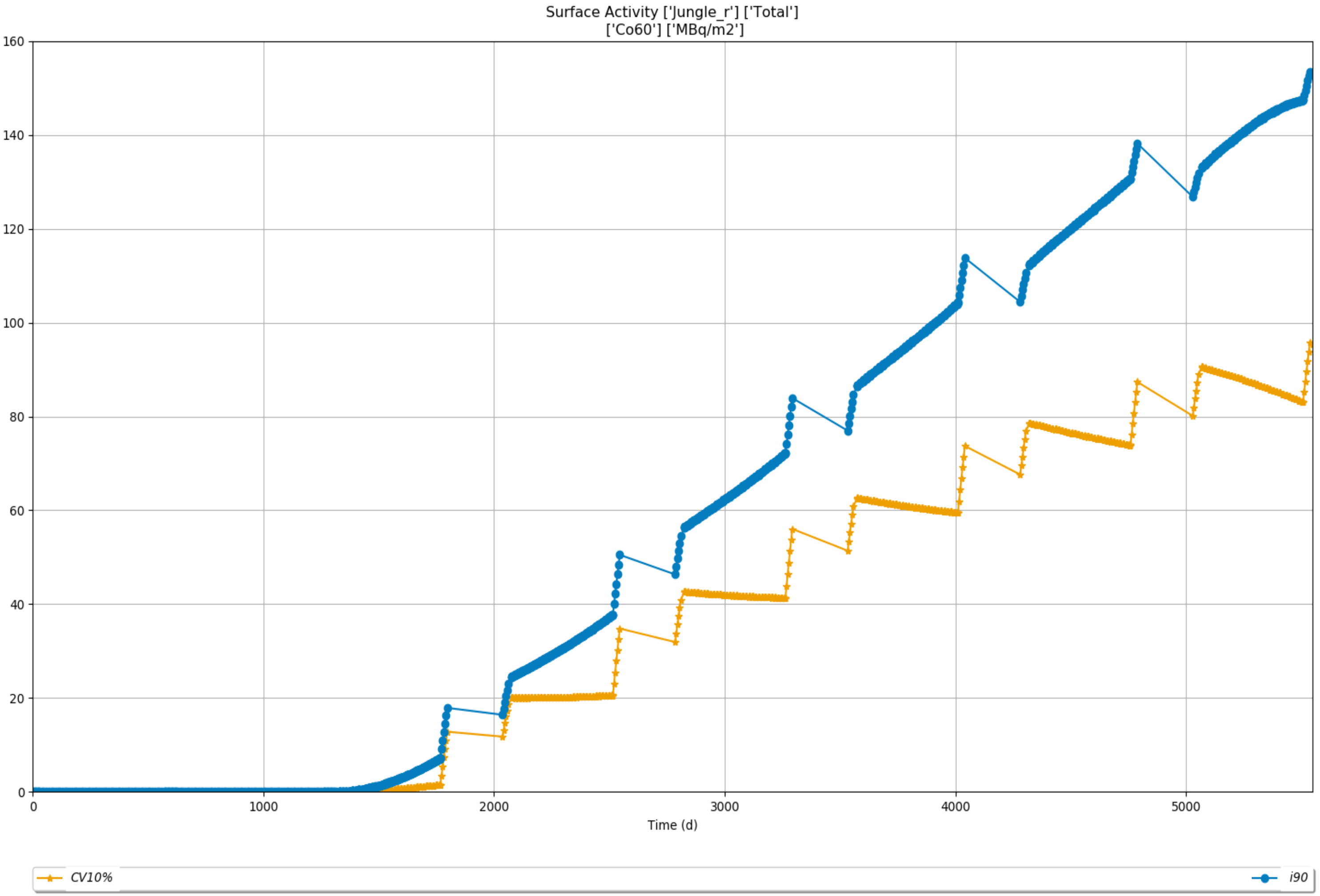
Limited impact of Li injection on the spreading of contamination for selected isotopes (gamma emitters)

