FROM RESEARCH TO INDUSTRY

MAGNETIC FIELD MANAGEMENT IN CRYOMODULES AND VERTICAL CRYOSTATS AT CEA-SACLAY

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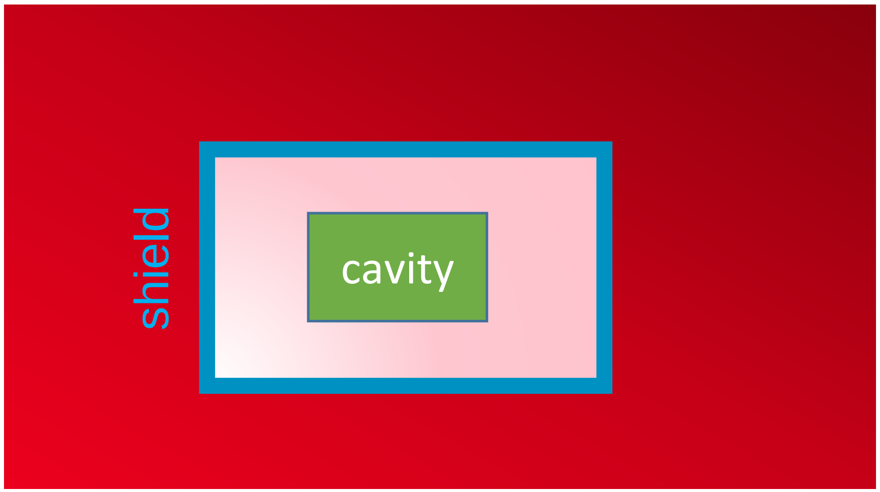
on behalf of CEA team

TTC/ARIES Topical workshop on flux trapping and magnetic shielding
8-9 November 2018 @ CERN

www.cea.fr

MAGNETIC FIELD MANAGEMENT

Define a magnetic field maximal value allowed closed to cavity : ***Bmax***

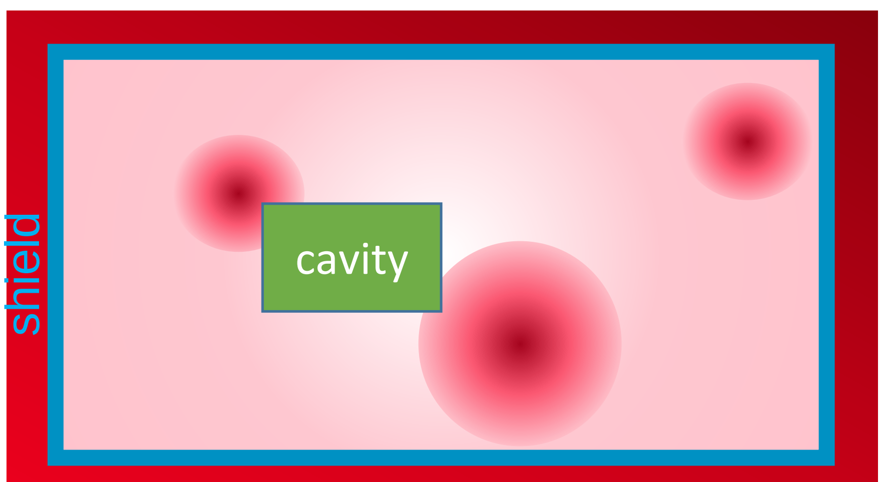


Evaluate the surrounding magnetic field ***Bout***

Provide magnetic shield with appropriate shield efficiency $S > \left|\frac{Bout}{Bmax}\right|$

Shield efficiency is determined by:

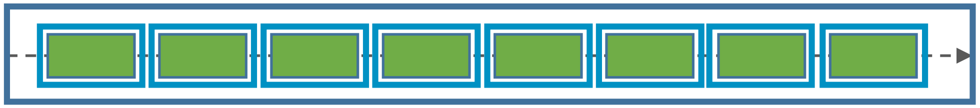
- Shield geometry
- Shield thickness
- Material permeability



