PSB Upgrade
LIU Project

PSB DUMP DESIGN

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Thanks to:

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Outline

- Beam parameters
- **C**onstraints, **C**onsiderations and **C**hoices
- Design proposal
- MC and thermo-mechanical analyses
- Shielding and Ancillaries
- Conclusions and ongoing work
- Next steps

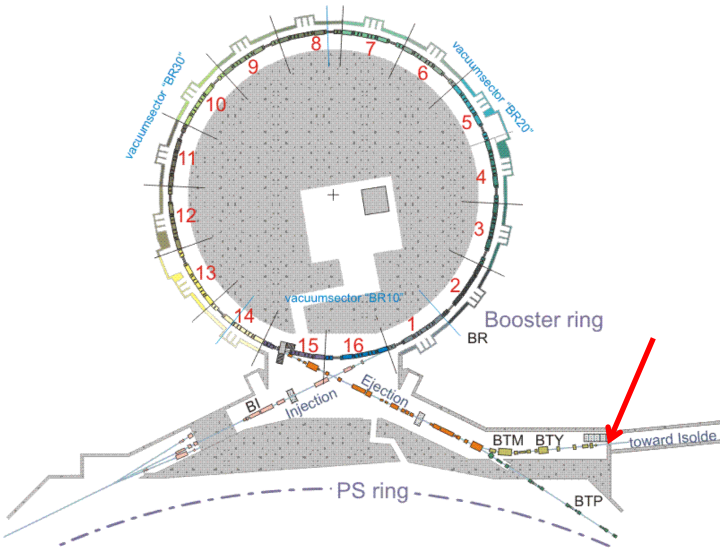
Beam Parameters

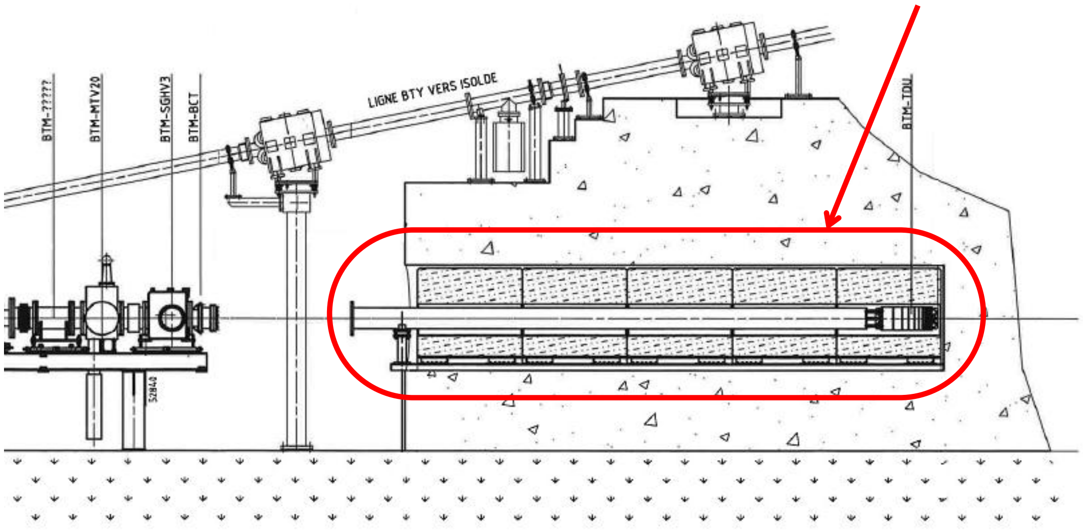
- **Design parameters:**
  - Max beam intensity: 1E14 p+/pulse
  - Beam energies: 1.4 & 2 GeV
  - Pulse length: 1.66 μs
  - Pulse period: 1.2 s (900ms not considered here)
  - Total Average beam power: 26.7 kW
  - Min beam size (1σ, H x V): 0.37 x 0.71 cm^2
- **Operational parameters:**
  - beam dumped: 10% operation, 50% commissioning
  - Use: 24h/day, 11m/year, 30years
  - 100% of minimum beam size (**conservative**)
  - Max intensity: 33% operation, 100% commissioning

Constraints

- **Lifetime**: 30 years, ~7.6E8 cycles (commissioning + operation), 7.24E21 p^+ at minimum beam size (≡ 2.7E22 p^+/cm^2)
- **Installation**: August 2013 at latest
- **Location**: same location as the old dump
- **Space limitation**: shielding removal, 5m-long 1m-dia cavity → use for dump core + cooling + new shielding

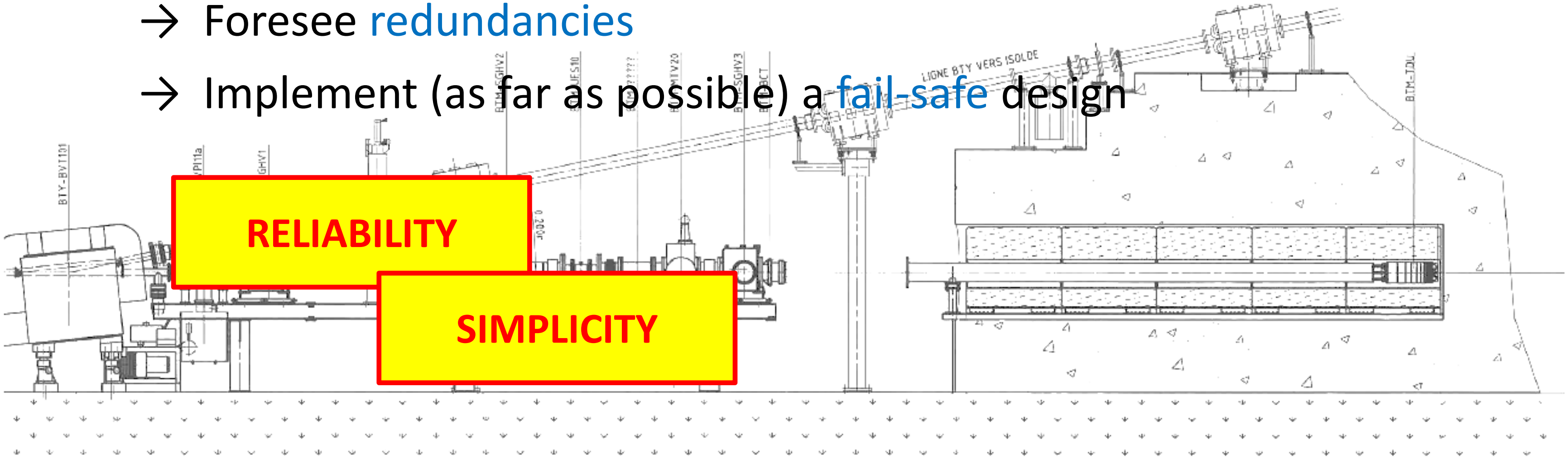
SAFETY FACTOR !





Considerations and Choices

- **Maximize Reliability**:
  - → Implement simple design (no vacuum, no welding, simplify assembly, ease & speed-up manufacturing)
  - → Minimize failure risk by maximizing safety margin
- **Access restrictions** (no easy for maintenance and min 4 months shutdown to eventually replace the dump):
  - → Implement a Ø (in-situ) maintenance design
  - → Foresee redundancies
  - → Implement (as far as possible) a fail-safe design



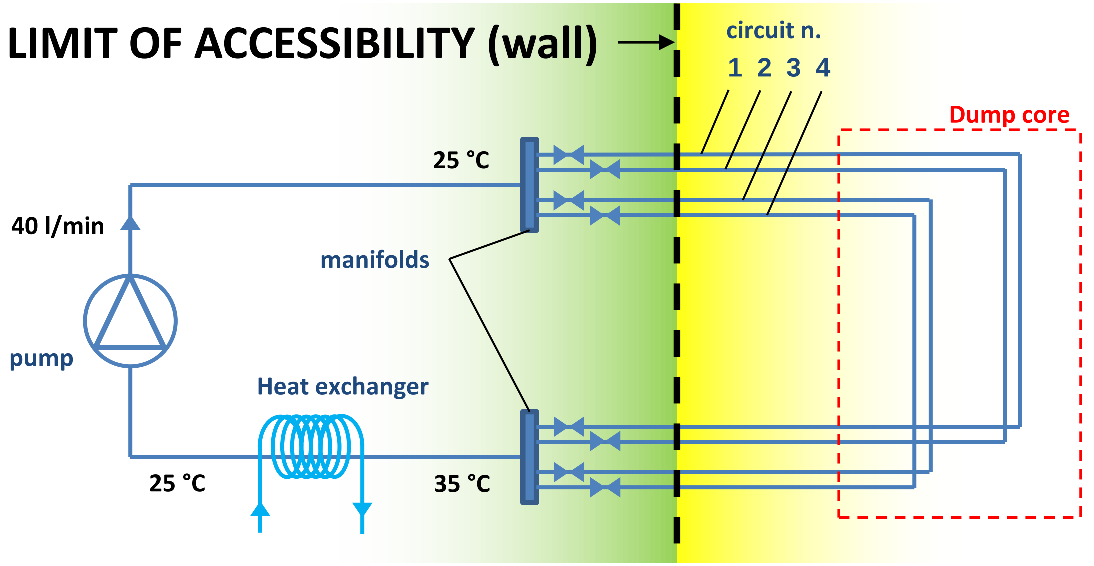
RELIABILITY

SIMPLICITY

Considerations and Choices

- **Operation & Cooling**:
  - Operation of the dump is continuous, 26.7kW
  - Active cooling is needed (thermal radiation + stagnant air not enough)
  - Forced air cooling is not possible → water cooling @ 22°C, min 40 l/min (min 60 l/min for 900ms RR)

