TIDVG

'Target Internal Dump Vertical Graphite'

Analysis and Proposed Solutions to Pressure Rises at the TIDVG, Induced by Repetitive Dumping during MD's.

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Under the supervision of M. Owen

Presentation Structure

- Part I: Introduction on ‘dumps’ in LSS1 and their relation with the rest of the accelerator.
- Part II: TIDV(G) design and operational problems.
- Part III: Origin and consequences of the problem.
- Part IV: Thermal system and deposition heating.
- Part V: Discussion of the external solution-options.
- Part VI: Discussion of the internal solution-options.
- Part VII: Solution trade-off and next steps to take.

Part I

Introduction on Dumps in LSS1 and Their Relation with the Rest of the Accelerator System.

I. Equipment in LSS1

- TIDP ‘Target Internal Dump Momentum’
  » Off-momentum collimator
- TIDH ‘Target Internal Dump Horizontal’
  » Low energy dump and horizontal aperture limiter
- TIDVG ‘Target Internal Dump Vertical Graphite’
  » High energy dump and vertical aperture limiter
- TBSJ ‘Target Beam Stopper …’
  » Injection dump

=> general design dates back from 1970-1980

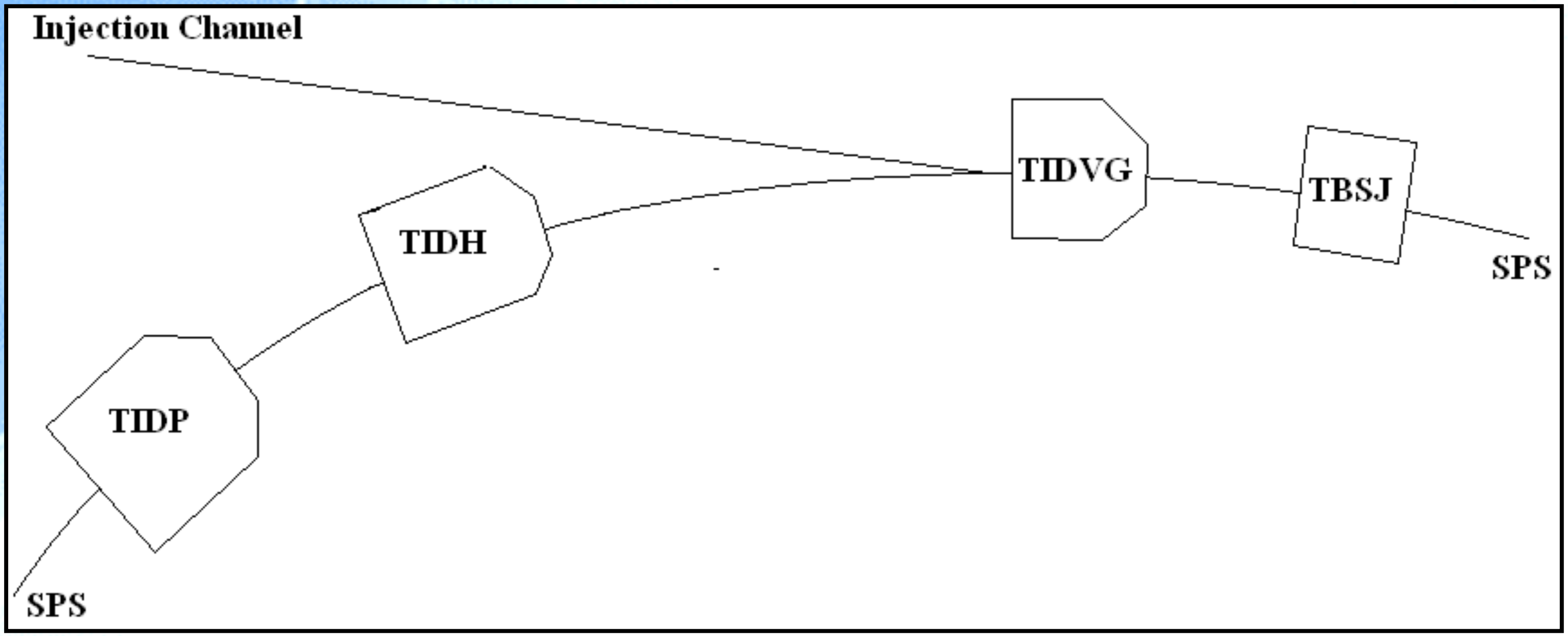
I.

Location in LSS1

- Why grouping them together?
  - » Highly radioactive
  - » TIDH and TIDVG are ‘served’ by same kicker magnets
- Same general design:
  - » Identical iron shielding
  - » Copper and/or aluminum core
- Can function with all beam-types
  - » Nominal LHC, CNGS, ions, etc…
  - » Also ultimate LHC, but (probably) not repetitive

I.

LSS1 Lay-out



II.

Part II

TIDVG Design and Operational Problems.

II.

SPS Beam Type

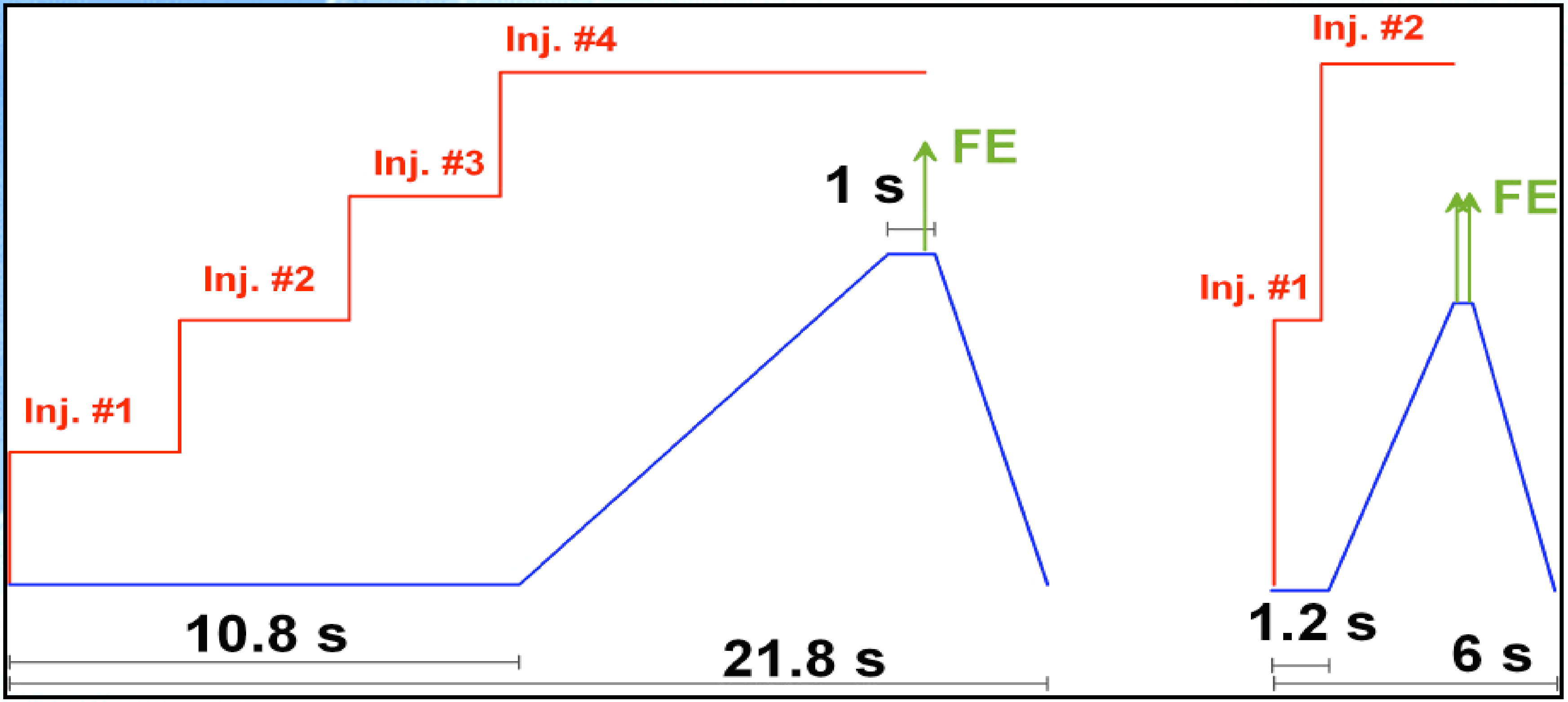
- Each application requires a beam with different properties: energy, intensity, structure…

- LHC-beam:
  - » Intensity (nominal): 1,15 . 10^{11} p/bunch; 3,3 . 10^{13} p/cycle
  - » Energy: 450 GeV/c
  - » Structure: 4 batches, 72 bunches; compressed in ~ 4/11th of the circumference of the SPS

- CNGS-beam:
  - » Intensity: 4,8 . 10^{13} p/cycle
  - » Energy: 400 GeV/c
  - » Structure: 2 batches filling almost completely the circumference of the SPS

II.

Beam Cycle: LHC & CNGS

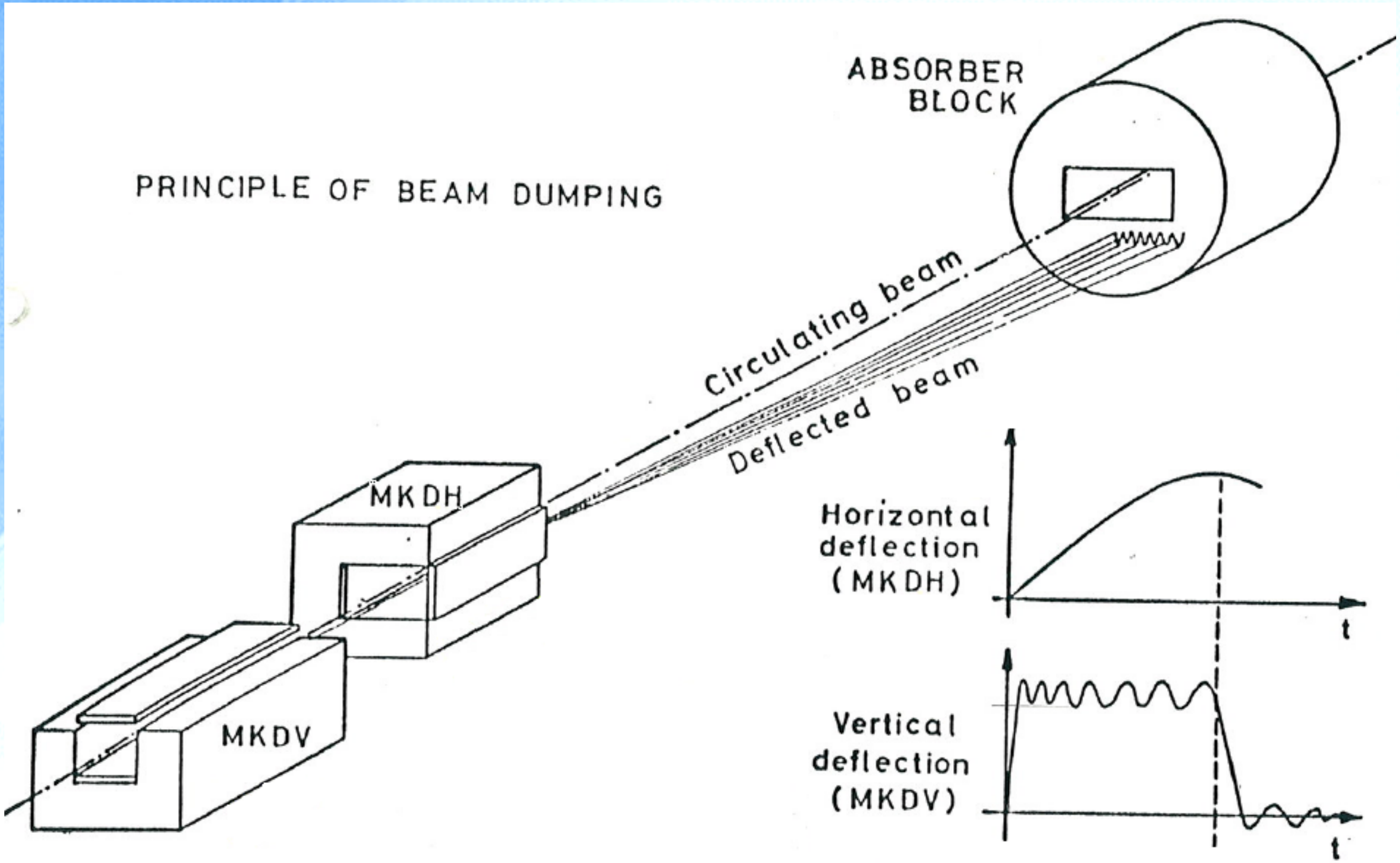


II.

Dumping System

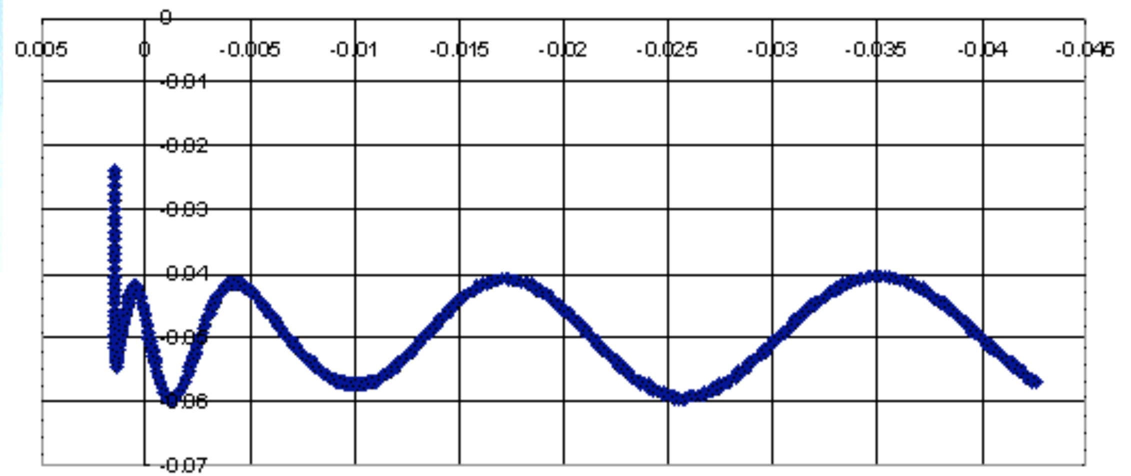
- When the beam can not be extracted: dumping of the beam using the dumping system (MD, emergencies...)
- The system consists of:
  - » Horizontal (MKDH) and vertical (MKDV) kicker magnets
  - » Beam-dumps TIDVG (E > 105 GeV/c) and TIDH (E < 37 GeV/c)
- Function of the kicker magnets:
  - » Deflect the beam its path.
  - » Create a deposition pattern, to diminish the local heat load.
- Function of the beam dumps:
  - » Absorb the beam.

II. Principle of Beam Dumping



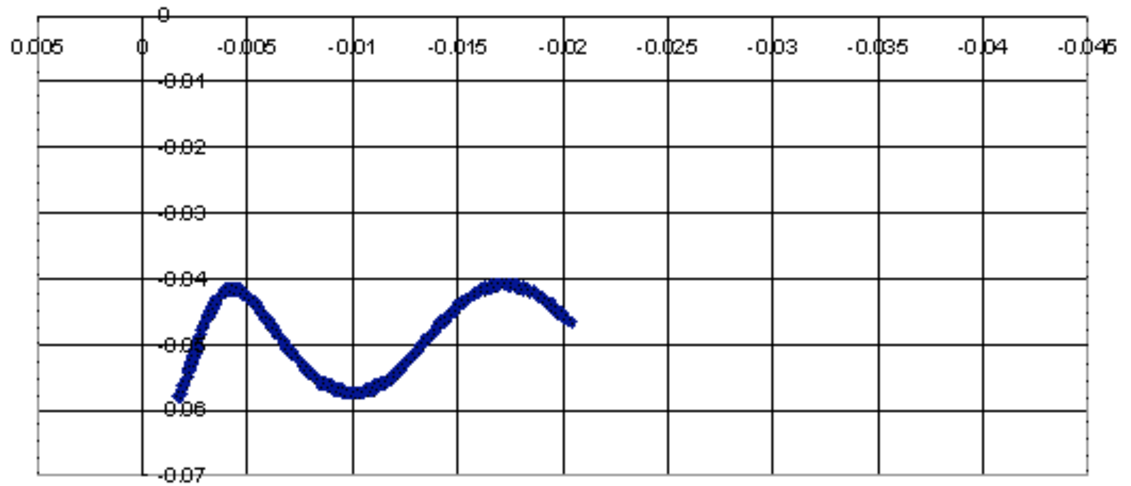
II. Deposition Pattern on (TIDVG)

- Shape depends on:
  - Kicker initialization time
  - Magnet pulse structure
  - Beam structure/length



- Top: CNGS-beam
- Bottom: LHC-beam

  (nominal, 4 batches)



- Pattern is fixed.

II.

