Moving Solid Metallic Targets for Pion Production in the Muon Collider / Neutrino Factory Project

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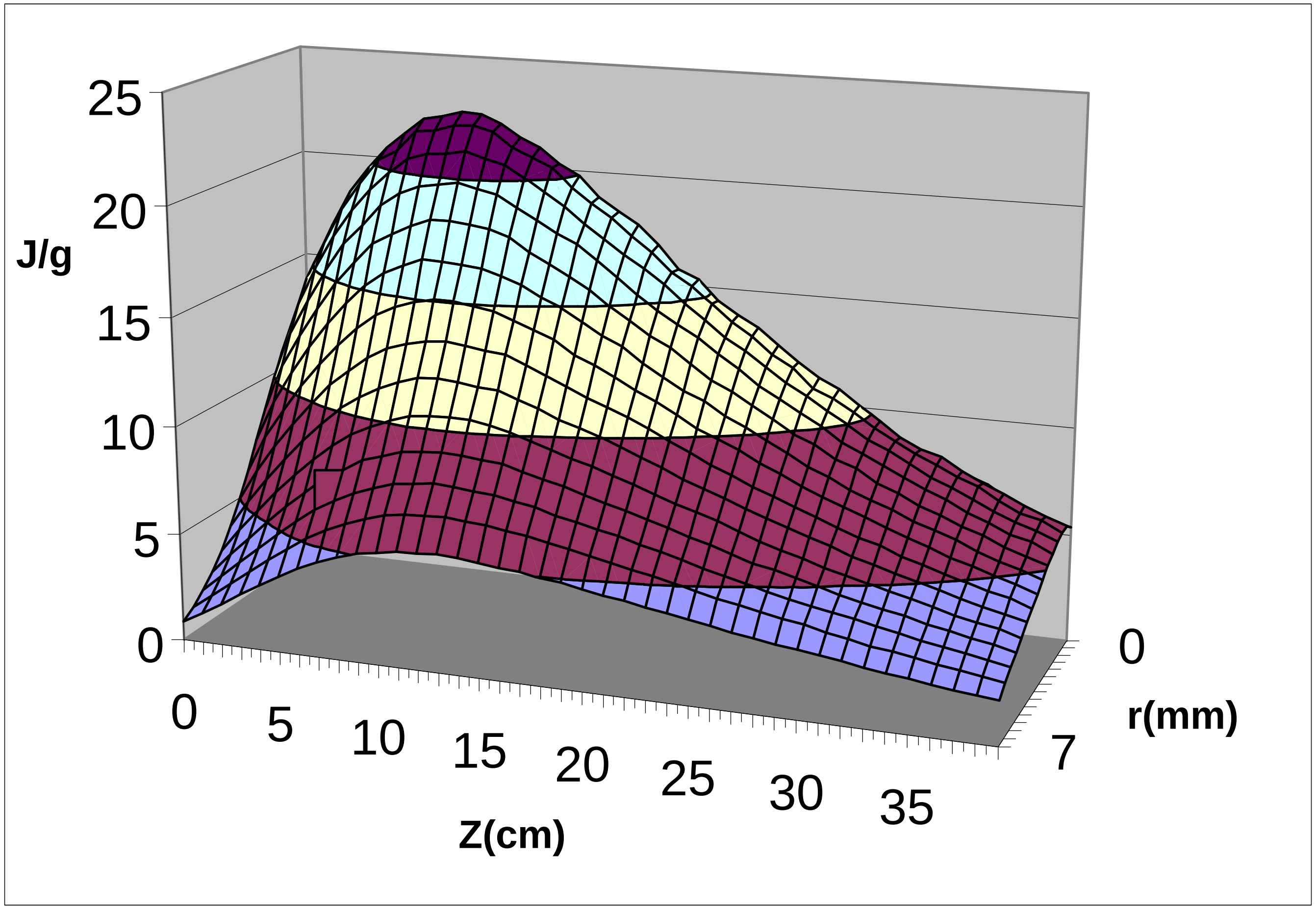
A previous (full text) version of this paper can be found at:

http://www-mucool.fnal.gov/mcnotes/public/pdf/muc0234/muc0234.pdf

	The Good News	The Bad News
Mercury Jets	E951 reached the J/g expected for the 1 MW option.	For the 1 MW option the J/cm will be 4 times larger.
	No damaging droplet velocities were observed.	At 15 m/s, ~70 liters/min of Hg will hit chamber walls.
Carbon-Carbon Targets	Simplest possible, stationary target.	One stationary spot will get maximum radiation damage.
	Radiation cooling will work.	The C-C weaves are not fine enough: $V_s \times \Delta t \ll$ fiber radius
	Sublimation rate in He will be acceptable.	Compared to Hg, the yield is ~50%



MARS data for a 3 mm rms radius 16TP beam on a 7.5 mm radius iron target.

Maximum energy density deposited by a 16TP, 24 GeV beam in an iron target.

Beam radius [mm rms]	.5	1	1.5	2	2.5	3	3.5
Target radius [mm]	1.25	2.5	3.75	5	6.25	7.5	8.75
Maximum energy density [J/g]	305	105	55.6	36.0	26.5	22.1	16.5

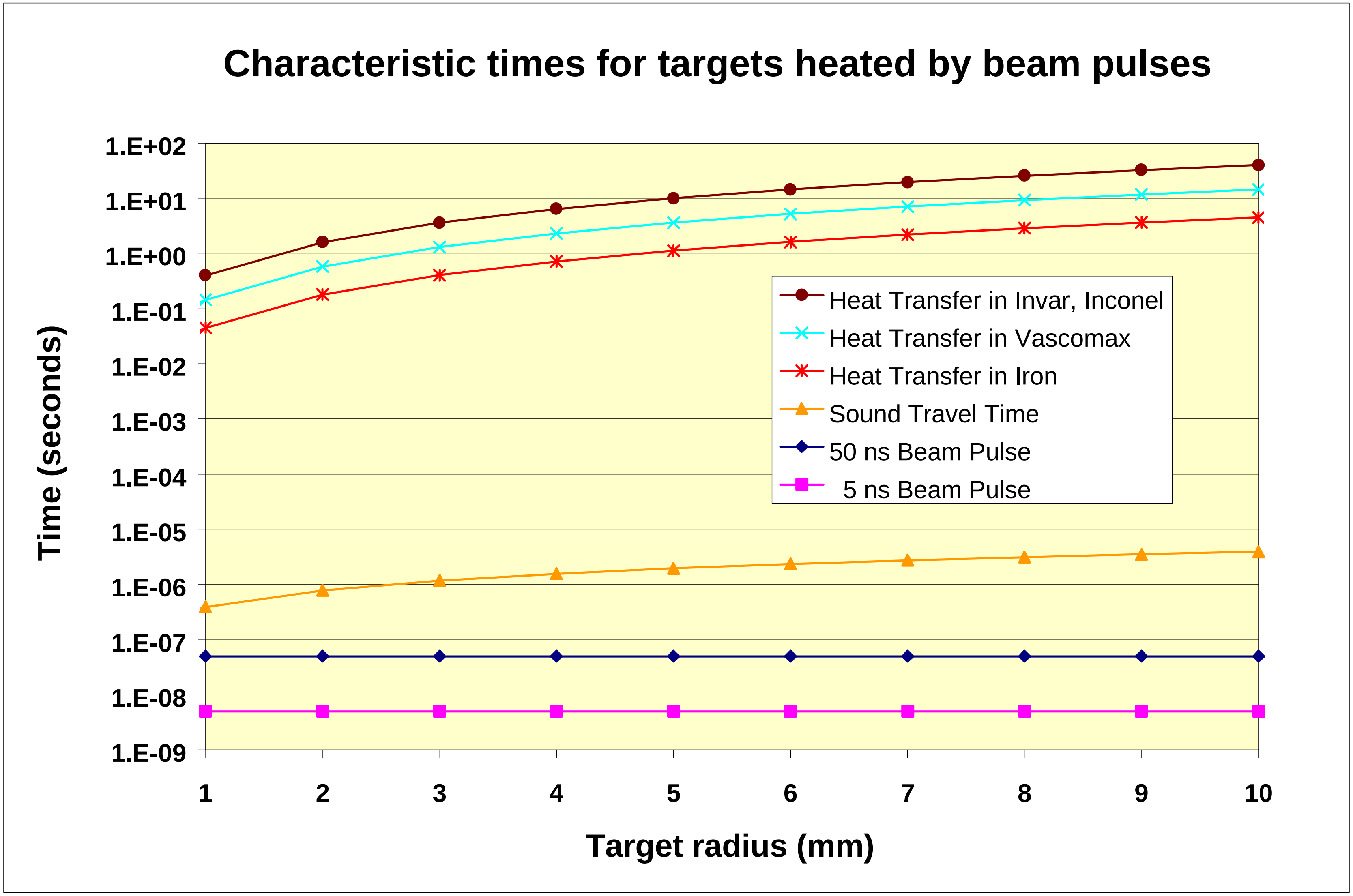
(The example for 7.5 mm target radius is used later for various estimates.)

Mechanical an thermal characteristics of the materials

	Density	Linear Exp. Coeff.	Young Modulus	Bulk Modu-lus	Poisson Ratio	Specific Heat @ constant pressure	Thermal Conducti-vity	Yield Stren-gth	Fatigue Endu-rance Limit
Symbol	ρ	α	Y	B	μ	c_p	λ	$\sigma_{0.2}$	σ_{-1}
Unit	g/cm^3	10^{-6} / ^0K	G Pa	G Pa		J/(g ^{0}K)	W/(m ^{0}K)	M Pa	M Pa
Iron	7.87	12.5	205	171	0.30	0.478	80	170	~85
Inconel 718	8.19	13.1	200	158	0.29	0.435	11.2	1034	586
VascoMax C-350	8.08	15.0	200	167	0.30	0.450	25.2	2242	758
Super Invar	8.15	0.63	144	88.9	0.23	0.515	10.5	276	~138

Typical Chemical Compositions (%).