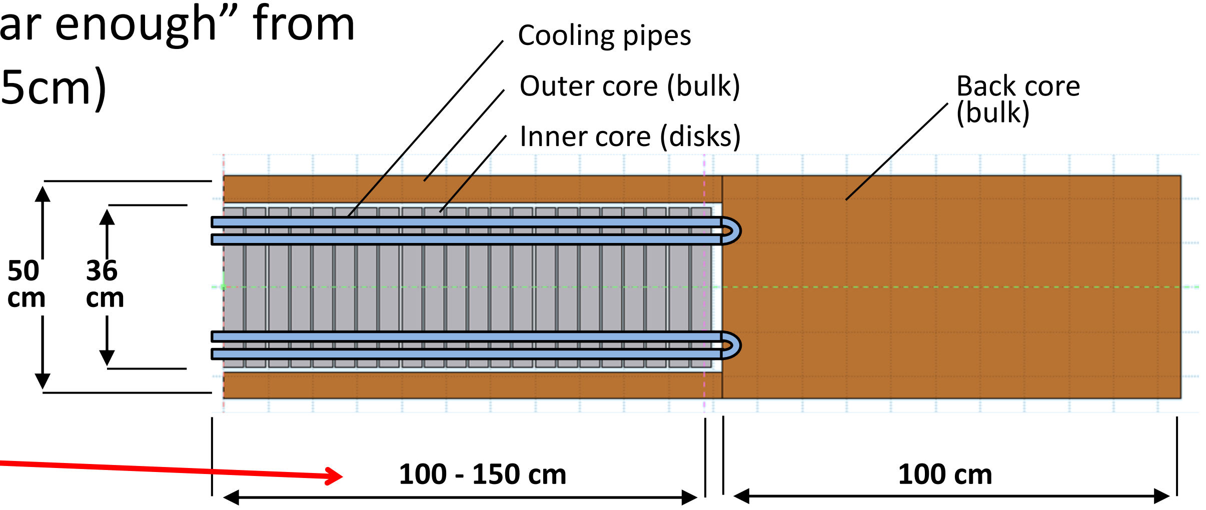
SAFETY FACTOR !



- redundancy (4/6 independent circuits, survival with 1)
- Limited erosion-corrosion in pipes with at least 2 active circuits (316L)
- Avoid welds → use of long (>7m) bended pipes

Considerations and Choices

- **Core minimum dimensions**:
  - → Minimum 140cm Cu-equivalent length to intercept all primary particles
  - → Minimum 50cm-dia to intercept 5σ of maximum beam size
- **Layout:**
  - Reduce stresses in the inner core: collection of several thick disks rather than a bulk block of material
  - Reduce stresses in the pipes: prefer clamps over welds
  - Cooling pipes “far enough” from beam axis (r = 15cm)



SAFETY FACTOR !

Considerations and Choices

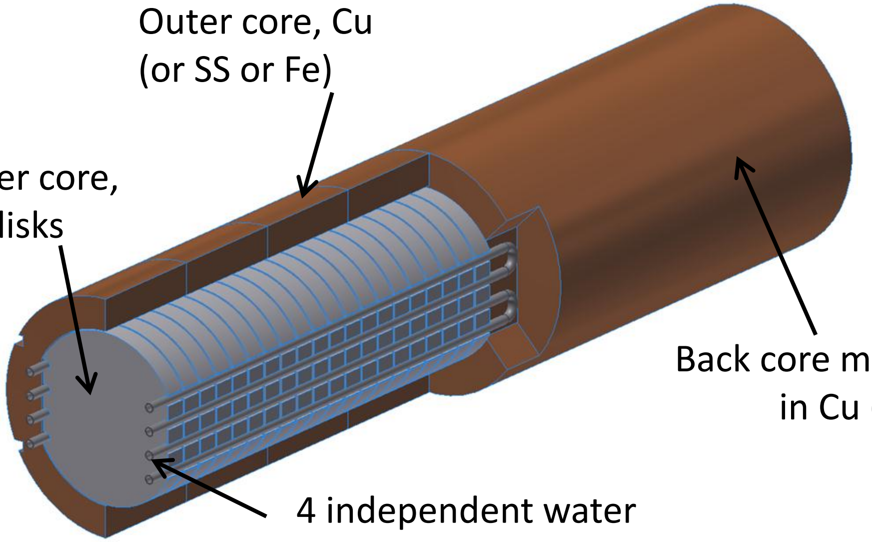
- **Materials:**
  - Avoid inert atmosphere
  - Use of well known classic materials
  - ↓-density & ↑-conductivity, relatively ↑-strength for inner core (absorber): (Ti, C), Al or Be
  - ↑-density & ↓-activation for the outer core and back core: SS, Cu or Cobalt reduced-Fe
  - Maximize long-term performance (↓-radiation damage, ↓-creep, ↑-corrosion resistance) and avoid Galvanic coupling

→ **Al + Cu is today baseline.**

→ **The proposal which follow is the results of many iterations between MC and thermo-mechanics.**

→ **All analyses at 2GeV, max intensity**

Design proposal



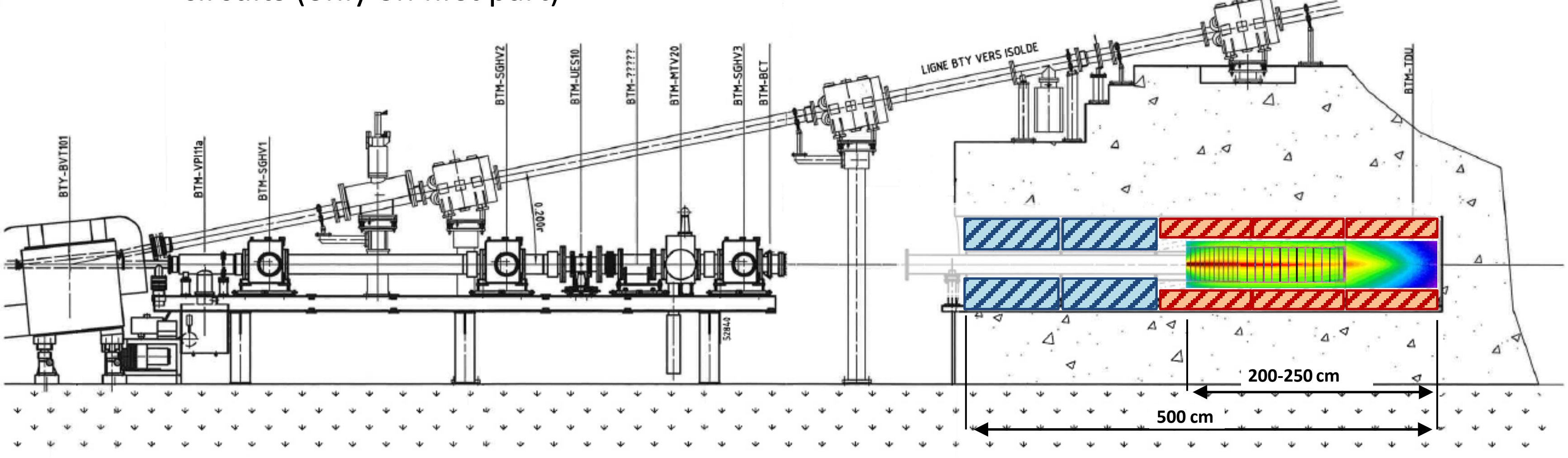
Outer core, Cu
(or SS or Fe)

Inner core,
Al disks

Back core made entirely
in Cu (or SS or Fe)

4 independent water
circuits (only on first part)

Al keeps levels of energy deposited by the impinging beam low (diluted), while Cu helps to release the heat generated in the back core and acts as a first shielding in the outer core.



