T2K Hadron Absorber (Beam Dump) simulations

Neutrino Beam and Instrumentation Workshop
August 2006

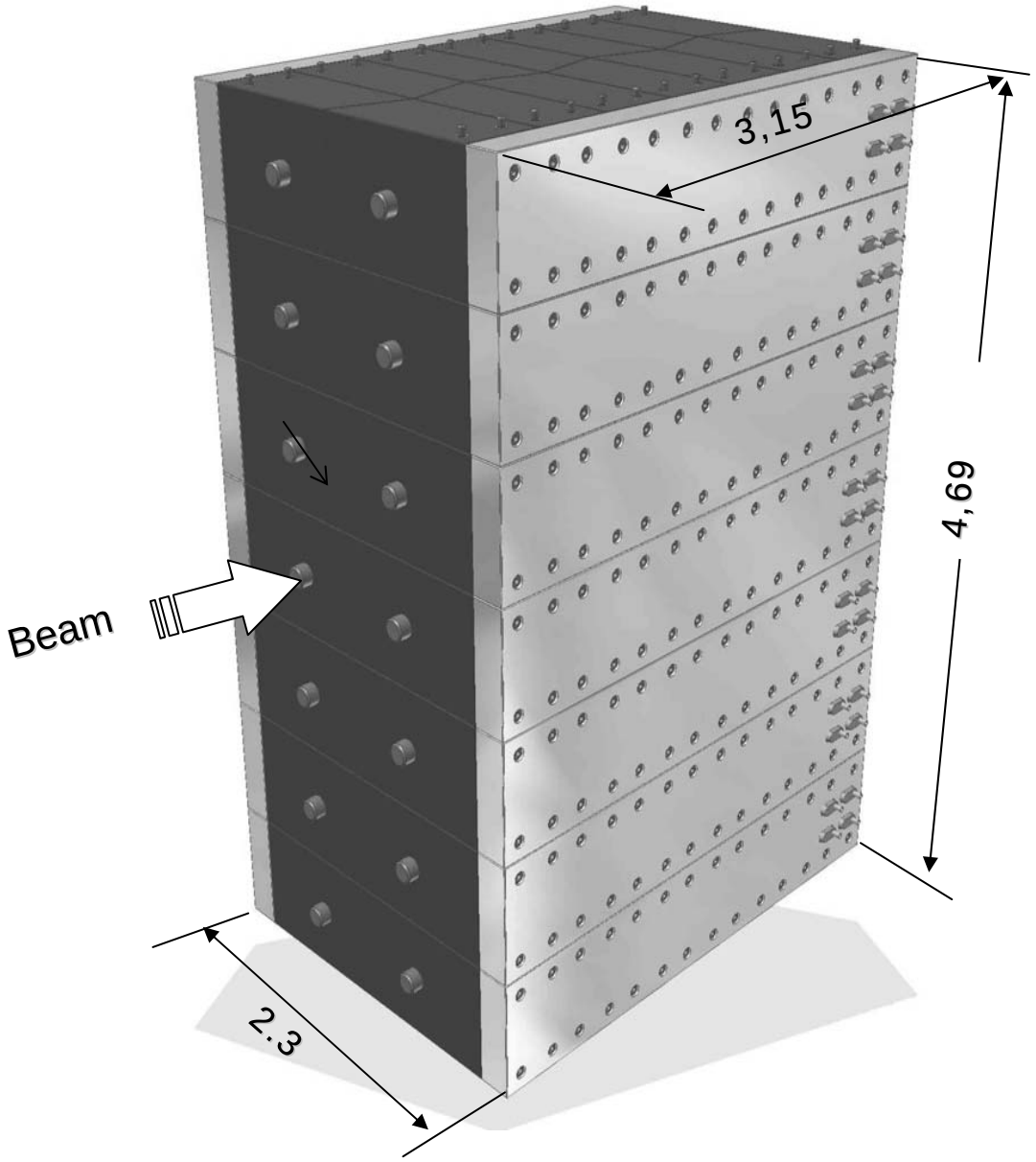
Chris Densham
Rutherford Appleton Laboratory

Hadron Absorber Challenges

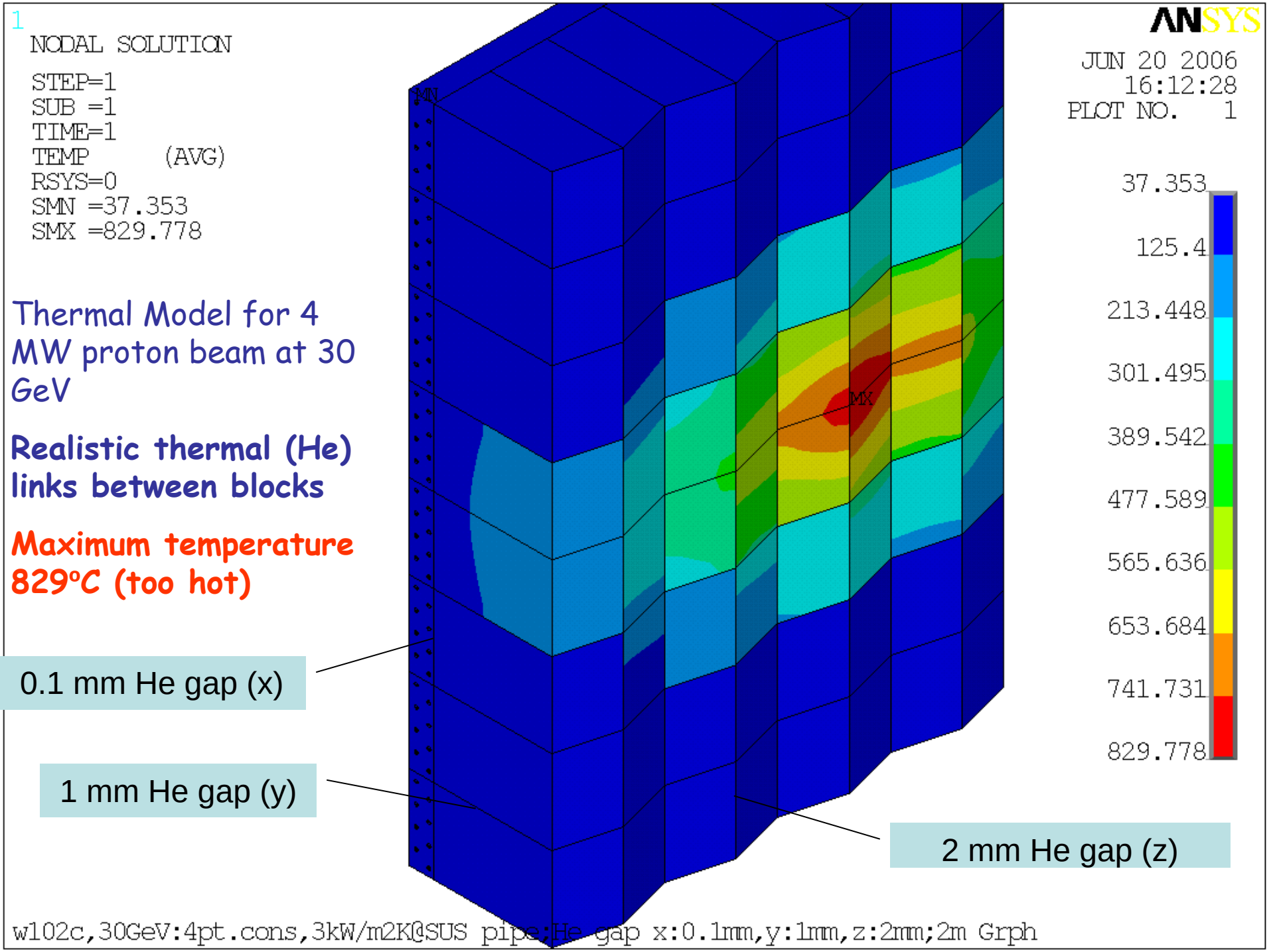
- ~1 MW heat load
- No maintenance after activation
- Cooling external to core to limit water activation
- Graphite temperature should not exceed 600°C to minimise oxidation in Decay Volume
- Low tensile strength of affordable graphite blocks: ~5 MPa // extrusion direction
  ~7-8 MPa _|_ to extrusion direction

