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

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Main difference between LEO and interplanetary flights:
→ no protection by terrestrial magnetic field →
exposure to different radioactive environment

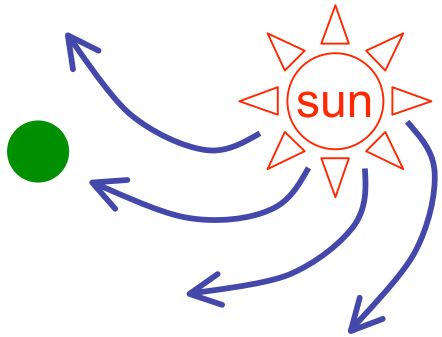
Let state the following problem:

is it possible to create a magnetic field similar
to the terrestrail one around a spacecraft in
a manned interplanetary mission
or around an inhabited ‘space base’ in deep space?

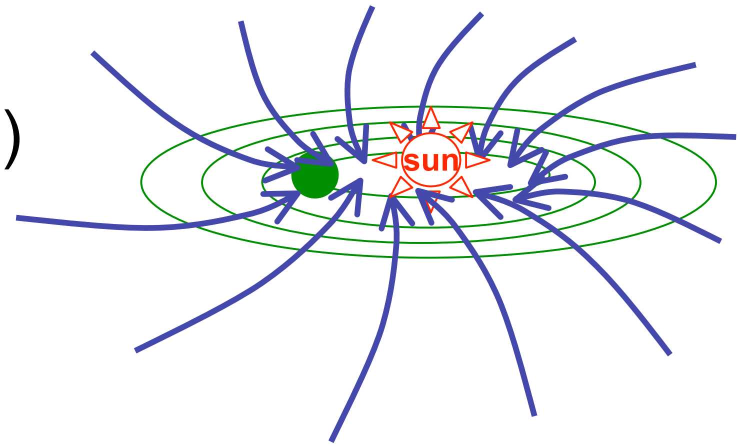
Cosmic Rays

Two main components:

Solar Cosmic Rays (SCR)



Galactic Cosmic Rays (GCR)



SCR

mainly protons

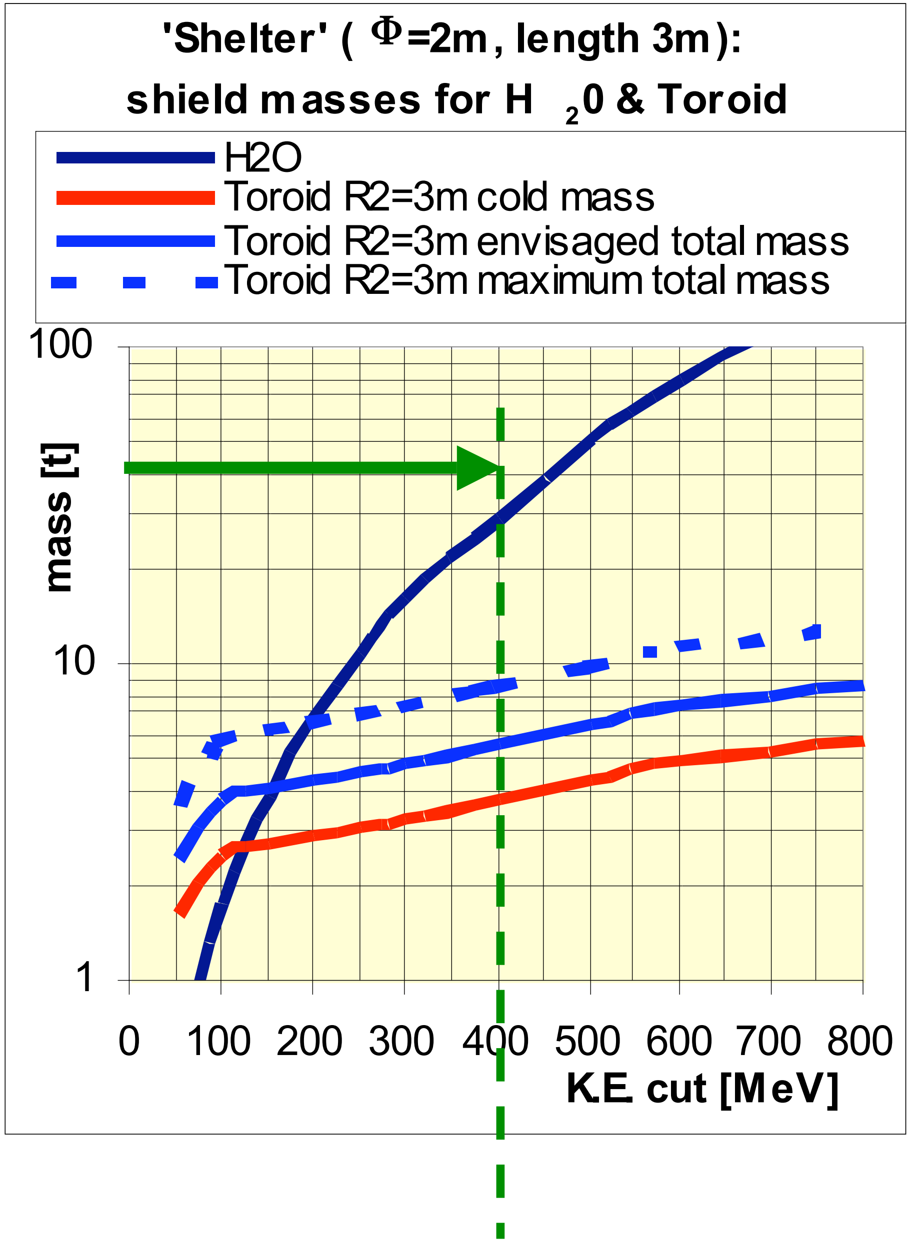
‘sporadic’ solar events

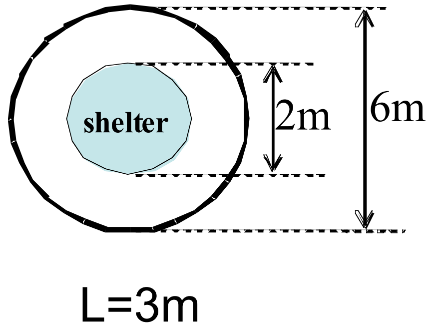
seldom (10 events / 55 years) fluence/event higher
than fluence of GCR/year (up to ≤ 400 MeV)

→ necessary a‘storm shelter’ ($V \approx 10m^3$, ‘spartan’)

→ passive shield possible (water 4-8 t)
highly-hydrogenated materials (such as polyethylene or water).