pH variation impact on corrosion rates is not simulated by power law in OSCAR

Avoid water baking
Clear benefit in terms of spreading of contamination

Action from RSE to discuss with SCOD/PBS to optimize Baking operation

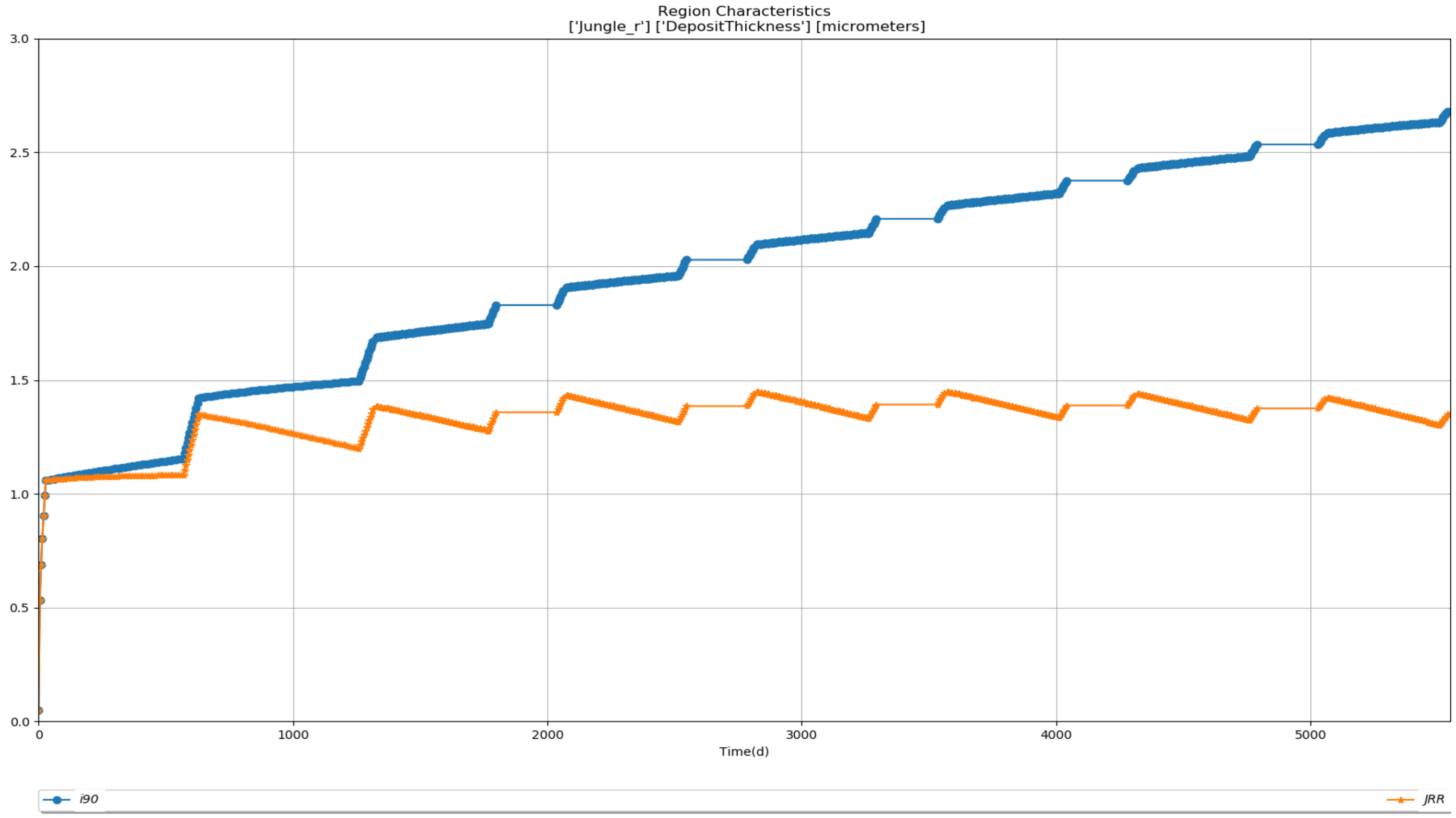
CVCS flow rate → keeping it constant



Impact of CVCS flow increase during baking

Feasibility check regarding the use of CVCS during baking
i.e. temperature and flow rate in CVCS, flow balance in the loop

