NASA Technical Memorandum 100620

Preliminary Estimates of Radiation Exposures for Manned Interplanetary Missions From Anomalously Large Solar Flare Events

(NASA-TM-100620) PRELIMINARY ESTIMATES OF
RADIATION EXPOSURES FOR MANNED
INTERPLANETARY MISSIONS FROM ANOMALOUSLY
LARGE SOLAR FLARE EVENTS (NASA) 16 p
CSCL 03B G3/93

N88-25427

Unclas
0148163

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May 1988

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ABSTRACT

Preliminary estimates of radiation exposures for manned interplanetary missions resulting from anomalously large solar flare events are presented. The calculations use integral particle fluences for the February 1956, November 1960, and August 1972 events as inputs into the Langley Research Center nucleon transport code BRYNTRN. This deterministic code transports primary and secondary nucleons (protons and neutrons) through any number of layers of target material of arbitrary thickness and composition. Contributions from target nucleus fragmentation and recoil are also included. Estimates of 5-cm depth doses and dose equivalents in tissue are presented behind various thicknesses of aluminum, water, and composite aluminum/water shields for each of the three solar flare events.

INTRODUCTION

As time progresses, there is an ever-increasing interest in launching a manned mission to the planet Mars. A major concern to interplanetary mission planners is exposure of the crew to highly penetrating and damaging space radiations. The two main sources of these radiations are galactic cosmic rays and solar particle events. Preliminary estimates of exposure from galactic cosmic rays were presented elsewhere (ref. 1). The purpose of the present report is to present preliminary estimates of radiation exposures from anomalously large solar flare events. For computational purposes, three major events were chosen: February 1956, November 1960, and August 1972. The 1956 event provided the most penetrating radiations. The 1972 event, the largest ever recorded (ref. 2), could have been mission-threatening for thinly shielded (< 2 g/cm^2) spacecraft.

In this report, preliminary estimates of total dose (rad) and total dose equivalent (rem) exposures in tissue (5-cm depth) behind various thicknesses of aluminum, water, and composite (aluminum and water) shielding are presented for each solar flare event. The calculations use the integral proton spectra (ref. 2) displayed in figure 1 as inputs into the transport code.

CALCULATIONAL METHODS

The incident solar flare spectrum for each of the three flare events is propagated through the target material using the Langley Research Center deterministic nucleon transport code, BRYNTRN, described in reference 3. These transport calculations include

a. ICRP-26 quality factors (ref. 4).

b. Dose contributions from propagating neutrons and protons.

c. Dose contributions resulting from target nuclear fragments produced by propagating neutrons and protons.

d. Dose contributions due to nuclear recoil.

Major shortcomings of the calculations are

a. A quality factor of 20 is assigned to all target fragments.

b. A quality factor of 20 is assigned to all target nucleus recoil events.

c. Calculations were for simple slab geometries (equivalent to isotropic incidence on spherical shells). This is conservative. A more careful treatment of geometry effects (ref. 2) will likely result in smaller dose estimates.

d. Calculations are representative of blood-forming organ doses (5-cm depth) only. Estimates for dose to the skin and eyes are also important and may be limiting (ref. 2), but are not presented here.

