Radiation exposure and mission strategies for interplanetary manned missions and interplanetary habitats

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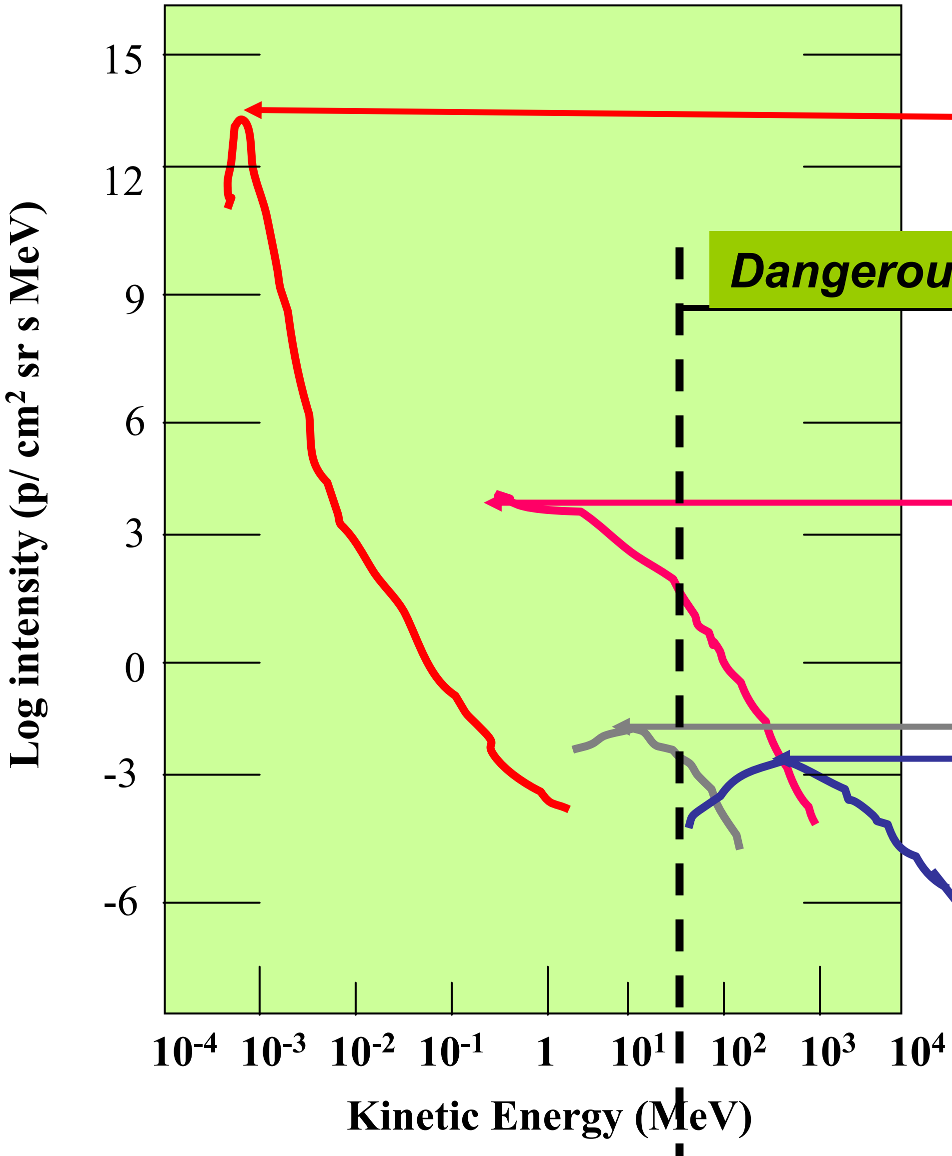
Spectra of energetic c.rays (indicative)

Mainly protons



Solar Wind
($flux=10^{16}flux_{GCR}$)

Comparison purpose

Sporadic, unpredictable

SCR
($flux_{max}=10^{6}flux_{GCR}$)

(ACR)

GCR

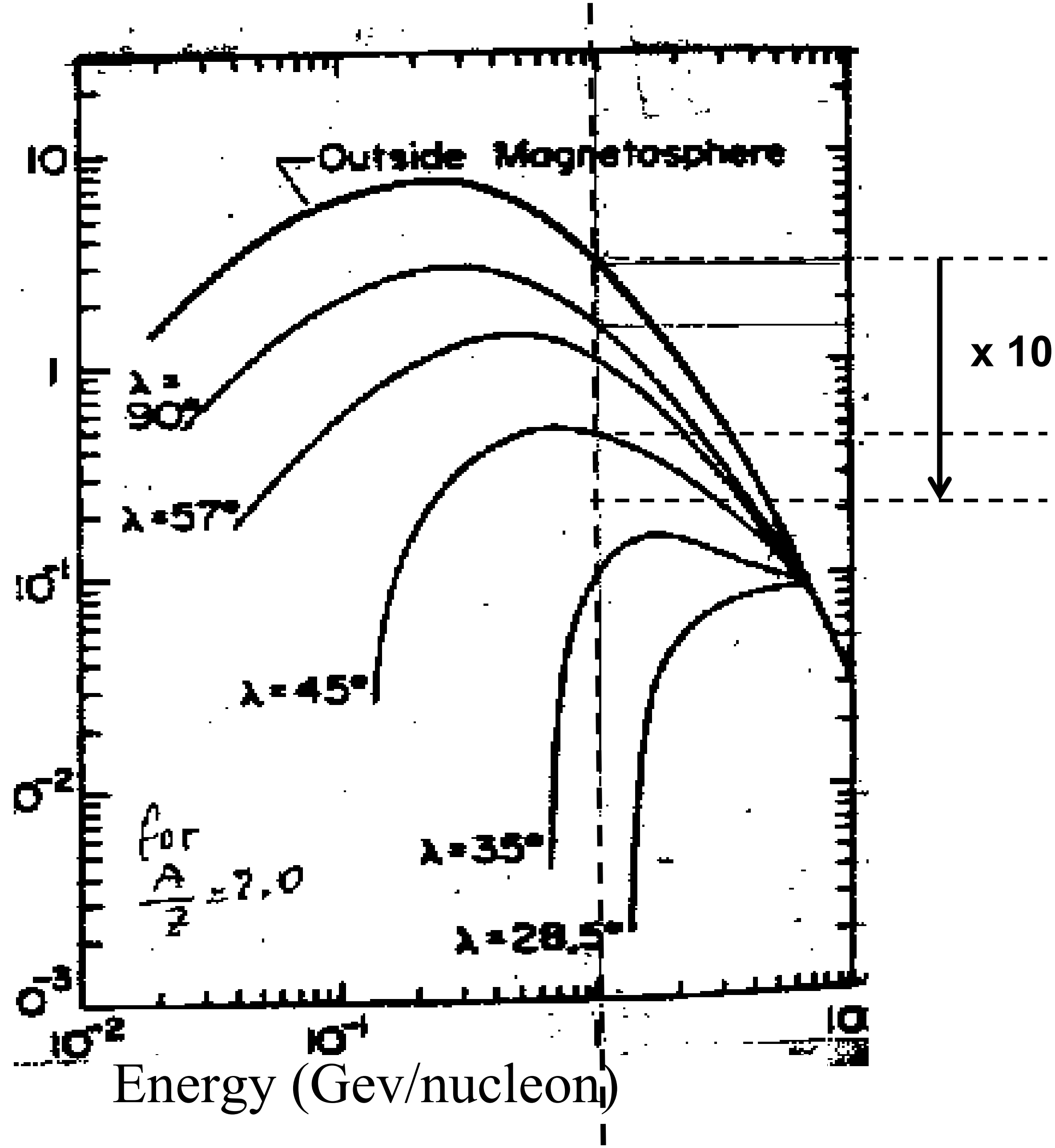
Penetrating SS from outside
≈ constant flux

We are protected from GCR by:

