Advance on the Neutron Converter for SPIRAL2

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on behalf of the LNL-BINP-GANIL/SPIRAL2, LEA collaboration
&
ISTC project #3782

Legnaro November 19, 2010 LEA-COLLIGA Workshop

Layout

Design of the Carbon Converter:

Design of the neutron converter
Test of single components
Activation of materials
Radiation damage (see J. Bermudez)

Delay Window:

Principle of delay window
Preliminary tests
Prototyping

Conclusions

Neutron Converter: Requirements

SPIRAL2 Project:

40 MeV deuterons   5 mA   200 kW   (1,25 mA, 50 kW)

2,4 kg Ucx   target

Main Goal: 10^{14} Fission/s   induced by neutron

Neutron Converter: 10^{12} n/cm^2 s

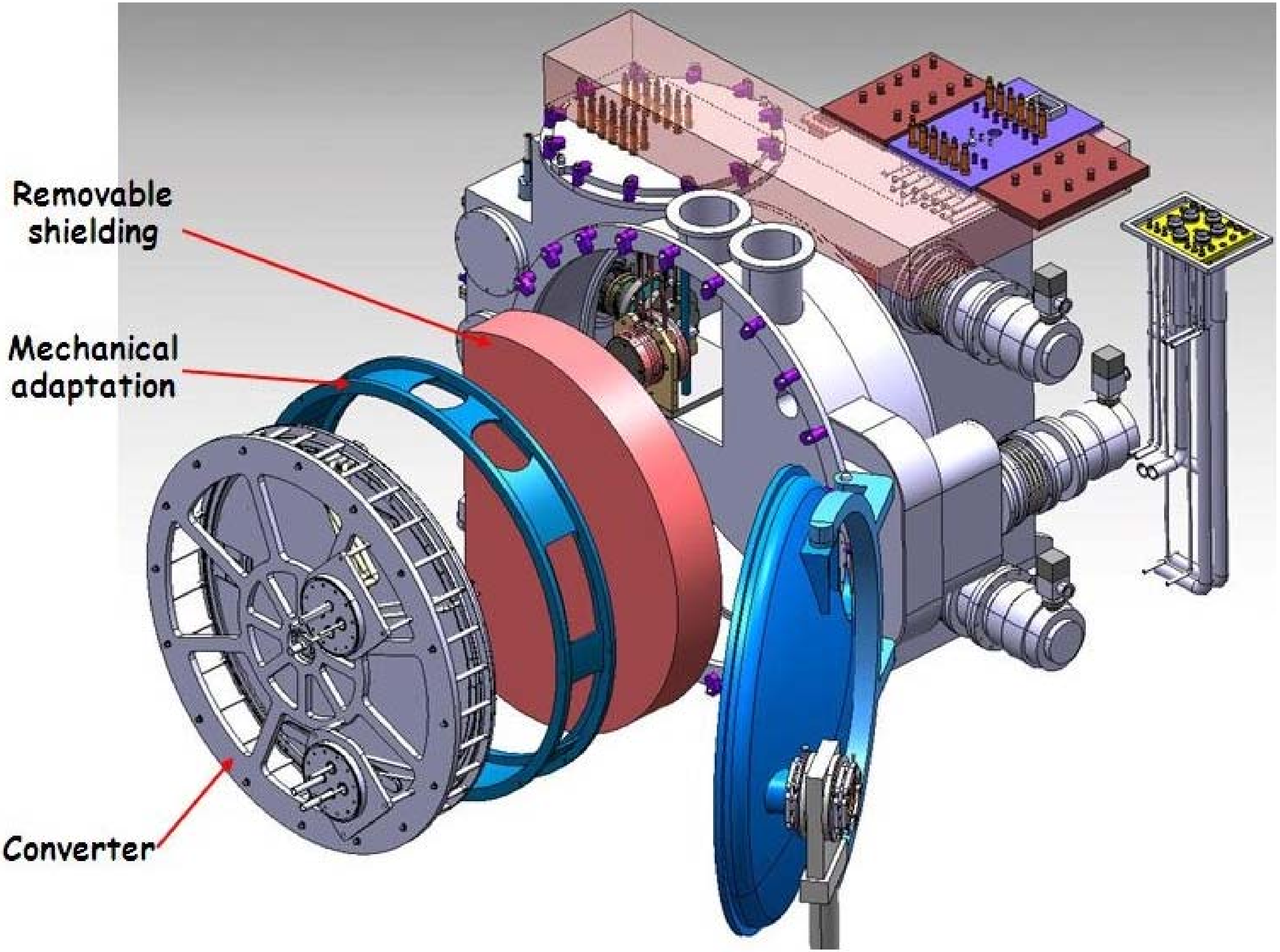
Rotating wheel with graphite as converter material

Working temperature up to 1850 °C

Radiation cooling

Neutron converter has been conceived to operate as "nuclear device"

The Neutron Converter



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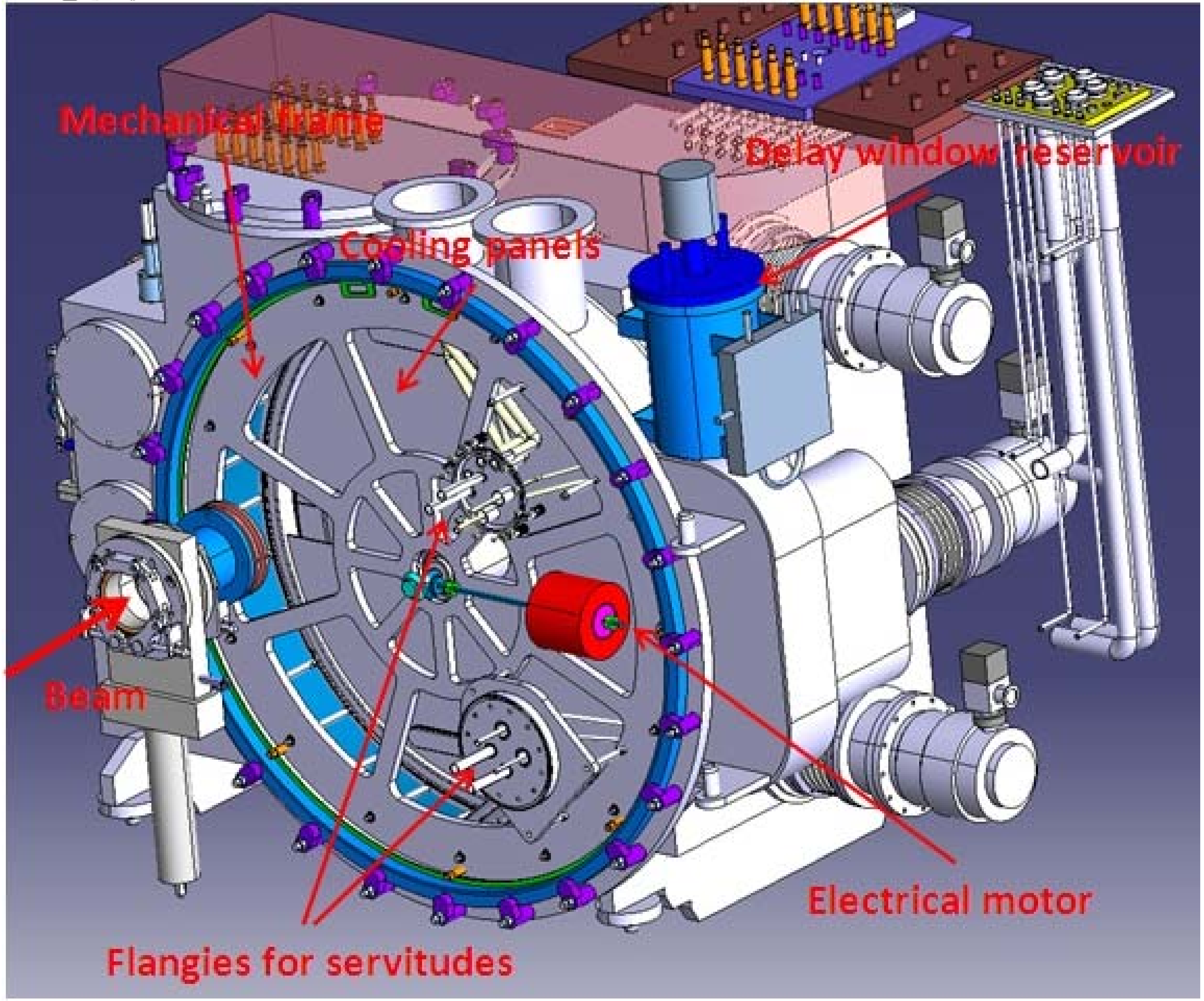

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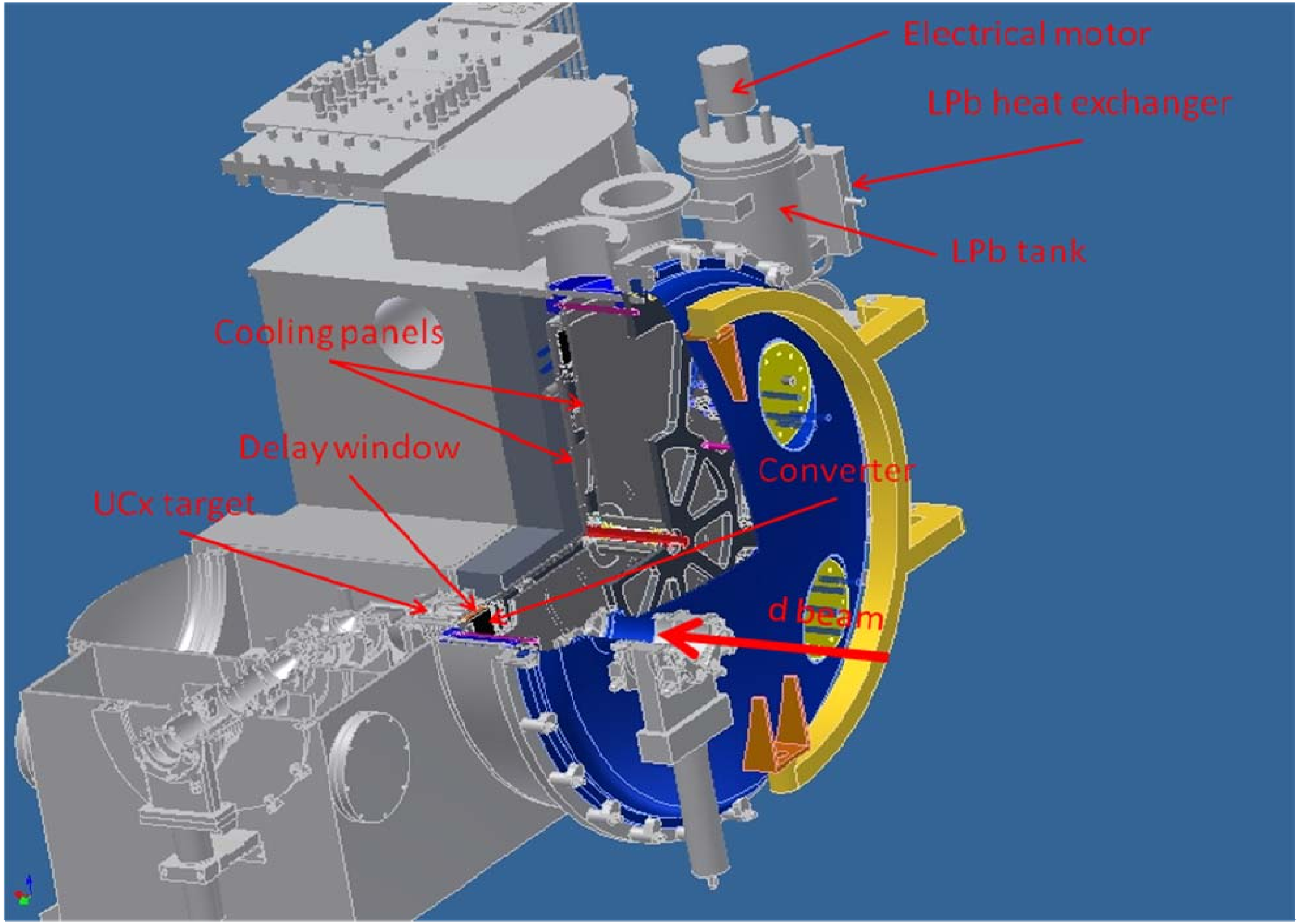
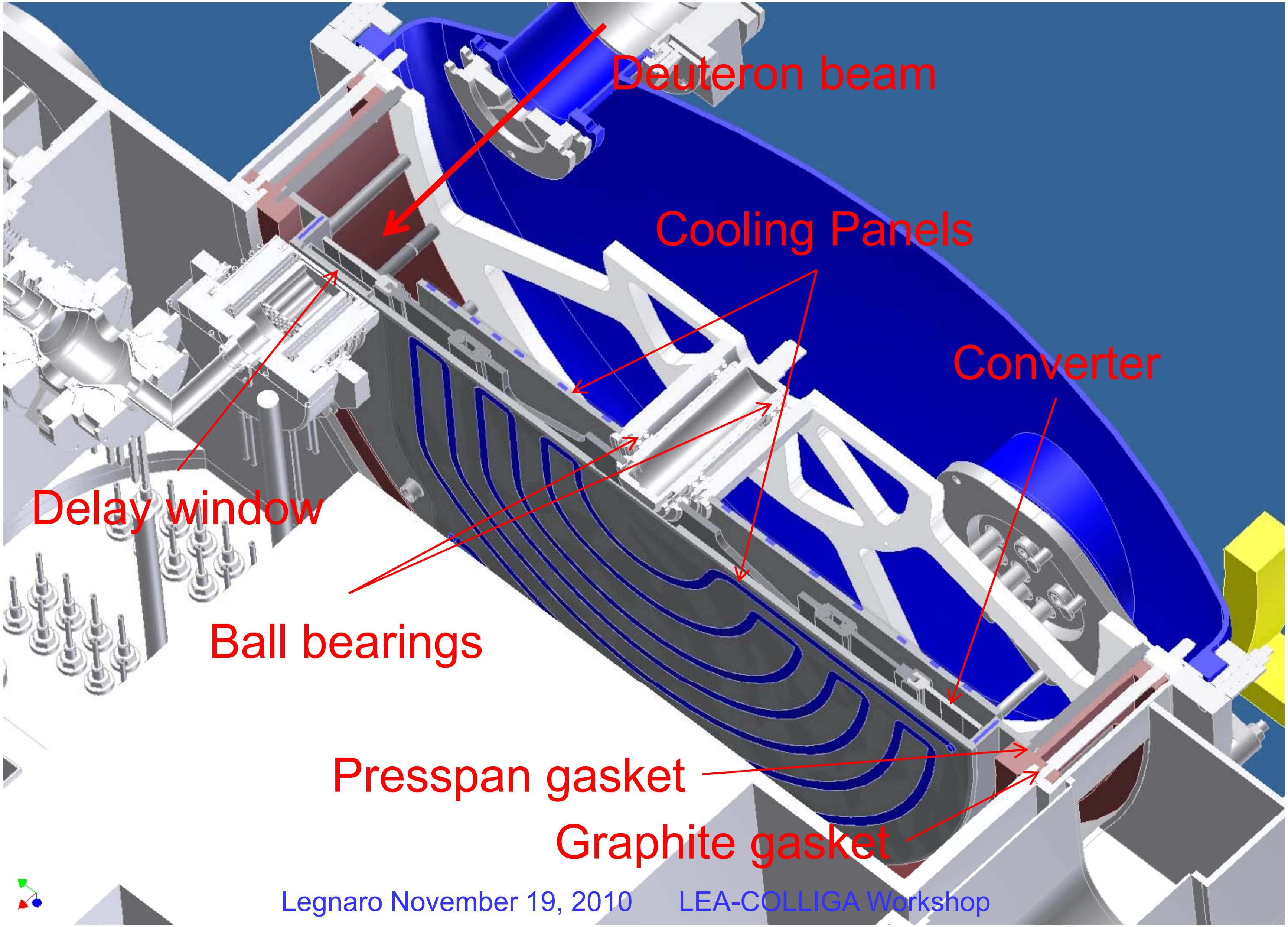
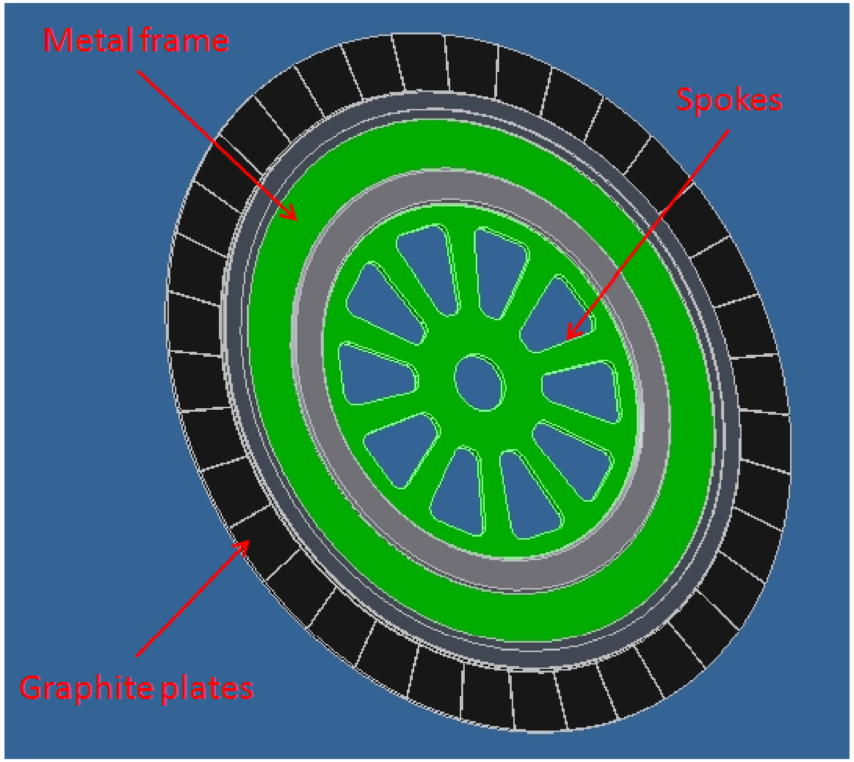


