Vacuum Science and Technology in Accelerators

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Aims

- To give a basic understanding of vacuum
  - Underlying physical principles
  - Some equations, little mathematics
  - Some limitations on what can be done
- The role of vacuum in accelerator design and operation
  - Why vacuum?
  - Constraints on vacuum design of accelerators
  - What's all the fuss about?

Session 1

Vacuum Requirements of Accelerators

Aims

- To give a brief overview of vacuum in general
- To understand why different types of accelerators require different vacuum levels
- To take a preliminary look at the vacuum design process for accelerators

Vacuum

- There's nothing in it!

	Particles m^{-3}
Atmosphere	2.5×10^{25}
Vacuum Cleaner	2×10^{25}
Freeze dryer	10^{22}
Light bulb	10^{20}
Thermos flask	10^{19}
TV Tube	10^{14}
Low earth orbit (300km)	10^{14}
SRS/Diamond	10^{13}
Surface of Moon	10^{11}
Interstellar space	10^{5}

Vacuum Units

- Vacuum – sub atmospheric pressure
- SI Unit – Pascal ($1Nm^{-2}$)
  - Atmosphere ~10^5 Pa
- In Europe – mbar (100 Pa)
- In USA/Asia – Torr (133 Pa)

Vacuum

- Much ado about nothing!
  - Nature abhors a vacuum
  - We have to work quite hard to get low pressures
    - Understand limitations
      - Outgassing
      - "Pumping"
    - Careful design and operation of vacuum systems
      - Performance (specification)
      - Economics

A reminder!

- For most purposes vacuum is just a tool
- Most users would prefer not to have to bother with it
- The accelerator physicists who determine the properties of the next generation of machines would like the vacuum engineer to design a vacuum system where -
  - The pressure is zero
  - The vacuum pumps and gauges take up no space
  - The cost is trivial

Accelerators

- Particle accelerators come in many shapes and sizes
  - Small LINACs
  - Medical Cyclotrons
  - Electrostatic
  - Synchrotrons
    - Leptons
    - Hadrons
  - Storage Rings
    - Synchrotron Light Sources
  - Colliders
    - LHC
    - ILC

- All need Vacuum to a greater or lesser extent e.g.
  - 10^{-5} – 10^{-6} mbar in small linacs, Van de Graafs
  - 10^{-7} – 10^{-8} mbar in proton synchrotrons
  - 10^{-9} – 10^{-10} mbar in synchrotron light sources
  - 10^{-11} – 10^{-12} mbar in antiproton accumulation rings

Accelerators

- The main reason is beam-gas interaction e.g. scattering
  - Single pass machines
    - Increases beam size (emittance)
    - Increases radiation hazard
    - Encourages recombination
  - Stored beam machines
    - Increases beam size
    - Reduces beam lifetime
    - Increases radiation hazard

Particle-gas interaction

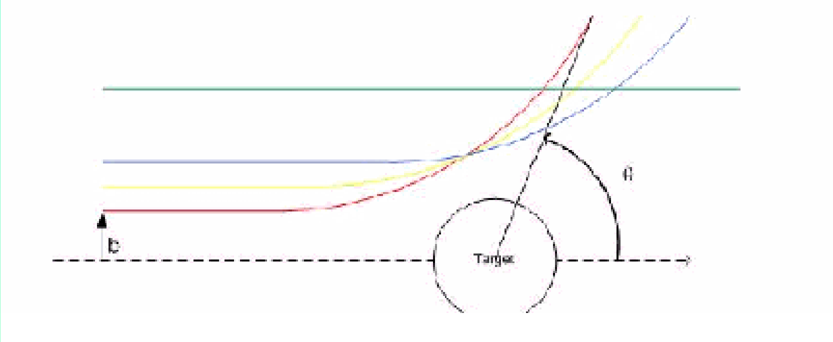
- Depends on number density and nature of gas molecule (and particles)
- Two types
  - Elastic
  - Inelastic
- Scatters particles out of beam
  - Hit wall or other obstruction
  - If not lost, increase beam size

Inelastic Scattering

- Any scattering that is not elastic
- Electromagnetic
  - Bremsstrahlung
  - Ionisation
  - Electron capture/loss
- Nuclear
  - Nuclear Reactions
  - Particle break up
  - Particle creation

