# Solid Absorbers in MICE Step IV

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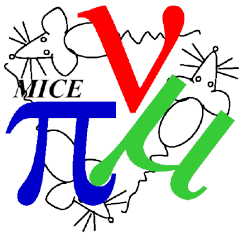
IIT/Fermilab

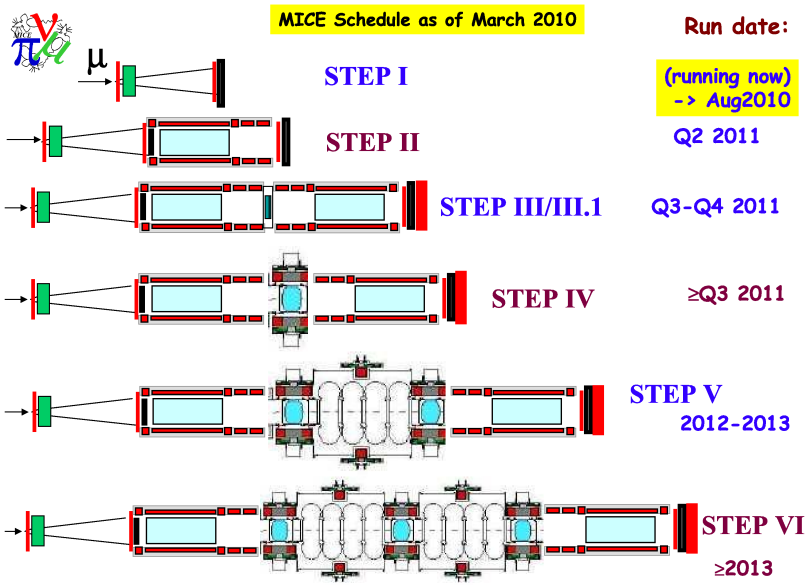
MAP Friday phone meeting, Fermilab




ILLINOIS INSTITUTE OF TECHNOLOGY

Fermilab

# Old MICE Schedule




- The original MICE schedule included Steps I through VI.
- Would allow running with one spectrometer solenoid (SS) in Step II, then two, with no absorber focusing coil (AFC) in between in Step III.
- For various reasons now both SS and AFC arrive around the same time.
- Go directly to Step IV.

# MICE Schedule

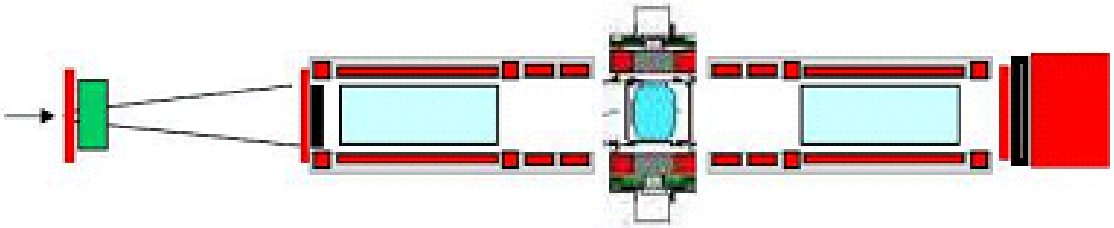
μ

MICE SCHEDULE
update February 2012 V1

Run date:

STEP I

EMR run Q2 2012

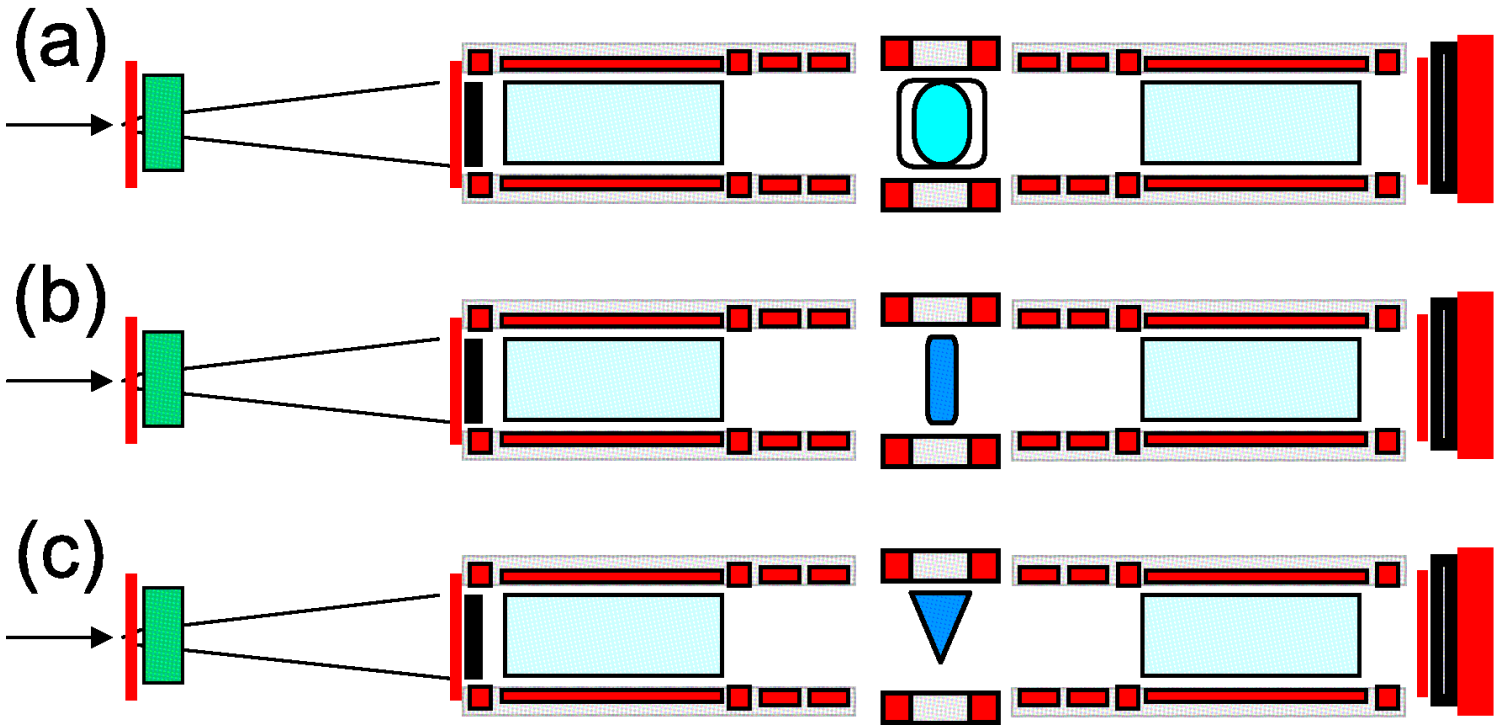


STEP IV

Q1 2013

- Step IV measurements will take 4 to 5 ISIS run periods (Feb–Dec 2013).
- First demonstration of muon ionization cooling.
- Whichever goes first: liquid Hydrogen (LH2) absorber or solid absorbers is still not decided (“stay flexible” mode).