Design Requirements

- *Aperture requirements*: protect neighbouring equipment.
- *Heat requirements*: absorb and transport heat to its cooling system, not to neighbouring equipment.
- *Absorption and radiation requirements*: absorb any possible SPS beam-type, whatever the dumping-frequency or time-frame might be.
- *Vacuum requirements*: do not pollute the vacuum
- *Robustness and reliability*: ‘Safe Life’ concept

=> i.e. beam in, nothing out

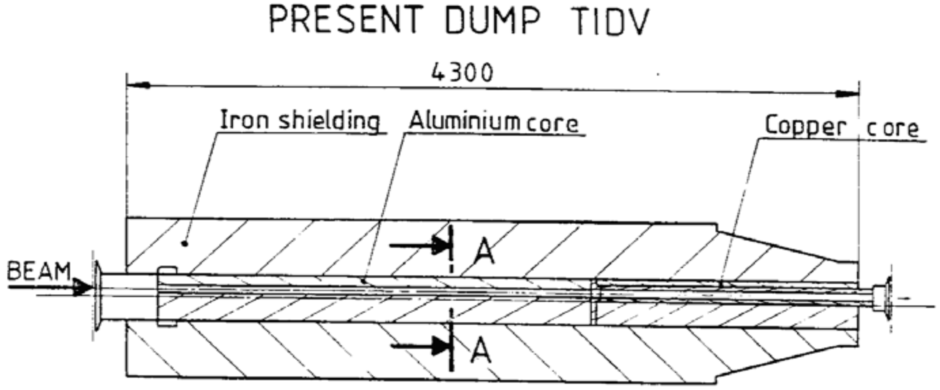
II. Design Concept

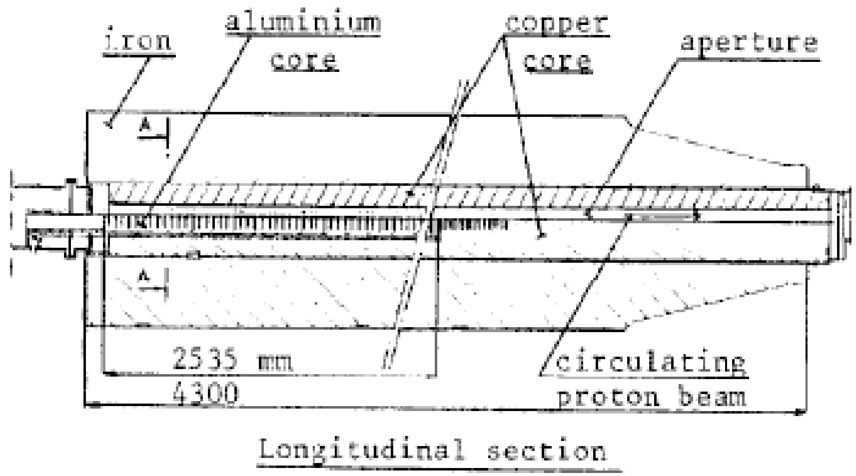
- Standardized (as it was until 2000)
  - *Aluminum blocks/plates*: primary beam absorber
  - *Copper core*: secondary beam absorber; cooling; vacuum-chamber
  - *Iron shielding*: radiation shielding; cooling

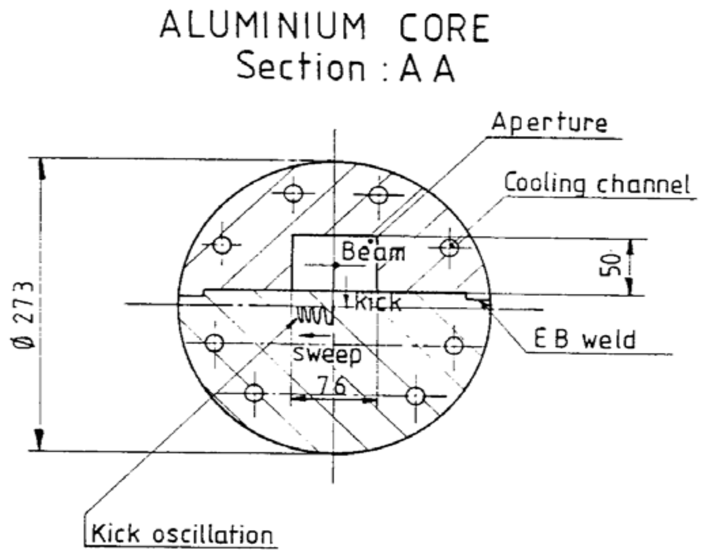
- Same engineers (S. Peraire, M. Ross, J.M. Zazula…)

  => creation of a 'family of dumps'

II. Design Concept (cont`)







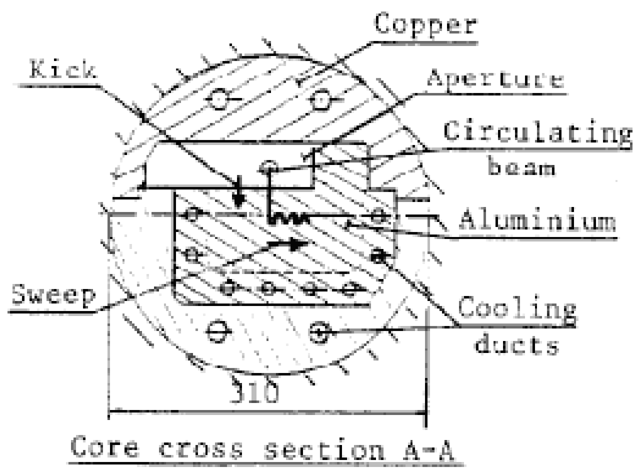
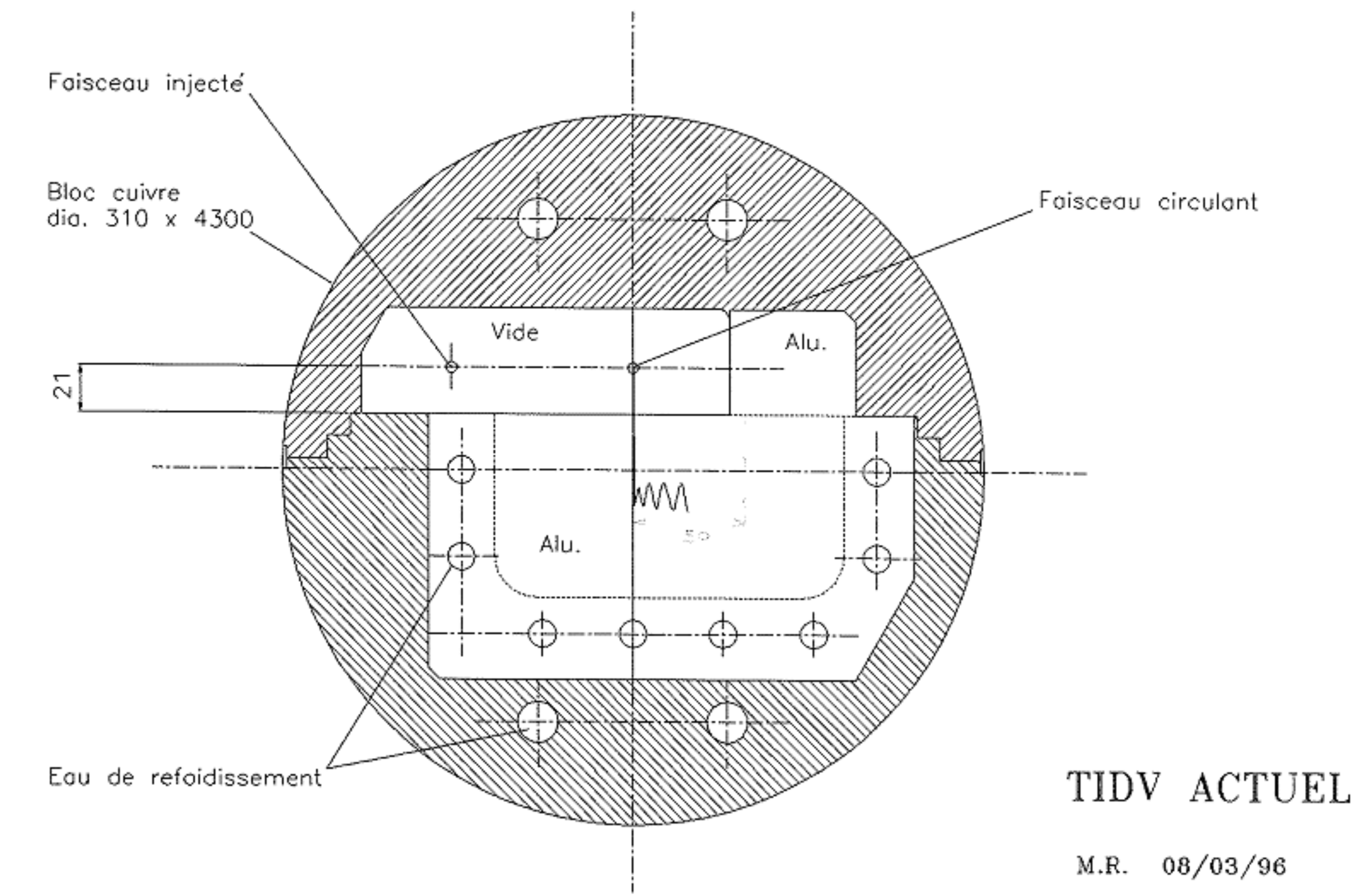


Fig. 1

The internal beam dump

II. Design Concept (cont`)

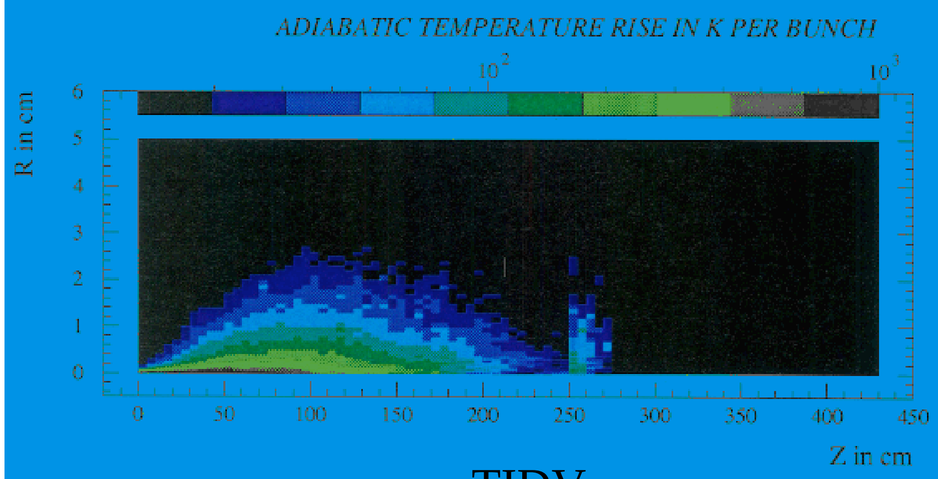


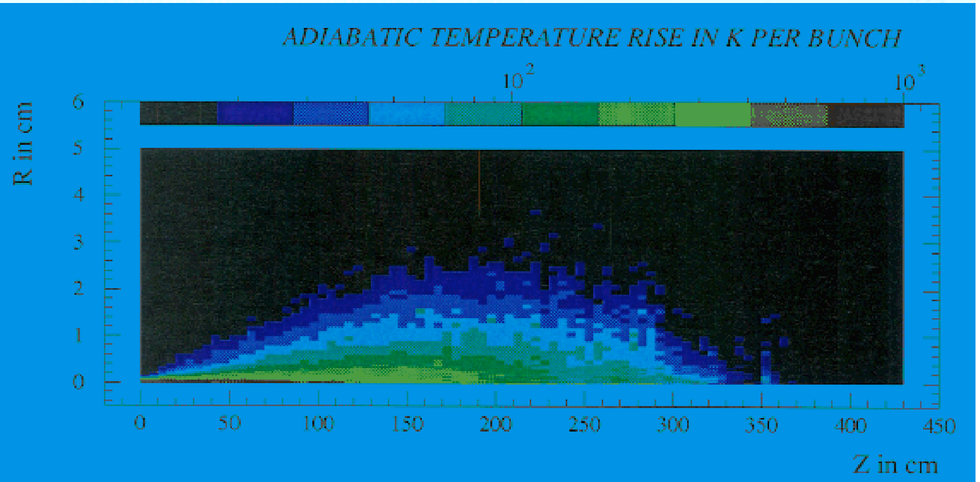
II. Design Concept (cont`)

- Higher energy: new design needed for absorber blocks
- No metal could survive a direct beam-impact at nominal intensity, but graphite (and Beryllium) could.
- Advantages:
  - It has a lower density and larger hadron interaction and radiation lengths. Thus the density of the deposited energy is much less concentrated on the beam axis and has much flatter longitudinal and radial shapes.
  - It has better thermal parameters: smaller specific heat and much higher melting point (and similar heat conductivity)
  - Comparable cost (at that time)

=> Graphite dilutes the beam

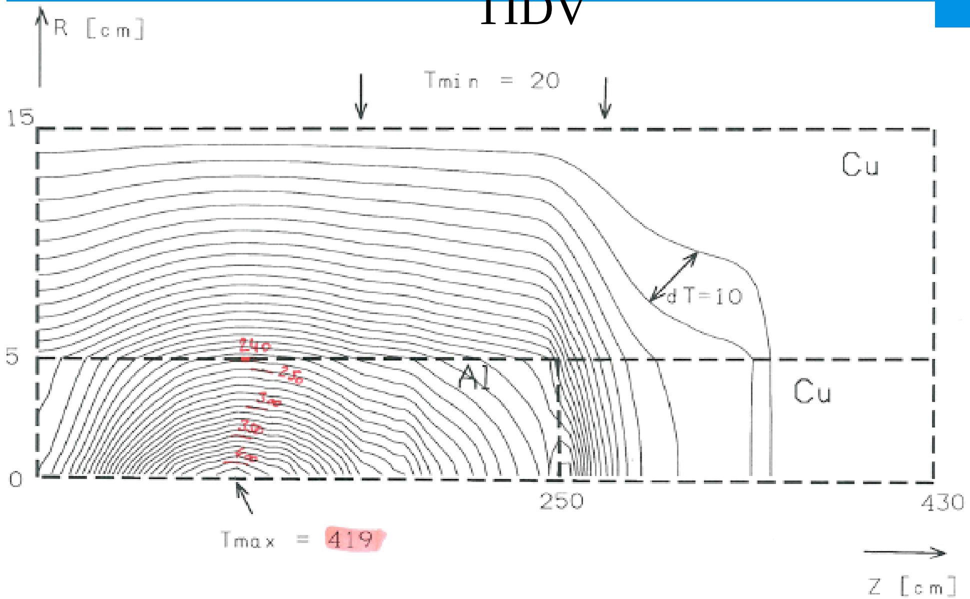
II. Design Concept (cont`)