Proscribe presence of magnetized elements close to the cavity

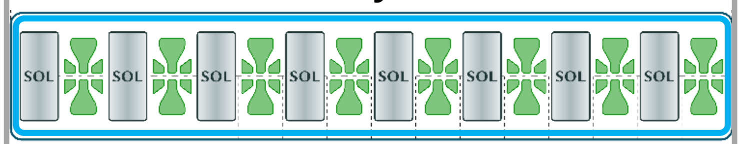
MAGNETIC SHIELDING FOR CRYOMODULES AND TEST CRYOSTATS AT CEA

ESS medium and high beta cryomodule

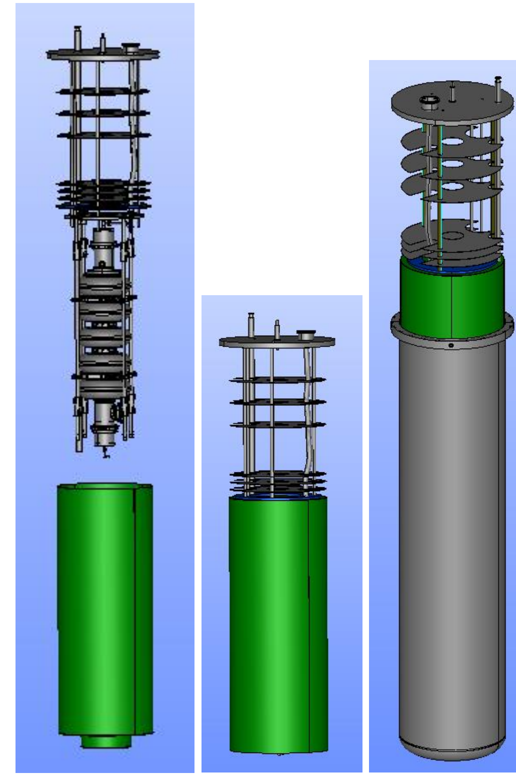


Design values:
Bint<2μT
achieved

IFMIF cryomodule



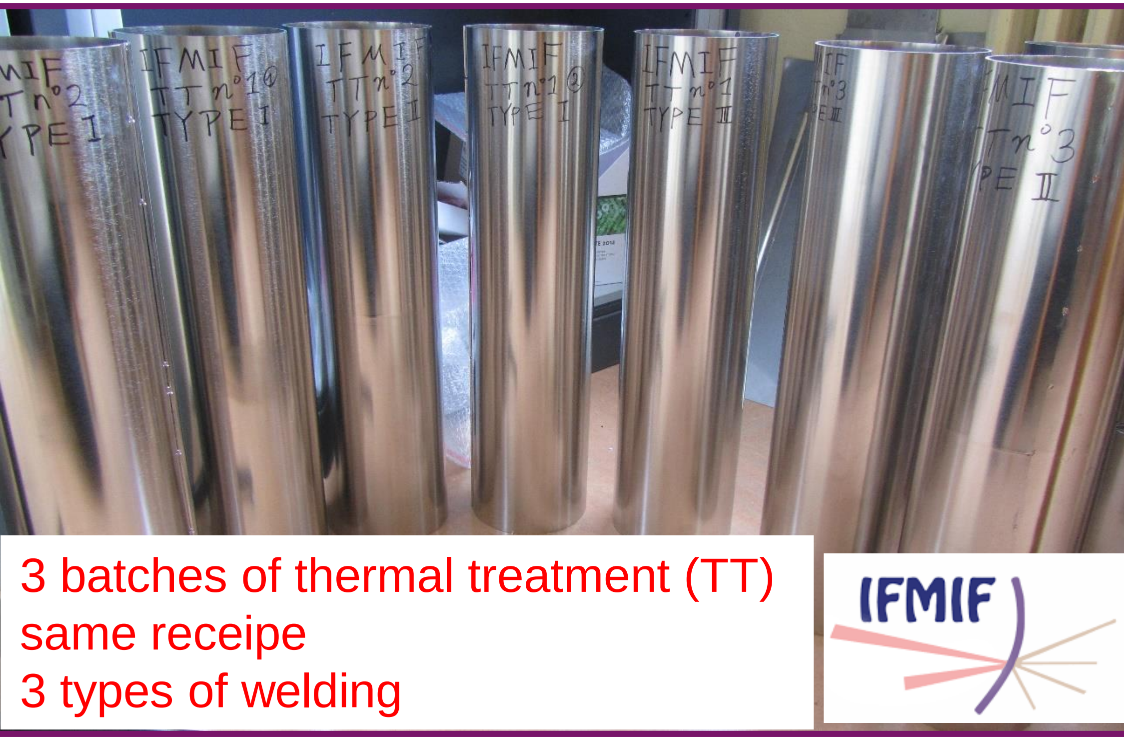
Horizontal test cryostat SATHORI



Vertical test cryostat

Under fabrication
Design value :
Bint<1μT

SAMPLES FOR MAGNETIC SHIELD QUALIFICATION



3 batches of thermal treatment (TT)
same receipe
3 types of welding

IFMIF

1 batch of thermal treatment (TT)
3 types of welding

ess

mumetal

aperam

MECA MAGNETIC

cryophy®

Diameter : D=155 mm
Length 600 mm
Thickness : e = 2 mm

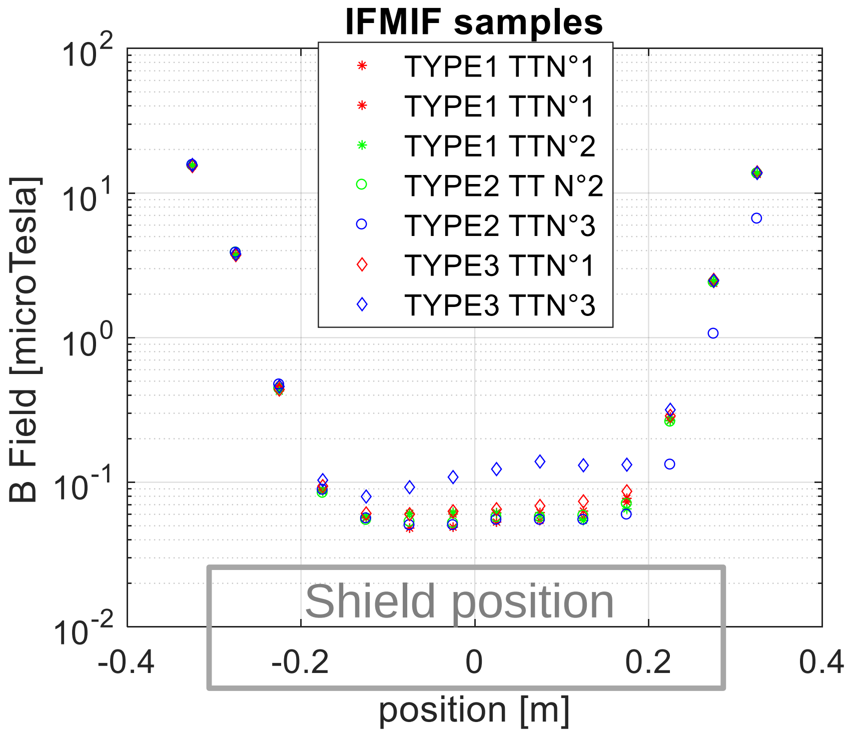
$$\left|\frac{Bout}{Bin}\right|_{trans} = \frac{\mu_r . e}{D}$$