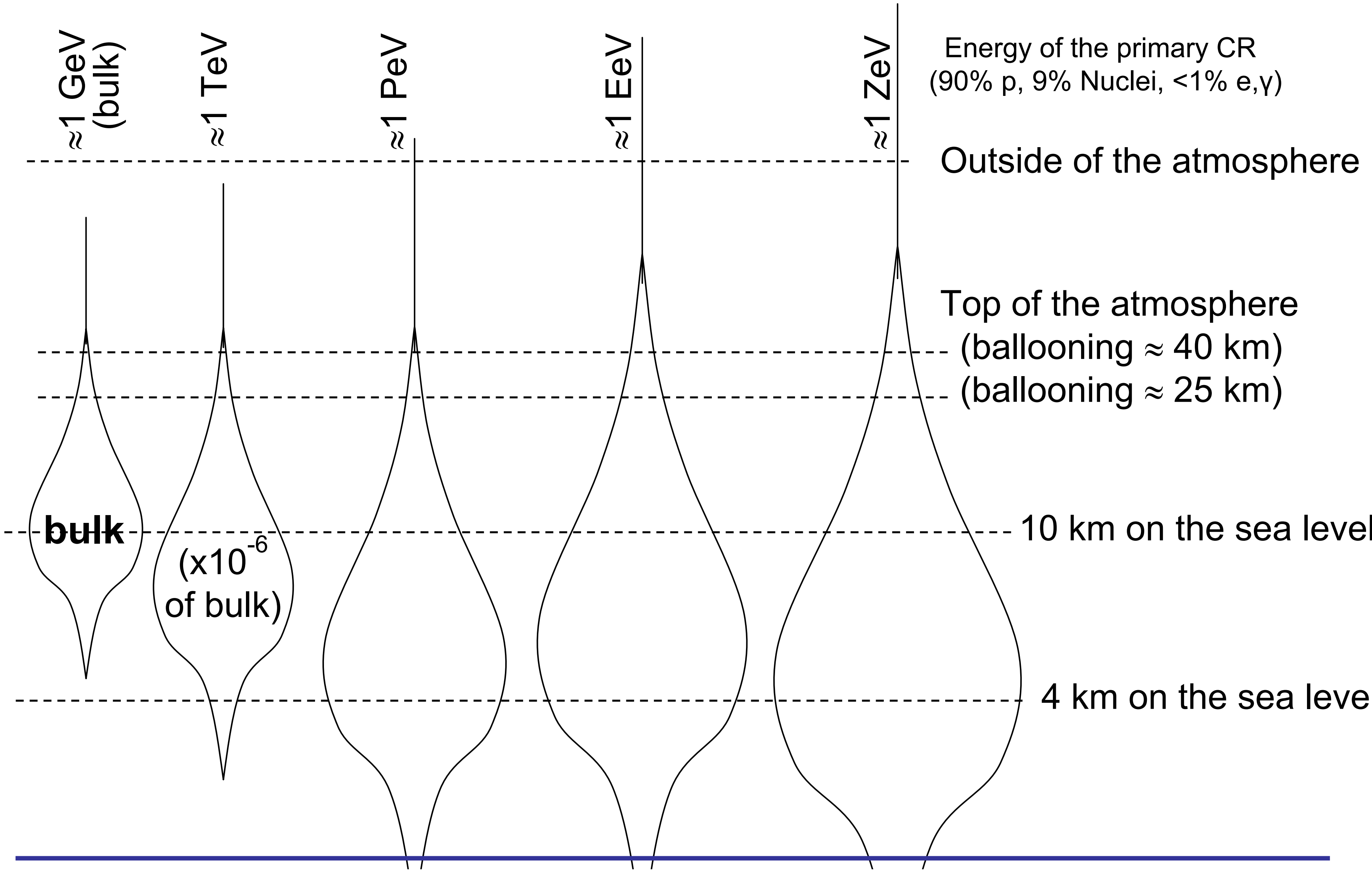
At 1 AU (Earth orbit) by solar magnetic field (solar wind) — 10^{-1} @ 1GeV, 10^{-2} @ 500 MeV

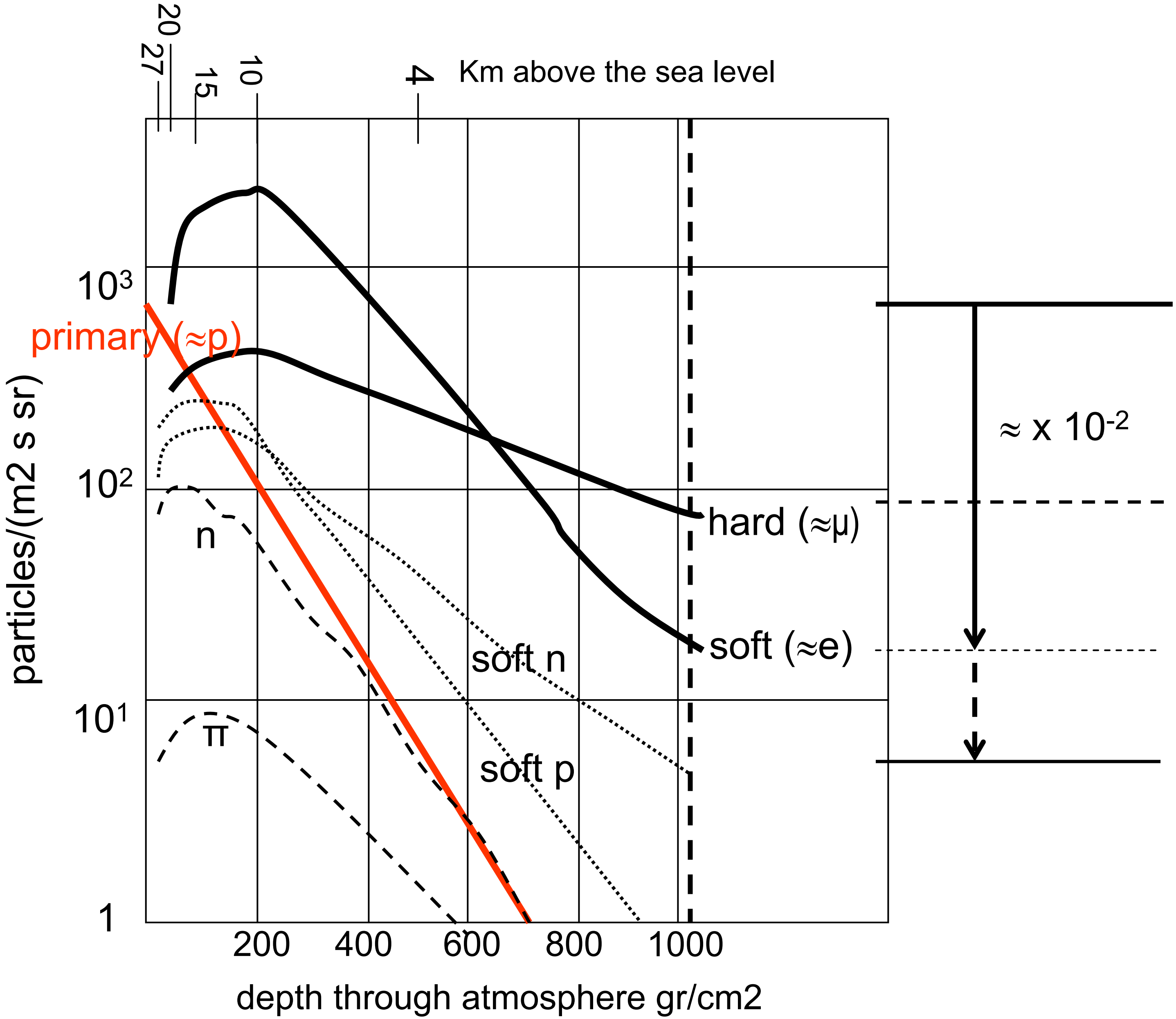
Near the Earth (about 10 R_{Earth}) by terrestrial magnetic field — 10^{-1} @ 1GeV At 45º latitude

On the Earth surface by the Earth atmosphere — a further 10^{-2} @ all latitudes


Outside Magnetosphere
λ = 90°
λ = 57°
λ = 45°
λ = 35°
λ = 28.5°
for A/Z = 2.0
x 10^-1
10
1
10^-1
10^-2
10^-3
10^-2
10^-1
10
Energy (Gev/nucleon)

Showers of CR in the atmosphere





Km above the sea level
27
20
15
10
4
10³
10²
10¹
1
particles/(m2 s sr)
primary (≈p)
n
π
soft n
soft p
hard (≈μ)
soft (≈e)
≈ x 10⁻²
200
400
600
800
1000
depth through atmosphere gr/cm2

Shielding in space is problematic:

Passive shielding (absorbers)

- enough for SCR (but huge masses needed)
- GCR very penetrating
- absorbers inefficient (secondary production)