Elastic Scattering

- Coulomb scattering

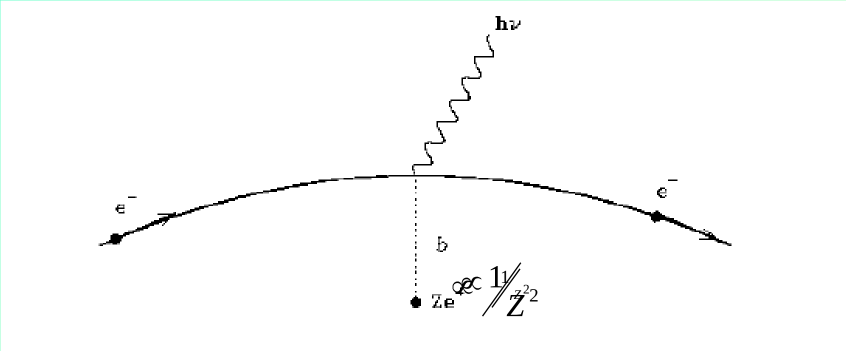


Cross section

$$\frac{d\sigma}{d\Omega}(\theta) = \left(\frac{ZZ'e^2}{4E} \right)^2 \frac{1}{\sin^4 \frac{\theta}{2}}$$

Inelastic Scattering

Bremsstrahlung (“Braking radiation”)



Average energy loss

$$\langle E \rangle = E_0 \cdot \exp\left(-\frac{x}{X_0}\right)$$

X_o is the “radiation length” $\propto 1/Z^2$

Inelastic Scattering

Ionisation

Energy loss

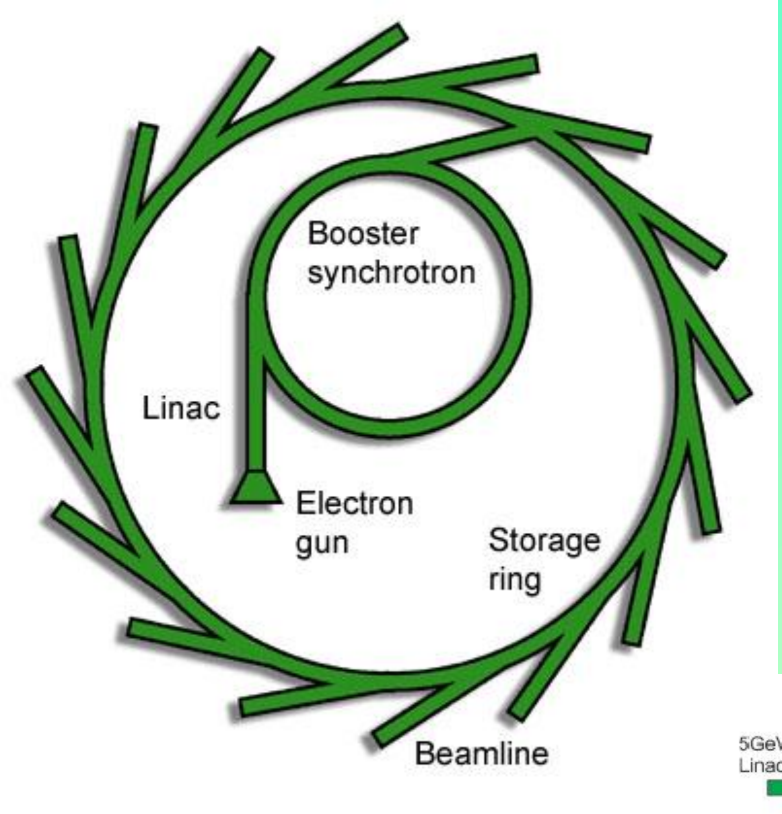
$$\left\langle \frac{dE}{dx} \right\rangle = -4\pi N_A r_e^2 m_e c^2 z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \gamma^2 \beta^2}{I^2} T^{max} - \beta^2 - \frac{\delta}{2} \right]$$

Accelerator Vacuum Specification

- From such considerations, the accelerator physicist will calculate the permissible beam-gas interactions to give the desired performance of the accelerator
- For this a basic design (lattice and apertures) will be required
- The vacuum specification will then (ideally) be a set of number densities of likely gas species at all points around the machine