Element	C	Al	Si	S	Ti	Cr	Mn	Fe	Co	Ni	Cu	Nb	Mo
Atomic Number	6	13	14	16	22	24	25	26	27	28	29	41	42
Inconel 718		0.5			1	19		19		52.5		5	3
Vasco Max C-350	.02	0.1	.05	.005	1.4		.05	63	12	18.5			4.8
Super Invar	.05	.07	.09	.01		.03	.4	62	5.4	31.8	.08		



Characteristic times for targets heated by beam pulses
Time (seconds)
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
1
2
3
4
5
6
7
8
9
10
Target radius (mm)
Heat Transfer in Invar, Inconel
Heat Transfer in Vascomax
Heat Transfer in Iron
Sound Travel Time
50 ns Beam Pulse
5 ns Beam Pulse

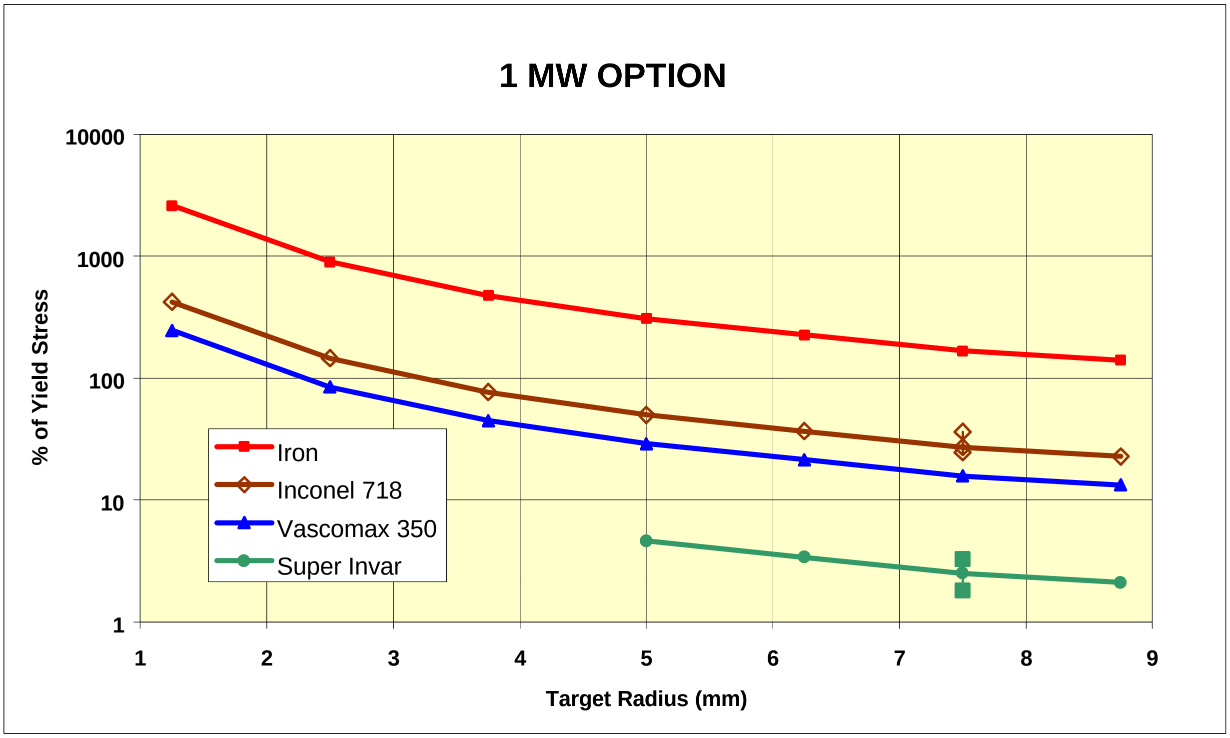

1 MW OPTION
10000
1000
100
10
1
% of Yield Stress
Iron
Inconel 718
Vascomax 350
Super Invar
1
2
3
4
5
6
7
8
9
Target Radius (mm)

Fig. 3

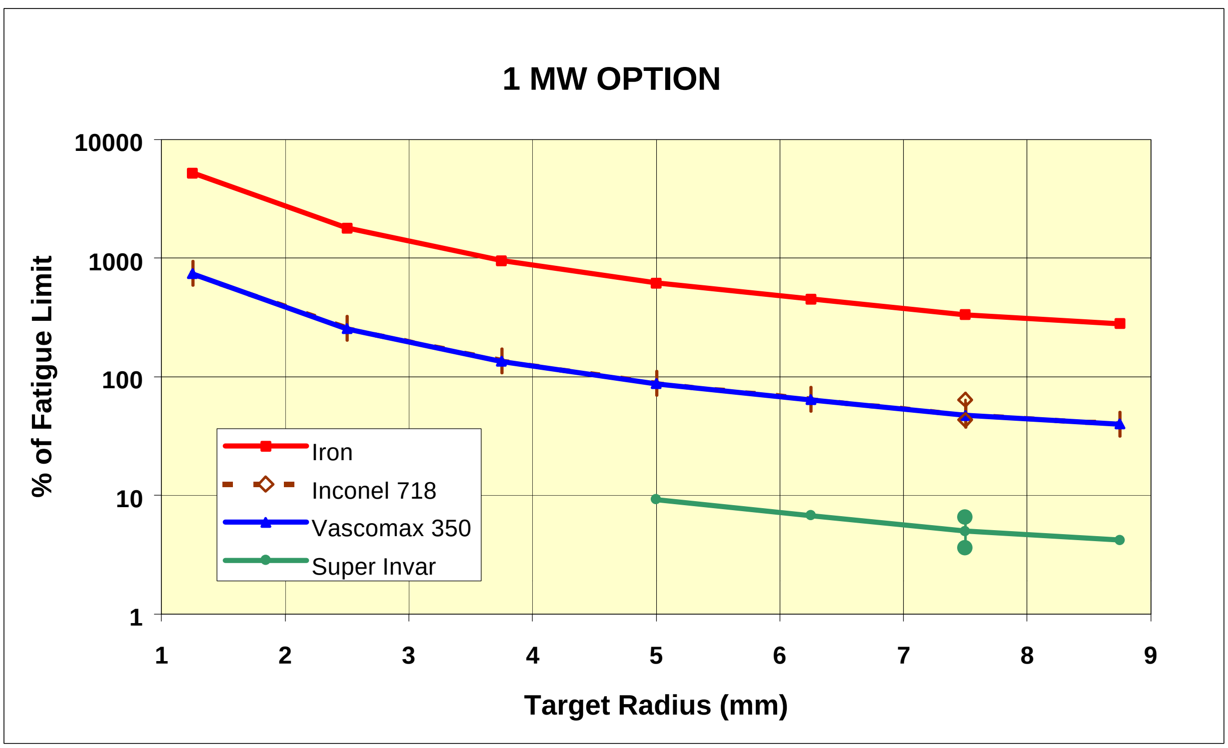

1 MW OPTION
10000
1000
100
10
1
% of Fatigue Limit
Iron
Inconel 718
Vascomax 350
Super Invar
1
2
3
4
5
6
7
8
9
Target Radius (mm)

Fig. 4

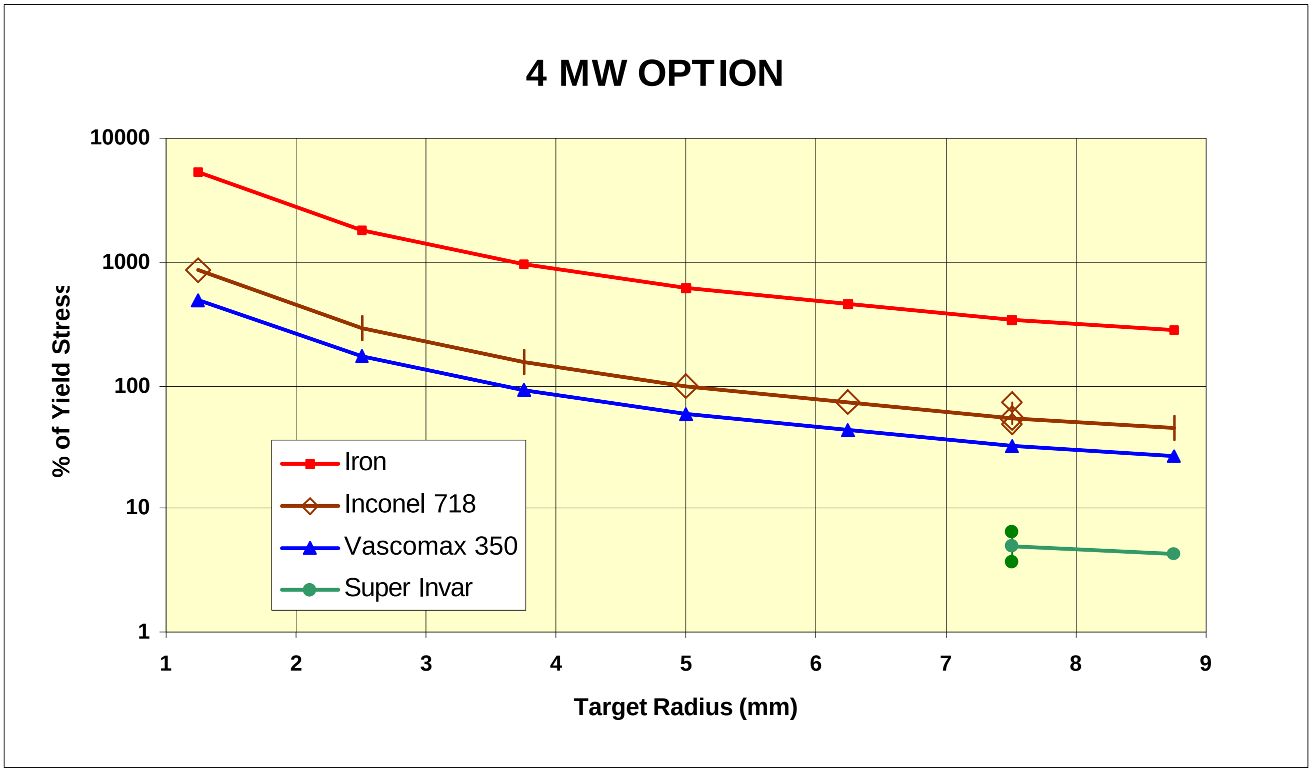

4 MW OPTION
% of Yield Stress
10000
1000
100
10
1
1
2
3
4
5
6
7
8
9
Target Radius (mm)
Iron
Inconel 718
Vascomax 350
Super Invar