Active systems are necessary for

- long duration manned missions

Active protection from CR: historical introduction

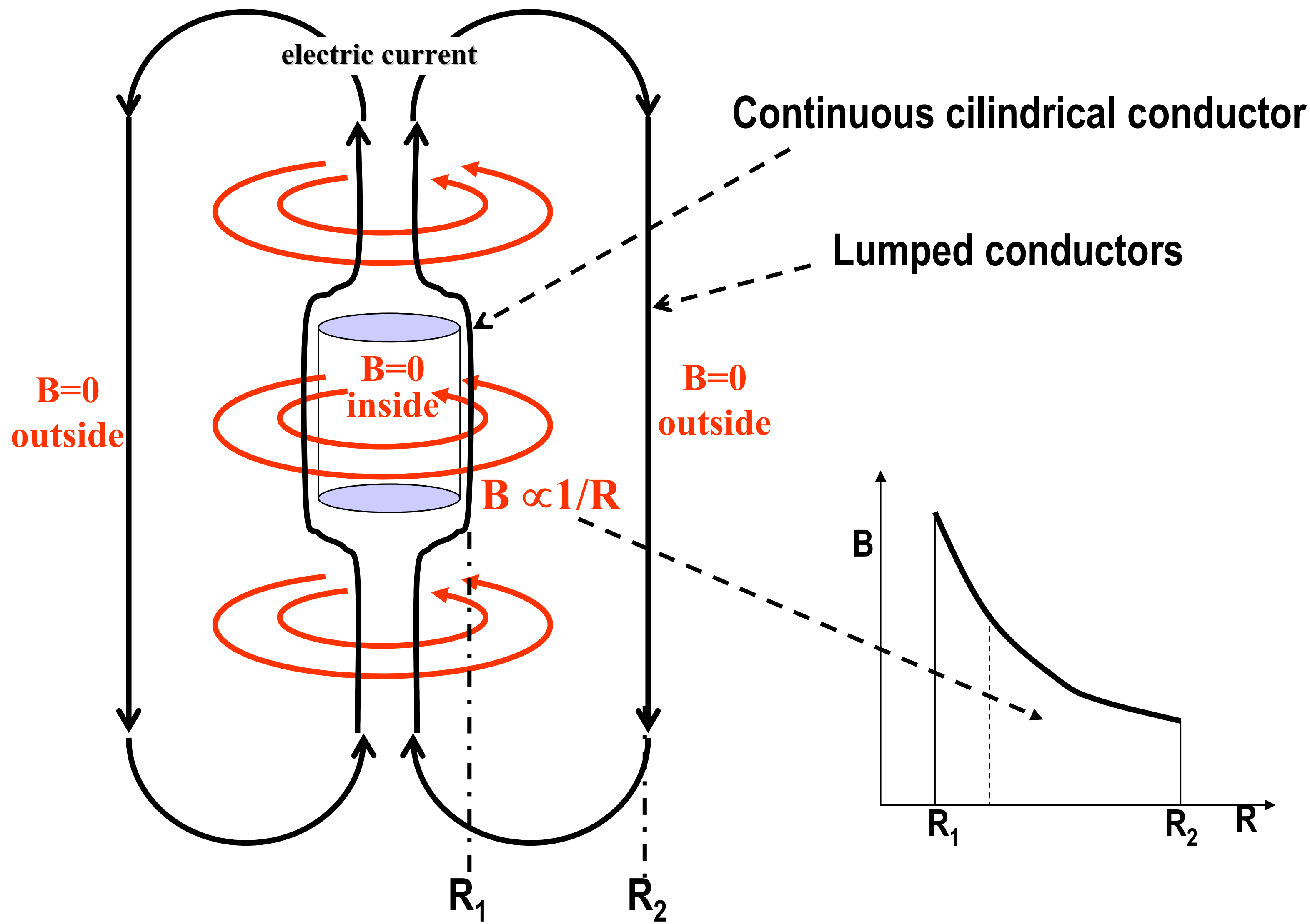
60s → 90s several ideas were considered, no technical projects
(mainly in USA)
(URSS: some work on superconductivity in space).

(1985-90 two feasibility study of the ASTROMAG facility
for CR on board of the Freedom SS.)

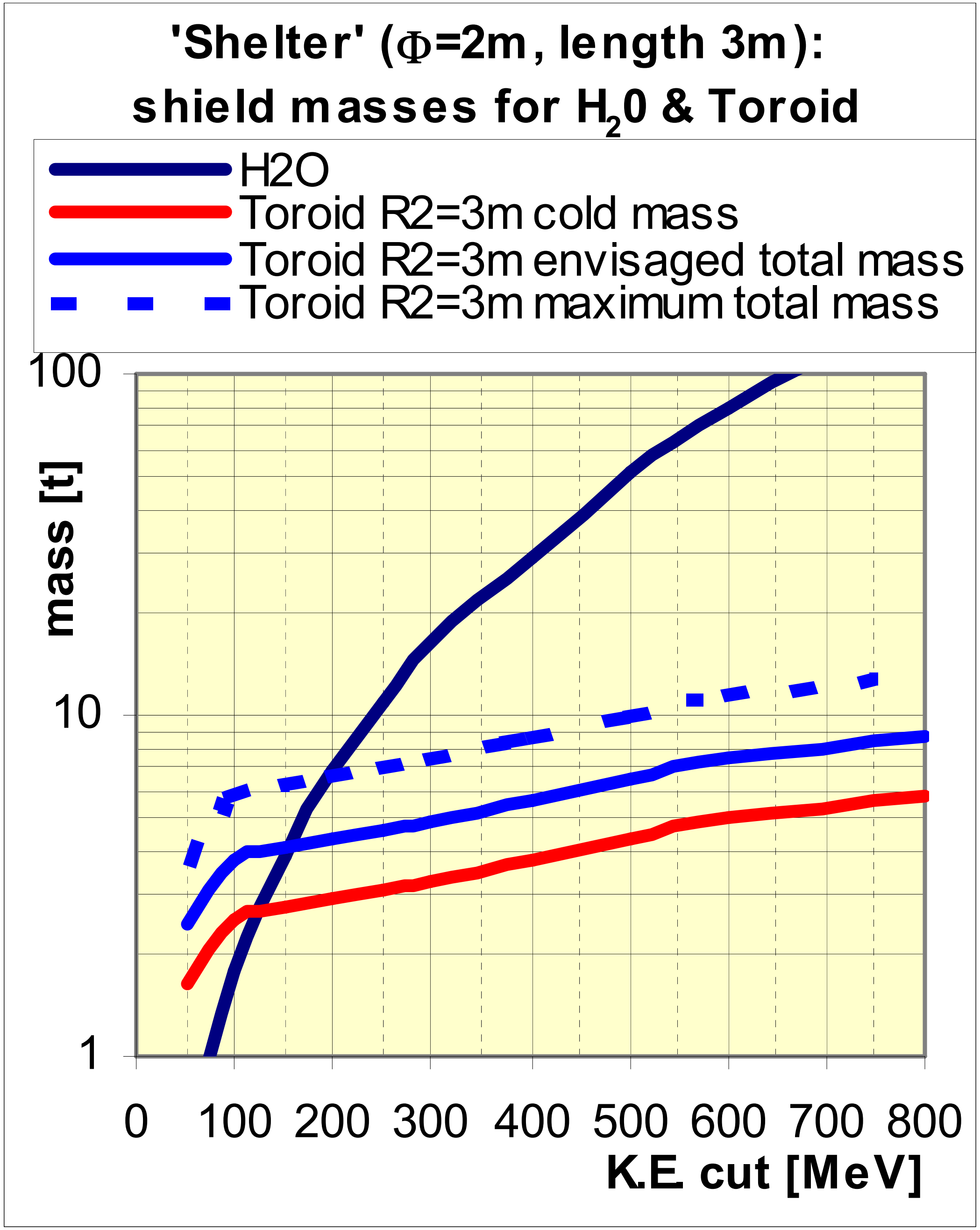
2000 review of available techniques and optimization of the working point for superconducting magnets for space applications
(INFN-Milan (L.Rossi and L.Imbasciati))

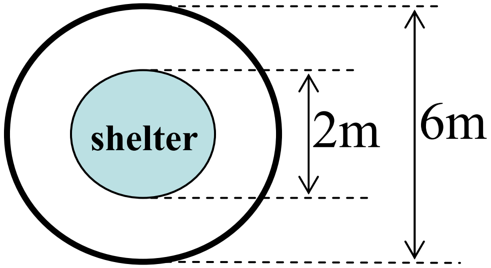
2002-2004 ESA international **Topical Team** on "Shielding from the cosmic radiation for interplanetary missions: active and passive methods"

2003-2004 WP "Review and development of active shielding concepts" of the contract **REMSIM** (Radiation Exposure and Mission Strategies for Interpl. Manned Missions) ESA-Alenia *(+EADS Astrium, REM, RxTec, INFN)*.



electric current
Continuous cilindrical conductor
Lumped conductors
B=0
outside
B=0
inside
B=0
outside
B ∝1/R
B
R
R1
R2
R1
R2





Hp:
NbSn sc cable Al sabilized
sc cable current ≤500 A/mm2
CFSM (cryocoolers)

