Syracuse University Interlibrary Loan

ILLiad TN: 351978

Borrower: DRB

Lending String: *SYB,UCW,AUM,PLF,RRR

Patron: Shepherd, Simon

Journal Title: ARS journal.

Volume: 31 **Issue:** 11
Month/Year: 1961 **Pages:** 1568-1570

Article Author: American Rocket Society.

Article Title: LEVY,; RADIATION SHIELDING OF SPACE VEHICLES BY MEANS OF SUPERCONDUCTING COILS

Imprint: [Easton, Pa.] American Rocket Society.

ILL Number: 28457251

Call #: TL780 .A613 Level 7

Location: sci

Item #:

CHARGE
Maxcost: $30.00IFM

Shipping Address:
Dartmouth College/Baker-Berry Library
6025 Wentworth Street
Hanover N.H. 03755

Fax: (603) 646-2167
Ariel: 129.170.117.37

ILLiad

THIS COPY WAS SENT TO YOU BY

SYRACUSE UNIVERSITY LIBRARY
SYB

PLEASE ARIEL RESEND REQUESTS WITHIN THREE WORKING DAYS

ARIEL: 128.230.235.142

OCLC ILL #__________________________

YOUR OCLC SYMBOL____________________

PAGES TO RESEND______________________

REASON______________________________

INTERLIBRARY LOAN
SYRACUSE UNIVERSITY
BIRD LIBRARY
PHONE: 315-443-2459
FAX: 315-443-9510

Technical Notes

Radiation Shielding of Space Vehicles by Means of Superconducting Coils[1]

RICHARD H. LEVY[2]

AVCO-Everett Research Laboratory, Everett, Mass.

ONE OF the major problem areas in connection with manned space flight is that of providing adequate protection against the various forms of ionizing radiation known to be present in space. There are three principal forms of this radiation; the first is due to the inner and outer Van Allen belts that are present at all times in specified regions in the vicinity of Earth. The second is the so-called background cosmic radiation that is present throughout the galaxy. The third, and in many respects the most important, originates in the beams of energetic protons emitted from the sun in solar flares; these vary widely in strength and also in frequency, maximum frequency occurring with sunspot maximum.

General Discussion

Shielding against the Van Allen belts is no longer the problem it was once thought to be. Dosage received in passing through them can be minimized by suitable trajectory shaping, and a quite modest amount of shielding appears to be sufficient to reduce the dose received in passing twice through each belt to a reasonable value on the order of 5 rem. The galactic cosmic rays form a quite different problem. In the first place the level is generally quite low (of the order of 5 to 12 rem/yr), so that trips of six months or so may be planned without taking special precautions against them. On the other hand it is fortunate that this is the case, since the typical energy of the galactic cosmic rays is so high that appreciable reduction of the dose rate is prohibitively expensive in terms of weight. The most important shielding problem, however, is posed by solar flares. It seems likely at present that prediction schemes can be devised that will make possible trips lasting up to a maximum of about two weeks for which the statistical probability of encounter of a large flare can be reduced to acceptable levels. However, trips longer than about two weeks will almost certainly involve shielding against large flares. Much of the information given above may be found, for instance, in (1).[3]

A simplified view of the shielding problem, and one that will be adequate for the purposes of this note, involves the specification of a proton energy such that if all protons of less than this energy are removed from the flux before striking the body, the resultant dose is tolerable. Given such a proton energy, the problem of solid shielding becomes a simple exercise; range-energy curves for protons are given for many substances in many references. Excluding hydrogen as too bulky and impractical, a number of elements have very similar stopping powers, including carbon, aluminum, and copper. Water is also considered by many as typical of this group. The difference between these substances is largely their rate of production of secondary neutrons; carbon appears to be best from this point of view, but water is not much worse. It should be noted that secondary neutron effects may play an important role in the determination of the critical proton energy.

For a two-week lunar type mission, the cutoff energy is around 200 Mev, resulting in water thicknesses on the order of 25 gm/sq cm. This in turn gives shielding weights that are high but not unreasonably so. The real problem is in longer trips, for which the cutoff energy is considerably higher. There are some conflicting estimates of just how high it is, and it is not the purpose of this note to attempt the resolution of that particular problem; 500 Mev to 1 Bev can be estimated with some confidence, and this gives thicknesses of the order of 100 to 300 gm/sq cm. When translated into reasonable surface areas for spacecraft, the resultant weights come out very high. Furthermore, these weights are mandatory in the sense that there is no room for reduction. In this note a possible alternative scheme of shielding will be discussed, which, whereas it does not appear to offer greatly reduced weights at present, is nevertheless capable of improvement, at least in principle, depending on the production of materials with higher strength to weight ratios.