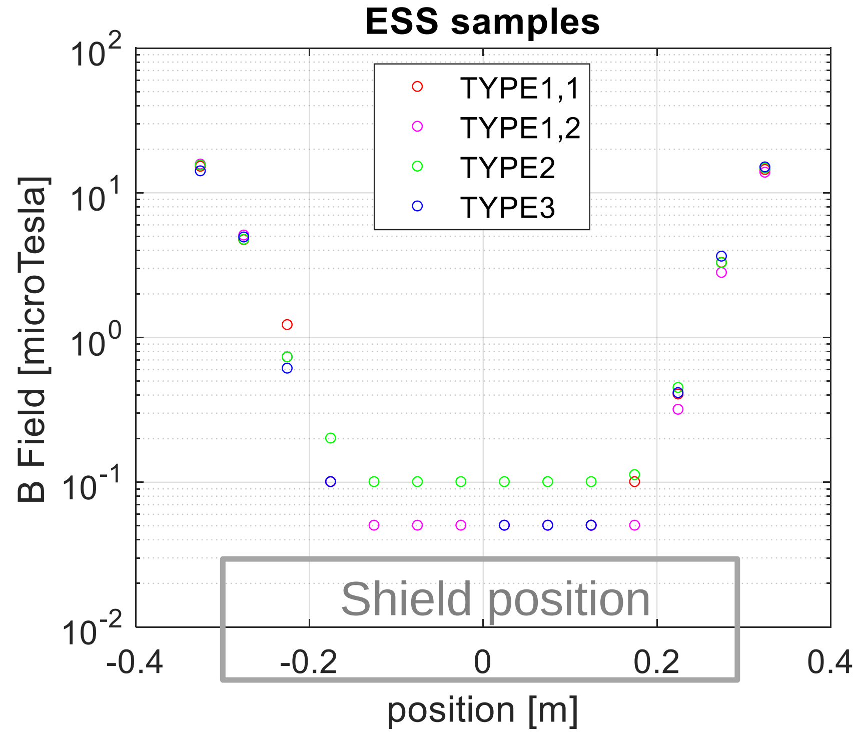

TYPE I
longitudinal
spot welding


TYPE II
radial full
welding


TYPE III
longitudinal
full welding

CYLINDRICAL SAMPLES IN AMBIENT FIELD AT RT ⇨ EFFECT OF TT AND WELDING TYPE



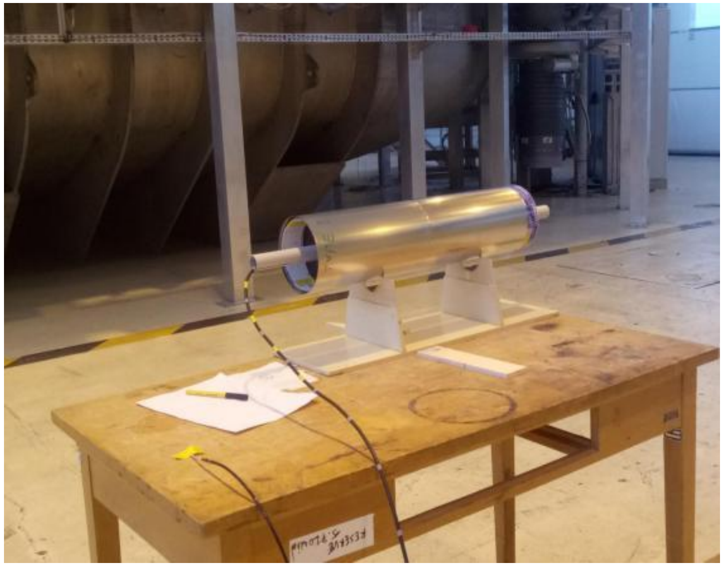


No effect of thermal treatment batch for IFMIF (was expected..)
No effect of welding type.

⇨in particular, no enhancement of the B field in the full radial welding region

TYPE II
radial full welding

MAGNETIC SHIELD CARACTERISATION IN VARIABLE FIELD : SETUP



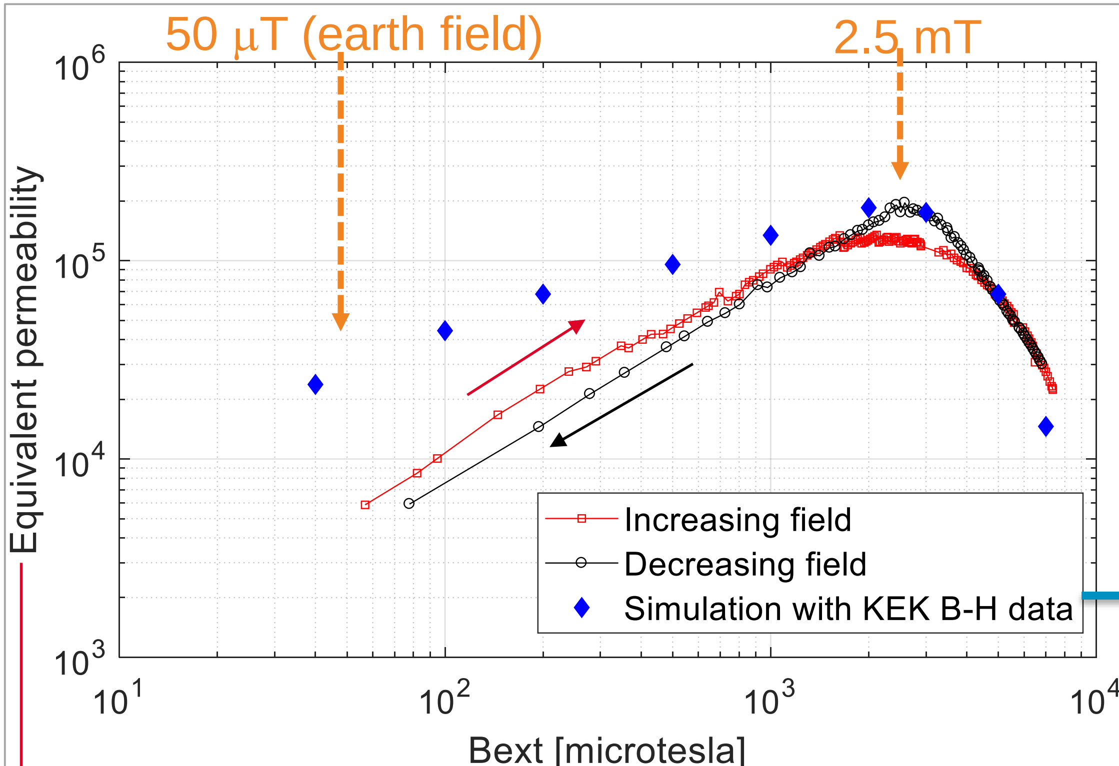
Experiments during JT60SA tests
⇨ Toroidal coil for fusion tested in Saclay cryostat.

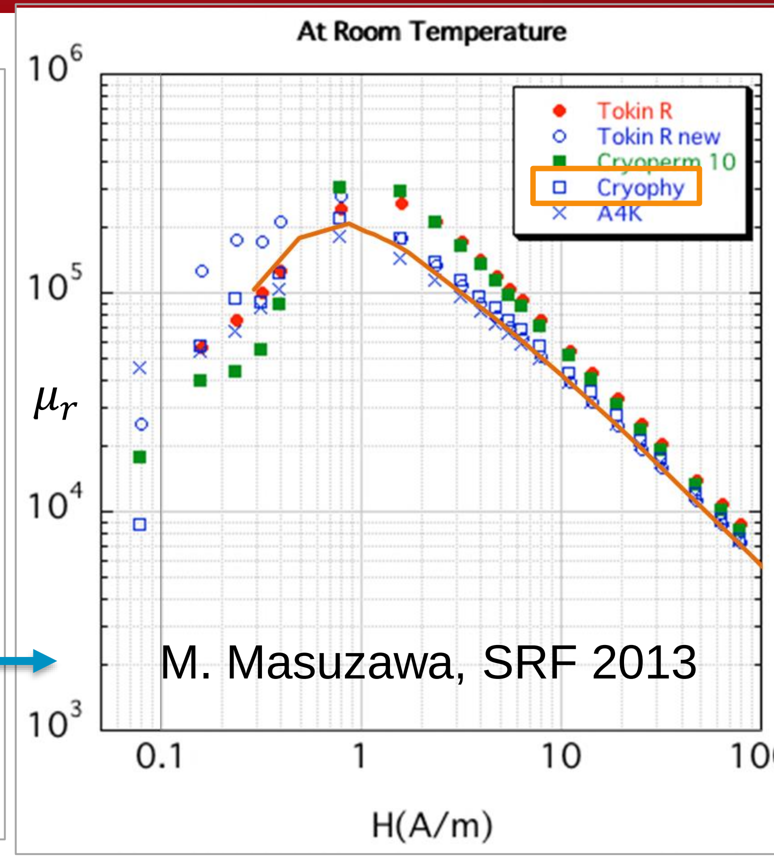
Current goes from up to 27,5 kA
Magnetic field goes to 2.7 T