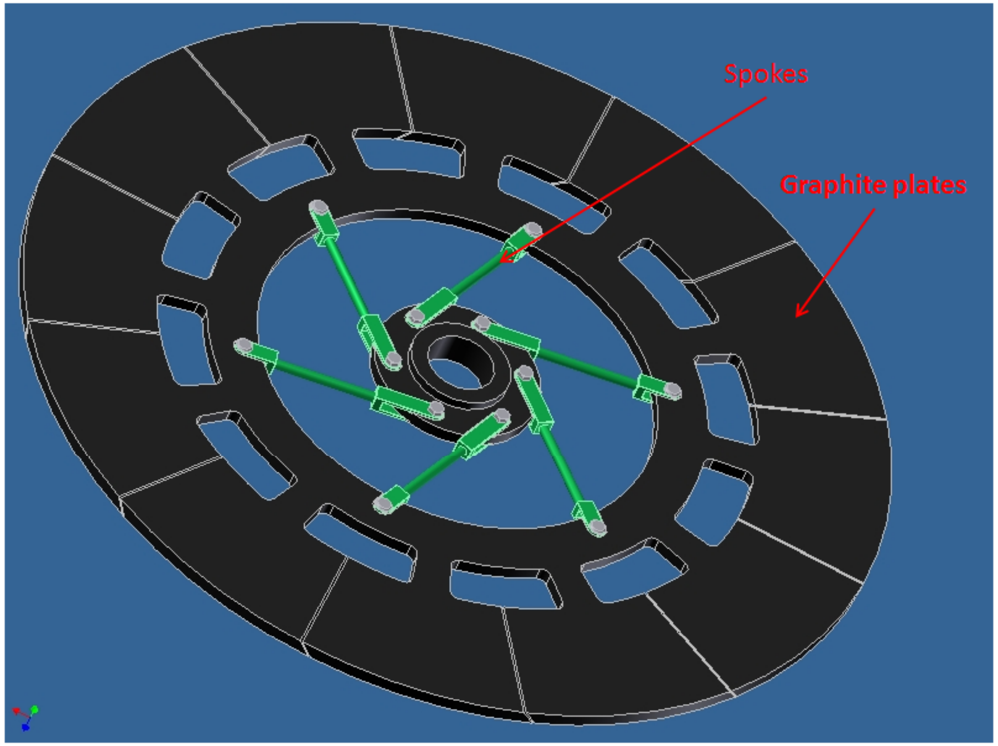
The Neutron Converter 200 kW



The Neutron Converter

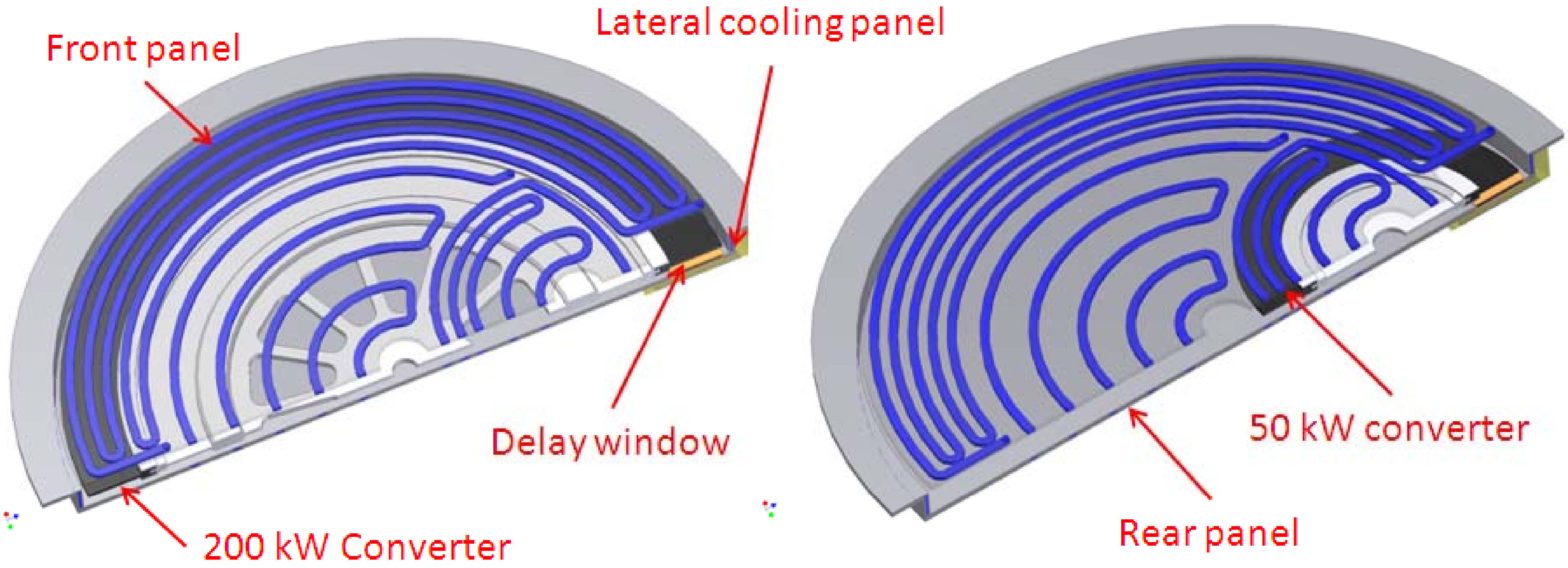


200 kW

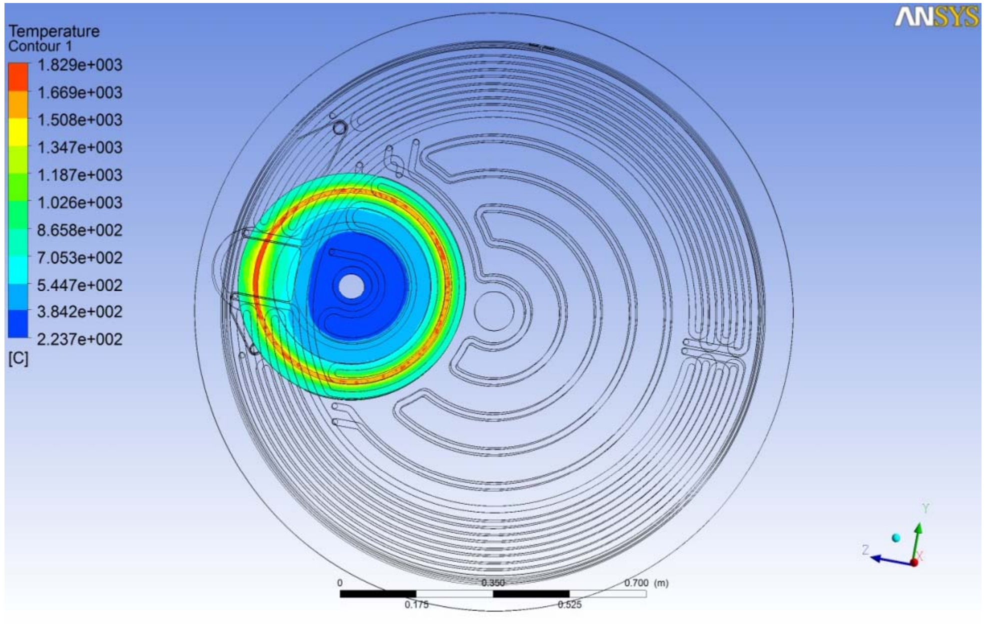


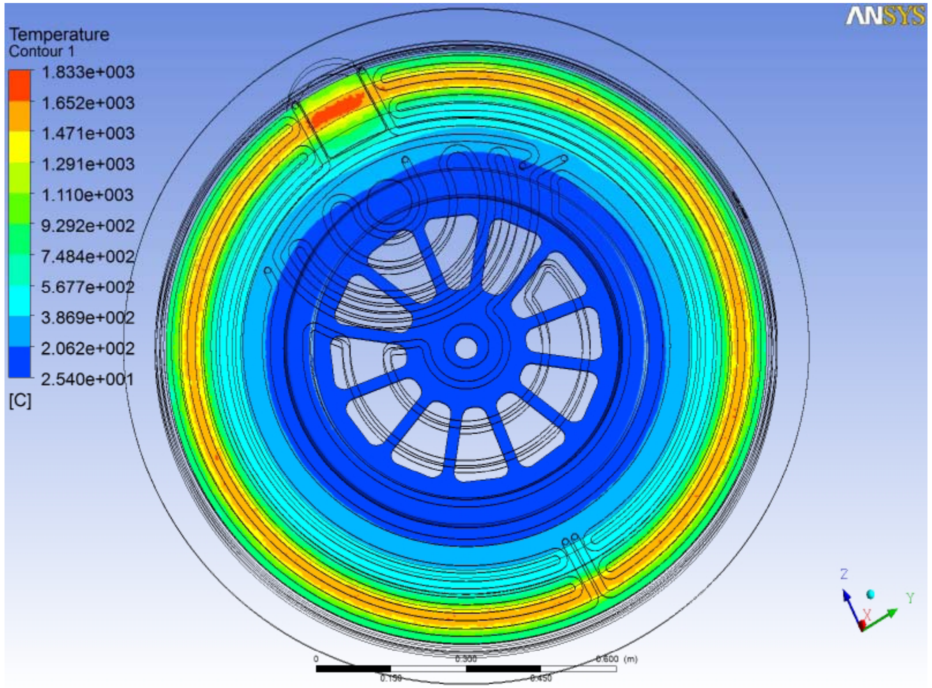
50 kW

The Neutron Converter



The Neutron Converter Temperature



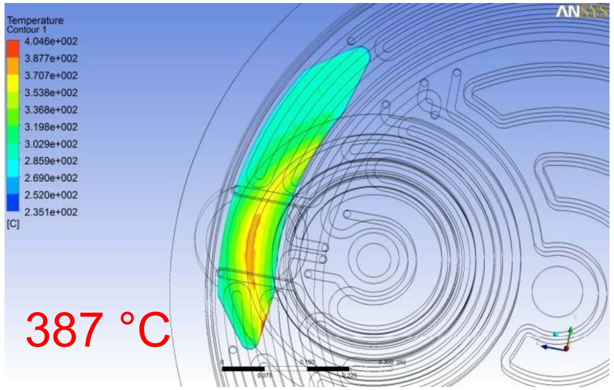


50 kW

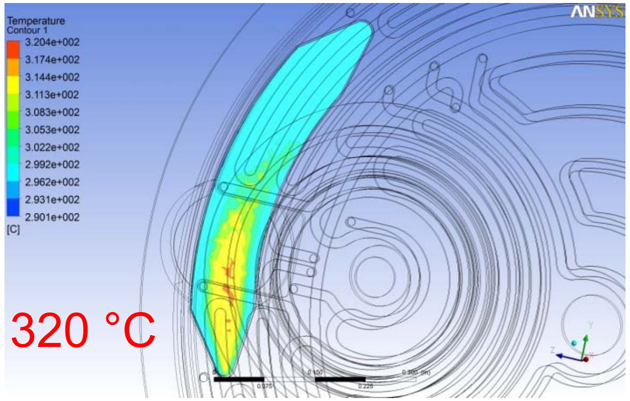
200 kW

Spiral2

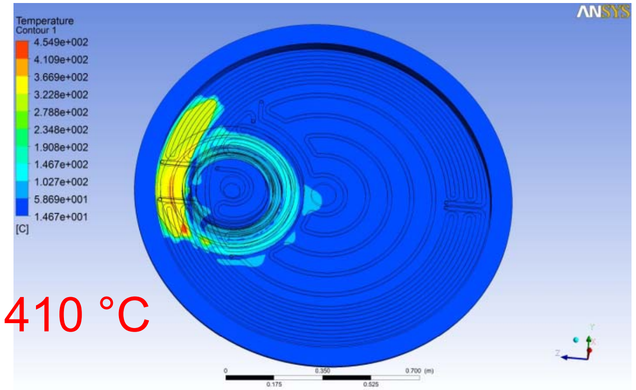
The Converter Temperature 50 kW



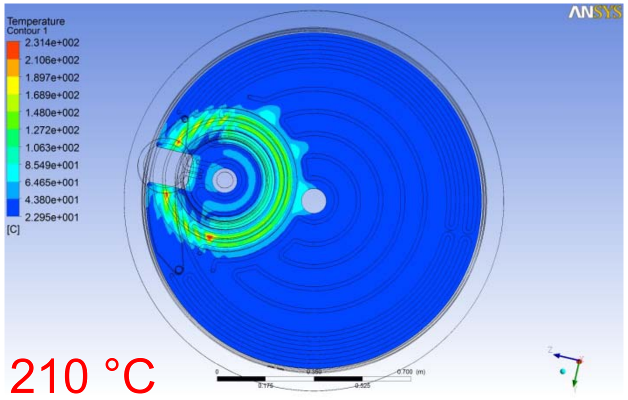
Metal DW



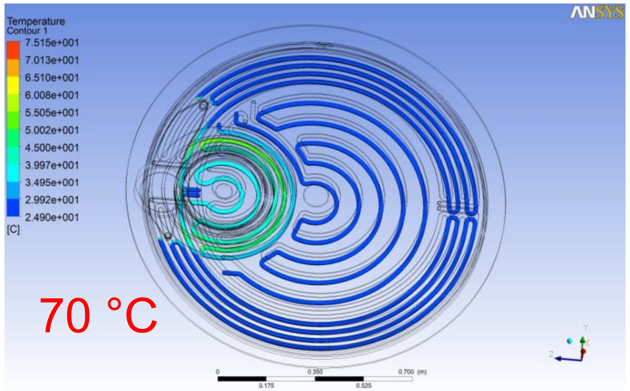
Lead DW



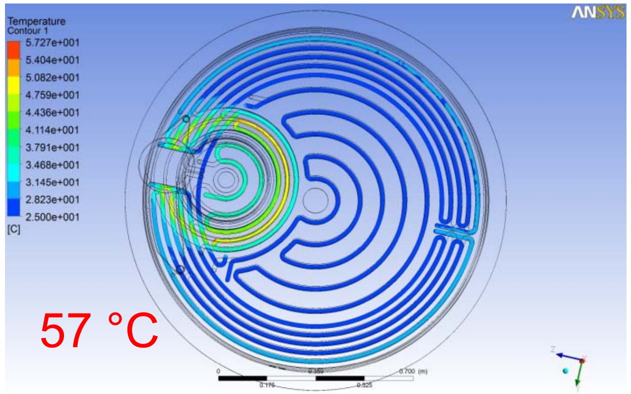
Rear Panel



Front Panel

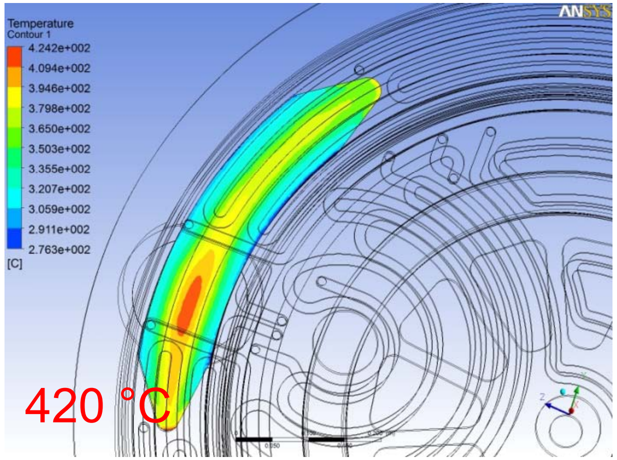


Water Rear Panel

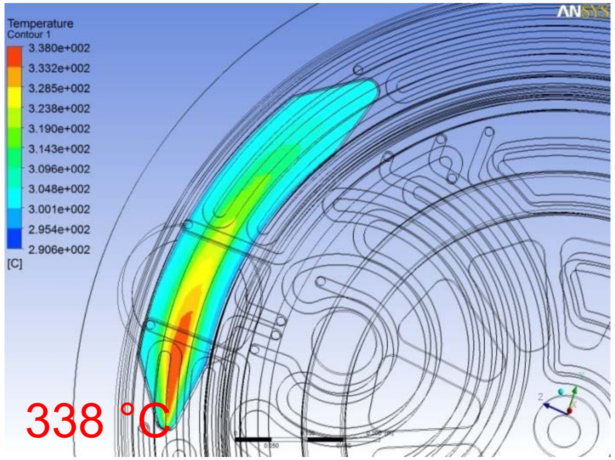


Water Rear Panel