Analysis of Magnetic Shielding

This alternative scheme is shielding by means of magnetic fields. Such a scheme has been considered (2), but rejected on the grounds of the excessive power needed to maintain the large fields required. This objection must be reconsidered in view of the introduction of the new high field superconductors. A coil made of such a material could be charged once and for all; then, provided only that it was protected by insulation against external heat sources, it would act as a permanent magnet.

The calculation of the shielding effect of a magnetic dipole has been well understood for many years in connection with the effect of Earth's field on cosmic rays. The results of this calculation are as follows: given a dipole of magnetic moment m and a particle with momentum to charge ratio p/e, the so-called Stormer radius $c = (em/4\pi p)^{1/2}$ can be defined. Then, if θ is the colatitude, the region inside the surface $r/c = [(1 + \sin^3 \theta)^{1/2} - 1]/\sin \theta$ is inaccessible to particles that originate at infinity and have the specified value of p/e or less. It is worth noting that when $\theta = \pi/2$ (in the equatorial plane) the shielded region extends only out to 41% of the Stormer radius. An axially symmetric space

---

Received Aug. 8, 1961.

[1] This research was supported by Headquarters, Ballistic Systems Div., Air Force Systems Command, USAF under Contract No. AF 04(647)-278.

[2] Principal Research Scientist. Member ARS.

[3] Numbers in parentheses indicate References at end of paper.

EDITOR'S NOTE: The Technical Notes and Technical Comments sections of ARS JOURNAL are open to short manuscripts describing new developments or offering comments on papers previously published. Such manuscripts are usually published without editorial review within a few months of the date of receipt. Requirements as to style are the same as for regular contributions (see masthead page).

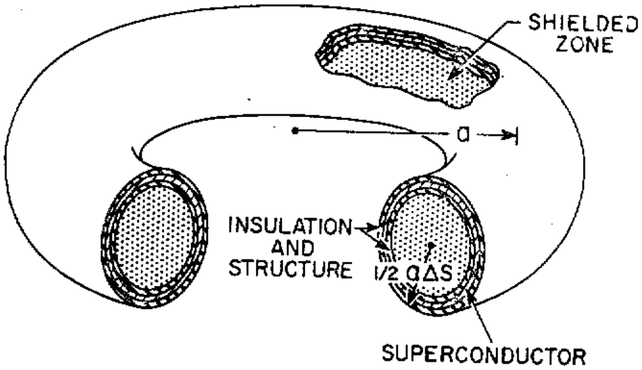

Fig. 1 Schematic of superconducting coil for radiation shielding

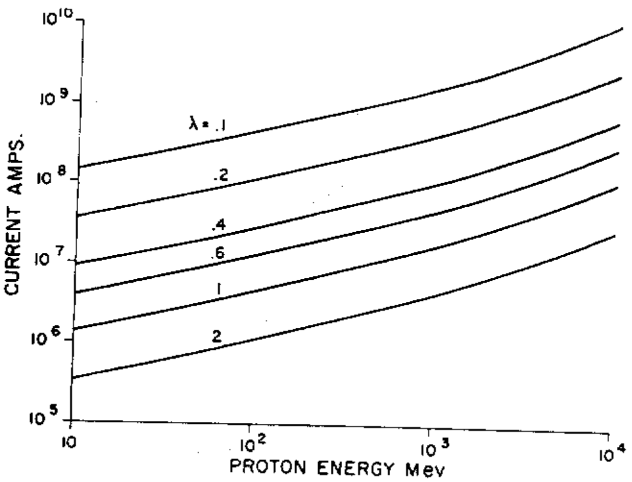

Fig. 2 Value of parameter $\lambda = a/c = (4p/\mu_0 eI)^{1/2}$

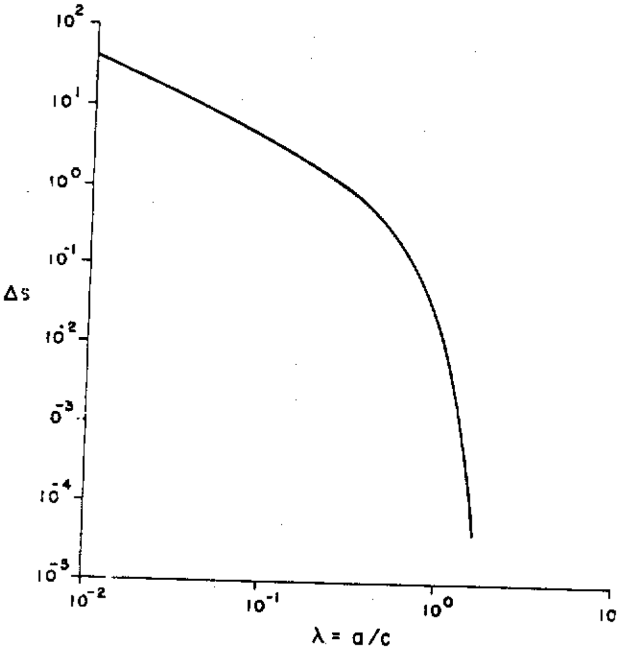

Fig. 3 Extent of radiation free zone in equatorial plane

vehicle of the shape defined above with a dipole with magnetic moment appropriate to the cutoff energy at its center would then be shielded, except against those particles arriving precisely from the polar directions.