Fig. 5

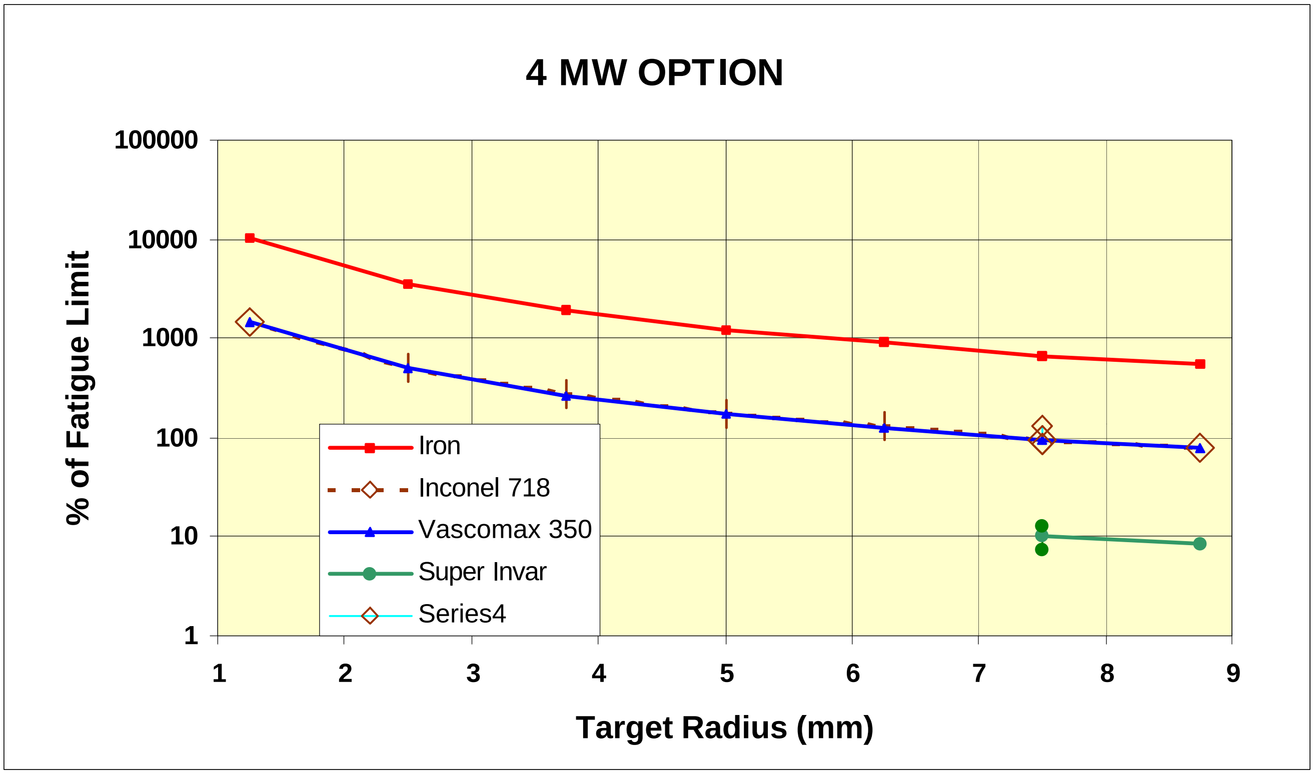

4 MW OPTION
% of Fatigue Limit
100000
10000
1000
100
10
1
1
2
3
4
5
6
7
8
9
Target Radius (mm)
Iron
Inconel 718
Vascomax 350
Super Invar
Series4

Fig.6

1 MW-option results for a 7.5 mm radius target

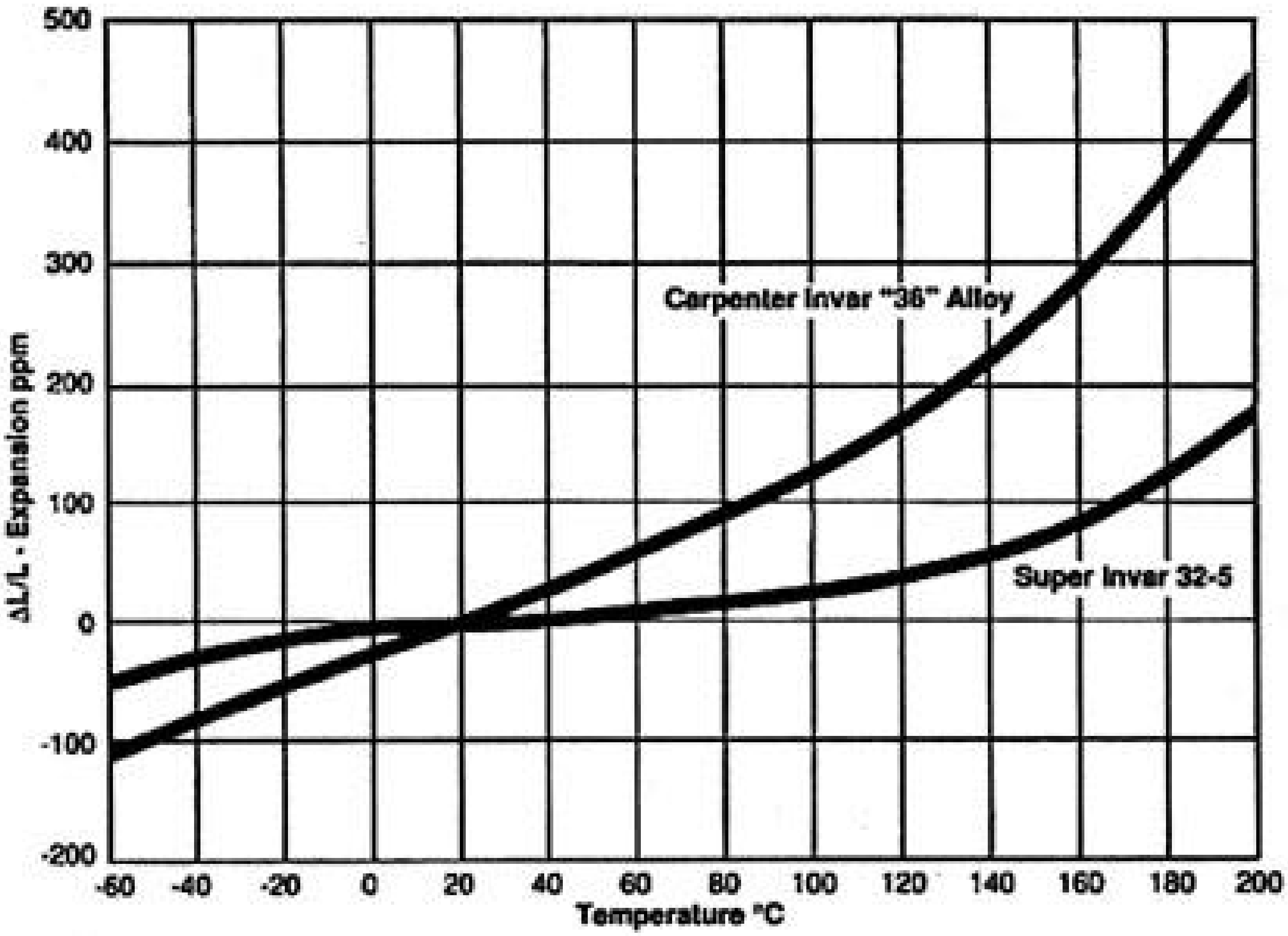
	Iron	Inconel 718	Vascomax C- 350	Super Invar
Maximum Stress/ Yield Stress	1.7	0.27 0.25	0.16	0.025 0.018
Maximum Stress/ Fatigue Limit	3.3	0.48 0.43	0.47	0.050 0.036

4 MW-option results for a 7.5 mm radius target

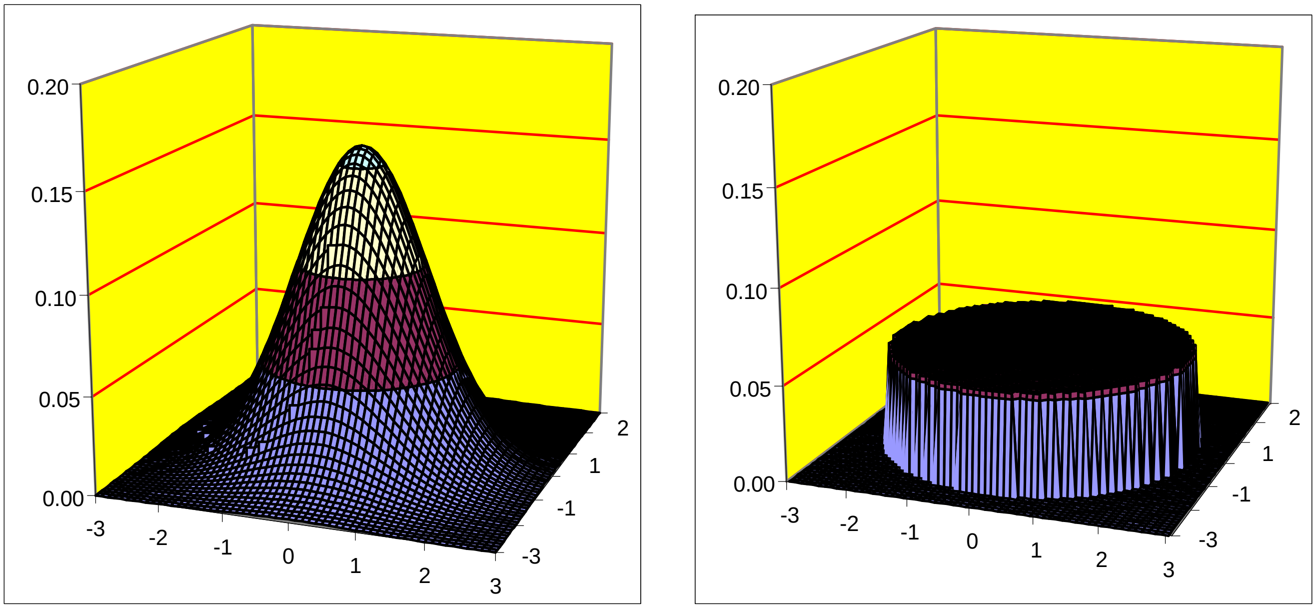
	Iron	Inconel 718	Vascomax C-350	Super Invar
Maximum Stress/ Yield Stress	3.4	0.54 0.49	0.32	0.05 0.04
Maximum Stress/ Fatigue Limit	6.7	0.95 0.87	0.94	0.10 0.07

Upper numbers in each box: Maximum beam pulse induced compression.