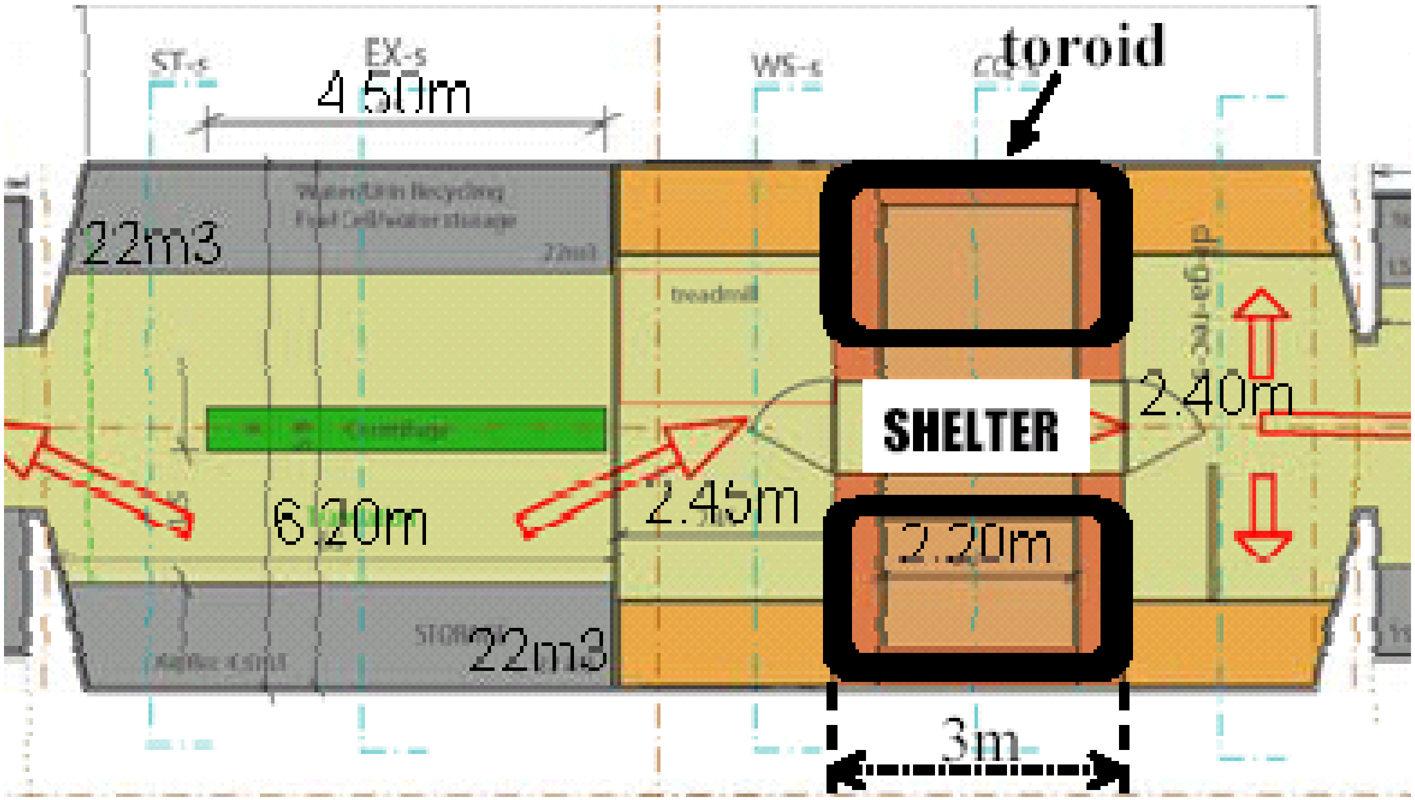
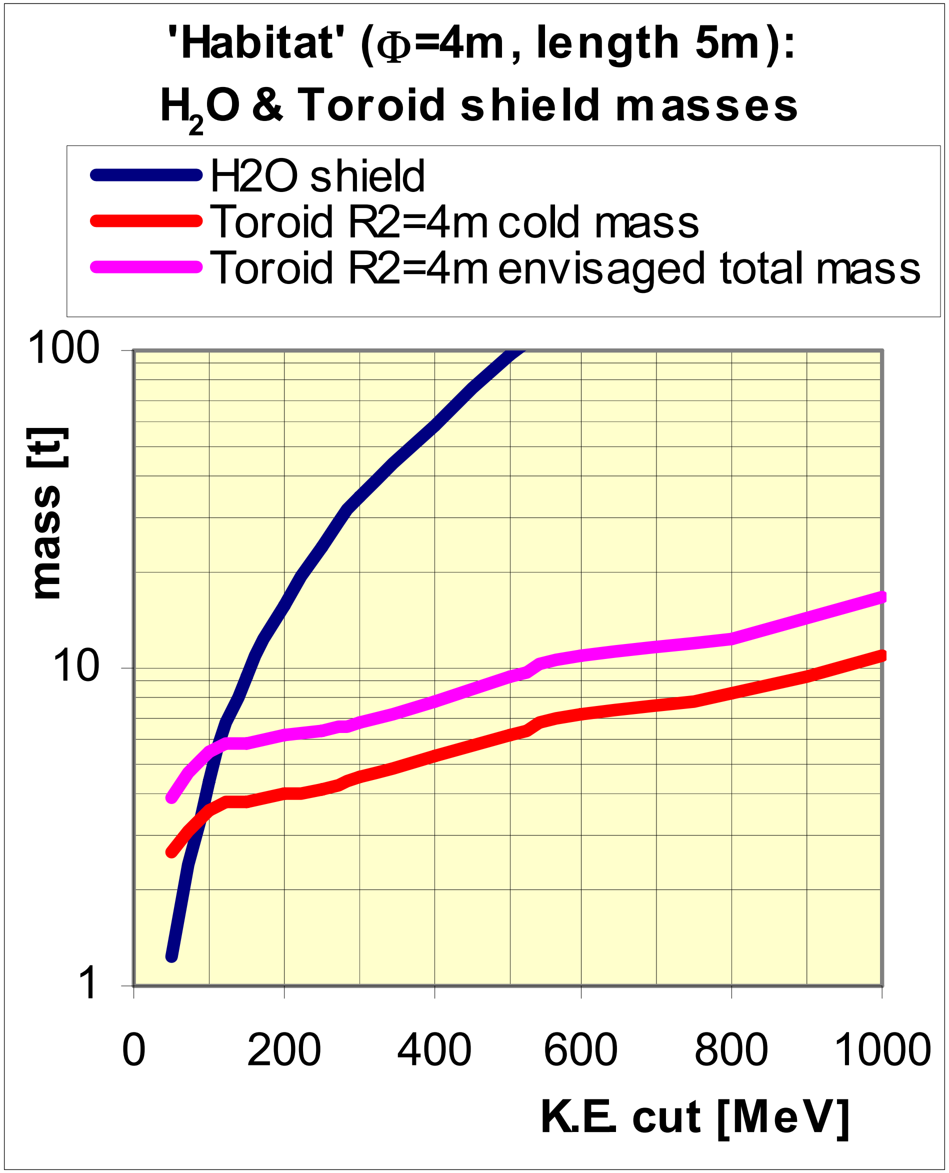
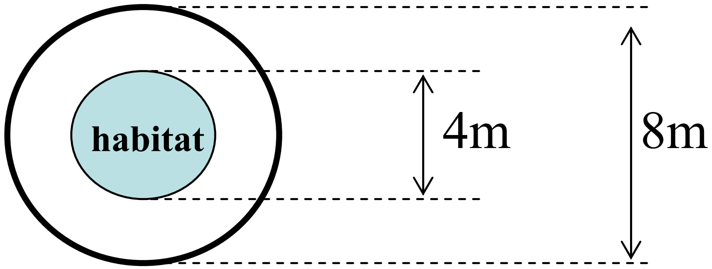


Fig.6.14 - Toroidal shelter (∅ 2m, length 3m) integrated in the habitat scheme of the AURORA CDF concept. At the outer diameter the electric current can be supposed to be returned by a few conductors.