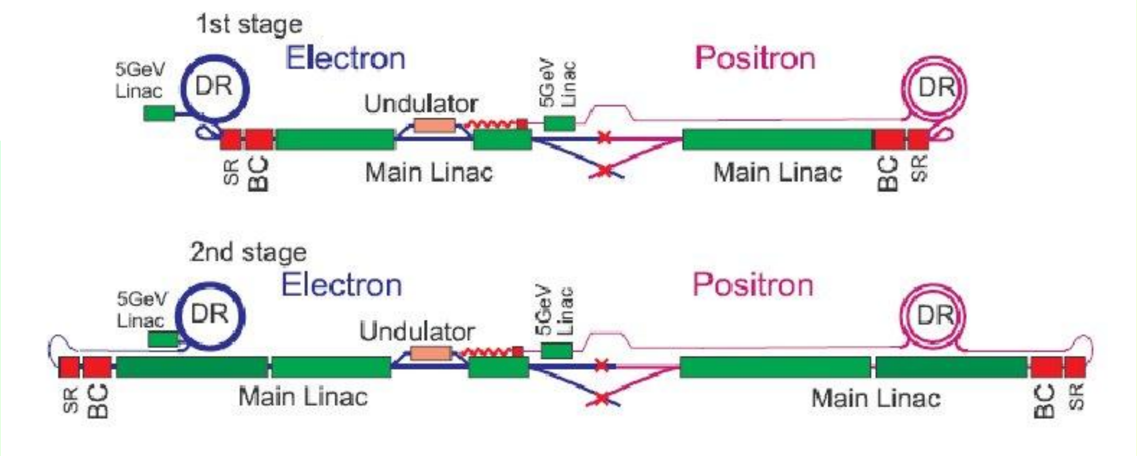
Accelerator Vacuum Design

- The task of the vacuum scientist/engineer is then to
  - design the containment system and any specialist mechanical items (e.g. scrapers, shutters, beam diagnostic devices)
  - calculate the size, number, position and types of the vacuum pumps necessary to achieve the specified number densities (or pressures)
    - for this a reasonable mechanical design/layout is required
  - Determine the necessary vacuum diagnostics



Booster synchrotron
Linac
Electron gun
Storage ring
Beamline

Design



1st stage
Electron
Positron
5GeV Linac
DR
Undulator
Main Linac
SR
BC
2nd stage

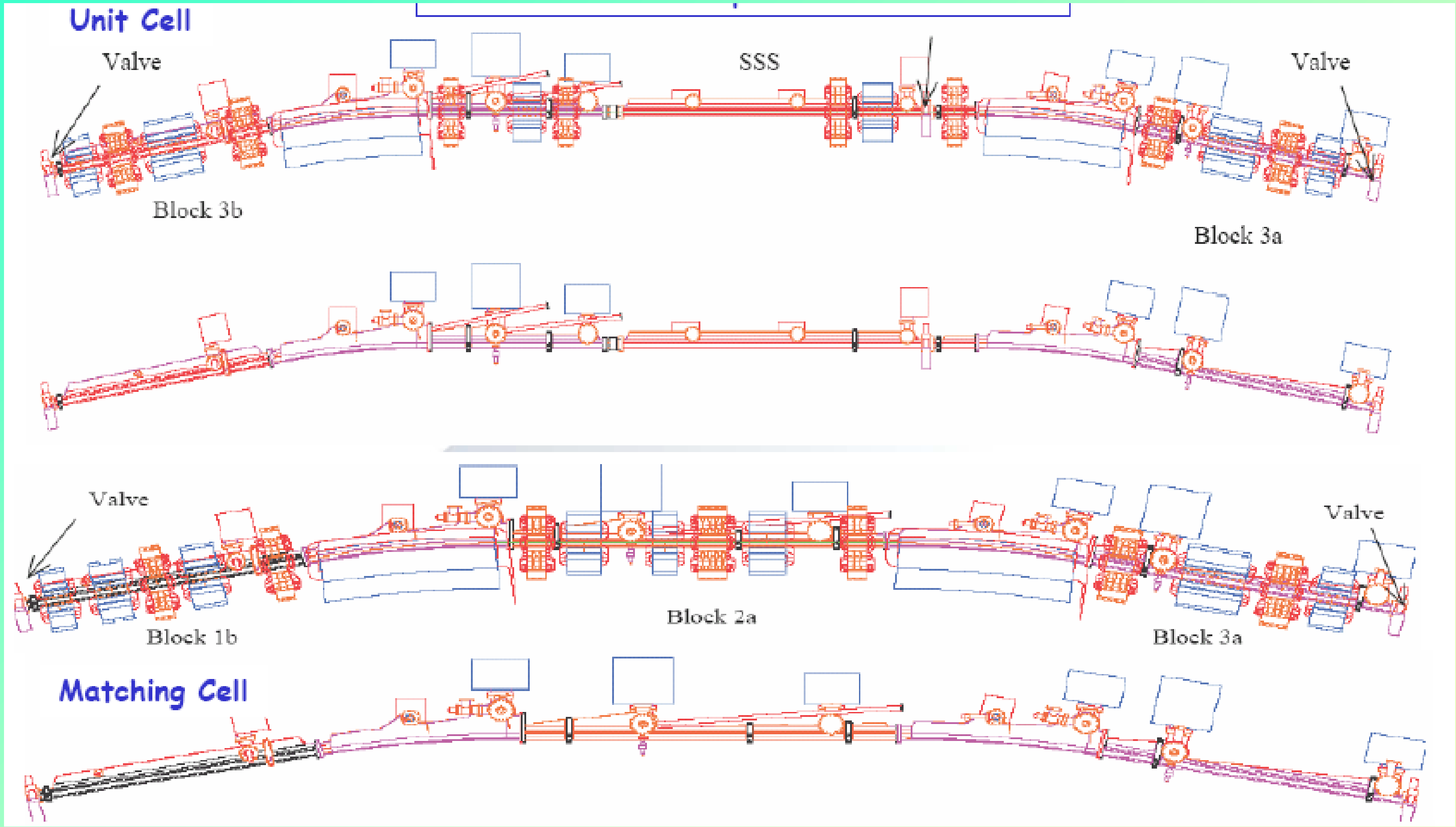
Why is meeting a vacuum specification not a simple process?