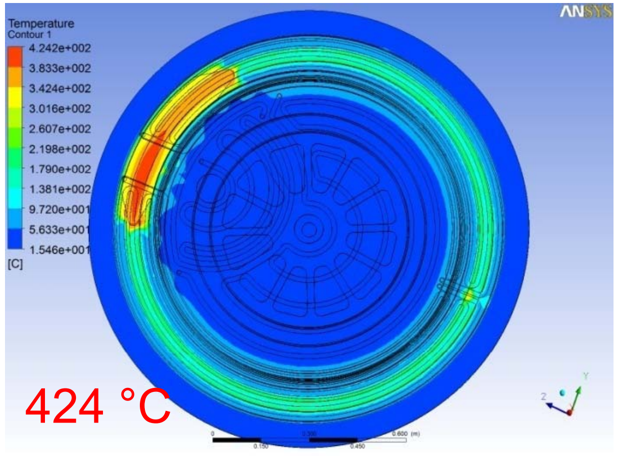
The Converter Temperature 200 kW



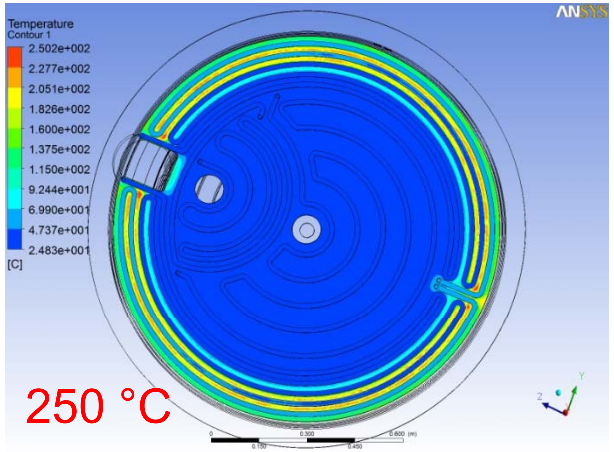
Metal DW



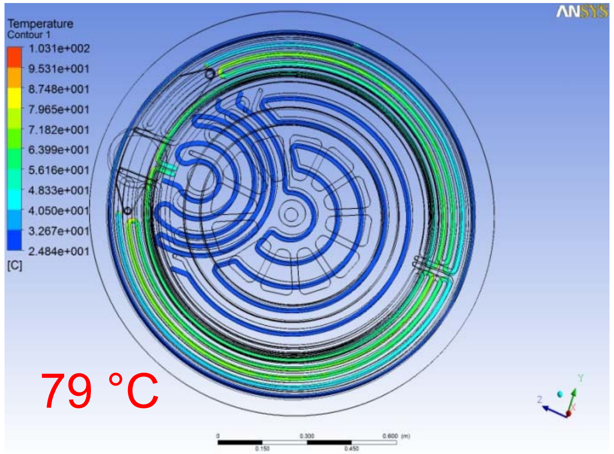
Lead DW



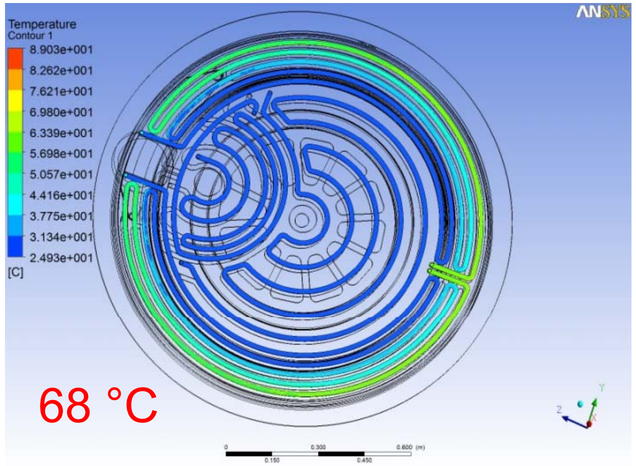
Rear Panel



Front Panel



Water Rear Panel



Water Rear Panel

Converter stress Parameters 50 kW

Max. converter temp. [^{0}C]	Target diameter [cm]	Max. metal temp. [^{0}C]	Max. t-m stress in graphite [Pa]	Max. t-m stress in metal [Pa]	Max. inertial stress (10 Hz) [Pa]
1850	52	485.5	2.52×10^7	5×10^6	3.44×10^6

Material	Max. t/m stress von Mises [Pa]	Max. t/m stress X-component [Pa]	Max. t/m stress Y-component [Pa]	Max. t/m stress Z-component [Pa]	Max. deformation [mm]
Graphite	2.49×10^7	2.17×10^7	1.26×10^7	4.12×10^6	0.56
Metal	3.85×10^7	2.71×10^7	3.72×10^7	3.84×10^7	0.29