RESULTS

Figures 2 and 3 display dose equivalent (in rem), as a function of water or aluminum shield thickness (in units of areal density, g/cm^2), for each of the three solar flare events. Clearly, the February 1956 event was the most penetrating. Unlike the August 1972 event, however, it would not be mission- or life-threatening for very thinly shielded spacecraft. For the August 1972 event, a thinly shielded spacecraft ($<$ 5 g/cm^2) would not provide adequate shielding as the estimated dose equivalents of 100-330 rem may incapacitate the crew as a result of radiation sickness, and could possibly be lethal (ref. 5). To reduce the estimated dose equivalents below the astronaut annual limit of 50 rem, approximately 10 g/cm^2 of water shielding or 13 g/cm^2 of aluminum shielding is required. The August 1972 flare is the limiting event for this case. To reduce the estimated exposures below the astronaut 30-day limit of 25 rem, a shield thickness of 20 g/cm^2 of water or 28 g/cm^2 of aluminum is required. The limiting event for this case is the February 1956 solar flare. Comparing these results with the estimated shielding requirements for galactic cosmic rays (figure 1 of reference 1) suggests that providing the 13 g/cm^2 of aluminum necessary to shield against galactic cosmic rays at solar minimum should also provide adequate shielding against large solar flares. Tables I through IV list values of dose (rad) and dose equivalent (rem) from each flare as a function of shield thickness and particle type. The column labelled protons includes contributions from the incident flare protons and secondary protons produced by the breakup of target nuclei. The column labelled HZE incorporates target nucleus fragmentation and nuclear recoil contributions. Clearly a significant fraction of the radiation dose equivalent comes from target nucleus contributions.

Finally, we note that for all shield thicknesses, doses and dose equivalents are lower behind water shields than behind equivalent thicknesses of aluminum. This is the result of the increased energy loss per collision by the incident and secondary nucleons propagating through the lighter mass constituents of water. These findings suggest that low-density materials such as polyethylene, or other polymers, may be more effective for shielding applications than conventional aluminum. To investigate the possibility of using composite shields consisting of aluminum (for structural integrity) and water (for shielding efficiency), we calculated doses and dose equivalents for each flare impinging upon shields consisting of aluminum and water layers of varying thicknesses. The results are displayed in Table V. Note that as the percentage thickness of water in the shield increases, the dose and dose equivalent decrease. Clearly, further studies aimed at replacing aluminum with lighter, but structurally sound materials are warranted for manned spacecraft applications.

CONCLUDING REMARKS

Preliminary estimates of radiation exposures resulting from anomalously large solar flare events are presented for interplanetary missions. Dose and dose equivalent values for each flare are presented as a function of shield thickness for aluminum, water, and composite aluminum/water shields. Although the main contributions arise from propagating protons, target nucleus fragmentation and recoil contribute significantly to the dose equivalent because of the large quality factor associated with them. For the calculations presented in this work, water appears to be a much more desirable shielding material than aluminum. These results suggest that a composite shield consisting of the minimum amount of aluminum necessary for structural integrity is the configuration of choice. Further studies involving polyethylene or other candidate organic composites are suggested.

REFERENCES

1. Wilson, John W.; Townsend, Lawrence W.; and Atwell, William: Preliminary Estimates of Galactic Cosmic Ray Exposures for Manned Interplanetary Missions. NASA TM 100519, 1987.

2. Wilson, John W.; and Denn, Fred M.: Preliminary Analysis of the Implications of Natural Radiations on Geostationary Operations. NASA TN D-8290, 1976.

3. Wilson, John W.; Townsend,Lawrence W.; Chun, Sang Y.; Buck, W. W.; Khan, Ferdous; and Cucinotta, Francis A.: BRYNTRN: A Baryon Transport Computer Code-Computation Procedures and Data Base. NASA TM 4037, 1988.

4. International Commission on Radiological Protection: Recommendations of the ICRP. ICRP Publication 26, 1977.

5. Space Science Board: Radiobiological Factors in Manned Space Flight. National Academy of Sciences Publication 1487, 1967.