- Some things are not well defined
  - Pumping speeds
  - Outgassing/desorption properties of materials
  - Accuracy of vacuum diagnostics
- It is difficult to get enough pumping to where it is required
- There are often conflicting requirements between different disciplines e.g. apertures

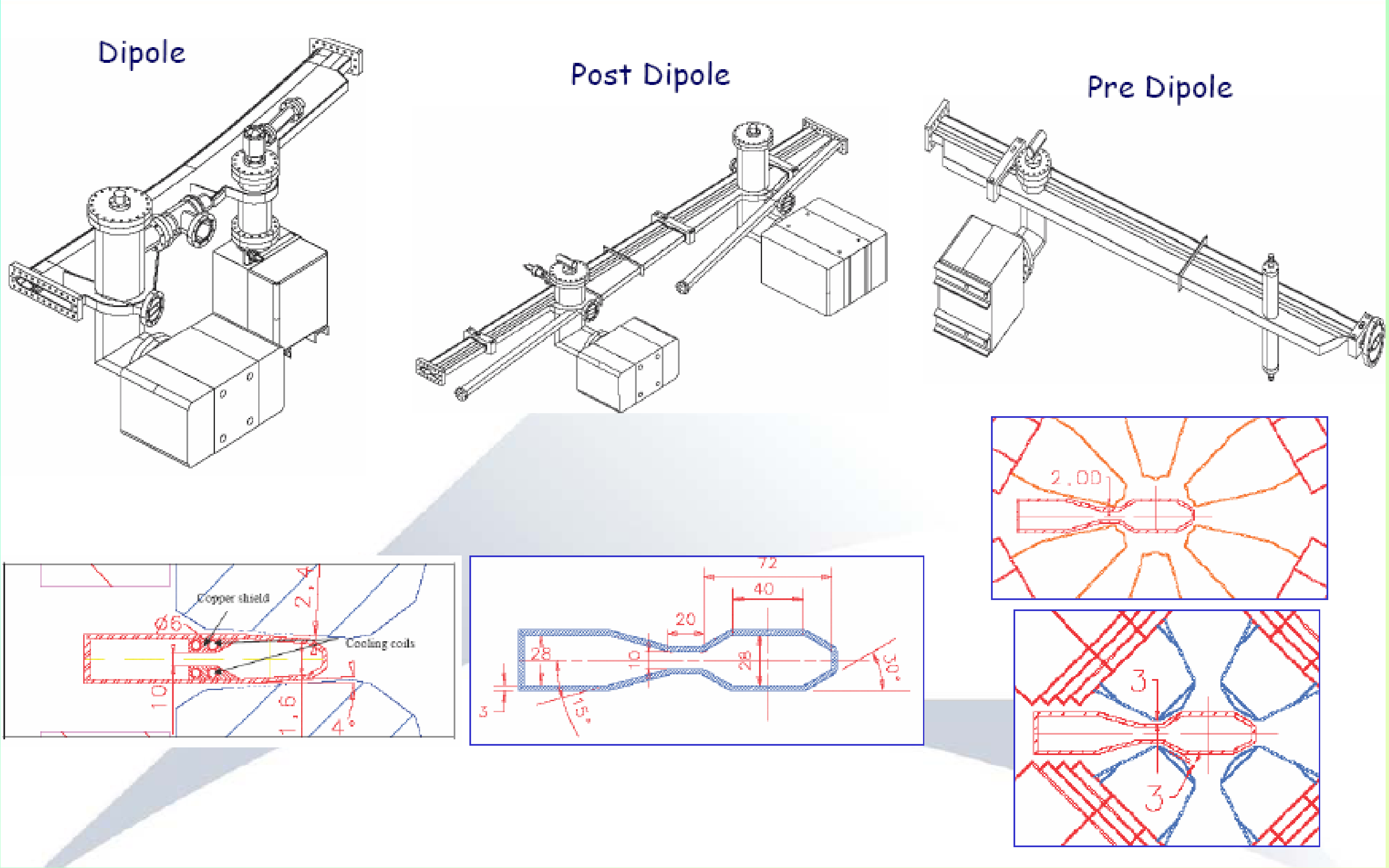
Why is meeting a vacuum specification not a simple process?

