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The ITER Earthing Topology:
Mesh-Common Bonding Network

J. Hourtoule D. Beltran
Electrical Engineering Division
ITER Organization

Outline

1. ITER introduction

2. EMC at ITER

3. Experiment in Alcator C-Mod Tokamak

4. Conclusions

Challenge N1: ITER performances

The principal goal:

- To design, construct and operate a Tokamak experiment at a scale which demonstrate the scientific and technological feasibility of fusion energy

- **ITER** is designed to confine a plasma in which α-particle heating dominates all other forms of plasma heating

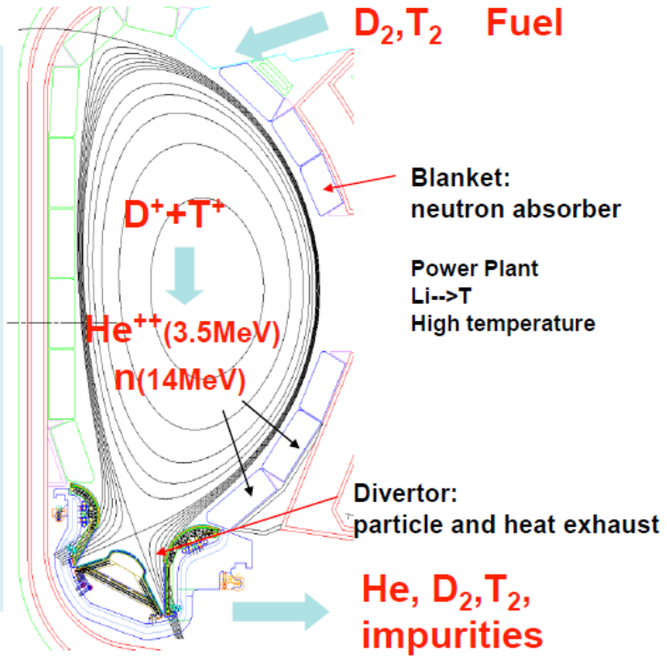
➔ITER will be the world's first experimental fusion reactor with a self-sustained burning plasma of several hundred seconds (Inductive operation) to several thousand seconds (Non-inductive operation) duration.

High precision measurement systems working have to operate in the same environment of high power radio frequency heating systems and high magnetic field.

Challenge N2: Nuclear installation

ITER Plasma:

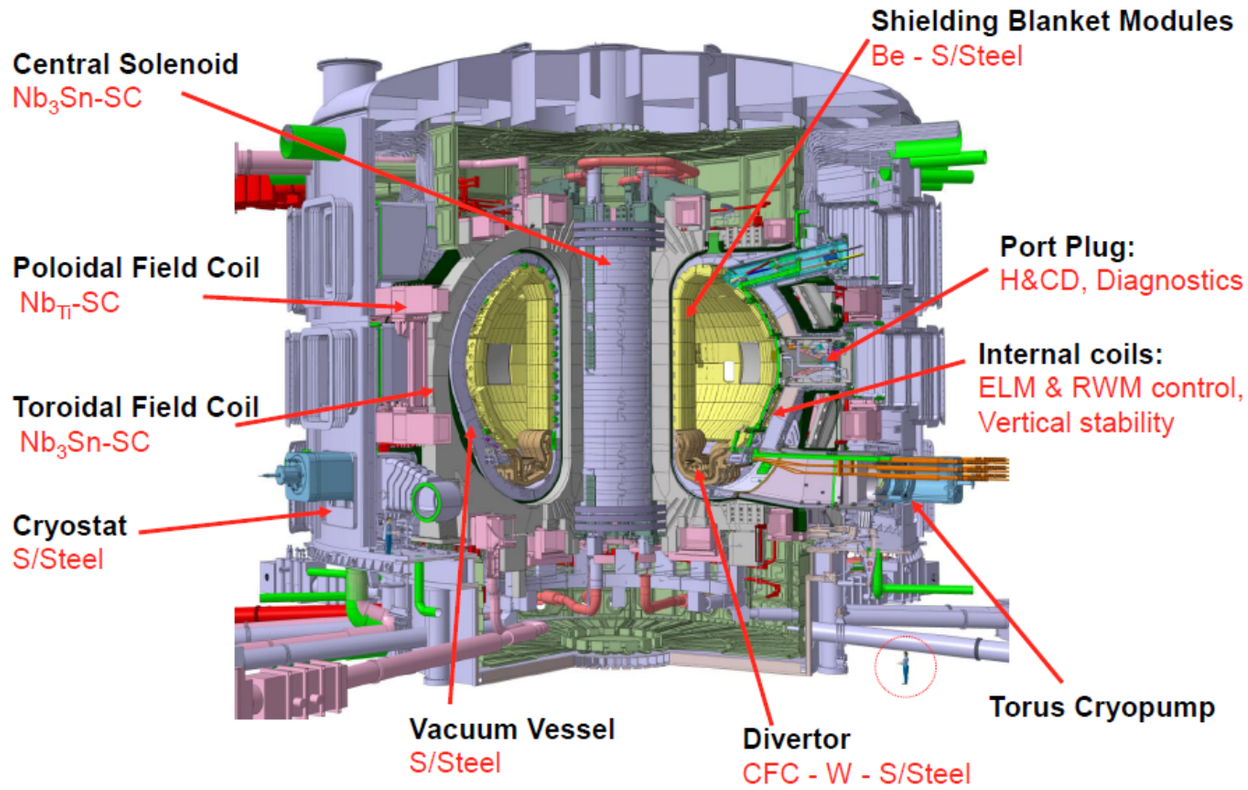
R/a:	6.2 m /2 m
Volume:	830 m^3
Plasma Current:	15 MA
Toroidal field:	5.3 T
Density:	10^{20} m^{-3}
Peak Temperature:	2×10^8 K
Fusion Power:	500 MW
Plasma Burn	300 - 500 s
("Steady-state"	~3000 s)



RCC-E code is a reference for EMI and shielding

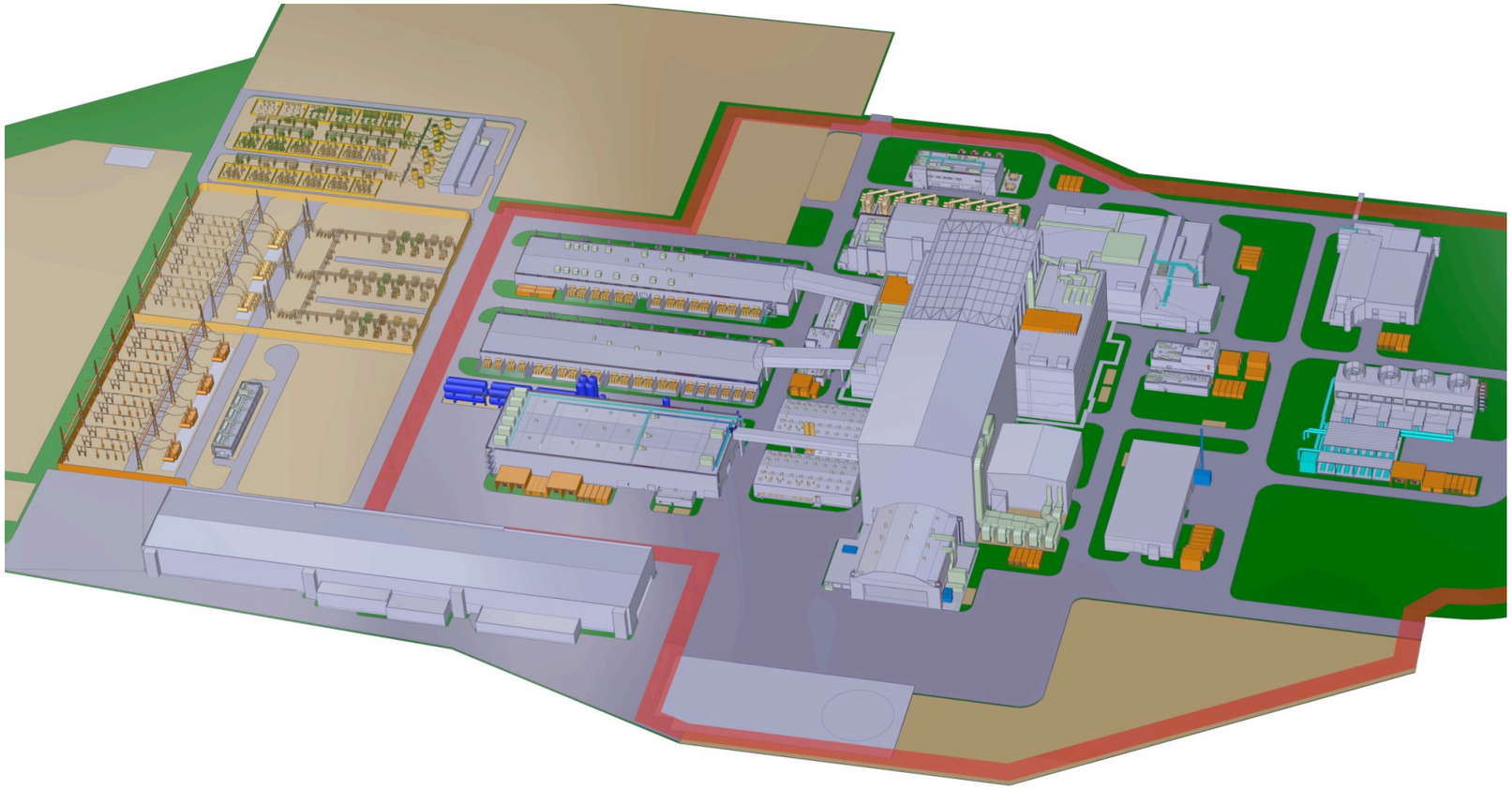
ITER is classified as nuclear installation, and must comply with the French nuclear design rules, including electrical and EMC requirements