→ magnetic shield saves 2/3 of the mass





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

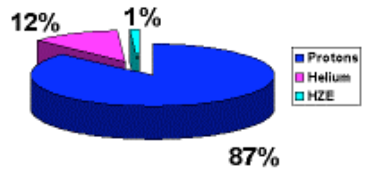
GCR

protons + ions

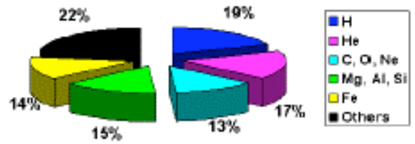
continuous flux (11 year cycle)

ratio Solar min / Solar Max (in Gy/y)

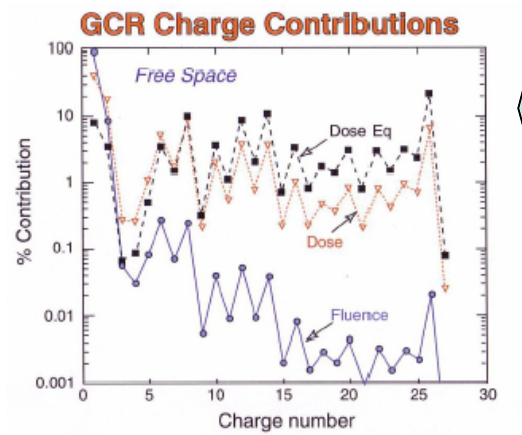
	proton	helium	iron
10 MeV	2.24	2.34	2.18
100 MeV	2.22	2.28	2.12
1 GeV	1.63	1.67	1.3
10 GeV	1.01	1.003	1



(a) Composizione della parte barionica dei GCR



(b) Contributo alla dose equivalente



→ ‘Dose’/year (Gy/y) ≥ carrier limits

Massive passive shielding:

also if enough for short manned missions (e.g. to Moon)

- unable to solve problem for long duration permanence in space because:

(a) passive shield not effective (ever couterproductive);

(b) protection of large volume 'habitat' (where men live and work) needed during the whole duration of mission .

from

'storm shelter' concept ($\approx 1m^3$/man)

to

'habitat' concept ($\approx 50-100m^3$/man)

Active protection from ionizing radiation:

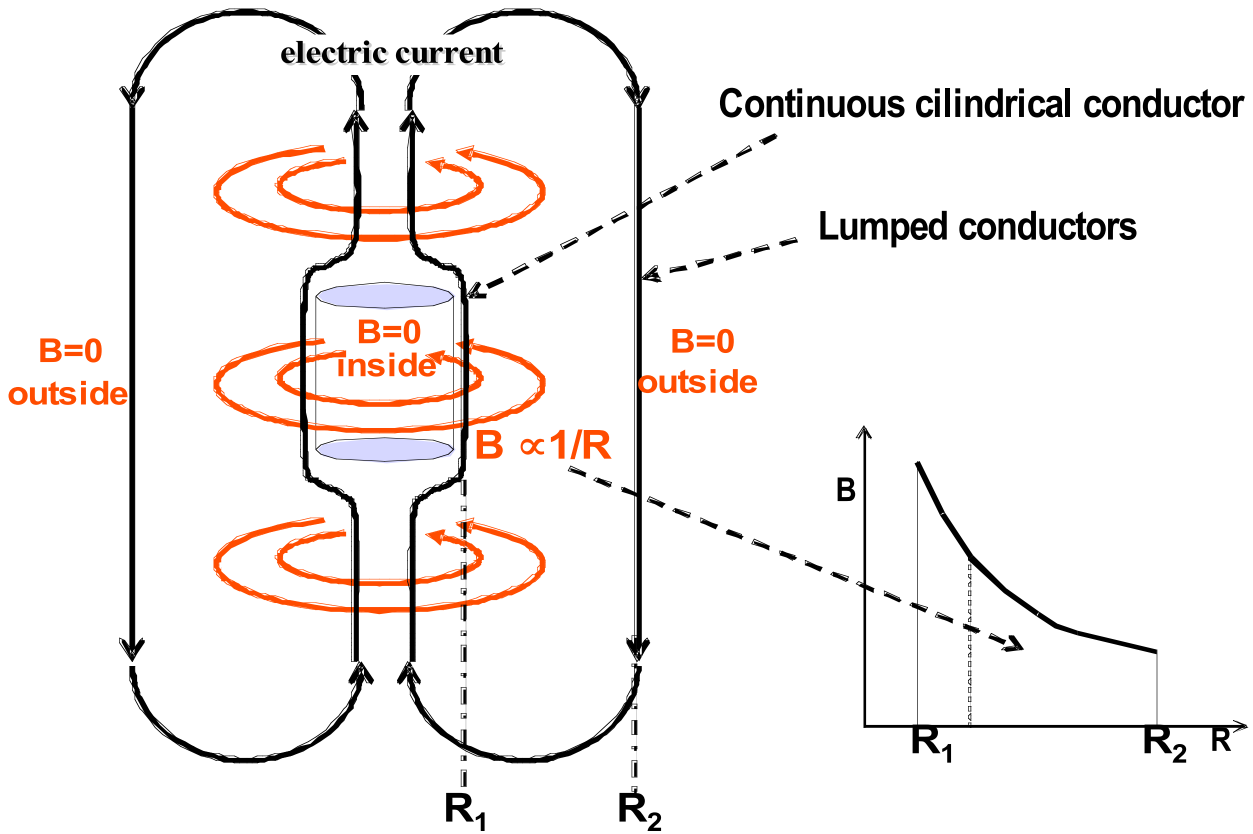
Work made in Europe

Activities in last decade in Europe

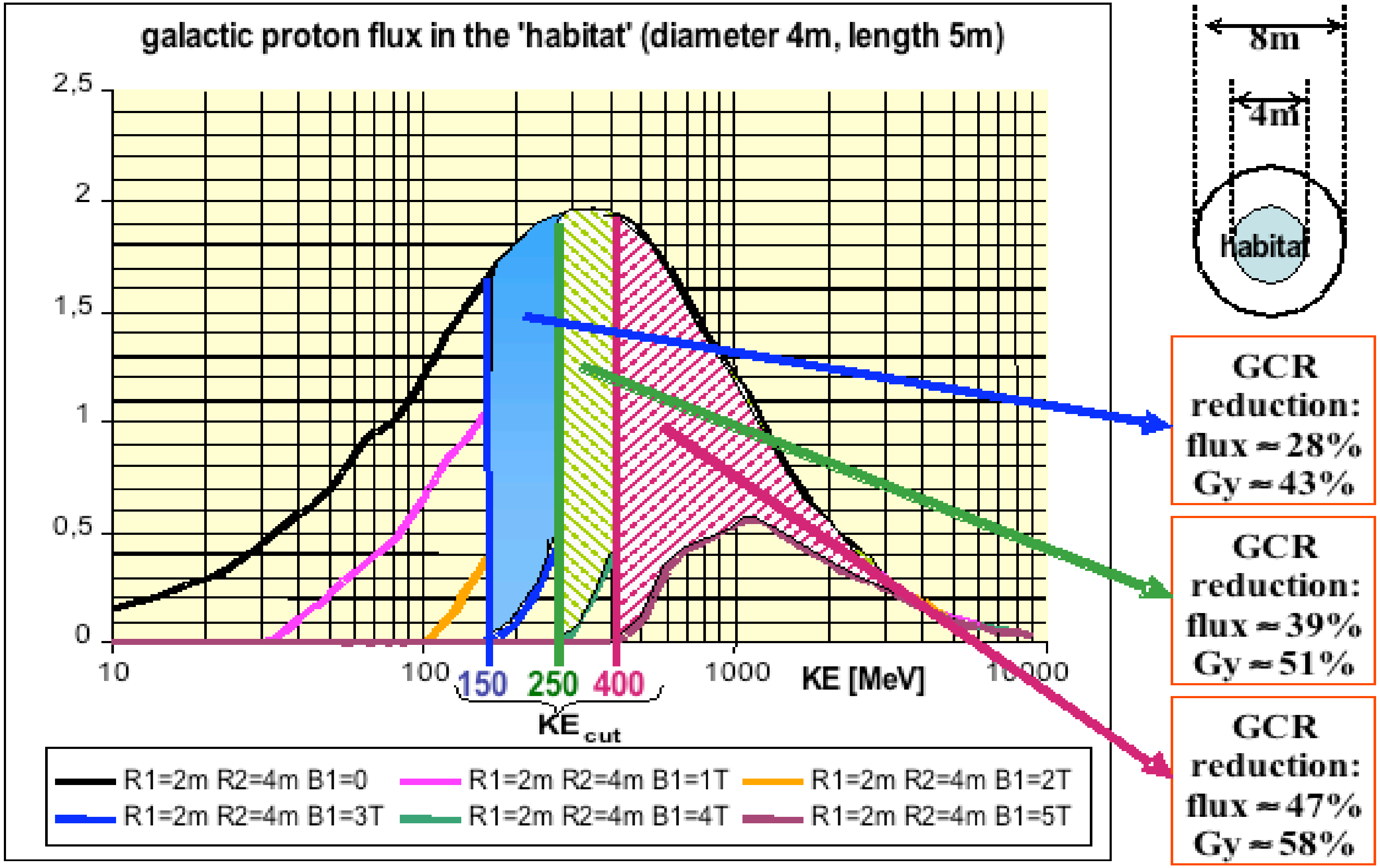
2002-2004 ESA international **Topical Team** on "**Shielding from the cosmic radiation for interplanetary missions: active and passive methods**"