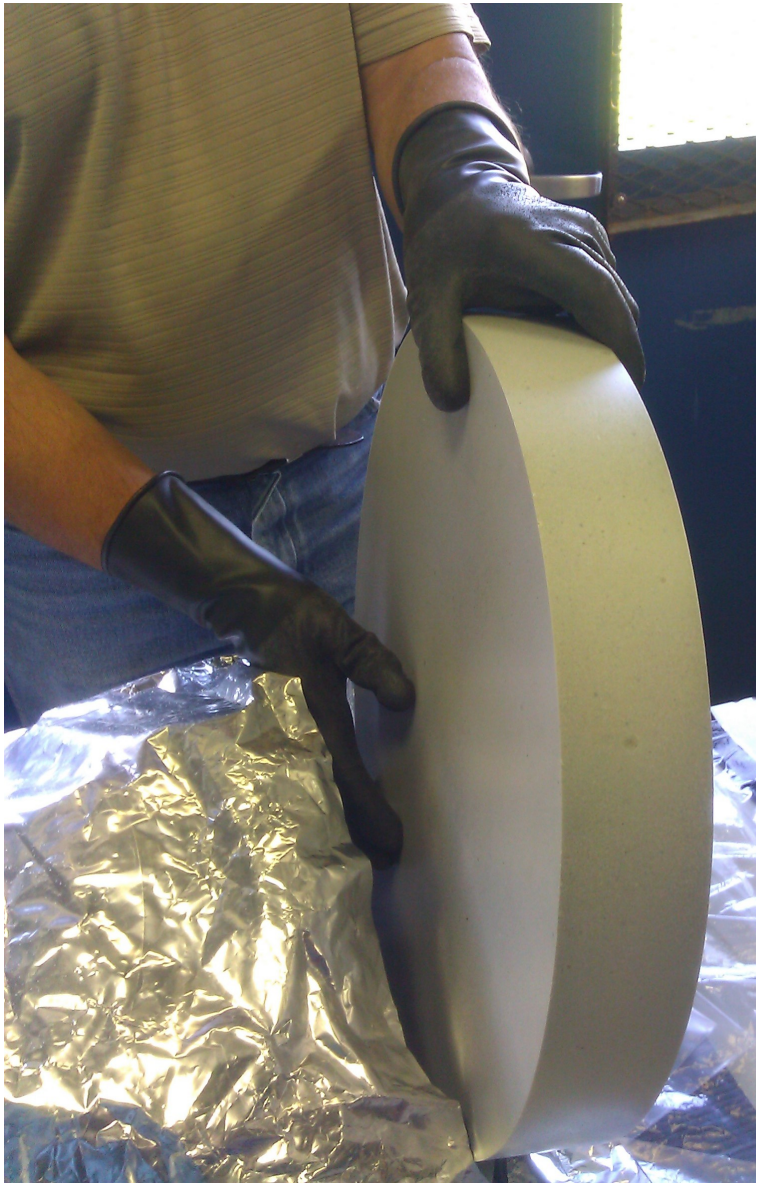
# Various absorbers

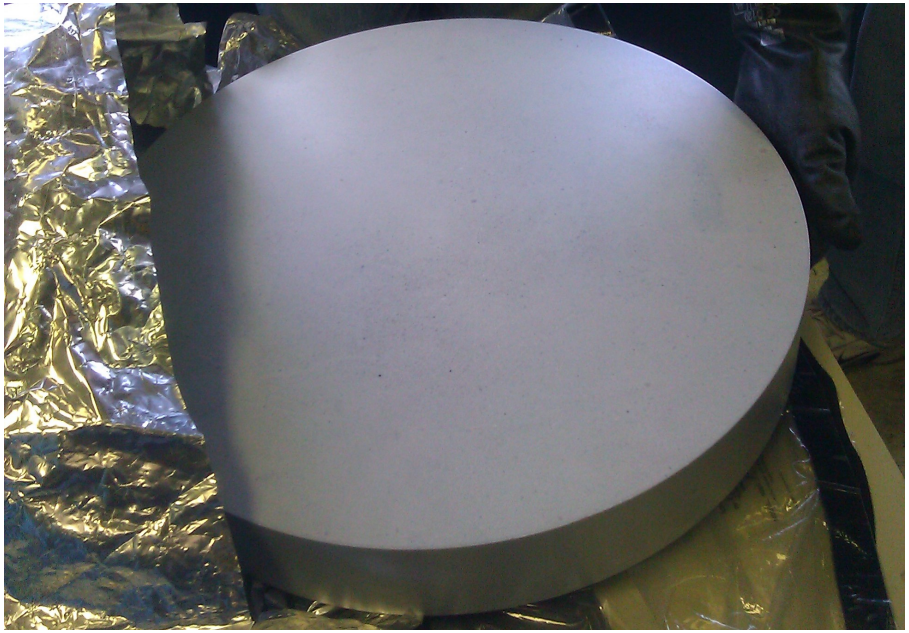



(a) liquid hydrogen; (b) solid flat (LiH, Al, PE); (c) solid wedge (LiH, PE)