Challenge N3: Complexity



Vacuum vessel, Cryostat, bioshield and galleries are very high density zones with huge number of mechanical and electrical devices

Challenge N4: World wide project



90% Procurement in-kind by the partners

Challenge N5: Machine size

ITER (2 football fields)

JET (0.22 football fields)
4.5 JET=1 football field

ITER will be 10 times bigger
than any Tokamak built in the last 30 years

Codes and standards

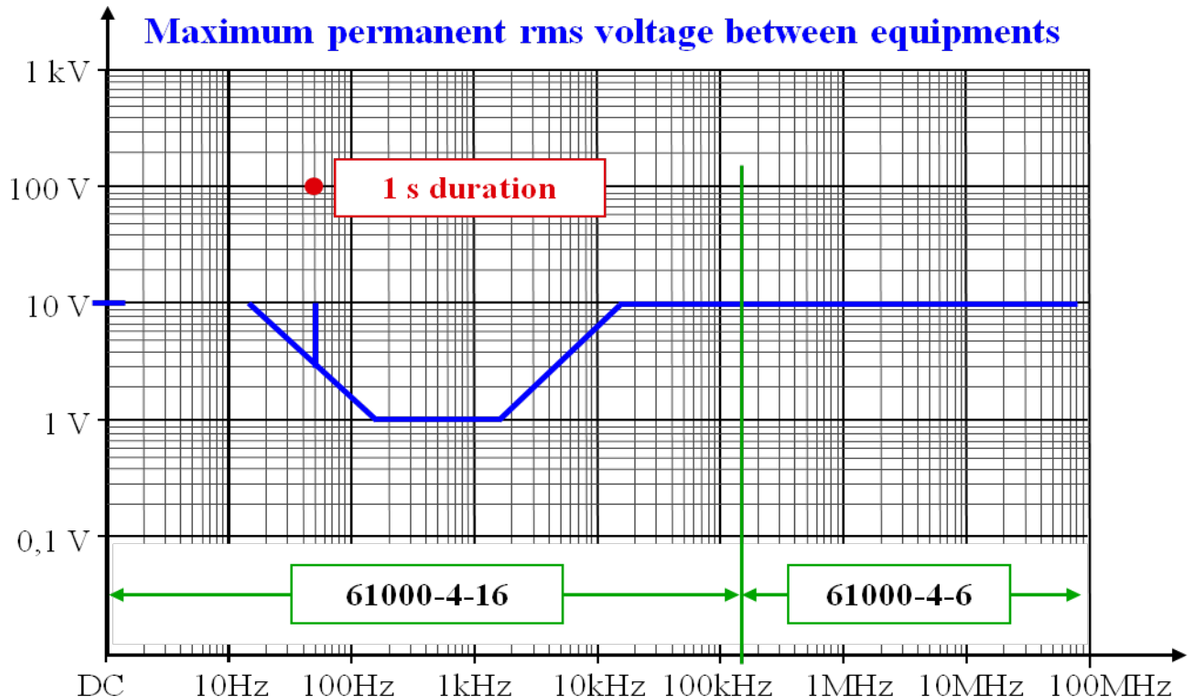
- **RCC-E:** Design and construction rules for electrical equipment of nuclear islands.
- **IEC 61000-5-2:** EMC-Installation and mitigation guidelines - Earthing and cabling
- **IEC 62305-1 to 4:** Protection against lightning
- **IEC 60364-5-54:** Electrical installations of buildings. Selection and erection of electrical equipment-Earthing arrangements, protective conductors and protective bonding conductors .
- **IEC 61000-6-2:** EMC-Generic standards - Immunity for industrial environments.
- **IEC 61000-4-16:** EMC-Testing and measurement techniques - Test for immunity toconducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
- **IEC 61000-6-4:** EMC-Generic standards - Emission standard for industrial environments.

- ITER specification for conducted emissions 30 Hz to 30 MHz

- ITER test specification for Magnetic field compatibility tests

Immunity I

IEC 61000-6-2, IEC 61000-4-16, IEC 61000-4-13



For fast transients (t_r = 5ns / t_h = 50 ns), the voltage is 1 kV for signal ports and 2 kV for power ports (according to 61000-4-4)

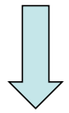
Immunity II

dB/dt -> IEC 61000-4-8

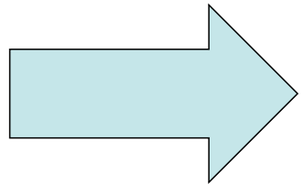
Location	Continuous Duration	Short-duration (1 to 3 sec)
Port-cell	23 mT/s	77 mT/s
Tokamak building (except port cells)	2.3 mT/s	7.8 mT/s

But specific test for equipments τ > 7 ms

B (120 mT – 5 mT)