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

Considered configuration:



Toroidal magnetic sheath for protecting a cylindrical volume inside



galactic proton flux in the 'habitat' (diameter 4m, length 5m)
2,5
2
1,5
1
0,5
0
10
100
1000
10000
KE [MeV]
150
250
400
KE_cut
R1=2m R2=4m B1=0
R1=2m R2=4m B1=1T
R1=2m R2=4m B1=2T
R1=2m R2=4m B1=3T
R1=2m R2=4m B1=4T
R1=2m R2=4m B1=5T
8m
4m
habitat
GCR reduction: flux ≈ 28% Gy ≈ 43%
GCR reduction: flux ≈ 39% Gy ≈ 51%
GCR reduction: flux ≈ 47% Gy ≈ 58%

Conclusions of both TT and REMSIM studies:

Cryogen Free Superconducting Magnets (CFSM) needed
Toroidal configuration profitable

therefore:

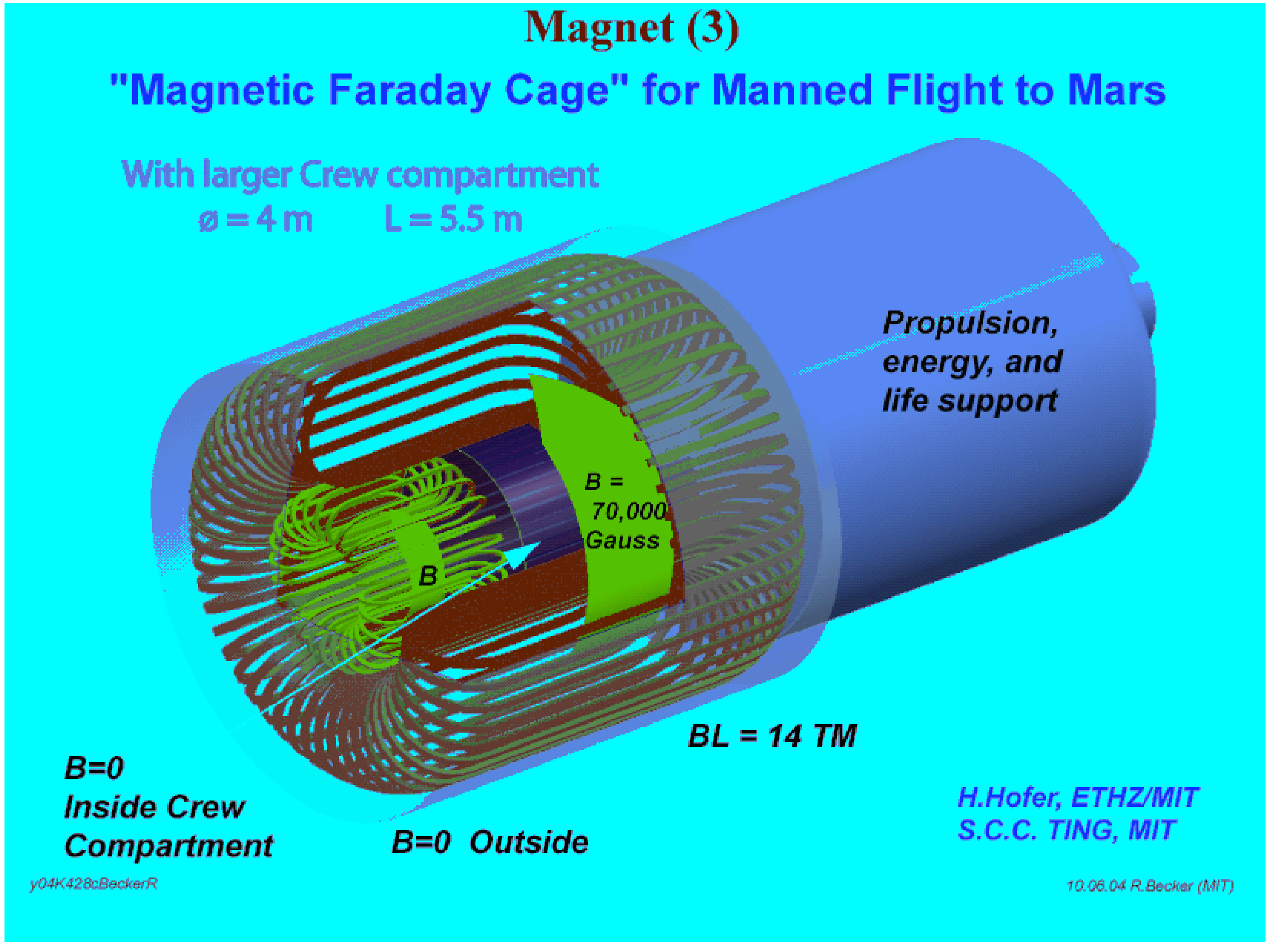
-First recommendation:
  develop HTS suitable for space applications

-Second recommendation:
  develop cryocoolers suitable for space

-Third recommendation:
  relatively low magnetic field in a large volume,
  i.e. the outer part of the system should be
  deployed or assembled in space.

