

Shielding Effectiveness of Sodium Alanate and Ammonia Borane for Galactic Cosmic Ray and Solar Energetic Particle Event Environments

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ABSTRACT

Estimates of the effectiveness of the high-hydrogen containing materials, sodium alanate and ammonia borane, are made by calculating dose and dose equivalent for the 1977 solar minimum and 1970 solar maximum galactic cosmic ray spectra and for the large solar particle event spectra from the space era event of August 1972 and comparing their shielding effectiveness with that of polyethylene.

INTRODUCTION

It has been known for some time that materials, which contain significant quantities of hydrogen constituents, are especially effective in shielding against high-energy space radiation present in the galactic cosmic ray and solar energetic particle event environments (1). In this work we investigate two such materials; sodium alanate and ammonia borane. Both have significant hydrogen content and might be more effective than conventional polyethylene (CH_2) as a potential shield material for space missions. The current study is limited to assessing their effectiveness as radiation shield constituents. No additional investigations involving other aspects of their suitability for spacecraft use, such as structural capabilities or toxicity, are made. To estimate their effectiveness as space radiation shield materials, calculations of organ dose and dose equivalent behind various thicknesses of materials are carried out for the 1977 solar minimum and 1970 solar maximum galactic cosmic ray (GCR) spectra, and for the August 1972 solar energetic particle event (SEP) spectrum from the space era. Comparisons with the shielding effectiveness of CH_2 are made.

CALCULATIONAL METHODS

Estimates of dose and dose equivalent as a function of depth in water are obtained for the assumed, incident GCR spectra using the deterministic space radiation transport code, HZETRN (2) developed at NASA Langley Research Center. The SPE spectrum is transported by the BRYNTRN code (3), also developed at NASA Langley Research Center. The incident radiation fields are altered by nuclear collisions with intervening materials in their passage through spacecraft structure and shielding and passage through body tissue overlaying critical organs (the human body provides some of its own shielding). Transport of these SPE protons and their reaction products (protons, neutrons, deuterons, tritons, helions, and alphas, and heavier ions) are modeled using the selected shield material and water to represent the soft body tissues overlying the critical organs of interest. Full details of the models can be found in the references.

MATERIALS – Sodium alanate (NaAlH_4) and ammonia borane (H_6NB) are materials containing large concentrations of hydrogen, which could provide improved shielding effectiveness against energetic space radiations. Ammonia borane is a colorless, flammable, waxy solid having a density of 0.78 g/cm^3 . Sodium alanate is a complex metal hydride (salt) with a density ranging from 0.7 to 1.2 g/cm^3 .

INCIDENT SPE PROTON SPECTRUM –Typically, SPE event spectra used as inputs into transport calculations are parameterized either with an exponential function in rigidity (momentum per unit charge) (4) or with a power law in energy, usually of a Weibull form (5). The latter

appears to give a better fit to the limited spectral data for protons with energies greater than 100 MeV than does the exponential in rigidity and was recommended as the more accurate parameterization to use in space radiation protection studies (6). For this study, calculations were carried out using the exponential in energy parameterization of the King spectrum for the August 1972 event that is embedded in the BRYNTRN code (2, 3).

INCIDENT GCR SPECTRA – The galactic cosmic ray environmental model of Badhwar and O'Neill (7) is used to generate the input spectra for the 1977 GCR Solar Minimum environment, and for the 1970 GCR Solar Maximum environment. The 1977 Solar Minimum spectrum was selected because it appears to be the most intense of the modern space era. The 1970 Solar maximum spectrum was selected because it was the previous solar maximum period prior to the 1977 minimum. Both of these spectra are commonly used to represent the GCR environment in these types of studies.

ORGAN DOSE CALCULATIONS - Doses are estimated for these assumed events using the HZETRN space radiation transport code (2) for the GCR spectra, the BRYNTRN code (3) for the SPE spectra, and the Computerized Anatomical Man human geometry model (8). The incident spectra and their nuclear reaction secondary products are transported through the ammonia borane or sodium alanate shielding and overlying body tissue (simulated with water) using the HZETRN or BRYNTRN codes. The CAM model body self-shielding distributions in combination with the HZETRN or BRYNTRN results are then used to calculate the dose and dose equivalent estimates to critical organs. The body organ self-shielding distributions are obtained using 512 rays, which cover the entire 4π solid angle surrounding a particular organ site. The body self-shielding distributions are representative of those for the 50th percentile USAF pilot (175 cm height and 70 kg mass). Doses are presented for the skin and bone marrow (BFO) since these are two of the major critical organs of interest for space radiation protection purposes. Eye doses and dose equivalents are not presented here since they are very similar to the values for the skin. The skin and BFO are distributed throughout the body. Therefore, doses and dose equivalents for them are obtained by averaging over 33 anatomical locations for each organ. Note that organ doses are given in units of centiGray (cGy), where 1 cGy = 0.01 Gy = 1 rad and 1 Gy = 1 J/kg. Organ dose equivalents are in units of centiSievert (cSv) where 1 cSv = 0.01 Sv = 1 rem and 1 Sv = 1 J/kg.

GCR SPECTRUM RESULTS

Tables 1-4 display organ dose and dose equivalent, for several depths of shielding for polyethylene, ammonia borane and sodium alanate shields, for the incident 1970 and 1977 GCR spectra.

From Table 1 we find that the organ doses are uniformly fairly small, which is to be expected for this solar maximum spectrum, since the interplanetary magnetic fields are highest at this time and tend to deplete the incoming GCR particle abundances at energies below several hundred MeV/nucleon by deflecting them away from the inner heliosphere. Note that ammonia borane appears to provide as much as 5% dose reduction over that provided by polyethylene. Note also that sodium alanate is not as effective as either ammonia borane or polyethylene.

Table 1. Annual skin and bone marrow (BFO) dose (cGy) versus shield areal density (g cm^{-2}) for the 1970 GCR spectrum.

Shield Areal Density	Polyethylene		Ammonia Borane		Sodium Alanate	
	Skin	BFO	Skin	BFO	Skin	BFO
5	5.6	5.4	5.4	5.3	6.0	5.5
10	5.3	5.2	5.1	5.0	6.0	5.5
20	5.0	5.0	4.8	4.8	5.8	5.4
50	4.4	4.4	4.2	4.1	5.4	5.1

In Table 2 we find that ammonia borane is a much better shield for reducing organ dose equivalent than sodium alanate. We also find that organ dose equivalents are as much as 10% smaller behind the ammonia borane shield when compared with the polyethylene shield.

Table 2. Annual skin and bone marrow (BFO) dose equivalent (cSv) versus shield areal density (g cm^{-2}) for the 1970 GCR spectrum.

Shield Areal Density	Polyethylene		Ammonia Borane		Sodium Alanate	
	Skin	BFO	Skin	BFO	Skin	BFO
5	18.0	13.0	16.7	12.2	21.4	14.0
10	13.4	11.1	12.0	10.2	17.5	12.5
20	9.6	9.3	8.7	8.7	13.4	10.9
50	7.6	7.6	7.4	7.4	10.4	9.7

The trends in shielding effectiveness noted in Table 1 for the organ doses from the 1970 GCR spectrum carry over for the organ doses from the 1977 GCR spectrum. Note that the ammonia borane shield appears to be slightly better at reducing organ doses than the polyethylene shield (as much as a 3% reduction). The sodium alanate shield, however, is slightly worse than the polyethylene shield at each areal density, organ doses being about 3% higher for the sodium alanate shield.