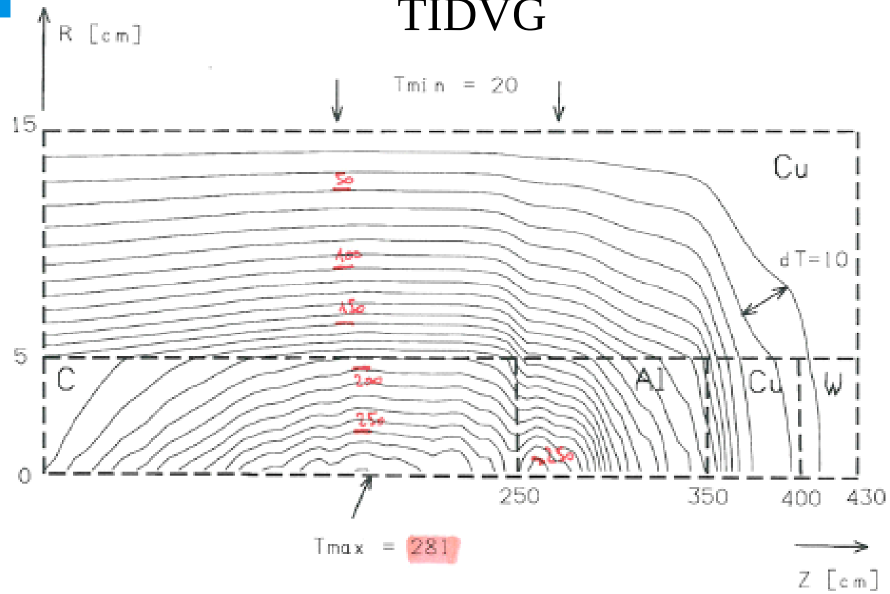




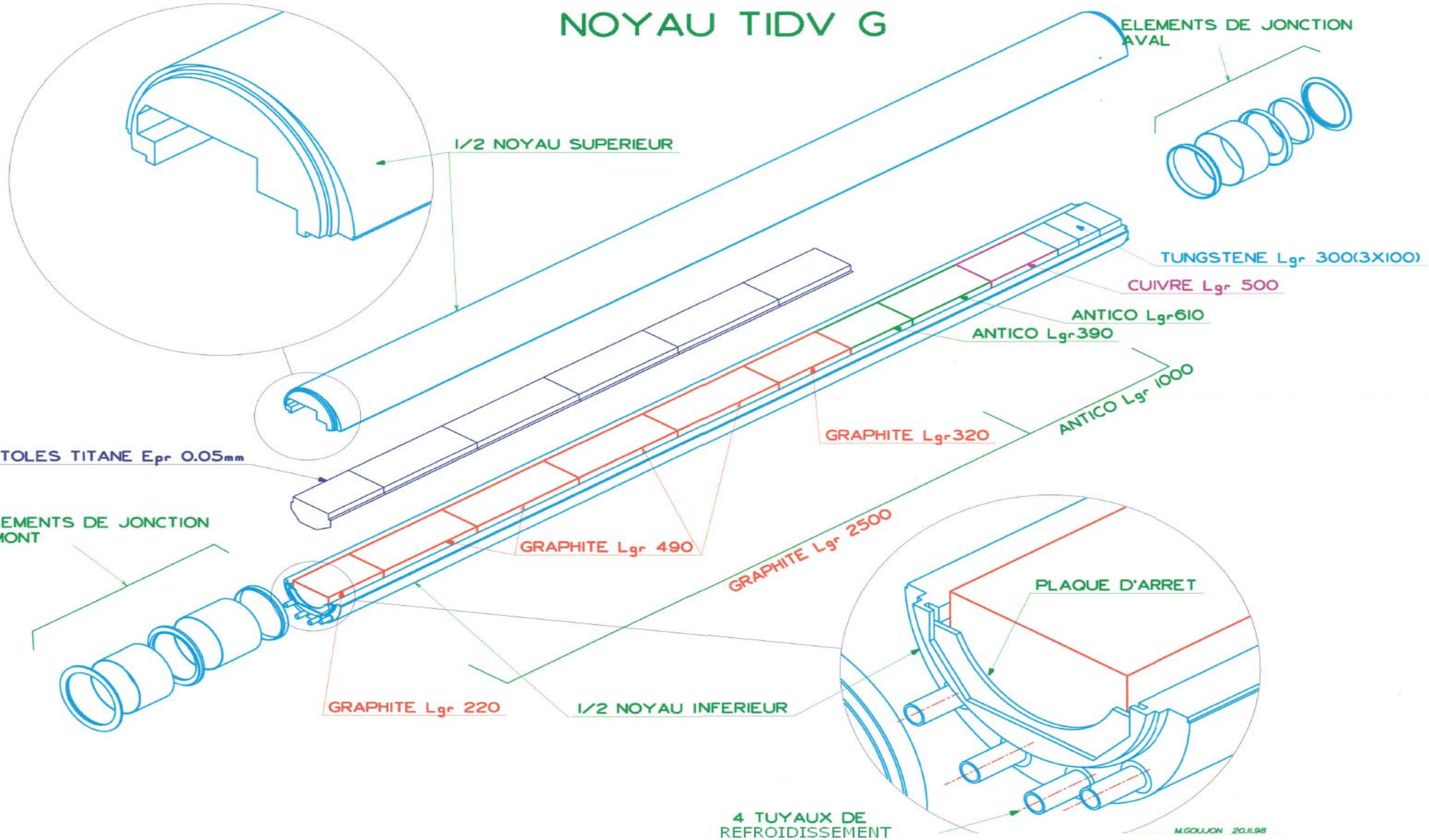
TIDV

TIDVG



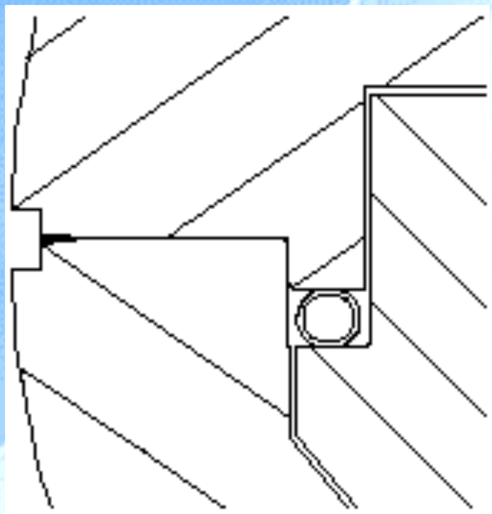


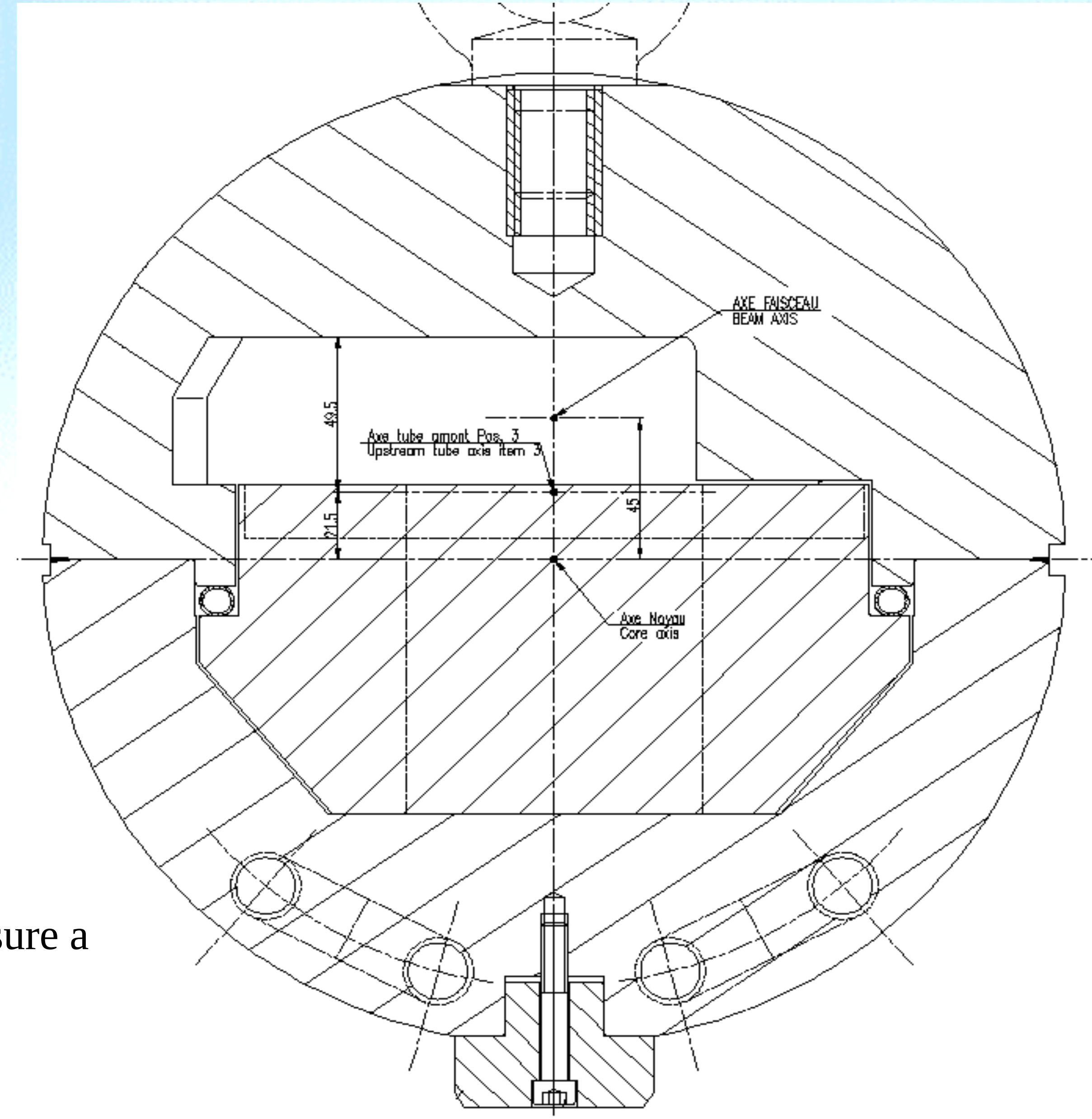
II. Design Concept (cont`)



II.

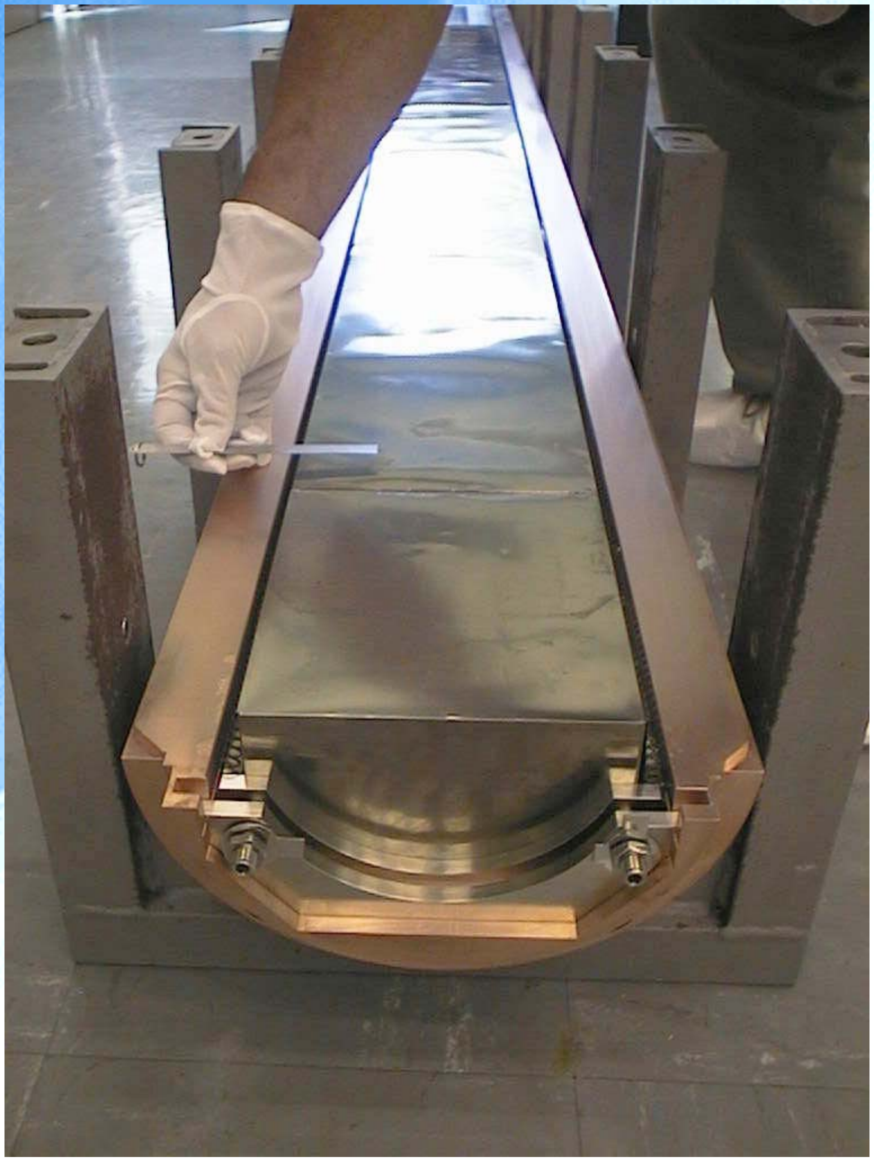
- TIDVG cross-section: related to heat extraction and limiting of the aperture!

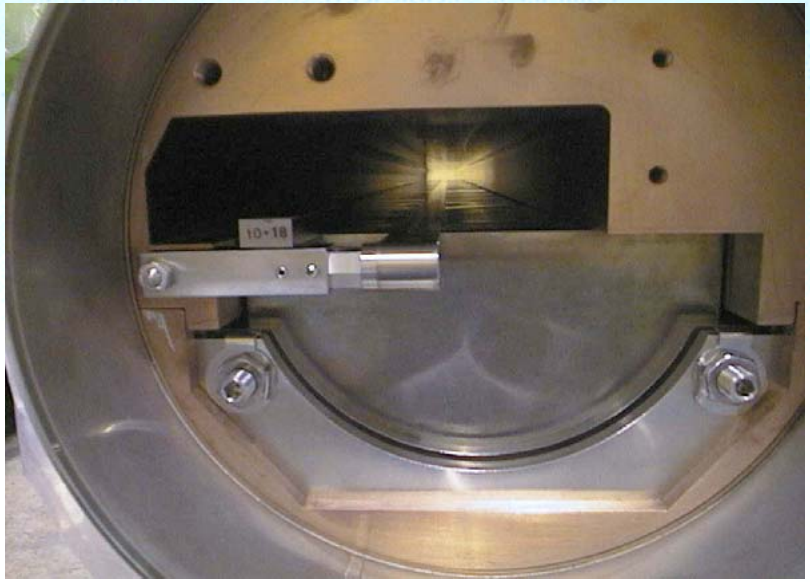


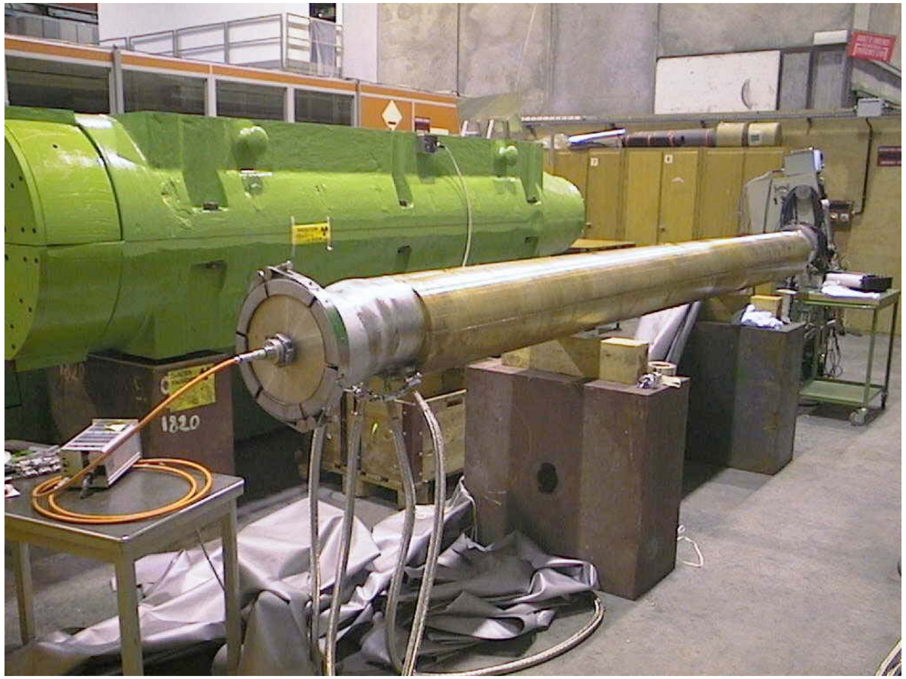


- Compression springs to insure a good thermal contact.
- Cooling from bottom

II.





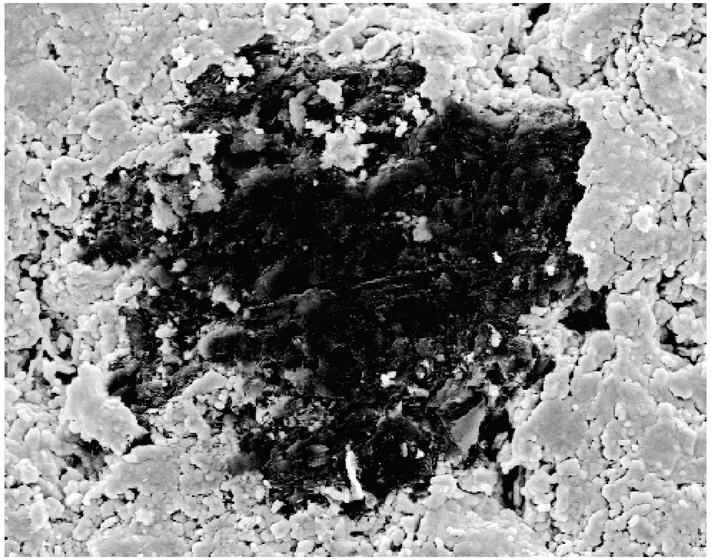


II.

Absorber Blocks

- Concept of increasing density: Graphite 2020PT, Aluminum, OFE Copper and (sintered) Tungsten.
- Titanium coating on Graphite to prevent dust (dust production is never proven). But the consequences for the MKP's can be large: short-circuiting.
- Coating itself was peeling off, thus: Titanium foil on the graphite blocks.

- Bake-out done on graphite:
  - ⇒ Baking-out at 400° C followed by coating with titanium and ending with again a bake-out at 400° C.
  - ⇒ Final bake-out of assembly at 150° C.



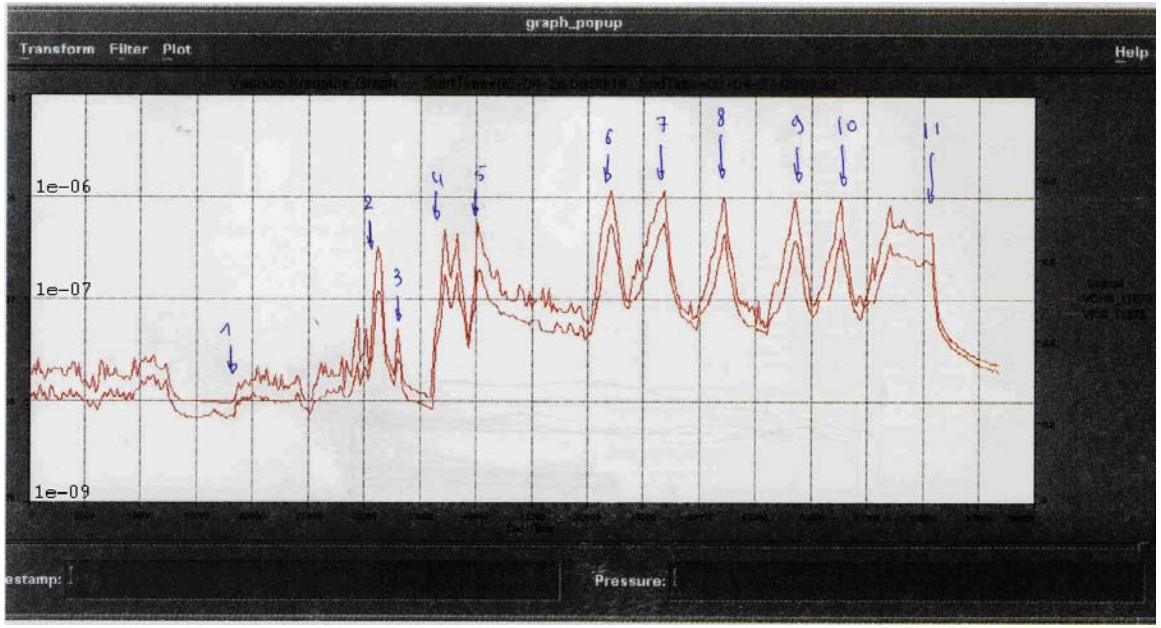
- Bake-out needed on Tungsten: 1000° C.
  => NOT done

II. Operational Problems

After commissioning in March 2000:

- Pressure peaks from the moment the beam was dumped.

(Repetitive dumping of $9 \cdot 10^{12}$ protons per cycle at 440 GeV.)



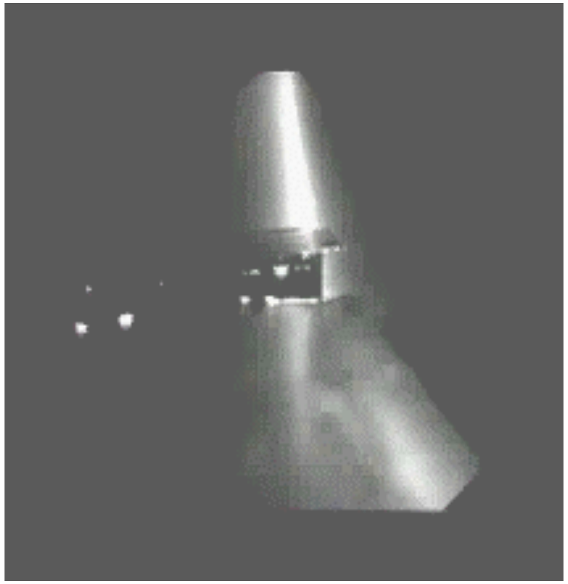
Consequence:

=> Shutdown of the beam due to pressure interlock system.

II. Operational Problems (cont`)

2. After ~3 years: the rupture of the Ti-foil due to asynchronic dumping.

   – Consequences:
     - » Functionality not impaired
     - » Limitation of the aperture
     - » A repair was needed



=> But impossible due to its high radioactivity

=> replacement of the dump

II.

TIDVG #2

- 2 spares were produced in 2000. One of them (named TIDVG #2) was opened and adapted.

- Adaptations:
  - Heat treatment of graphite blocks at 1000° C before the coating was applied.
  - New surface pretreatments enabled a better coating => Ti-foil was not necessary anymore.
  - Studies advised to do a in-situ bake-out at 250° C. But this was limited by the water bake-out system its maximum temperature of 150° C.

- Finally, the welding was slightly adapted and the new TIDVG was installed in February 2006.

III.