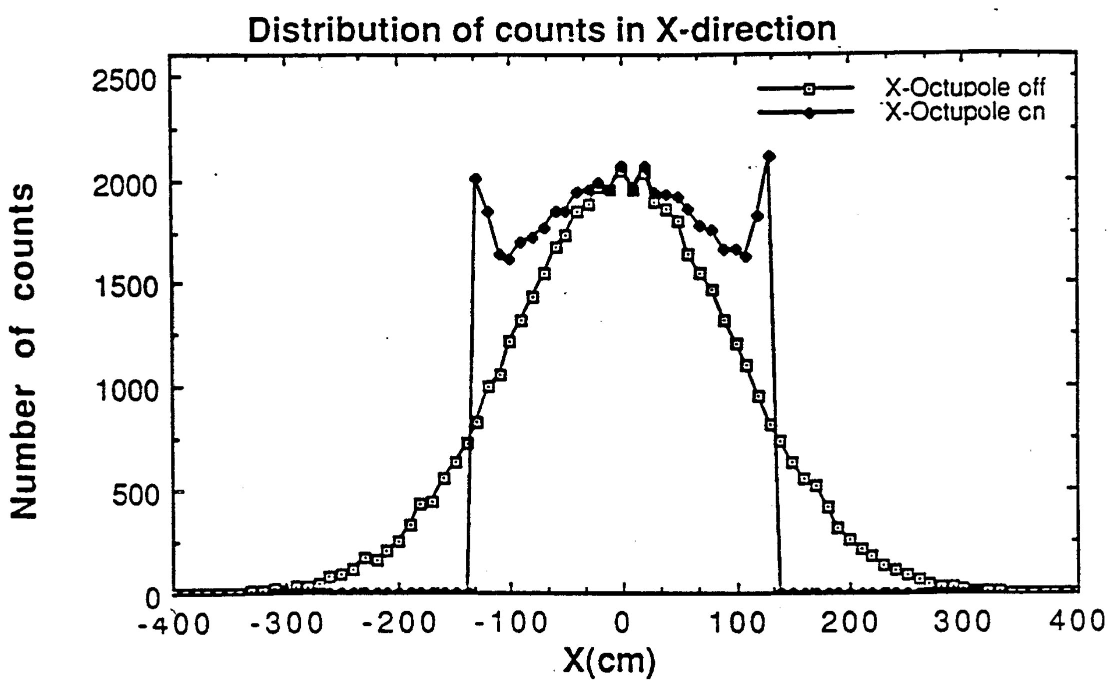
Lower number in each box: ANSY calculated maximum von Mises stress during subsequent oscillations.



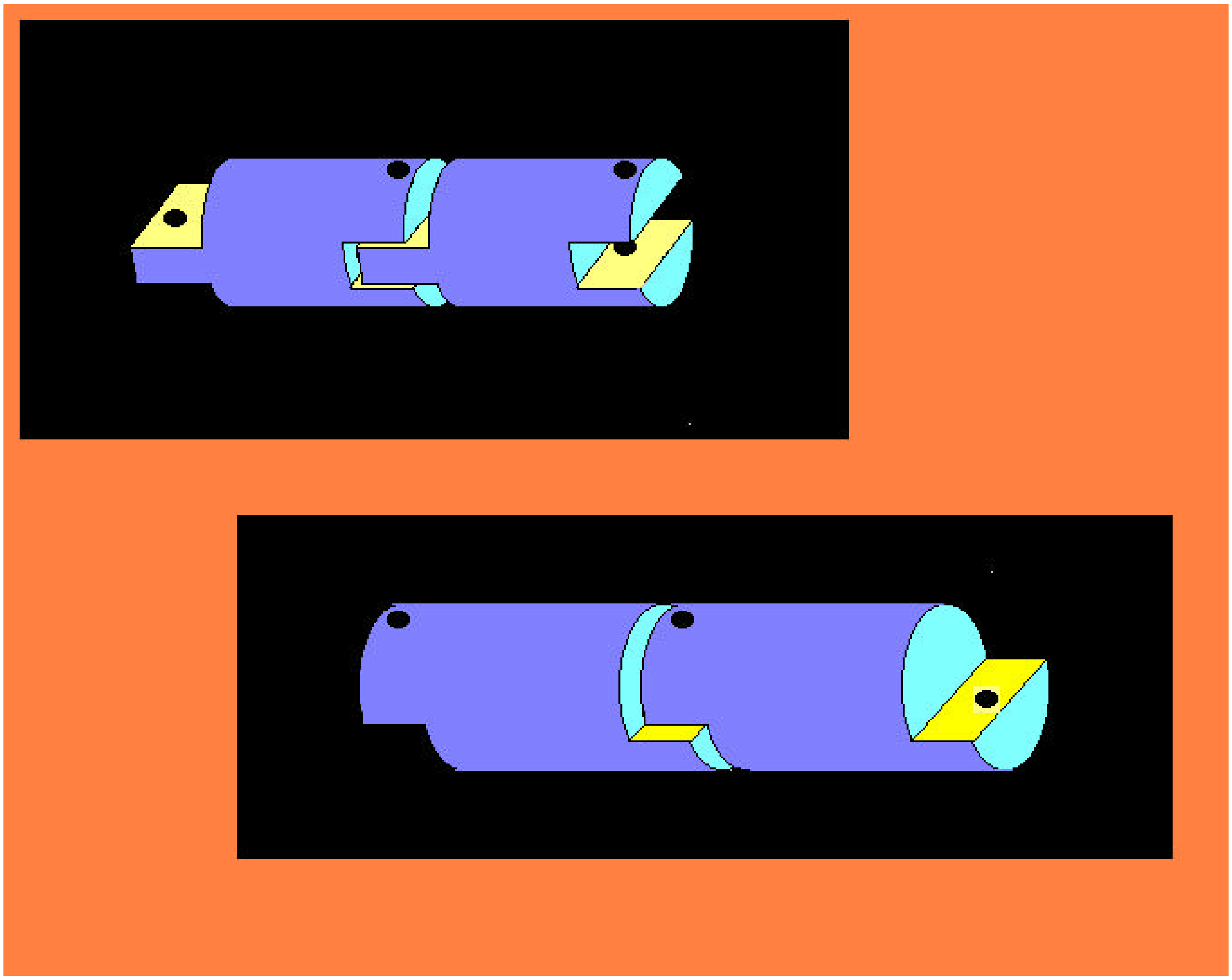
Linear expansion as a function of temperature for Invar and Supper Invar alloys.

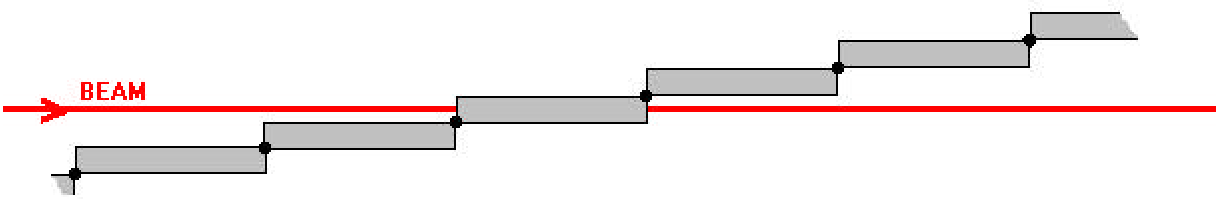


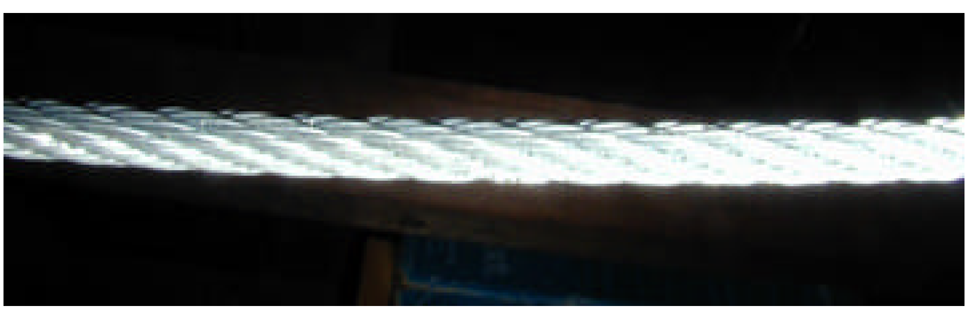
Comparison of a doubly Gaussian beam profile (a) with an ideal flat profile (b) containing the same number of particles.



Octupole-lens generated beam profile compared to a Gaussian profile with the octupole turned off.

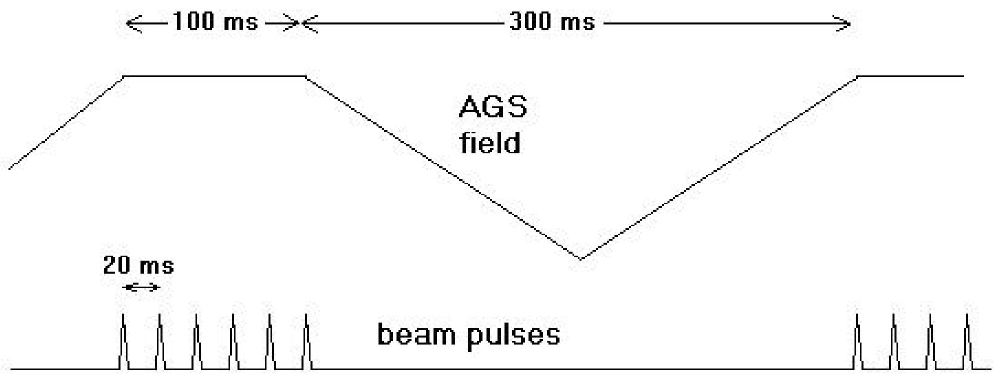






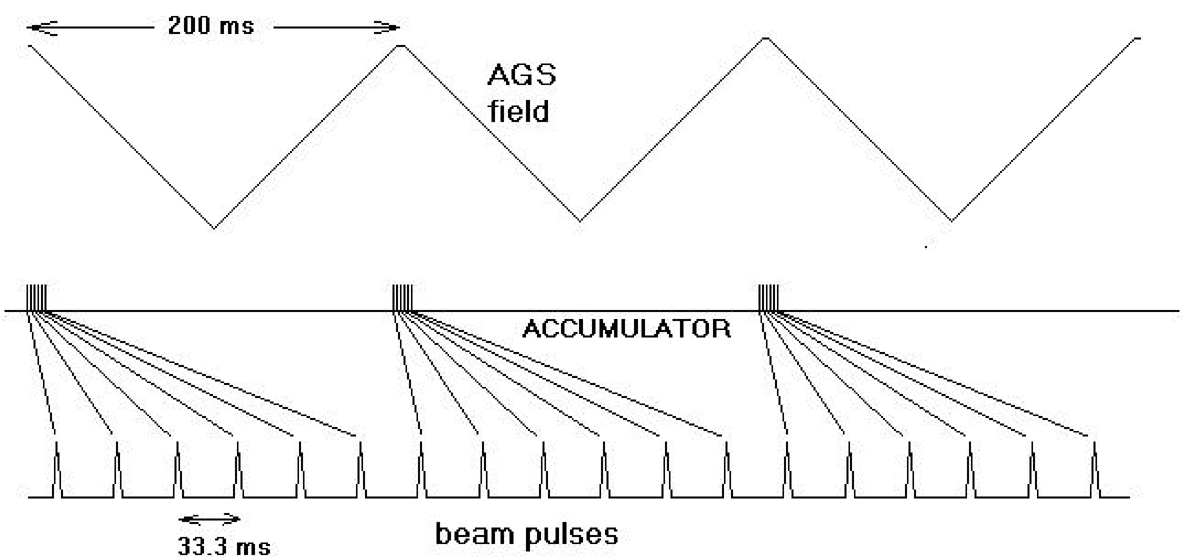
Schematic examples of metallic chain and cable targets.