Whereas this result is interesting, it will be shown later that the dipole configuration is undesirable from the structural point of view. If the magnetic field is to be generated by a current carrying superconductor, a realistic configuration would be a single turn coil made from a hollow tube of superconductor. Other configurations have been studied, but do not yield basically different results. It can be shown that for the single turn coil there is a toroidal shielded region surrounding the wire, roughly circular in cross section. It is clearly expedient, in order to avoid wasted field, to place the superconductor at the boundary of the shielded region; this will not alter the field in the region of interest. Living quarters inside such a superconducting torus will then be radiation free (up to the design particle energy). A schematic diagram of such a device is shown in Fig. 1.

Quantitatively, the shielding calculation may be summarized as follows: if I is the circulating current, a nondimensional parameter $\lambda = a/c = (4p/\mu_0 eI)^{1/2}$ can be defined. Values of λ are shown in Fig. 2. The cross-sectional radius of the shielded torus is then given by $r_e = (1/2)a\Delta s$, where Δs is a function of λ and is plotted in Fig. 3. It can be seen that Δs falls very rapidly with increasing λ, whereas small values of λ imply very large values of I. It may be anticipated that on closer analysis an optimum value of λ will appear.

This closer analysis involves a more detailed look at the principal components of a coil of the type being described. For the present purposes the coil may be thought of as consisting of the superconducting coil itself, the structure required to support the magnetic forces, and the insulation necessary to maintain the appropriate low temperatures. It will appear that the structure is by far the most important of these three items. It will be sufficient to consider as representative the structure required to support the bursting hoop stress on the coil. If ρ_s and σ_w are the density and working stress of the structural material to be used, simple considerations (4) show that the mass of structure required is given by

$$(\mu_0 \rho_s I^2 a/2\sigma_w)\ (1 + \ln a/r_e)$$

The variation of this quantity with the square of the current is a natural consequence of the energy connected nature of the structure. It is this structural term that will prevent λ from being as small as we like. The mass of the actual superconductor turns out to be far less than the mass of structure, based upon an aluminum structure at 50,000 psi, a superconductor with a density of about 8.4 gm/cu cm, a current carrying capacity of about 10^5 amps/sq cm, and a critical field in the general neighborhood of 10^5 gauss. (These properties correspond roughly to the niobium tin compound discussed in (3), but may be thought of as the first in a new series of greatly improved superconductors.) If we denote the density and current carrying capacity of the superconductor by ρ_c and j_c respectively, the mass of superconductor is easily shown to be $2\pi\rho_c Ia/j_c$. The insulation needed to maintain the superconductor at the required temperature is proportional to the surface area of the device and increases with the mission length. However, all cases studied resulted in such low values that this item will not be considered any further here.

If a given shielded volume $V = (1/2)\pi^2 a^3(\Delta s)^2$ is decided on, then for a given cutoff energy the shape and total mass of the coil for various currents can be found. As indicated above, such an analysis yields an optimum value for λ; this value turns to be about 0.6. The mass is not too sensitive to it. Using the optimum value of λ, the mass of a superconducting shield can be plotted against the shielded volume. Using the range energy curves for protons in water, similar curves for a spherical solid shield can be plotted. These results are shown in Fig. 4 and constitute the essential results of this note.

Conclusions

The following conclusions may be drawn from Fig. 4: first, the superconducting shield is lighter for a given proton energy when either large volumes or very energetic protons are considered; second, the absolute masses involved are very large by present day standards, but it must be remembered that shielding of the type described will be positively required for all manned space missions lasting more than about two weeks, so that these missions are not possible at all until vehicles of this size can be used; third, the advantage of the superconducting shield is considerably enhanced, since in the shielding process the protons do not strike the coil but are deflected; as a result there is no generation of secondary neutrons, so that comparisons should not be made on the basis of the same proton energy; rather, for a given mission, the cutoff energy appropriate to the solid shield will be higher than that appropriate for the superconductor.