Table I - Depth-Dose Equivalent (rem) in Tissue (5-cm depth) as a Function of Water Shield Thickness for Three Anomalously Large Solar Flare Events

Thickness (g/cm^2)	Protons	HZE	Total Dose Equivalent
	February 1956 Event		
1	43.2	10.6	53.8
2	37.9	10.1	48.0
5	29.3	9.2	38.5
10	23.2	8.3	31.5
15	20.0	7.6	27.6
20	17.7	7.1	24.8
25	16.0	6.6	22.6
30	14.5	6.2	20.7
40	12.1	5.3	17.4
50	9.9	4.6	14.5
75	7.0	2.5	10.5
100	4.3	2.3	6.6
	November 1960 Event		
1	82.9	11.1	94.0
2	71.8	10.2	82.0
5	51.3	8.1	59.4
10	33.9	5.9	39.8
15	24.2	4.5	28.7
20	17.9	3.5	21.4
25	13.6	2.8	15.4
30	10.5	2.3	12.8
40	6.6	1.6	8.2
50	4.0	1.2	5.2
75	1.8	0.6	2.4
100	0.5	0.3	0.8
	August 1972 Event		
1	287.8	23.1	310.9
2	222.5	18.7	241.2
5	113.8	10.8	124.6
10	45.5	5.2	50.7
15	21.0	2.9	23.9
20	10.6	1.8	12.4
25	5.7	1.1	6.8
30	3.2	0.8	4.0
40	1.1	0.5	1.6
50	0.4	0.3	0.7
75	0.1	0.1	0.2
100	0.03	0.05	0.08

Note: 1 g/cm^2 of water is equivalent to a 1 cm thickness of water.

Table II - Depth-Dose (rad) in Tissue (5-cm depth) as a Function of Water Shield Thickness for Three Anomalously Large Solar Flare Events

Thickness (g/cm^2)	Protons	HZE	Total Dose
February 1956 Event			
1	43.1	0.5	43.6
2	37.8	0.5	38.3
5	29.3	0.5	29.8
10	23.2	0.4	23.6
15	19.9	0.4	20.3
20	17.7	0.4	18.1
25	15.9	0.3	16.2
30	14.5	0.3	14.8
40	12.0	0.3	12.3
50	9.9	0.2	10.1
75	7.0	0.2	7.2
100	4.3	0.1	4.4
November 1960 Event			
1	82.7	0.6	83.3
2	71.7	0.5	72.2
5	51.2	0.4	51.6
10	33.8	0.3	34.1
15	24.1	0.2	24.3
20	17.9	0.2	18.1
25	13.6	0.1	13.7
30	10.5	0.1	10.6
40	6.5	0.1	6.6
50	4.1	0.1	4.2
75	1.8	0.04	1.8
100	0.55	0.01	0.56
August 1972 Event			
1	286.9	1.2	288.1
2	221.9	0.9	222.8
5	113.5	0.5	114.0
10	45.4	0.3	45.7
15	21.0	0.1	21.1
20	10.6	0.1	10.7
25	5.6	0.1	5.7
30	3.2	0.04	3.2
40	1.1	0.02	1.1
50	0.41	0.02	0.43
75	0.09	<0.01	0.09
100	0.03	<0.01	0.03

Note: 1 g/cm^2 of water is equivalent to a 1 cm thickness of water.

Table III - Depth-Dose Equivalent (rem) in Tissue (5-cm depth) as a Function of Aluminum Shield Thickness for Three Anomalously Large Solar Flare Events

Thickness (g/cm^2)	Protons	HZE	Total Dose Equivalent
	February 1956 Event		
1	44.7	10.8	54.5
2	40.1	10.4	50.5
5	31.9	9.7	41.6
10	25.6	8.9	34.5
20	20.0	8.0	28.0
50	12.7	6.0	18.7
	November 1960 Event		
1	86.0	11.5	97.5
2	76.5	10.7	87.2
5	57.6	8.9	66.5
10	40.3	6.9	47.2
20	23.3	4.6	27.9
50	6.9	1.9	8.8
	August 1972 Event		
1	306.5	24.5	331.0
2	249.9	20.8	270.7
5	144.9	13.5	158.4
10	67.6	7.5	75.1
20	19.7	3.2	22.9
50	1.4	0.7	2.1

Note: 1 g/cm^2 of aluminum is equivalent to a thickness of 0.37 cm of aluminum.