Converter Stress Parameters 200 kW

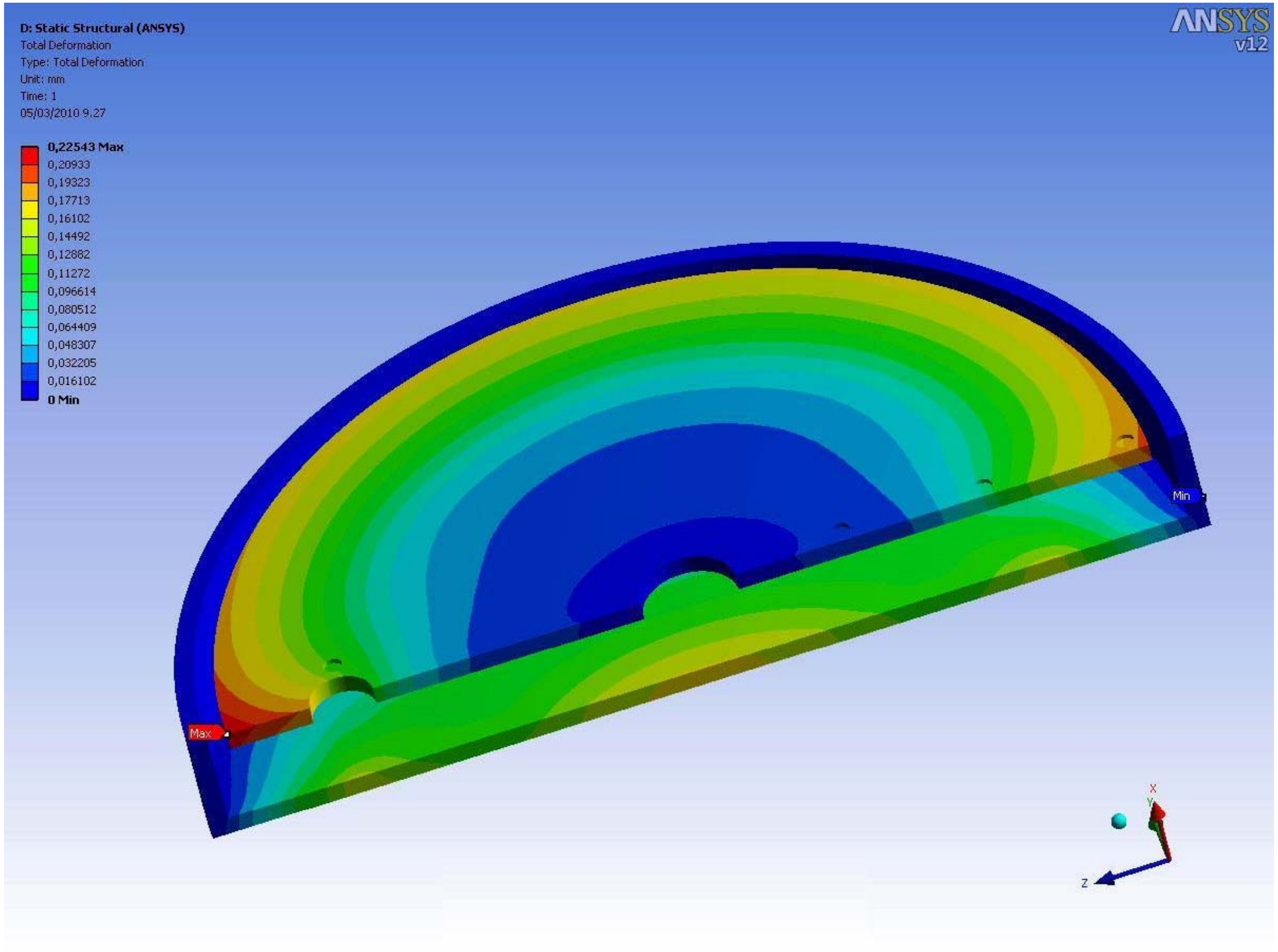
Max. converter temp. [^{0}C]	Target diameter [cm]	Max. metal temp. [^{0}C]	Max. t-m stress in graphite [Pa]	Max. t-m stress in metal [Pa]	Max. inertial stress (10 Hz) [Pa]
1857	120	554	2.9×10^{7}	2×10^{8}	5×10^{7}

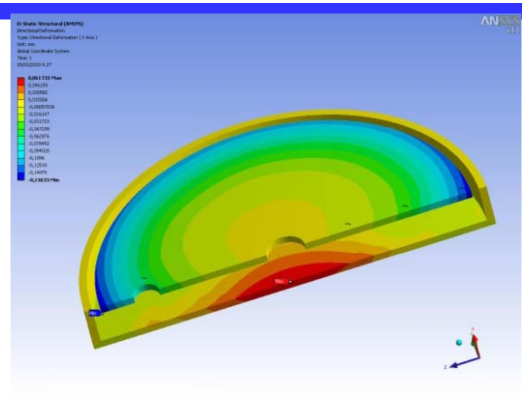
Material	Max. t/m stress von Mises [Pa]	Max. t/m stress X-component [Pa]	Max. t/m stress Y-component [Pa]	Max. t/m stress Z-component [Pa]	Max. deformation [mm]
Graphite	3.16×10^{7}	3.25×10^{7}	2.03×10^{7}	2.85×10^{6}	0.18
Metal	3.8×10^{8}	10^{8}	1.3×10^{8}	1.45×10^{8}	0.63

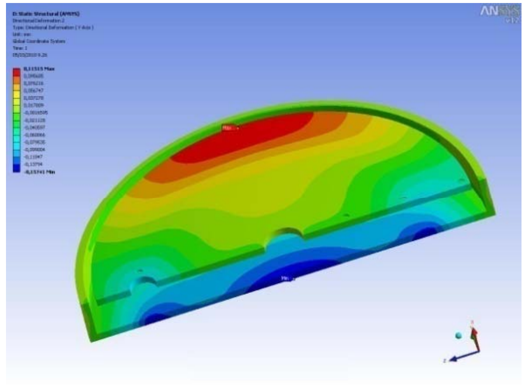
Converter Water Cooling

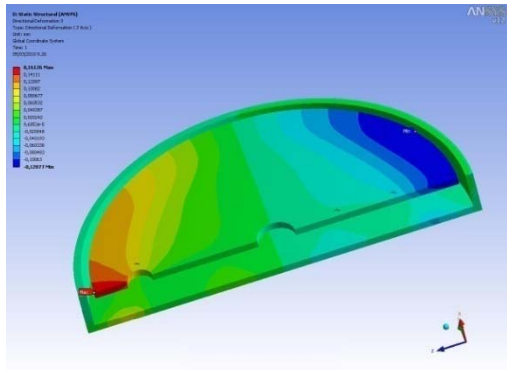
Water parameters		Mesure unit	Converter 50 kW	Converter 200 kW
Water temperature inlet to all channels		°C	25	25
Maximum water temperature	channel #1	°C	30,1	32,4
	channel #2	°C	61,5	40,3
	channel #3	°C	75,1	79,4
	channel #4	°C	67,8	79,7
	channel #5	°C	53,4	64,7
	channel #6	°C	30,1	26,8
	channel #7	°C	57,3	28,8
	channel #8	°C	52,1	88,9
	channel #9	°C	54,1	89
Pressure drop over the water	channel #1	Pa	1,46 e+05	1,51 e+05
	channel #2	Pa	1,02 e+05	1,01 e+05
	channel #3	Pa	1,42 e+05	1,47 e+05
	channel #4	Pa	1,52 e+05	1,53 e+05
	channel #5	Pa	1,40 e+05	1,42 e+05
	channel #6	Pa	1,48 e+05	1,08 e+05
	channel #7	Pa	1,02 e+05	1,01 e+05
	channel #8	Pa	1,91 e+05	1,92 e+05
	channel #9	Pa	1,91 e+05	1,91 e+05
Water consumption channels		l/s	0,33	0,33
Water velocity at the inlet, average value		m/s	3	3
Water velocity at the outlet, average value	channel #1	m/s	2,07	2,32
	channel #2	m/s	2,32	2,33
	channel #3	m/s	2,32	2,26
	channel #4	m/s	2,05	1,98
	channel #5	m/s	2,38	2,45
	channel #6	m/s	2,14	3
	channel #7	m/s	2,12	1,84
	channel #8	m/s	2,22	2,10
	channel #9	m/s	2,05	1,85

The Neutron Converter 200 kW



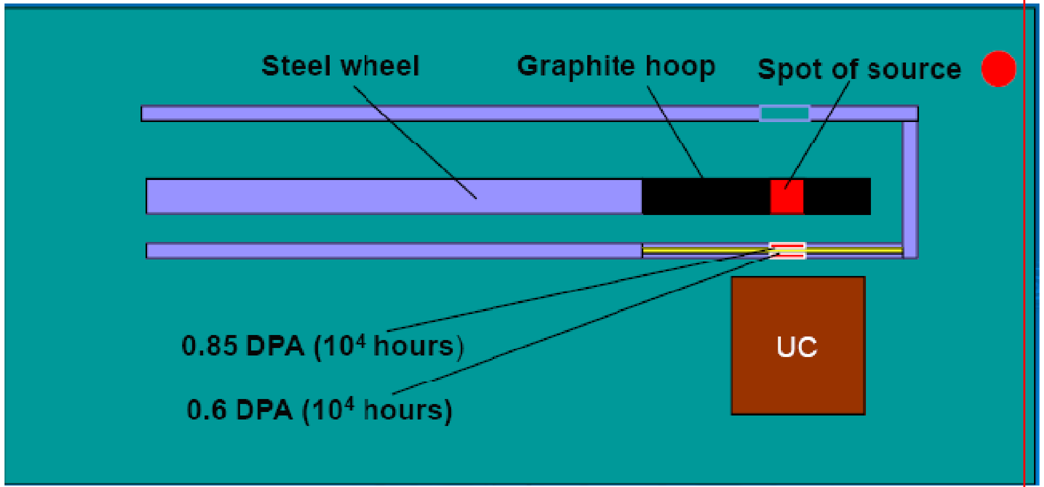






Total mechanical deformation

Activation and Radiation Damage at 200 kW



Activation of Graphite induced by Deuterons (^{13}N, ^{11}C)

β+ activity	(saturation)	~2 10^3 Ci,
Cooling time	1 h	~ 50 Ci,
	2 h	~ 2 Ci,
	6 h	2.5 10^{-3} Ci

Displacement Per Atom induced by Deuterons (10^4 h) :

In Graphite ~50 DPA

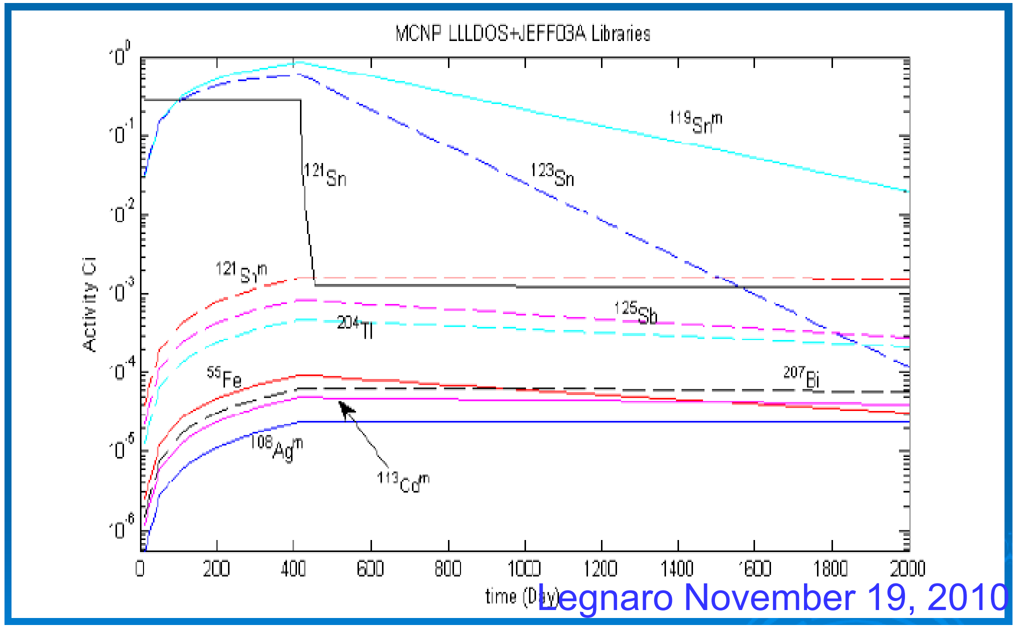
In Steel

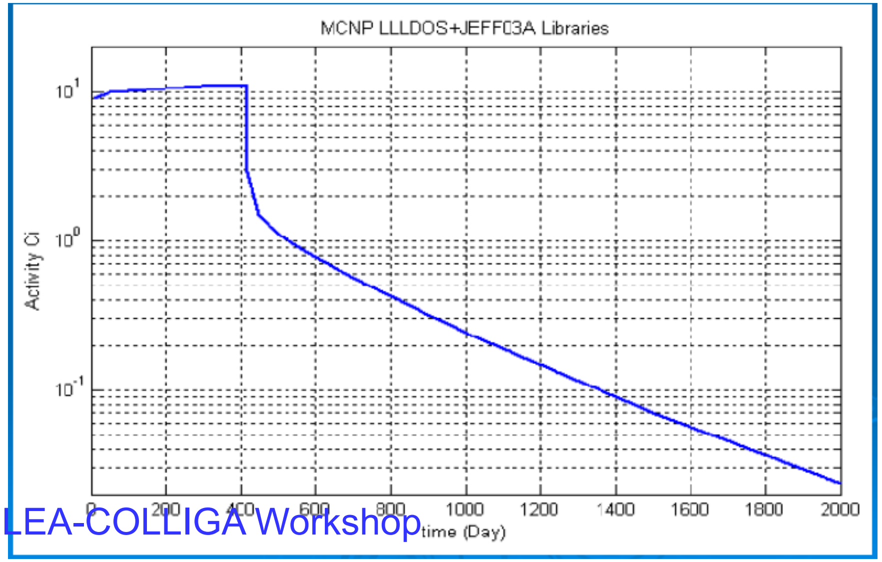
maximum (Delay Window) ~1 DPA

Wheel 10^{-3} – 10^{-2} DPA

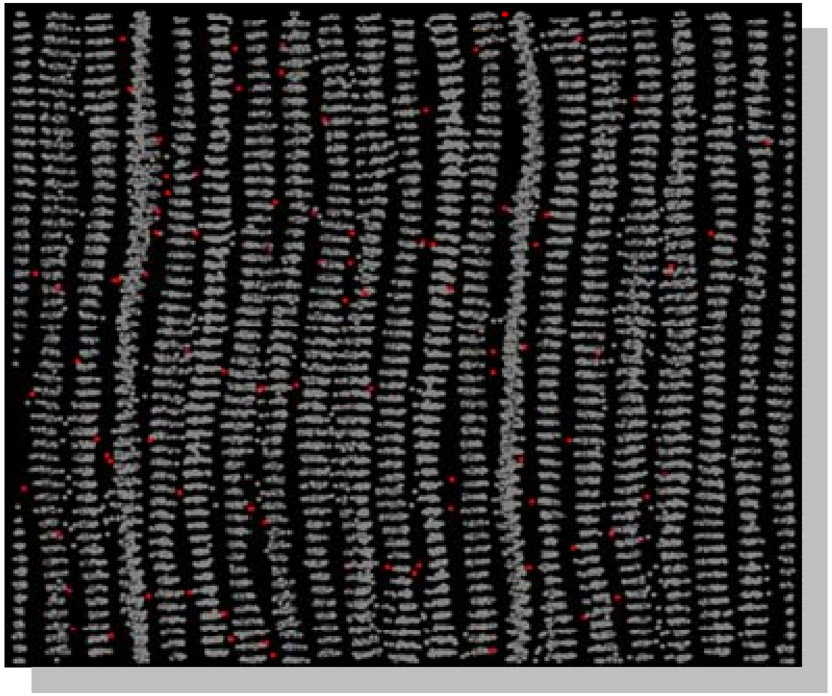
Annealing effect is not considered in calculations.