1 MW OPTION



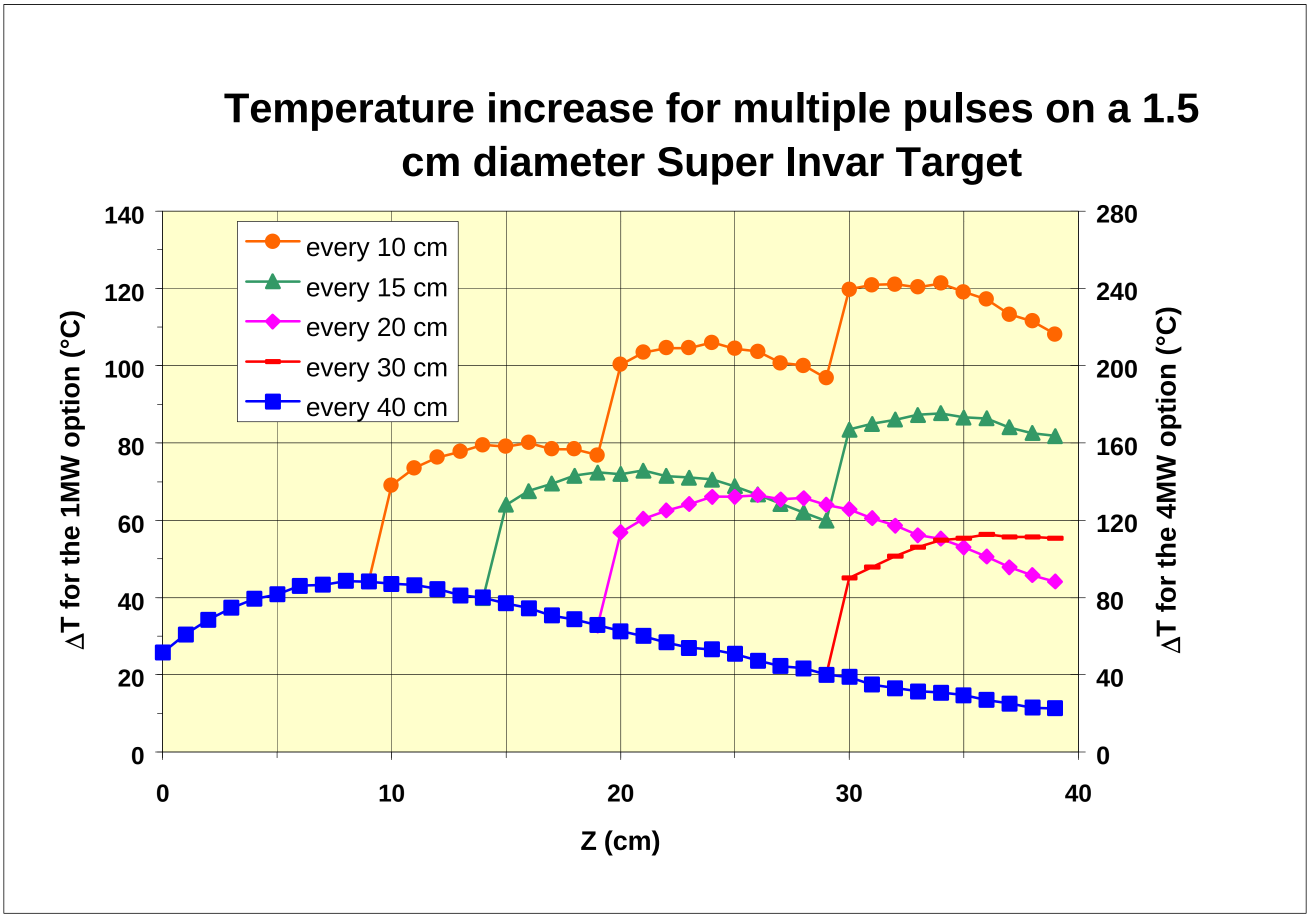
15 pulses per second
66.7 kJ per pulse
17.3 TP per pulse

4 MW OPTION

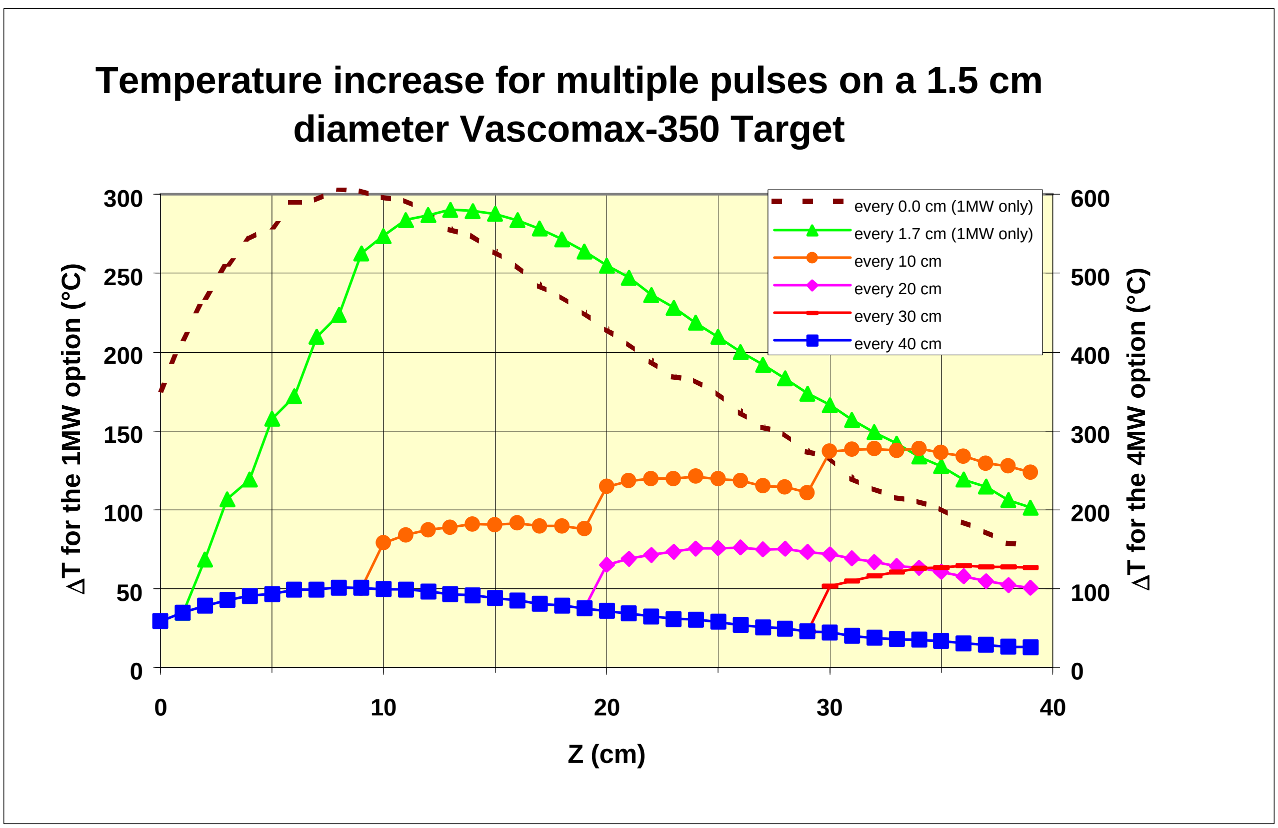


30 pulses per second
133 kJ per pulse
34.7 TP per pulse

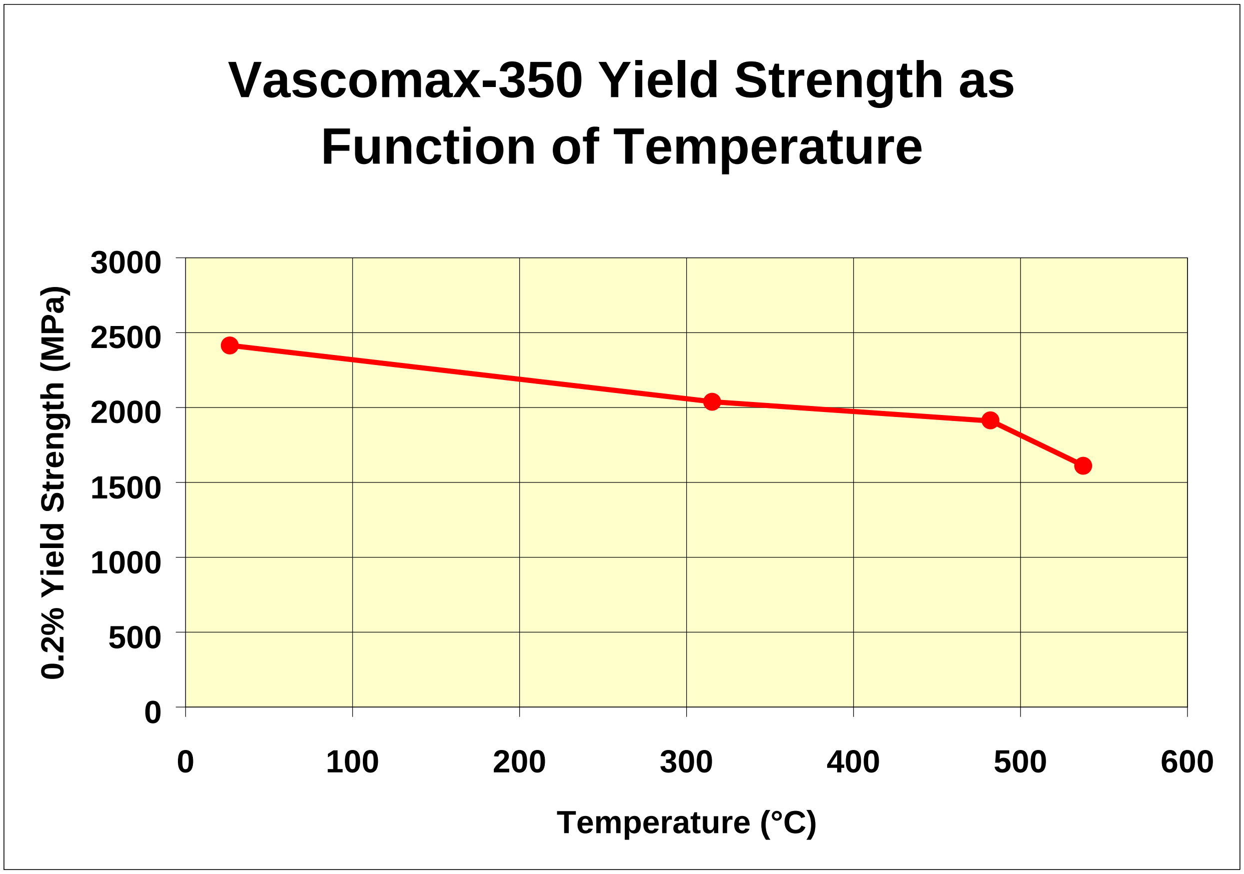
Proton beam pulse sequences for the proposed 1 MW and 4 MW options.