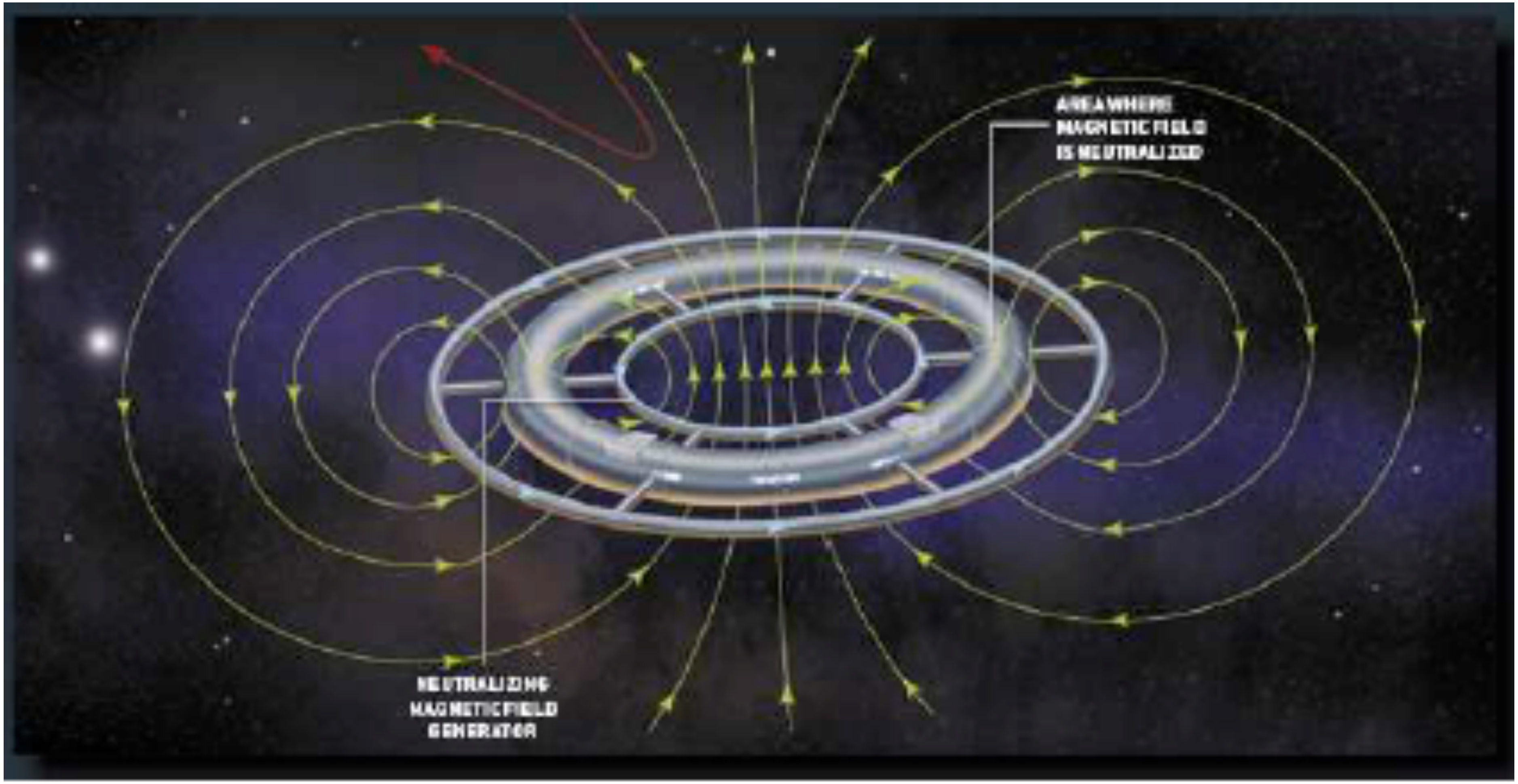
Active protection from ionizing radiation:

Activities in USA



diameter 4m lenght 5m volume 69m3
coil diameter 9,5m magnetic field from 11 to 5 T

Dose reduction inside ≈ 90%



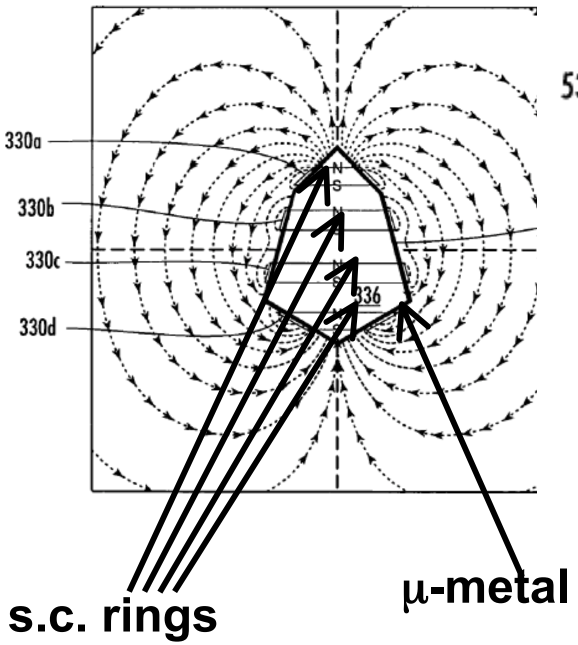
futuristic system (Parker), consisting of a large diameter ring, the current runs on its external surface and the magnetic field reproduces the terrestrial dipole, while, by suitable dimensioning of the whole system, is null inside the volume of the ring.

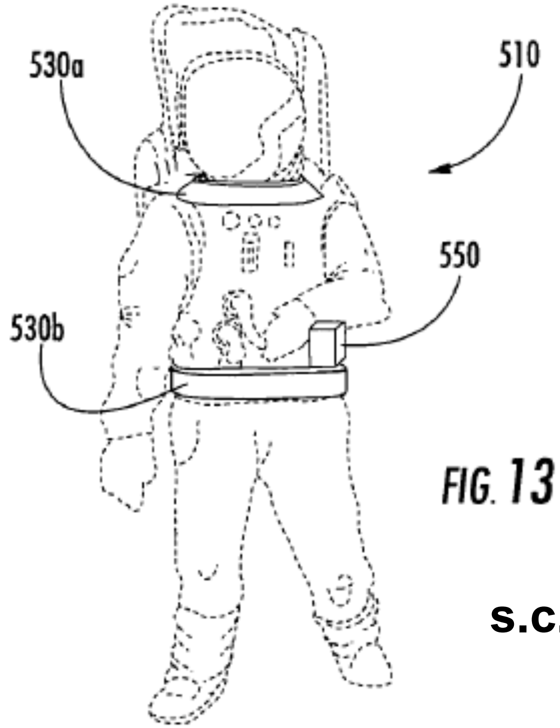
United States Patent
Kinstler

(10) **Patent No.:** **US 7,484,691 B2**
(45) **Date of Patent:** **Feb. 3, 2009**

METHOD AND DEVICE FOR MAGNETIC SPACE RADIATION SHIELD PROVIDING ISOTROPIC PROTECTION

Inventor: **Gary A. Kinstler**, Torra
Assignee: **The Boeing Company**, (US)





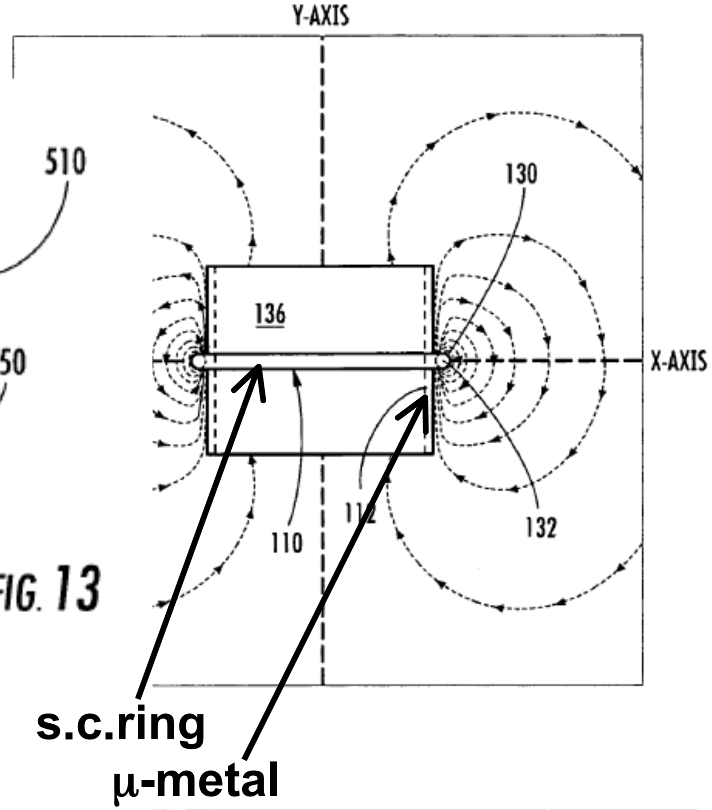
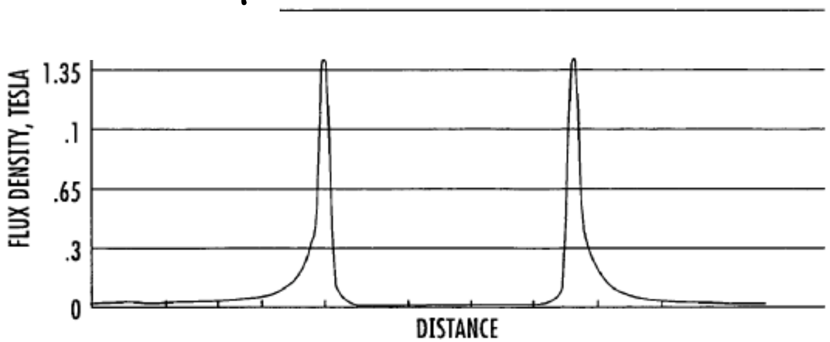


FIG. 13



Active protection from ionizing radiation

further step:

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

from

‘habitat’ concept (≈50-100m^3/man)

to

deep space base (≥1000m^3 & large crew)

The until now performed activity can be updated and continued, because in last years:

(a) **Diffuse wide experience** in realizing and operating huge volume and huge stored energy s.c.magnets @ accelerators.