Hp:
NbSn sc cable Al sabilized
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The studies of the past must be updated for several reasons:

Realization and operation
of **huge volume and stored energy superconducting magnets** for
elementary particle physics experiments

Remarkable technical developments of
high temperature superconductors (in particular MgB2 material) and
of the **cooling technique** (cryocoolers for the N2 shielding of AMS-2)

Future missions will be more and more addressed to the
use of **space as a 'forth dimension'**,
such as a collective property for implementing services of
economical and social benefit
involving more and more **private investments**,
with the Space agencies supplying the needed
technical competences, quaranties and controls
in conformity with the political indications of the respective governments

Signals in this direction:

First instances of space tourism

Successes of the SpaceShipTwo private spacecraft

Sudies for the use of Moon for extraction of useful materials (e.g.He3)

Studies for the ‘production’ of large quantity of water on the Moon

‘MoonBase’ initiative activities

Awareness of the importance of using the Lagrange points for achieving scientific results and for supporting commercial activities (e.g L1 for Moon, and Space Highways for transfer of materials)

Expected evolution of human presence in space:

Space Stations → astronauts

⇩

Space bases → astronauts and specialized personnel

⇩

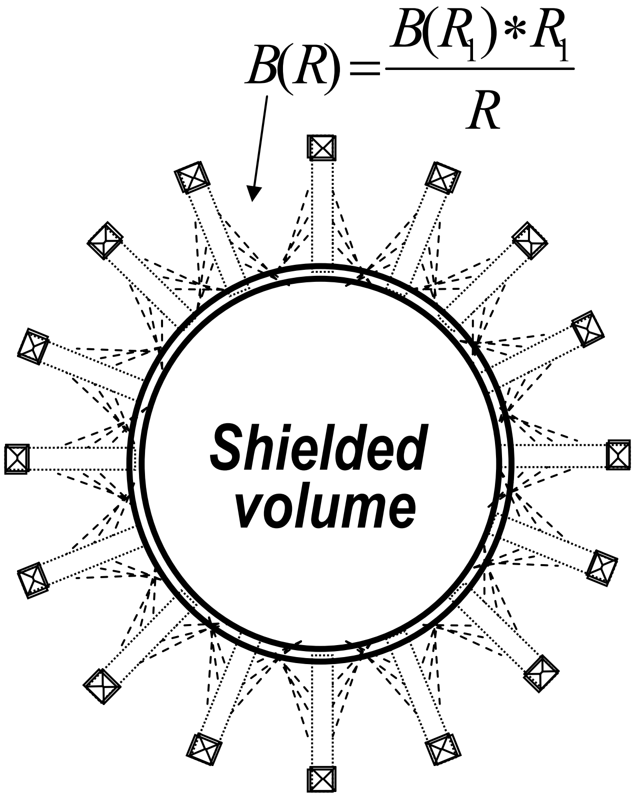
Space 'complexes' → astronauts, specialized personnel and common citizens

<u>further step in GCR protection</u>:

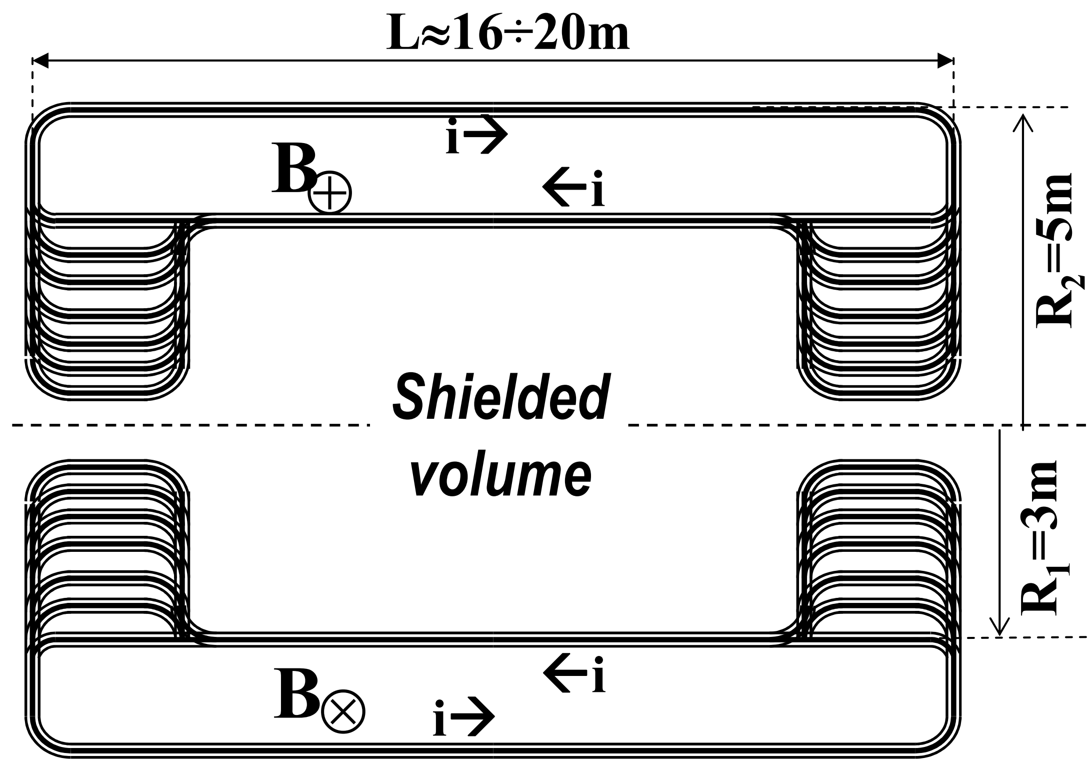
Long permanence in ‘deep’ space
not only
for a relatively small number of astronauts
but also
for citizens conducting ‘normal’ activities

<u>Minimum basic assumptions for the ‘habitat’:</u>

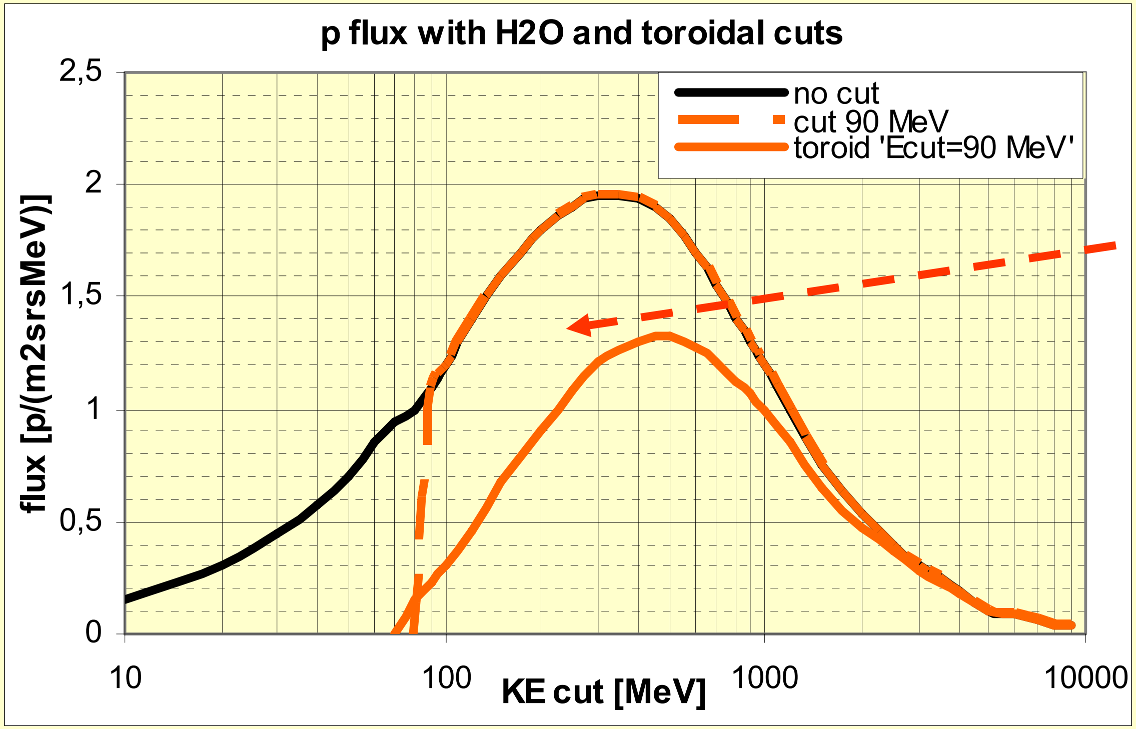
Volume to be protected: Ǿ ≥6m, L=10m
Shroud of the transportation system: Ǿ 10m, L>16m