Part III

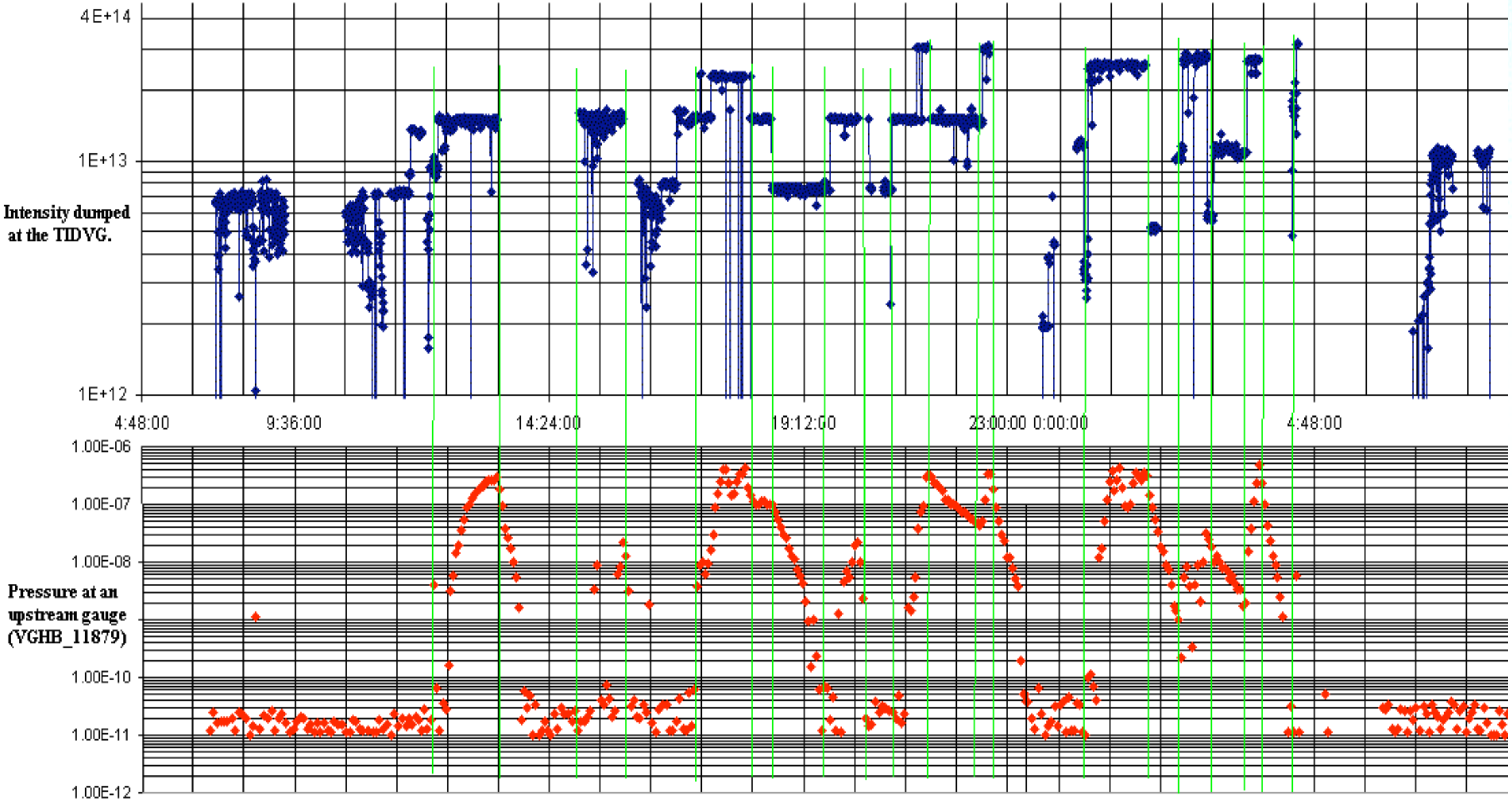
Origin and Consequences of the Problems.

III.

Symptoms

- The adaptations to the baking-out schedule have not decreased the pressure rises.
- Normal dumping of a beam does not causes excessive pressure rises, only when the beam is dumped repetitively during MD's.
- In preparation of the LHC, most of the MD's are done with the nominal LHC beam-type (cycle-length = 21.8 s).
- Higher intensities lead to a higher pressure-rise. But the exact relation is hard to construct, as exact data is hard to find.

III. Symptoms (cont')



III. Origin of Pressure Rise: Outgassing

- Originating from: Tungsten or Graphite blocks

- Outgassing is driven by:
  - Temperature, depends on:
    - » Nature of the heat-deposition
    - » Effectiveness of the cooling system
  - Internal concentration of pollutants, depends on:
    - » Material properties
    - » But also on the production/assembly process

- If the operational temperature is higher than the bake-out temperature, outgassing is likely to occur.
  - Graphite final bake-out temperature was only (maximally) 150° C.
  - Tungsten was not baked out, apart from the assembly bake-out.

III. Origin of Pressure Rise: Outgassing

- For Graphite this is detrimental: as it has been in contact with the open air during the assembly process (multiple weeks) it will have reabsorbed a lot of moisture.

- For Tungsten, it is not as clear what the consequences are. If it was not initially polluted by hydrocarbons, the outgassing might be minimal.

III. Origin of Pressure Rise: e-cloud?

- E-clouds: passing of a positively charged beam through the aperture => emission of electrons from the walls => avalanche effect => emissions of adsorbed gas-molecules from the walls => sharp pressure rise
- E-clouds depend on a lot of parameters:
  - Intensity/Energy
  - Cross-section geometry
  - Materials of the aperture
  - Beam-structure
  - …

=> No proof! Only hints:

- Pressure rise appears more easily during operation of LHC beam than during the operation of the CNGS-beam.
- Small aperture stimulates e-clouds.
- Unexplainable pressure peaks in detailed measurement-data.

III. Origin of Pressure Rise: e-cloud?

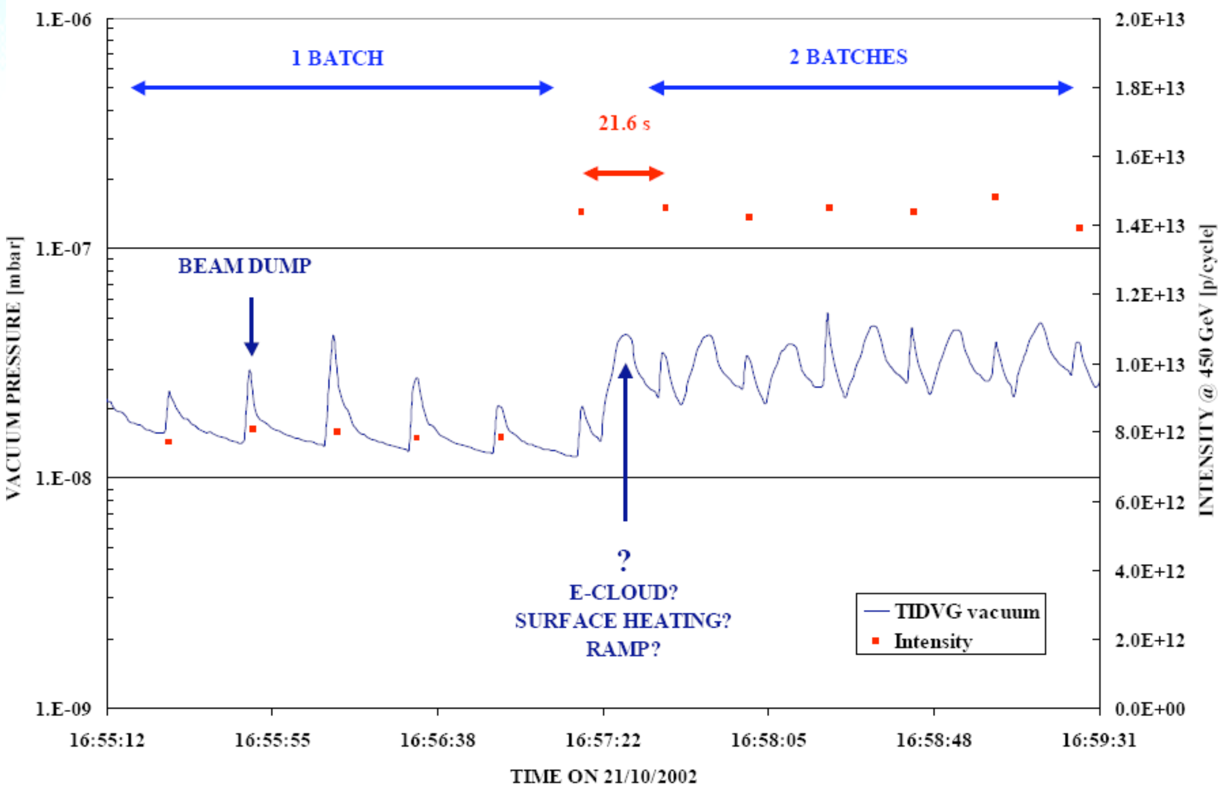
But: no pressure peaks are observed during normal operation. Can the heating of the TIDVG trigger the formation of the e-cloud?

(more heat => higher secondary emission?)

Simulation by G. Rumolo was planned, but until now it was not done.

It is inconclusive until now,

but it seems not very likely.



III. Consequences: Interlock

- Multiple interlock systems: initiate dumping of the beam, put MKP's in safe mode or close valves => ending of SPS run.
- Pressure readings by:
  - ion pumps (trigger sector valves)
  - pressure gauges (triggers fast and sector valves)
- Threshold for hardware-interlock: ~ 10^{-6} mbar.

- Software interlock: avoid shutdown of MKP's.
- Threshold for software-interlock: ~ 2. 10^{-7} mbar.
- Water circuit interlock: closes water-valves

  => This is contra-productive, thus it has been removed.
  (by M. Owen and M. Donze in February 2008)

Note: Ion pump just behind TIDVG is not functioning.

Part IV

Modeling of Thermal System and Deposition heating.

IV. Why a Deposition Simulation

- It is not known what the heating is in the case of repetitive dumping (previous simulation from 1996 used different geometry and assumptions)

- Overheating can damage the dump.

- The thermal behavior of the TIDVG is detrimental for the outgassing-rate.

- The proposed solutions to the pressure rise depend on this behavior.

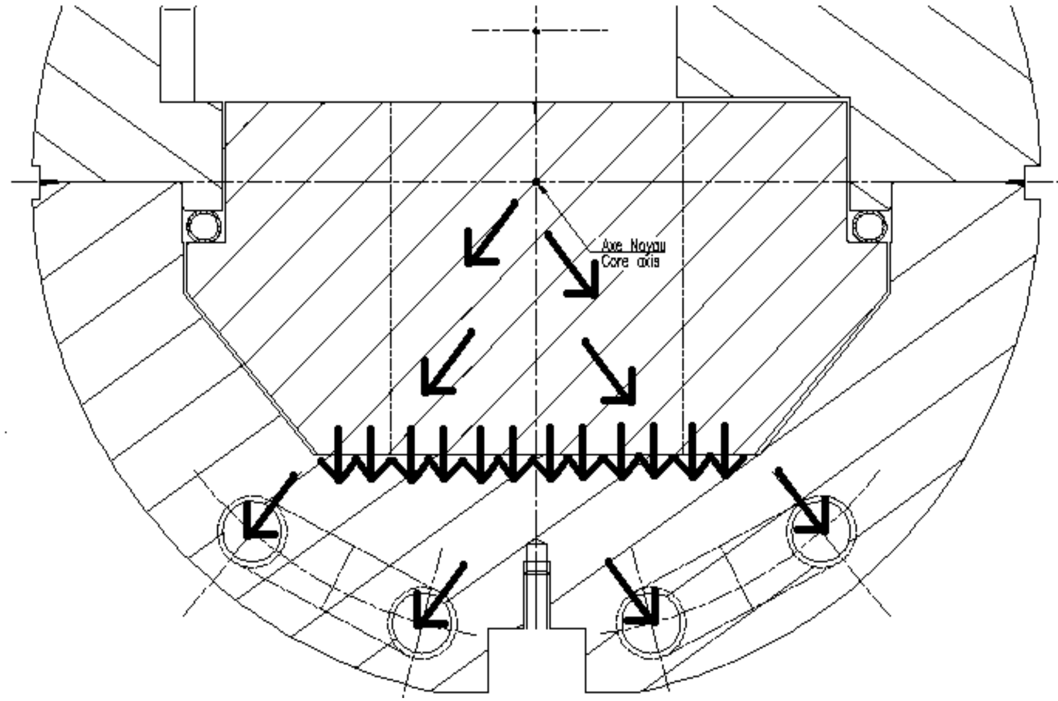
IV. General Cooling System

- The 4 dumps in LSS1 are on the same closed cooling system (due to their radioactivity).
- The water gets cooled in a heat-exchanger by the magnet water-circuit => 25° C minimal.
- Parallel branching: optimal cooling for each dump.
- Pressure interlock on water-circuit.

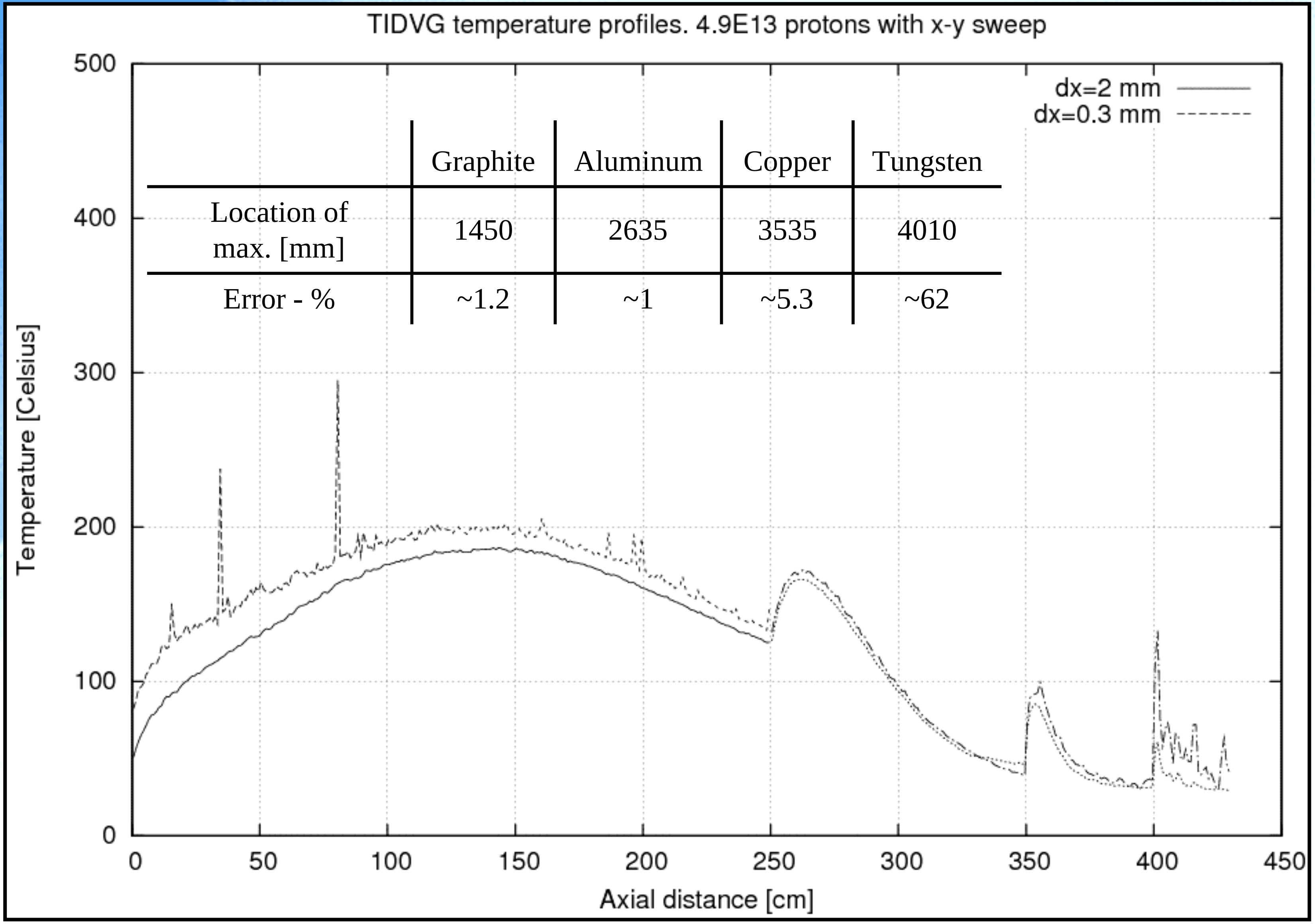
Heat Transfer in Core

Concept: get heat from absorber-blocks to the graphite.

- Efficiency determined by:
  - the conductance of the absorber blocks
  - the conductance through the contact-surface (absorber block vs. copper)
  - the conductance through the copper shells
  - the water cooling efficiency

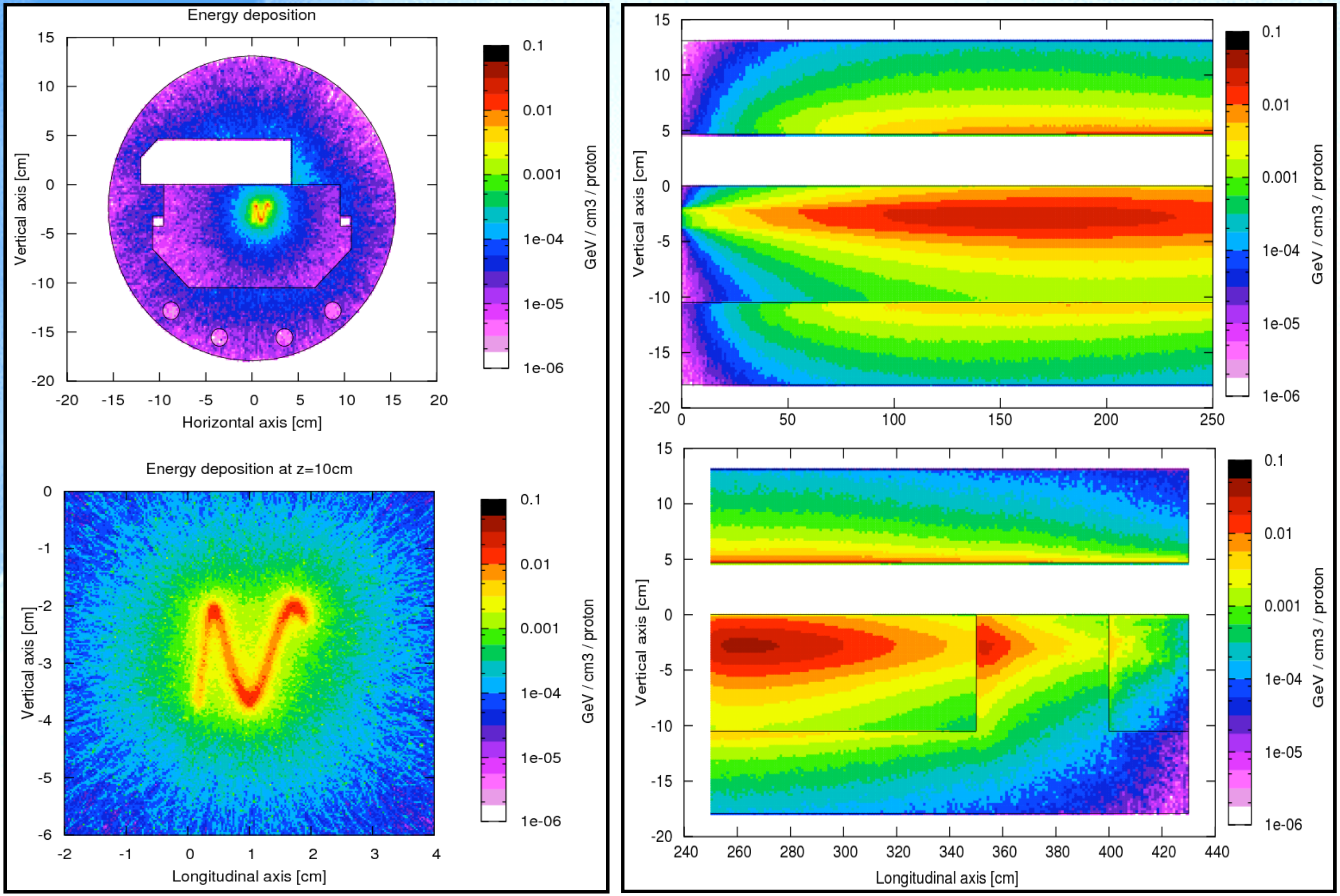


IV.