Supplier certification
or
Custom test

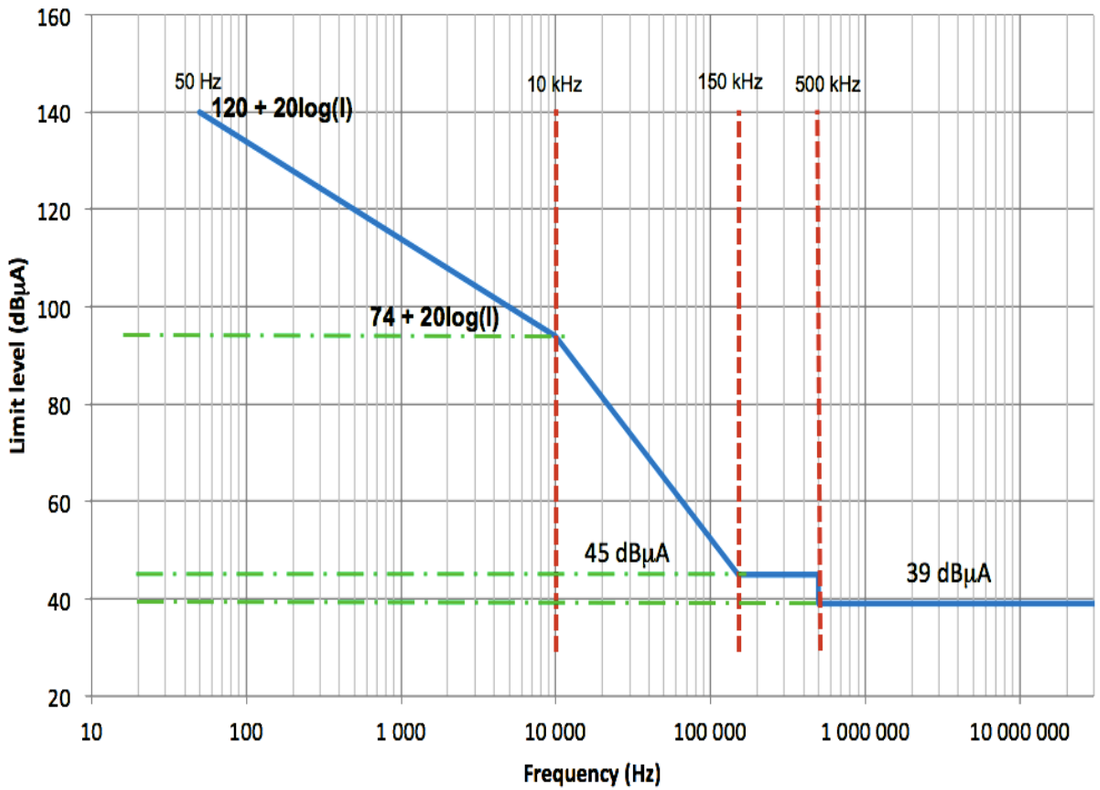


Change location
or
Magnetic shielding

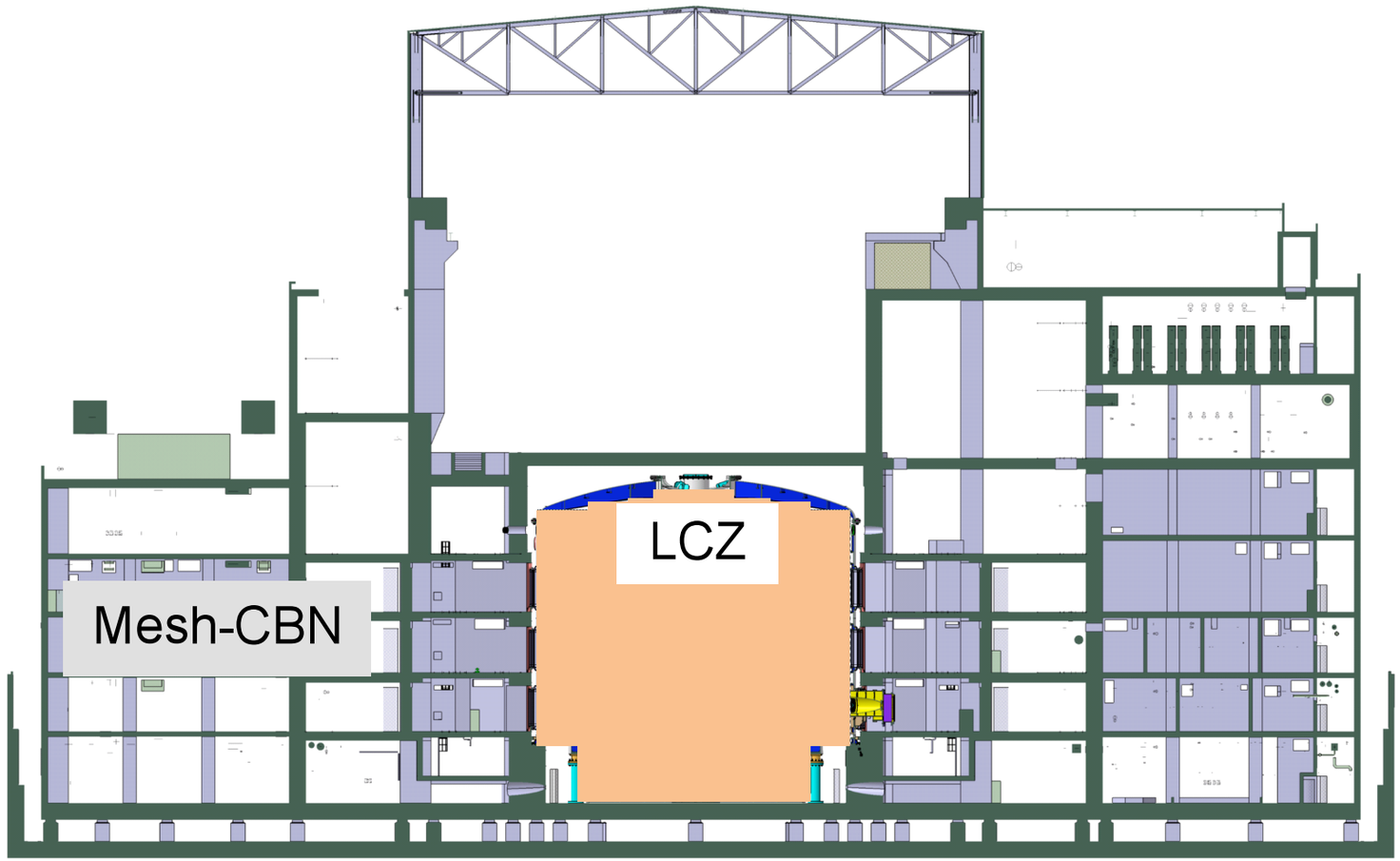
Emission

Based on

- MIL STD 461 CE 101-2
- IEC 61000-6-4



Bonding zones



Mesh-CBN: Common bonding network
LCZ: Loop Control Zone

Loop Control Zone (LCZ)

- Applies within cryostat and vacuum vessel

  to prevent loop currents that could distort the magnetic fields that contain the plasma

- A single bonding path per item of equipment

  ("single-point bonding")

- Equipment isolated at 0.5 kV

  (max. loop voltage during worst-case plasma disruption: **250** V)

- Exceptions are treated case-by-case

(e.g. ports, blanket)

Mesh-Common Bonding Network

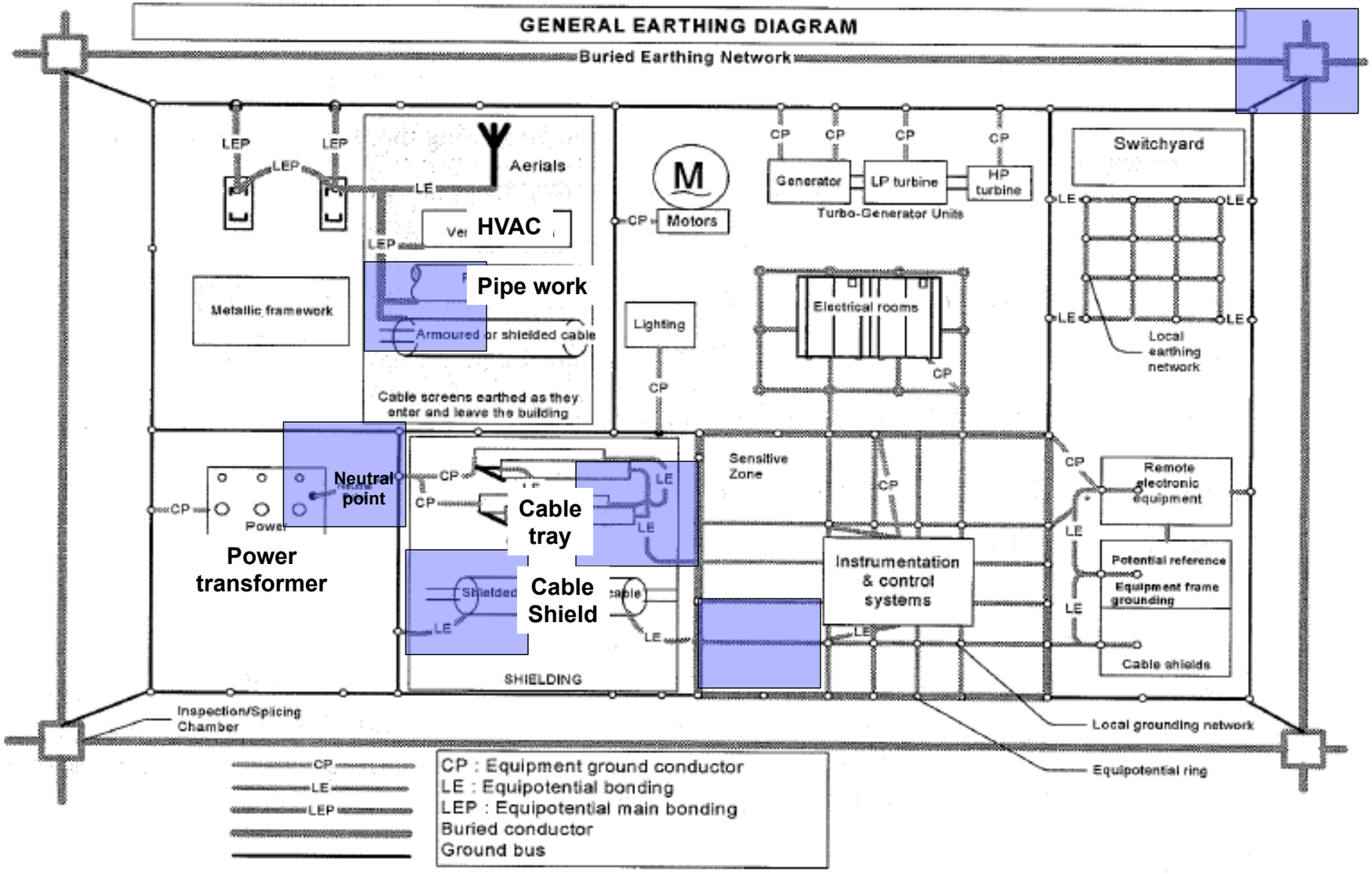
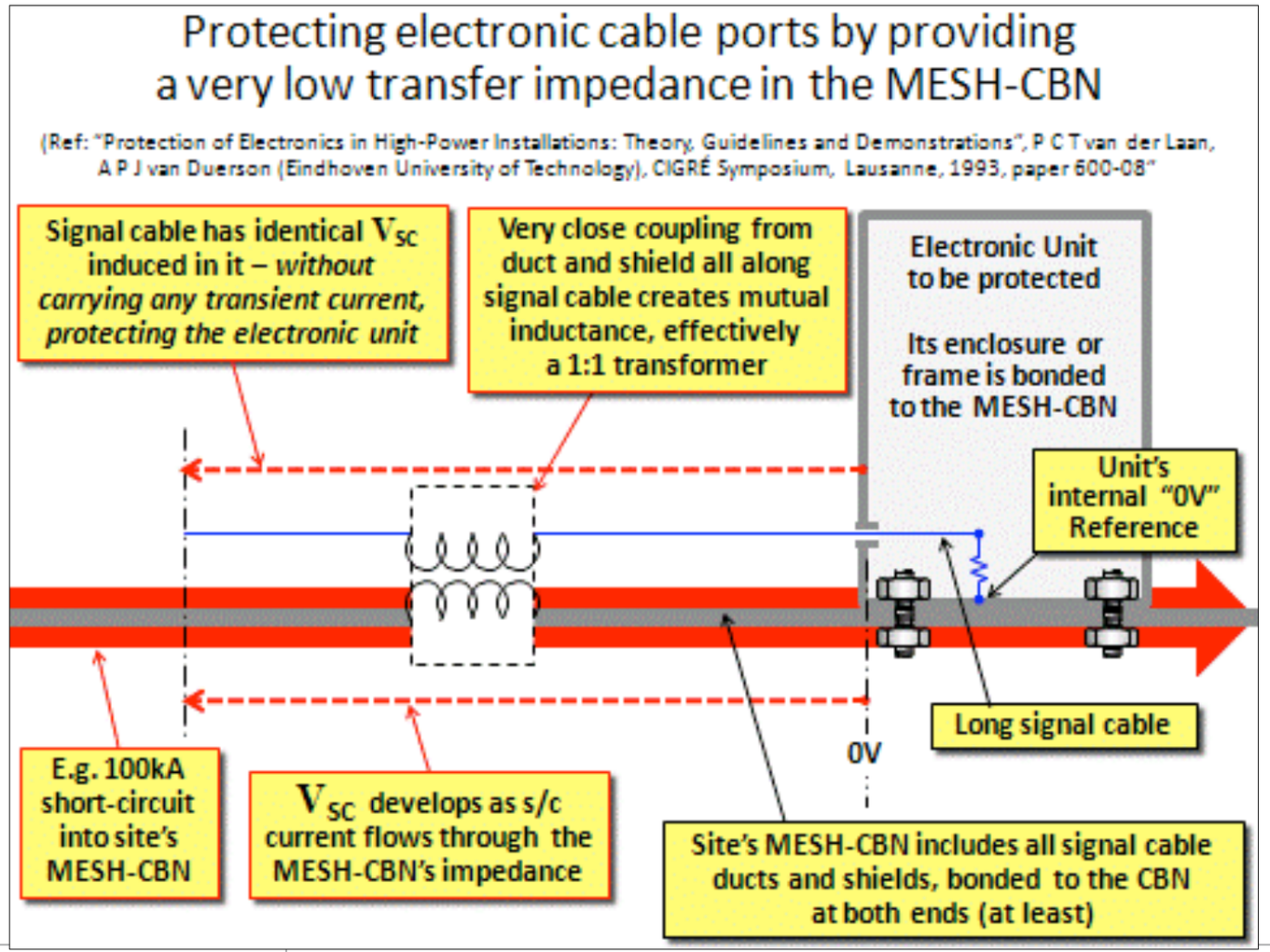