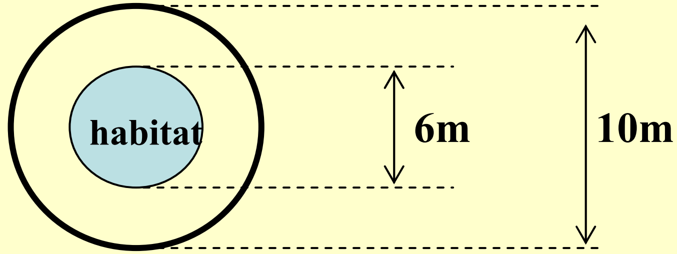
Transverse section

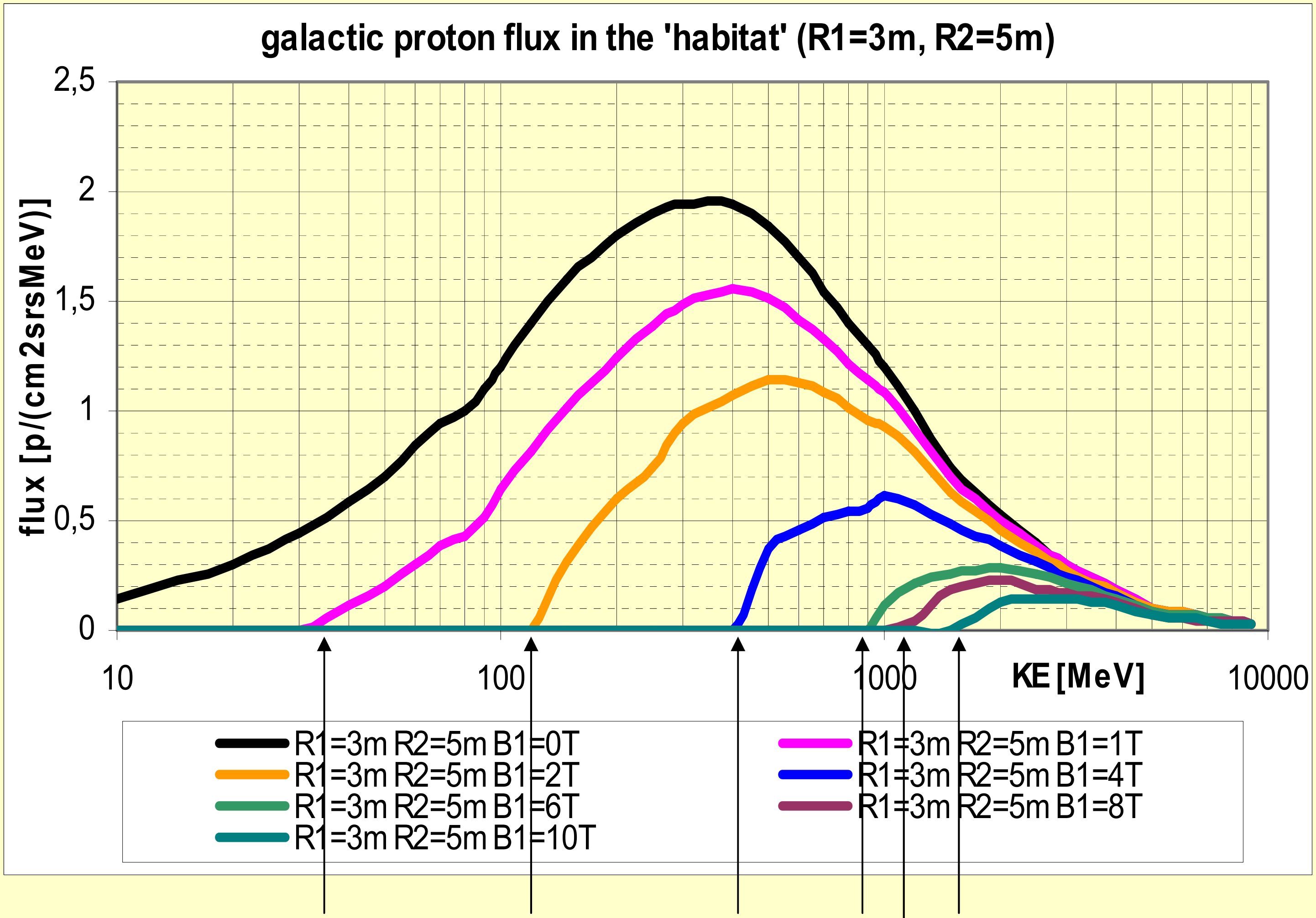


longitudinal section



GCR:
dose reduction between absorber cut and toroid cut
28%





15% **34%** **59%** **75%** **80%** **85%**

GCR dose (Gy) reduction

Technological criteria

- **C**ryogen **F**ree **S**uperconducting **M**agnet -→ ***cryocoolers***

-‘ideal cable’ for space applications (Turin university + Alenia)
thin MgB2 cable produced by the in-situ method in a titanium sheath stabilized outside in aluminum:

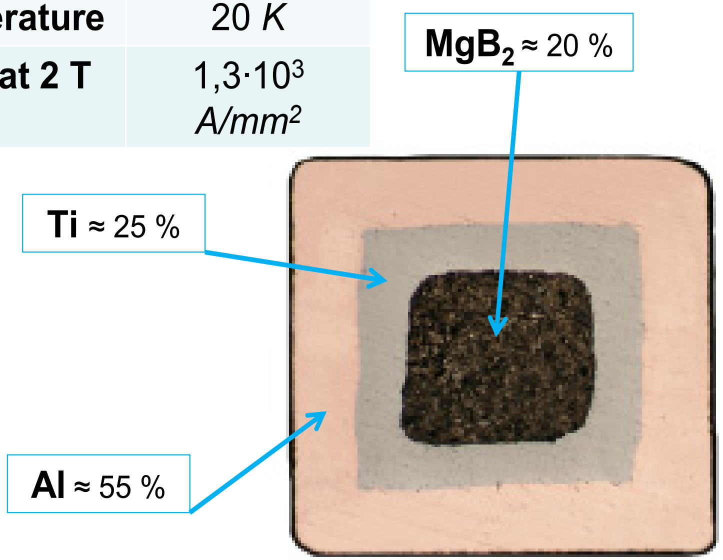
Characteristic	Value
Averaged density	2,96 *g/cm*^{3}
Diameter of the cable	200 *μm*
Section of MgB2	$6{,}28 \cdot 10^{-3}$ *mm*^{2}
Operation temperature	20 *K*
Critical current at 2 T	$1{,}3 \cdot 10^3$ *A/mm*^{2}

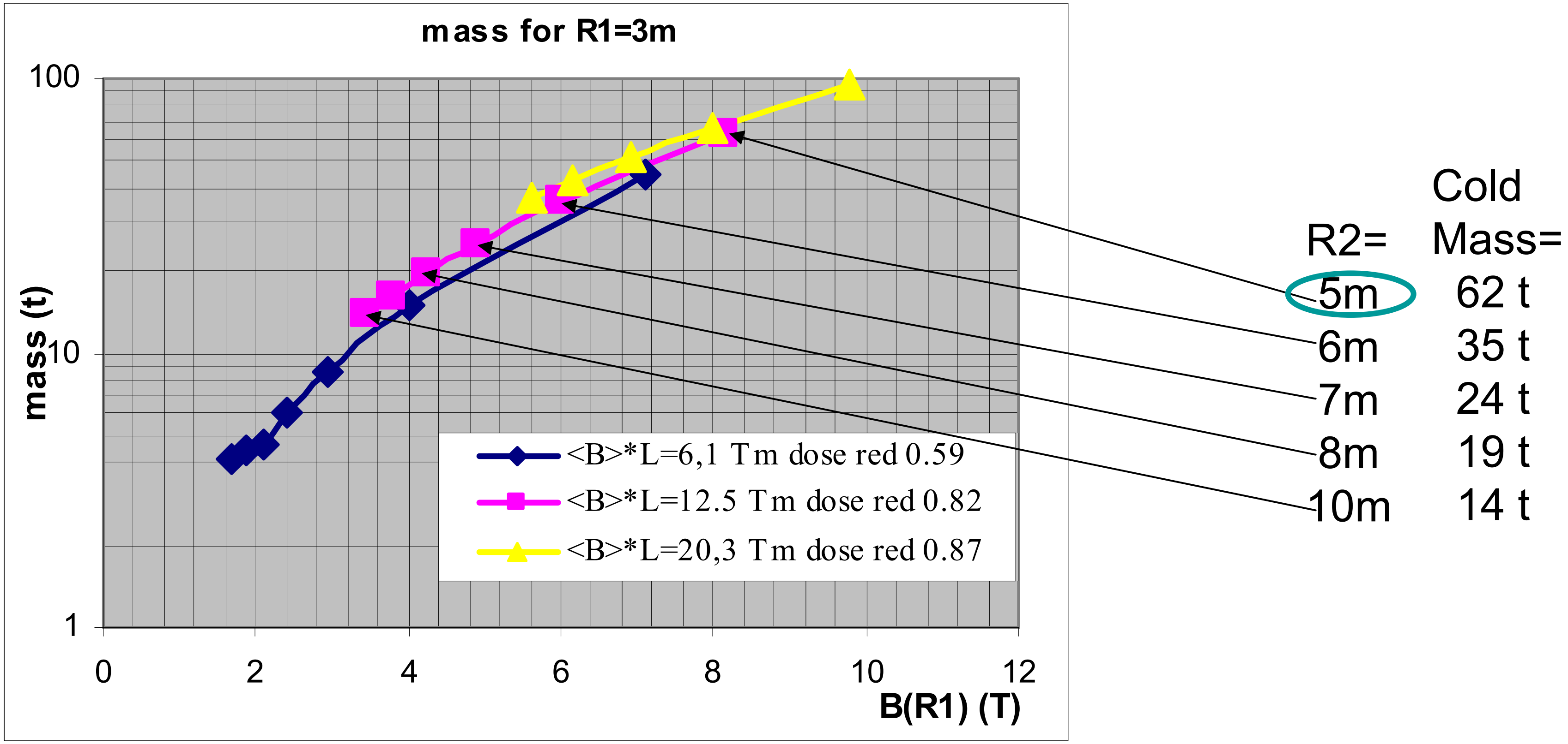
Ideal cable

- Medium operating temperature (20k)

- Low density (3 g/cm3)

- Small section: cables less suffering current and temperature instability, and distributing current in the surrounding cables in case of bad functioning.