In this area, B goes up to 7.5 mT, transverse to shield and ~homogen

We measured field inside/outside the shield

MAGNETIC SHIELD CARACTERISATION IN VARIABLE FIELD : RESULTS





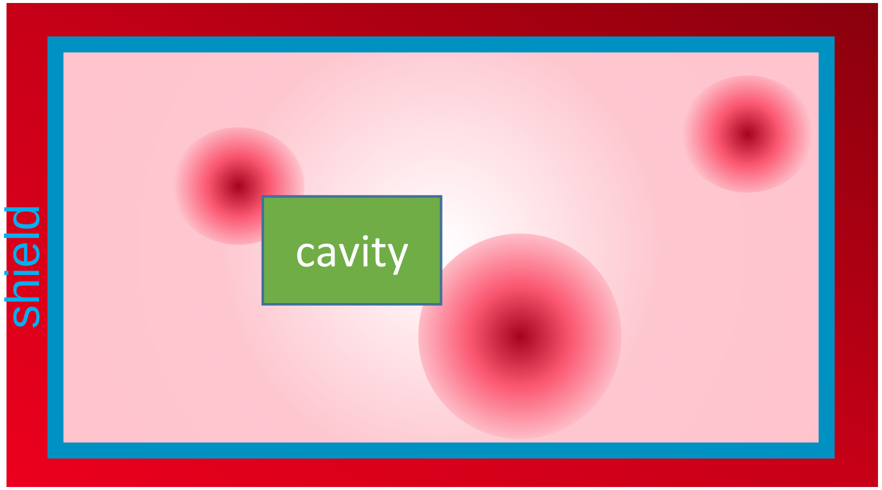
$$\mu_{r,eq} = \left|\frac{Bout}{Bin}\right|_{trans} \frac{D}{e}$$

Hysteresis effect observed

Note that field inside the shield is the same before/after experiment

⇨ **the shield has not been magnetized**

MAGNETIC FIELD MANAGEMENT



Proscribe presence of magnetized elements close to the cavity

- Parts already magnetized
- Parts that could be magnetized by the solenoid

Supports, flanges, … in stainless steel
Invar rods
…

Q: how far must be a given element from the cavity?
A: far enough so radiated magnetic field that is lower than minimum value allowed on cavity
But… how can this be predicted from element properties ?
And in particular: how can this be predicted from **raw material** properties?

MAGNETIZATION OF METALLIC ELEMENTS

3 stainless steel supports
1 invar bar

All parts have been characterized before/after

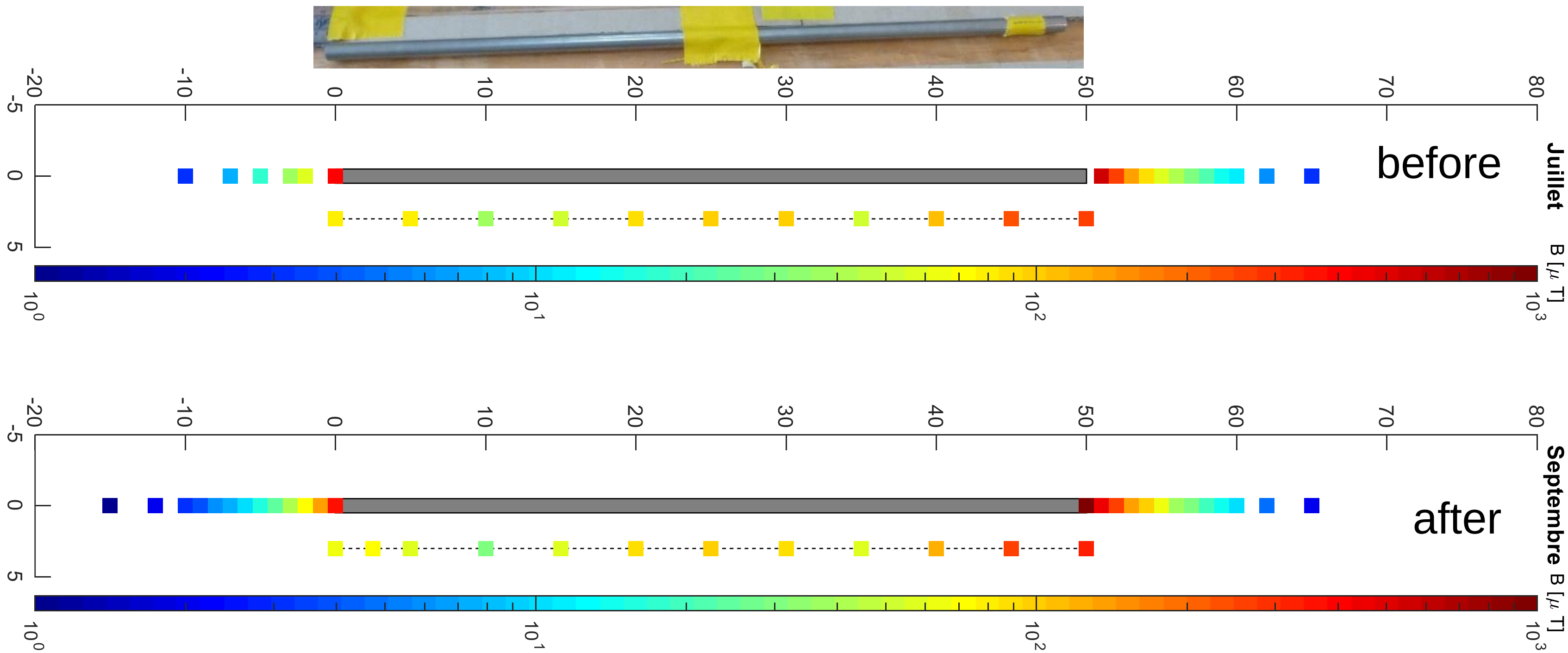
- Stainless steel supports : μ_r , surrounding field
- Invar bar : surrounding field