CCLRC
Rutherford Appleton Laboratory

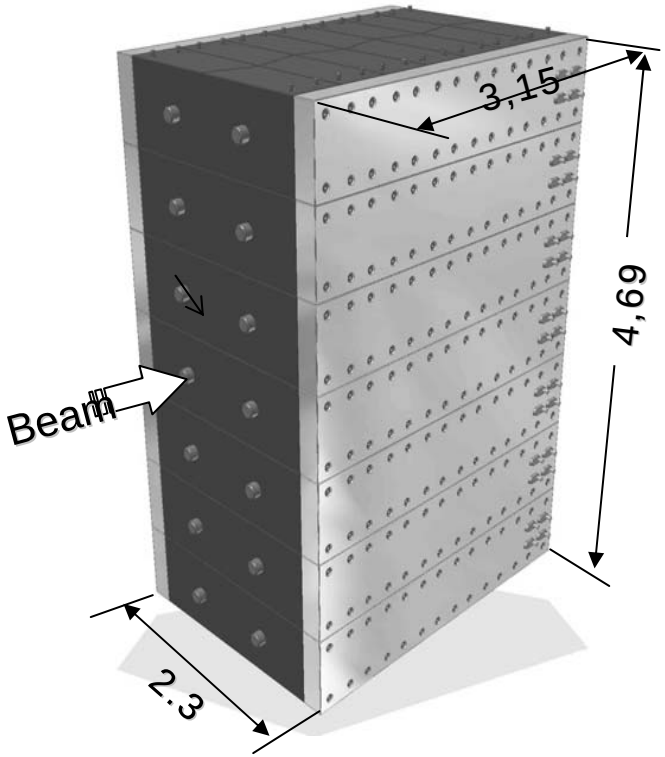
T2K Hadron Absorber graphite



Graphite Blocks
+ cooling module
layout

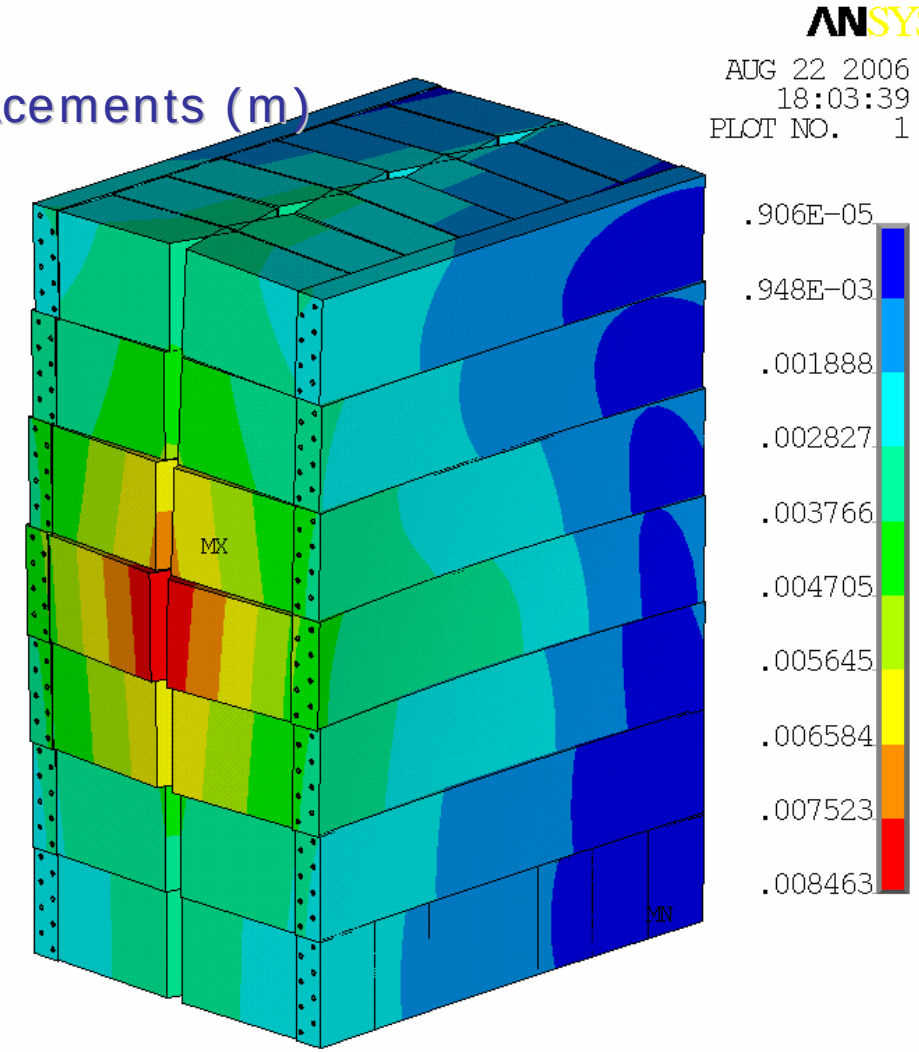

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
SMN =37.353
SMX =829.778
ANSYS
JUN 20 2006
16:12:28
PLOT NO. 1
37.353
125.4
213.448
301.495
389.542
477.589
565.636
653.684
741.731
829.778
MN
MX
Thermal Model for 4 MW proton beam at 30 GeV
Realistic thermal (He) links between blocks
Maximum temperature 829°C (too hot)
0.1 mm He gap (x)
1 mm He gap (y)
2 mm He gap (z)
w102c,30GeV:4pt.cons,3kW/m2K@SUS pipe;He gap x:0.1mm,y:1mm,z:2mm;2m Grph

T2K Hadron Absorber graphite

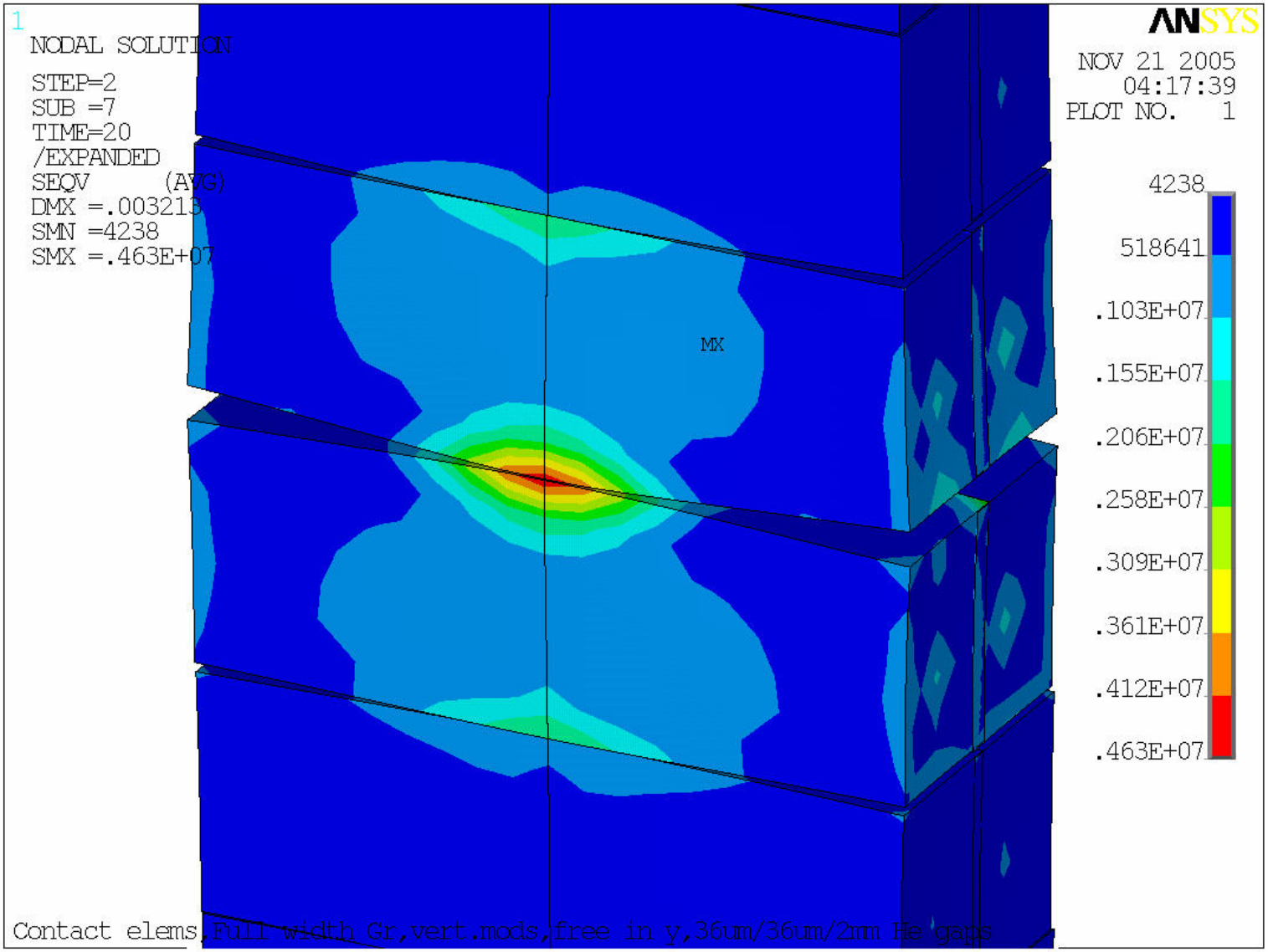


Graphite Blocks + cooling module layout

Displacements (m)