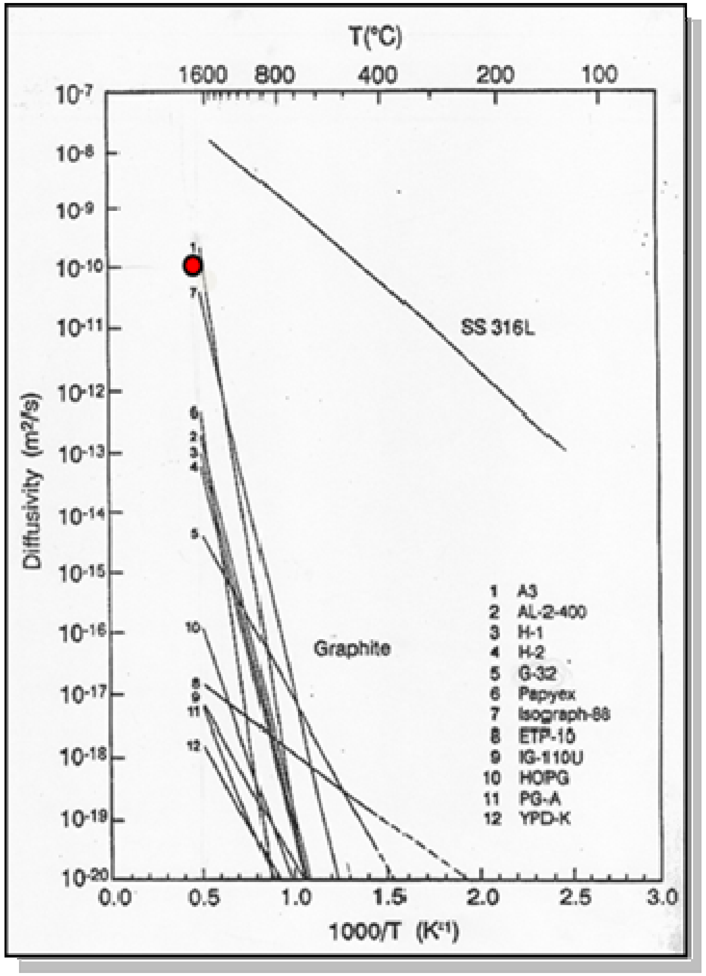
Main activation from LPb





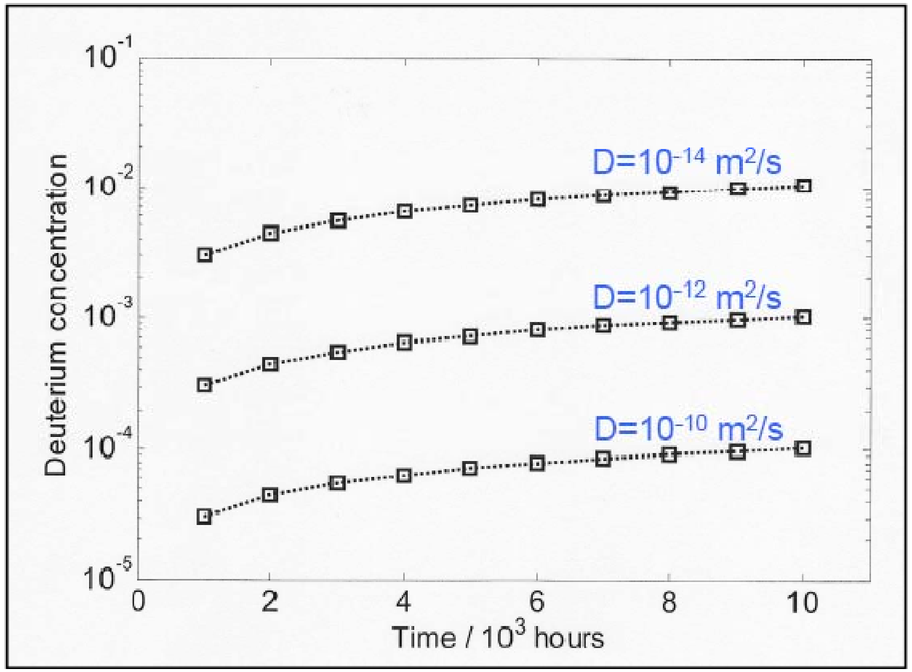
Deuteron Mobility in Graphite: MD Simulation

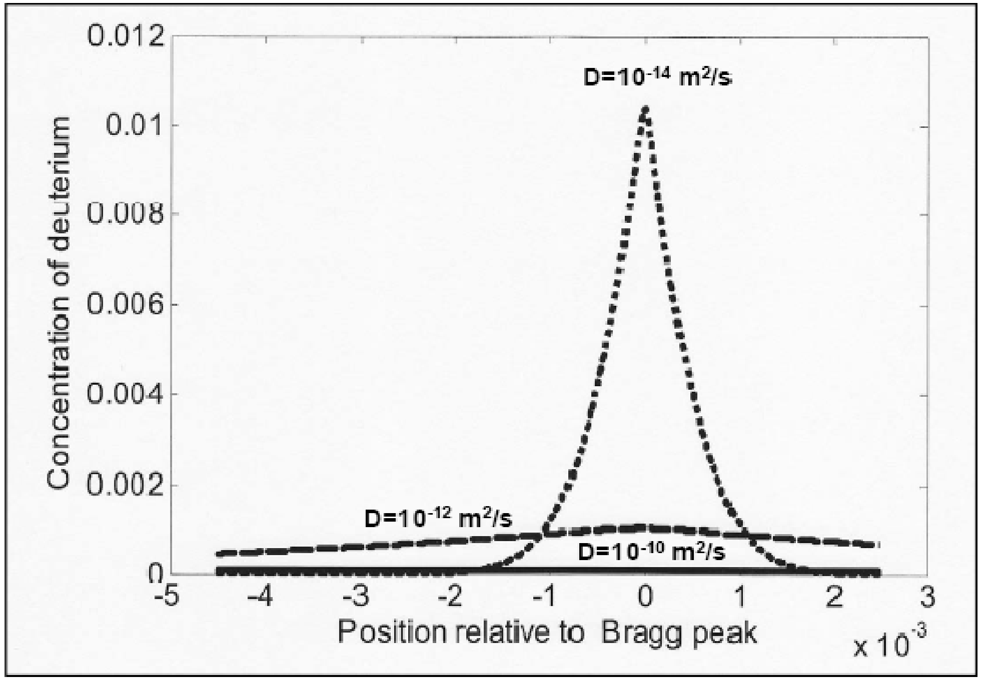




Simulations: the graphite sample contain ~30 000 atoms and 100 atoms of hydrogen (deuterium) were distributed inside. The time step of integration is 0.1 fs. The behavior of the system of hydrogen atoms was tracked up to 0.2 ns. From the analysis of the hydrogen trajectories the hydrogen mobility was evaluated in the given conditions of the simulation.

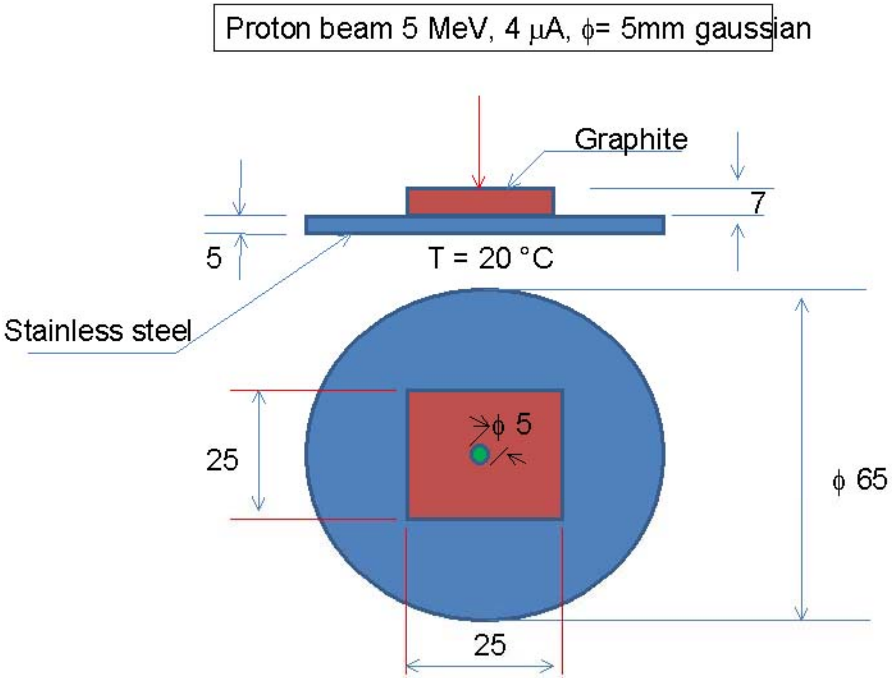
Deuteron Concentration in Graphite

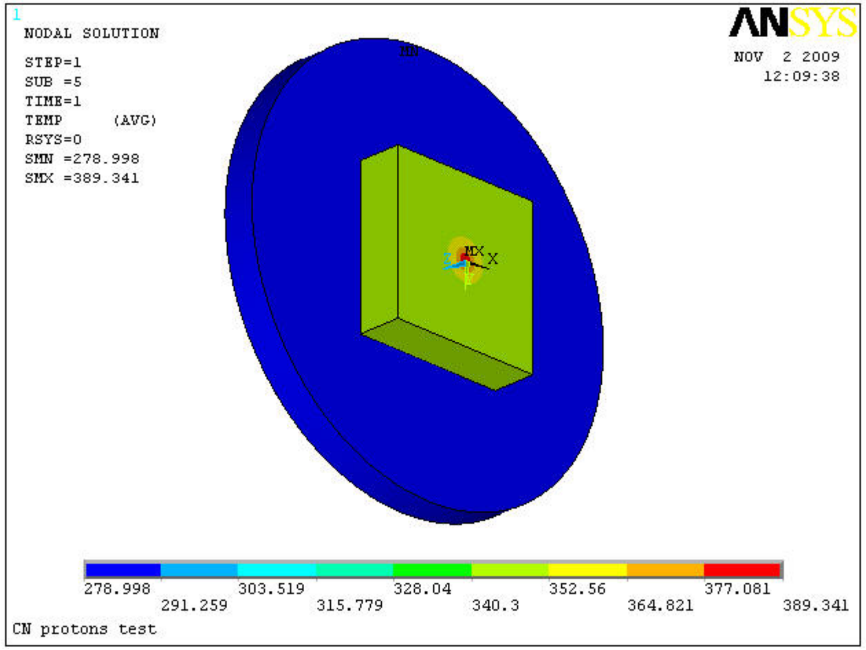




Radiation Damage: Test with Protons

The CN accelerator of LNL may deliver 6 MeV, 4 μA proton beam, with a current density of about 20 mA/cm^2. In about 20 hours was possible to induce in graphite more than **1 dpa**. Deformation and changes in the graphite structure have been measured by profilometry, XDR and SEM techniques. First experiment was performed October 26.