(b) **Technical developments** on superconducting materials (HTS cables, MgB_2 cables) and cryocoolers.

(c) **Evolution from exploration strategy → exploitation:**
- asteroids before Mars??
- private investments (for implementing services from space)
- space agencies supplying competences, guaranties and controls.

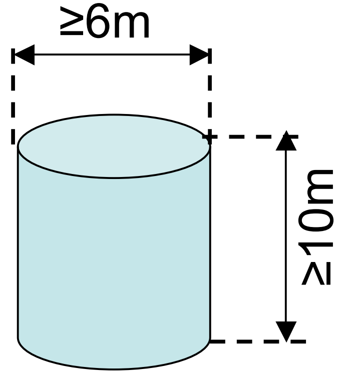
(d) **Steps of this evolution:**
- space tourism;
- SpaceShipTwo spacecraft;
- studies for extracting useful materials from Moon and asteroids;
- awareness of Lagrange points advantages for transfering infrastructures, permanent stations of transit and logistics (space highways)

Basic criteria

Toroidal configuration
CFSM system (NO liquid helium evaporation!)

'Habitat' fully protected from SCRs.
'Habitat' guaranties a factor >4 reduction of GCR dose

Volume of the 'habitat' to be protected:
≥ 1000 m^3 (e.g. Ǿ ≥6m, L≥10m)
(Shroud of the transportation
system: Ǿ≤10m, L=16m)



Basic philosophy for a 'Space Base' in deep space:

All the modules linked to the protected 'habitat'
The protected 'habitat' can be reached in a few minutes
from any point of the Space Base

Technological criteria

- Cryogen Free Superconducting Magnet → ***cryocoolers***

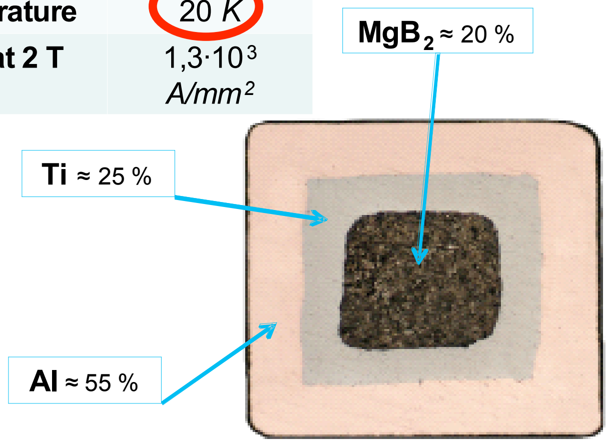
- 'ideal cable' for space applications (Turin university + ThalesAleniaSpace)

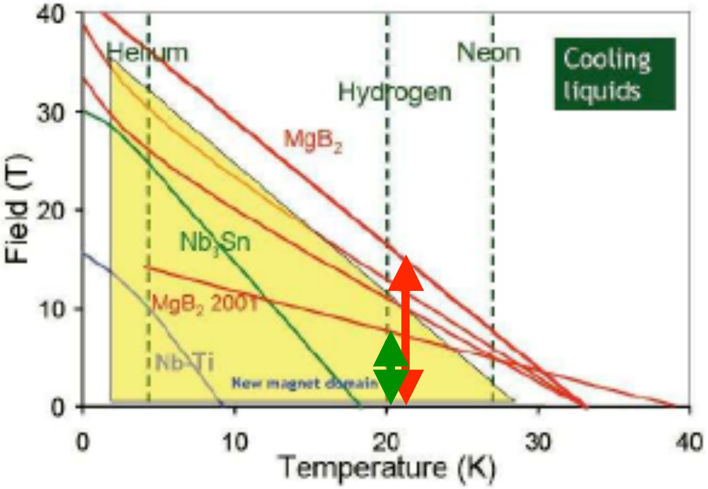
  thin MgB_2 cable produced by the in-situ method in a titanium sheath stabilized outside in aluminum:

  - Medium operating temperature (20K)
  - Low density (3 g/cm^3)
  - Small section: cables less suffering current and temperature instability, and distributing current in the surrounding cables in case of bad functioning.

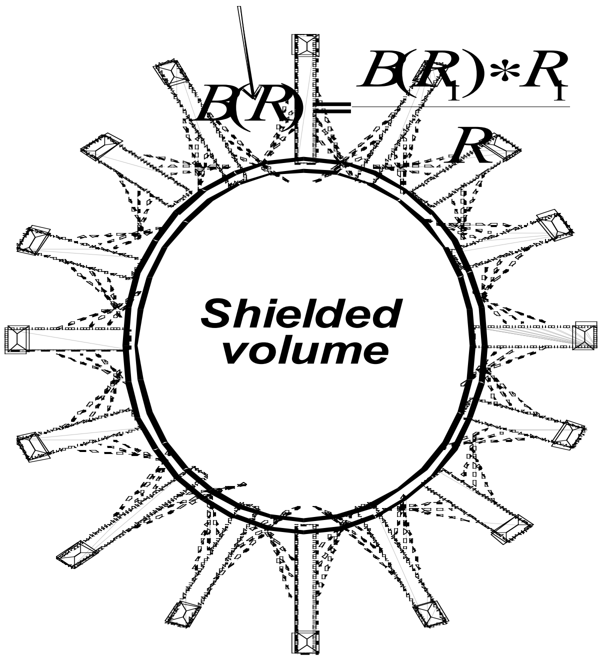
Characteristic	Value
Averaged density	2,96 *g/cm*^{3}
Diameter of the cable	200 _*m*
Section of MgB2	6,28·10^{-3} *mm*^{2}
Operation temperature	20 *K*
Critical current at 2 T	1,3·10^3 *A/mm*^{2}