Maximum thermal expansion = 8.5 mm

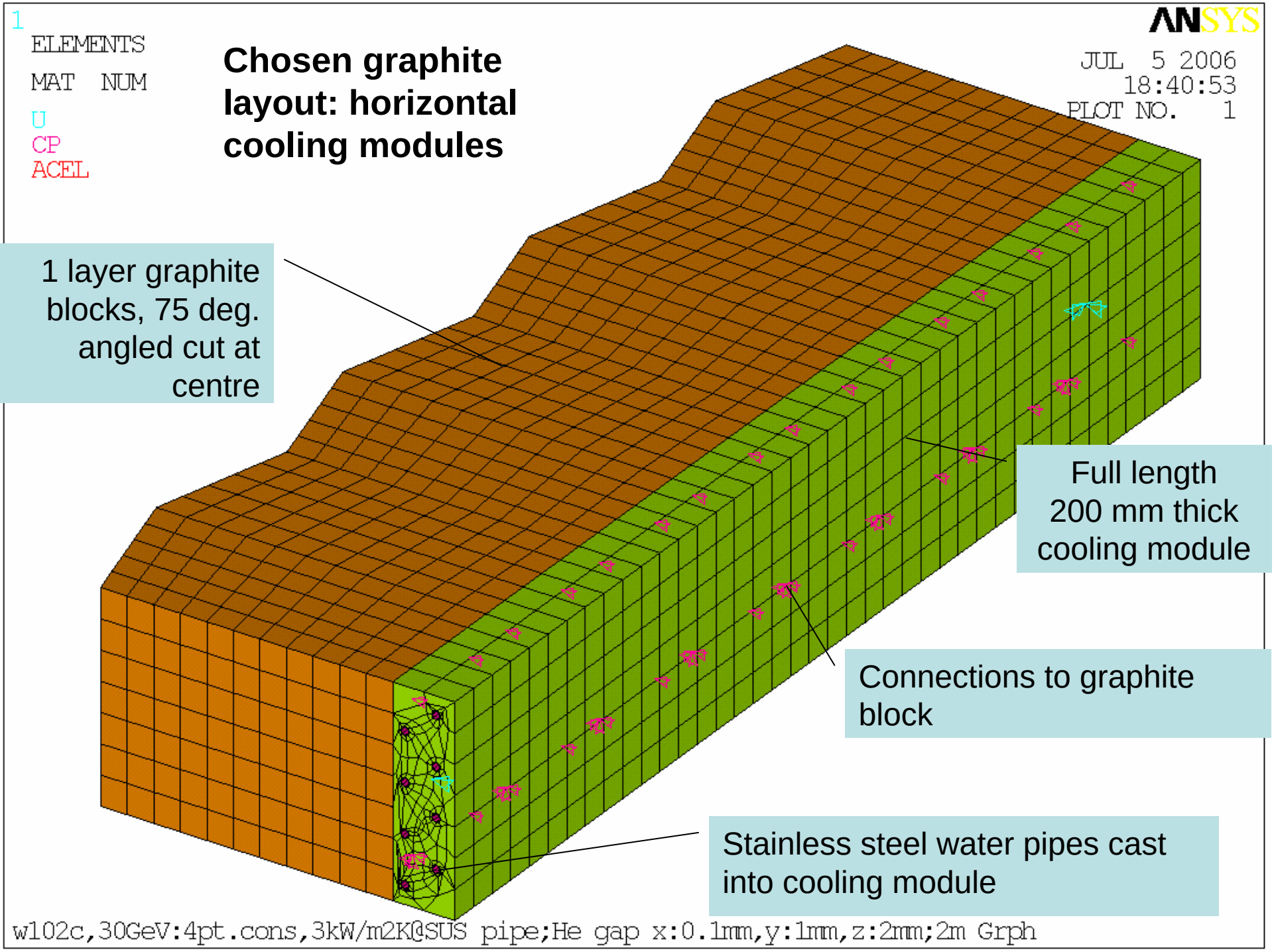


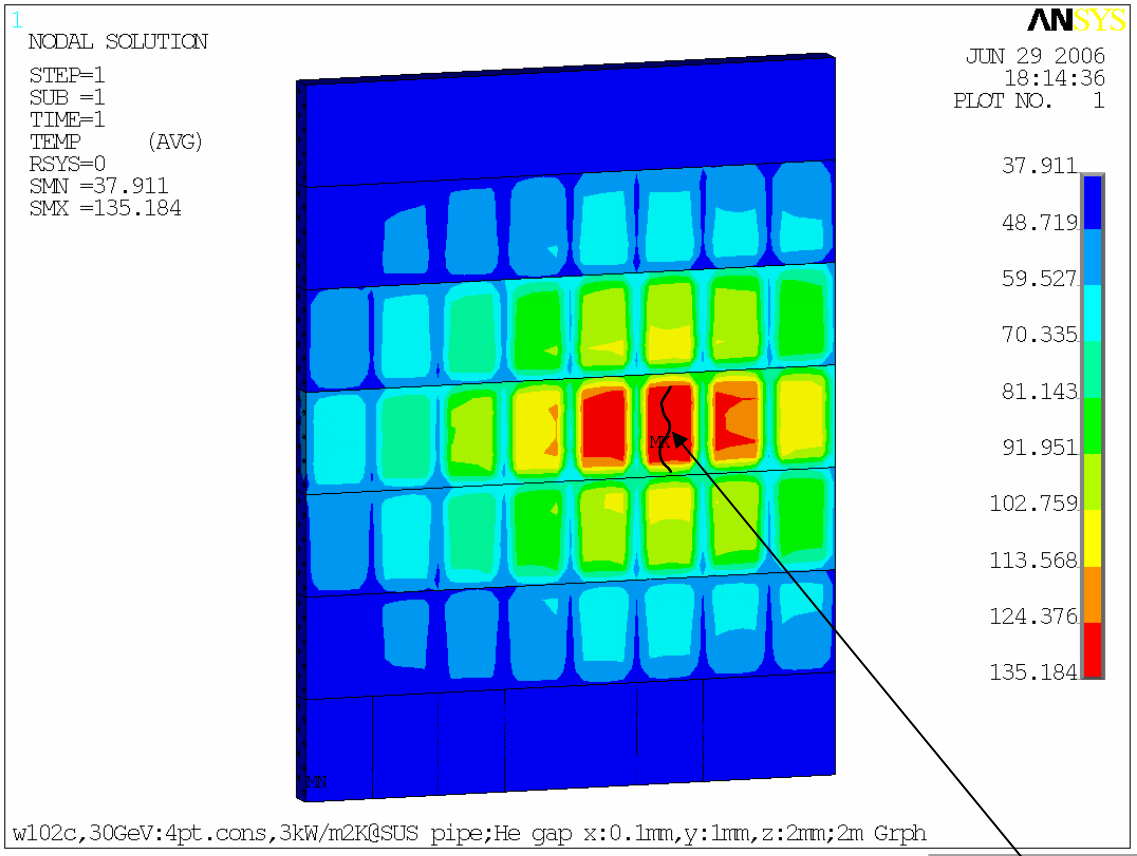
Stresses in full width graphite blocks

Max. stress = 4.6 MPa

~= Tensile strength

Hence propose to split blocks along centreline


1
ELEMENTS
MAT NUM
U
CP
ACEL
ANSYS
JUL 5 2006
18:40:53
PLOT NO. 1
Chosen graphite layout: horizontal cooling modules
1 layer graphite blocks, 75 deg. angled cut at centre
Full length 200 mm thick cooling module
Connections to graphite block
Stainless steel water pipes cast into cooling module
w102c,30GeV:4pt.cons,3kW/m2K@SUS pipe;He gap x:0.1mm,y:1mm,z:2mm;2m Grph