Figure D 4410-f1: General earthing & grounding network diagram

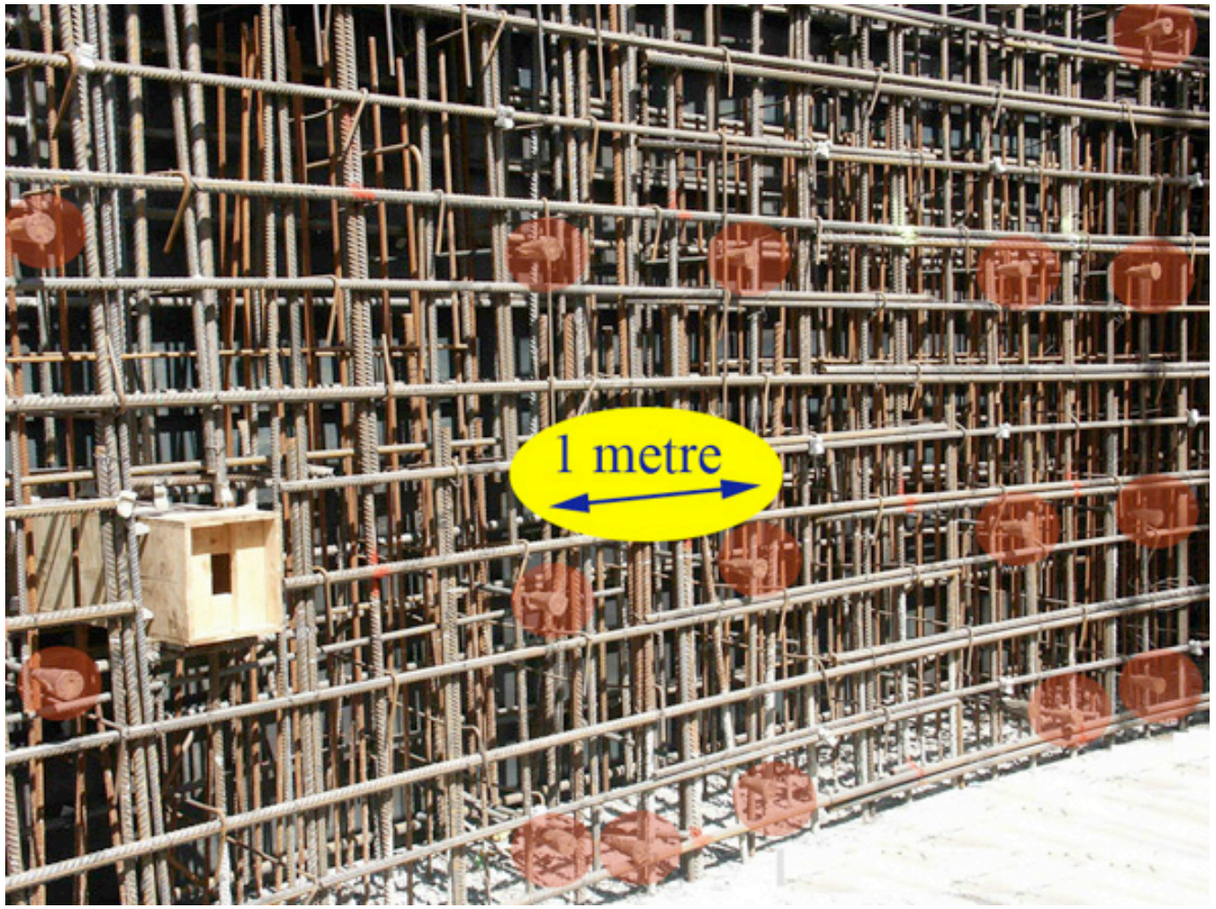
Mesh-Common Bonding Network

LF: low Mesh-CBN impedance
HF: shielding & mutual inductance

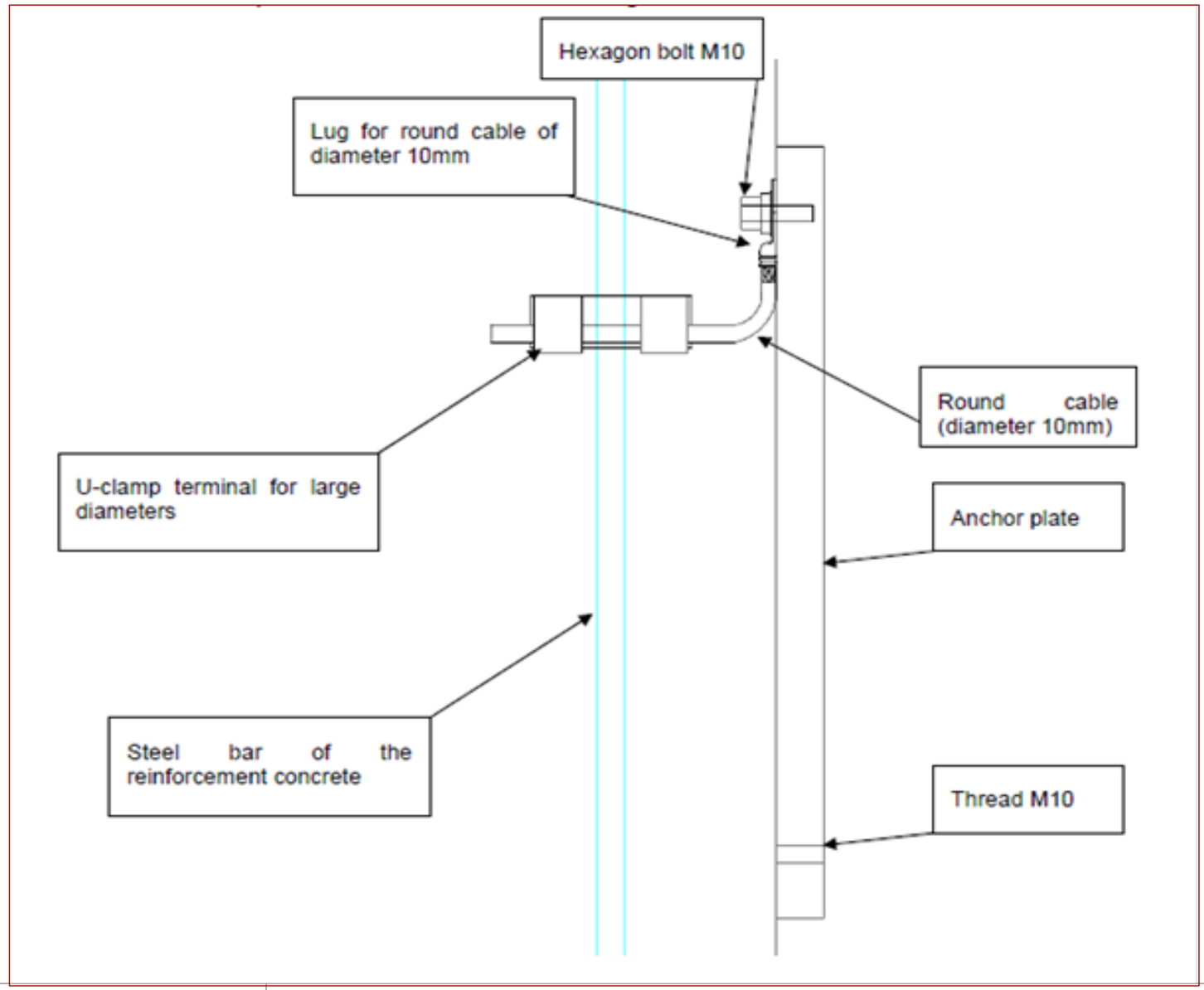


Mesh-CBN

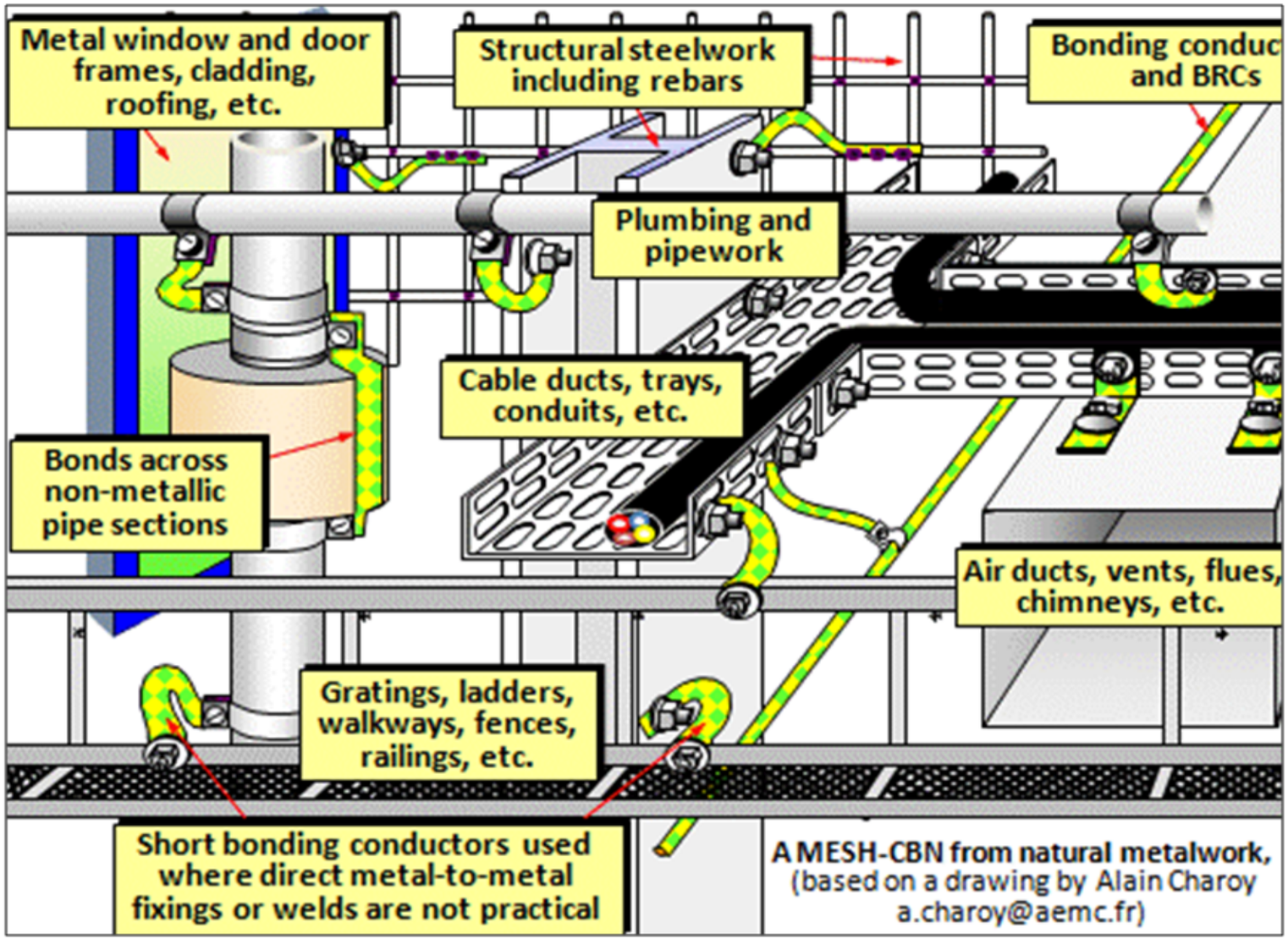
Re-bars (1x1 mesh in Tokamak): R_{DC}<1 mΩ, L=1 μH