Table IV - Depth-Dose (rad) in Tissue (5-cm depth) as a Function of Aluminum Shield Thickness for Three Anomalously Large Solar Flare Events

Thickness (g/cm^2)	Protons	HZE	Total Dose
February 1956 Event			
1	44.6	0.5	45.1
2	40.0	0.5	40.5
5	31.8	0.5	32.3
10	25.5	0.4	25.9
20	20.0	0.4	20.4
50	12.7	0.3	13.0
November 1960 Event			
1	85.8	0.6	86.4
2	76.3	0.5	76.8
5	57.5	0.4	57.9
10	40.2	0.3	40.5
20	23.3	0.2	23.5
50	6.8	0.1	6.9
August 1972 Event			
1	305.5	1.2	306.7
2	249.2	1.0	250.2
5	144.5	0.7	145.2
10	67.3	0.4	67.7
20	19.6	0.2	19.8
50	1.3	0.1	1.4

Note: 1 g/cm^2 of aluminum is equivalent to a thickness of 0.37 cm of aluminum.

Table V - Dose (rad) and Dose Equivalent (rem) in Tissue (5-cm depth) as a Function of Composite Aluminum/Water Shield Thickness for Three Anomalously Large Solar Flare Events

Thickness (g/cm^2)			Total Dose (rad)			Total Dose Equivalent (rem)		
Total	Aluminum	Water	Feb 56	Nov 60	Aug 72	Feb 56	Nov 60	Aug 72
5	1	4	30	53	120	39	61	131
	2	3	31	54	125	40	62	137
	5	0	32	58	145	42	66	158
10	1	9	24	35	47	32	40	53
	2	8	24	35	49	32	41	55
	5	5	25	37	55	33	43	61
	10	0	26	41	68	35	47	75
15	1	14	20	25	22	28	29	25
	2	13	21	25	23	28	30	26
	5	10	21	26	25	29	31	28
	10	5	22	28	30	30	33	33
20	5	15	19	19	12	26	23	14
	10	10	19	20	14	26	24	17
	20	0	20	24	20	28	28	23

Note: 1 g/cm^2 of aluminum (water) is equivalent to an aluminum (water) thickness of 0.37 cm (1 cm).