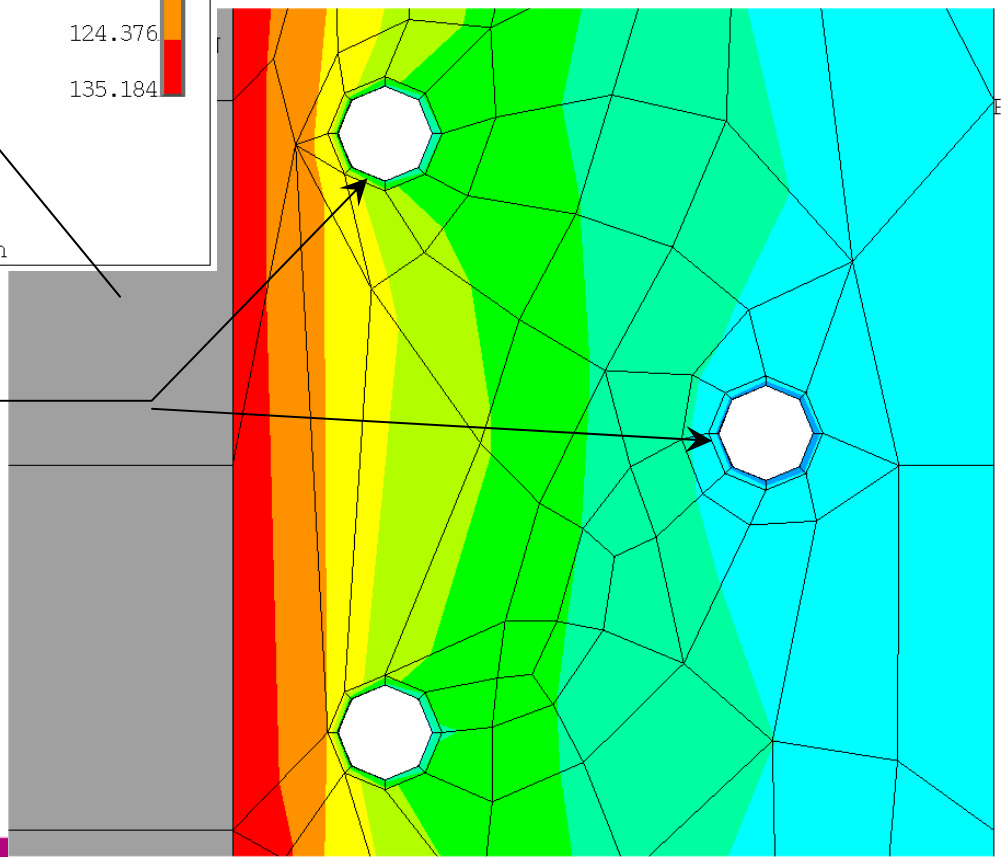


Cooling module temperatures

Maximum temperature = 135 C

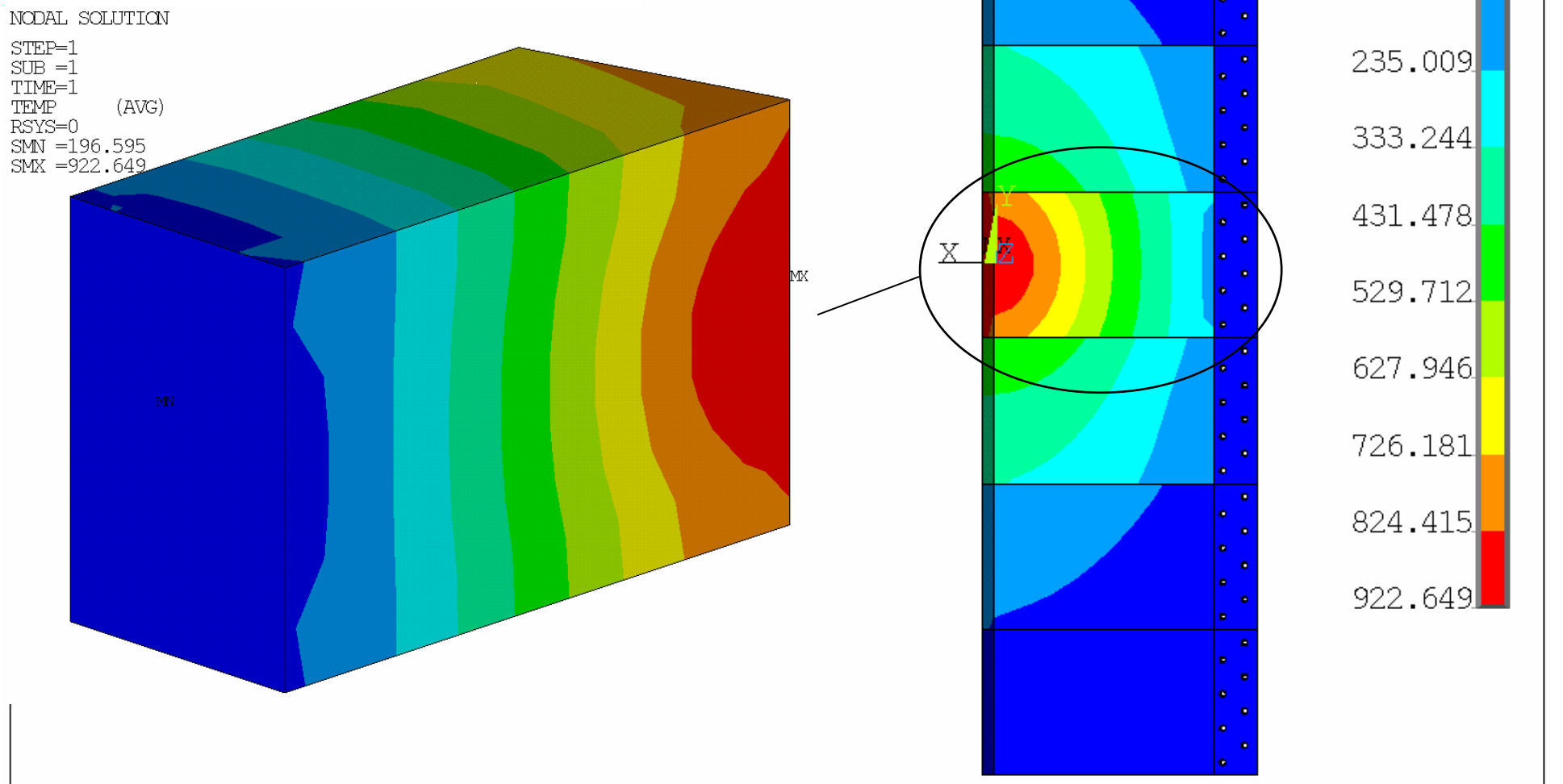
3,000 W/m2/K
Water cooling

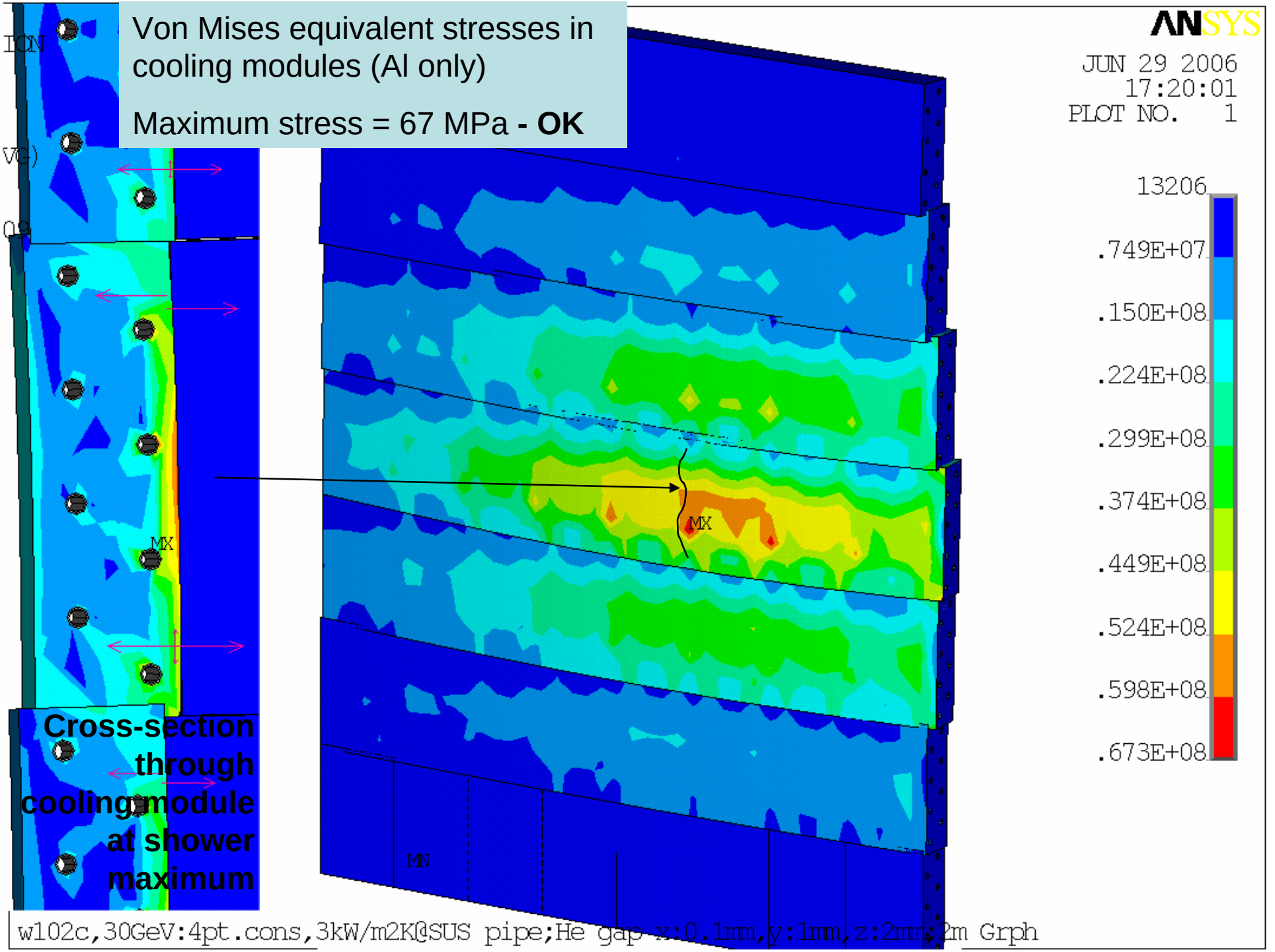
Cross-section through cooling module at shower maximum