	Graphite	Aluminum	Copper	Tungsten
Location of max. [mm]	1450	2635	3535	4010
Error - %	~1.2	~1	~5.3	~62

IV.



Energy deposition
Vertical axis [cm]
Horizontal axis [cm]
GeV / cm3 / proton
Energy deposition at z=10cm
Vertical axis [cm]
Longitudinal axis [cm]
GeV / cm3 / proton
Vertical axis [cm]
GeV / cm3 / proton
Vertical axis [cm]
Longitudinal axis [cm]
GeV / cm3 / proton

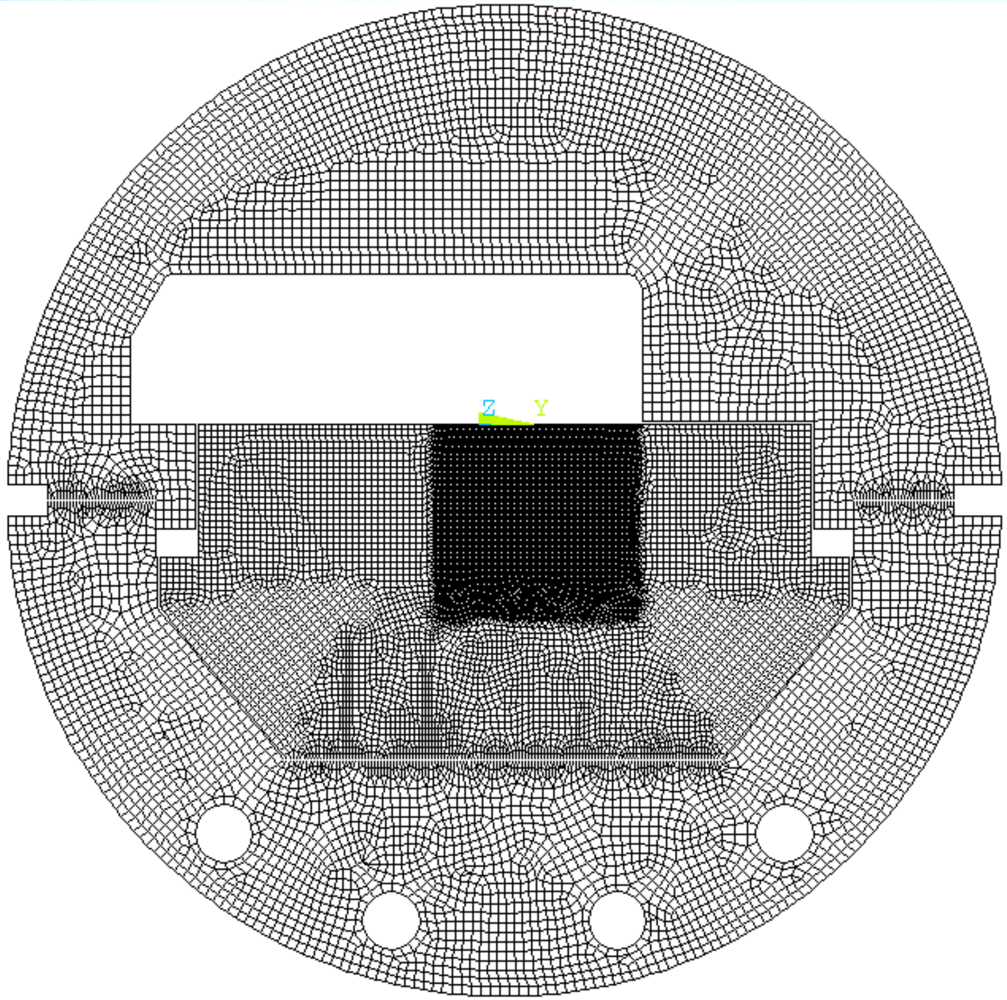
IV.

ANSYS mesh:

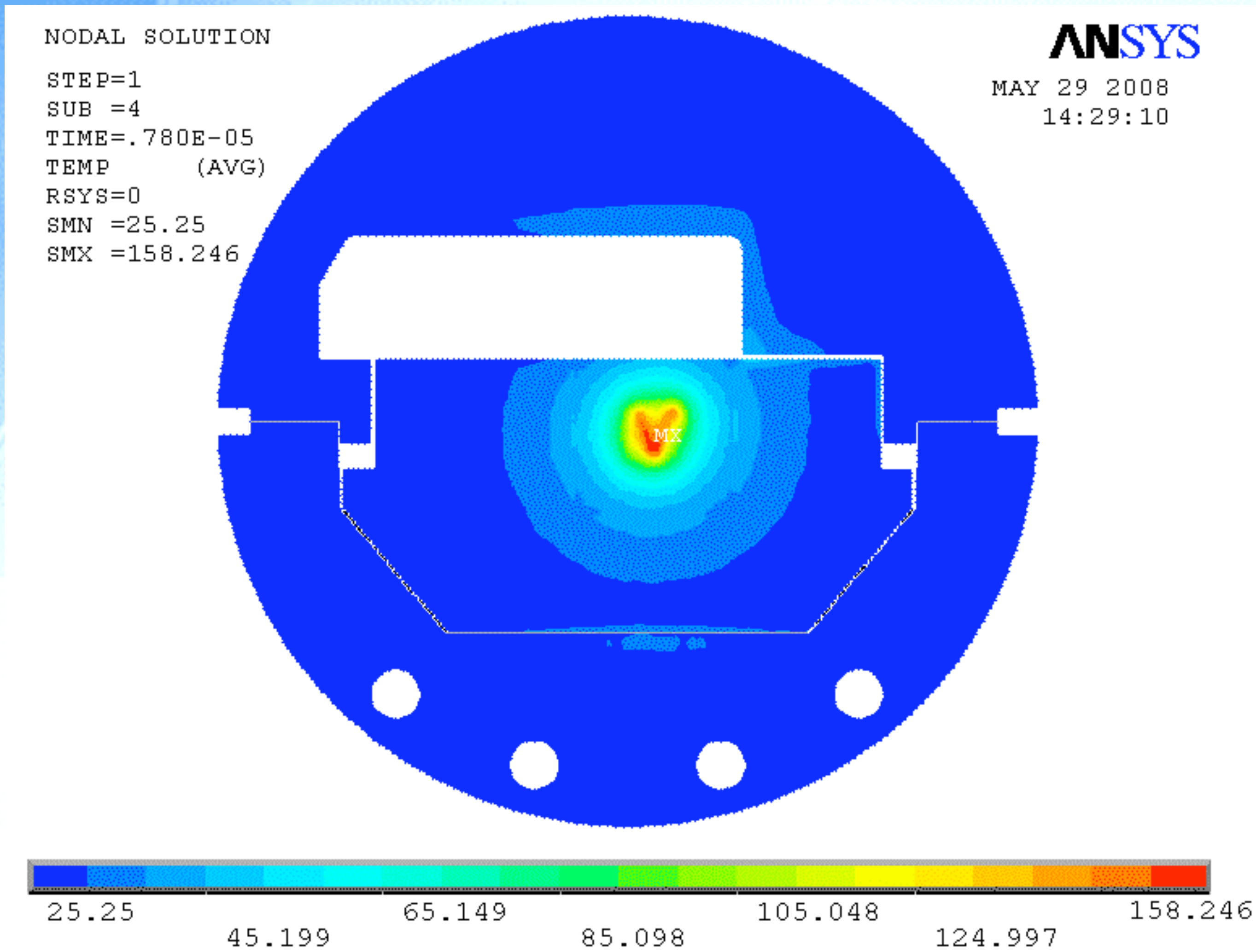
- Results with a higher FLUKA-resolution at the deposition region

=> denser mesh.

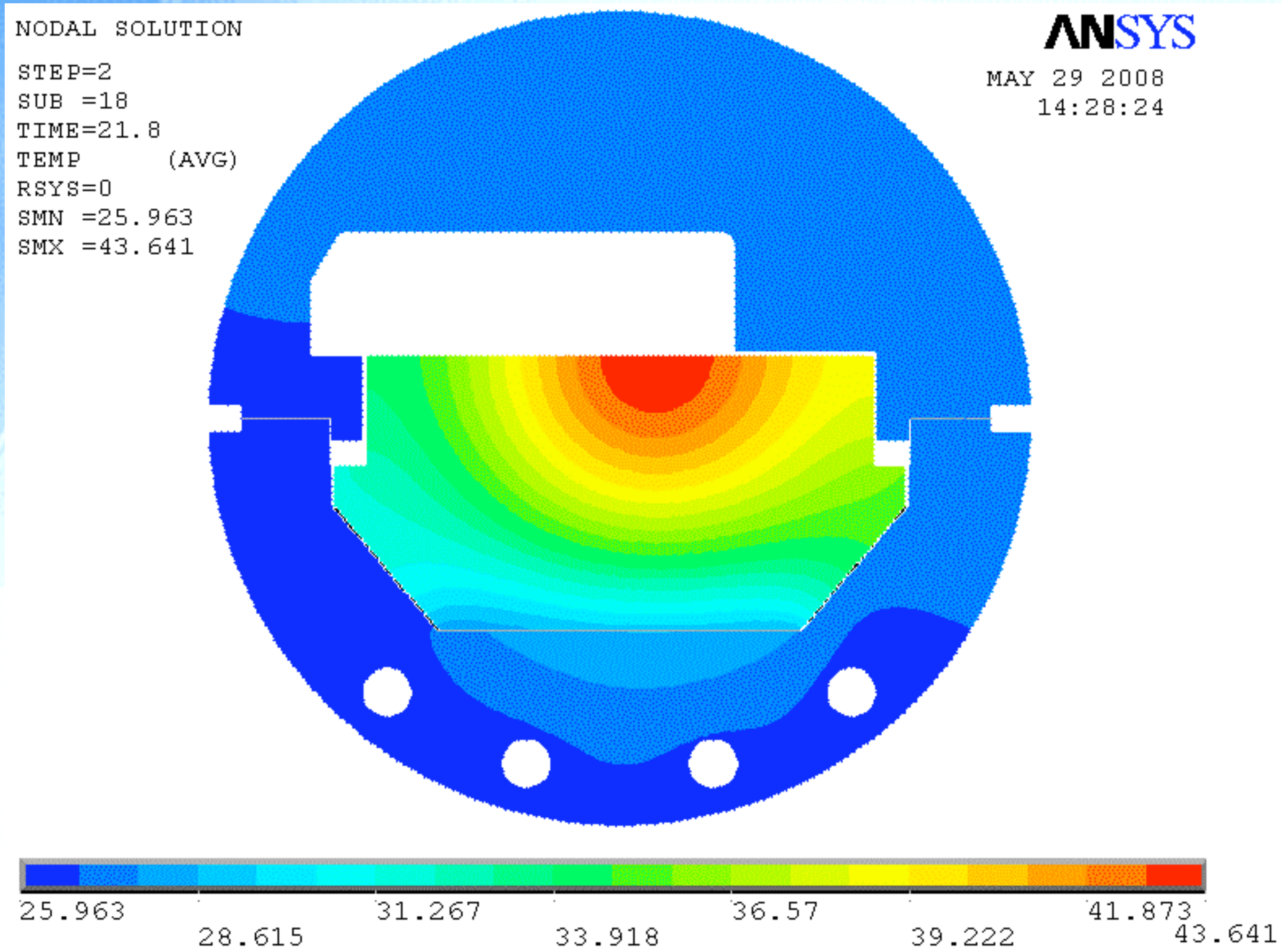
- Same model was used for all sections.