Experiments during JT60SA tests

External field at parts position: ~ 14 mT

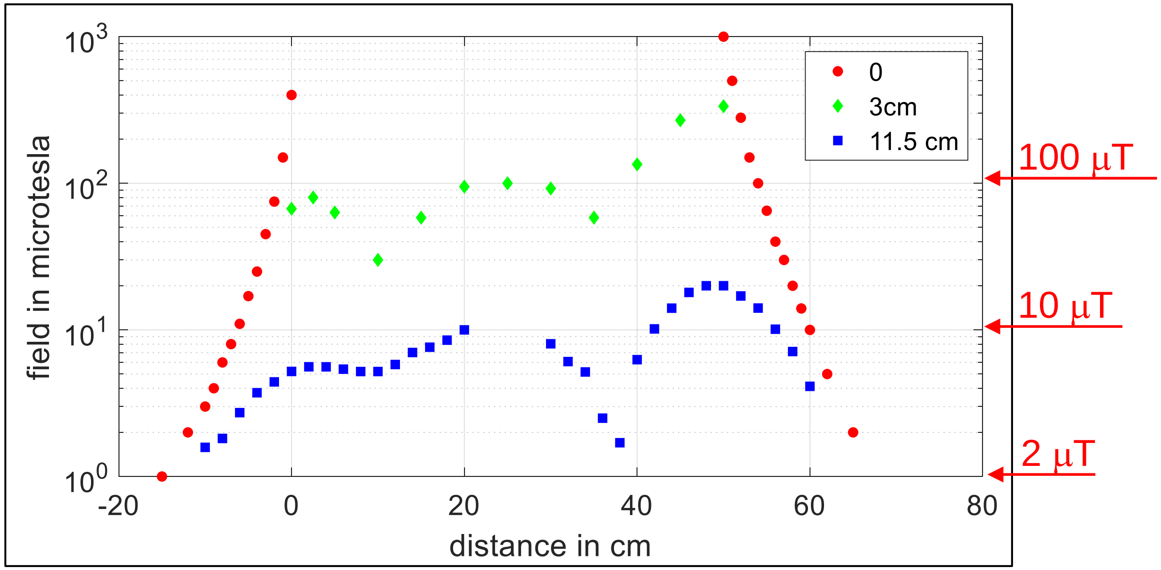
INVAR BAR MAGNETIZATION

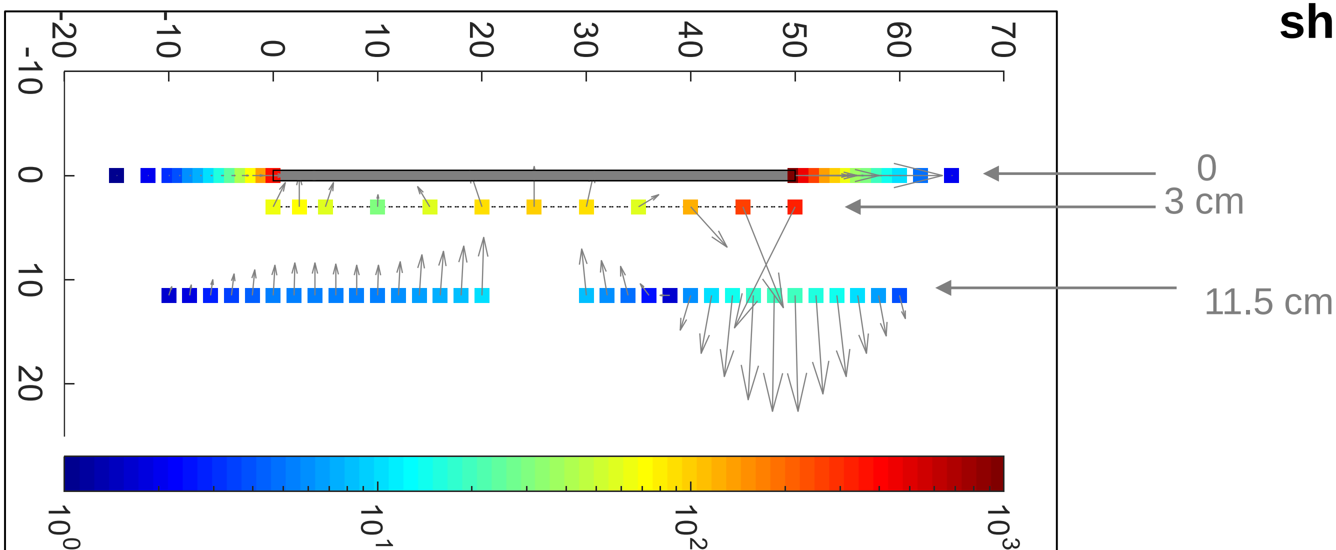
Invar bar has been exposed to a transverse field of 14 mT