Temperature increase for multiple pulses on a 1.5 cm diameter Super Invar Target
every 10 cm
every 15 cm
every 20 cm
every 30 cm
every 40 cm
ΔT for the 1MW option (°C)
ΔT for the 4MW option (°C)
Z (cm)
0
20
40
60
80
100
120
140
0
40
80
120
160
200
240
280
0
10
20
30
40

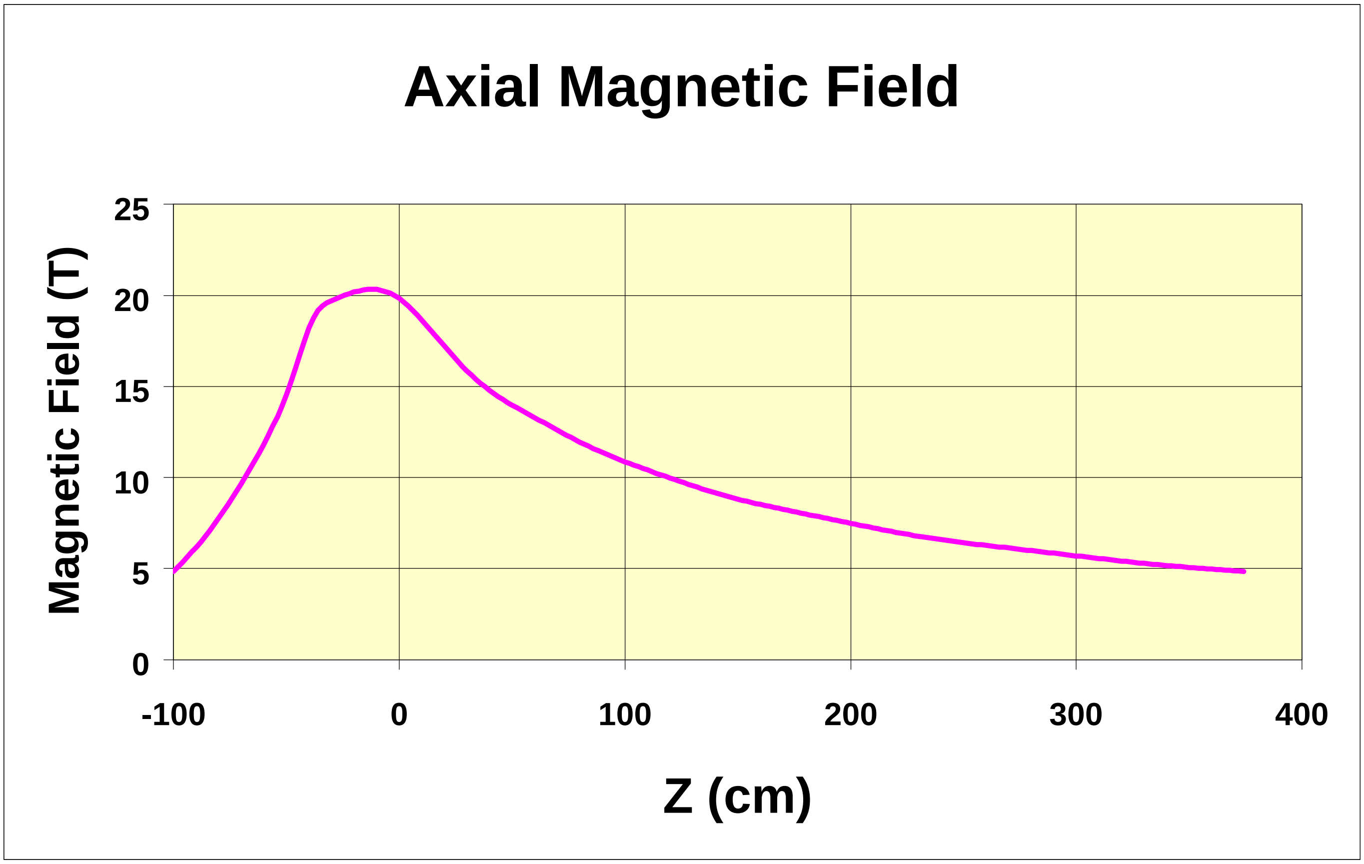


Temperature increase for multiple pulses on a 1.5 cm diameter Vascomax-350 Target
every 0.0 cm (1MW only)
every 1.7 cm (1MW only)
every 10 cm
every 20 cm
every 30 cm
every 40 cm
ΔT for the 1MW option (°C)
ΔT for the 4MW option (°C)
Z (cm)
0
50
100
150
200
250
300
0
100
200
300
400
500
600
0
10
20
30
40