Pipe Roughness – Jungle Gym 12microns vs 2

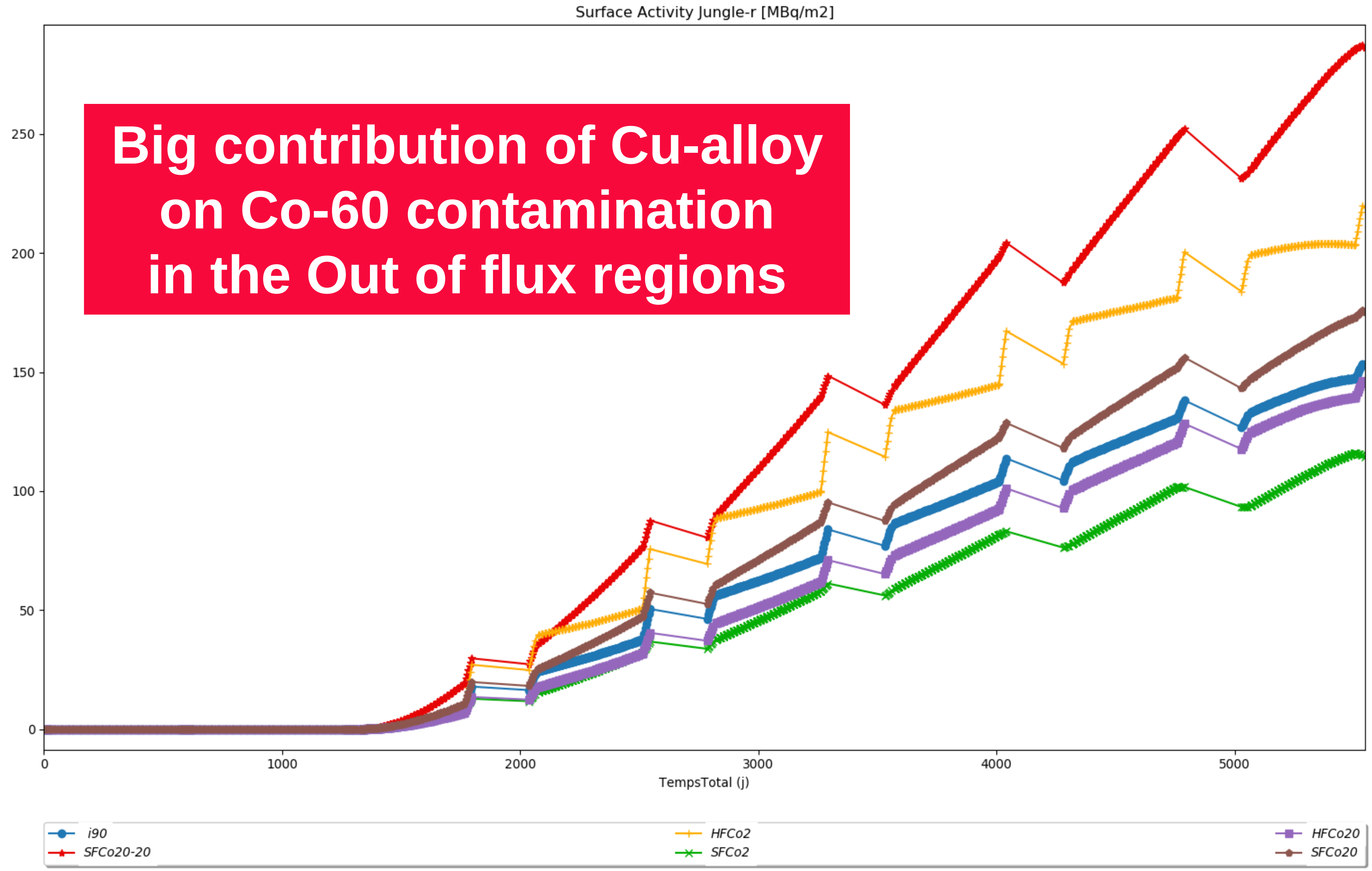


Impact on Jungles surface activity

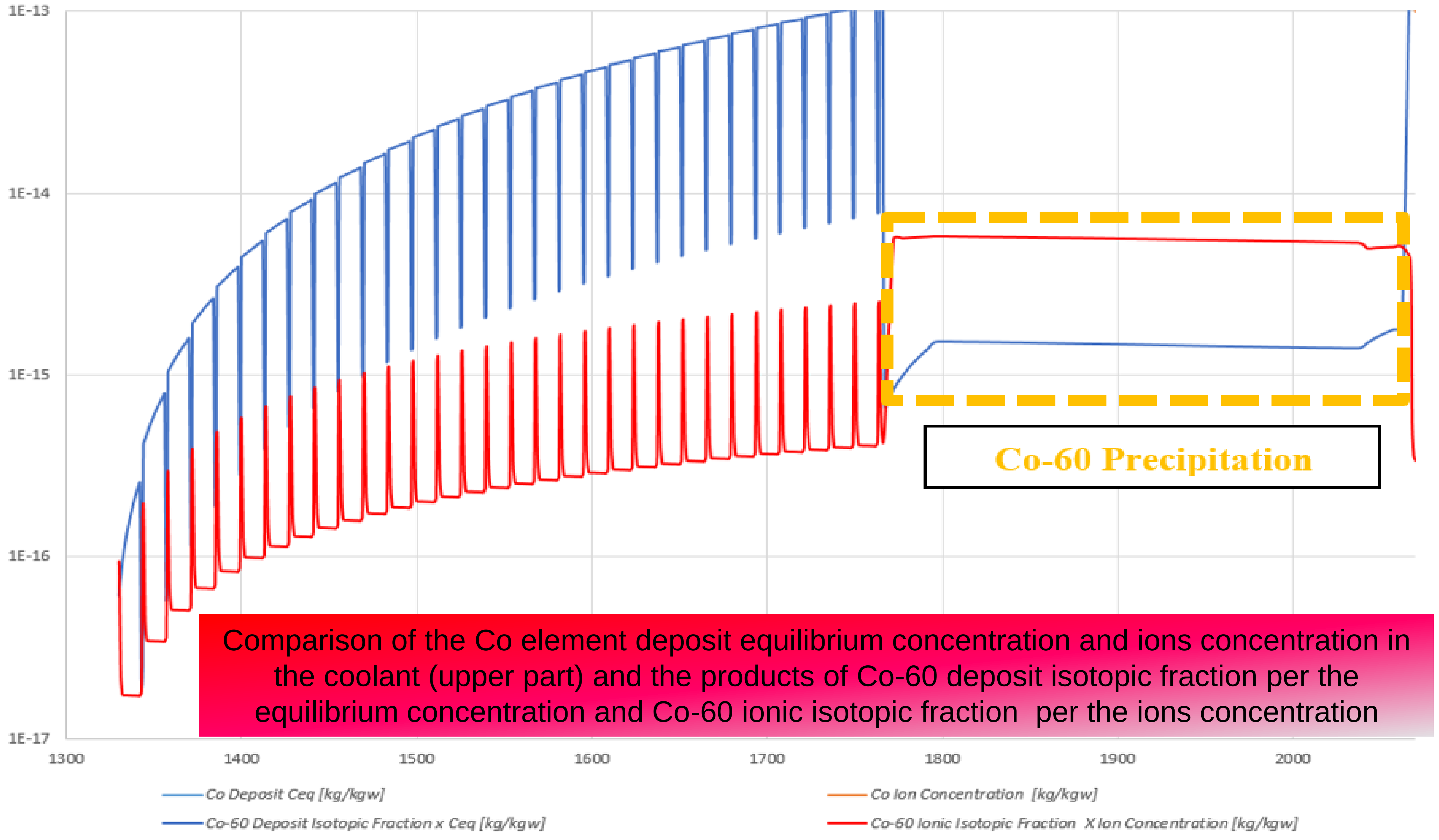
Lower activity due to the deposit erosion occurring in the 2 microns case

Potential impact on other surfaces/regions

Origin of Co content



Co60 precipitation



Comparison of the Co element deposit equilibrium concentration and ions concentration in the coolant (upper part) and the products of Co-60 deposit isotopic fraction per the equilibrium concentration and Co-60 ionic isotopic fraction per the ions concentration