# Flat absorber and support

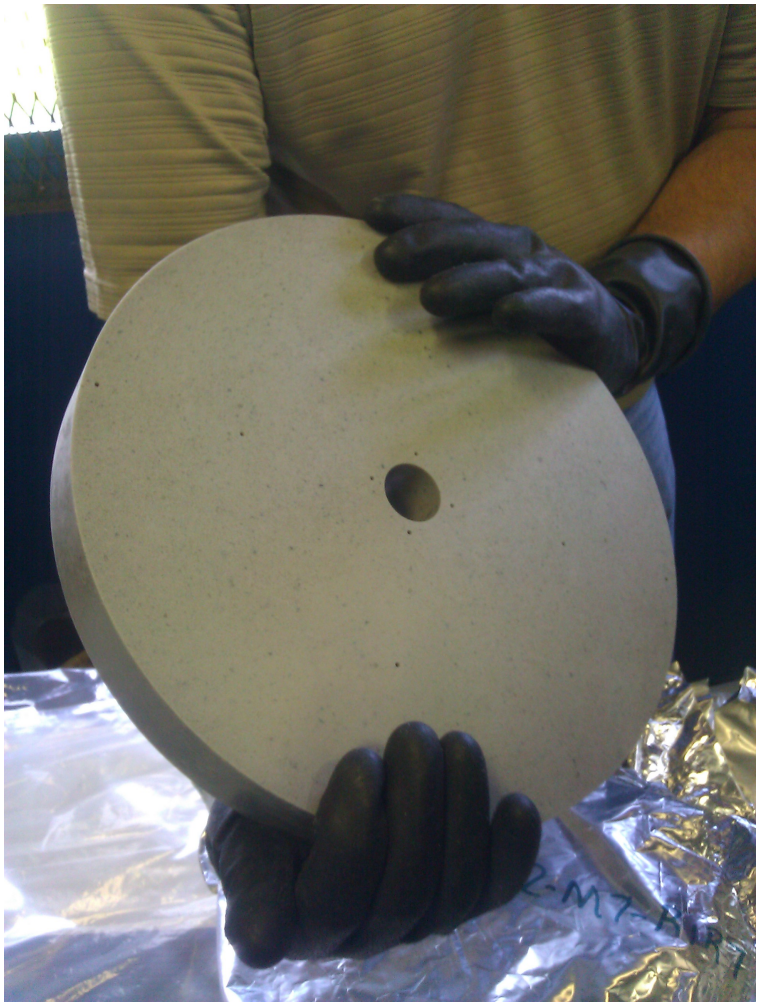
# Flat LiH absorber

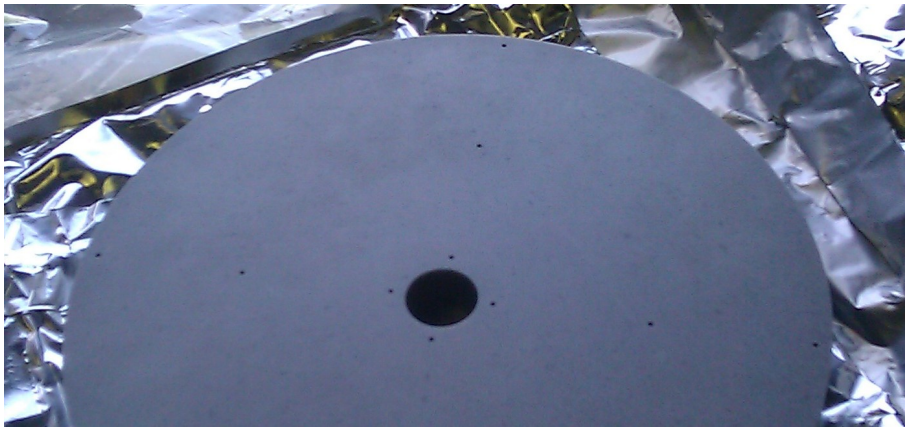




- LiH absorber is at Fermilab now.
- Engineering drawings have been finalized, approved, sent to Fermilab.
- Absorber support will be fabricated at Fermilab, details are being worked out.

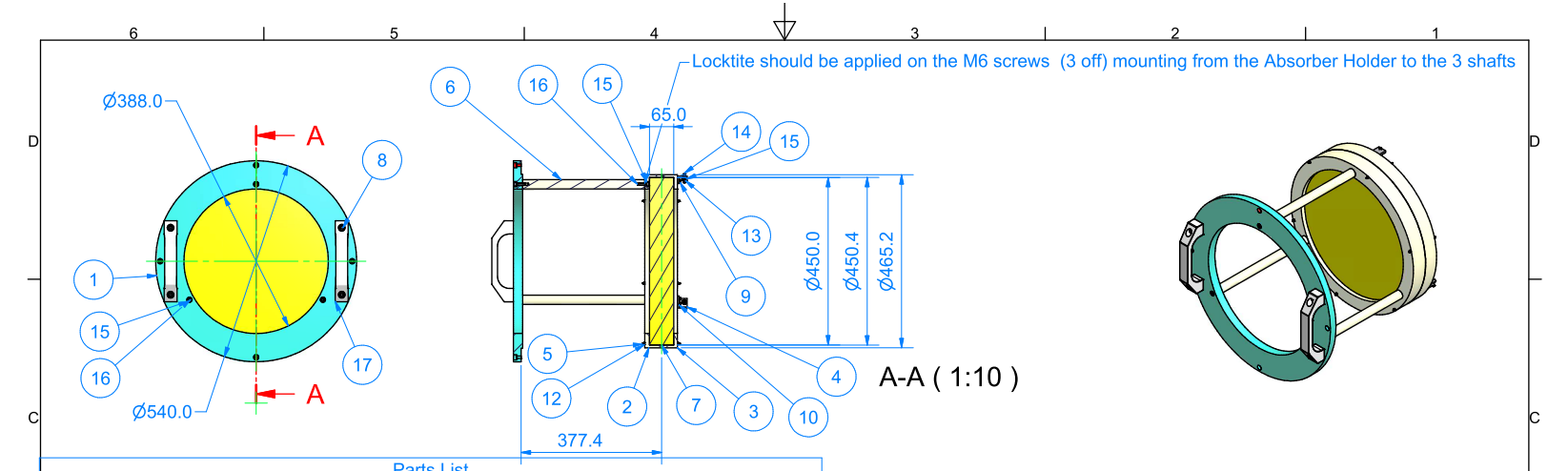
# LiH for Thermal Tests





- Smaller diameter disk, coated.
- Hole in the middle for the heater.
- Smaller holes for thermal probes.
- Will be tested at Fermilab shortly.

# Flat LiH absorber support




Parts List

| ITEM | QTY | PART NUMBER | DRAWING NUMBER | MATERIAL | MASS |
|---|---|---|---|---|---|
| 1 | 1 | Mounting Plate | MICE_FA_PT02_00 | Tufnol | 3.479 kg |
| 2 | 1 | Flat Disc Holder | MICE_FA_PT03_00 | Tufnol | 1.411 kg |
| 3 | 1 | Flat Disc Holder Cover | MICE_FA_PT04_00 | Tufnol | 1.159 kg |
| 4 | 3 | Bracket | MICE_FA_PT05_00 | Stainless Steel | 0.043 kg |
| 5 | 6 | M3 SS stud | MICE_FA_PT06_00 | Stainless Steel | 0.006 kg |
| 6 | 3 | Shaft 1 | MICE_FA_PT07_00 | TUFNOL 10G40 | 0.304 kg |
| 7 | 1 | solidabsorber _ LiH | Provided by FemiLab | LiH | 8.477 kg |
| 8 | 4 | SHC Screw M8 x 40 | Purchase item | Stainless Steel | 0.020 kg |
| 9 | 6 | SHC Screw M4 x 6 | | Steel, Mild | 0.002 kg |
| 10 | 6 | 4 Plain washer | | Stainless Steel | 0.000 kg |
| 11 | 12 | M3 Plain Washer | Purchase item | Stainless Steel | 0.000 kg |
| 12 | 12 | M3 Nut | | Stainless Steel | 0.000 kg |
| 13 | 3 | M6 Nut | Purchase item | Stainless Steel | 0.003 kg |
| 14 | 3 | M6 SS Thrust Screw | Wixroyd 34042.W0276 | SS body Delrin POM | 0.001 kg |
| 15 | 9 | M6 Plain Washer O.D 12 mm | Purchase item | Stainless Steel | 0.001 kg |
| 16 | 6 | SHC Screw M6 x 25 | Purchase item | Stainless Steel | 0.009 kg |
| 17 | 2 | Wixroyd Handle | Wixroyd 79120.W0180-8 | Thermoplastic | 0.212 kg |
| 18 | 4 | SS helicoil M8 x 16 | | | |
| 19 | 6 | SS helicoil M6 x 12 | | | |
| 20 | 6 | SS helicoil M4 x 6 | | | |
| 33 | 8 | M8 washer ISO 7092 | ID 8.4, OD 15 | Stainless Steel | 0.002 kg |
| 34 | 4 | M8 spring lock washer | IS 6735, | Steel, SS | 0.001 kg |