Mesh-CBN

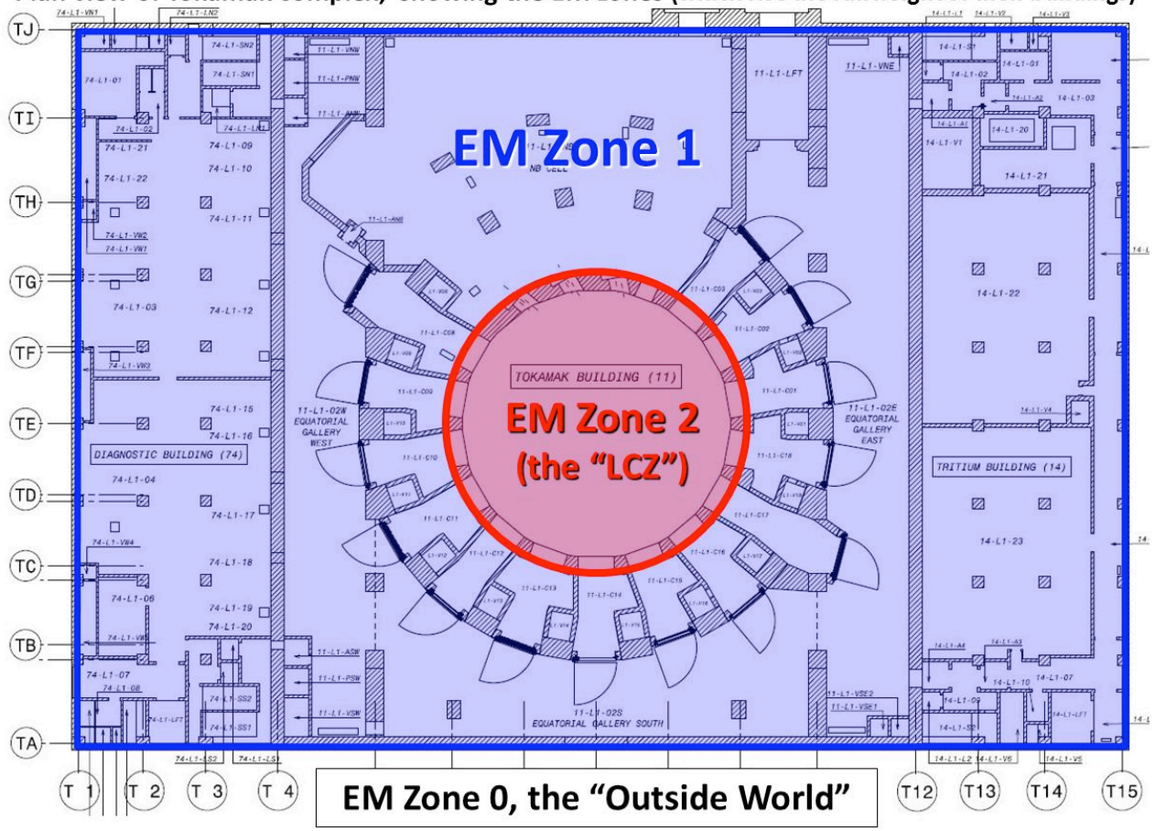

Hexagon bolt M10
Lug for round cable of diameter 10mm
Round cable (diameter 10mm)
U-clamp terminal for large diameters
Anchor plate
Steel bar of the reinforcement concrete
Thread M10

Mesh-CBN


Metal window and door frames, cladding, roofing, etc.
Structural steelwork including rebars
Bonding conduc and BRCs
Plumbing and pipework
Cable ducts, trays, conduits, etc.
Bonds across non-metallic pipe sections
Air ducts, vents, flues, chimneys, etc.
Gratings, ladders, walkways, fences, railings, etc.
Short bonding conductors used where direct metal-to-metal fixings or welds are not practical
A MESH-CBN from natural metalwork,
(based on a drawing by Alain Charoy
a.charoy@aemc.fr)

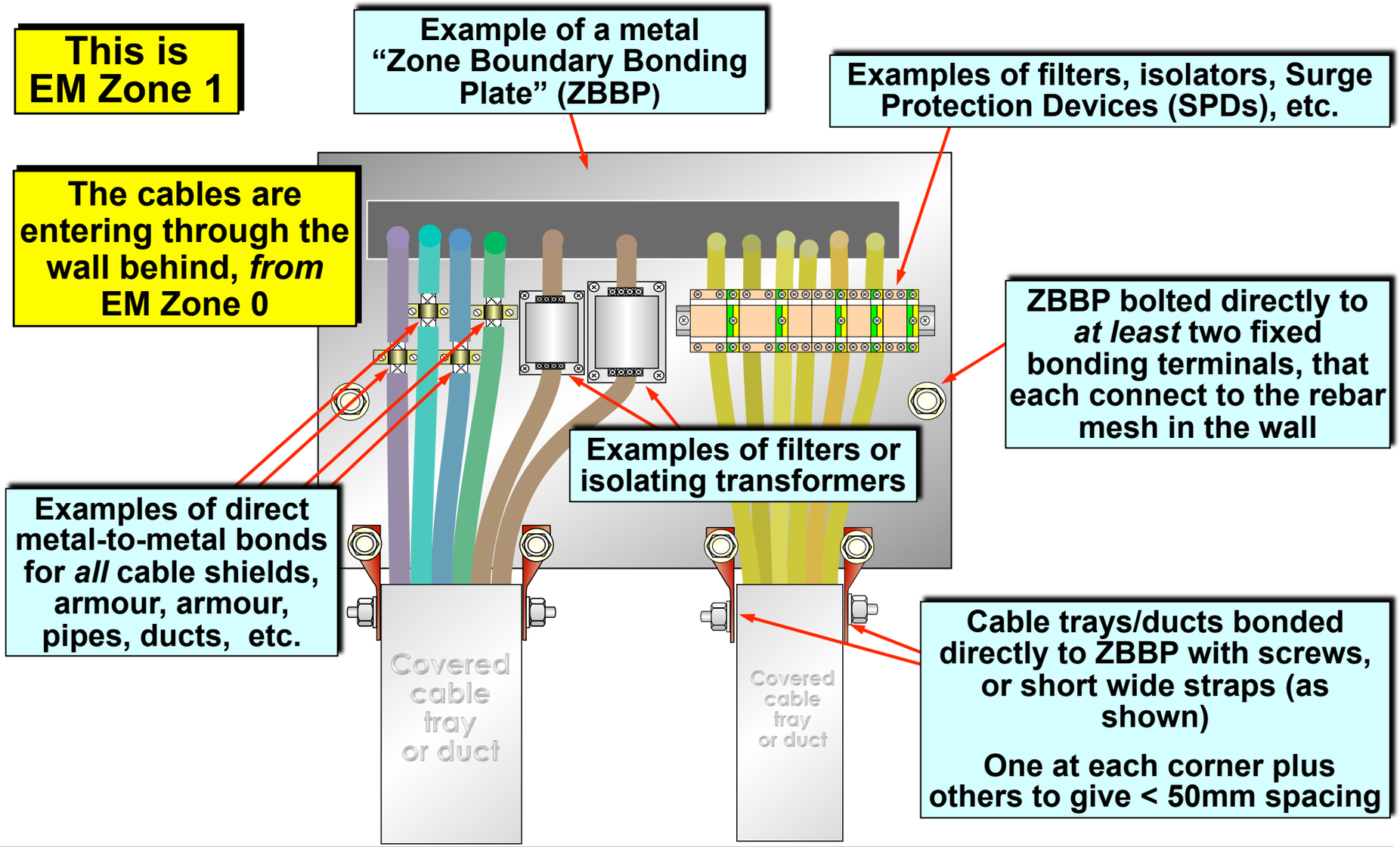
EM Zoning

Plan view of Tokamak complex, showing the EM zones (which rise the full height of their buildings)