Design proposal

- **Inner Core :**
  - Aluminum type **A60xx** (60, 61, 63) provides the best in terms of mechanical strength, thermal conductivity, corrosion and radiation resistance at the lowest cost (inner core = 6 kchf).
  - ↑k helps reducing the risk when reducing to 1 cooling pipe (T remain quite uniform)
  - Be would provide a higher design safety margin, but very expensive (inner core = 150 kchf)
- **Outer & Back Cores :**
  - Cu and SS equivalent for RP. Cu helps release heat better, SS releases less pre-stress in time at ↑T.
  - Cobalt reduced-Fe or SS are better for RP and may be a viable compromise (↑-cost, to be studied…)

Design proposal

Property @ RT	unit	316L	A96061 T651*	C10700 H02*	↓Co-Fe ↓Co-SS
Yield Str **Y_T**	MPa	250-300	253	300-400	-
Elongation at break **A%**	%	40-50	8.9	15	-
Young Modulus E	GPa	194	70	117-126	-
Fatigue @1E7 cycles **S_F**	MPa	240	102	105	-
Max Service **T_S** - Indicative	C	800	170	300	-
Thermal Conductivity λ	W/m C	13	168	387	-
Specific Heat **c_P**	J/kg C	486	953	385	-
Thermal expansion α	1/C	1.7E-5	2.4E-5	1.67E-5	-

A% ↑

$\frac{\alpha E}{c_P Y}$ ↓

T_S ↑

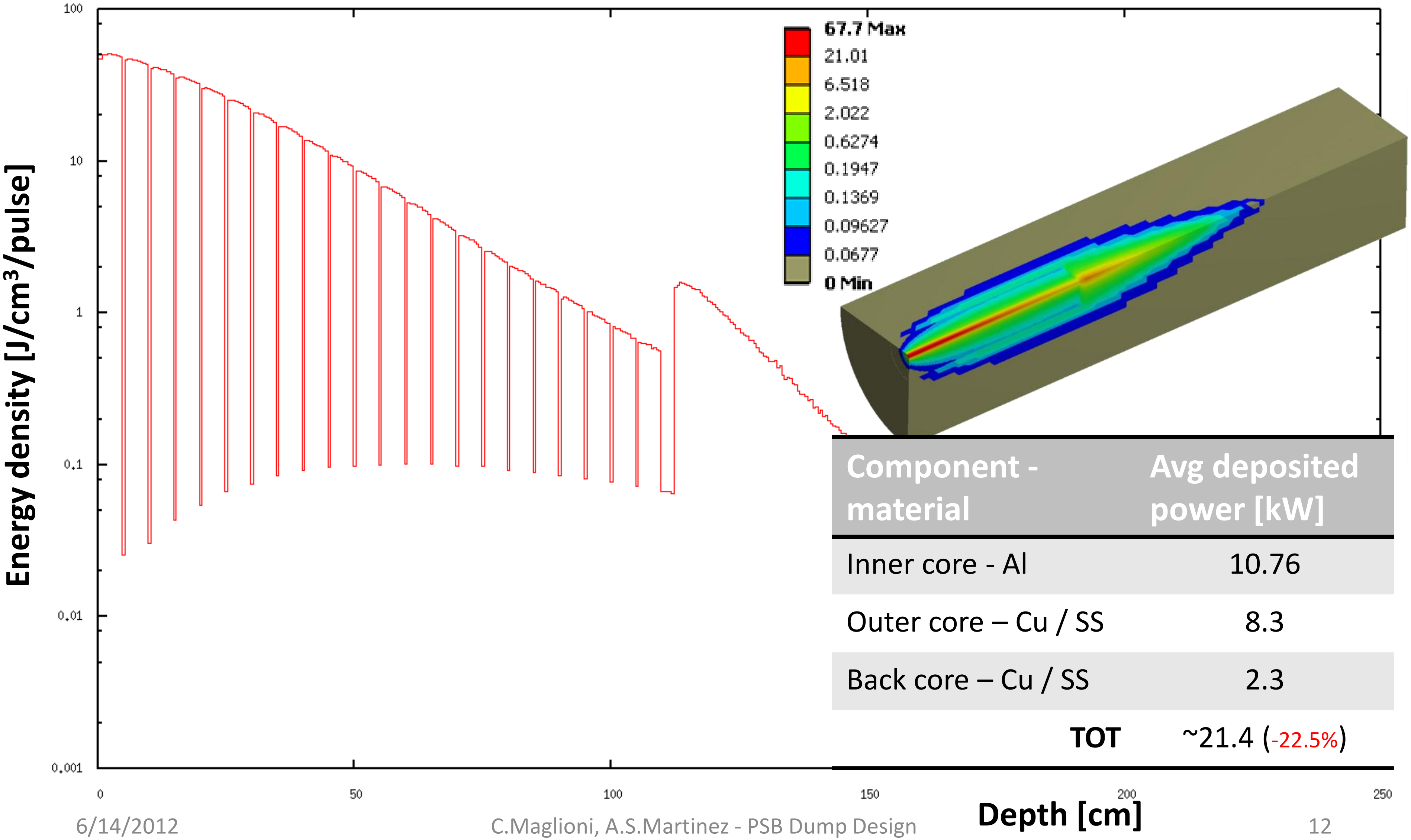
λ ↑

Possible ↓Co-Iron and Steels:

- 316L(N)-IGX (iter grade, ↑literature, data), EU?
- AL 29-4C (UNS S44735) → USA
- 304L VIMVAR → UK, USA

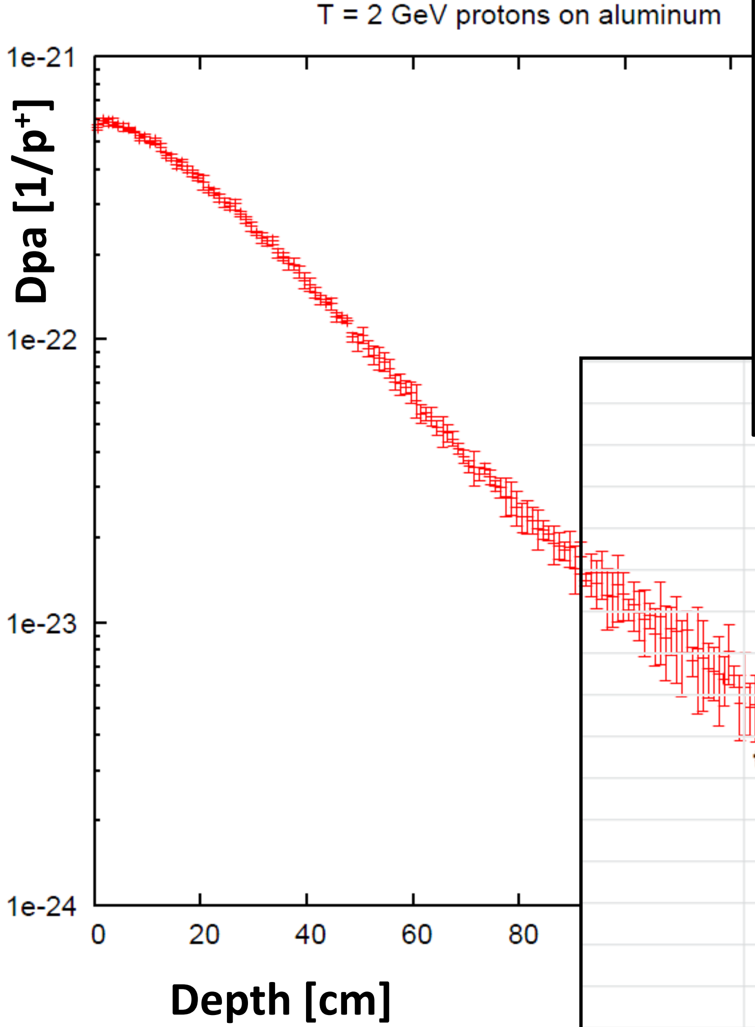
??cost??

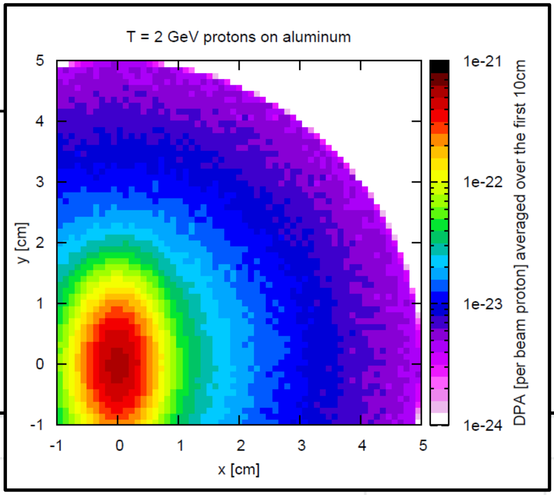
Monte Carlo Analyses



Component - material	Avg deposited power [kW]
Inner core - Al	10.76
Outer core – Cu / SS	8.3
Back core – Cu / SS	2.3
TOT	~21.4 (-22.5%)

Radiation Damage in Al





30% safety margin (optic may change)