Table for Absorber Material Option

| Absorber material | Density g/cm3 | Absorber thickness | Spacer thickness | Rack weight |
|---|---|---|---|---|
| LiH | 0.82 | 65 mm | 0 | 16.385 kg |
| Be | 1.848 | 34 mm | 15.5 mm | 18.872 kg |
| Poly E | 0.935 | 52 mm | 6.5 mm | 16.047 kg |
| C | 2.265 | 25 mm | 20 mm | 18.152 kg |
| Al | 2.7 | 23 mm | 21 mm | 18.922 kg |
| Ti | 4.54 | 15 mm | 25 mm | 20.12 kg |
| Cu | 8.96 | 8 mm | 28.5 mm | 20.85 kg |

REVISION HISTORY

| REV | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| 1 | Add Washer and spring for the mounting the handle | 21/03/2012 | |

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PROJECT: MICE_Flat Absorber Mounting

TITLE: Flat Absorber Holding Cradle_LiH

GENERAL TOLERANCES:
X ± 0.5
X.X ± 0.1
X.XX ± 0.05
X.XXX ± 0.005
ALL DIMENSIONS ARE IN MM UNLESS OTHERWISE STATED
DO NOT SCALE
3rd ANGLE PROJECTION

IDENTIFICATION NUMBER: MICE_FA_AS02_R1

SCALE: 1:10 | DATE OF ISSUE: 21/03/2012 | MATERIAL:

TECHNICAL REFERENCE:

DOCUMENT TYPE: | NUMBER OFF: 1

CHECKED BY:

DOCUMENT STATUS: | COMPONENT WEIGHT: 16.207 kg

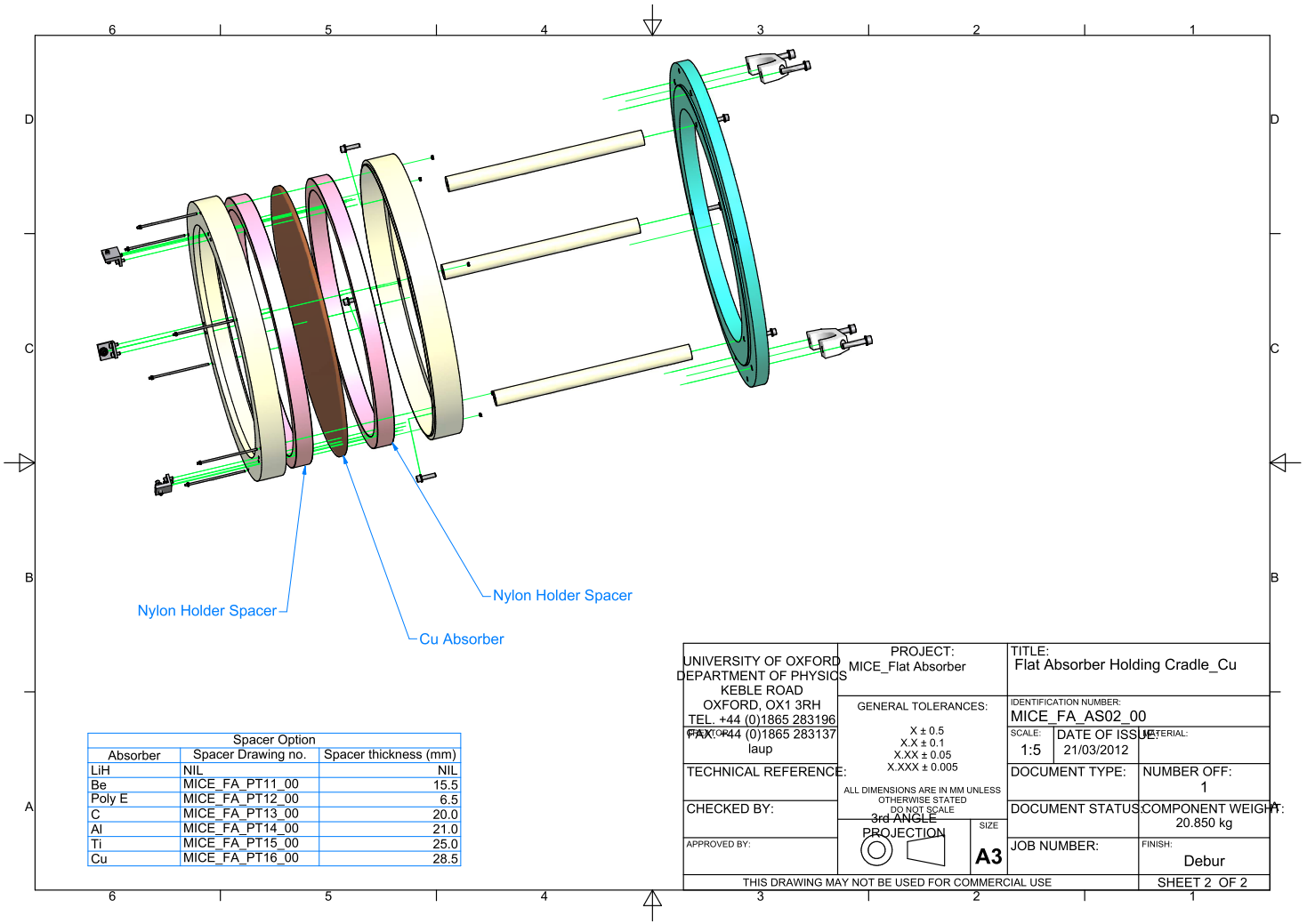
APPROVED BY:

SIZE A3

JOB NUMBER: | FINISH: Debur

THIS DRAWING MAY NOT BE USED FOR COMMERCIAL USE | SHEET 1 OF 2

# Flat absorber support, other materials




| Spacer Option | | |
|---|---|---|
| Absorber | Spacer Drawing no. | Spacer thickness (mm) |
| LiH | NIL | NIL |
| Be | MICE_FA_PT11_00 | 15.5 |
| Poly E | MICE_FA_PT12_00 | 6.5 |
| C | MICE_FA_PT13_00 | 20.0 |
| Al | MICE_FA_PT14_00 | 21.0 |
| Ti | MICE_FA_PT15_00 | 25.0 |
| Cu | MICE_FA_PT16_00 | 28.5 |

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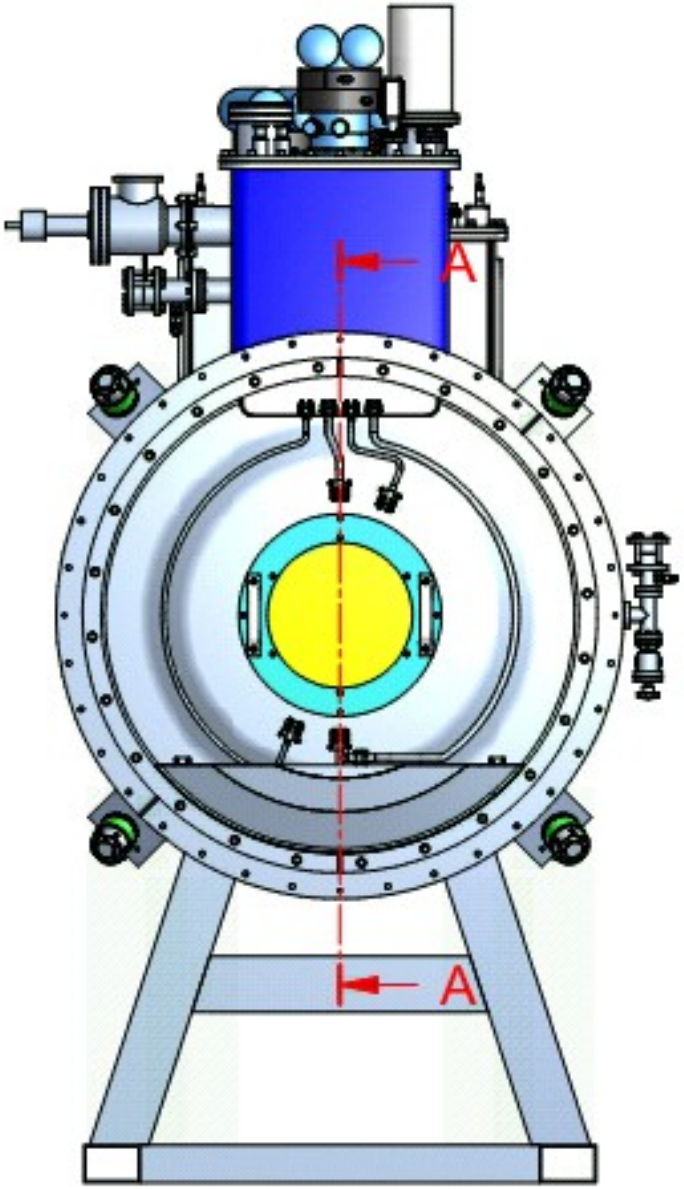
PROJECT: MICE_Flat Absorber

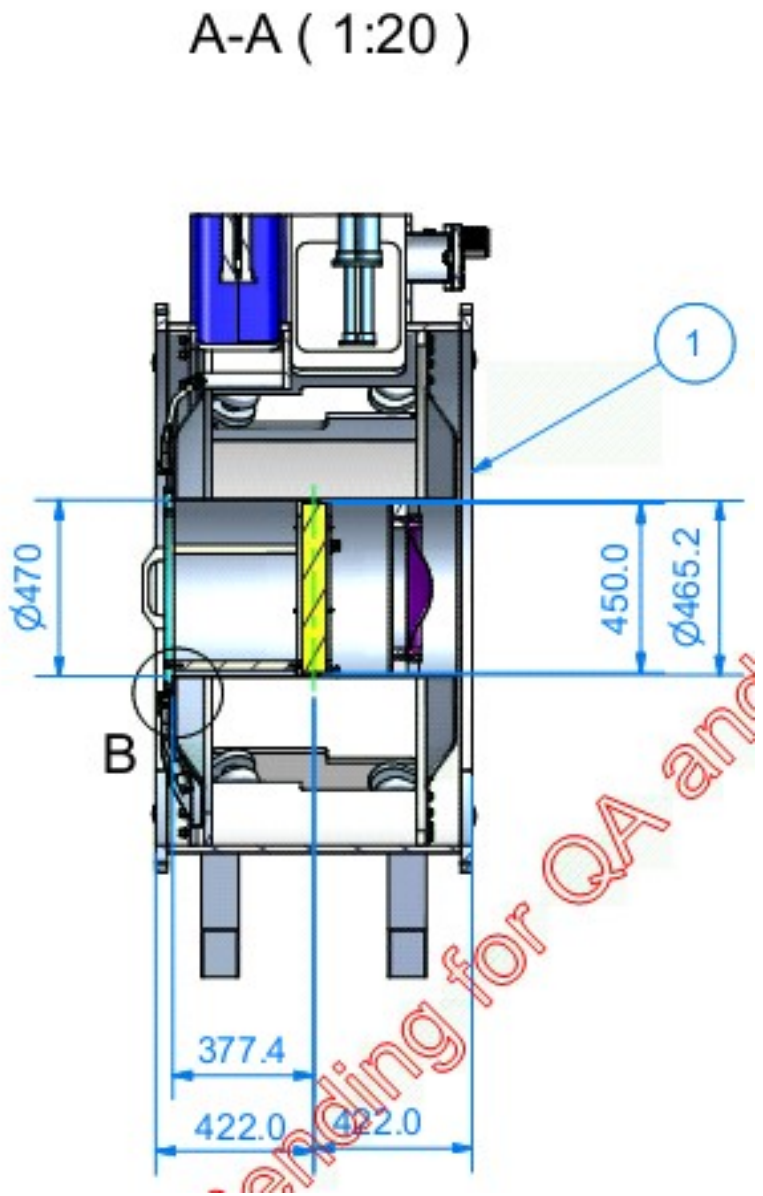
GENERAL TOLERANCES:
X ± 0.5
X.X ± 0.1
X.XX ± 0.05
X.XXX ± 0.005
ALL DIMENSIONS ARE IN MM UNLESS OTHERWISE STATED
DO NOT SCALE
3rd ANGLE PROJECTION

TITLE: Flat Absorber Holding Cradle_Cu
IDENTIFICATION NUMBER: MICE_FA_AS02_00
SCALE: 1:5
DATE OF ISSUE: 21/03/2012
MATERIAL:
DOCUMENT TYPE:
NUMBER OFF: 1
DOCUMENT STATUS:
COMPONENT WEIGHT: 20.850 kg
SIZE: A3
JOB NUMBER:
FINISH: Debur
TECHNICAL REFERENCE:
CHECKED BY:
APPROVED BY:
THIS DRAWING MAY NOT BE USED FOR COMMERCIAL USE
SHEET 2 OF 2

- Other materials allow to look at different equilibrium emittances.