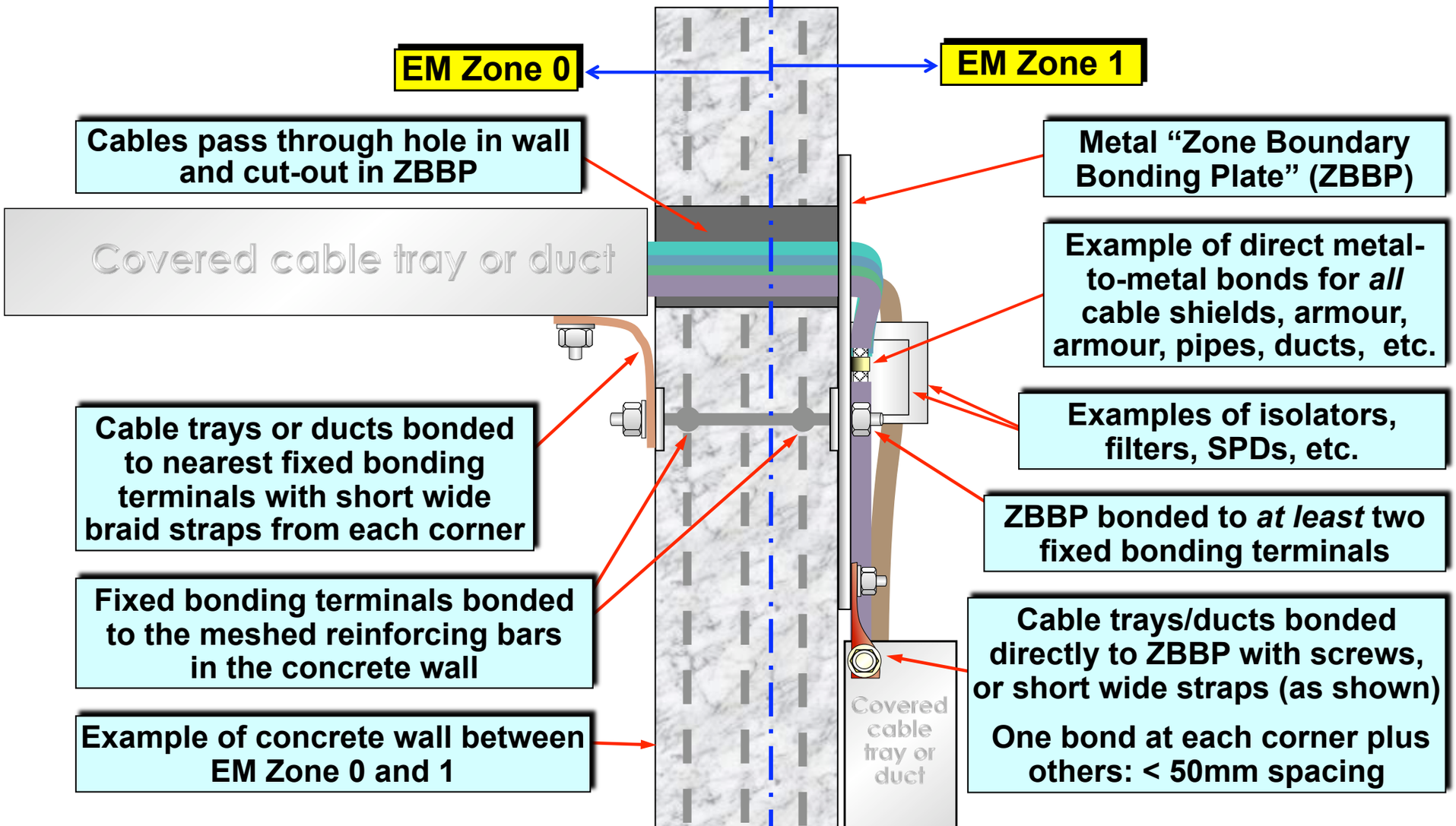


- Bonding at boundary EM Zone 0/1 uses:
  direct bonding to Mesh-CBN; shielding; filtering;
  surge protection; galvanic isolation, etc.,
  all mounted on a "ZBBP"

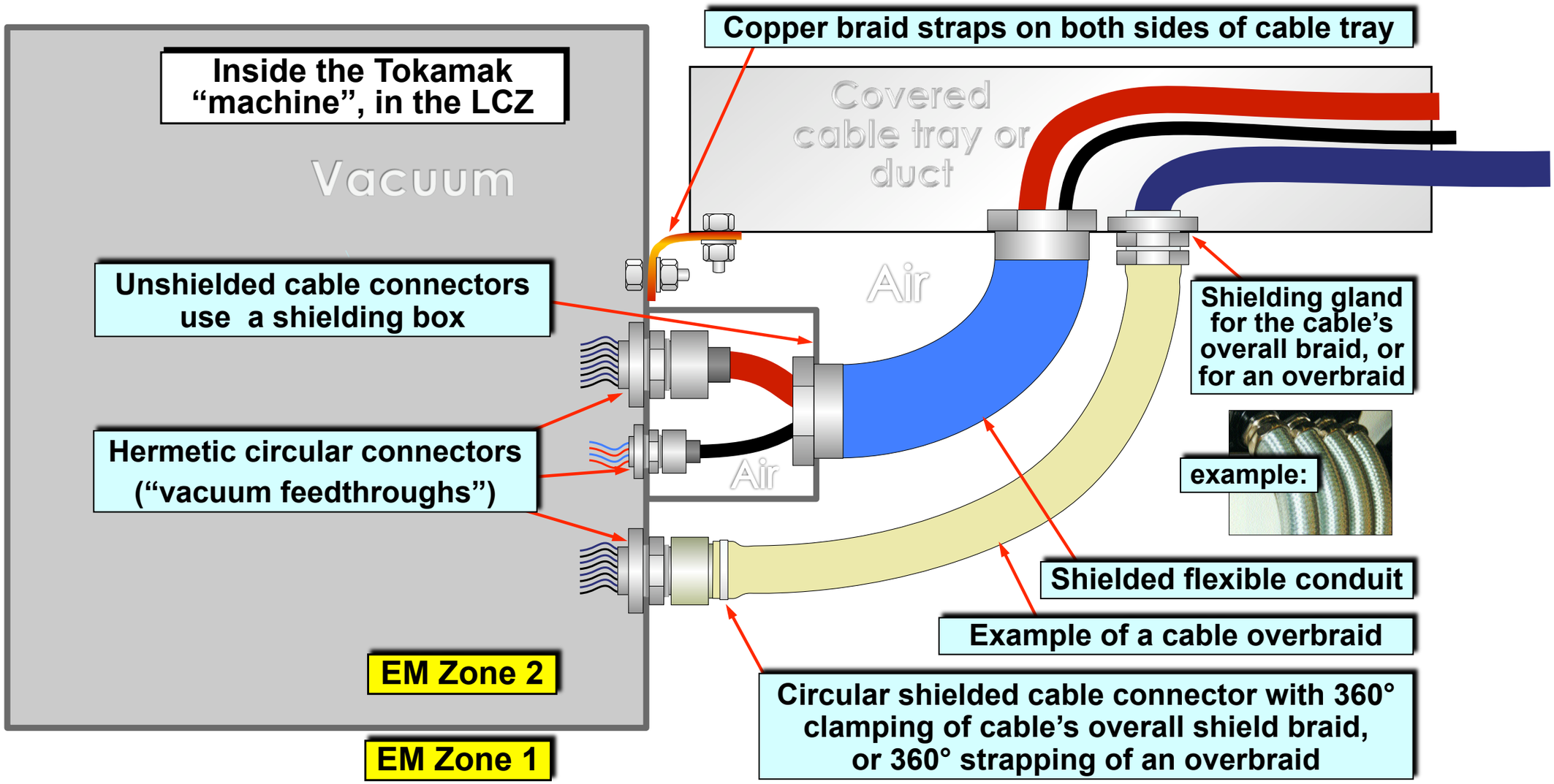
A “Zone Boundary Bonding Plate” (ZBBP)