- No swelling expected
- 50% embrittlement
- 30% hardening

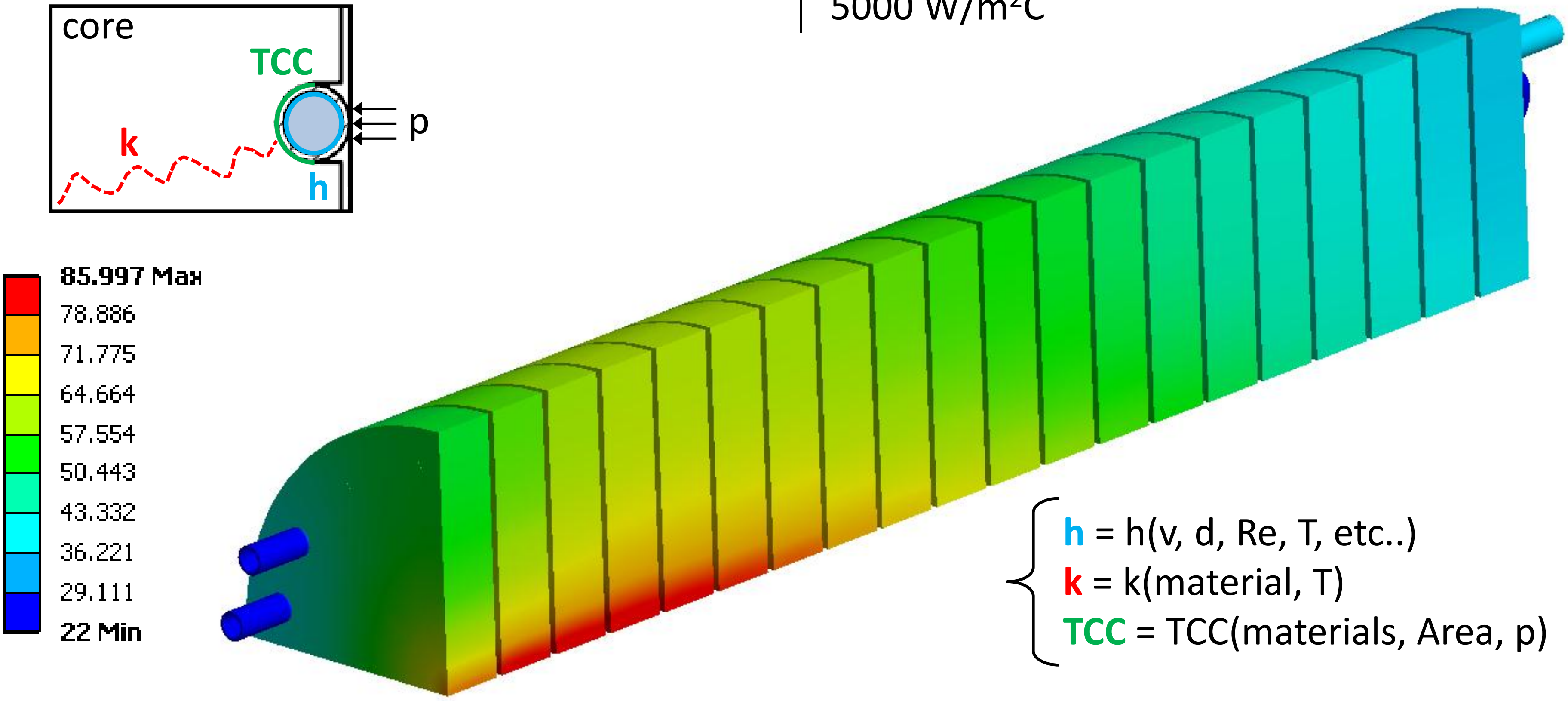
			source	notes
Al damage threshold	27	eV	F. Cerutti	
peak dpa	6.00E-22	dpa/p+	F. Cerutti	
cycle period	1.20	s	K. Hanke	
tot n cycles -op	7.23E+08	cycles	K. Hanke	
tot n of p+ dumped -op	7.23E+21	p+		if always at max intensity
tot n of p+ dumped -op	3.60E+21	p+		1/3 @ max I, 2/3 @ 1/4*i
tot n cycles -comm	3.94E+07	cycles		
tot n of p+ dumped -comm	1.97E+21	p+		1/1 @ max intensity
tot n of p+ dumped	7.24E+21	p+		
max intensity	1.00E+14	p+/pulse	K. Hanke	
tot peak dpa	4.34	dpa		
fluence fast n on 6063	1.90E+22	n/cm2		@ 117 C
PSB dump core	2.75E+22	p+/cm2		@ ~100 C
expected increase of Yield	27%		literature	hardening
expected increase of Ultimate Strength	28%		literature	hardening
expected decrease of Elongation %	-51%		literature	embrittlement

Thermal Steady Analyses

Steady-state temperature T [°C] of inner core with nominal cooling conditions ←

- A96061 core
- 316L pipes (Øi 16mm, 2mm thick…)

- 40 l/min equally distributed on 4 circuits
- Nominal convection coefficient
$h(T = 25\text{-}35\ C) = 3800 – 4200\ W/m^2C$
- Thermal Contact Conductance pipes-Al = $5000\ W/m^2C$

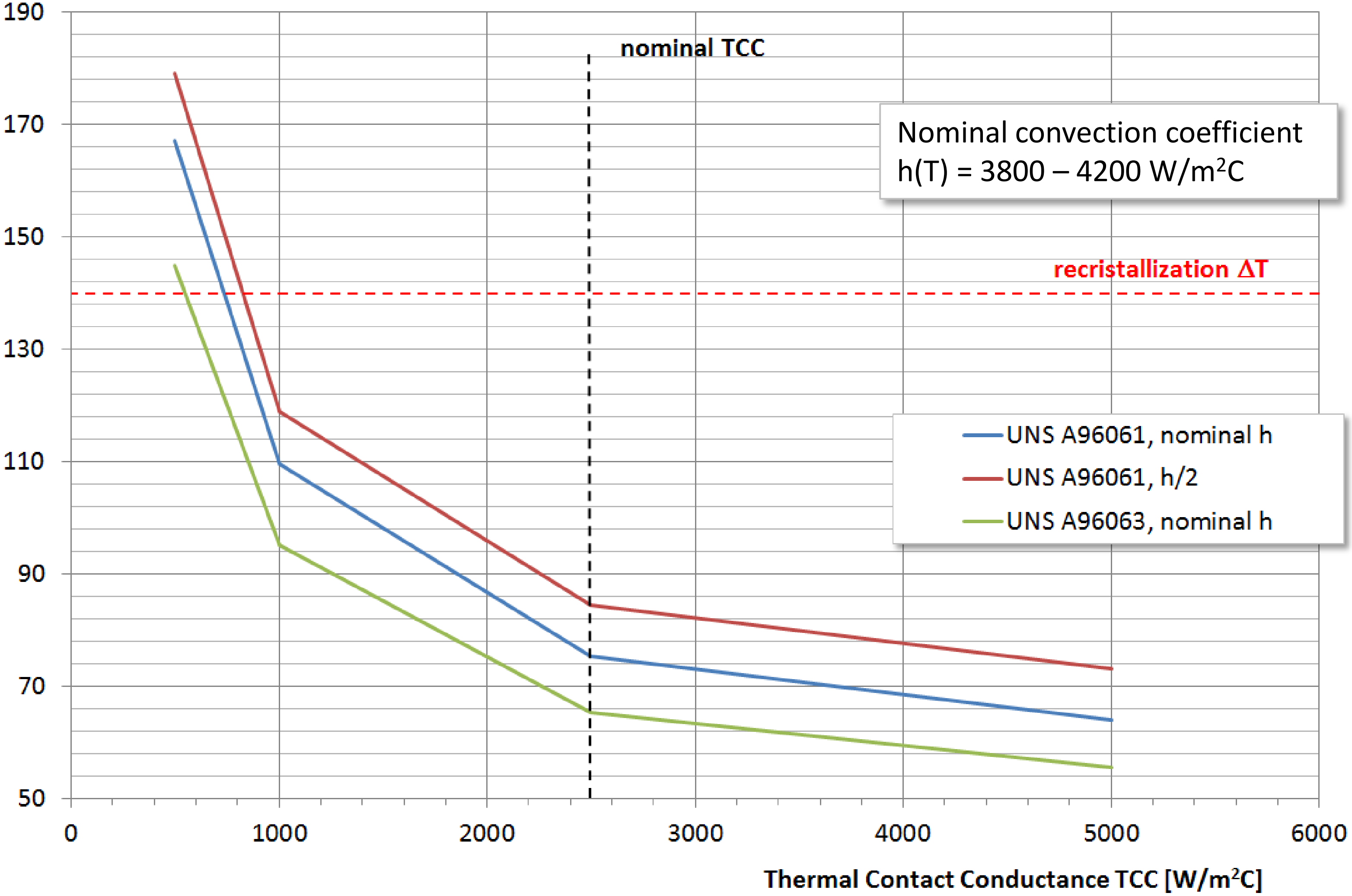


h = h(v, d, Re, T, etc..)
k = k(material, T)
TCC = TCC(materials, Area, p)