Ideal cable

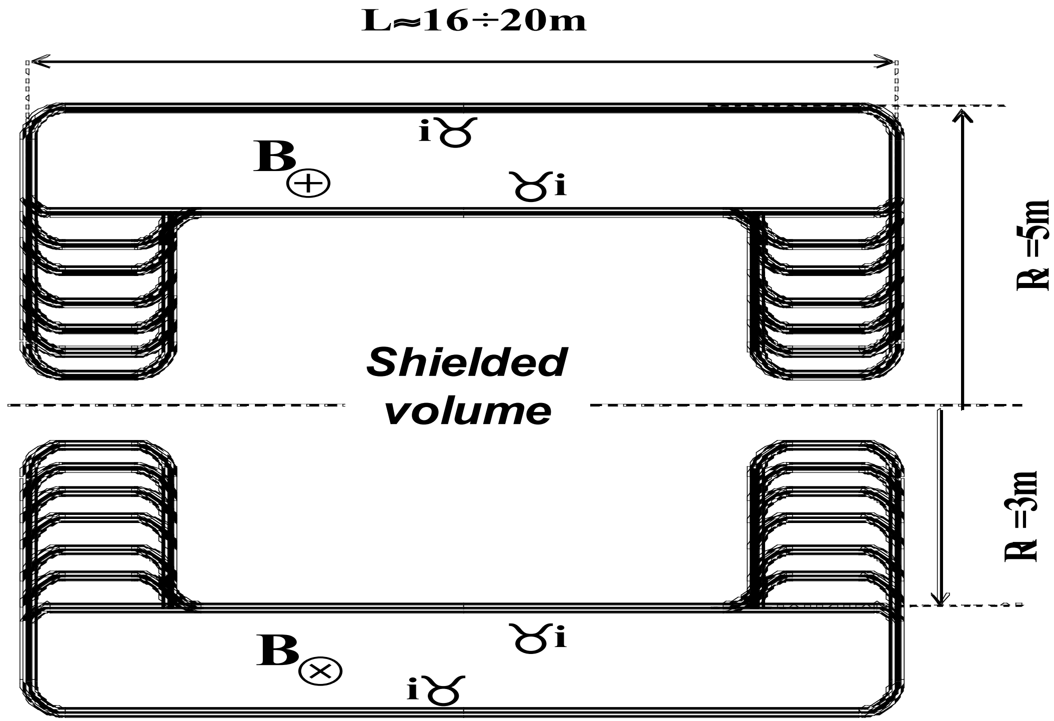




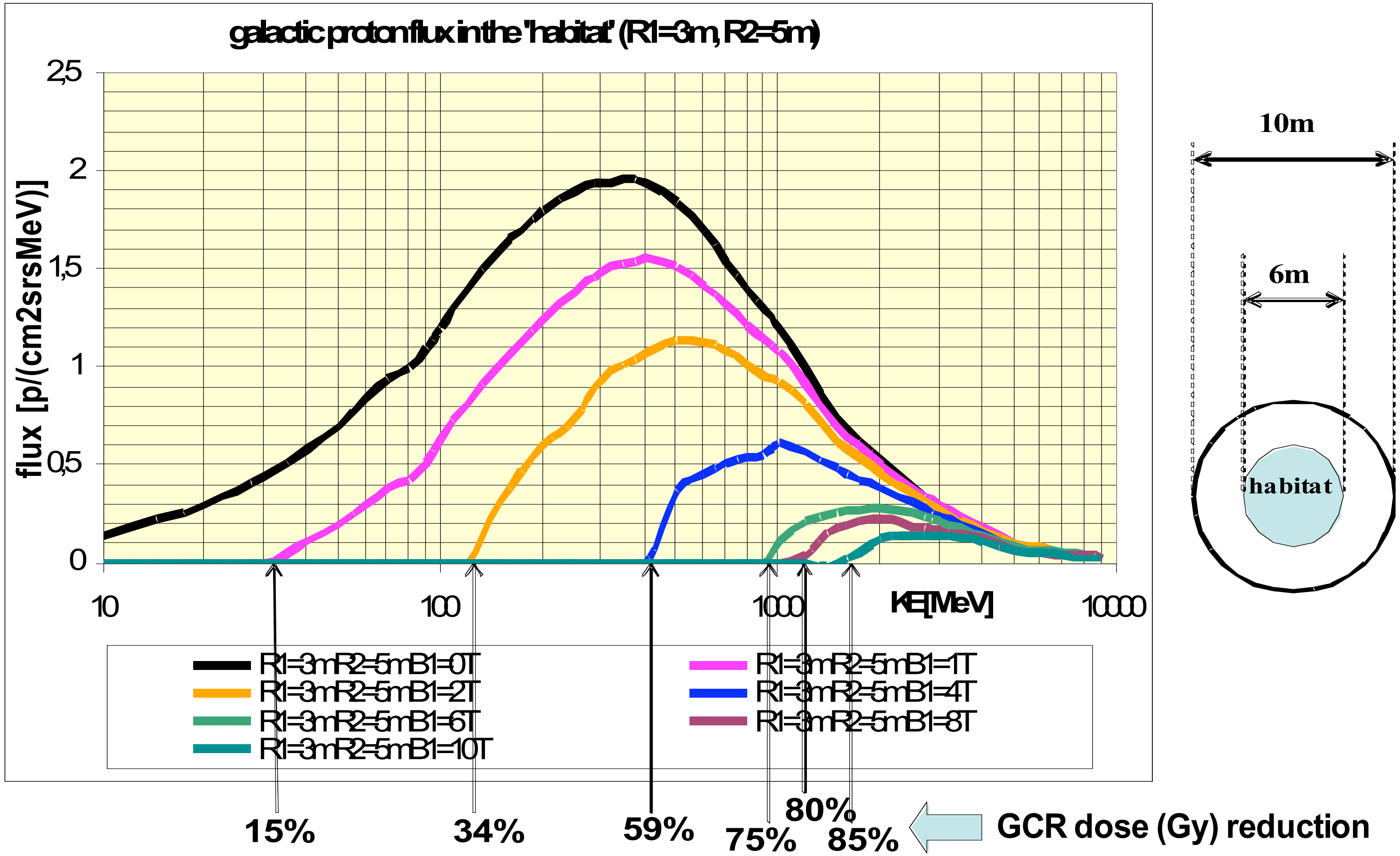
Configuration assumed to evaluate the protection of a 6m diameter cylindrical habitat.



