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Errata

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Weyland, M.D.; Atwell, W.; Cucinotta, F.A.; Wilson, J.W.; Hardy, A.C.

In the computation of excess cancers and mortalities in this paper, a conversion to SI units of two variables was inadvertently omitted. The correction lowered the risks by varying degrees of magnitude. The corrected results are given in the following tables. The secondary particle contribution has been lowered by a factor of 2 for the total risk at 10 g/cm^2. The conclusions remain the same with the exception of specific referenced numerical risks which have been corrected herein. The authors apologize for these errors and regret any inconvenience this omission may have caused.

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ABSTRACT

This study investigated radiation exposures and cancer induction/mortality risks for several major solar particle events (SPE's). The SPE's included in this study are: February 1956, November 1960, August 1972, October 1989, and the September, August, and October 1989 events combined. The three 1989 events were treated as one since all three could affect a single lunar or Mars mission. A baryon transport code was used to propagate particles through aluminum and tissue shield materials. This study utilized a free space environment for all calculations. Results show the 30-day blood forming organs (BFO) limit of 25 rem was surpassed by all five events using 10 g/cm^2 of shielding. The BFO limit is based on a depth dose of 5 cm of tissue, while this study utilized a more detailed shield distribution of the blood forming organs. A comparison between the 5 cm depth dose and the dose found using the BFO shield distribution shows the 5 cm depth value slightly higher than the BFO dose. The annual limit of 50 rem was exceeded by the August 1972, October 1989, and the three combined 1989 events with 5 g/cm^2 of shielding. Cancer mortality risks ranged from 1.5 to 17 % at 1 g/cm^2 and 0.5 to 1.1 % behind 10 g/cm^2 of shielding for the five events. These ranges correspond to those for a 45 year old male. It is shown that secondary particles comprise about 1/3 of the total risk at 10 g/cm^2 of shielding. Utilizing a computerized Space Shuttle shielding model to represent a typical spacecraft configuration in free space at the August 1972 SPE, average crew doses exceeded the BFO dose limit.

1. INTRODUCTION

The primary radiation concerns during manned space flights are the trapped radiation belts surrounding the earth, galactic cosmic rays (GCR), and solar particle events (SPE). While trapped radiations are limited in spatial extent and can largely be avoided, the low intensity GCR's are always present and the SPE's are potentially of high intensity although limited in time and spatially unavoidable except deep within the Earth's magnetic field. A large SPE during a lunar or Mars mission, where the spacecraft is not protected by the Earth's geomagnetic field, could have acute as well as chronic adverse health effects on improperly shielded crewmembers (Townsend et al., 1990). The effects of protons, the primary radiation associated with an SPE, on the body are subject to uncertaintes due to the high Linear Energy Transfer (LET) secondary particles produced from target fragmentation (Cucinotta, 1991).

This study investigated human organ radiation exposures behind different depths of aluminum for some past major SPE's in free space. The doses used herein were derived explicitly from the SPE's and exclude the GCR contribution which would be present and significant on long duration exploratory class missions. The skin, eye, and BFO doses were compared with the limits currently used by NASA. Cancer risks were attained for each organ and summed to give a total risk of excess cancers and cancer mortalities from these SPE's. To illustrate the importance of secondary particles, risks were calculated and shown for both the primary and secondary particles for one of the flares. Doses and risks were also obtained for two dosimeter locations aboard the current Space Shuttle, giving a complex and realistic example differing from simple slab geometries. This study could be used as baseline data in determining a safe and reasonable thickness of shielding for a manned space exploration vehicle and an associated "storm shelter."

2. BACKGROUND

The energetic charged particles originating from a solar particle event were propagated through aluminum and tissue shielding material using the code BRYNTRN (Wilson, et al.,1989). BRYNTRN is a baryon transport model which utilizes the Boltzmann equation in a straight ahead approximation. The transport code BRYNTRN was linked to the Computerized Anatomical Man (CAM) model (Billings, Yucker, 1973) in order to obtain organ doses behind various thicknesses of aluminum shielding. The CAM model was developed in the early 1970's, and with updates remains as one of the best geometrical and anthropomorphically correct computer models available. It is based on 50^{th} percentile standing U.S. Air Force man.