Thermal Steady Analyses

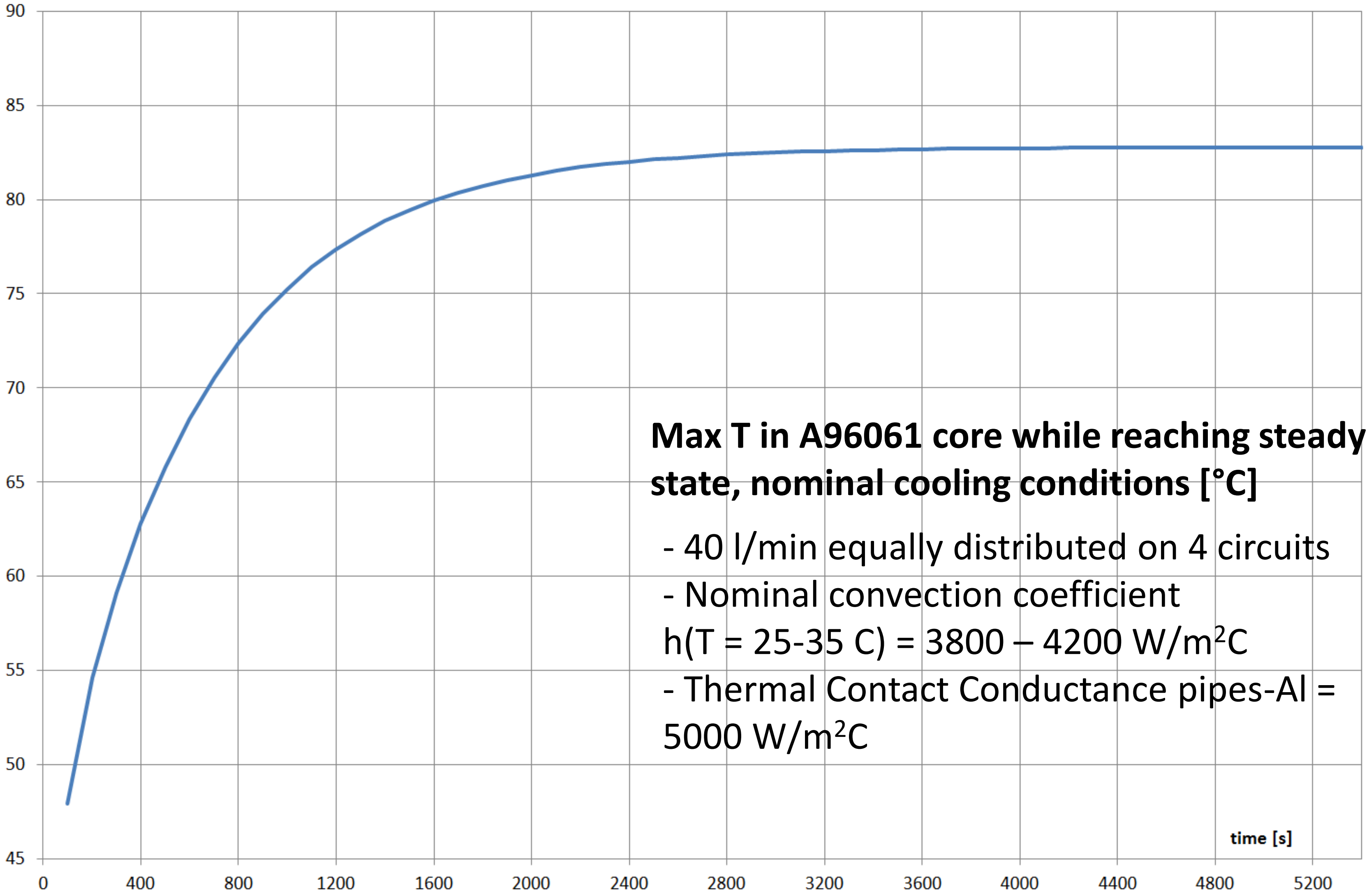
TCC is as important as ***h*** and ***k***, but more difficult to get and to control

Max ΔT in A96061 core in steady-state [°C]



Nominal convection coefficient
h(T) = 3800 – 4200 W/m^{2}C

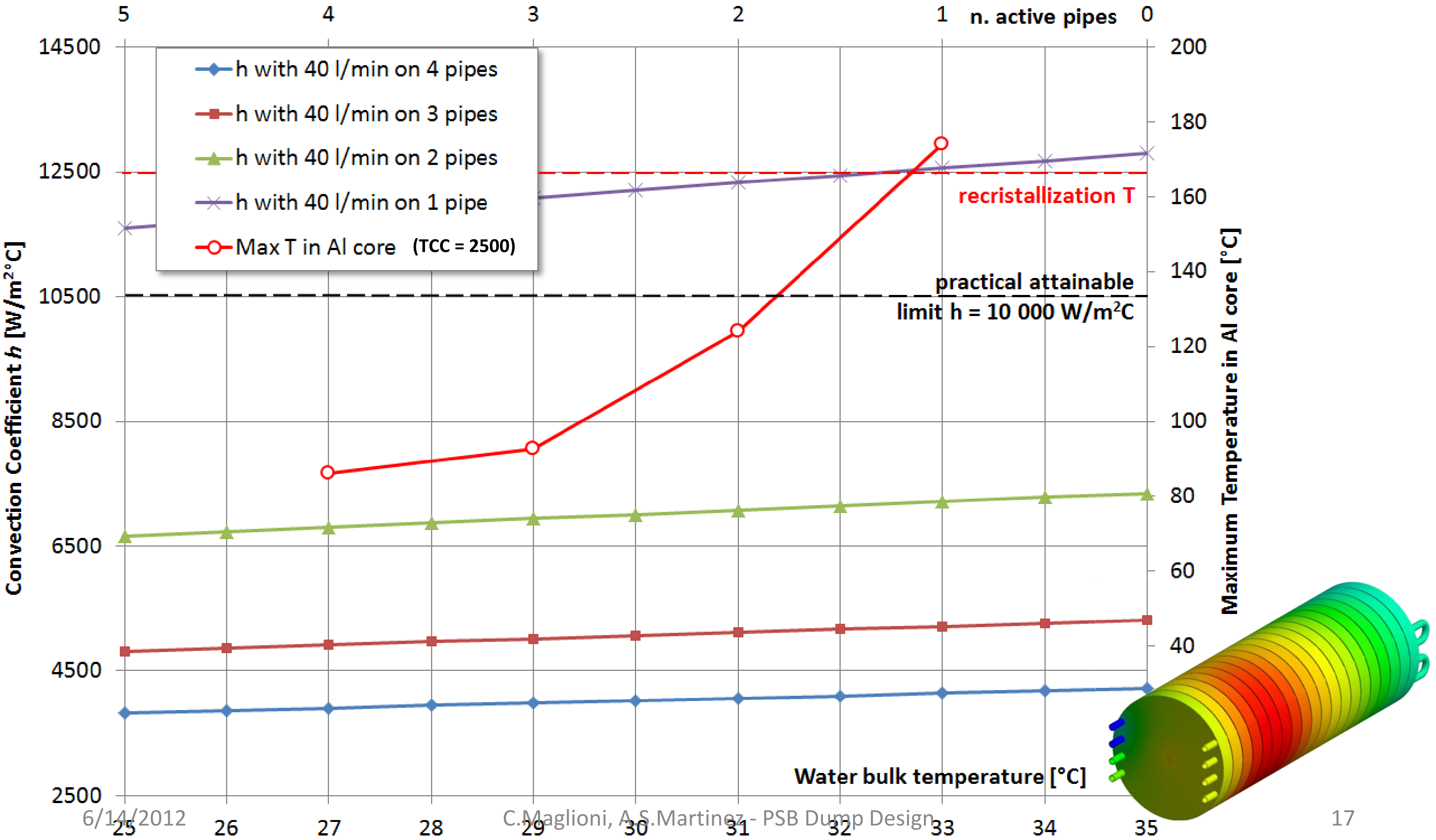
Thermal Transient Analyses



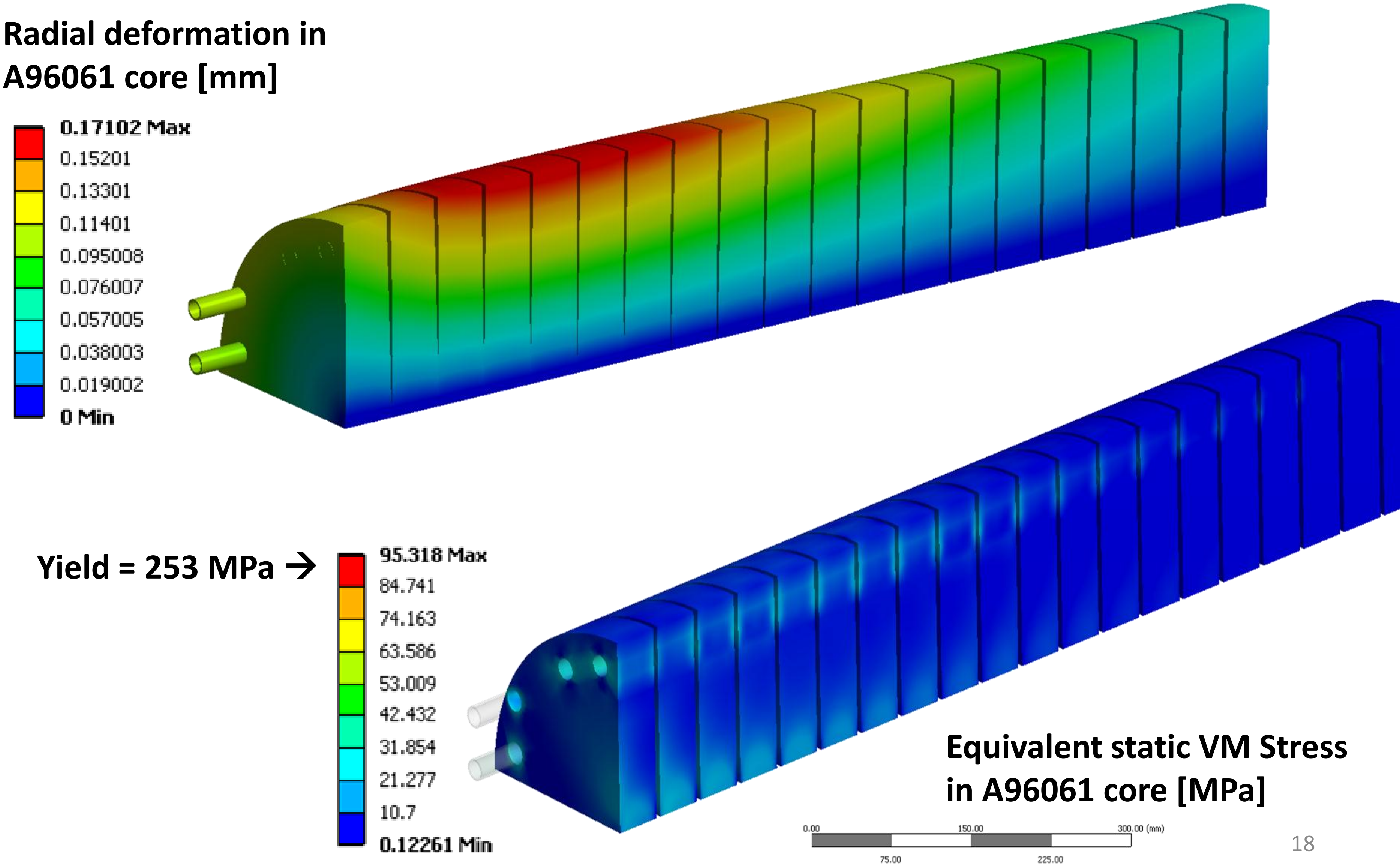
Max T in A96061 core while reaching steady state, nominal cooling conditions [°C]