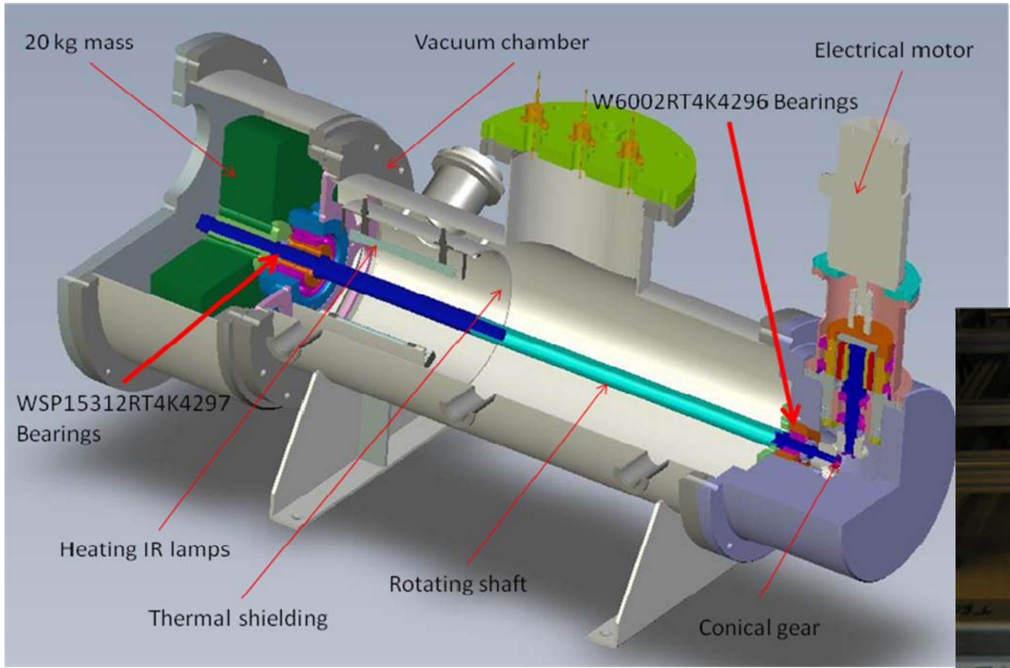


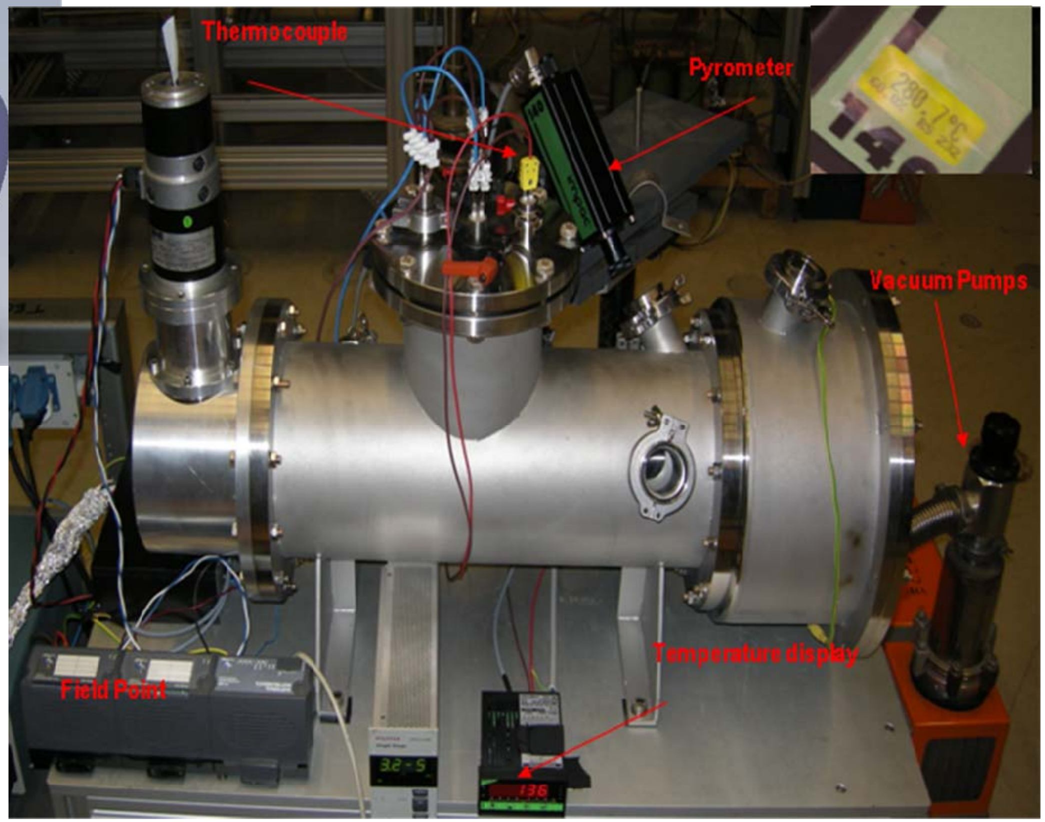


Local Temperature about 300 °C

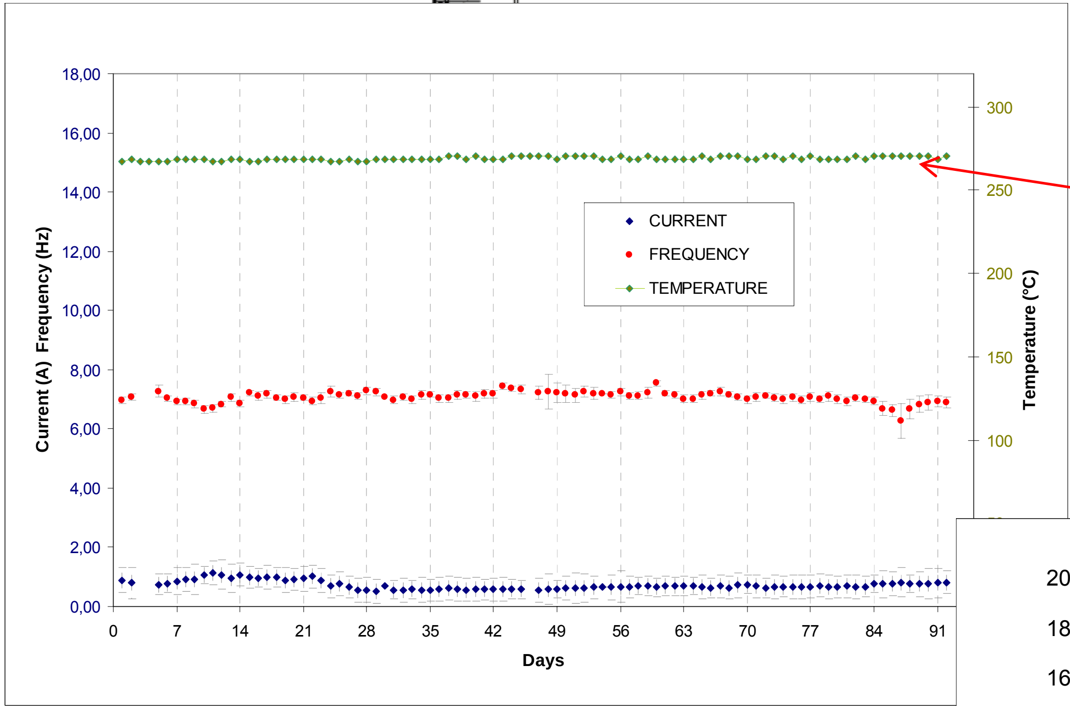
See J. Bermudez

Ball Bearings Test



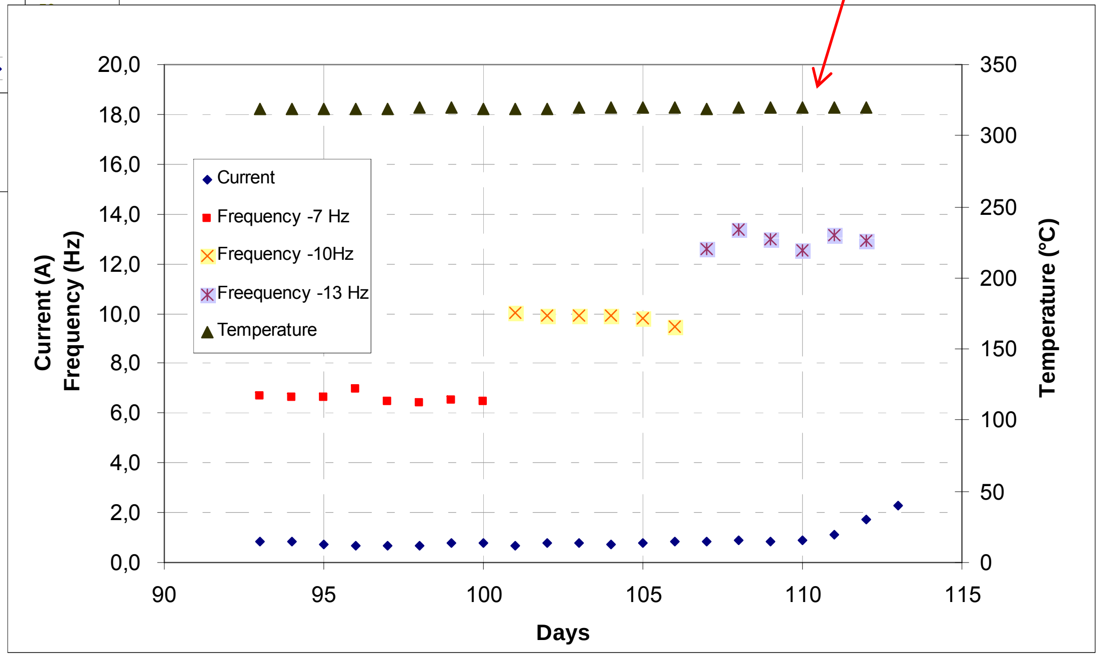


Ball Bearings Test



Goal: 90 days of operation at >250 °C

320 °C

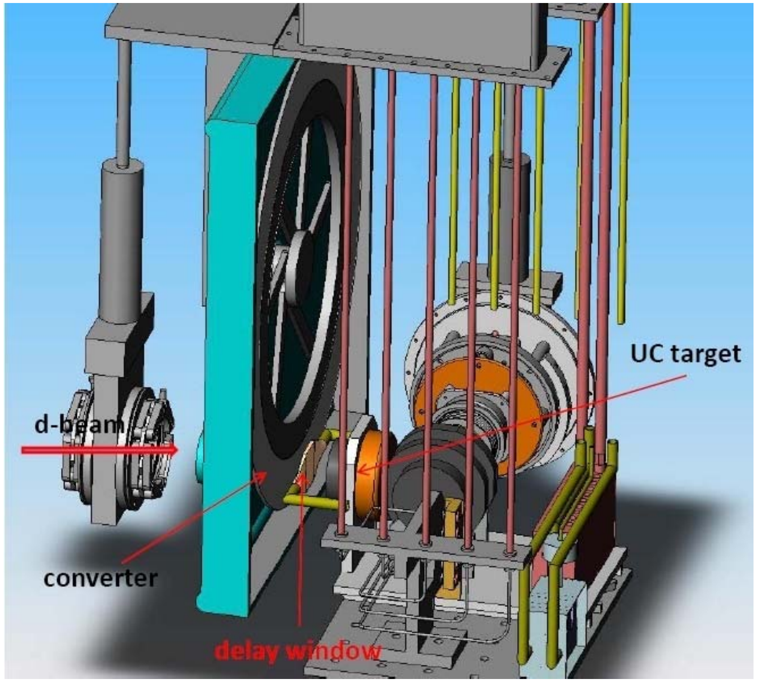


Delay Window: Concept

Goal: To protect the UC target from the direct high power deuteron beam.
Concept: A continuous flow of Liquid Pb at high temperature (>300 °C) is circulating inside a panel properly shaped (delay window) and located between the converter and the UC target.

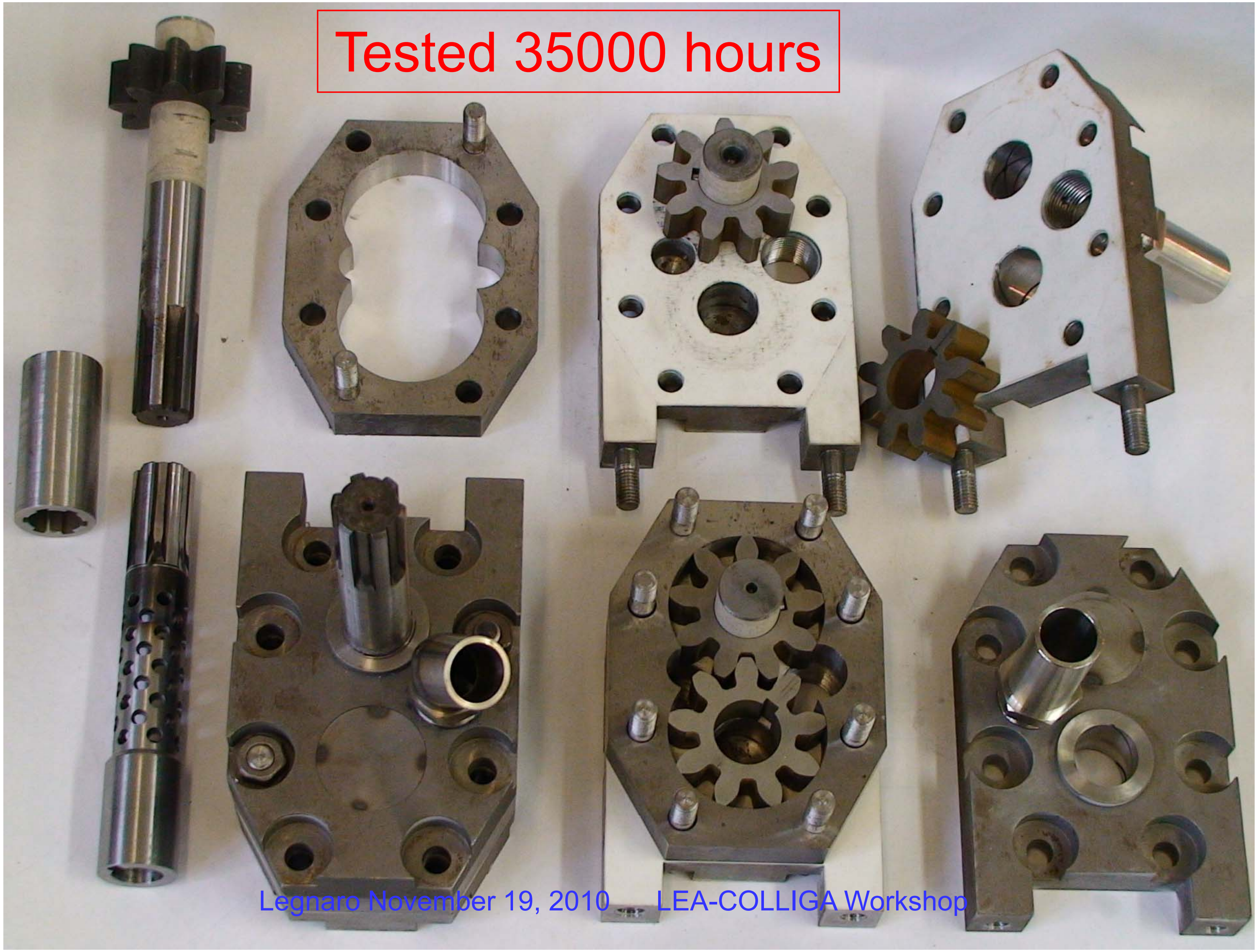
The thickness of the lead is selected to stop completely the beam.

After melt the first wall of "delay window" the Liquid Pb fall down on the bottom of the "production module" where solidify, until the Pb reservoir will be empty.