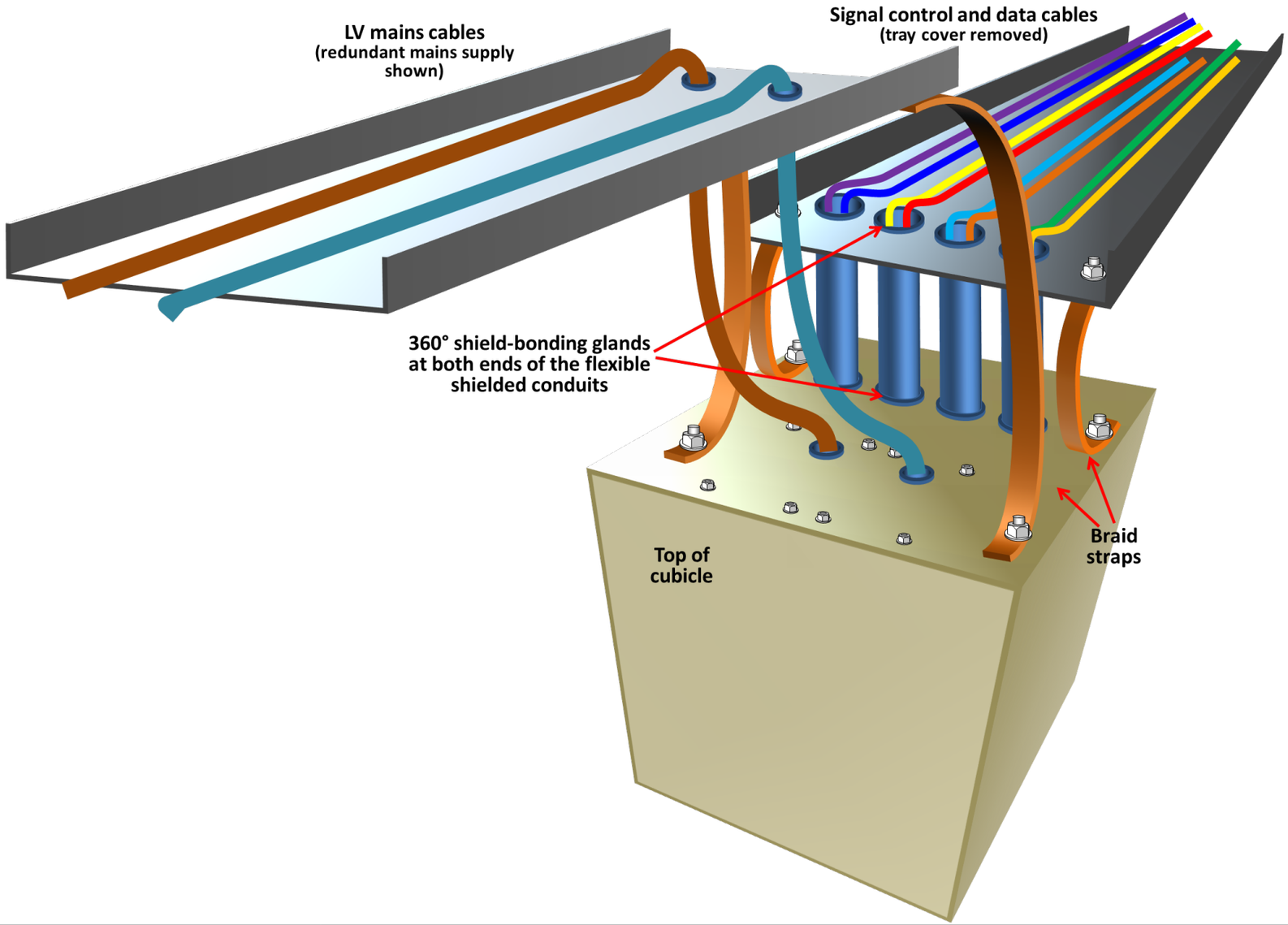
Another view of the example ZBBP



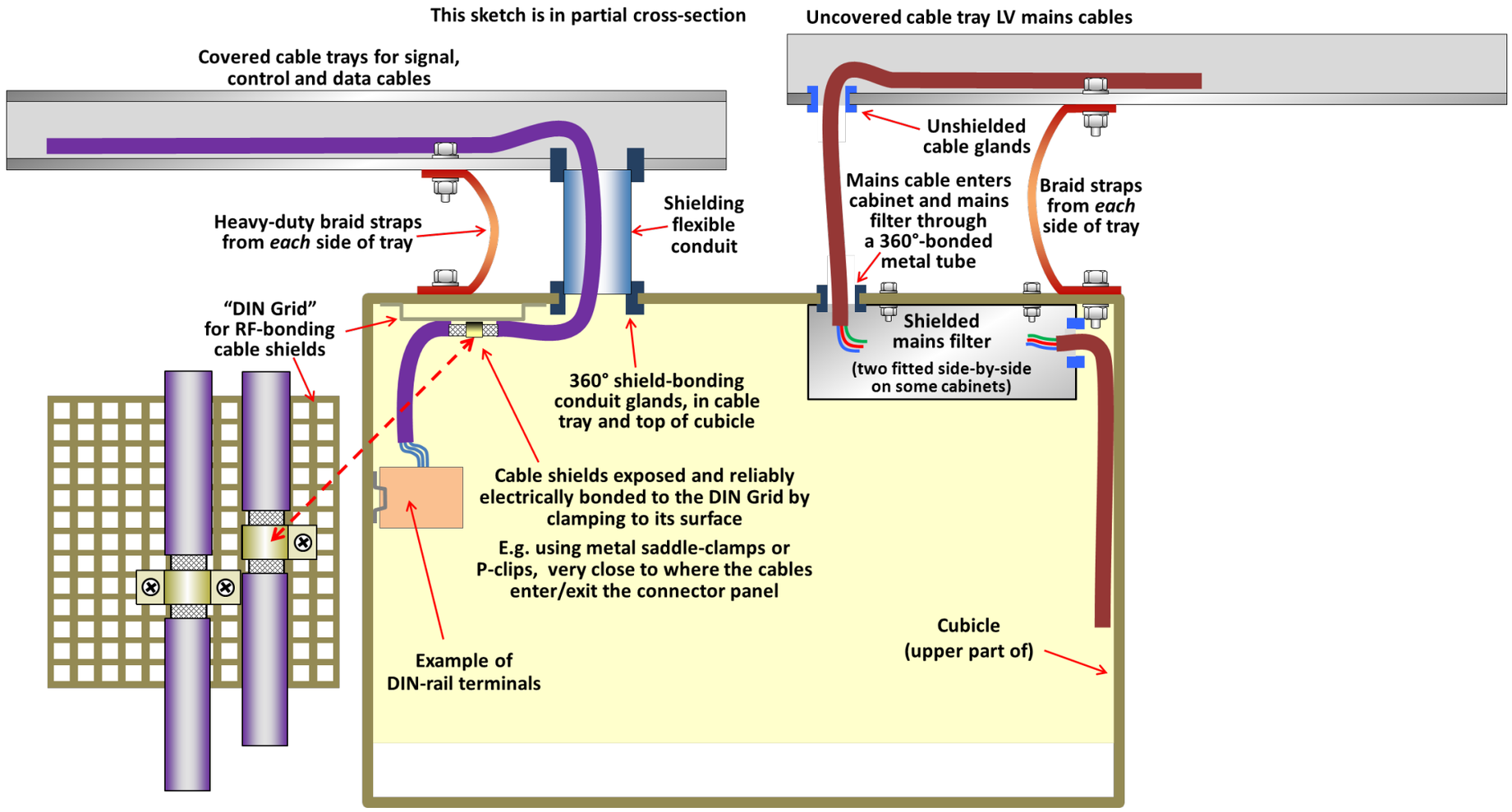
The EMC Zone 1/2 boundary (bonding to the Machine)