- 40 l/min equally distributed on 4 circuits
- Nominal convection coefficient h(T = 25-35 C) = 3800 – 4200 W/m^{2}C
- Thermal Contact Conductance pipes-Al = 5000 W/m^{2}C

…working with less pipes…



Structural Steady Analyses



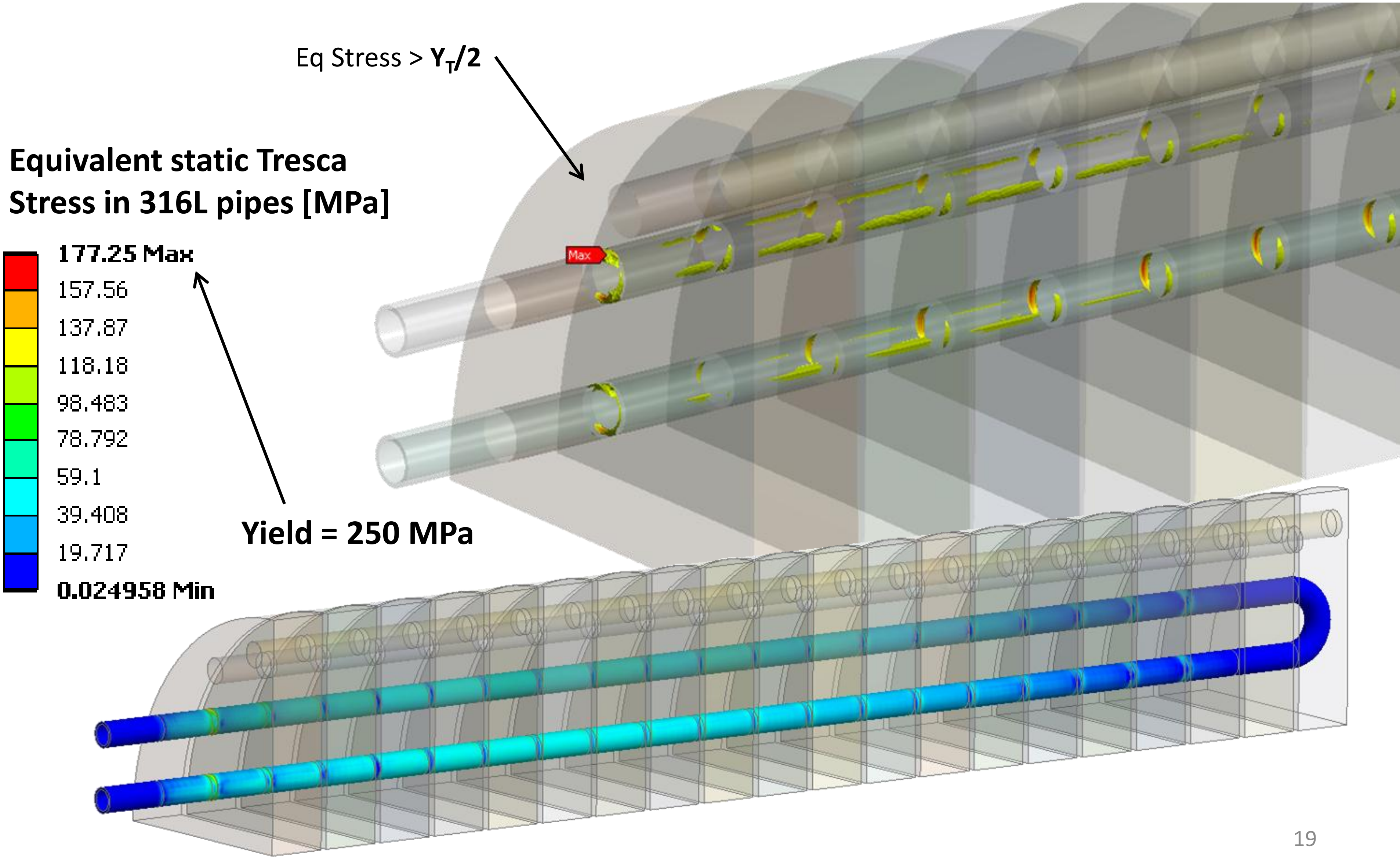
Radial deformation in A96061 core [mm]

Yield = 253 MPa →

Equivalent static VM Stress in A96061 core [MPa]

Structural Steady Analyses

Equivalent static Tresca Stress in 316L pipes [MPa]