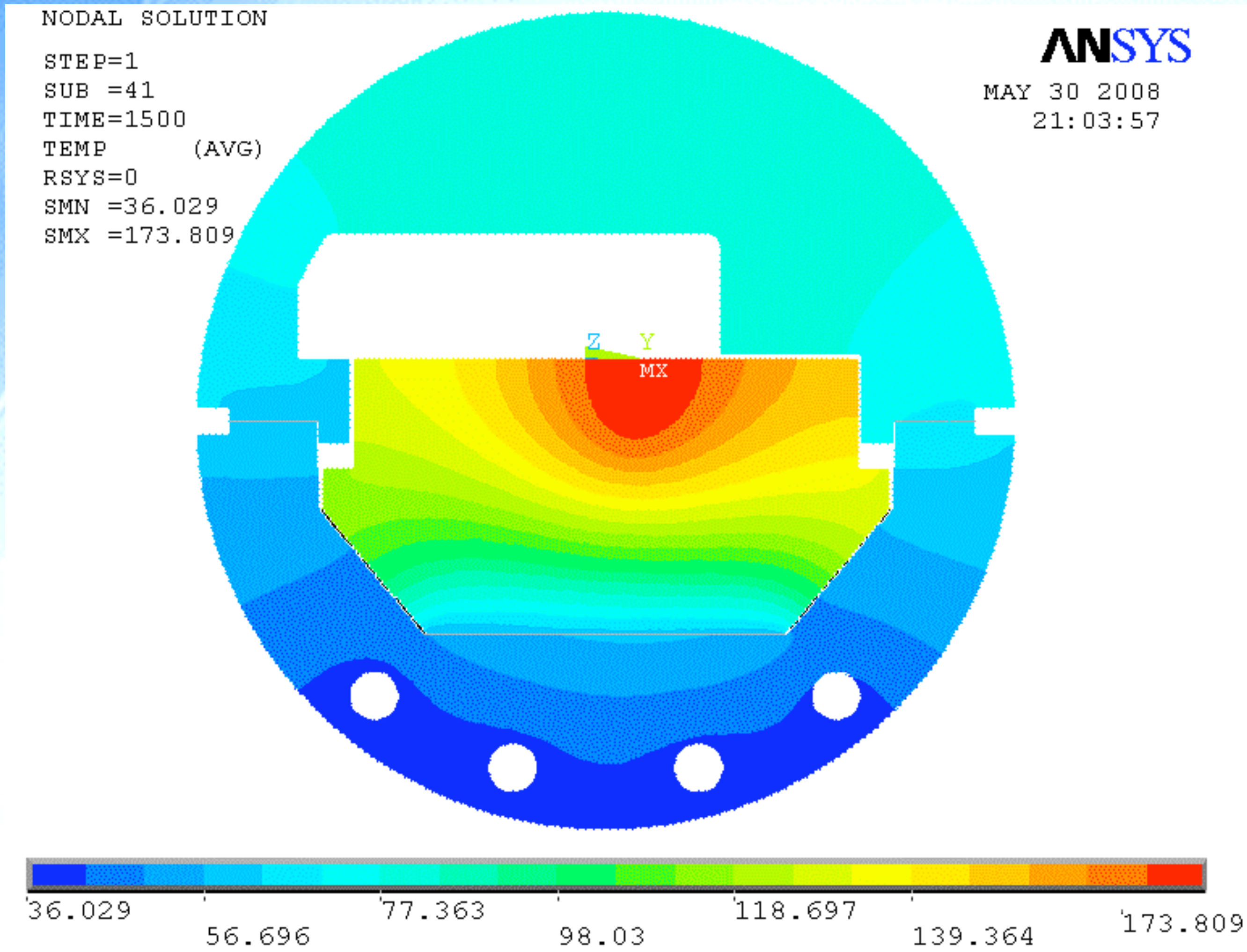
IV. Graphite: Transient 7.8 μs



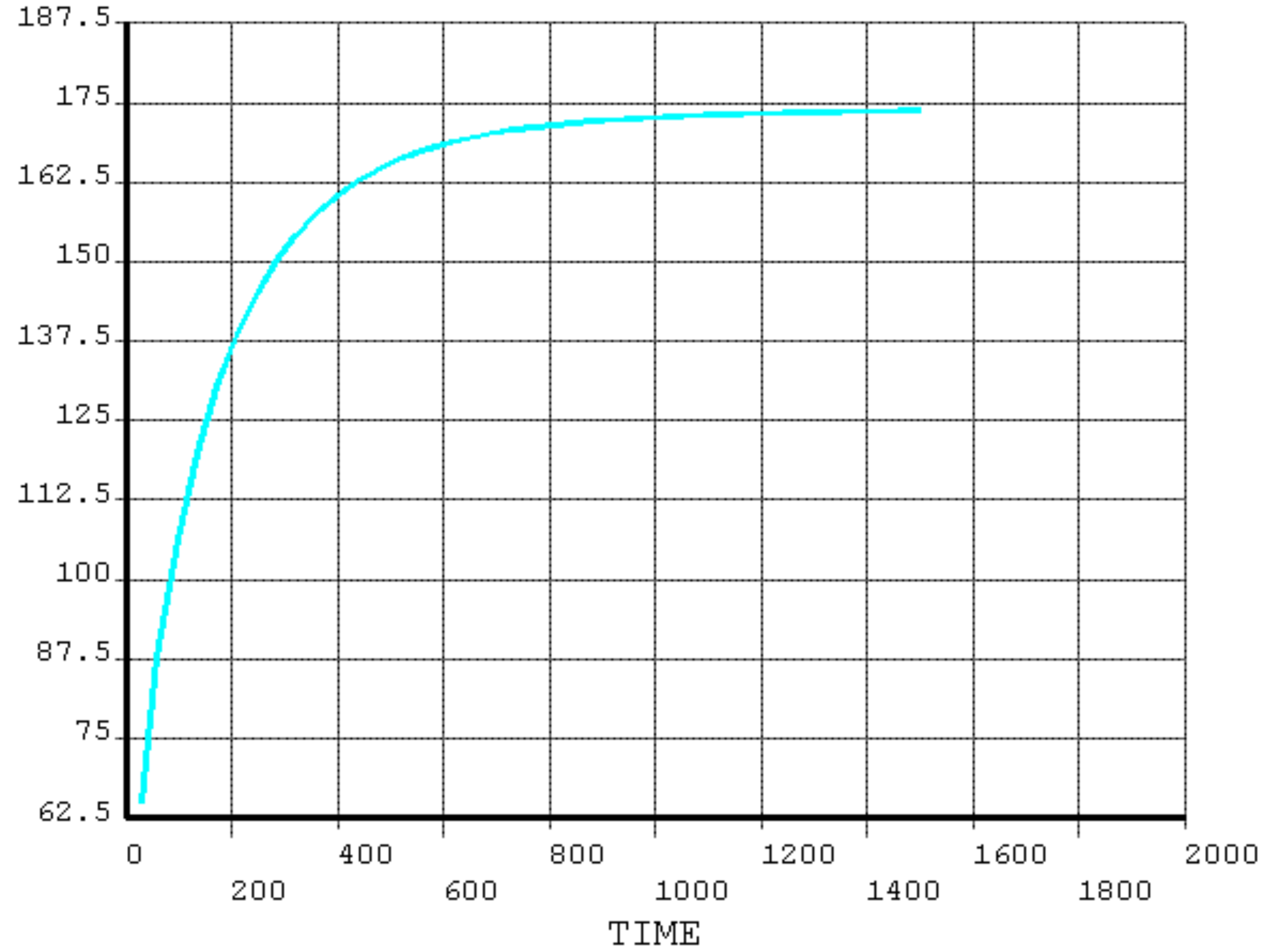
IV. Graphite: Transient 21.8 s



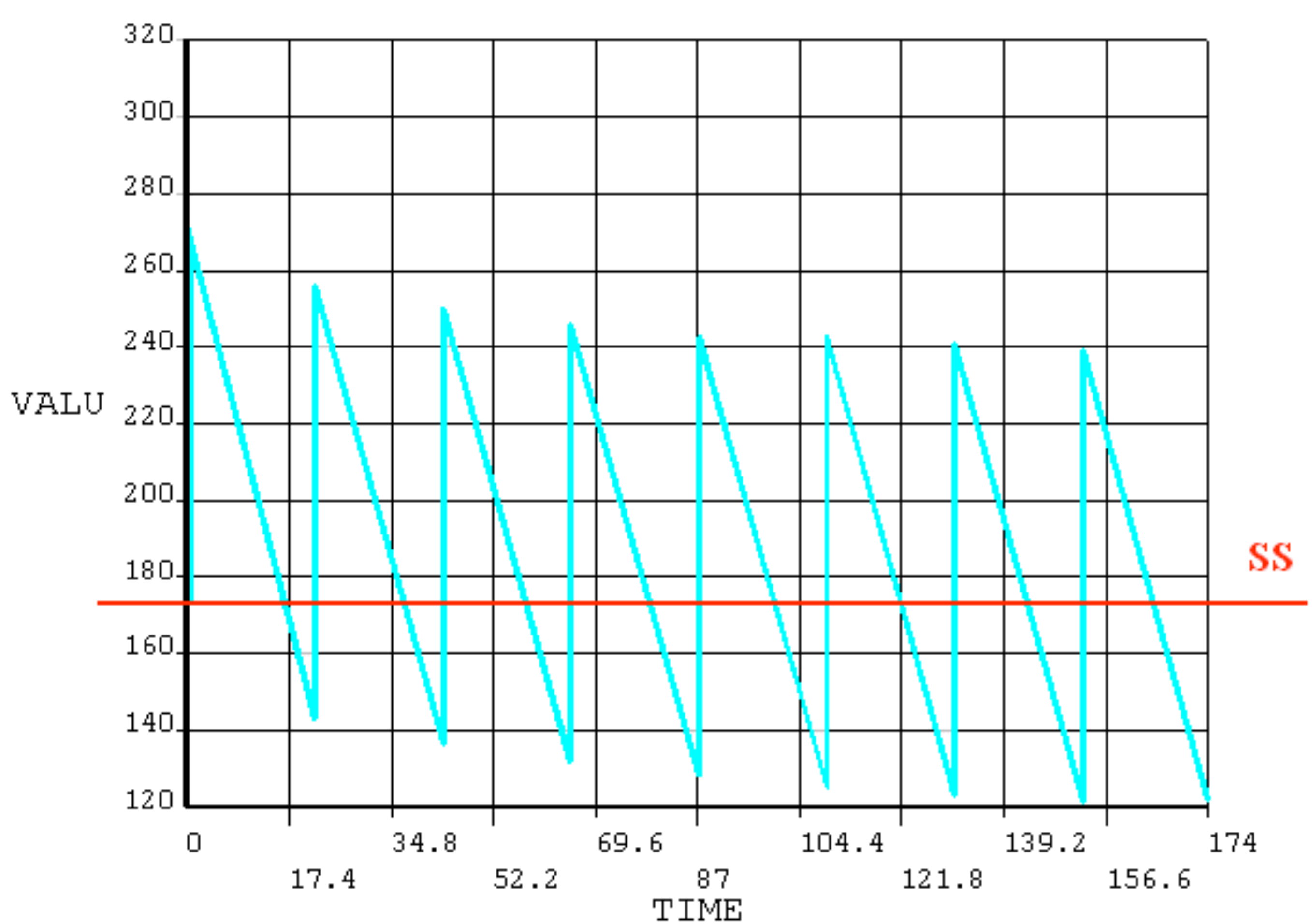
IV. Graphite: Steady State



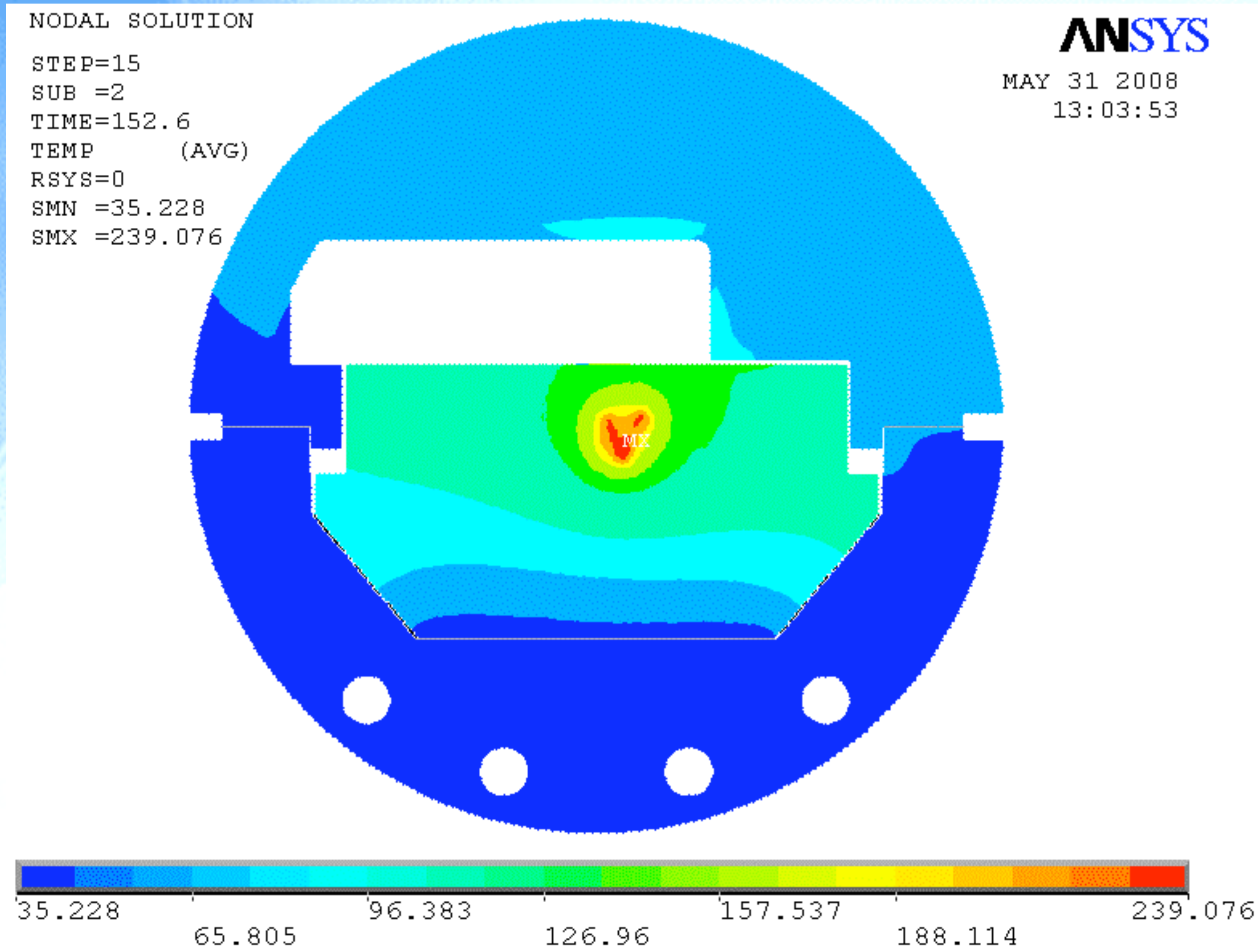
IV. Graphite: Steady State (cont')