No significant difference

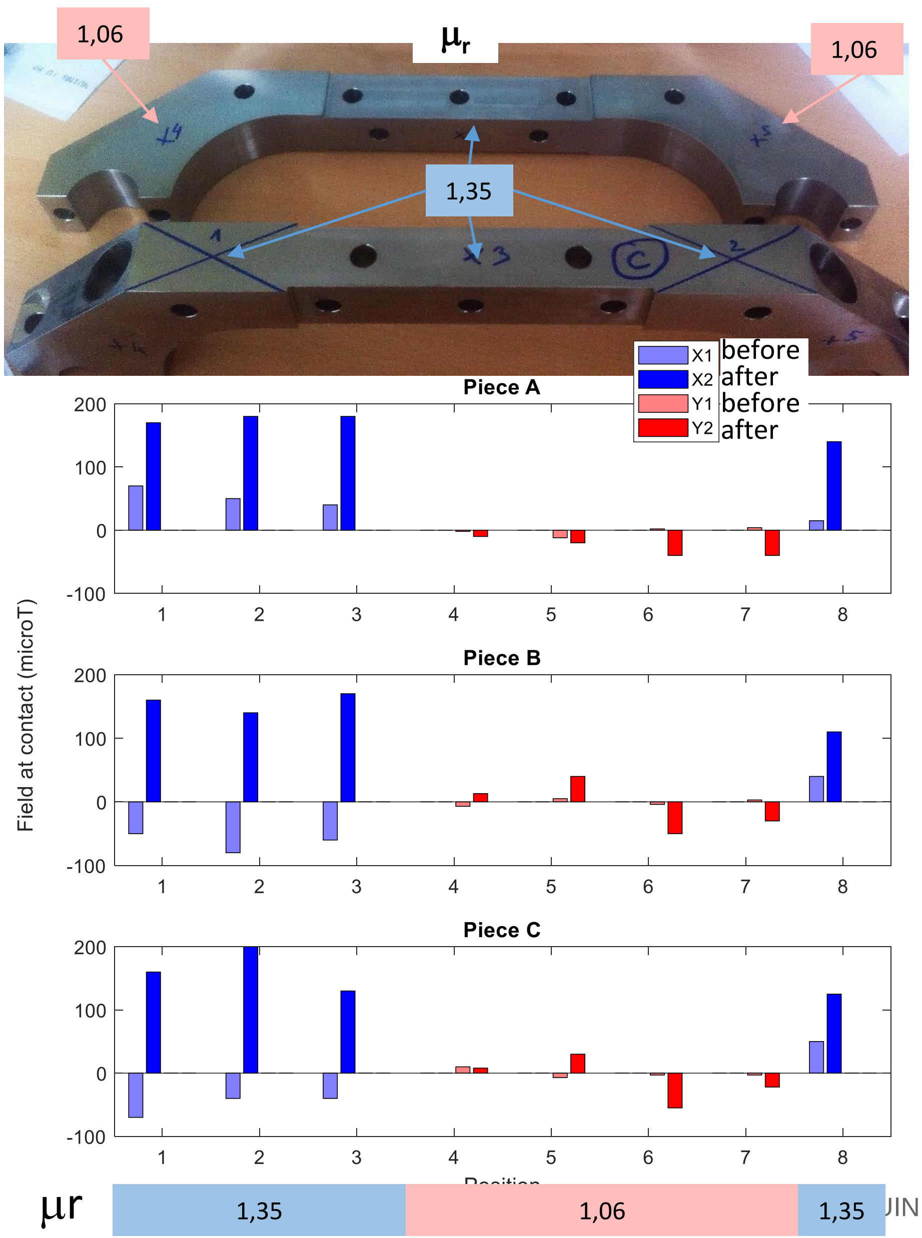
FIELD AROUND INVAR BAR

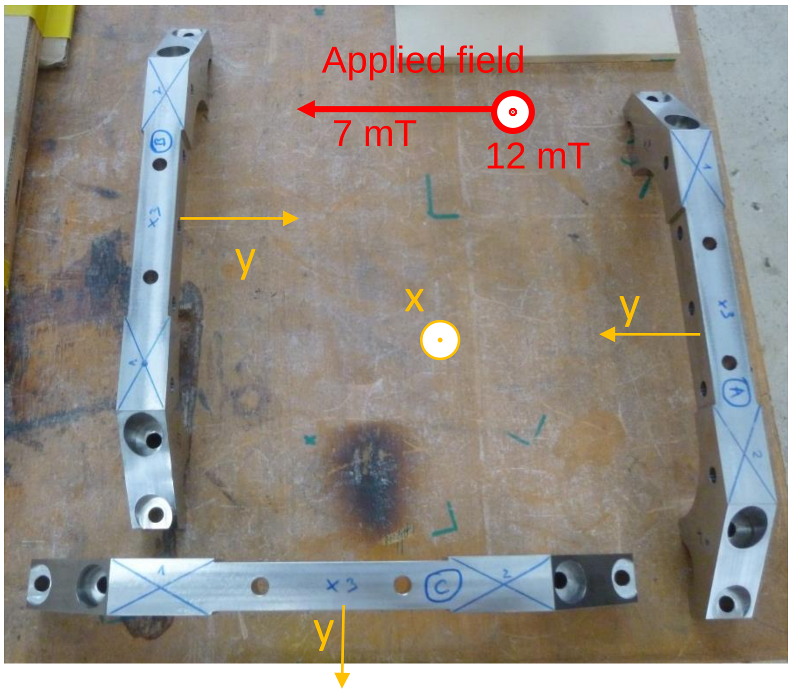




At 11.5 cm from the bar, B field goes up to 20 µT…
Obviously, invar bar is the dangerous element, and has to be shielded

STAINLESS STEEL SUPPORTS MAGNETIZATION



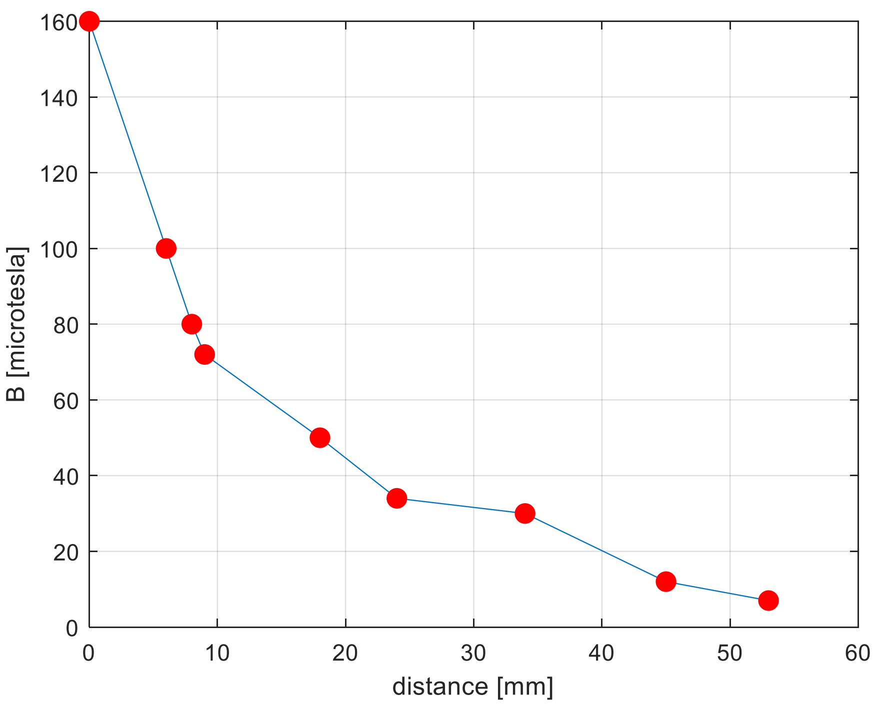


Conclusions:

For areas with μ_r = 1,35 : clear vertical magnetization : ≃200µT at contact.

For areas with μ_r = 1.06 : magnetization has been modified but no clear effect of the applied field effect.