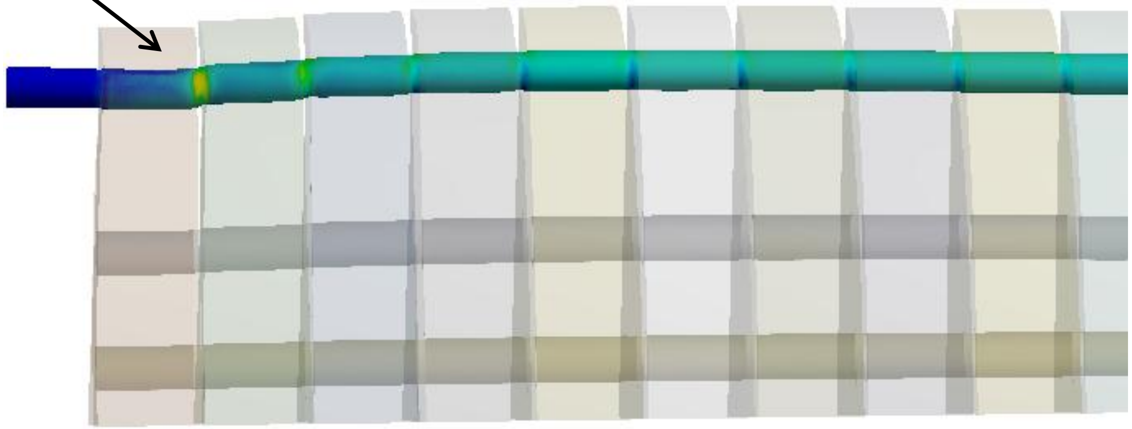


Eq Stress > $\mathbf{Y_T/2}$

Yield = 250 MPa

Structural Steady Analyses

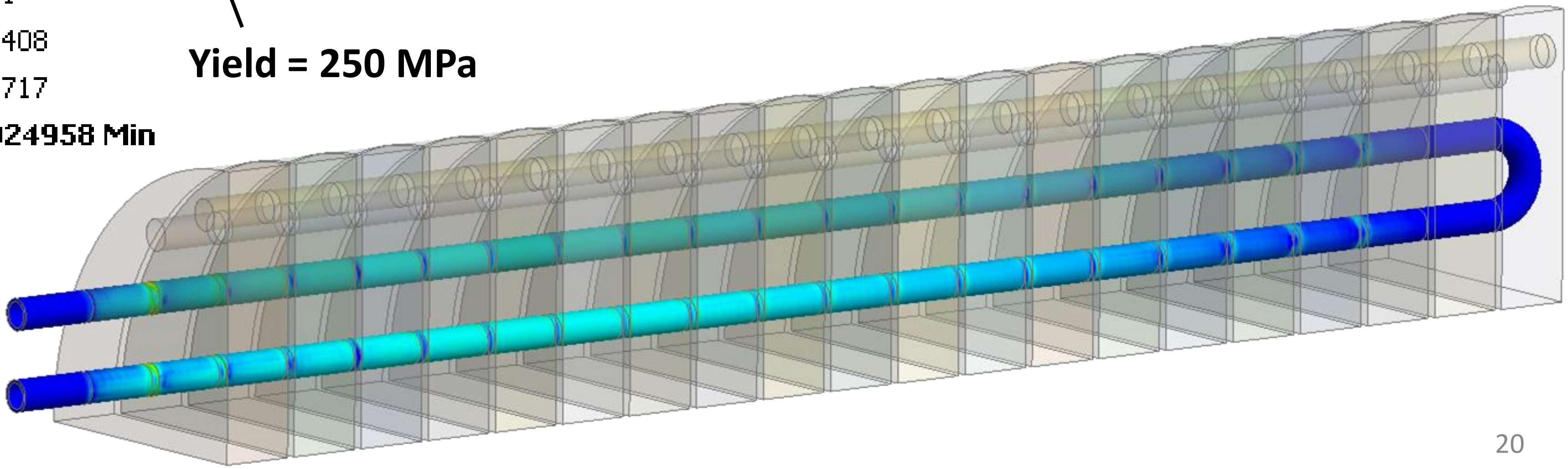
Max here



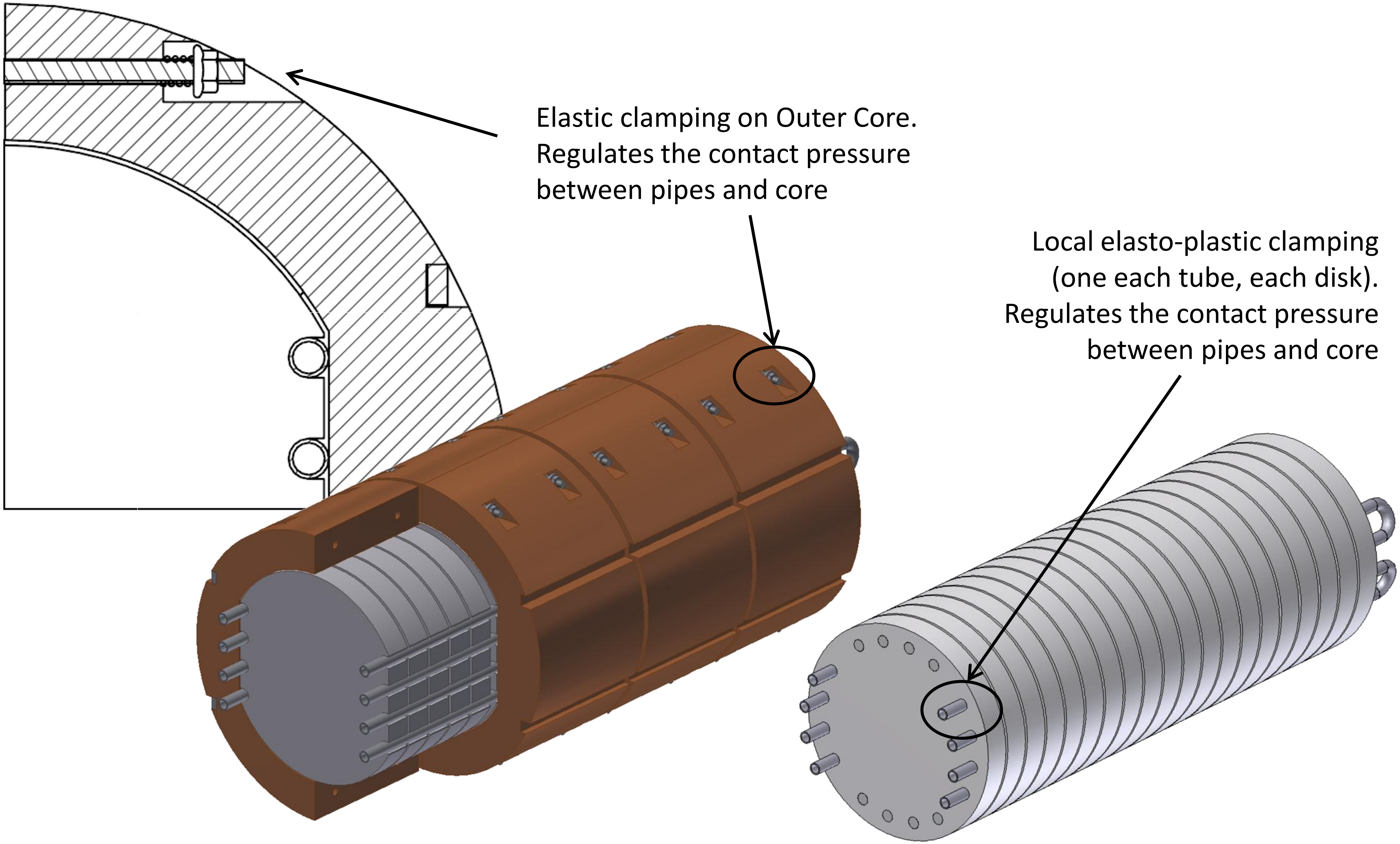
Equivalent static Tresca Stress in 316L pipes [MPa]

177.25 Max
🟥 157.56
🟧 137.87
🟨 118.18
🟩 98.483
🟩 78.792
🟩 59.1
🟦 39.408
🟦 19.717
🟦 **0.024958 Min**

Yield = 250 MPa



Design proposal



Elastic clamping on Outer Core.
Regulates the contact pressure
between pipes and core

Local elasto-plastic clamping
(one each tube, each disk).
Regulates the contact pressure
between pipes and core

Shielding and Ancillaries

- **Shielding**:
  - ~20% of energy escape the core. The design of the shielding is in progress by RP
  - “Available to fill” 50 cm gap between the dump core and the wall
  - Trolley to slide in shielding + core in design with DO
- **Ancillaries:**
  - Implementation of water leak containment
  - Implementation of endoscopy cavity for off-beam monitoring
- **Cabling & Control:**
  - Thermocouples for core on-line monitoring
  - T sensors and flow meter for the cooling circuit
  - Remote control for valves (manifold) of the cooling circuit

Conclusions & ongoing work

- **The design address considerable number of constraints :**
  - → Beam and operational parameters
  - → Location, logistics
  - → Material and cooling
  - → Reliability, lifetime, space limitation, simplicity
- **Ongoing verifications :**
  - → Static Structural analysis with 3,2,and 1 pipe only
  - → Fine thermo-mechanical analysis of back & outer cores
  - → Dynamic Structural analysis + fatigue life assessment of Al core
  - → Assessment of variability of *k* with radiation damage
  - → Pipe connection – detailed development
  - → Choice of (long) pipe supplier

Next steps

- Final choice of materials and study ↓-Co steel option **< 01/07/12**
- Design of core/pipe connection **< 01/08/12**
- Iterations MC/thermo-mechanics (simulations) ⍰ optimization of design (energy deposition, escaping particles and thermal stresses) **< end summer ’12**
- dump eng specification **< end summer ’12 (but > func spec!)**
- Final global design: beam dump core + shielding (from RP) **< end summer ‘12**
- ALARA and dismantling/assembly procedure **< 01/12/12**
- Look into **900ms** option ?