# Flat LiH absorber mounting



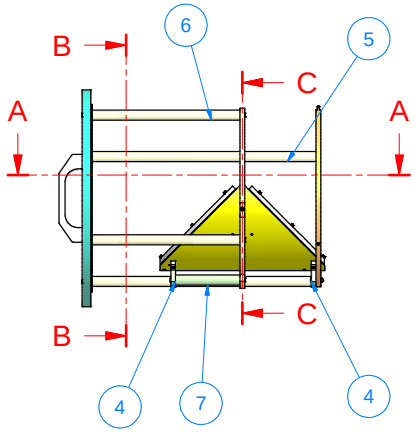



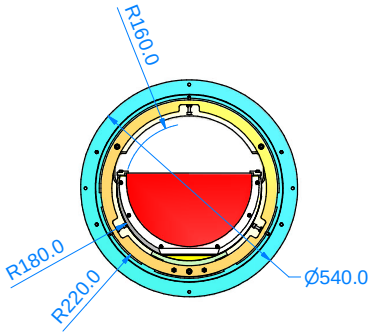
# Comments on the drawings

- The weight of the rack with the absorber is around 16-18 kg (depending on the material).
- Absorber support outer radius is 465.2 mm, AFC bore inner radius is 470.0 mm, clearance is limited.
- Handles are helping, but we will need some overhead support to move the absorber in and out.
- Other materials will be used for thorough equilibrium emittance formula testing, hence the spacers for Al, PE, etc.
- Handles are removable to avoid interference between the SS and AFC modules.

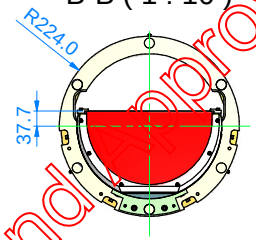
# Wedge absorber support

# 90 Degree Wedge Absorber Support

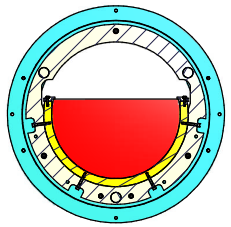


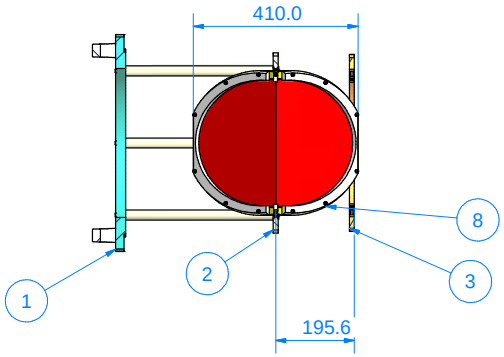

B-B ( 1 : 10 )




C-C ( 1 : 10 )



A-A ( 1 : 10 )




Parts List

| ITEM | QTY | PART NUMBER | DRAWING NUMBER | MATERIAL | Weight |
|---|---|---|---|---|---|
| 1 | 1 | Mounting Plate | MICE_WA_PT02_00 | Tufnol | 3.480 kg |
| 2 | 1 | Center Plate | MICE_WA_PT03_00 | Tufnol | 0.806 kg |
| 3 | 1 | End Plate | MICE_WA_PT04_00 | Tufnol | 0.544 kg |
| 4 | 2 | Absorber Support1 | MICE_WA_PT05_00 | Tufnol | 0.093 kg |
| 5 | 3 | Shaft1 | MICE_WA_PT06_00 | Tufnol 10G40 | 0.376 kg |
| 6 | 3 | Shaft2 | MICE_WA_PT07_00 | Tufnol 10G40 | 0.248 kg |
| 7 | 2 | Shaft3 | MICE_WA_PT08_00 | Tufnol 10G40 | 0.107 kg |
| 8 | 1 | Wedge Absorber Holder Assembly | MICE_WA_SA05_00 | | 11.508 kg |
| 9 | 10 | SHC screw M6 x 16 | Purchase item | Stainless Steel | 0.007 kg |
| 10 | 8 | SHC screw M6 x 25 | Purchase item | Stainless Steel | 0.009 kg |
| 12 | 22 | Washer- M6 | Purchase item | Stainless Steel | 0.001 kg |
| 13 | 4 | SHC screw M8 x 40 | Purchase item | Stainless Steel | 0.023 kg |
| 16 | 5 | Nut M6 | Purchase item | Stainless Steel | 0.002 kg |
| 17 | 3 | Thrust Screw - M6 | Wixroyd 3402W756 | Stainless Steel | 0.001 kg |
| 18 | 2 | Wixroyd Handle | Wixroyd 7912.W180-8 | Plastic | 0.217 kg |
| 21 | 8 | SHC Screw M5 x 30 | | Stainless Steel | 0.007 kg |
| 22 | 8 | Washer M5 | | Stainless Steel | 0.000 kg |



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CREATOR: laup

TECHNICAL REFERENCE:

CHECKED BY:

APPROVED BY:

PROJECT: MICE_Wedge Absorber

GENERAL TOLERANCES:
X ± 0.5
X.X ± 0.1
X.XX ± 0.05
X.XXX ± 0.005

ALL DIMENSIONS ARE IN MM UNLESS OTHERWISE STATED
DO NOT SCALE

3rd ANGLE PROJECTION

SIZE: A3

TITLE: Wedge Absorber Holding Cradle

IDENTIFICATION NUMBER: MICE_WA_SA03_00

SCALE: 1:10

DATE OF ISSUE: 03/08/2011

MATERIAL:

DOCUMENT TYPE:

NUMBER OFF: 1

DOCUMENT STATUS:

COMPONENT WEIGHT: 19.355 kg

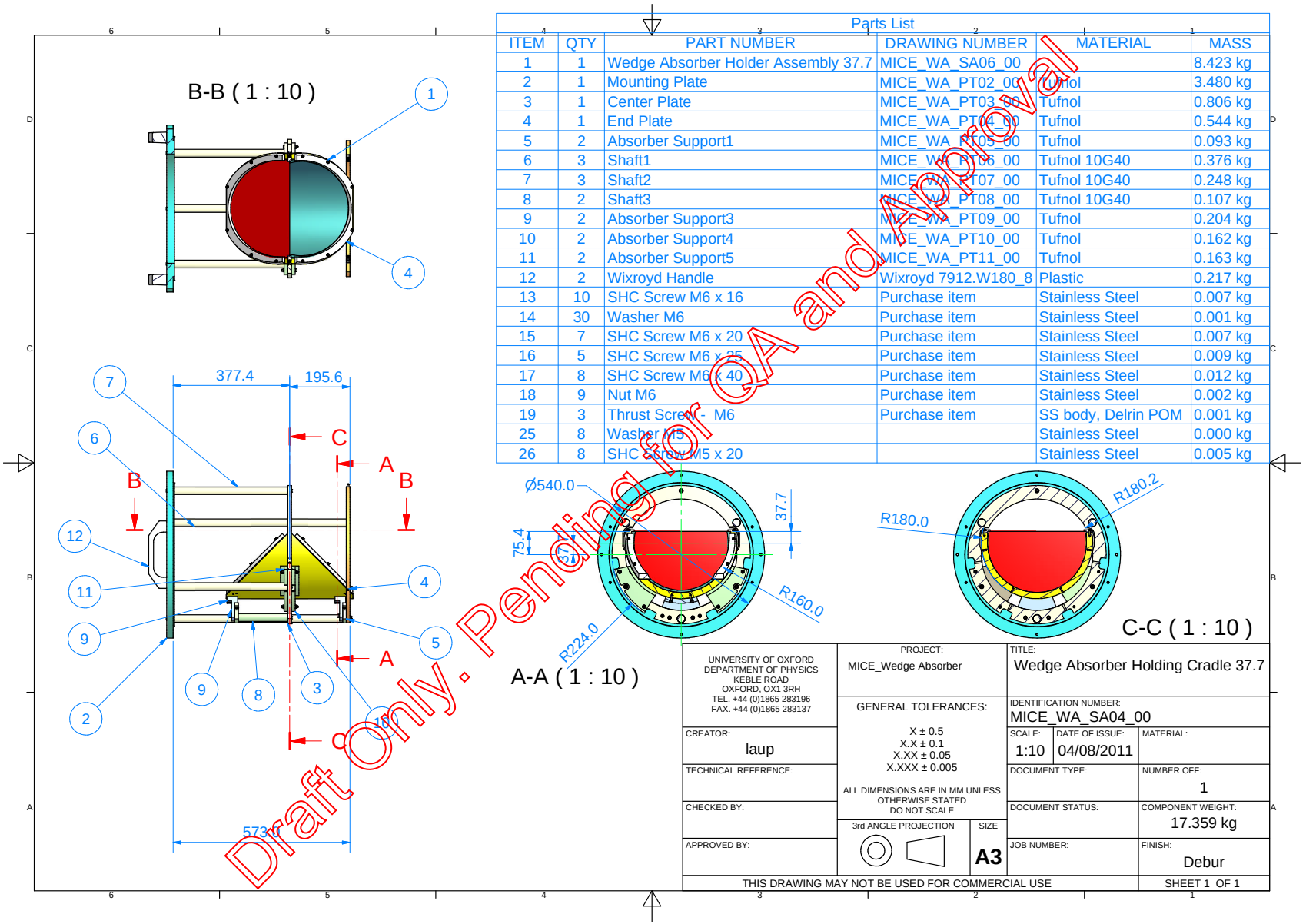
JOB NUMBER:

FINISH: Debur



SHEET 1 OF 1

# 45 Degree Wedge Absorber Support




Parts List

| ITEM | QTY | PART NUMBER | DRAWING NUMBER | MATERIAL | MASS |
|---|---|---|---|---|---|
| 1 | 1 | Wedge Absorber Holder Assembly 37.7 | MICE_WA_SA06_00 | | 8.423 kg |
| 2 | 1 | Mounting Plate | MICE_WA_PT02_00 | Tufnol | 3.480 kg |
| 3 | 1 | Center Plate | MICE_WA_PT03_00 | Tufnol | 0.806 kg |
| 4 | 1 | End Plate | MICE_WA_PT04_00 | Tufnol | 0.544 kg |
| 5 | 2 | Absorber Support1 | MICE_WA_PT05_00 | Tufnol | 0.093 kg |
| 6 | 3 | Shaft1 | MICE_WA_PT06_00 | Tufnol 10G40 | 0.376 kg |
| 7 | 3 | Shaft2 | MICE_WA_PT07_00 | Tufnol 10G40 | 0.248 kg |
| 8 | 2 | Shaft3 | MICE_WA_PT08_00 | Tufnol 10G40 | 0.107 kg |
| 9 | 2 | Absorber Support3 | MICE_WA_PT09_00 | Tufnol | 0.204 kg |
| 10 | 2 | Absorber Support4 | MICE_WA_PT10_00 | Tufnol | 0.162 kg |
| 11 | 2 | Absorber Support5 | MICE_WA_PT11_00 | Tufnol | 0.163 kg |
| 12 | 2 | Wixroyd Handle | Wixroyd 7912.W180_8 | Plastic | 0.217 kg |
| 13 | 10 | SHC Screw M6 x 16 | Purchase item | Stainless Steel | 0.007 kg |
| 14 | 30 | Washer M6 | Purchase item | Stainless Steel | 0.001 kg |
| 15 | 7 | SHC Screw M6 x 20 | Purchase item | Stainless Steel | 0.007 kg |
| 16 | 5 | SHC Screw M6 x 25 | Purchase item | Stainless Steel | 0.009 kg |
| 17 | 8 | SHC Screw M6 x 40 | Purchase item | Stainless Steel | 0.012 kg |
| 18 | 9 | Nut M6 | Purchase item | Stainless Steel | 0.002 kg |
| 19 | 3 | Thrust Screw - M6 | Purchase item | SS body, Delrin POM | 0.001 kg |
| 25 | 8 | Washer M5 | | Stainless Steel | 0.000 kg |
| 26 | 8 | SHC Screw M5 x 20 | | Stainless Steel | 0.005 kg |

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CREATOR: laup

TECHNICAL REFERENCE:

CHECKED BY:

APPROVED BY:

PROJECT: MICE_Wedge Absorber

GENERAL TOLERANCES:
X ± 0.5
X.X ± 0.1
X.XX ± 0.05
X.XXX ± 0.005
ALL DIMENSIONS ARE IN MM UNLESS OTHERWISE STATED
DO NOT SCALE

3rd ANGLE PROJECTION

SIZE: A3

TITLE: Wedge Absorber Holding Cradle 37.7

IDENTIFICATION NUMBER: MICE_WA_SA04_00

SCALE: 1:10 | DATE OF ISSUE: 04/08/2011 | MATERIAL:

DOCUMENT TYPE: | NUMBER OFF: 1

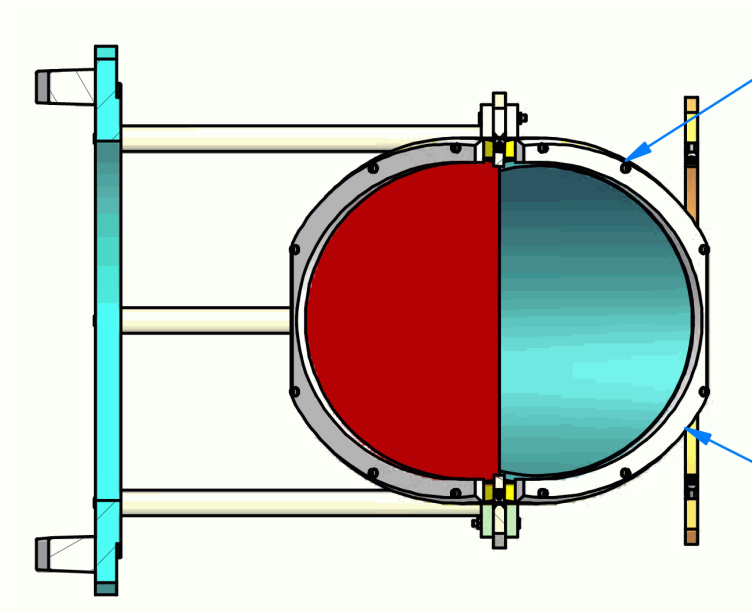
DOCUMENT STATUS: | COMPONENT WEIGHT: 17.359 kg

JOB NUMBER: | FINISH: Debur

THIS DRAWING MAY NOT BE USED FOR COMMERCIAL USE

SHEET 1 OF 1

# Comments on the drawings



- Same basic design as for the flat absorber, more rods and extra ring to enforce the construction (due to non-symmetry).
- The primary orientation of the wedge will be ”on its side” (so that the figure above is a side view).
- In the 45-degree half-wedge arrangement there is a thin spacer holding the wedge in place (blue piece in the figure above).

# Step IV run plan

# Aims of Step IV

$$\frac{d\varepsilon_n}{dz} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle \frac{dE}{dX} \right\rangle + \frac{\beta_t \left(0.014\ \text{GeV}\right)^2}{2\beta^3 E m_\mu X_0}$$

- Demonstrate ionization cooling with materials typical of the cooling channels under consideration (liquid Hydrogen, LiH).
- Wedge absorbers: demonstrate longitudinal emittance reduction.
- Verify the cooling formula for various materials, beam parameters, optics settings.
- Develop and thoroughly test simulation and analysis tools.

# Before we start

- No material in the cooling channel (one dedicated ISIS run, presumably Feb 2013).
- Check/understand magnet performance: ramp coils individually, compare data with simulation.
- Check/understand the lattice: set the cooling channel parameters to the baseline $\varepsilon = 6\pi$ mm·rad, $p = 200$ MeV/c, run large emittance beam, scan beam momentum from 170 to 230 MeV/c.
- Repeat test with a different $\beta$ function setting (time-permitting).
- Look at different reference momenta settings (240, 200, 140 MeV/c), emittance settings (10, 6, 3 $\pi$ mm·rad), $\beta$ function settings (42, 25, 15, 7 cm) magnetic configuration (flip, non-flip).

# Step IV configurations

A (rather long) table of various configurations we may want to consider:

| Parameters | | | | Step IV Configurations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Field flip | Beta [cm] | Momentum [MeV/c] | Emittance [mm rad] | Empty channel | Liquid Hydrogen | LiH disk | Al disk | PE disk | LiH 90° wedge | LiH 45° wedge |
| Yes | 42 | 240 | 10 | | + | + | + | | + | + |
| Yes | 42 | 240 | 6 | + | + | + | + | + | + | + |
| Yes | 42 | 240 | 3 | | + | + | | + | + | + |
| Yes | 42 | 200 | 10 | + | + | + | + | | + | + |
| Yes | 42 | 200 | 6 | + | + | + | + | + | + | + |
| Yes | 42 | 200 | 3 | + | + | + | | + | + | + |
| … | … | … | … | … | … | … | … | … | … | … |
| No | 7 | 240 | 10 | | + | + | | | | |
| No | 7 | 240 | 6 | + | + | + | | | | |
| No | 7 | 240 | 3 | | + | + | | | | |
| No | 7 | 200 | 10 | | + | + | | | | |
| No | 7 | 200 | 6 | + | + | + | | | | |
| No | 7 | 200 | 3 | | + | + | | | | |
| | | | | 14 | 36 | 36 | 9 | 9 | 24 | 24 |
| | | | | | | | | | Total: | 152 |

# Basic operation times

| | |
|---|---|
| Change flip/non-flip magnet configuration<br>(run down magnets, swap cables, check, run up) | $\sim$1 day |
| Change momentum and $\beta$ of the cooling channel<br>(retune focusing coils, matching coils, possibly SS) | $\sim$0.5 day |
| Change beam momentum and emittance<br>(magnet retuning, change diffuser setting) | $\sim$1 hr |
| Collect 100k of useful muons | $\sim$2 hrs |
| Replace one absorber with another | $\sim$8 days |
| All empty channel configurations (14)<br>All LH2 (or flat LiH) absorber configurations (36)<br>Additional flat absorbers (Al, PE) (9+9+absorber change)<br>All 90° (or 45°) wedge absorber configurations (24) | $\sim$11 days<br>$\sim$18 days<br>$\sim$16 days<br>$\sim$12 days |

Table: Basic operation time estimate

# Step IV configurations (contd.)

- 152 configurations/settings, further refinement is required.
- One way to reduce the number of configurations is to use a global online reconstruction tool (under development now) that allows to do some preliminary analysis in real-time and reject some configurations based on that analysis.
- Hardware configurations vs ISIS runs (dates are preliminary):
  - Empty channel (Feb 2013);
  - Liquid Hydrogen absorber (May 2013);
  - Flat solid absorbers, LiH and other materials (July 2013);
  - Wedge absorbers, 90° and 45° LiH (October 2013);
  - One more ISIS run may be available in Step IV configuration (November 2013).

# Summary

- LiH flat absorber is complete, LiH wedge is underway.
- Final versions of the engineering drawings for flat absorbers were approved, sent to Fermilab, now at the machine shop for a quote.
- Final versions of the drawings for the wedge absorber have not been approved yet, we will have a meeting on that next week.
- Procedures to send the absorbers to RAL are under discussion.
- Detailed Step IV run plan is being discussed and updated (next iteration = upcoming MICE collaboration meeting in Glasgow).
- Step IV measurements will take 4 to 5 ISIS run periods (2013).