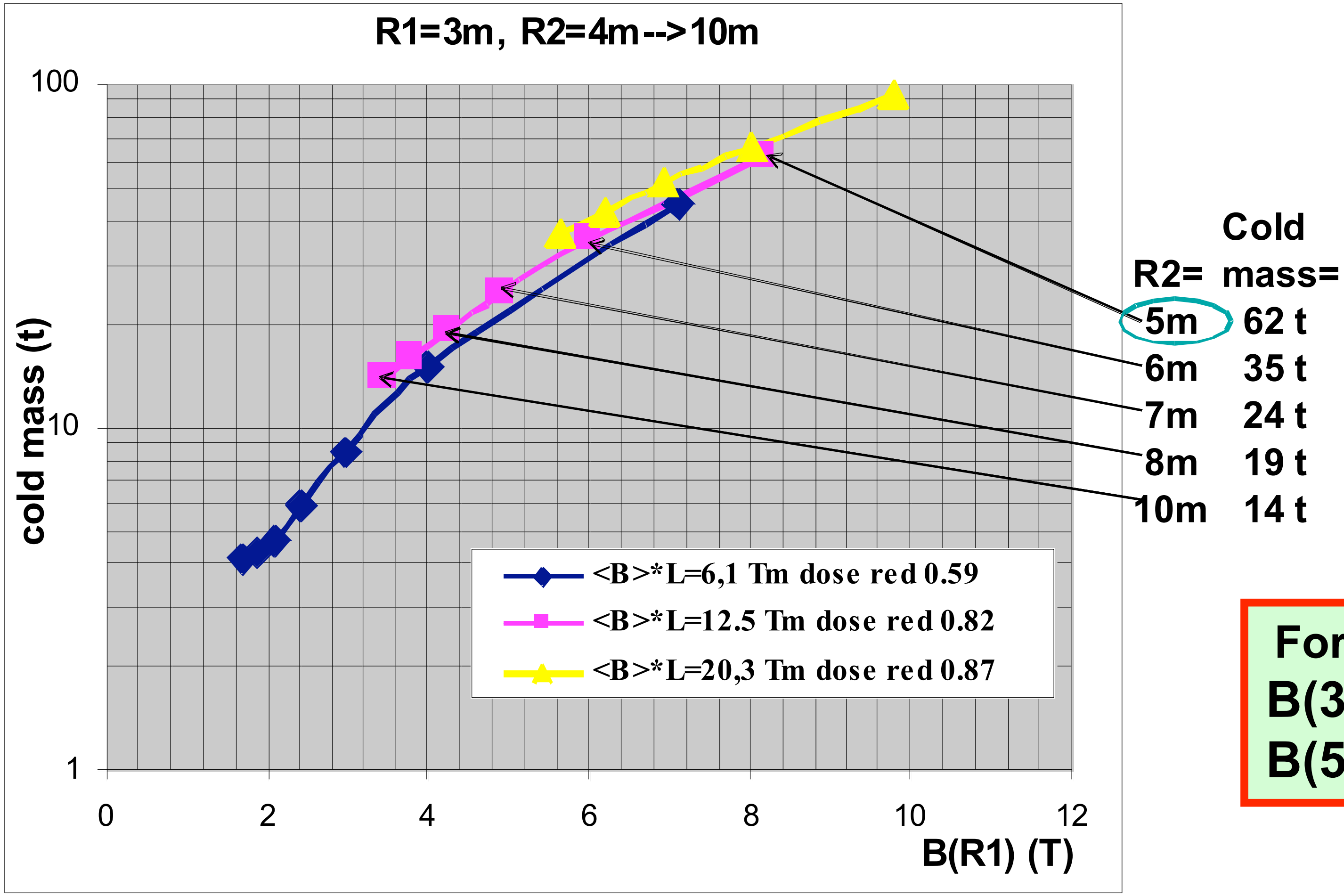
Transverse section



longitudinal section



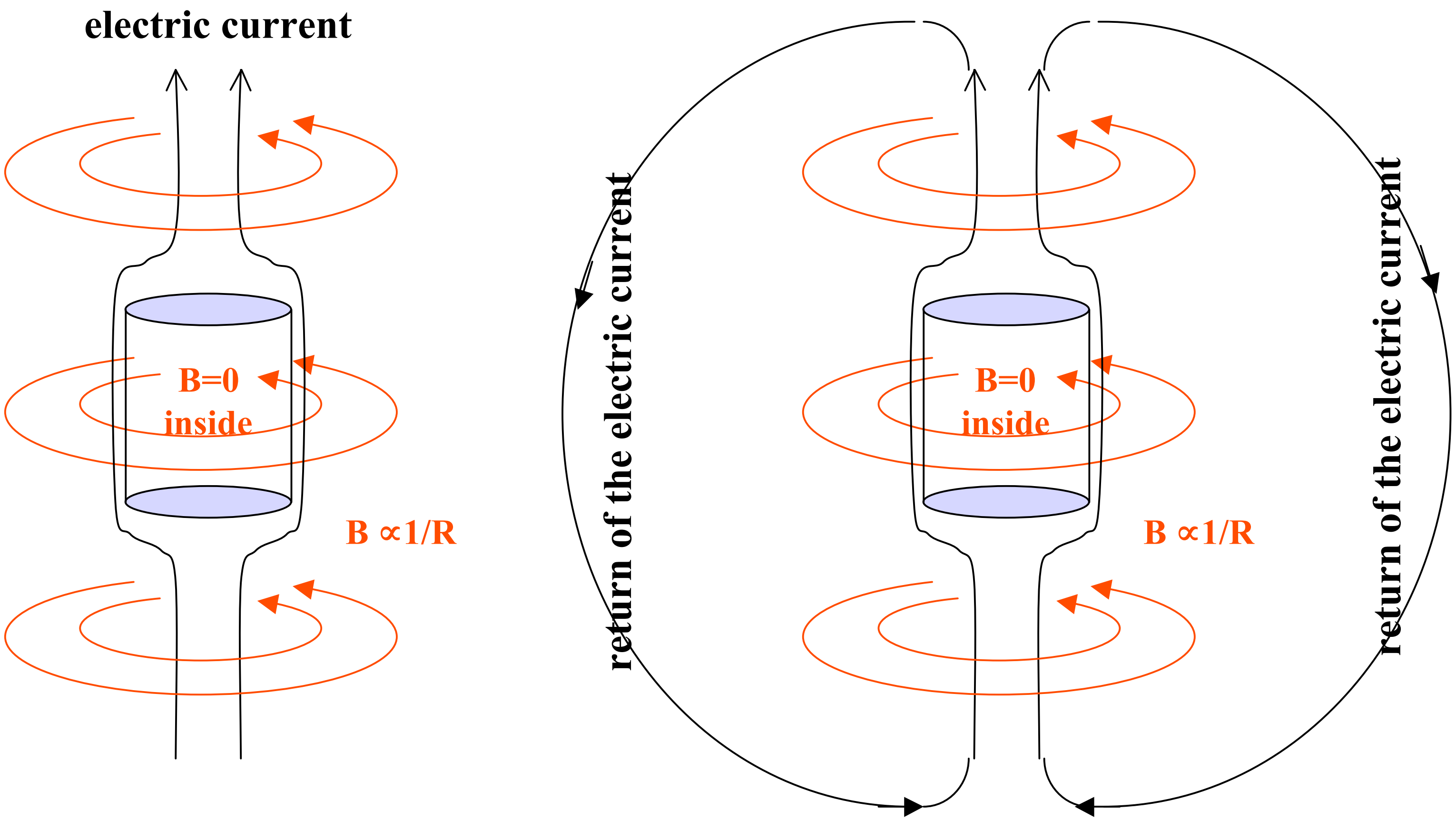
Reduction of the galactic proton flux inside the habitat. The corresponding reduction of the dose due to GCR flux is reported at the bottom of the figure for different values of the maximum magnetic field (1, 2, 4, 6, 8, 10T) of the system.