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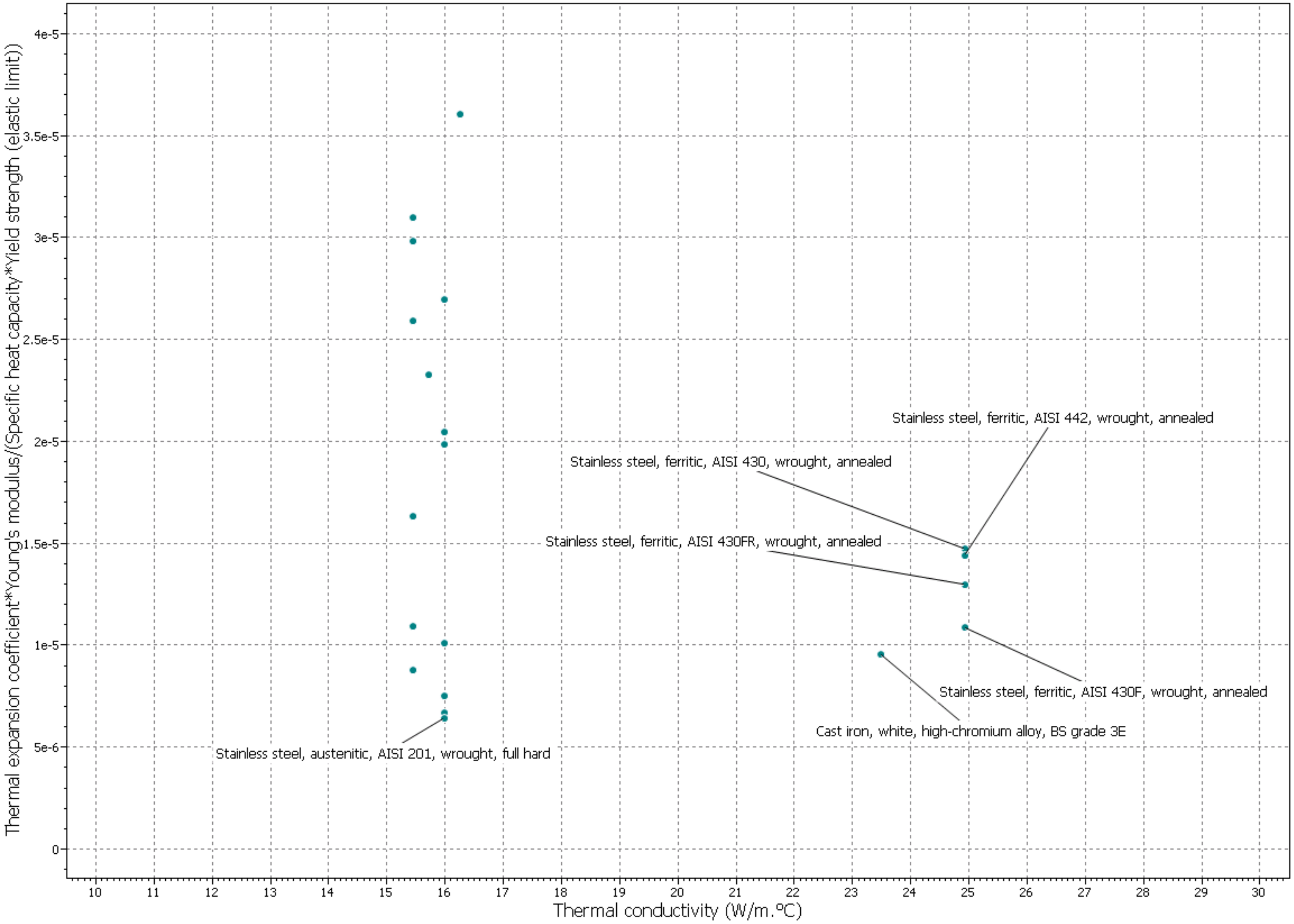
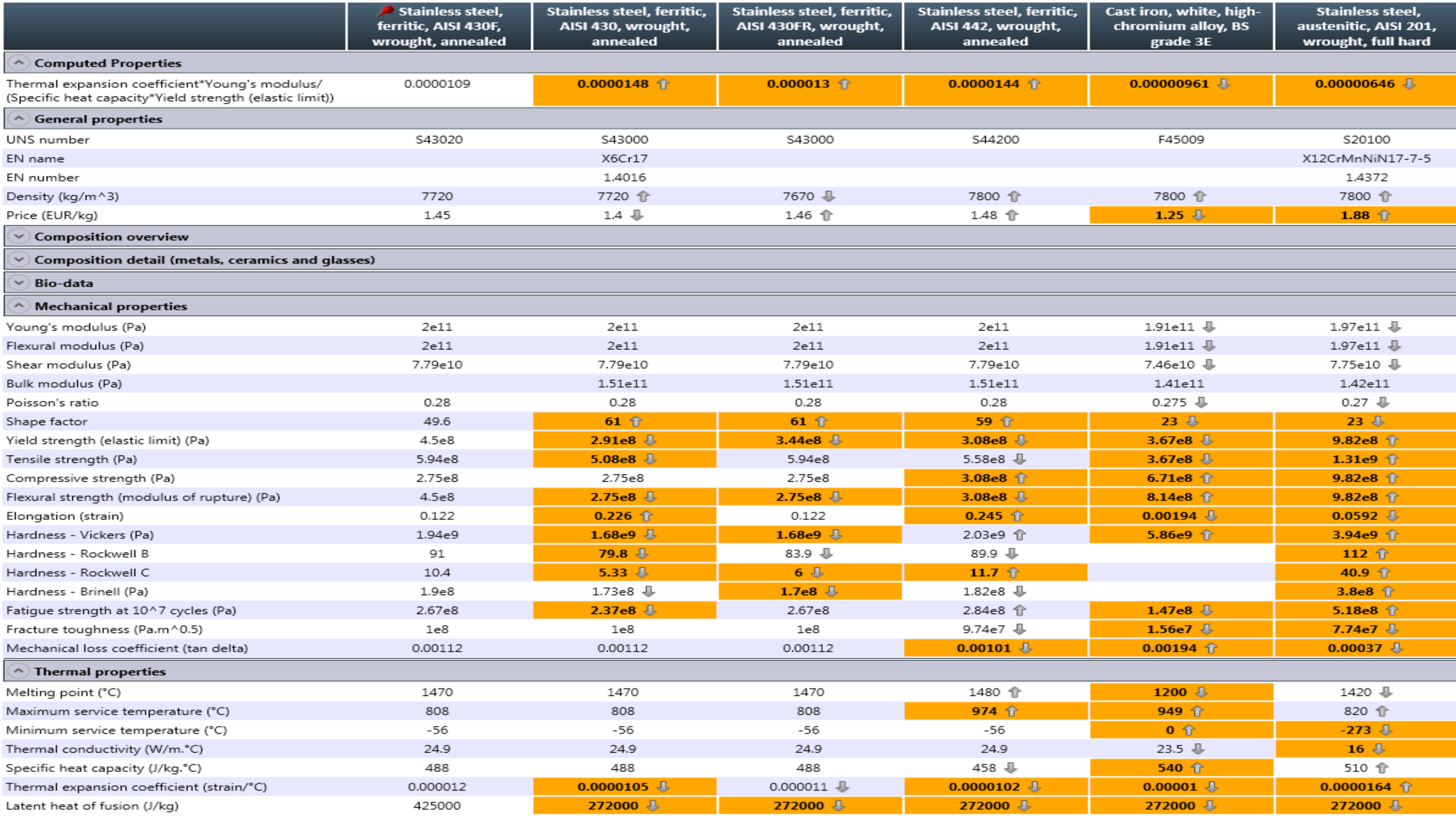
Thanks

Design proposal



Design proposal



	Stainless steel, ferritic, AISI 430F, wrought, annealed	Stainless steel, ferritic, AISI 430, wrought, annealed	Stainless steel, ferritic, AISI 430FR, wrought, annealed	Stainless steel, ferritic, AISI 442, wrought, annealed	Cast iron, white, high-chromium alloy, BS grade 3E	Stainless steel, austenitic, AISI 201, wrought, full hard
Computed Properties						
Thermal expansion coefficient*Young's modulus/(Specific heat capacity*Yield strength (elastic limit))	0.0000109	**0.0000148 ↑**	**0.000013 ↑**	**0.0000144 ↑**	**0.00000961 ↓**	**0.00000646 ↓**
General properties						
UNS number	S43020	S43000	S43000	S44200	F45009	S20100
EN name		X6Cr17				X12CrMnNiN17-7-5
EN number		1.4016				1.4372
Density (kg/m^3)	7720	7720 ↑	7670 ↓	7800 ↑	7800 ↑	7800 ↑
Price (EUR/kg)	1.45	1.4 ↓	1.46 ↑	1.48 ↑	**1.25 ↓**	**1.88 ↑**
Composition overview						
Composition detail (metals, ceramics and glasses)						
Bio-data						
Mechanical properties						
Young's modulus (Pa)	2e11	2e11	2e11	2e11	1.91e11 ↓	1.97e11 ↓
Flexural modulus (Pa)	2e11	2e11	2e11	2e11	1.91e11 ↓	1.97e11 ↓
Shear modulus (Pa)	7.79e10	7.79e10	7.79e10	7.79e10	7.46e10 ↓	7.75e10 ↓
Bulk modulus (Pa)		1.51e11	1.51e11	1.51e11	1.41e11	1.42e11
Poisson's ratio	0.28	0.28	0.28	0.28	0.275 ↓	0.27 ↓
Shape factor	49.6	**61 ↑**	**61 ↑**	**59 ↑**	**23 ↓**	**23 ↓**
Yield strength (elastic limit) (Pa)	4.5e8	**2.91e8 ↓**	**3.44e8 ↓**	**3.08e8 ↓**	**3.67e8 ↓**	**9.82e8 ↑**
Tensile strength (Pa)	5.94e8	**5.08e8 ↓**	5.94e8	5.58e8 ↓	**3.67e8 ↓**	**1.31e9 ↑**
Compressive strength (Pa)	2.75e8	2.75e8	2.75e8	**3.08e8 ↑**	**6.71e8 ↑**	**9.82e8 ↑**
Flexural strength (modulus of rupture) (Pa)	4.5e8	**2.75e8 ↓**	**2.75e8 ↓**	**3.08e8 ↓**	**8.14e8 ↑**	**9.82e8 ↑**
Elongation (strain)	0.122	**0.226 ↑**	0.122	**0.245 ↑**	**0.00194 ↓**	**0.0592 ↓**
Hardness - Vickers (Pa)	1.94e9	**1.68e9 ↓**	**1.68e9 ↓**	2.03e9 ↑	**5.86e9 ↑**	**3.94e9 ↑**
Hardness - Rockwell B	91	**79.8 ↓**	83.9 ↓	89.9 ↓		**112 ↑**
Hardness - Rockwell C	10.4	**5.33 ↓**	**6 ↓**	**11.7 ↑**		**40.9 ↑**
Hardness - Brinell (Pa)	1.9e8	1.73e8 ↓	**1.7e8 ↓**	1.82e8 ↓		**3.8e8 ↑**
Fatigue strength at 10^7 cycles (Pa)	2.67e8	**2.37e8 ↓**	2.67e8	2.84e8 ↑	**1.47e8 ↓**	**5.18e8 ↑**
Fracture toughness (Pa.m^0.5)	1e8	1e8	1e8	9.74e7 ↓	**1.56e7 ↓**	**7.74e7 ↓**
Mechanical loss coefficient (tan delta)	0.00112	0.00112	0.00112	**0.00101 ↓**	**0.00194 ↑**	**0.00037 ↓**
Thermal properties						
Melting point (°C)	1470	1470	1470	1480 ↑	**1200 ↓**	1420 ↓
Maximum service temperature (°C)	808	808	808	**974 ↑**	**949 ↑**	820 ↑
Minimum service temperature (°C)	-56	-56	-56	-56	**0 ↑**	**-273 ↓**
Thermal conductivity (W/m.°C)	24.9	24.9	24.9	24.9	23.5 ↓	**16 ↓**
Specific heat capacity (J/kg.°C)	488	488	488	458 ↓	**540 ↑**	510 ↑
Thermal expansion coefficient (strain/°C)	0.000012	**0.0000105 ↓**	0.000011 ↓	**0.0000102 ↓**	**0.00001 ↓**	**0.0000164 ↑**
Latent heat of fusion (J/kg)	425000	**272000 ↓**	**272000 ↓**	**272000 ↓**	**272000 ↓**	**272000 ↓**