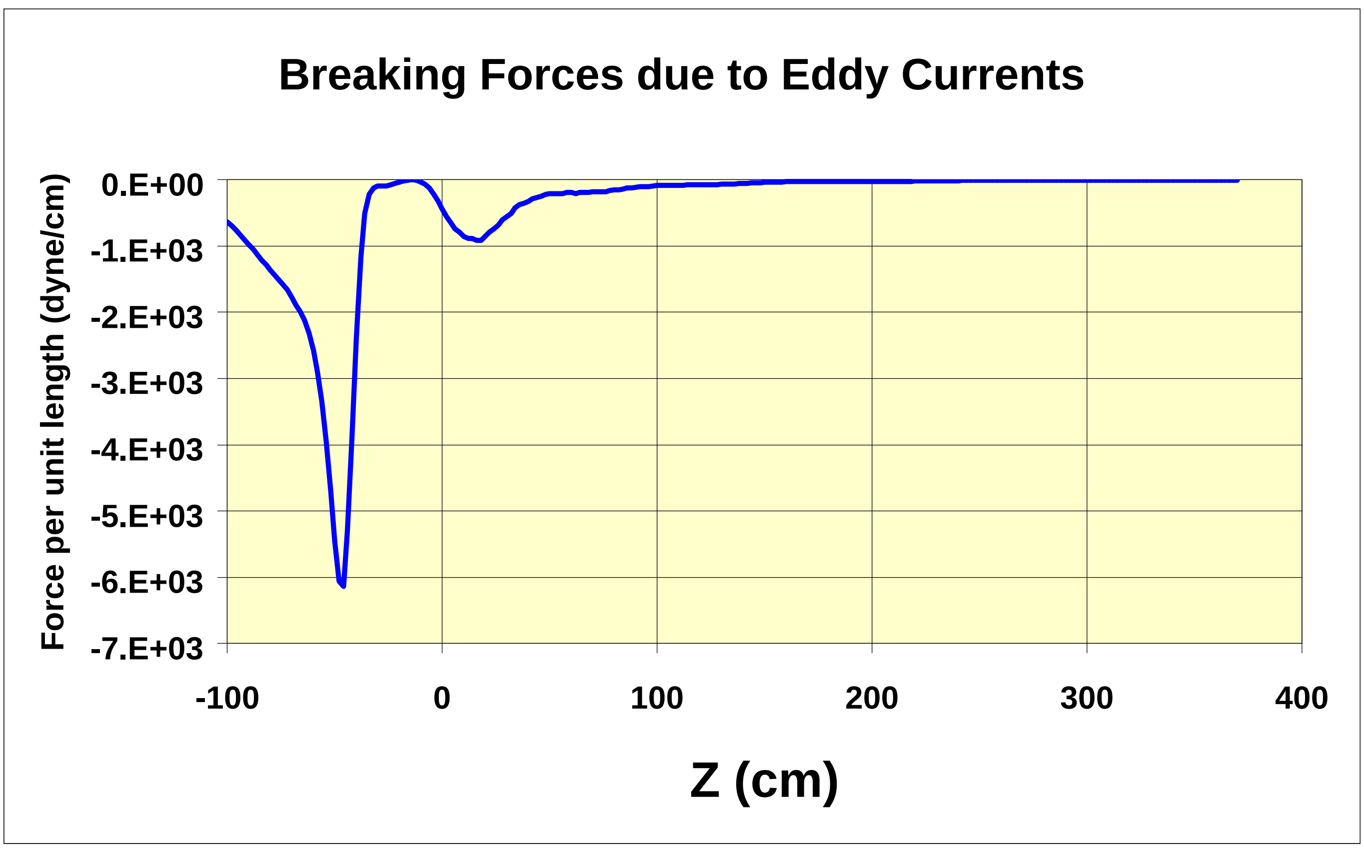


Examples of target velocities and lengths

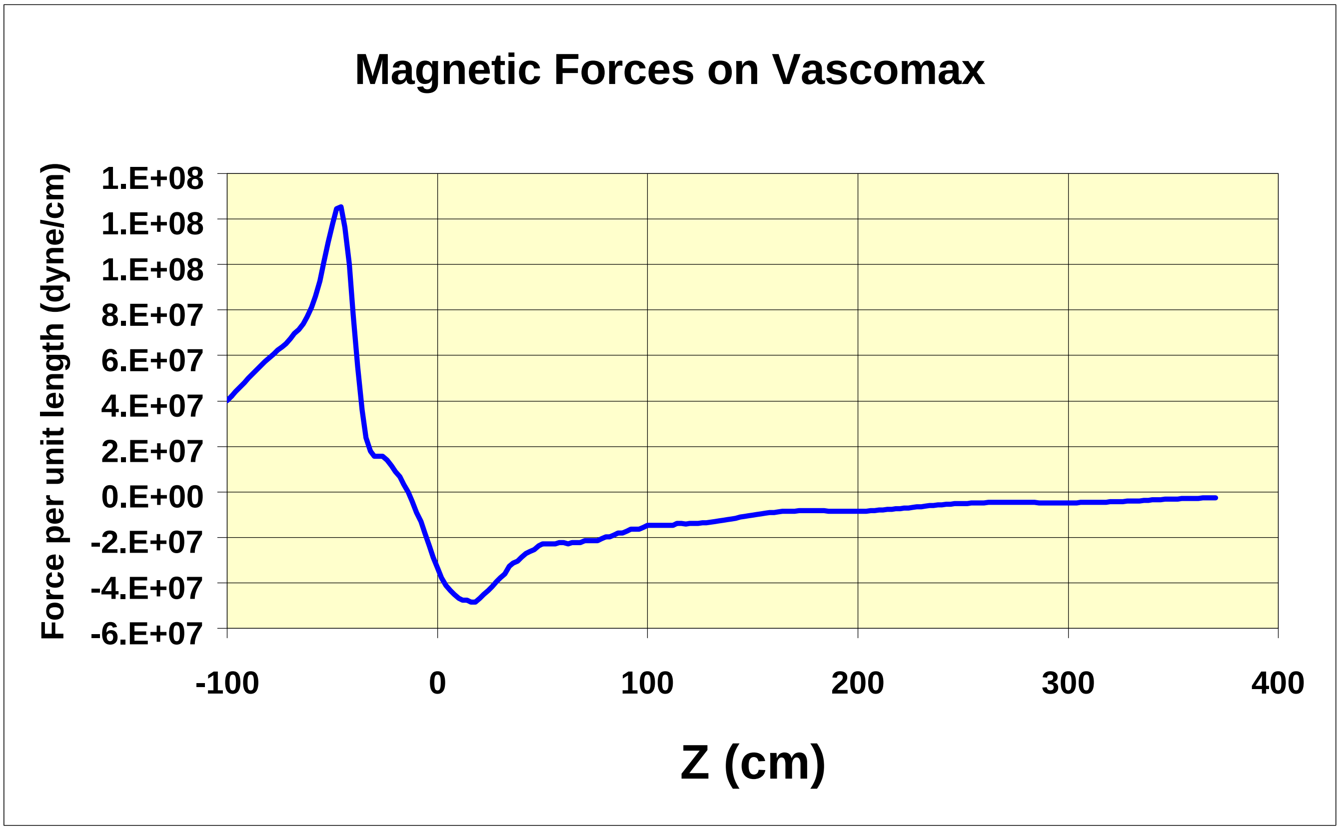
	Velocity (continuous motion)	Minimum length (continuous motion)	Average Velocity (intermittent motion)	Minimum length (intermittent motion)
	m/s	m	m/s	m
Super Invar - 1 MW Option	7.5	175		
Vascomax C-350 - 1 MW Option	0.85	16.8	1.0	18
Super Invar - 4 MW Option	12.0	274		
Vascomax C-350 - 4 MW Option	3.0	34		



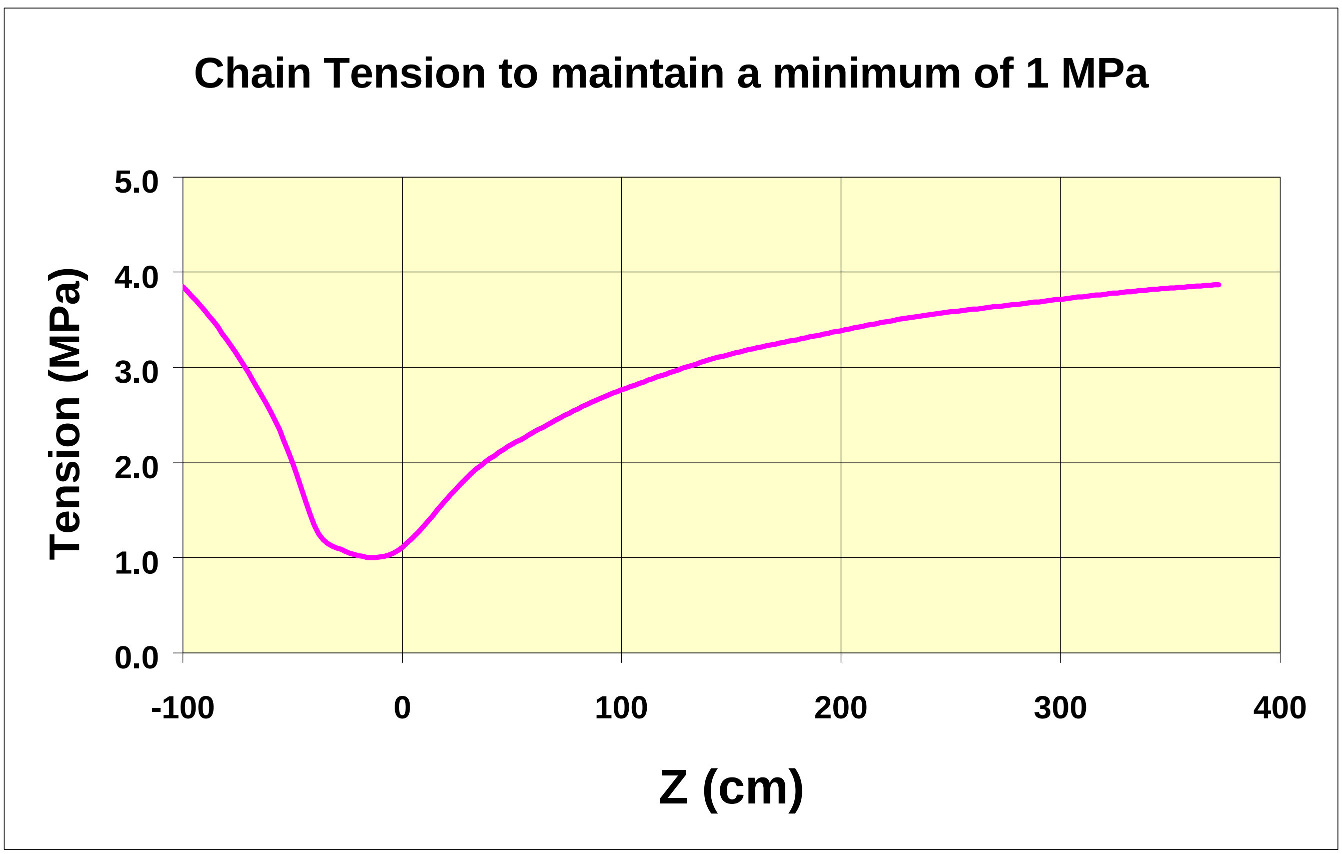
Axial magnetic field calculated for the 20T solenoid arrangement described in the Feasibility Study



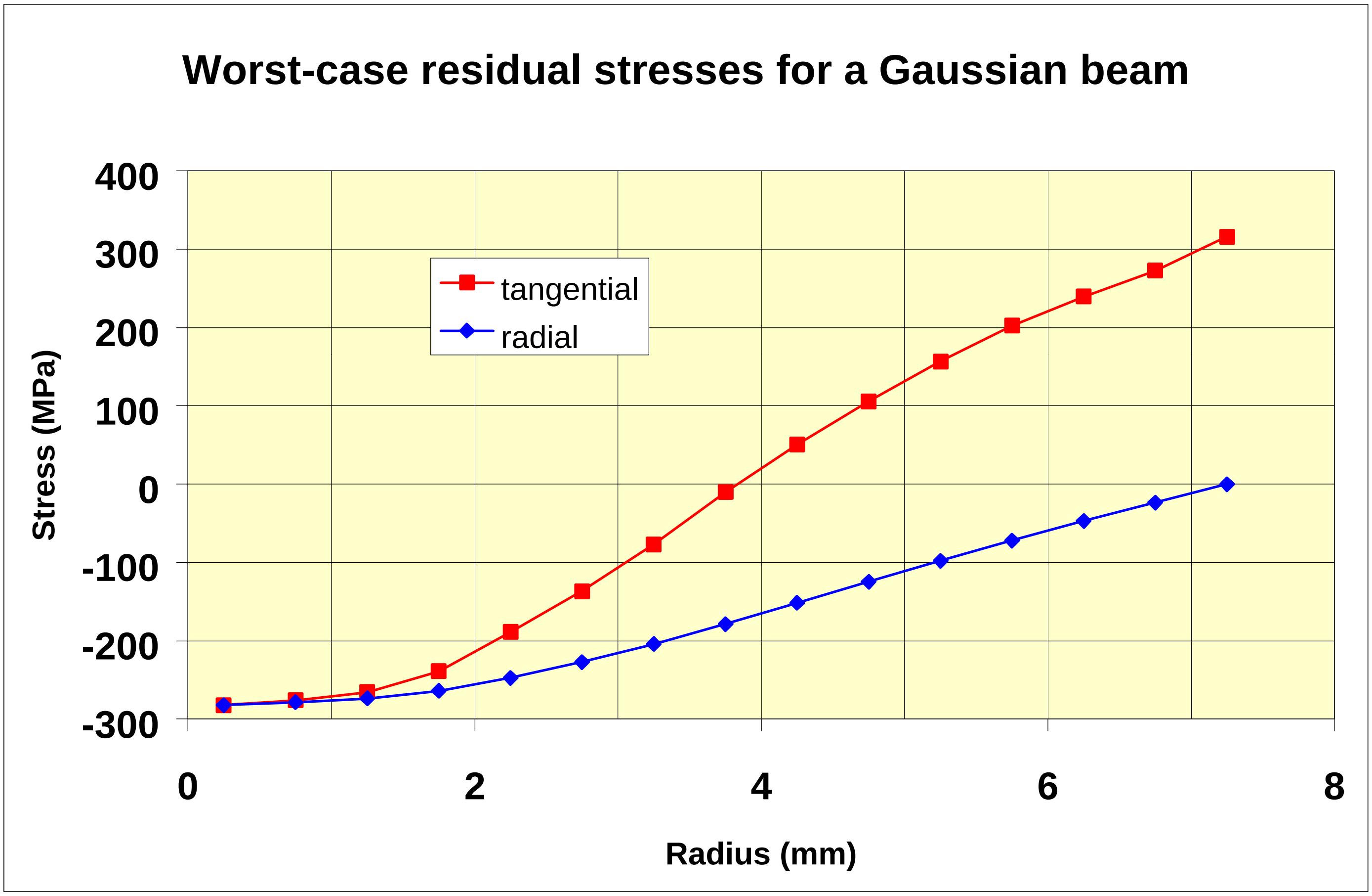
Breaking forces per unit target length due to Eddy currents in a 1.5 cm diameter Vascomax target moving axially at 12 m/s through the 20T field.