To conclude, it may be of interest to calculate various parameters for a particular case. Choose, for example, a coil capable of protecting 100 m^3 (corresponding to 20 or 30 men) against 1 Bev protons. We find the optimum λ is 0.7, $a = 13$ m, $r_e = 0.62$ m, $I = 3.7 \times 10^7$ amps, and the total mass is 3.76×10^5 kg, of which 92% is structure. In contrast, a water shield protecting the same volume (but in the shape of a 2.9-m radius sphere) weighs 8.5×10^5 kg without considering the secondaries.

Further details of the work described in this note may be found in (4).

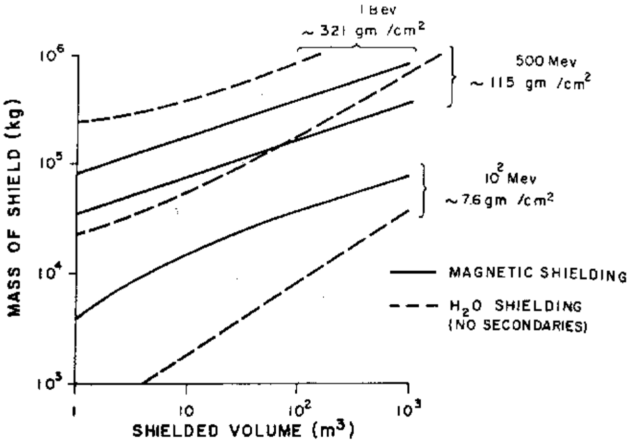

Fig. 4 Optimized shielding weights

References

1 Newell, H. E. and Naugle, J. E., "Radiation Environment in Space," *Science*, vol. 132, no. 3438, Nov. 18, 1960, pp. 1465–72.

2 Dow, N. F., "Structural Implications of the Ionizing Radiation in Space," *Proc.* Manned Space Stations Symposium, Los Angeles, Calif., April 20–22, 1960.

3 Kunzler, J. E., Beubler, E., Hsu, F. S. L. and Wernick, L. F., "Superconductivity in Nb_3Sn at High Current Density in a Magnetic Field of 88 K Gauss," *Physical Review Letters*, vol. 6, Feb. 1, 1961, pp. 89–91.

4 Levy, R. H., "Radiation Shielding of Space Vehicles by Means of Superconducting Coils," *Avco-Everett Research Lab. Research Rep. 106*, August 1961.

Lunar Landing Vehicle Propulsion Requirements[1]

J. RICHARD WROBEL[2]
ROBERT R. BRESHEARS[3]

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, Calif.

THE PURPOSE of this analysis is to develop generally applicable criteria for the design of a lunar-landing vehicle propulsion system. Variations of the landing maneuver, such as oblique entry, hovering, lateral translation, and multiple burning phases, have been omitted in this first analysis of the problem. The effect of any of these variations would perhaps best be studied in a specific vehicle analysis since needs vary, depending on the mission chosen. A weighted average value of gravity appropriate for the altitude spread encountered may be used for those situations in which the ignition altitudes are appreciably large compared with the lunar radius. An appropriate choice of the gravity value and impact velocity will make this analysis applicable for use in computing the optimum vertical descent on any atmosphere-free celestial body.

The characteristics of lunar transfer trajectories have been discussed rather thoroughly in the recent literature by several authors (1–4).[4] The trajectory parameter of interest is the relative velocity with which an unbraked vehicle would strike the lunar surface. This velocity is determined by integrating the effect of the forces acting on the vehicle as it traverses the Earth-Moon transfer trajectory. Values of this impact velocity are available in the literature for various Earth-Moon transit times. A plot of the average impact velocity vs. transit time from Earth is presented in Fig. 1. The impact velocity represents the impulsive velocity decrement that would be necessary to stop the vehicle if applied just prior to contact with the lunar surface. For finite thrust levels (nonimpulsive velocity additions), the total effective decrement is greater than this impact velocity due to the kinematic inefficiency of burning while traversing a gravitational field.

The descent under power is simplified by the following five assumptions, leaving the trajectory equations linear and solvable in closed form.

1 Gravity g is constant during deceleration.
2 Descent is made vertical to the lunar surface.
3 Propellant exhaust velocity and mass rate of expulsion are constant with time.
4 The descent to the surface is free of atmospheric drag forces.
5 Vehicle velocity and altitude are simultaneously zero at the end of burning.

Under these assumptions, the form of the differential

Presented at the ARS Semi-Annual Meeting, Los Angeles, Calif., May 9–12, 1960; revision received Sept. 5, 1961.

[1] This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NASw-6, sponsored by NASA.

[2] Development Engineer, Propulsion Div. Member ARS.

[3] Development Engineer, Propulsion Div.

[4] Numbers in parentheses indicate References at end of paper.