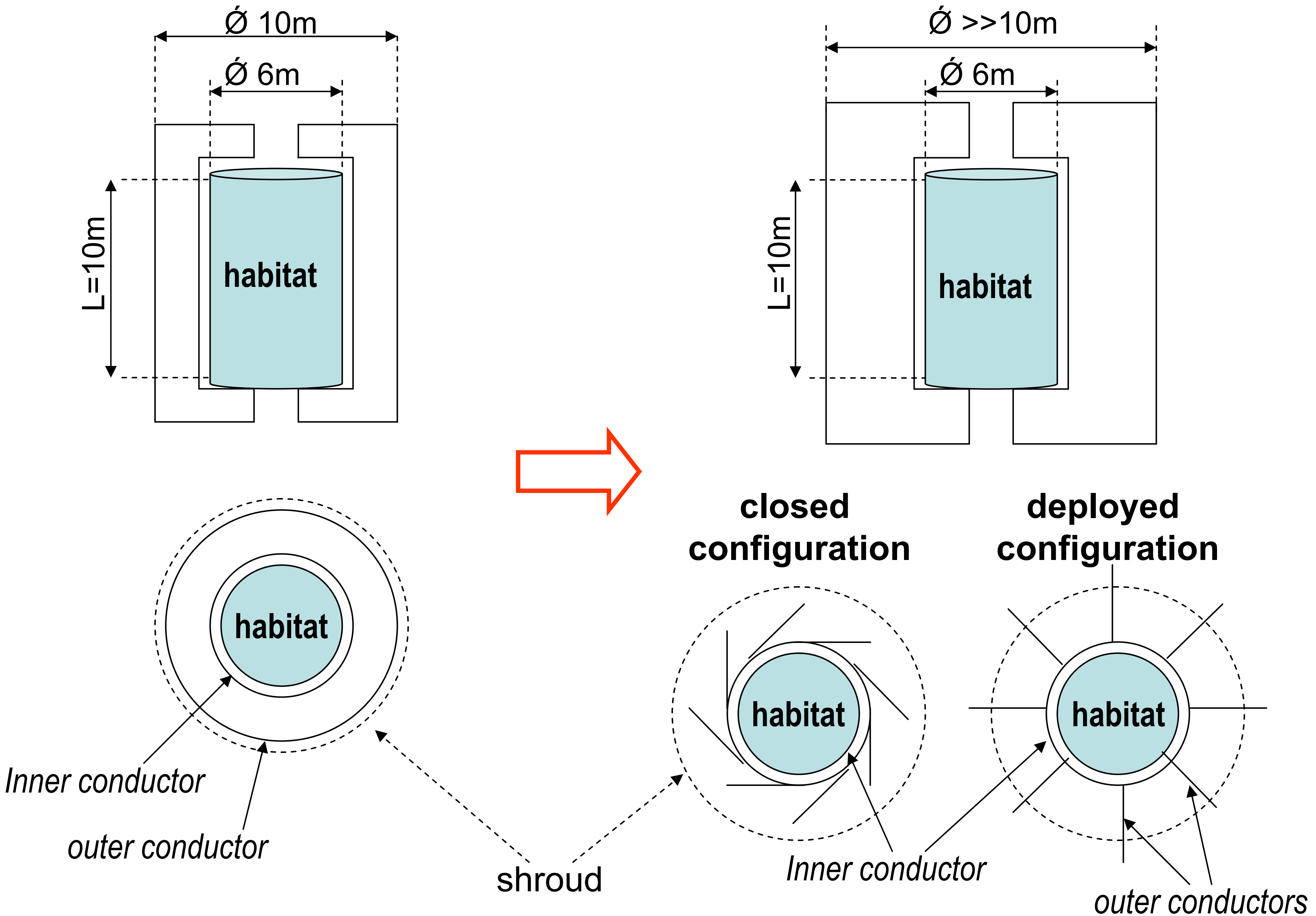
Cold mass for current density in sc cable $1kA/mm^2$ @ 2T

Minimum basic assumptions for the 'habitat':

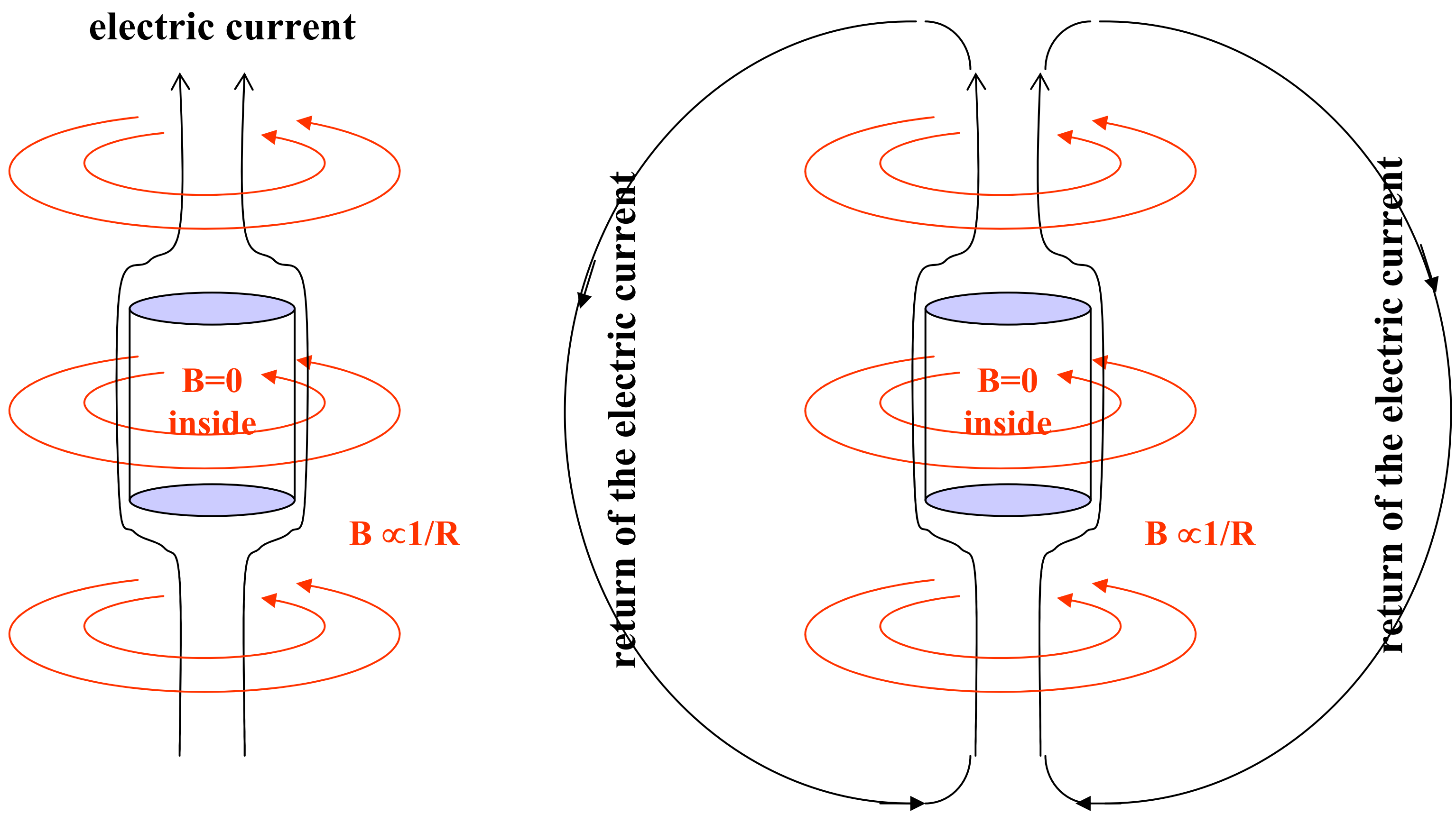
Volume to be protected: Ǿ ≥6m, L=10m
Shroud of the transportation system: Ǿ 10m, L>16m

However:

deployment of return current circuit
must be considered
from the very beginning



Ø 10m
Ø 6m
L=10m
habitat
Ø >>10m
Ø 6m
L=10m
habitat
closed configuration
deployed configuration
habitat
habitat
habitat
Inner conductor
outer conductor
shroud
Inner conductor
outer conductors



- in a **toroidal configuration** the field diminishes at the increasing of the radius, making easier to support the ponderomotive forces.
- the outer part of the system must be **deployed or assembled** in space.