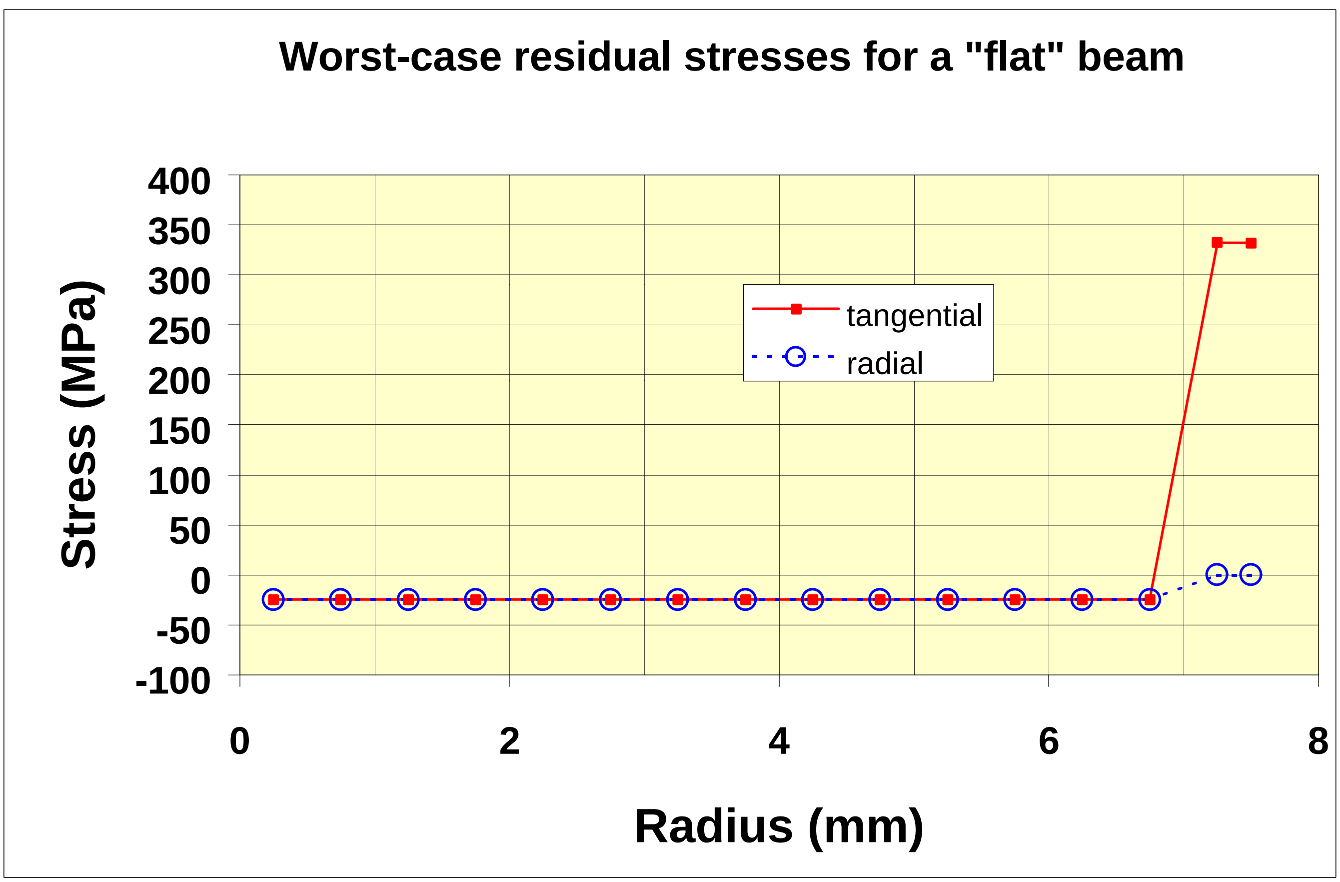


Magnetic forces on a 1.5 cm diameter Vascomax C-350 target placed in the 20T field.

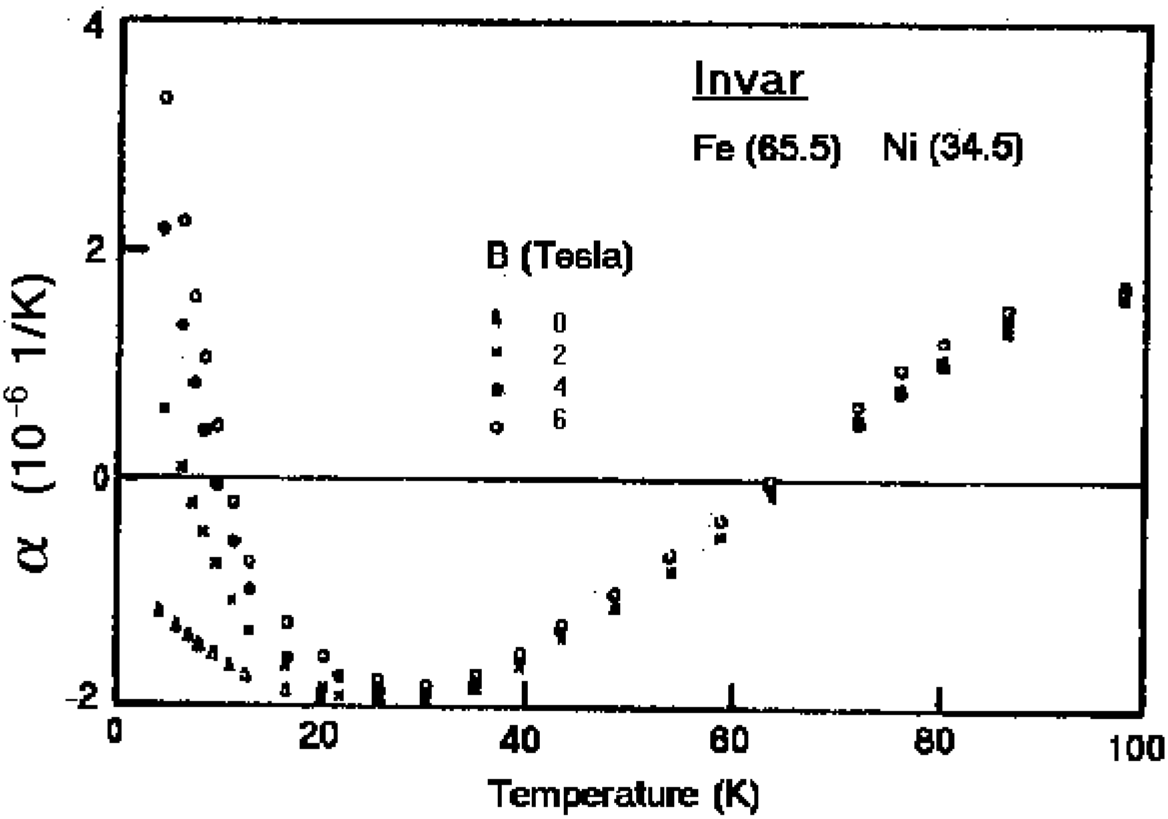


Tension as a function of position for a 1.5 cm diameter Vascomax C-350 target placed in the 20 T field. In this example, an external tension is applied to achieve a minimum tension of 1 MPa.

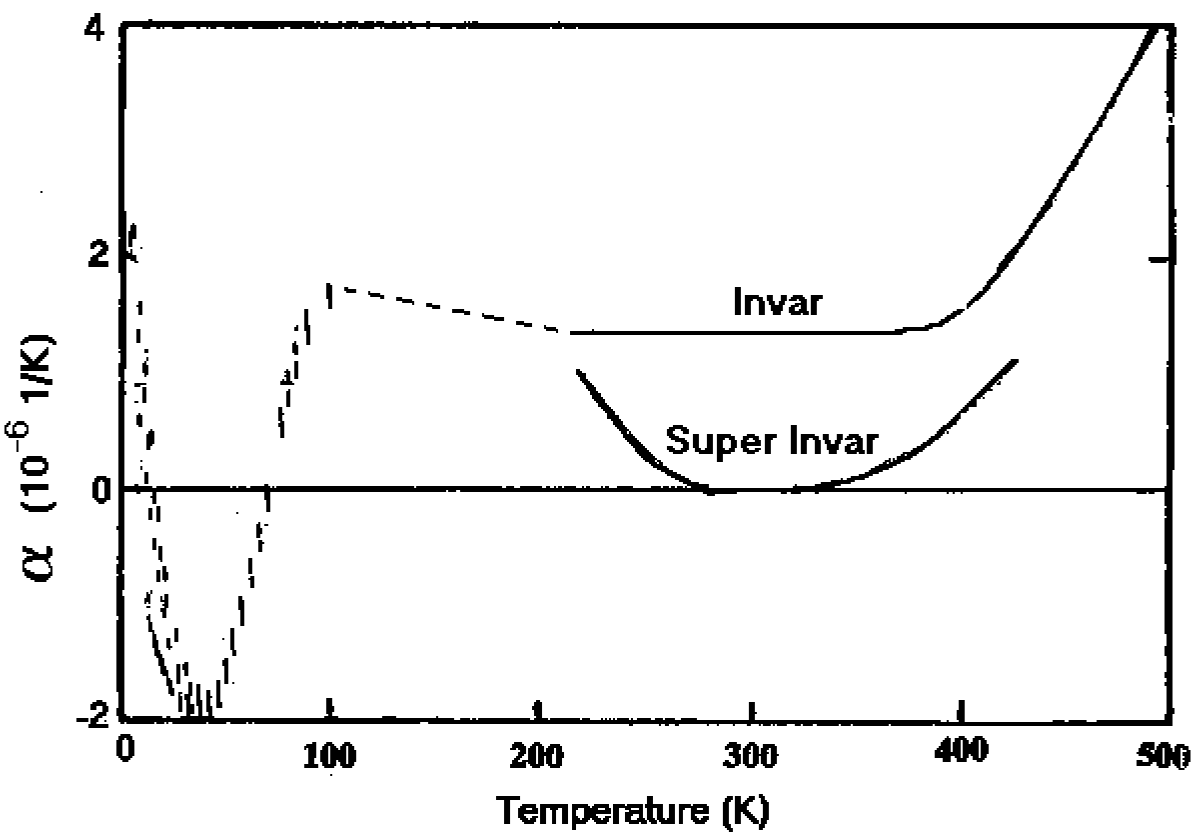




Worst case residual stresses in Vascomax after 5 17.3TP pulses on a stationary target.



Invar linear expansion coefficient as a function of temperature and magnetic field



Low temperature data combined with known expansion coefficients at higher temperatures.

Comparison of advantages and disadvantages the three alloys considered.

MATERIAL	ADVANTAGES	DISADVANTAGES
Super Invar	Largest margin for thermal shock tolerance. Absence of large magnetic forces.	Narrow temperature range and low heat conductivity leading to the need for long chains or cables. The largest uncertainty regarding deleterious effects of radiation damage.
Vascomax C-350	Largest tensile strength. Good heat conductivity allowing the use of relatively short chains or cables.	The material is strongly ferromagnetic and will be subject to large magnetic forces
Inconel 718	Good fatigue endurance limit similar to Vascomax C-350. Moderate magnetic forces.	Poor heat conductivity (similar to Super Invar) requiring long chains or cables, but not as long as for Super Invar since the temperature range is not as small.

CONCLUSION: Solid metallic targets offer viable alternatives.