FIELD AROUND MAGNETIZED SS SUPPORT

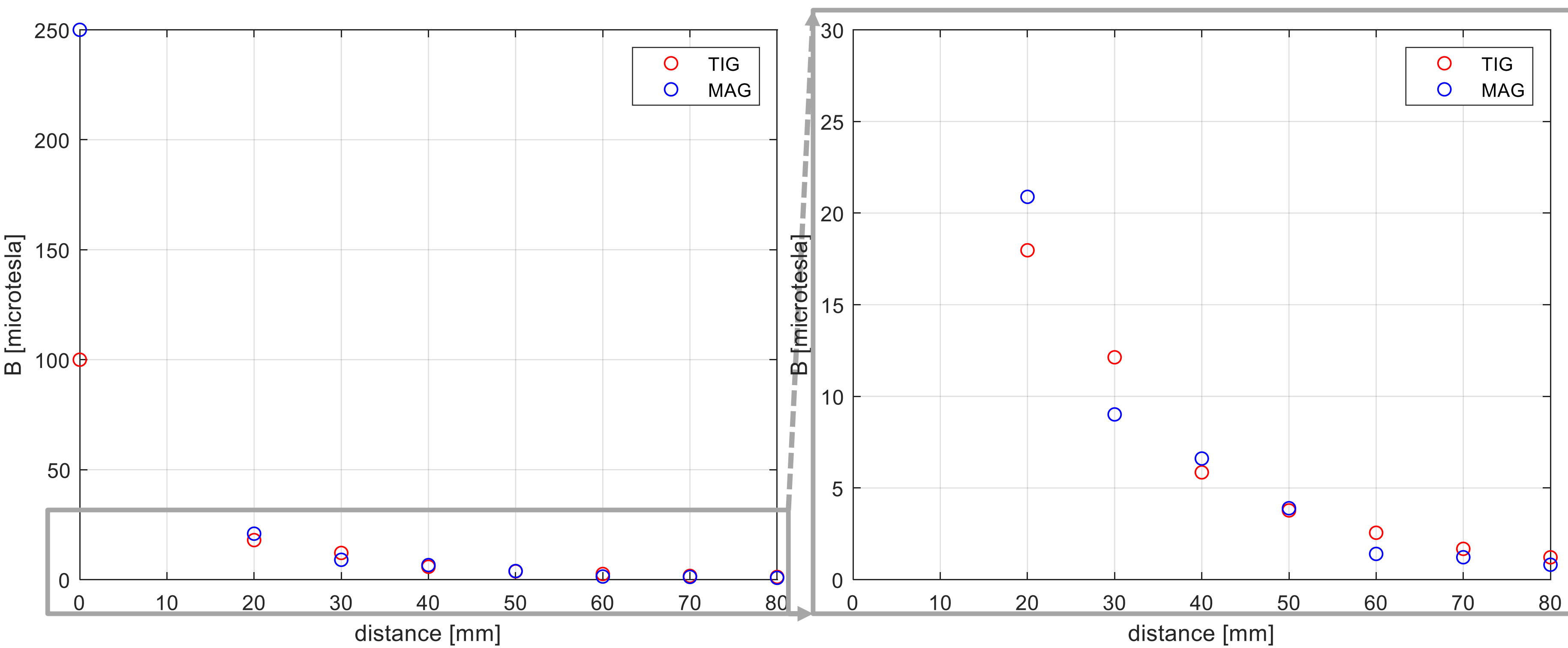


Field becomes lower than 5 μT after 50 mm

FIELD AROUND WELDED SS SHEETS

304 LN sheets from OutokumpU
welding rod in SS
μ_r between 1.5 and 2 on welding

Measured without extra magnetization



MAGNETIC PROPERTIES DEGRADATION

Stainless steel sheets or blocks
Permeability between 1-1.05
No magnetic field

welding → / machining → / cold working →

Permeability increased above 1.5
Magnetic field generation

All austenitic stainless steels are paramagnetic (nonmagnetic) in the fully austenitic condition as occurs in well-annealed alloys.

The permeability increases with cold work due to deformation-induced martensite, a ferromagnetic phase.

The susceptibility of a particular grade to becoming ferromagnetic when heavily cold worked depends on the stability of the austenite, which, in turn, depends on chemical composition and homogeneity.

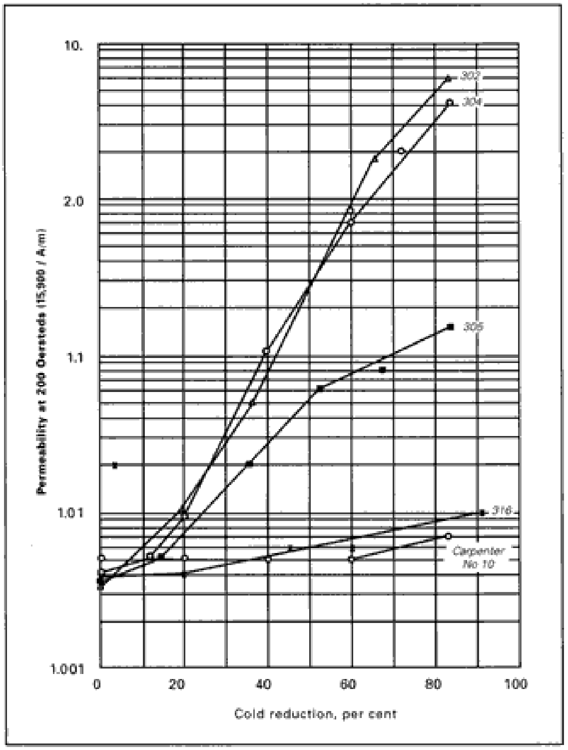
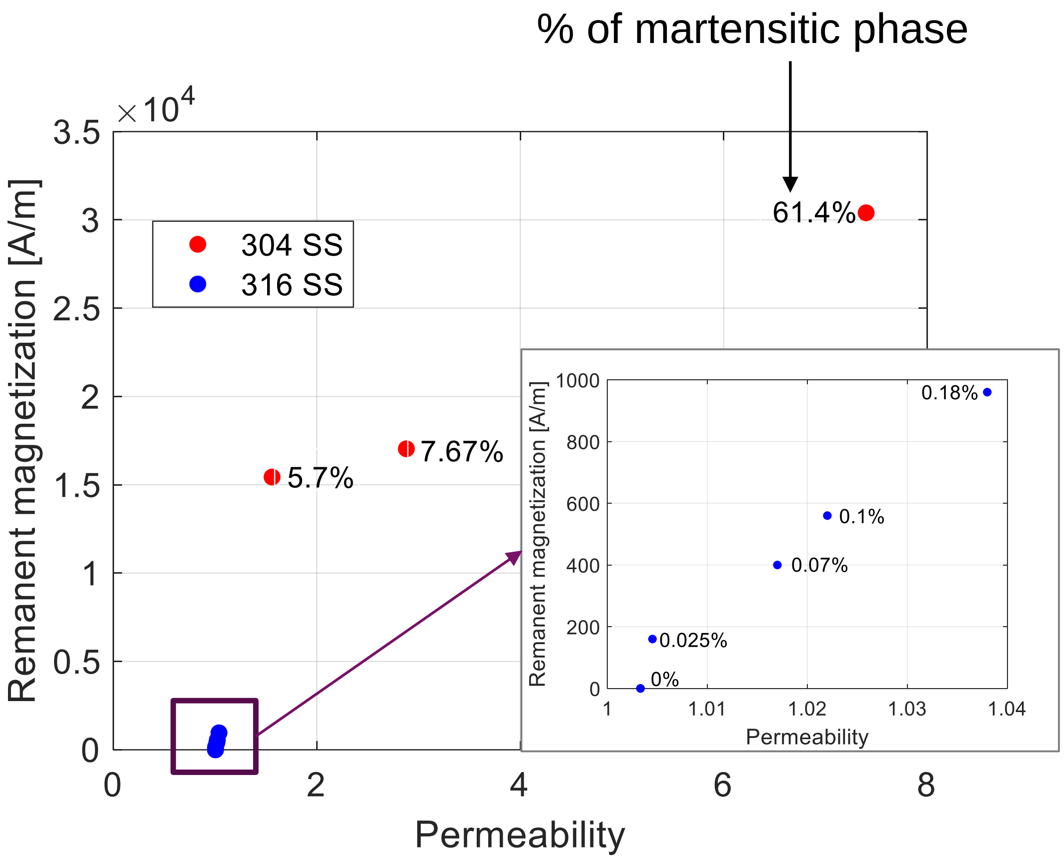


Figure 1: When cold working is employed, some normally nonmagnetic austenitic steels become substantially ferromagnetic.