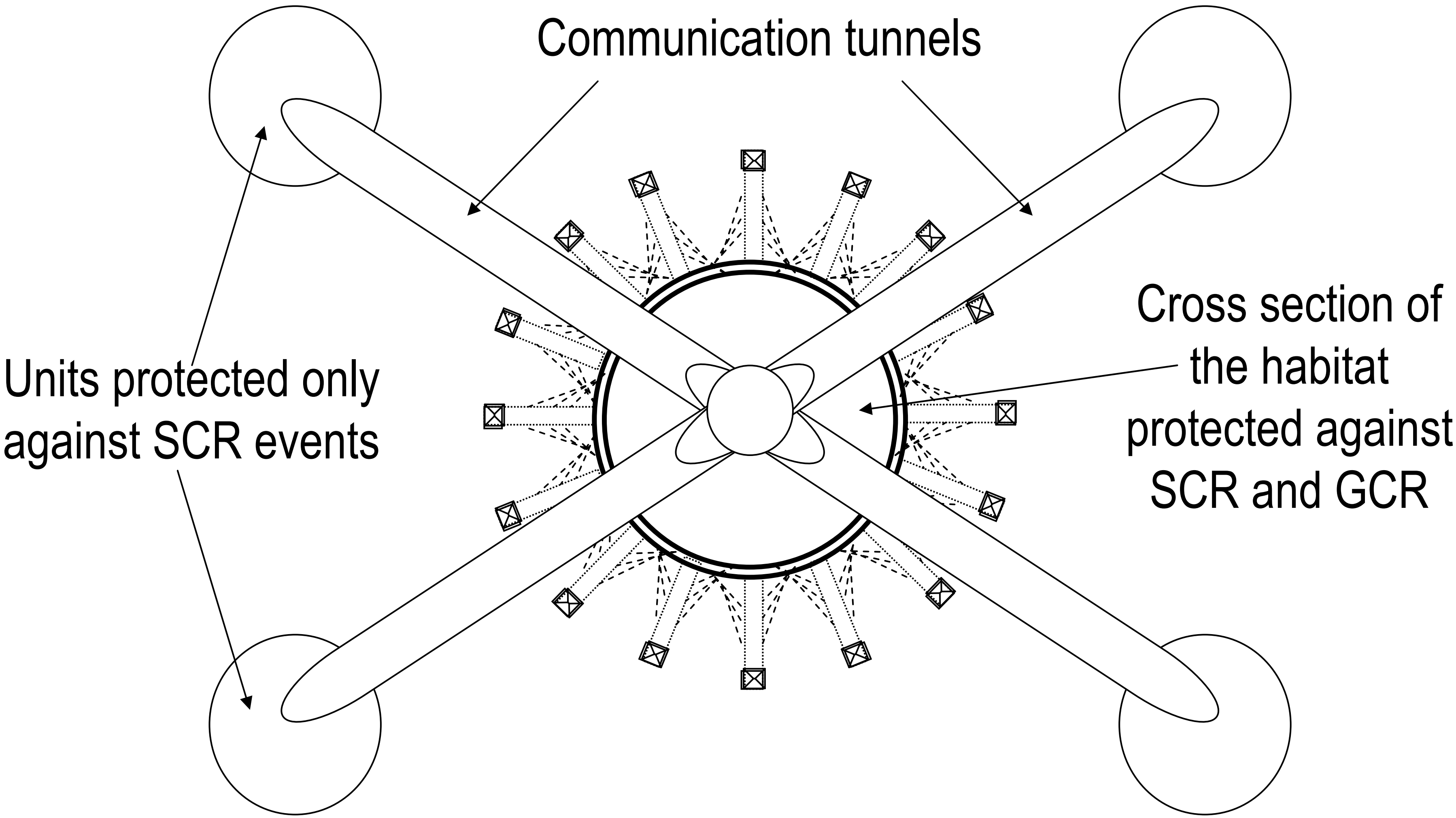
Basic philosophy for the ‘Space Complex’:

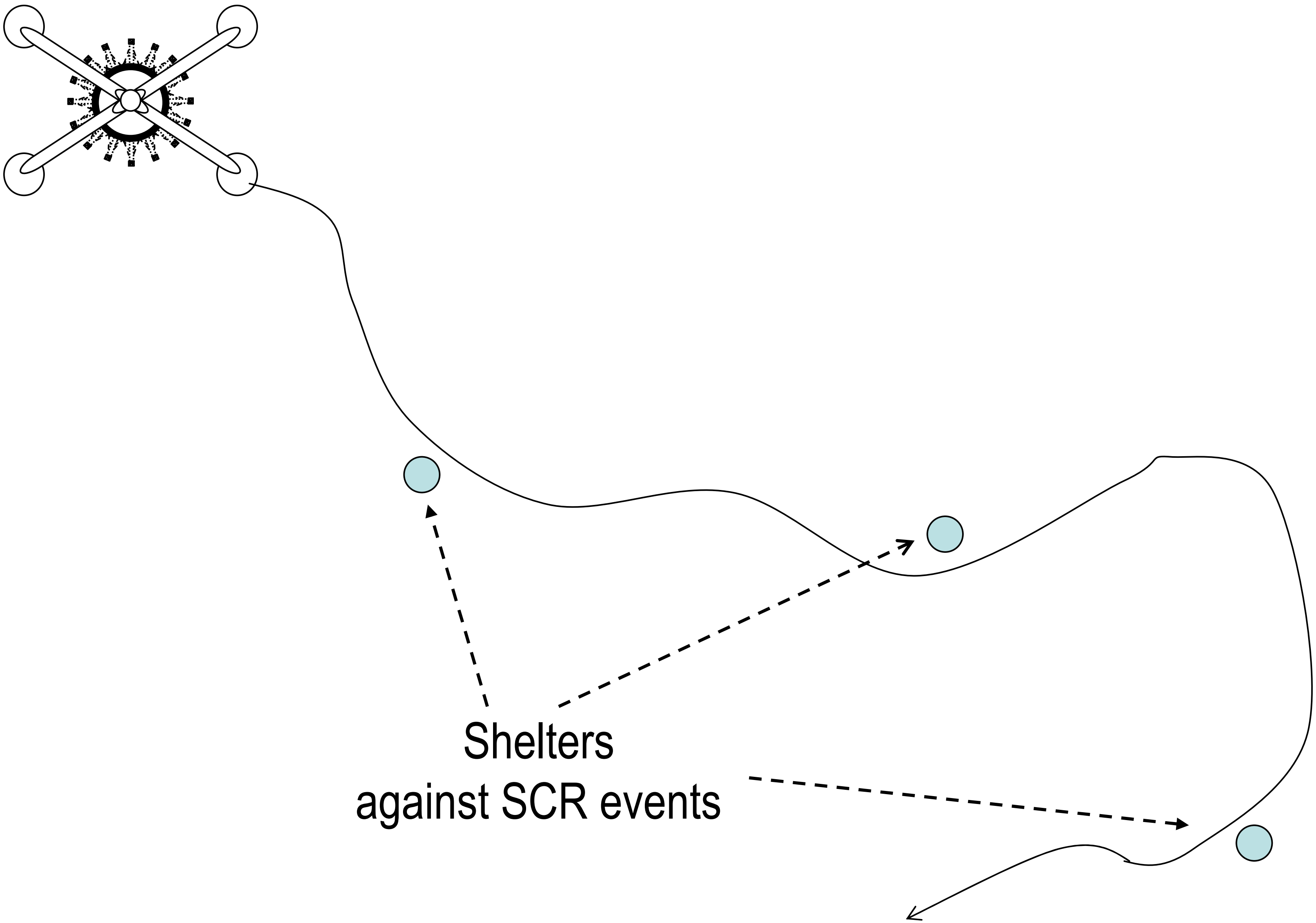
All the modules linked to the protected ‘habitat’
Protected ‘habitat’ can be reached in a few minutes from any point of the Space Complex
‘Habitat’ fully protected from SCR’s.
‘Habitat’ guaranties a factor 5 reduction of GCR dose @ solar minimum

Furthermore:

Journeys during periods of maximum solar activity

Long permanences (>1 year) during periods of maximum solar activity


Communication tunnels
Units protected only against SCR events
Cross section of the habitat protected against SCR and GCR


Shelters
against SCR events

Conclusions

An adequate protection from GCR to a large human community in space is a <u>complex problem</u>, which can be solved in an adequate time provided that a long program of study and R&D will be set up in due time and with the due resources.

It is therefore urgent a professional approach toward the study, project, realization and test of materials, mechanisms, systems, and finally 'space demonstrators', and their integration in manned exploration programs.

Furthermore protection from CR is

- a '<u>niche</u>' where physicists can contribute
- an <u>occasion of collaboration</u> between labs and space agencies
- <u>new technologies</u> to be developped for space propulsion
  (magnetic lenses to control divergence and density of charged material for real-time control of thrust and direction,
  to concentrate it in small volume for further acceleration,
  magnetic bottle for suitable reactions, etc..)