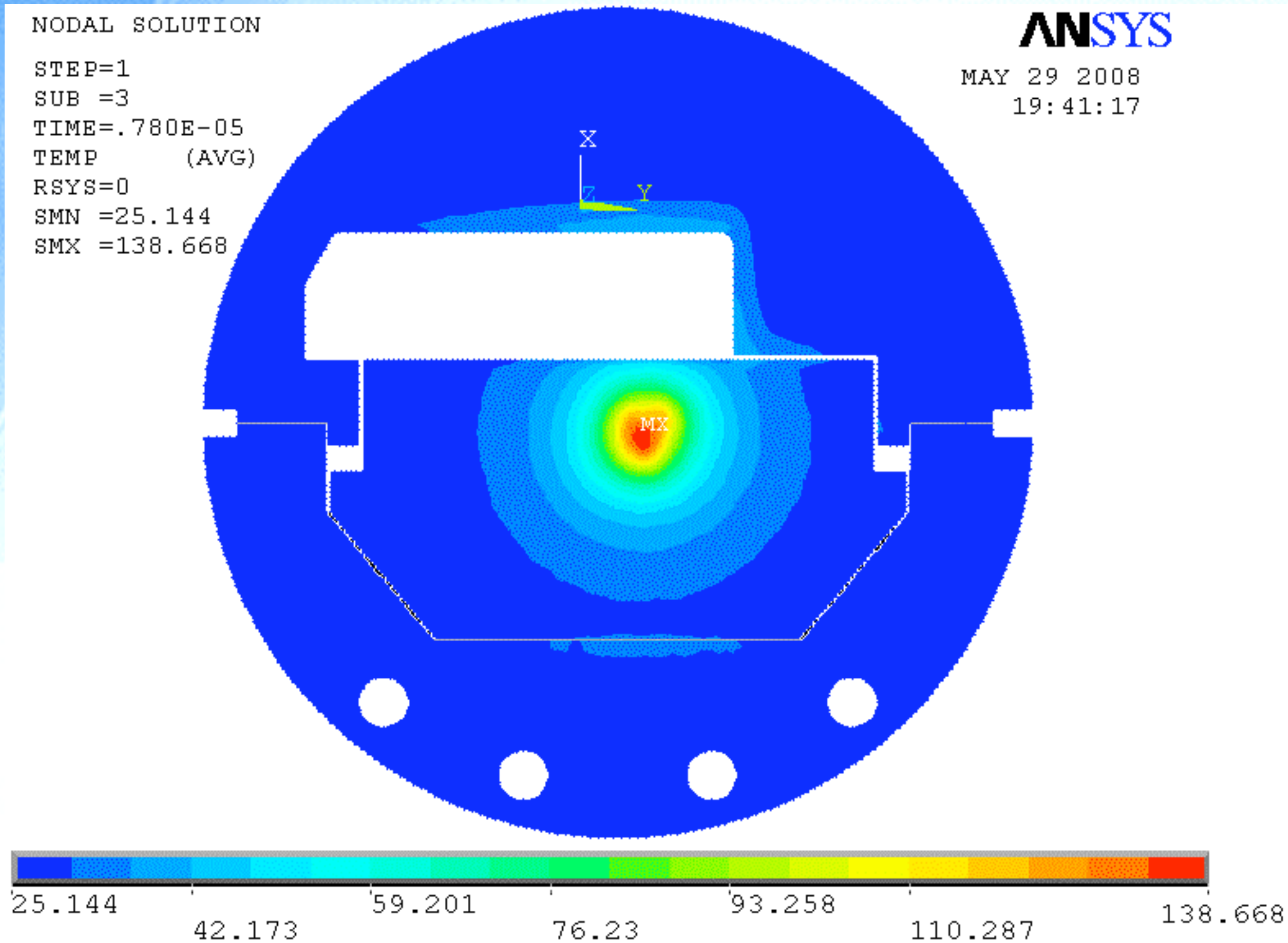
IV. Graphite: Fluctuation around SS



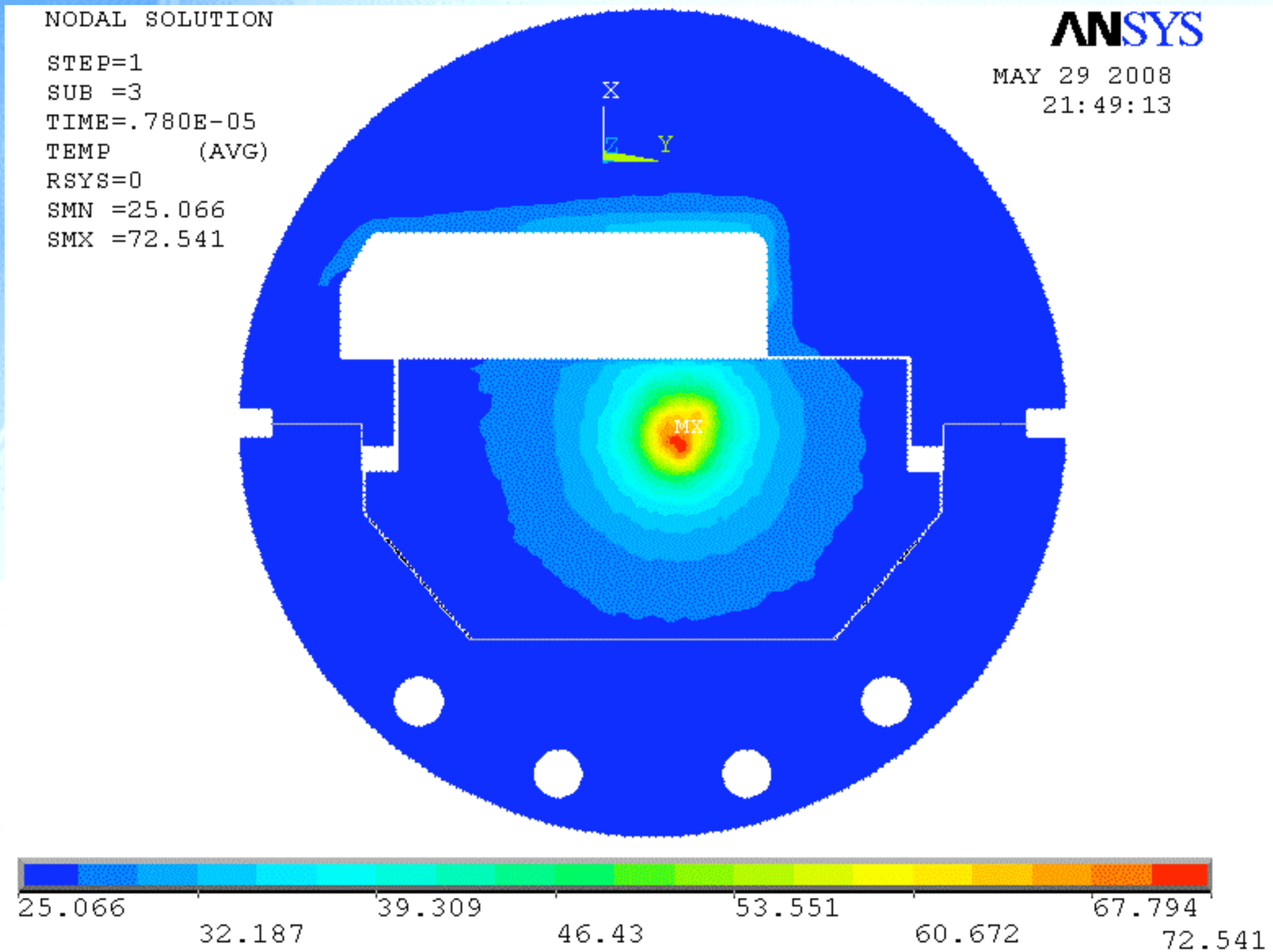
IV. Graphite: Maximal T. - Fluctuation



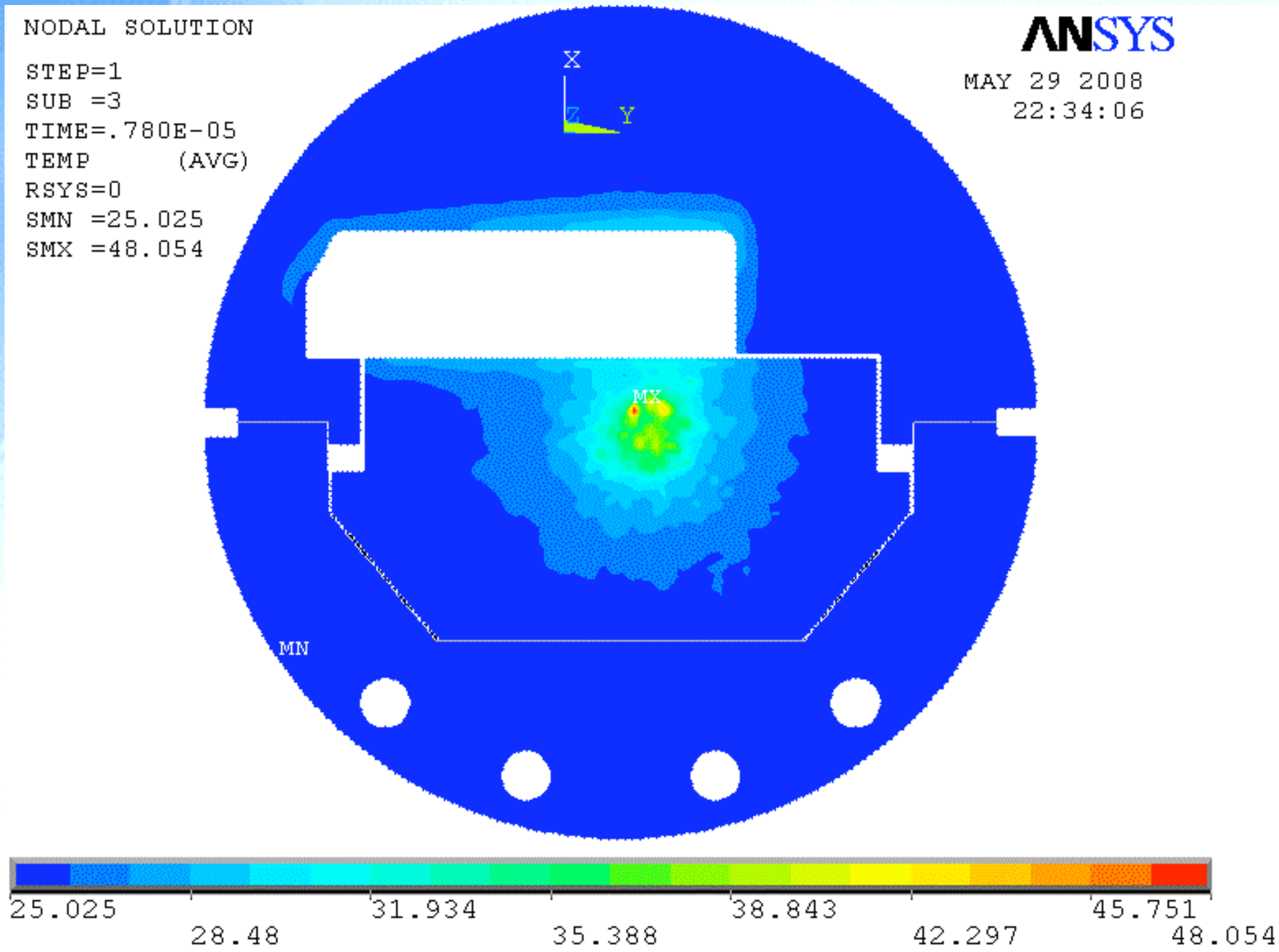
IV. Aluminium: Transient 7.8 μs



IV. Copper: Transient 7.8 μs

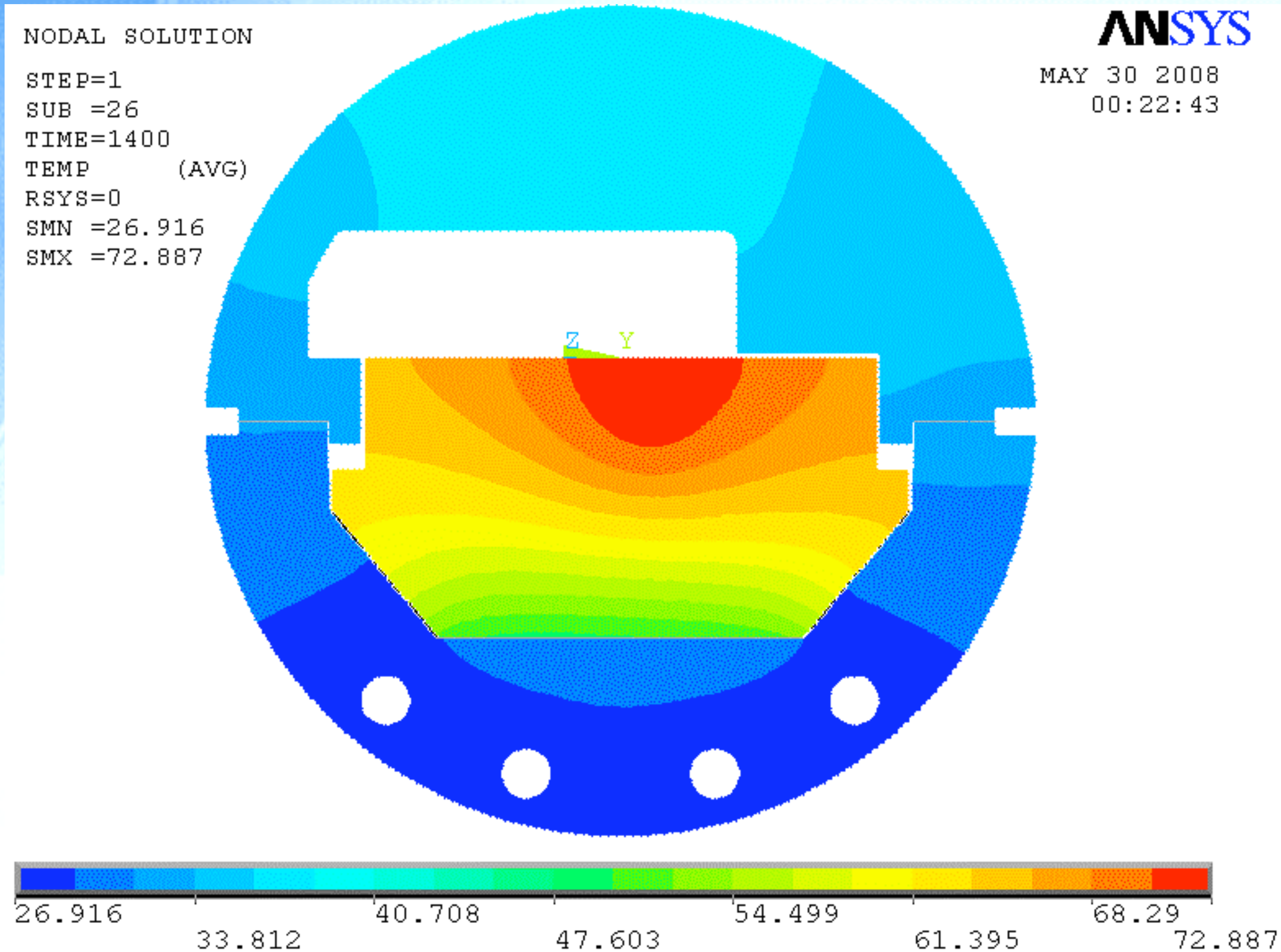


IV. Tungsten: Transient 7.8 μs

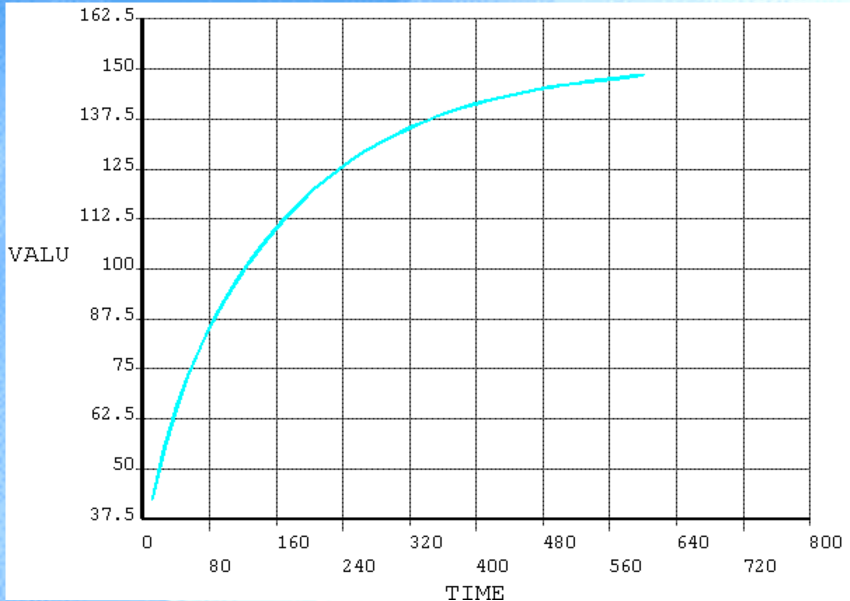


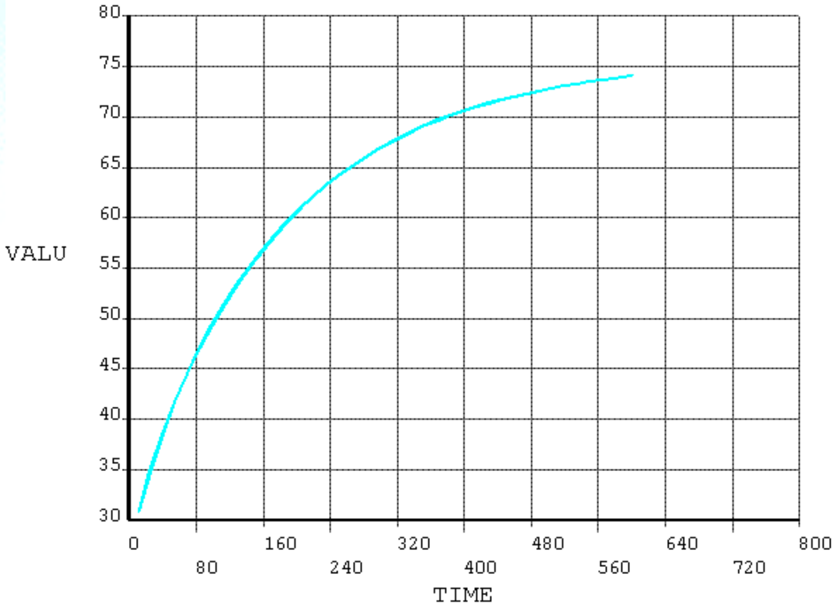
IV.

Tungsten: Steady State



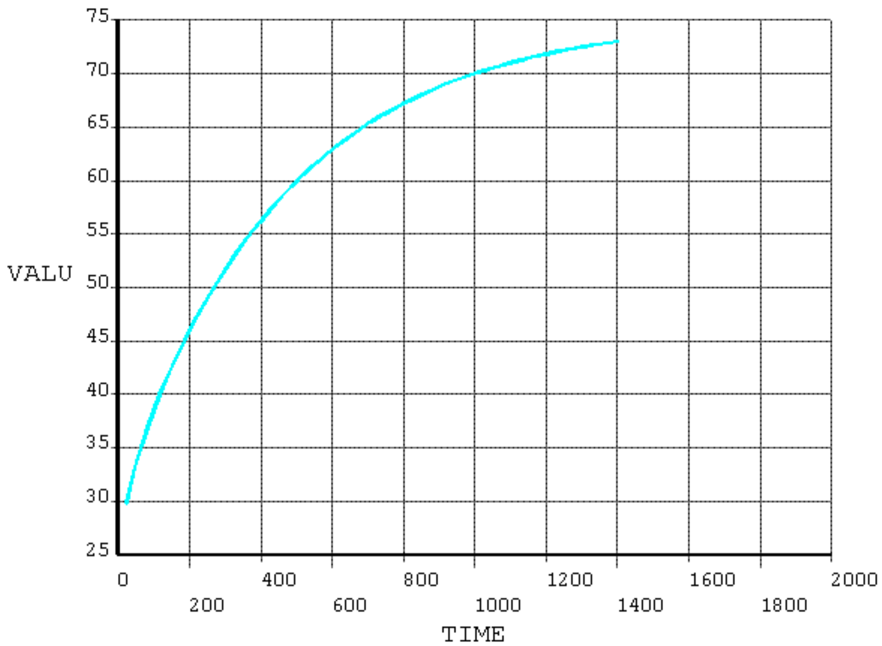
IV. Metals: Conservative Estimation for SS





Al.

Cu.



W.

IV.

Conclusion of the simulation

	T max. Graphite	T max. Aluminum	T max. Copper	T max. Tungsten
7.8 μs	~ 160° C	~ 140° C	~ 75° C	~ 50° C
21.8 s	~ 45° C			
SS average	~ 175° C	~ 150° C	~ 75° C	~ 75° C
SS peak	~ 240° C			

- Contrary to expectations: relatively low temperatures in graphite, but much more than final bake-out temperature (~ 150 ° C).
- Outgassing?
  - Certainly in Graphite
  - In Tungsten: probably.

Part V

Discussion of the External Solution-Options.

V. Concept: Change the System

1. Limit the conductivity of the gas between the TIDVG and the MKP’s (~ 8 m downstream).
2. More regular pumping-power.
3. Dedicated pumping using NEG-coating inside the vacuum-chamber of the QDA 11910 (in between the TIDVG and the MKP’s).
4. Changing the location of the complete dumping system.
5. Constructing a vacuum chamber inside the MKP’s aperture.

V. 1. Limit Conductivity

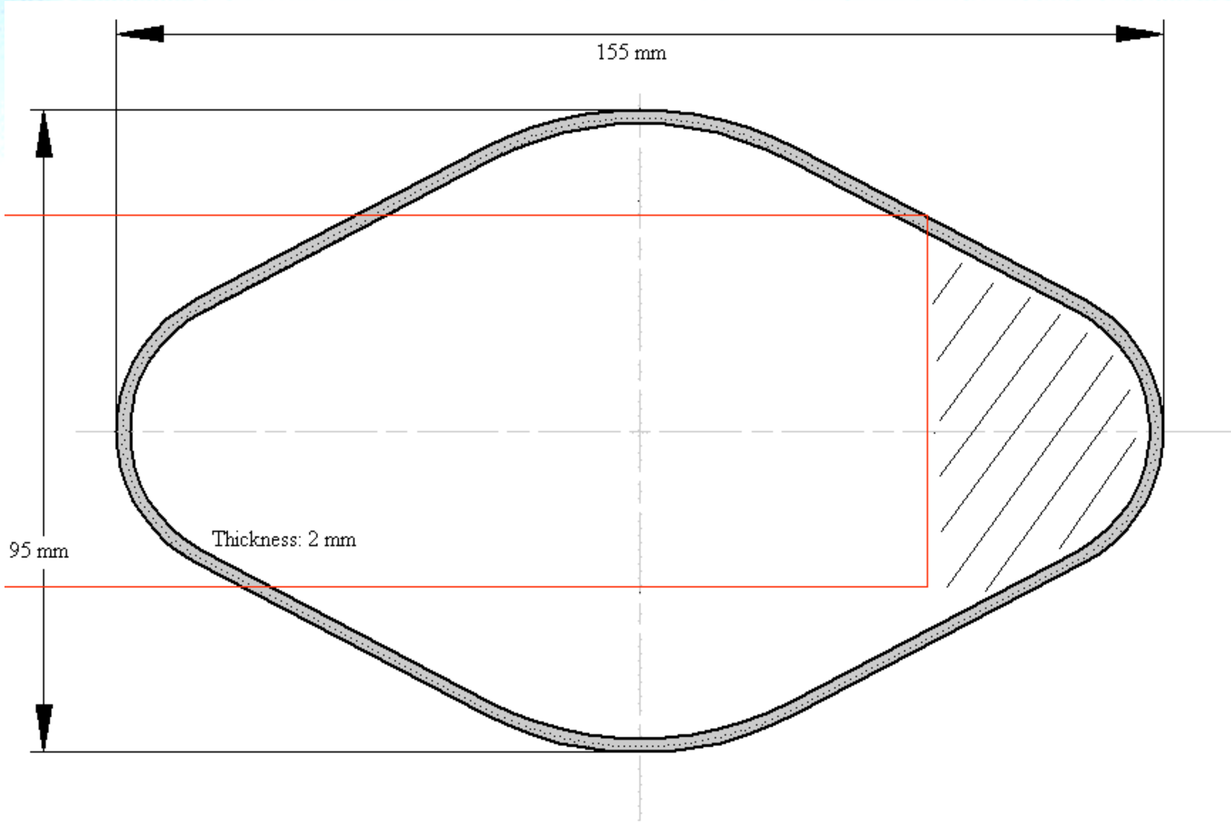
- Gas-flow = molecular flow
- According to the theory of molecular flow, most important parameter is: diameter.

  => Small diameter = small conductivity
- Only changeable diameter in between the MKP's and the TIDVG is: QDA.
- Apertures are determined by beam size and electrical conductivity requirements.
- Changing aperture will affect beam behaviour.

V. 1. Limit Conductivity (cont')

- QDA aperture
- Red line: 'TIDVG shadow'
- Vertically: area must be kept free to cope with β fluctuation.
- Shaded area: part which could be left out (~15%).
- According to calculations: conductivity is reduced by 20%.

  => **not enough...**



V.

2. Increase Pumping Power

- The pumping power experienced at each side of the TIDVG is ~ 300 l/s.
- Adding one ion pump (400 l/s) just downstream of the TIDVG could double this figure for this side.
- Orders of magnitude increase in pressure due to outgassing => a marginal effect on the pressure.
- And no room to install extra pumps…

V. 3. NEG-Coating in the QDA

- Initiated a study by: Pedro Costa Pinto (TS/MME).
- Outgassing >> achievable pumping speed according to M. Jimenez.
- Effort was continued under impulse of G. Arduini.
- No further advancements since then.

V. 4. Change the location of the system

- This is an option which might be interesting when the complete SPS is updated.
- Has been considered in a study:

  => negative advice.

  – A suitable location is hard to find
  – High cost
  – Complete redesign necessary

V.

5. Vacuum chamber in MKP's

- Vacuum chamber should be made from a non-metallic material: ceramics.
- Ceramics => thick-walled vacuum chamber.
- But: aperture of MKP's are already critically small to enable correct functioning.
- Building adapted versions of the MKP's would become extremely expensive.

=> not an option.

VI.

Part VI

Discussion of the Internal Solution-Options.

VI. Concept: Change the TIDVG

- Restricted to the last spare: TIDVG#3.
  - TIDVG#1 in radioactive storage
  - TIDVG#2 installed (and very radioactive)
- Restricted also by functionality requirements and current lay-out.
- Combination of different options needed.

VI.