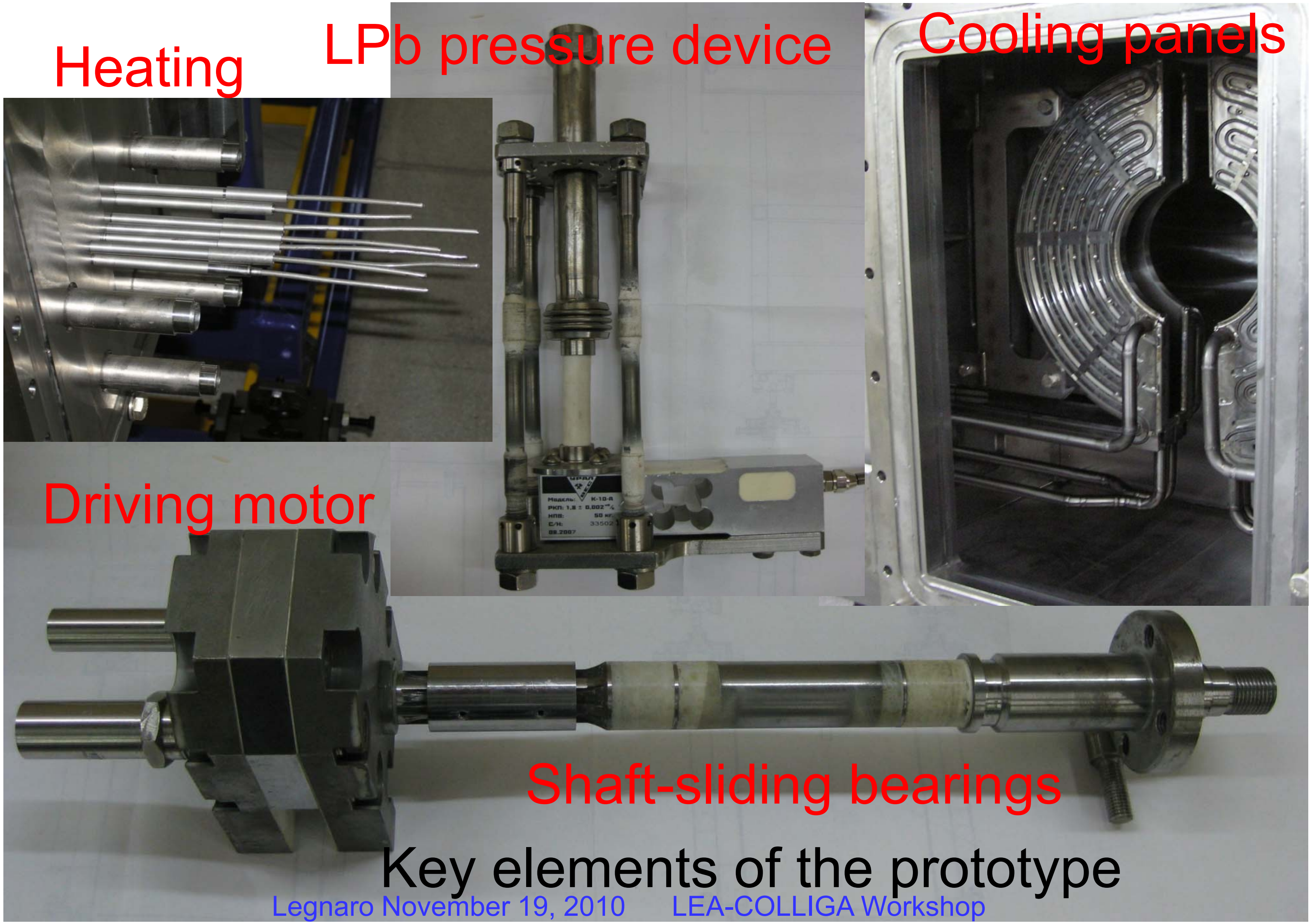


thickness of Liquid Pb jet	**5 mm**
width of the delay window	**60 mm**
thickness of the walls (stainless steel)	**2 mm**
velocity of the Liquid Pb	**<2,0 m/s**
temperature of Liquid Pb jet	**<1740 °C b.p.**
time of melting first wall	**~ 5 ms**
evacuation rate of Liquid Pb in case of failure	**~ 0,5 l/s**
active protection time in case of failure	**~ 60 s**

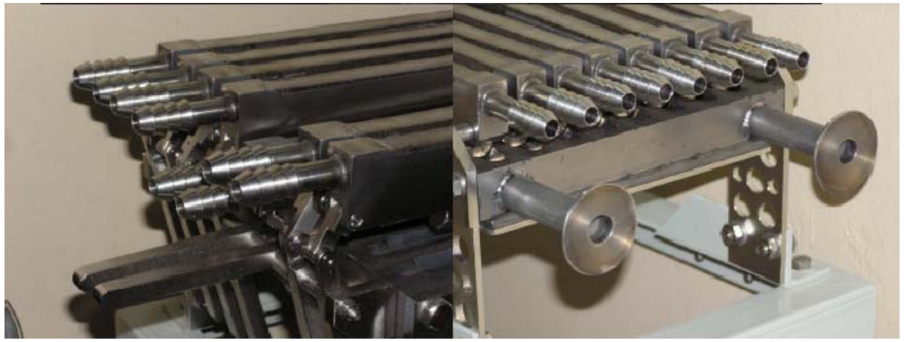
Pump for LPb system

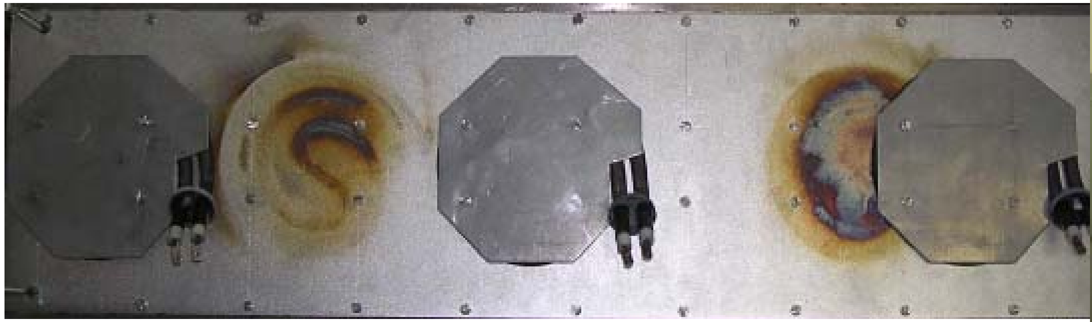


Liquid Lead Component's Test



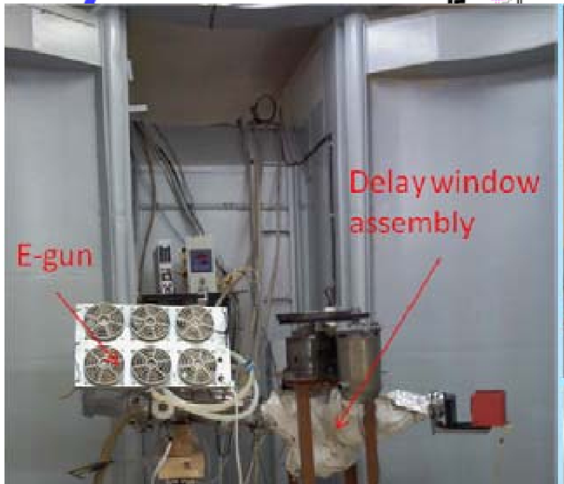
Test of the Heat exchanger

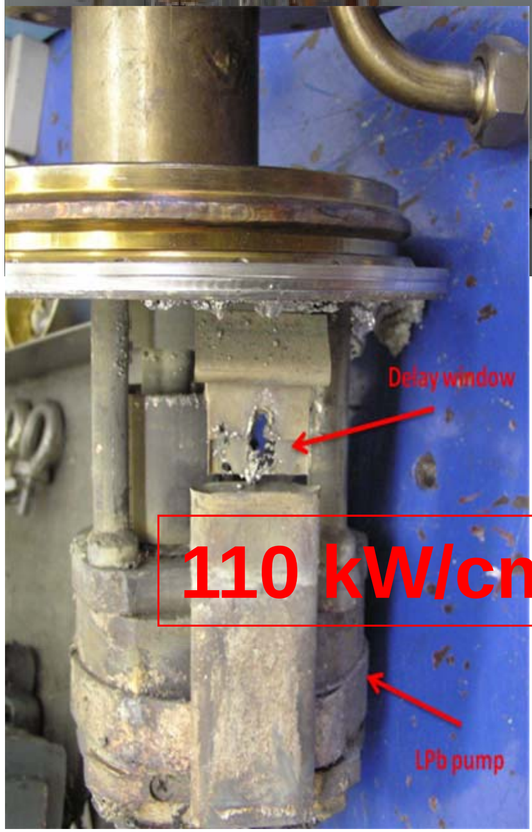




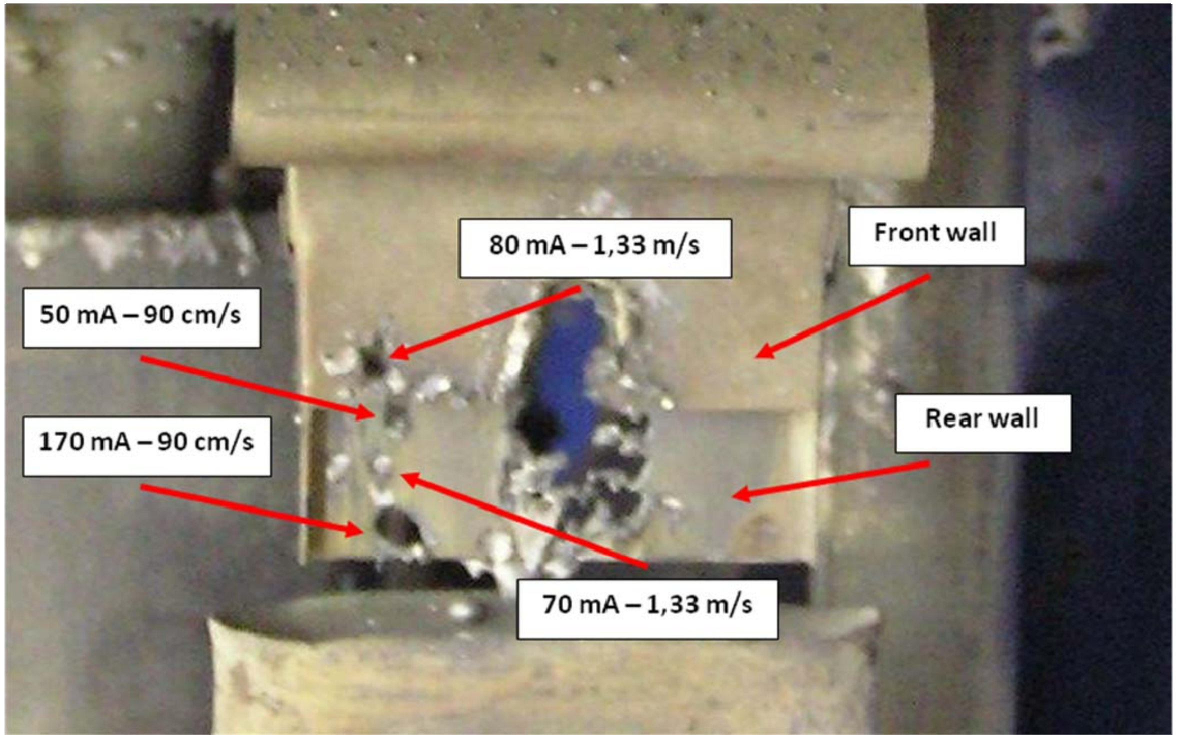
Test bench for the LPb cooling system

Delay window: 1rt test experiment





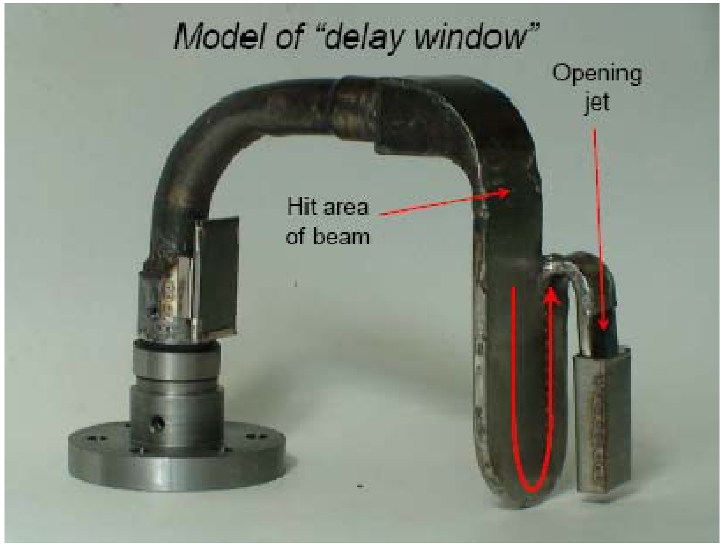
110 kW/cm²



SPIRAL2 at 200 kW ⟹ 60 kW/cm²

Beam current [mA]	Beam power [kW]	LPb velocity [m/s]	Location	Spot size [mm]
50	3,0	0,9	LPb	1,2
70	4,2	1,33	LPb	0,9 – 1,0
80	4,8	1,33	Front wall	2,3
80	4,8	1,33	Rear wall	1,2
170	10,2	0,9	LPb	3,2 x 2,5