- Vacuum calculations are difficult and time consuming
- A good technical solution may be too expensive
- Several design iterations are usually required to reach a satisfactory compromise

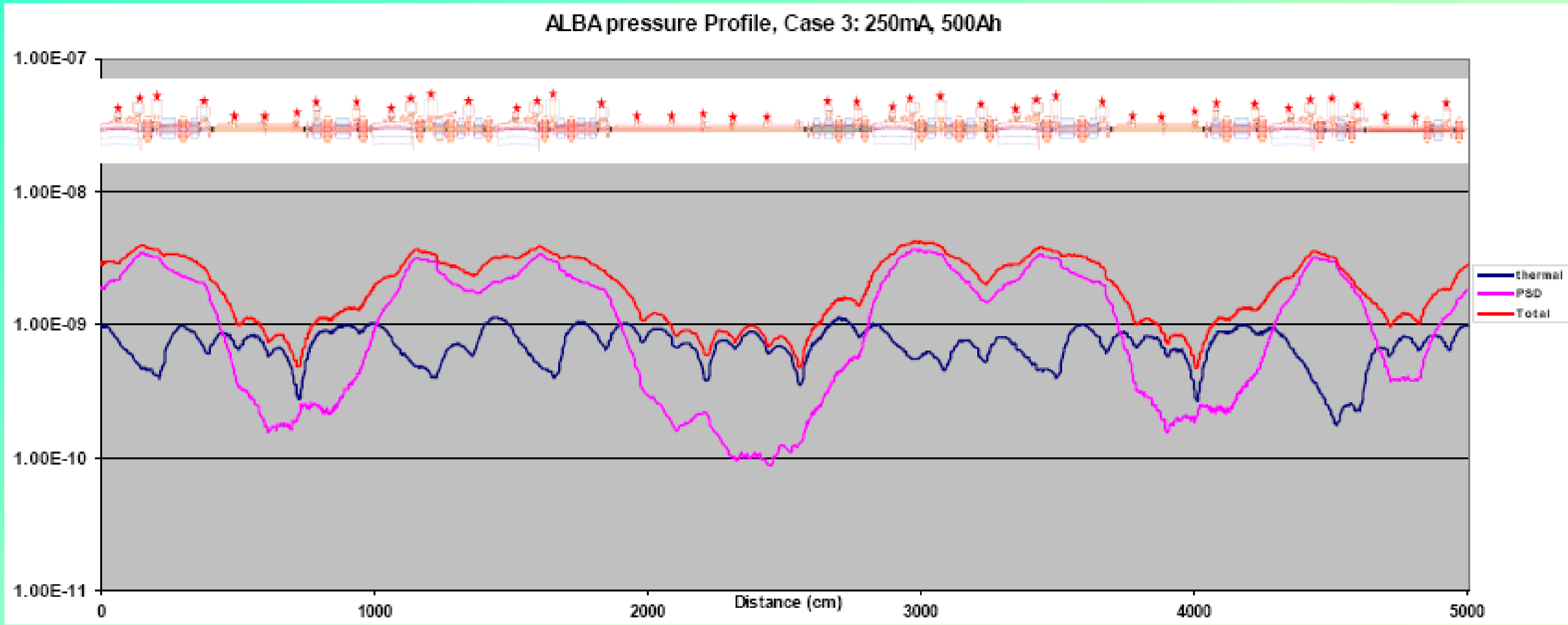
An example


Unit Cell
Valve
SSS
Valve
Block 3b
Block 3a
Valve
Valve
Block 1b
Block 2a
Block 3a
Matching Cell

An example


Dipole
Post Dipole
Pre Dipole
Copper shield
Cooling coils
2.00
72
40
20
28
10
28
30°
15°
3
3
3

An example


ALBA pressure Profile, Case 3: 250mA, 500Ah
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
0
1000
2000
3000
4000
5000
Distance (cm)
thermal
PSD
Total

Select Bibliography

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