Temperatures at cross section through shower max

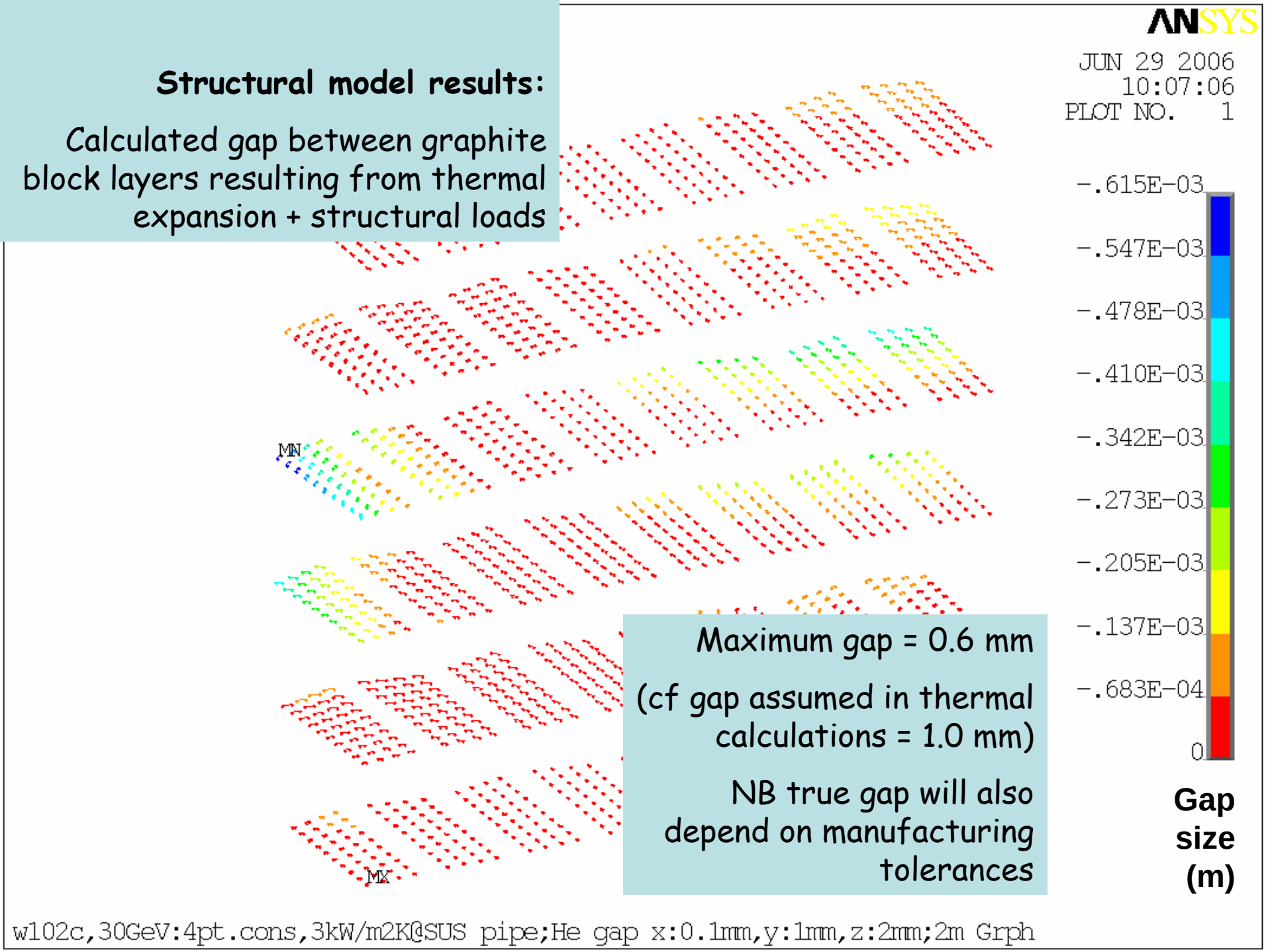
(4 MW beam power)




Von Mises equivalent stresses in cooling modules (Al only)
Maximum stress = 67 MPa - **OK**
ANSYS
JUN 29 2006
17:20:01
PLOT NO. 1
13206
.749E+07
.150E+08
.224E+08
.299E+08
.374E+08
.449E+08
.524E+08
.598E+08
.673E+08
MX
MN
Cross-section through cooling module at shower maximum
w102c,30GeV:4pt.cons,3kW/m2K@SUS pipe;He gap x:0.1mm,y:1mm,z:2mm;2m Grph

Structural model results:

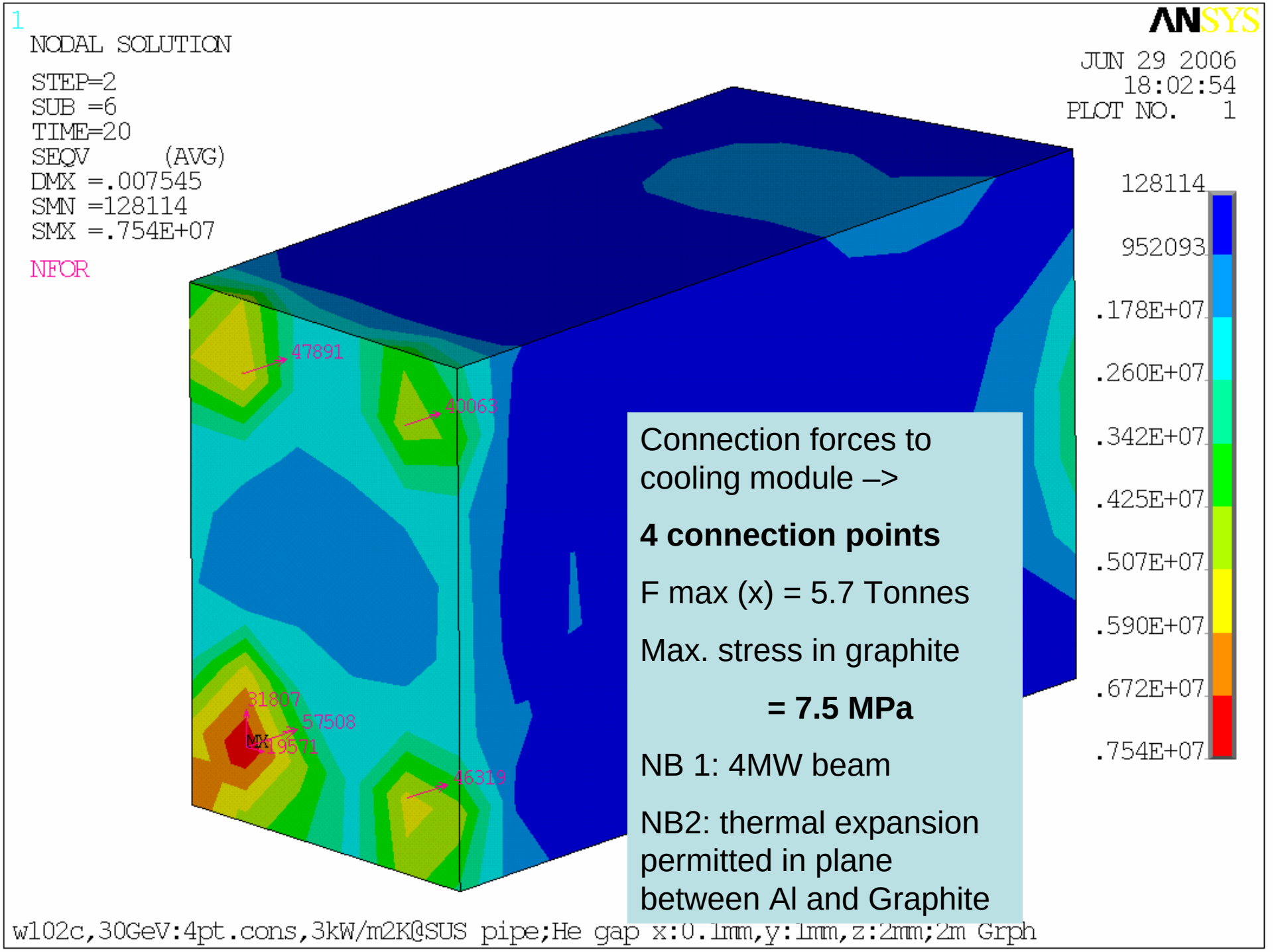
Calculated gap between graphite block layers resulting from thermal expansion + structural loads