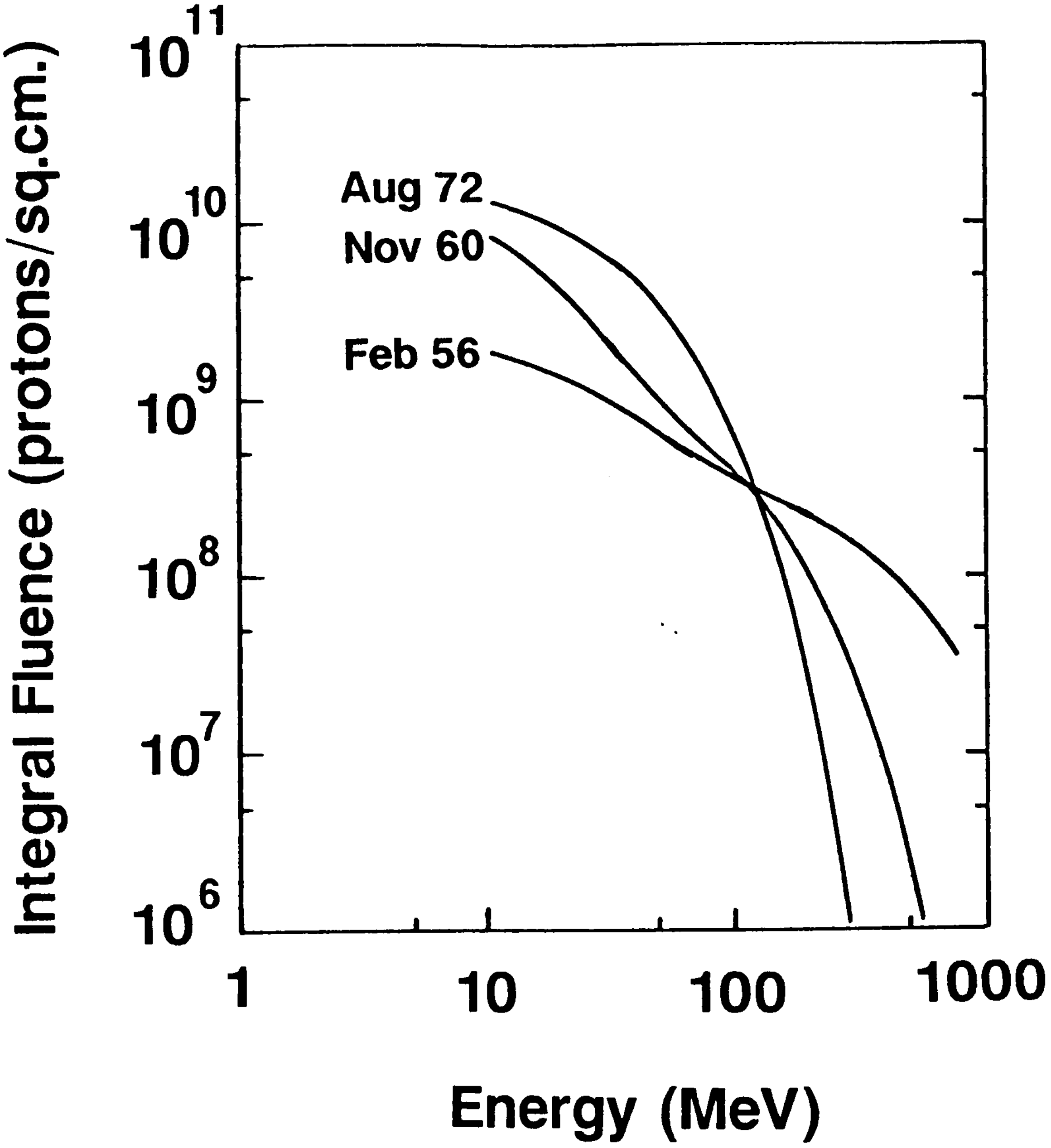

Figure 1. - Integral particle fluence, as a function of energy, for three anomalously large solar flare events.