General Options:

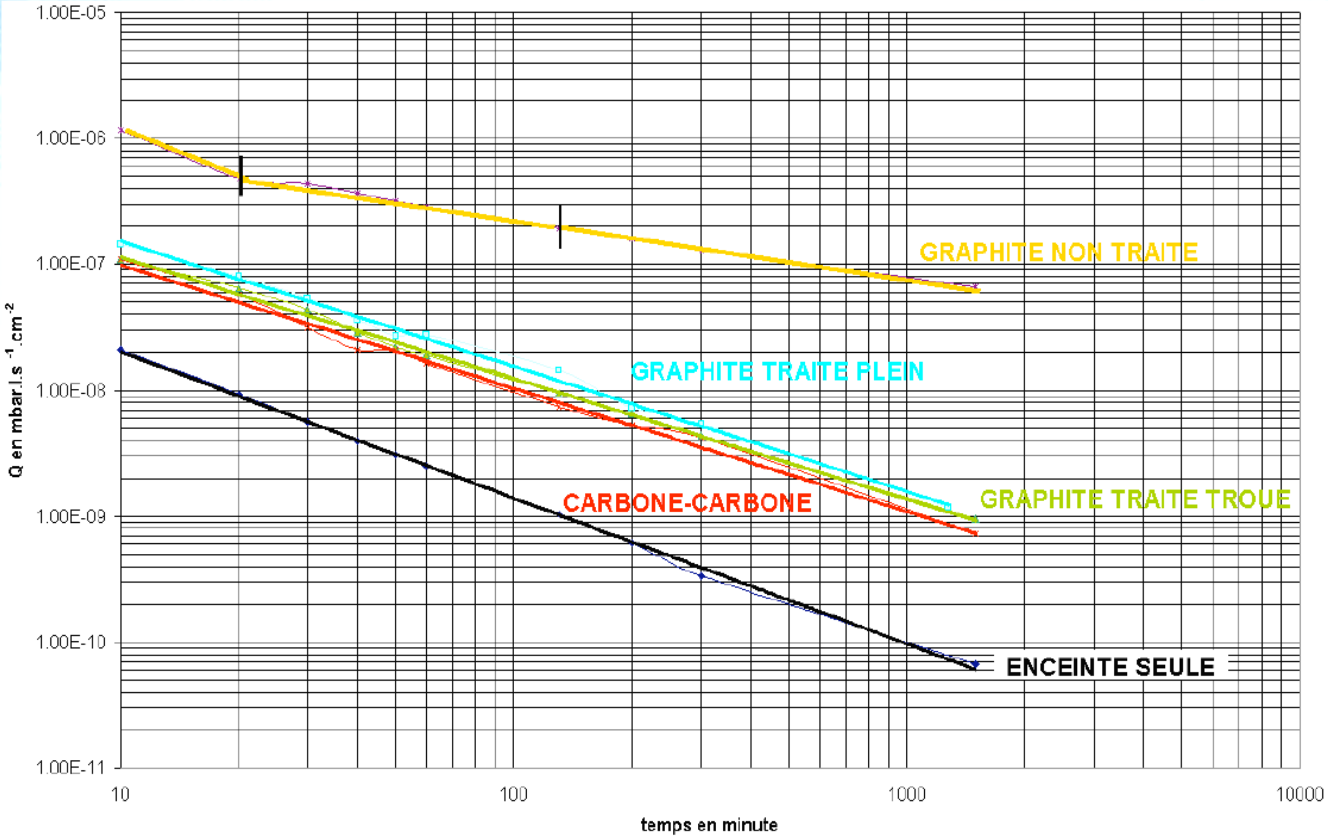
- Improving outgassing/ gas conductance properties:
  1. Design new graphite absorber blocks to decrease outgassing
  2. Eliminate ‘outgassing-bottlenecks’.
  3. Separate regions: dumping region & aperture

- Redefining thermal system:
  1. Limit the temperature rise during dumping
  2. Enable better bake-out of assembly

VI. New absorber block: material

- Graphite is still the best qualified material.
- Using a different graphite?

The most can be gained by changing the pre-treatment, not the graphite.



VI. New absorber block: material (cont')

- Changing the density to 'steer' the outgassing

  ⇒ Longitudinal density variation is a key-concept of the dump and it is optimized in this way. Lateral density changes would lead to local temperature extremes which depend on the impact-location. Depending on the design, this might be hard to predict: losing reliability.

  ⇒ Effectiveness of concept is not proven.

VI.

Coating

- A coating makes the graphite difficult to bake-out. And it will remain polluted longer.
- As it is considered necessary to prevent the formation of graphite, 2 possibilities exist:
  - Use a completely impermeable coating
    - ⇒ Technically impossible
  - Use a coating which is as thin as possible
    - ⇒ Limit is already reached

VI. Gas Conduction Optimization

- Outgassing holes to enhance bulk outgassing
  - » Negligible effect according to test results
- Outgassing channels between surfaces:
  - » Effective against virtual leaks
  - » Would enhance the bake-out of the assembly
  - » Trade-off necessary between contact surface needed for cooling and used for outgassing-channels.
  - » Small channels can have distinct effect.
  - » Has been applied on certain collimators.

VI. Physical Separation

- The ultimate achievement would be to separate the aperture from the absorber-blocks.

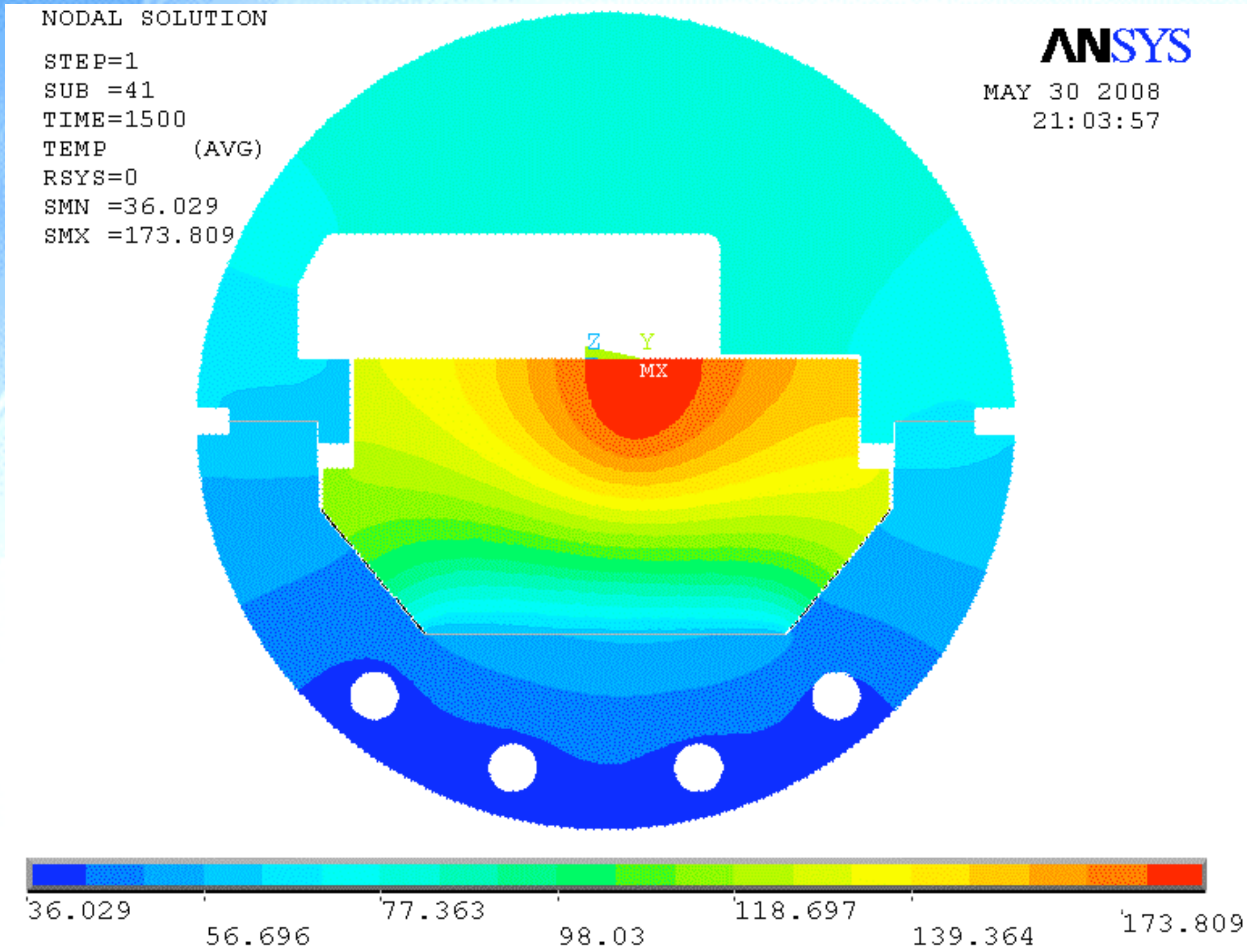
- Problematic is the uncertainty of the beam.
  - A barrier above the absorber blocks would have to be very thin (like a foil…), but also would have to survive a direct impact of the beam.
  - Available options are not very reliable…

VI. Redefining Cooling System

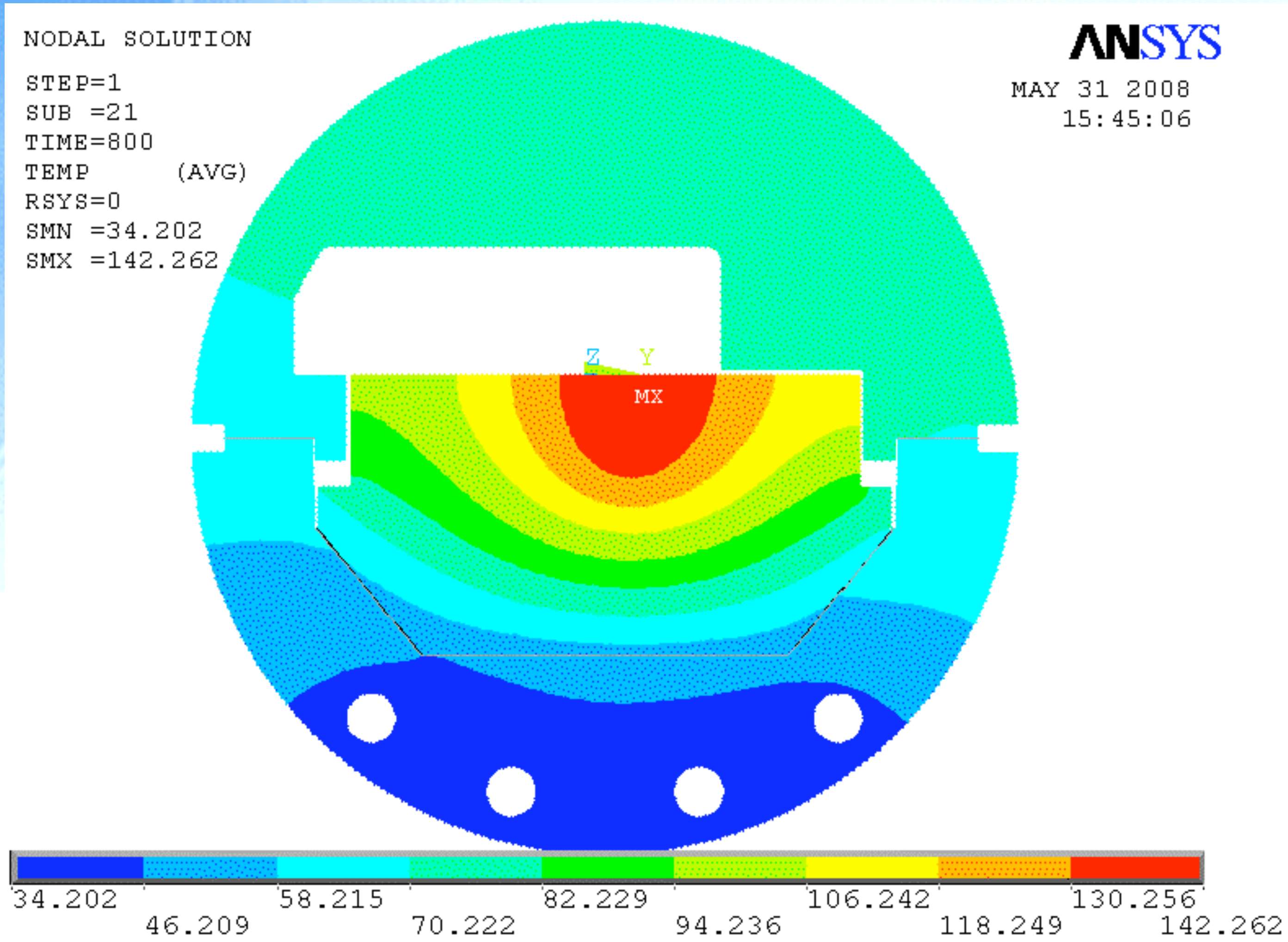
- Cooling of the copper shells works fine: good contact conductance, copper remains well cooled…
- Main bottle-neck is the heat conductivity of the graphite: path from centre of deposition to the contact surface is too long.

  => Clamp sides of block against copper to increase contact surface for cooling.

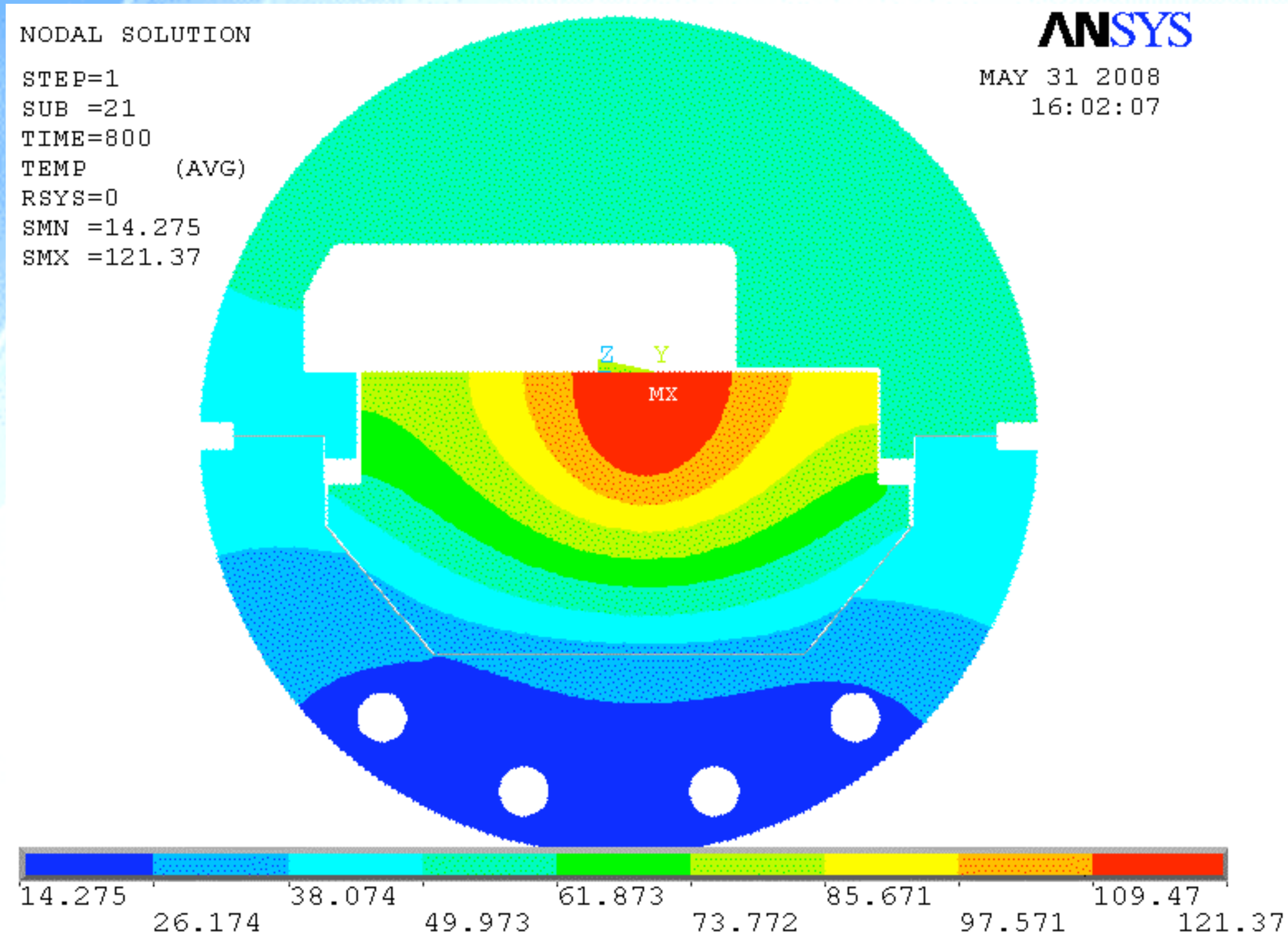
VI. Normal Average SS



VI. SS with Large Contact Surface



VI. SS with Larger Contact Surface & Extra Cooling (water = 5° C)



VI.

Effects:

- Larger contact surface: SS -30° C.
  - » Losing efficiency by implementing outgassing channels.
- Cooling from 25° to 5° C: SS - 20° C.
  - » But practically this is quite hard to achieve.
- Increasing the heat extraction towards the iron shielding is not expected to help a lot
  - » It does not resolve a bottle-neck.
  - » The copper core needs the gap to cope with thermal expansion

VI.

In-situ Bake-out

- One problem: Copper shells are restricted to a maximum temperature due to the nature of their production process: no final heat-treatment was done.
- Bake-out temperature needs to go up to 300° C min.
- Remote controllable
- 2 options:
  - Infrared radiators (have successfully been applied before):
    - » Contra: Probably to voluminous for this application
    - » Pro: Copper can be kept cool
  - Coax cables:
    - » High temperatures, thus a very good thermal contact is needed.
    - » Extra pieces to clamp it against the graphite, isolate it from the copper.

VI. In-situ Bake-out (cont')

- Simplicity is the key: no repair possible…
  $\Rightarrow$ again: Safe Life Design.

- Heating from the outside (thus the copper) is not advised: much higher powers would be needed to obtain an elevated temperature in the graphite.

  (But clamping of coax-cable would be easier.)

VII.

Part VII

Solution Trade-off and Next Steps to Take.

VII. Important Factors

- Only one spare remaining.
- In the near future: general upgrade of SPS.

- Thus: updating and installation of TIDVG#3 would have as consequences:
  - » Throwing away of a working piece of equipment (TIDVG#2)
  - » Necessitating the (expensive) production of a new spare for only a few year until the next update arrives

  - » Opening of the sector does not cause a reset of the situation
  - » New version should finally work constantly during all MD's.

VII. Option I

- Leave the current TIDVG installed
  - » Try to limit the opening of the sector
  - » Then the core will be more and more conditioned
- Adapt the spare:
  - » Heat treat and re-machine the copper (& add outgassing channels)
  - » Install an (remotely controllable) heating system using coax wires to bake the graphite to at least 300° C whenever needed.
  - » Do the 1000° C bake-out and the recoating of the graphite.
  - » Do the 1000° C bake-out of the Tungsten blocks.

=> But do not install until failure of TIDVG#2.

- Afterwards, prepare for the SPS upgrade.

VII.

Option II

- Start as fast as possible with the design of the new dumping system. And try to produce a type of ‘hybrid dump’ that can be used in both the present situation and in the SPS upgrade.

- Keep the spare as an emergency spare without extra adaptations. But it will not be very functional due to its initial outgassing behaviour.

=> higher risk involved

VII.

Continuation

- Measurements/simulation of possible e-clouds at the dump.
- Further investigation by the vacuum-department for:
  - clear guidelines about the design, operation and treatment of graphite equipment. Especially for these high performance applications.
  - The influence of coatings on outgassing behaviour

Thank you all!

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  A. Ijspeert; CERN/SPS/81-9
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- p24: *Studies of Beam Losses from Failures of SPS Beam Dump Kickers*
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- p26: *The Millenium Dump TIDVG Commisioning – April 2000* M. Ross SL-Note-2000-050 BT
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- p35: *Motivations to go to 450 GeV* G. Arduini
- p43,44: Roberto Rocca
- p69: *Graphite Outgassing Measurements for UHV Applications*
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