Maximum gap = 0.6 mm

(cf gap assumed in thermal calculations = 1.0 mm)

NB true gap will also depend on manufacturing tolerances


1
NODAL SOLUTION
STEP=2
SUB =6
TIME=20
SEQV (AVG)
DMX =.007545
SMN =128114
SMX =.754E+07
NFOR
ANSYS
JUN 29 2006
18:02:54
PLOT NO. 1
128114
952093
.178E+07
.260E+07
.342E+07
.425E+07
.507E+07
.590E+07
.672E+07
.754E+07
47891
40063
31807
57508
MX
19571
46319
Connection forces to cooling module –>
4 connection points
F max (x) = 5.7 Tonnes
Max. stress in graphite
= 7.5 MPa
NB 1: 4MW beam
NB2: thermal expansion permitted in plane between Al and Graphite
w102c,30GeV:4pt.cons,3kW/m2K@SUS pipe;He gap x:0.1mm,y:1mm,z:2mm;2m Grph

CCLRC
Rutherford Appleton Laboratory

Connection forces to cooling module –>

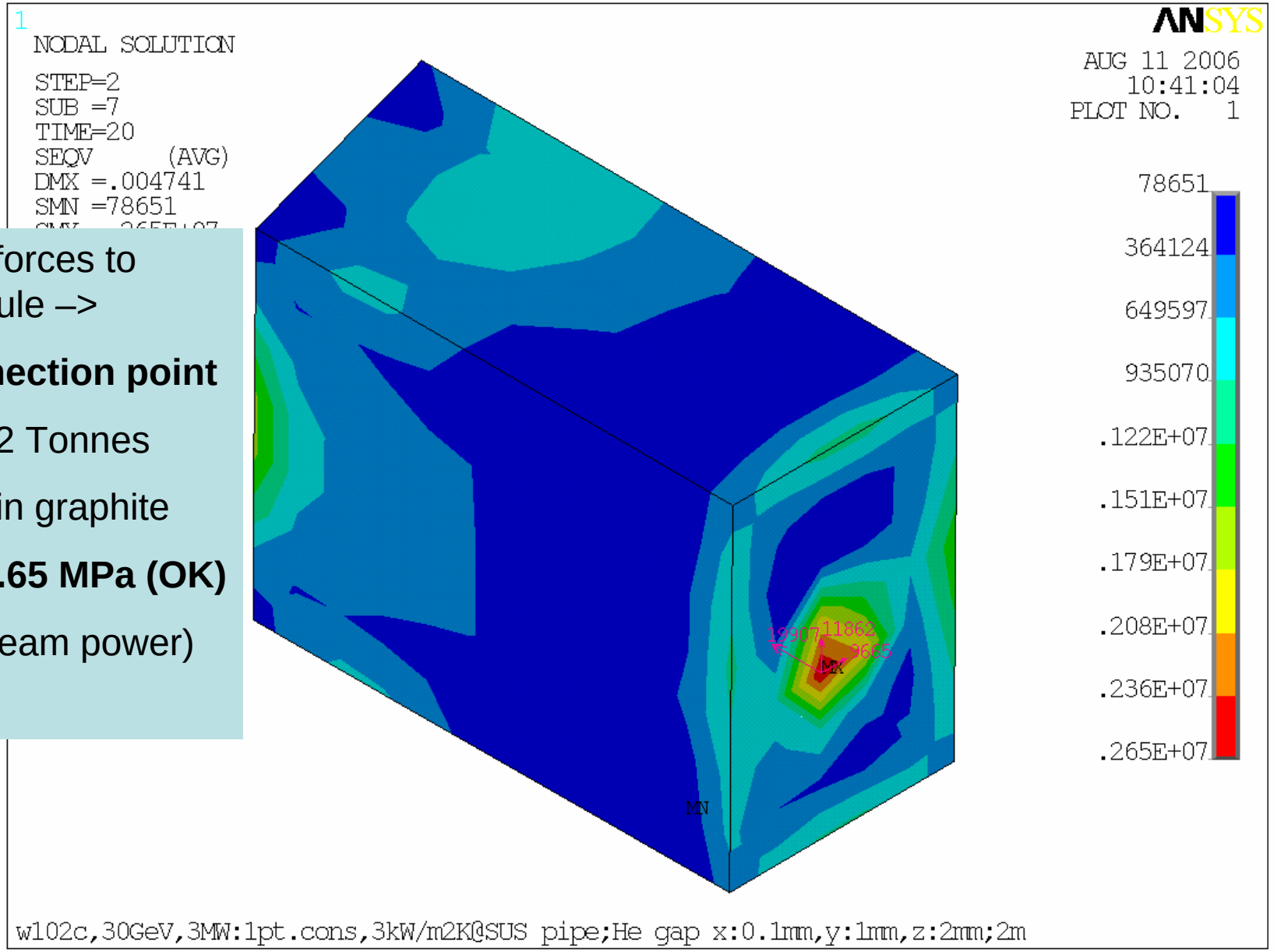
Single connection point

F max (x) = 2 Tonnes

Max. stress in graphite

= **2.65 MPa (OK)**

(NB 3 MW beam power)



CCLRC Rutherford Appleton Laboratory

Downstream of graphite: Copper?

CJD 2006/03/23	#Run	1	2	3	4	5	6	7
Beam parameter case		w108b	w108	w108b	w108	w108b	w108	w108b
Decay Volume length	m	94	94	94	94	94	94	94
Beam energy	GeV	30	40	30	40	30	40	30
Divergence	mrad							
Beam power	MW	4		4		4		4
Beam centre posn.		centre		centre		centre		centre
Graphite thickness	m	3.15		3.15		3.15		3.15
Number of Cu blocks in (z)		5		5		5		5
Copper block length (z)	m	0.18		0.18		0.18		0.18
Number of Cu blocks high (y)		1		2		2		1
Copper block height (y)	m	4.75		2.375		2.375		4.75
Number of Cu blocks across width (x)		2		2		2		2
Copper block width (x)	m	0.95		0.95		0.95		0.95
Copper block centre cut angle	deg	45		45		45		45
Assumed vertical He gap(y) between Cu blocks	mm*	0		0		0		0
Assumed He gap(z), between blocks in Z	mm*	10		10		10		10
Cooling water temperature	C	35		35		35		35
Convection at cooling surface (= x-width)	W/m2K	600		600		600		1200
Friction coefficient between blocks	mu	0.1		0.1		0.1		0.1
Main support location		Base		Base		Sides		Base
Results: Copper								
Max Temp	C	215	279		288	222	288	
Temperature Difference i-(i0)	C	-	*64*		*73*	*7*	*73*	
Max. Temp on cooled surface at sides	C	120	142		148	124	148	
Max Von Mises stress at block centreline	**MPa**	**95.7**	**140**		**40**	**?**	**39.7**	
Centreline max. displacement Ux	mm	1.2	1.5		1.9	3.2*	4	
Centreline min. displacement Ux	mm	-8.9	-11.4		-12.7	1.0*	1.3	
Calc. Max. Vert. Gap btw blocks(dUy)	mm	0	0			1.86*	2.28	
Max. Uy Cu at top	mm	10.6	12.5		13.4	10.5*	12.4	
Max. Uz	mm	1.5			1.9		0.5	