CARPENTER

RELATION BETWEEN PERMEABILITY AND REMNANT FIELD



What really matters for us is the remnant field

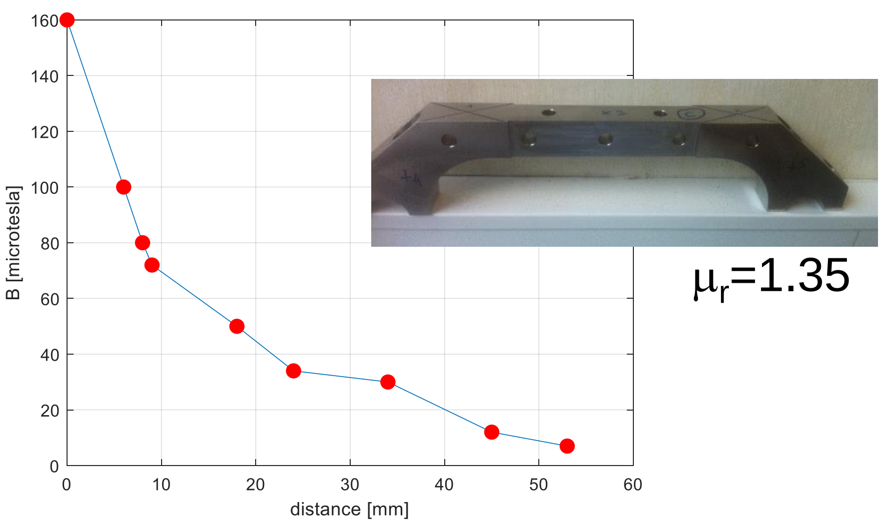
There is strong correlation between permeability and remnant field

Data extracted from:

Magnetic measurements of martensitic transformation in austenitic stainless steel after room temperature rolling, Mumtaz et al. Journal of Materials Science (2004)

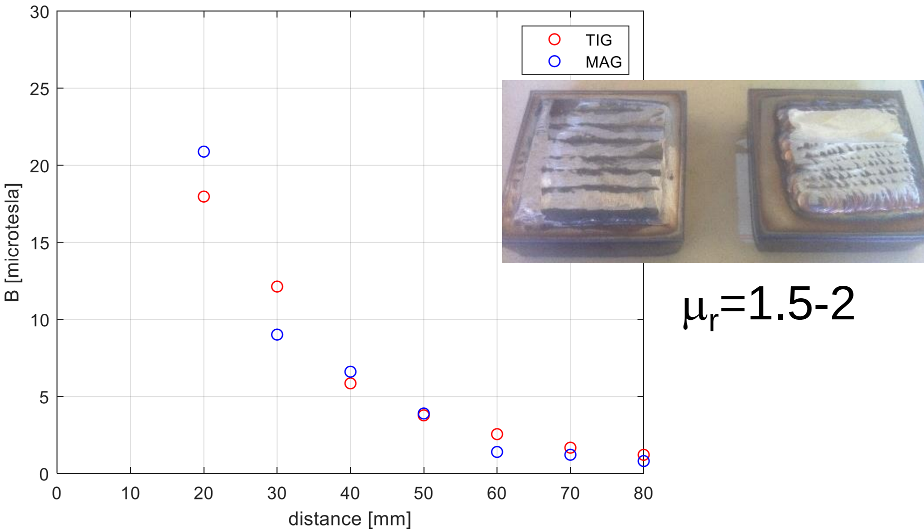
Martensitic transformation in SUS 316LN austenitic stainless steel at RT, Manjanna et al. Journal of Materials Science (2008)

RELATION BETWEEN PERMEABILITY AND RADIATED FIELD



μ_r=1.35

At 50 mm, B=10 μT



μ_r=1.5-2

At 50 mm, B=4 μT

Depends on material history, material size…

WHAT SHOULD WE ASK TO MANUFACTURERS ?

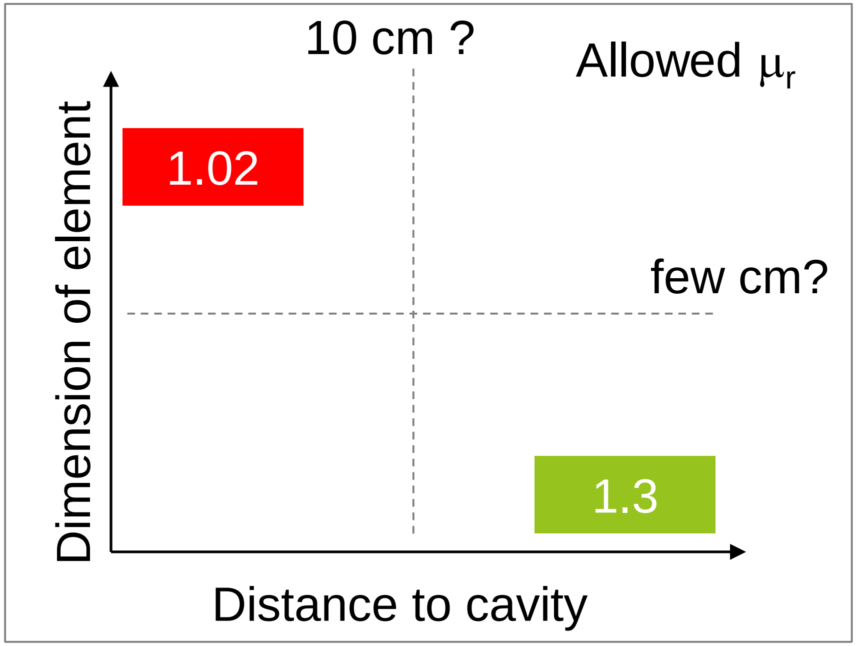
For stainless steel components, one has to fix a maximal permeability allowed value

At CEA, we used to ask for : **maximal value = 1.02**
But, this can be very hard to obtain
Some manufactured are not able to guarantee, esp. after machining and welding
How much is it necessary ?

We should give different max values depending on dimension/position on elements

We could focus on μ_r of the most critical elements

We are working on how to set up such an « abacus »



CONCLUSION

Magnetic hygiene

Provide appropriate magnetic shielding around cavity

Proscribe elements which could radiate magnetic field close to cavity

Be able to properly define the expected properties of these elements.