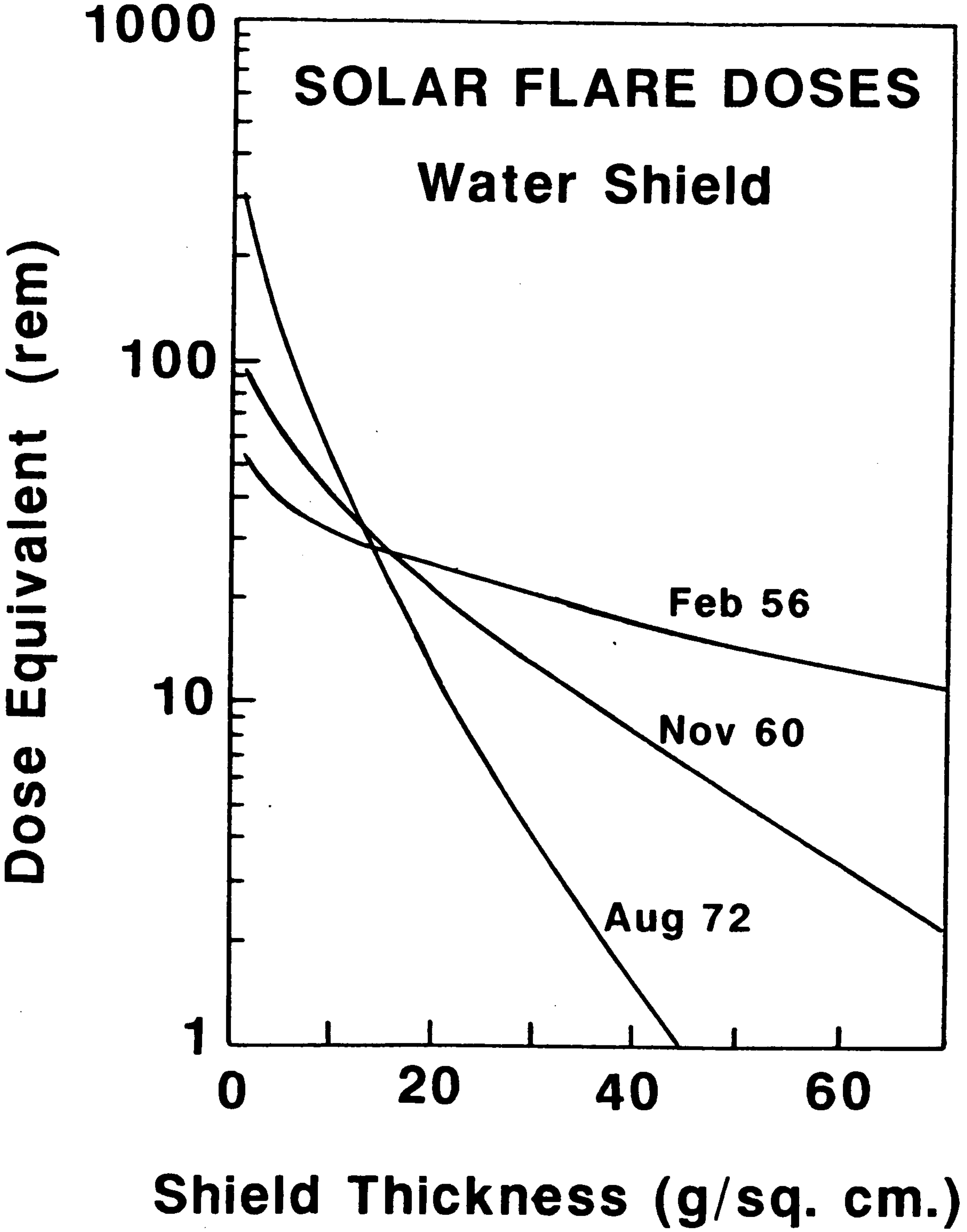

Figure 2. - Dose equivalent in tissue (5-cm depth), as a function of water shield thickness, resulting from three anomalously large solar flare events.