CCLRC Rutherford Appleton Laboratory

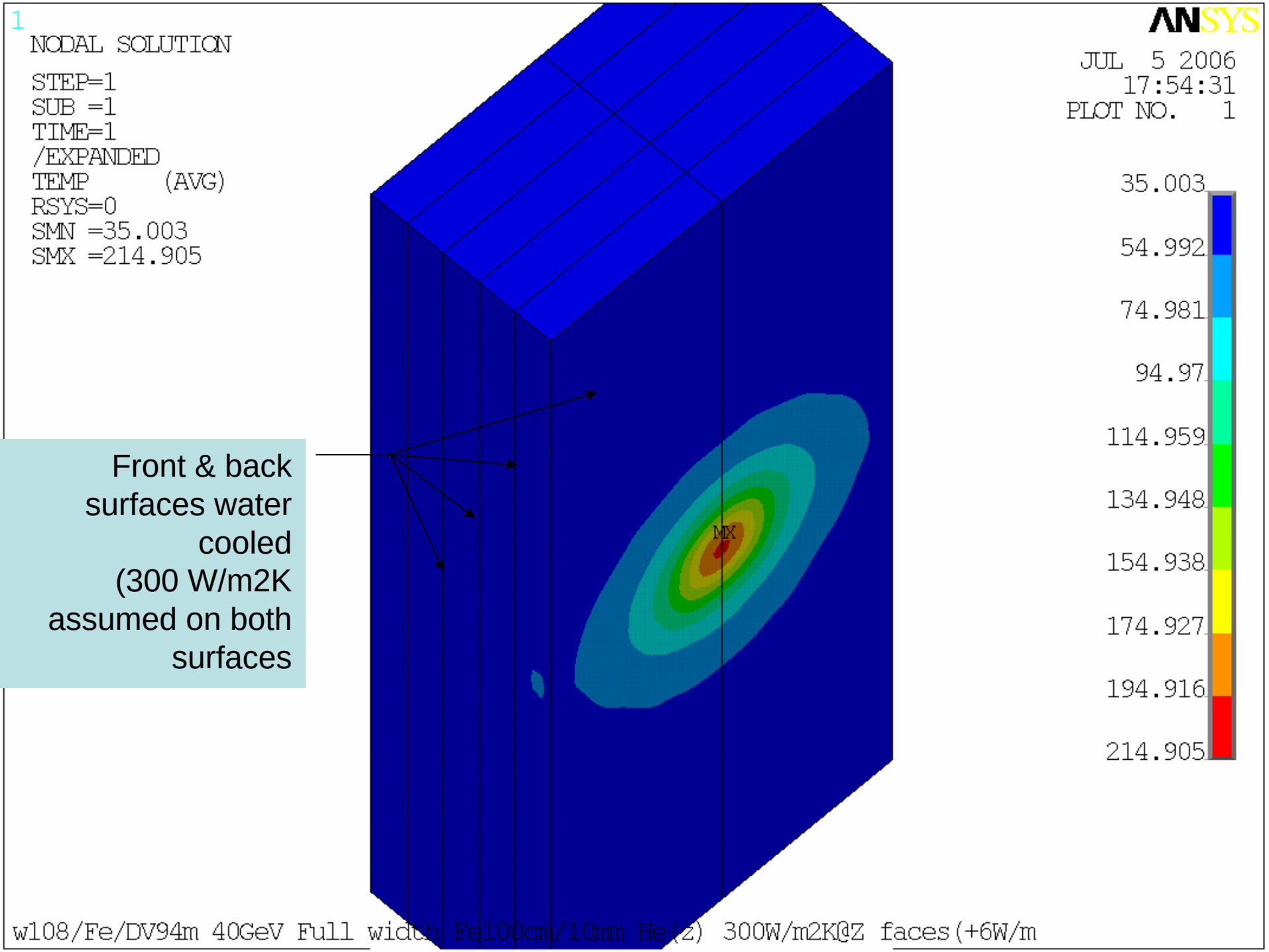
Downstream of graphite: Copper?

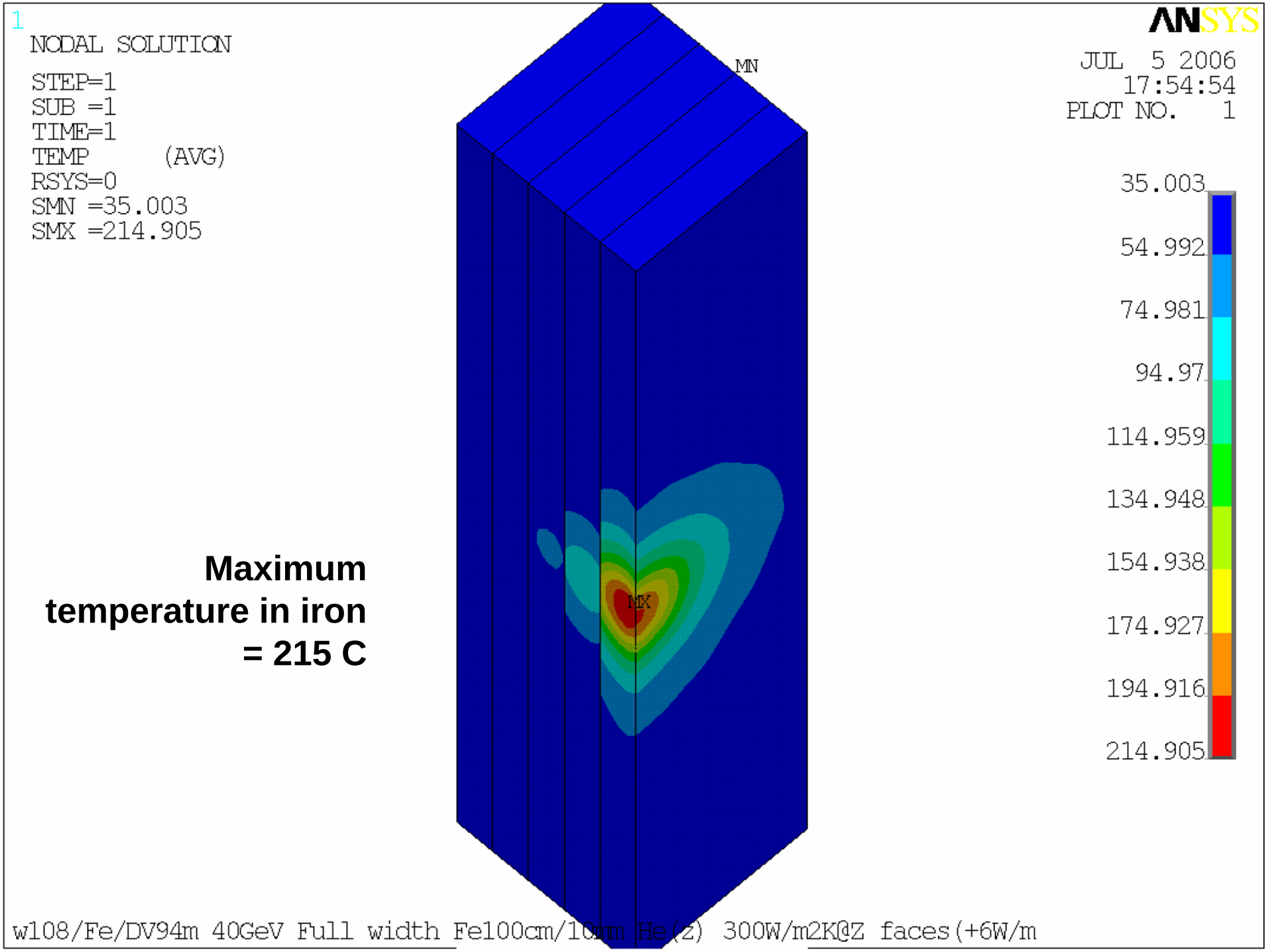
CJD 2006/03/23	#Run	1	2	3	4	5	6	7
Beam parameter case		w108b	w108	w108b	w108	w108b	w108	w108b
Decay Volume length	m	94	94	94	94	94	94	94
Beam energy	GeV	30	40	30	40	30	40	30
Divergence	mrad							
Beam power	MW	4		4		4		4
Beam centre posn.		centre		centre		centre		centre
Graphite thickness	m	3.15		3.15		3.15		3.15
Number of Cu blocks in (z)		5		5		5		5
Copper block length (z)	m	0.18		0.18		0.18		0.18
Number of Cu blocks high (y)		1		2		2		1
Copper block height (y)	m	4.75		2.375		2.375		4.75
Number of Cu blocks across width (x)		2		2		2		2
Copper block width (x)	m	0.95		0.95		0.95		0.95
Copper block centre cut angle	deg	45		45		45		45
Assumed vertical He gap(y) between Cu blocks	mm*	0		0		0		0
Assumed He gap(z), between blocks in Z	mm*	10		10		10		10
Cooling water temperature	C	35		35		35		35
Convection at cooling surface (= x-width)	W/m2K	600		600		600		1200
Friction coefficient between blocks	mu	0.1		0.1		0.1		0.1
Main support location		Base		Base		Sides		Base
Results: Copper								
Max Temp	C	215	279		288	222	288	
Temperature Difference i-(y)	C	-	*64*		*73*	*7*	*73*	
Max. Temp on cooled surface at sides	C	120	142		148	124	148	
Max Von Mises stress at block centreline	**MPa**	**95.7**	**140**		**?**	**?**	**39.7**	
Centreline max. displacement Ux	mm	1.2	1.5		1.9	3.2*	4	
Centreline min. displacement Ux	mm	-8.9	-11.4		-12.7	1.0*	1.3	
Calc. Max. Vert. Gap btw blocks(dUy)	mm	0	0			1.86*	2.28	
Max. Uy Cu at top	mm	10.6	12.5		13.4	10.5*	12.4	
Max. Uz	mm	1.5			1.9		0.5	

China has bought all the copper!