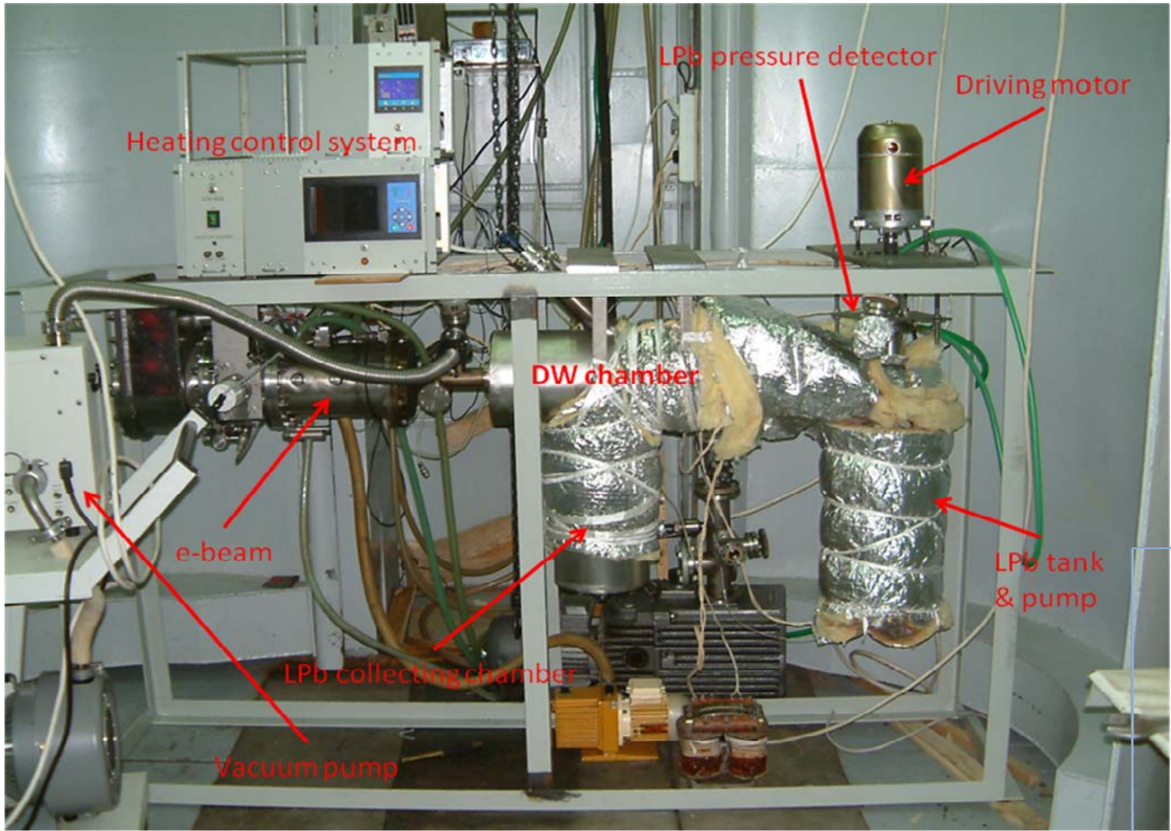
Delay window: 2nd test experiment

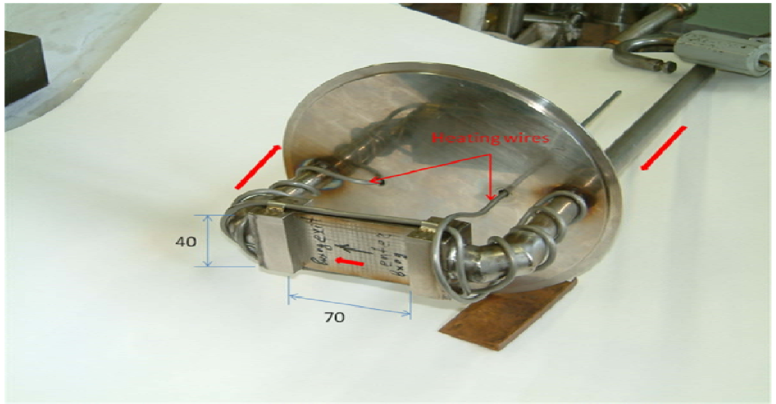


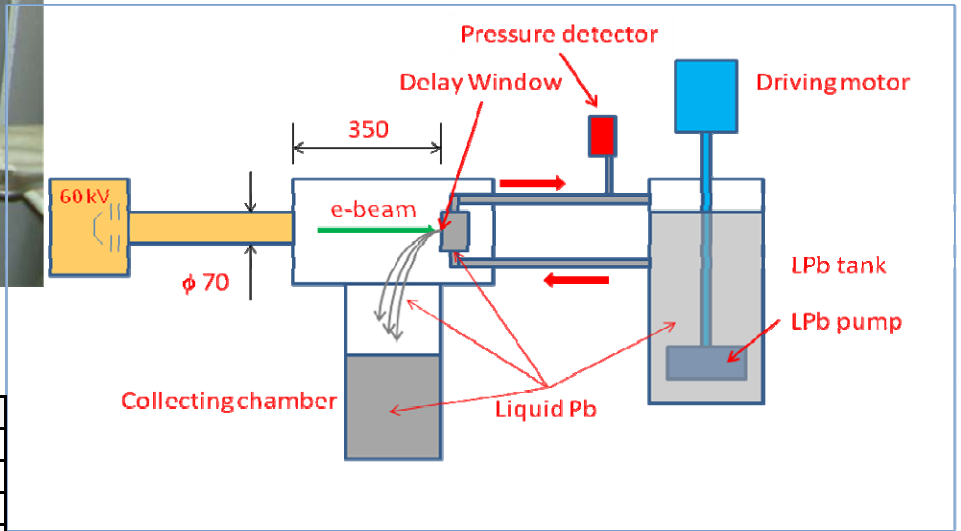
Power density of **160 kW/cm^2** (240 mA current, 60kV and 2σ=3.4 mm beam size). Lead thickness = 3 mm.

20% pressure drop detected.

Delay window: 3rd test experiment

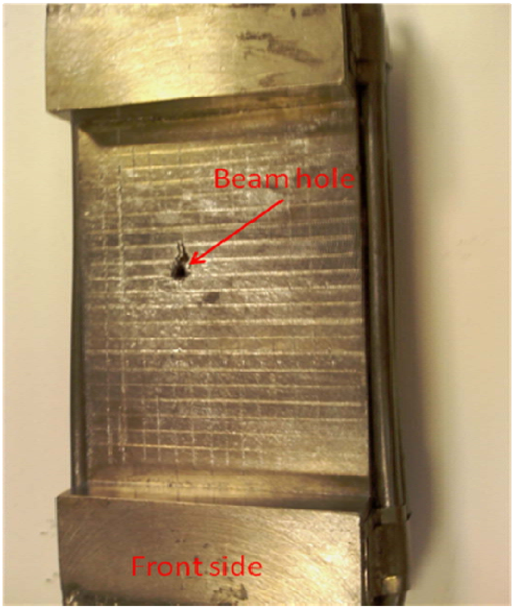


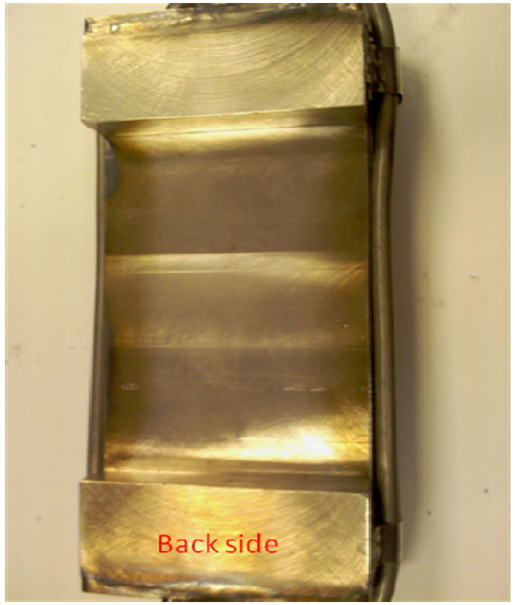




Parameter	Measure unit	Value
Thickness of LPb jet (100 MeV deuteron)	mm	5
Width of the delay window	mm^2	70 x 40
Thickness of the walls (stainless steel)	mm	2
Velocity of the Liquid PbSn	m/s	1,4
Temperature of LPb jet	°C	350
Active protection time in case of failure	s	60

Delay window: 3rd test experiment



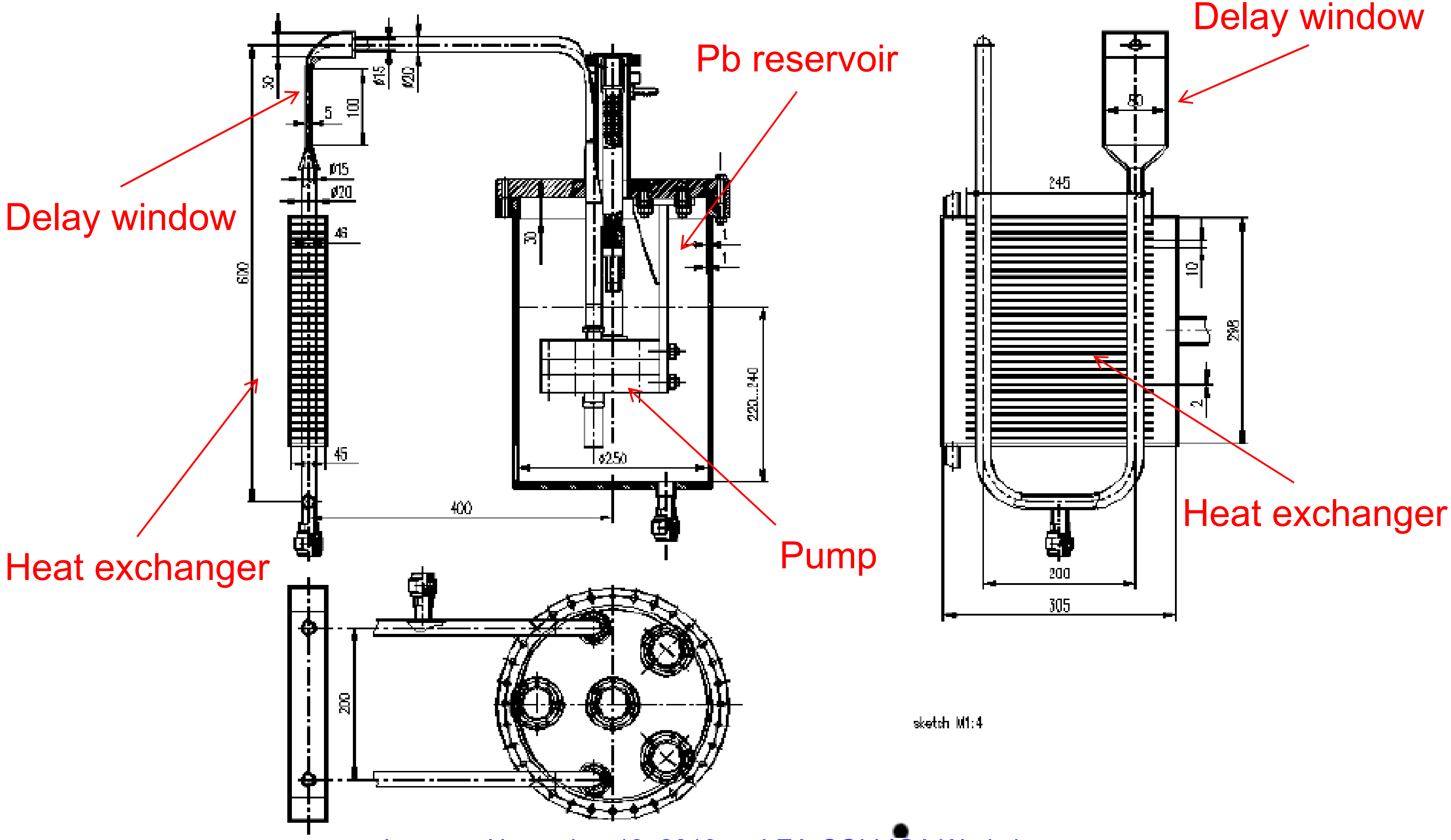


Parameter	Before melting	After melting
e-beam current	---	45 mA
Beam diameter (2σ)	1,7 mm	1,7 mm
Beam power density	---	**120 kW/cm^2**
Time of the measurements	---	**120 s**
Vacuum pressure	3,4 x 10^{-5} mbar	3 x 10^{-4} mbar
Motor absorbed current	28 A	25 A
LPb pressure	Unstable	Unstable

Delay window: Long Term Test

Long term test
Test of the heat exchanger

Delay window: Long Term Test



Materials Selection

Steel	Stress [MPa]	Time to destruction [h]	Test temperature [°C]
X12H22T3MP	700	>10000	500
X12H22T3MP	350	10000	600
X12H22T3MP	450	1500	600
X12H22T3MP	300	10000	650
X12H22T3MP	250	10000	700
X15H35T3B2Yu	570	10000	550
X15H35T3B2Yu	450	10000	600
X15H35T3B2Yu	300	>>10000	600
X15H35T3B2Yu	240	10000	700

Steel	C	Si	Mn	Cr	Ni	Ti	Al	V	Mo	Fe
DIN 17240	< 0,08	< 1	< 2	14,5	26	2,1	< 0,8	0,3	1,25	Base
JIS G-4311	< 0,08	< 1	< 2	13,5 16	24 27	1,9 2,3	0,35	0,1 0,5	-	Base
AISI 316 Unite States	0,08	1,0	2,0	16 18	10 14	-	-	-	2 3	Base

Properties	TM-1	AXF-5Q	Unit
Density	1,82	1,78	g/cc
Porosity	20	20	%
Particle Size	10	5	μm
Ultimate Tensile Strength	40	60	MPa
Modulus of Elasticity	10	11	GPa
Flexural Strength	60	99	MPa
Compressive Yield Strength	110	145	MPa
Electrical Resistivity	0,0012	0,00147	ohm-cm
CTE, linear	8,20	7,90	μm/m-°C
Thermal Conductivity	105	95	W/m-K

Procedures for Safety & Quality Assurance.

Procedures for drawings and traceability.

Method and procedures to prepare the call for tender (Cahier des charges);

Reference documents (for quality assurance)

Conclusions

- Basing on prototype test, the thermo-mechanical design of converter has been done and the main parameters have been defined;

- Critical components are been tested (bearings, lead pump & motor,…);

- Radiation activation and radiation damage calculations have been performed;

- Tests on radiation damage of graphite due to deuteron beam are in progress;

- Three tests of the delay window were already successfully performed;

- The“nuclearized” integration of the converter in the Production Module is going to the end.

- The goal is start the procedures for the tender for the construction of the converter and delay window end 2010 or beginning 2011 and get the first prototype at the end 2011.