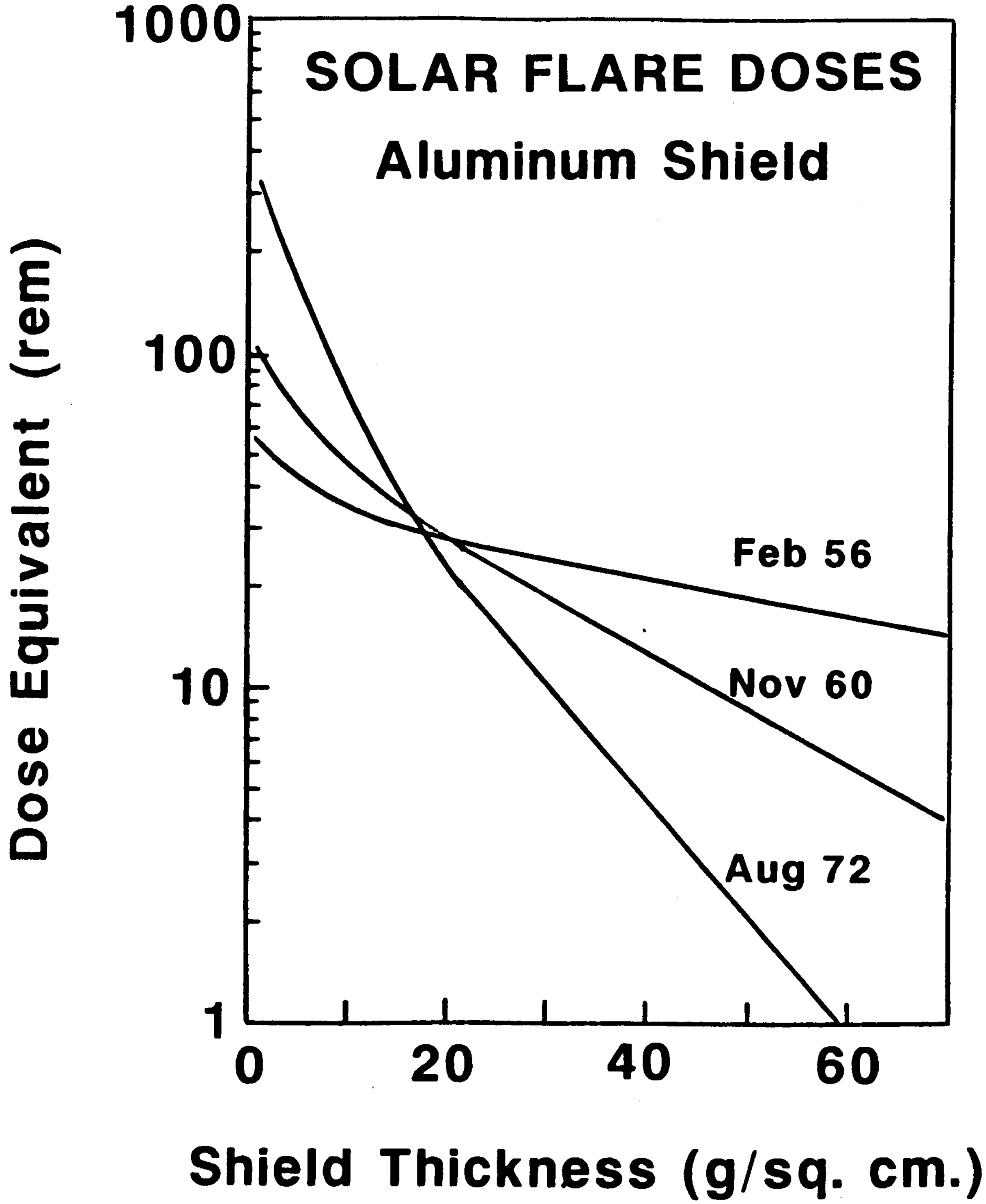

Figure 3. - Dose equivalent in tissue (5-cm depth), as a function of aluminum shield thickness, resulting from three anomalously large solar flare events.

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Report Documentation Page

1. Report No. NASA TM-100620	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Preliminary Estimates of Radiation Exposures for Manned Interplanetary Missions From Anomalously Large Solar Flare Events		5. Report Date May 1988
		6. Performing Organization Code
7. Author(s) Lawrence W. Townsend John E. Nealy John W. Wilson		8. Performing Organization Report No. 199-22-76-01
		10. Work Unit No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Preliminary estimates of radiation exposures for manned interplanetary missions resulting from anomalously large solar flare events are presented. The calculations use integral particle fluences for the February 1956, November 1960, and August 1972 events as inputs into the Langley Research Center nucleon transport code BRYNTRN. This deterministic code transports primary and secondary nucleons (protons and neutrons) through any number of layers of target material of arbitrary thickness and composition. Contributions from target nucleus fragmentation and recoil are also included. Estimates of 5-cm depth doses and dose equivalents in tissue are presented behind various thicknesses of aluminum, water, and composite aluminum/water shields for each of the three solar flare events.

17. Key Words (Suggested by Author(s)) Radiation Doses Solar Flares Interplanetary Missions		18. Distribution Statement Unclassified - Unlimited Subject Category - 93	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 15	22. Price A02

NASA FORM 1626 OCT 86