Recommendations for ALARA

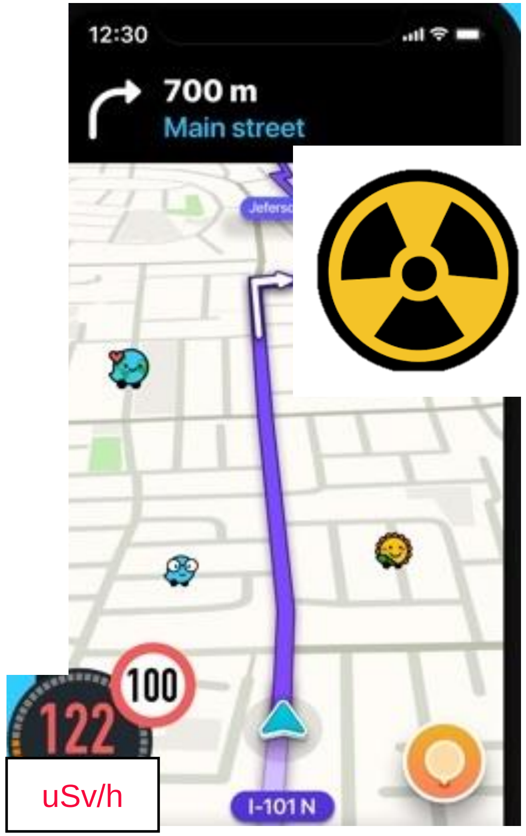
Implement roughness reduction for maintenance and inspection activities impacting ORE

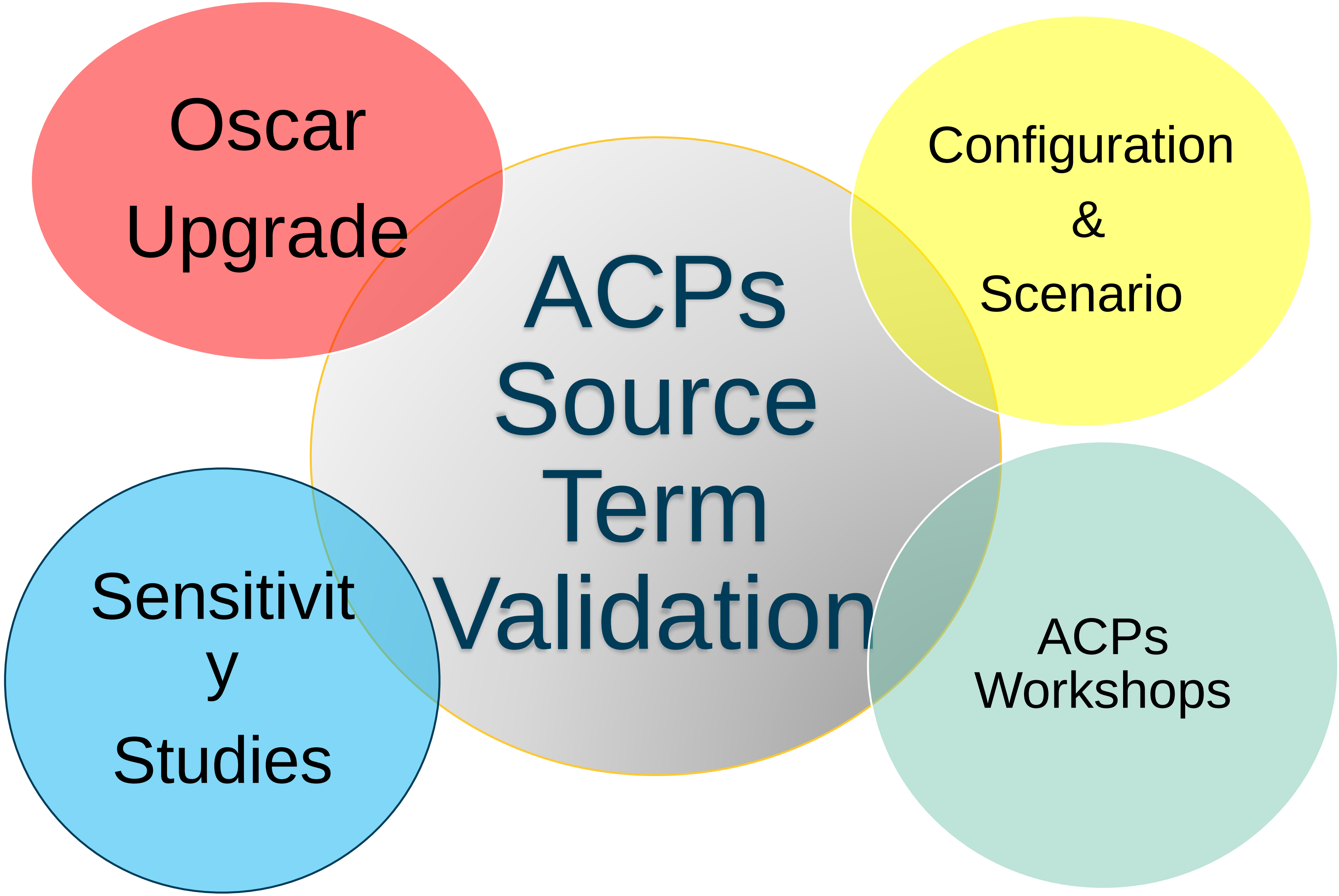
Study alternatives to baking or if not possible,