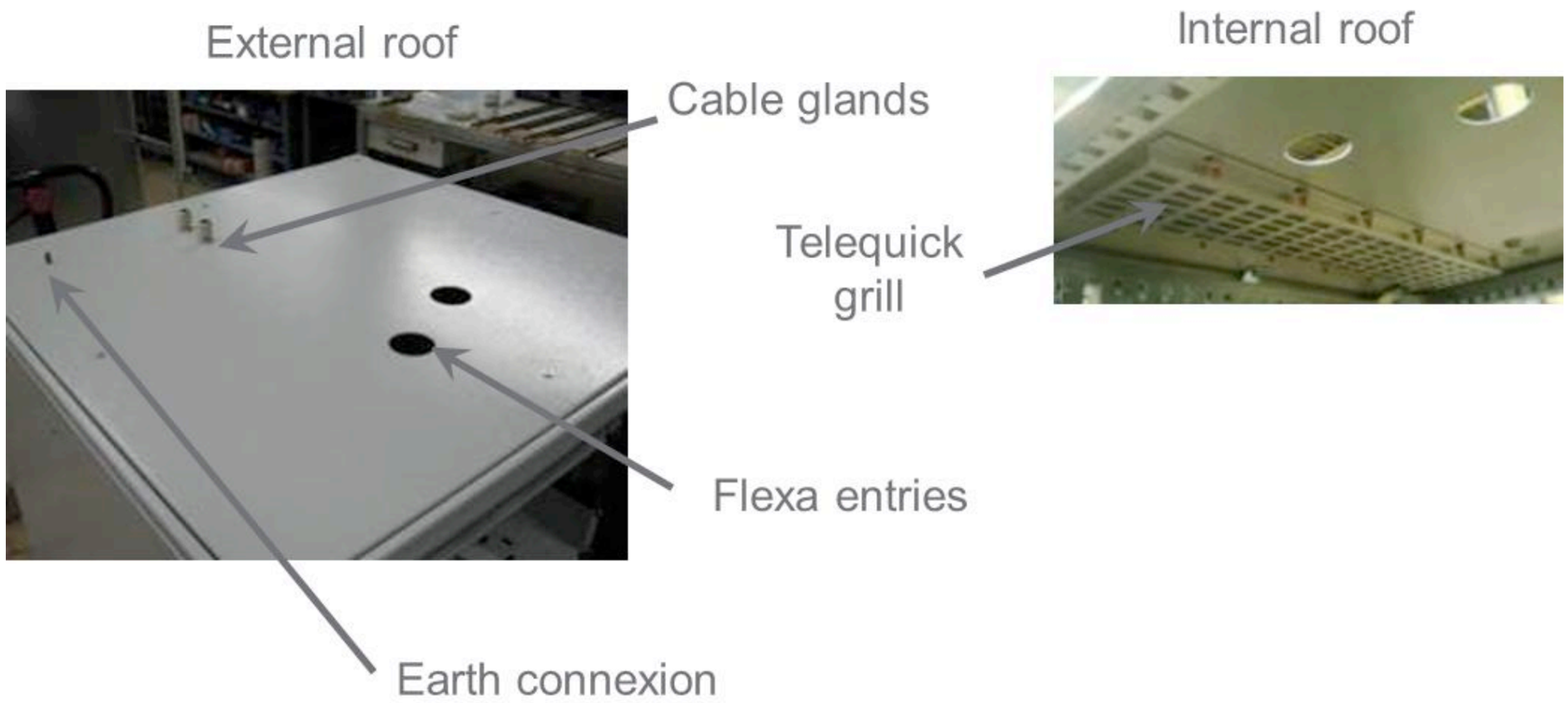
Cubicle bonding



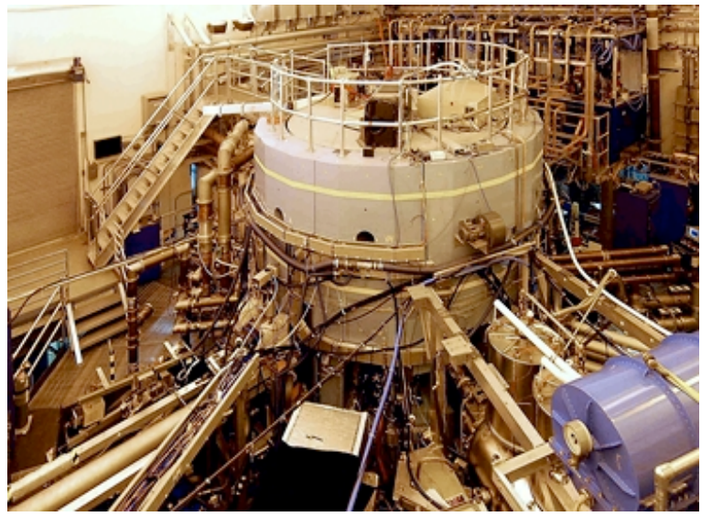
Cubicle bonding

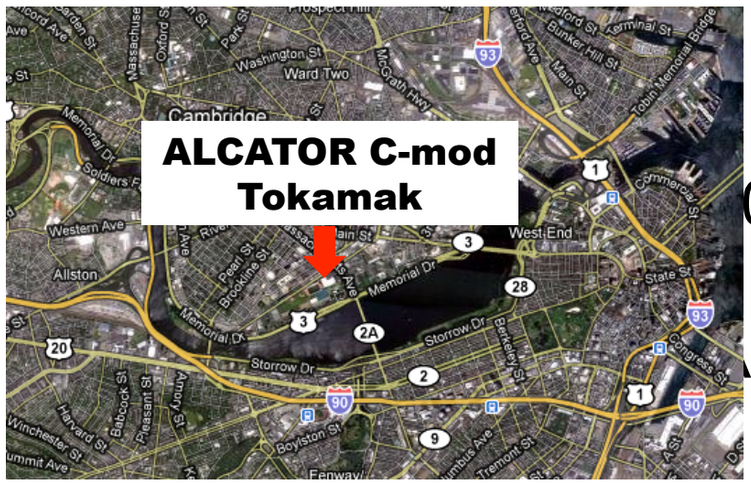


Cubicle bonding



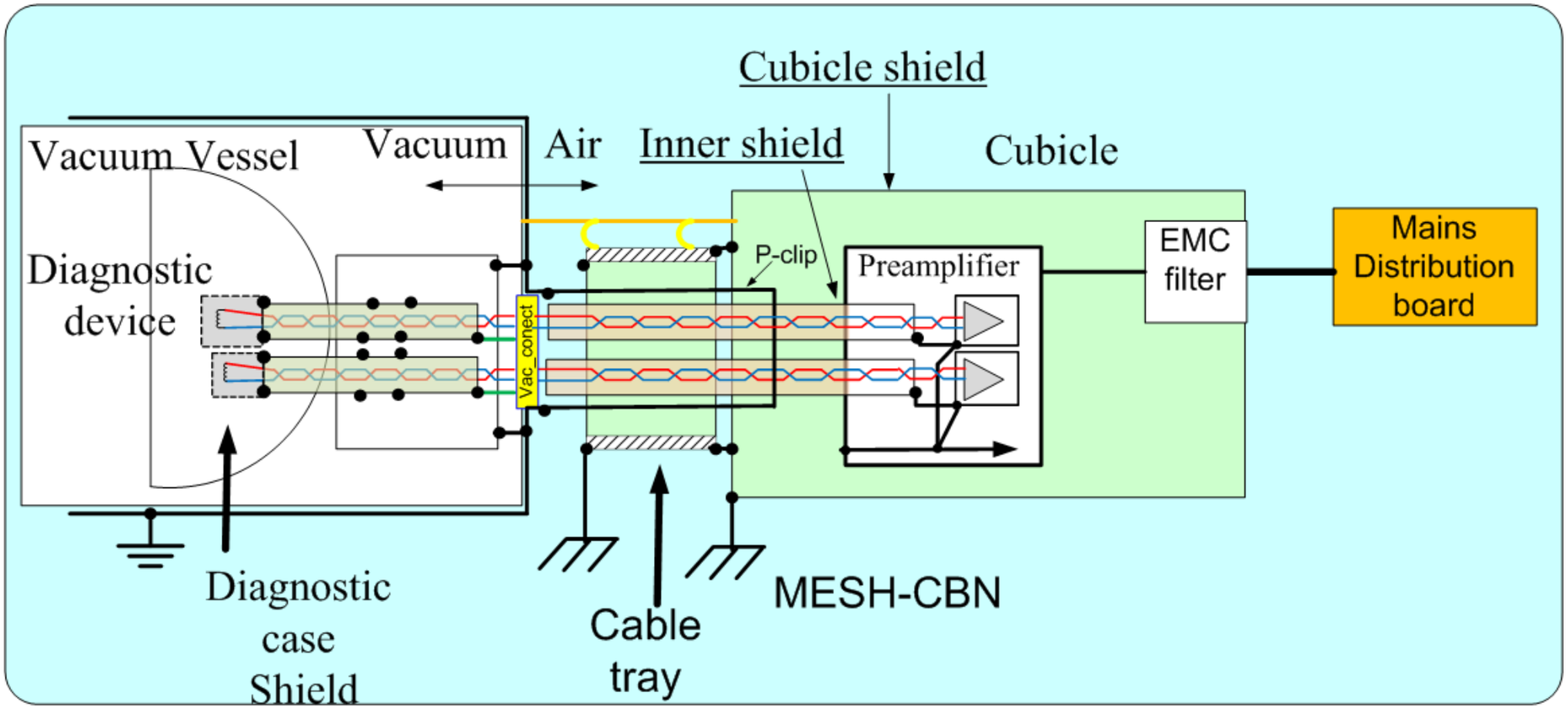
Experiment in Alcator C-Mod Tokamak



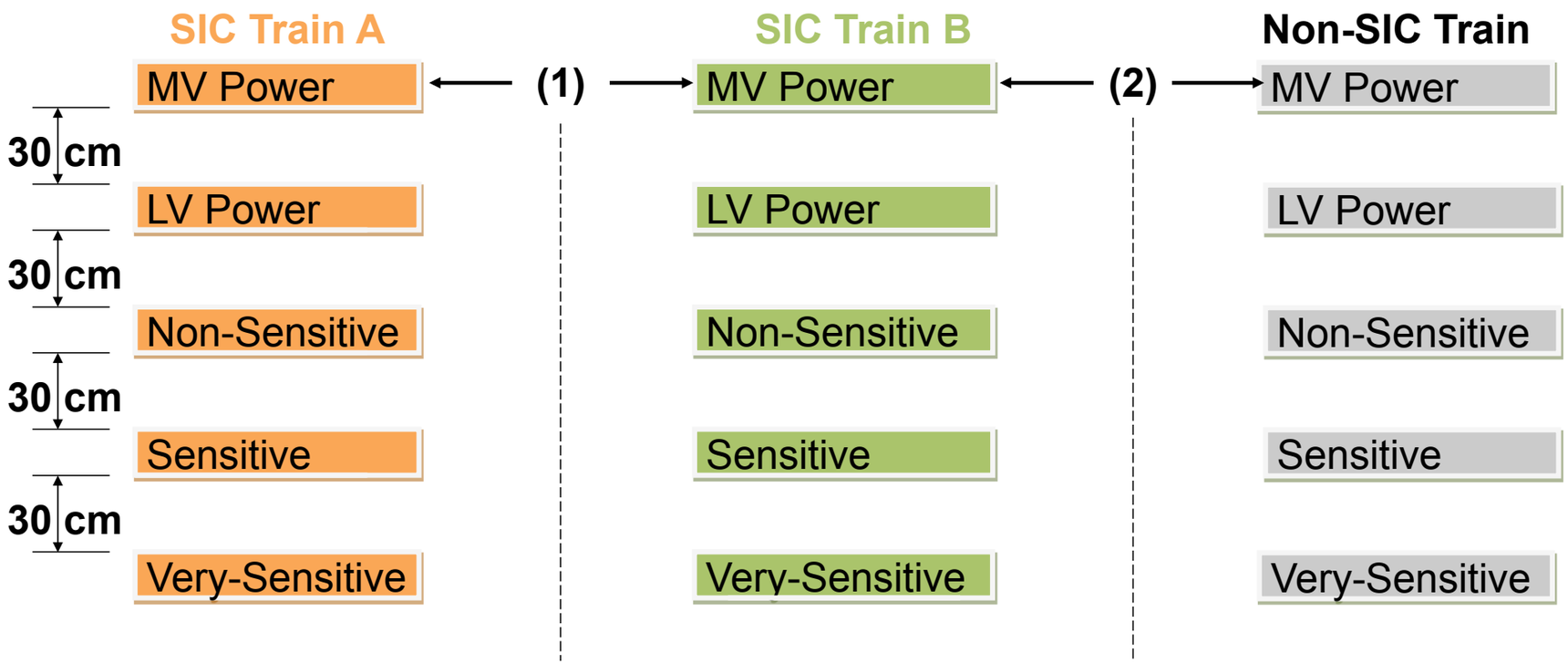


0 μOhm (ITER 10 μOhm)
(ITER 500 ms)
(ITER 15 MA)

Experiment in Alcator C-Mod Tokamak



Cable segregation & rules



Cabling design and installation rules (ITER Report IDM: 335VF9)

- Cable tray installation
- Cable installation (separation & segregation rules)
- EMC

Conclusion

1. Safe design (RCC-E)
2. Design following high-power industrial well-proven methods
3. Immunity & Emission control
4. Mesh-CBN outside cryostat
5. HF Shielding for diagnostics
6. Cable segregation

Many fusion experiments with Single-Point-Earthing …

But largest fusion facilities Multi-Point-Earthing …

… **If wrong choice > 10 years of work after installation**

Acknowledgments

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K. Armstrong
www.cherryclough.com

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www.aemc.fr

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www-lmj.cea.fr

Alcator C-Mod
R. Granetz
www.psfc.mit.edu

PPPL
C. Neumeyer
www.pppl.gov

Procon
B. Plana
proconsystems.net

CRPP Lausanne
A. Perez
www-lmj.cea.fr

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D. Bouillez
www.schneider-electric.fr

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Thanks for your attention

Any Question ?