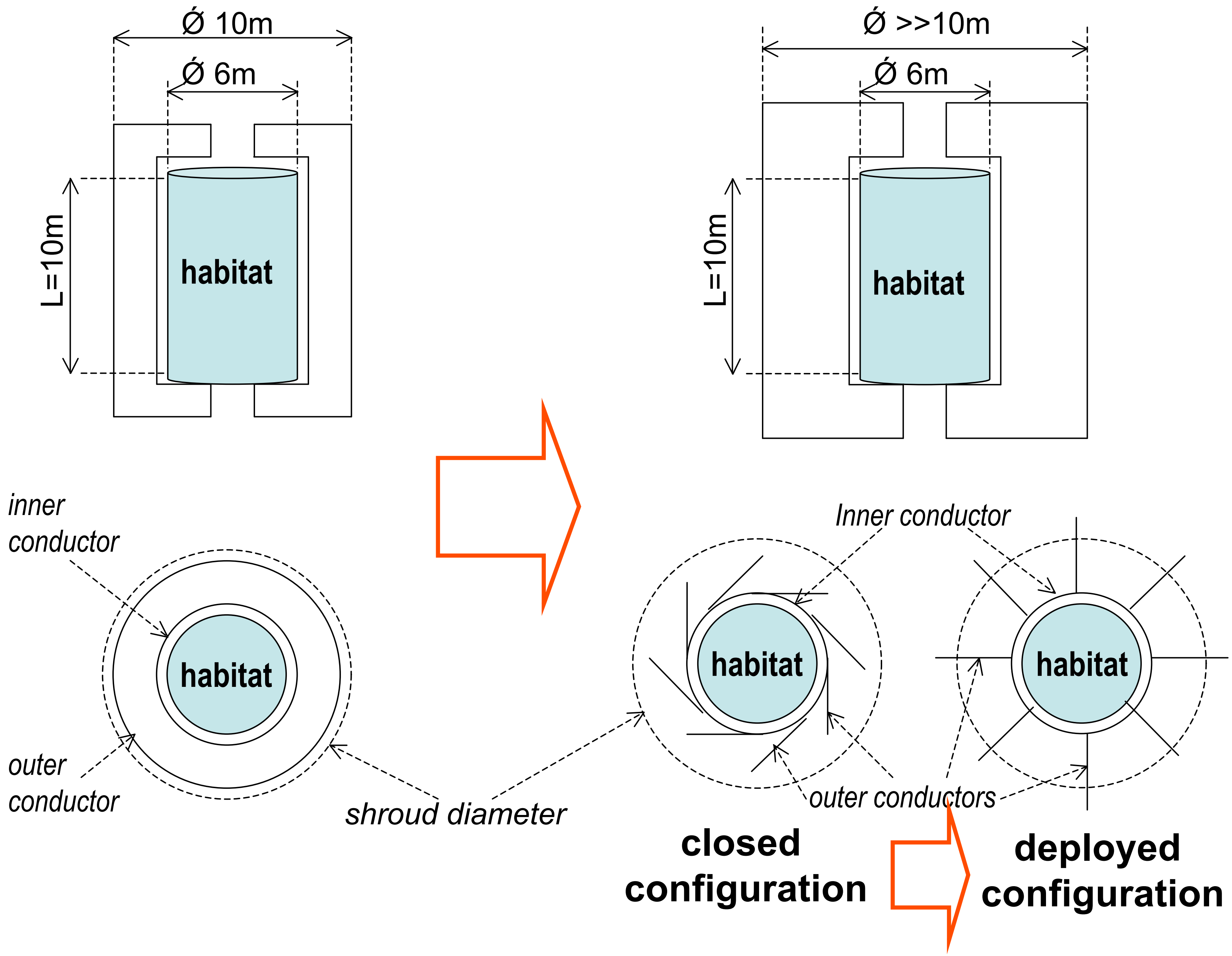
For R_2=5m:
B(3m) = 8T
B(5m) = 5T

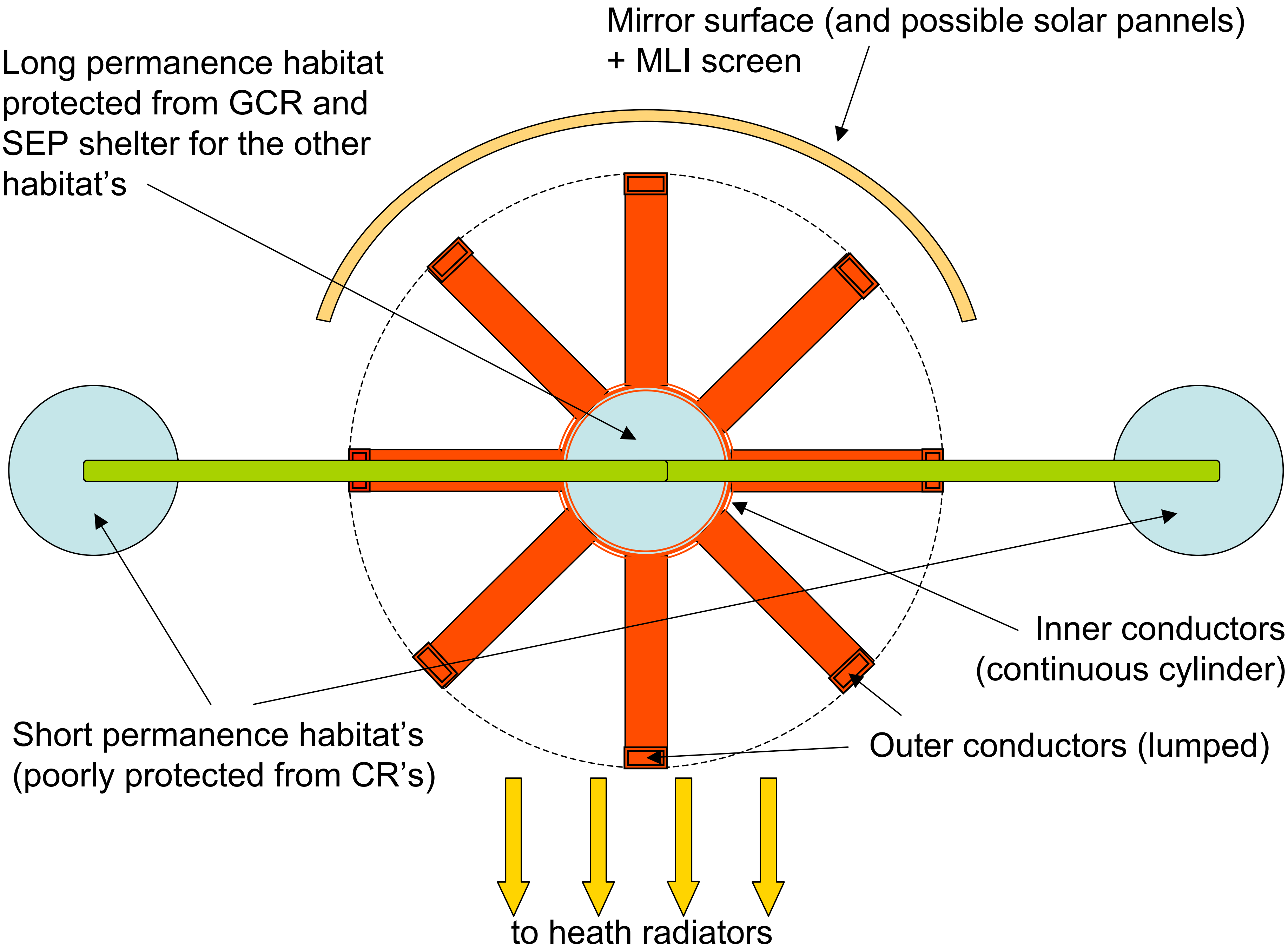
Current density in MgB_2 cable 1kA/mm^2 @ $B(R_1) \leq 2T$, 1kA/mm^{2}x2/$B(R_1)$ @ $B(R_1) > 2T$

Cold mass of the system realized by MgB_2 sc cable, for the values 6.1, 12.5, 20.3 Tm of the bending power <B>(R2-R1) (corresponding to 0.59, 0.82, 0.85 reduction of the GCR dose) and several values of the outer diameter as a function of the maximum magnetic field intensity.*



- the solenoidal configuration is not adequate and must be adopted a **toroidal configuration** where the field diminishes at the increasing of the radius;
- the outer part of the system should be **deployed or assembled** in space.


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


Mirror surface (and possible solar pannels)
+ MLI screen
Long permanence habitat
protected from GCR and
SEP shelter for the other
habitat's
Inner conductors
(continuous cylinder)
Outer conductors (lumped)
Short permanence habitat's
(poorly protected from CR's)
to heath radiators

Items to be still studied:

heath shielding + cryocoolers

artificial gravity

Conclusions

An adequate protection from GCR of a large human community in space is a complex problem, which can be solved 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 ‘niche’ where physicists can contribute
- an occasion of collaboration between labs and space agencies
- new technologies 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..)

<u>Cryogen Free Supercoducting Magnet</u> concept (by-products of)

Protection from SCR:

1) 'storm shelters' for SCR
2) protection of single astronaut
3) protection of rover on celestial body surface
4) satellites in alongated orbits

Control and focalization of charged particle beams:

5) propulsion: M2P2,
   PMWAC,
   VASIMR,
   CrossFire FUSOR
   MPD thrusters (require high B)
6) maneuvring

On ground applications:

7) Ion medical beam cryogen-free handling for treatment
8) NMR cryogen free for diagnostic in hospitals
9) Levitation vehicles

Thank you for your attention