Study impact of the CVCS flow rate increase

Limit baking frequency and duration

ACPs Roadmap [9GYSM6 v1.0]



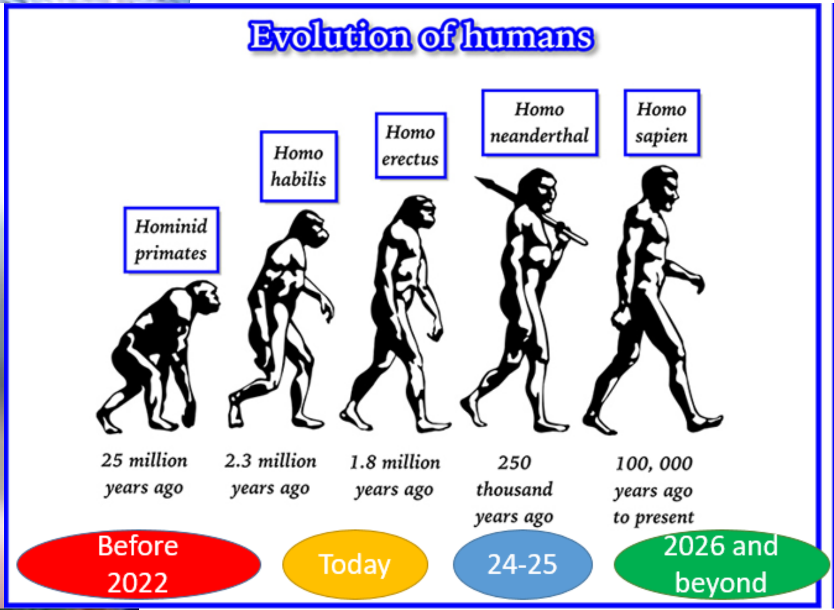


ACPs Programme

Objectives

Resources

Schedule



ACPs Programme - Objectives

Validation of OSCAR input data (corrosion laws + chemistry)

Consolidation of OSCAR results + uncertainties

Definition of the Safety Margins applicable at ITER ACPs source term

Proposal of DRMs (Safety Engineering) verified by OSCAR results in collaboration with CIO and concerned PBSs

ORE assessment update

validated Dose Reduction Measures and ACPs source term + safety margins

International synergy including fusion and fission experts (with REAL operational experience) to **pragmatically** support ITER safety demonstration on ACPs source term

ACPs Programme - Timeline

2018
ACPs assessment [XNXW3N]

2019-2022
NIE Studies: ORE update on the basis of the previous OSCAR model

New OSCAR Fusion Version 1.4a showed higher ACPs source term

2023
- NEW TCWS models
- Corrosion laws for CuCrZr
- Simplified Test Loop
- Technical Meeting
- IO - ACPs Workshop

2024
- Review of the TCWS models
- Update of the corrosion laws
- Update of OSCAR models
- Proposal for DRMs
- Uncertainties assessment

2025
- Review and validation of OSCAR corrosion rates
- Definition of the domain of validity of OSCAR simulation for ITER systems
- Consolidate Uncertainties assessment
- Proposal of safety margins
- Validation of the ACPs source term for the safety demonstration

2026
Safety demonstration based on ACPs upper and lower estimates

AFP

2023
ACPs Source Term Update

2024
ACP Source Term + Uncertainties

2025
ACPs Source Term Validation

Thank you!

iter
china eu india japan korea russia usa