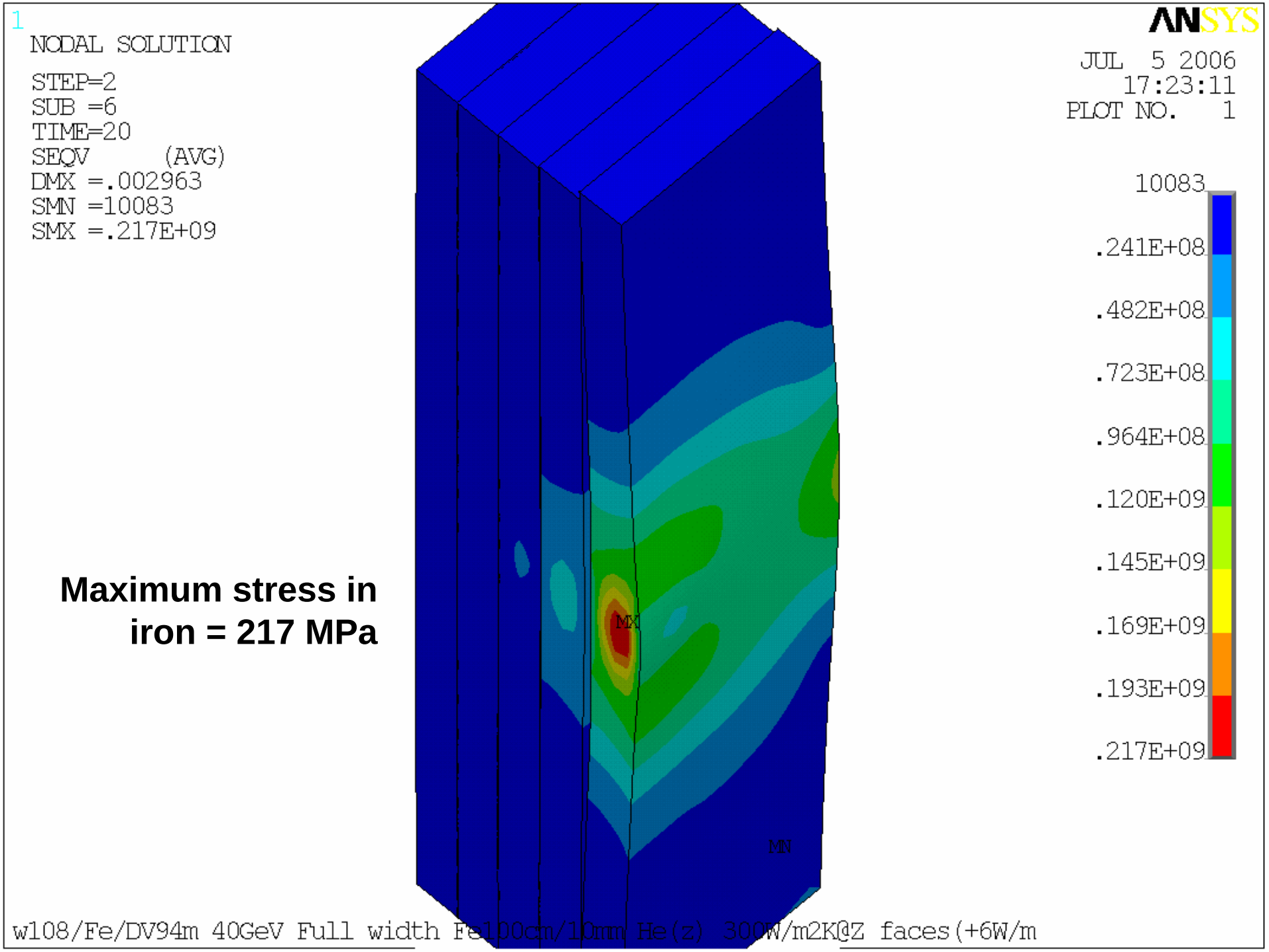
Quick look at copper free dump: Iron blocks directly downstream of graphite

- 5 x 200 mm Fe plates = 1 m Fe
- Front + back surface of each Fe block cooled by 300 W/m2K
- Power input to Fe scaled from Cu data by density (Ishida-san)

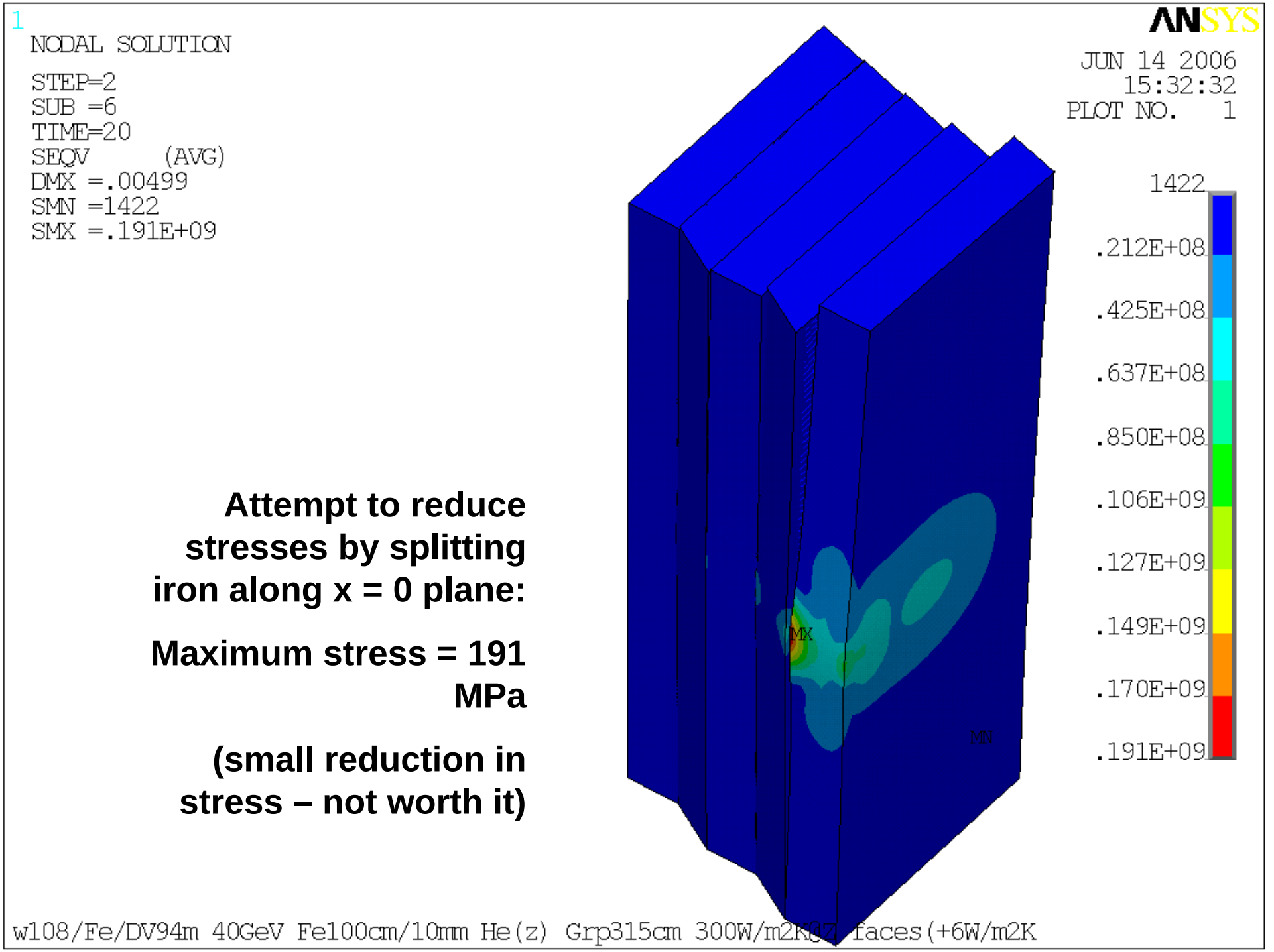

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
TEMP (AVG)
RSYS=0
SMN =35.003
SMX =214.905
ANSYS
JUL 5 2006
17:54:31
PLOT NO. 1
35.003
54.992
74.981
94.97
114.959
134.948
154.938
174.927
194.916
214.905
MX
Front & back surfaces water cooled (300 W/m2K assumed on both surfaces
w108/Fe/DV94m 40GeV Full width Fe100cm/10mm He(2) 300W/m2K@Z faces(+6W/m



Maximum temperature in iron = 215 C



Maximum stress in iron = 217 MPa



Attempt to reduce stresses by splitting iron along x = 0 plane:

Maximum stress = 191 MPa

(small reduction in stress – not worth it)

CCLRC
Rutherford Appleton Laboratory

Conclusions

- Graphite temperatures acceptable for up to 3 MW beam operation
- Single point connection for each graphite block to cooling module is preferable to multi-point connections
- Splitting graphite blocks along centreline reduces stresses to acceptable level
- Downstream copper core planned to be replaced with iron and plate coil water cooling. More work needed to reduce stresses