Risks were assigned to each organ based mostly on data collected in a report to the National Institutes of Health (NIH) concerning radioepidemiological tables (Rall, et al., 1985). The risk coefficients used by the NIH working group could have substantial uncertainties associated with the age- and sex-specific values (NCRP 98, 1989). One reason for this uncertainty stems from transforming mortality rates to incidence rates based on vital statistics data (NCRP 98, 1989). The linear quadratic (L-Q) equation used in the National Council on Radiation Protection and Measurements report No. 98 (NCRP 98), was derived by scaling the linear Biological Effects of Ionizing Radiation (BEIR) coefficients (NAS / NRC, 1980) by a factor related to low or high doses at low dose rates. The NCRP 98 committee defines acute and protracted doses using 5 rad/day as a dividing line. A dose received at a rate greater than 5 rad/day is considered acute whereas less than 5 rad/day is a protracted dose. All the doses discussed in this study fall under the acute situation. This factor is termed the Dose Rate Reduction Factor (DRRF) (NCRP 98, 1989). The L-Q coefficient for the acute situation is:

$$\text{Risk coefficient} = \text{BEIR coefficient} \times \frac{D}{(DRRF)}\left[1+\frac{D}{1.16}\right] \qquad \text{Eq. 2.1}$$

where: D = the acute dose in gray (Gy),

1.16 Gy = the assumed cross-over dose point for which the dose-squared contribution equals the linear contribution (Rall et al., 1985).

The assumed DRRF is 2.5 according to the NCRP 98. These coefficients were then used to express predicted lifetime risks and mortalities from cancer among 1000 persons, both age- and sex-specific. An L-Q relationship was used for all organs excluding the thyroid, where a linear relationship exists. The risks for varying acute organ doses could be obtained from the NCRP 98 tables with the following equation:

$$E_n = E_T \frac{\left[D_n \times \left[1 + \frac{D_n}{1.16}\right]\right]}{\left[D_T \times \left[1 + \frac{D_T}{1.16}\right]\right]} \qquad \text{Eq. 2.2}$$

where: D_n = the new dose

E_n = excess cancers for the new dose

D_T = dose used in NCRP 98 tables

E_T = specific cancer excess associated with dose D_T.

The lifetime radiation risks computed in this report were representative of cancer sites in which the NIH Working Group provided risk coefficients (Rall, et al., 1985) and for "other" cancers. It has been shown that most cancers can be caused by radiation; however, there is little or no evidence of radiation causing chronic lymphocytic (CL) leukemia (NCRP 98, 1989). The leukemia risks given herein do not include this type of malignancy and will be designated as the "sum of non-CL leukemia." One excess cancer per million person-year-rad was assigned for "other" sites by the BEIR committee and coefficients were then computed by assuming them to be proportional to those for deaths from all cancers, except leukemia, in the atomic bomb survivors of both sexes combined (NCRP 98, 1989). The organs of reference used in the "other" site category are tumors of the oral cavity, rectum, gallbladder, uterine corpus, uterine cervix, ovary, brain, bone, connective tissue, prostate and testis, and melanoma, lymphoma, and Hodgkin's disease (NCRP 98, 1989).

This study used dose equivalent numbers in place of absorbed doses to account for the higher LET values associated with space radiation. It should be noted that the risks shown in this study are subject to significant uncertainty due to the many assumptions used in computing final values. These risks are best estimates using available data and methods for risk projections.

3. PROCEDURE

The code BRYNTRN was run for six past significant SPE's including February 1956, November 1960, August 1972, August 1989, September 1989, and October 1989. The 1989 events were combined for one case since all three SPE's could have affected a single lunar or Mars mission. The October 1989 flare was also used singularly because of its size. The code was modified to transport SPE particles through seven different depths of aluminum and 16 different thicknesses of tissue (H_2O in the code). BRYNTRN was set up such that the particles were transported through the 16 depths of tissue following the propagation through each thickness of aluminum. Organ doses were interpolated using these data in conjunction with organ shield distributions from the CAM model. The shield distributions are obtained by selecting a dose point in the organ and ray tracing isotropically to outside the body. These organ doses could then be applied to equation 2.2 to obtain organ-, age-, and sex-specific risks. A short code, RISK, was written to accomplish this task. To show the contribution of secondary particles, the output of BRYNTRN was modified to give doses from both secondary and primary particles. Following this, the same procedure described above was followed to obtain risks. This was done only for the August 1972 flare. To show organ doses and risks in a situation other than slab geometries, two dosimeter locations (DLOC) on the current Space Shuttle were chosen, historically the points with the highest and lowest dose readouts, and put into free space for the August 1972 flare. These results were obtained by interpolating the BRYNTRN output twice, first through the Shuttle using its shield distribution model, and then through the body. Risks were then found following the methodology described above.

4. RESULTS

Selected organ doses and dose equivalents vs. thickness of aluminum shielding are shown in figures 1 - 10. These plots give a good indication of where additional shielding produces only a small decrease in doses. A comparison of the BFO, skin, and eye doses with the limits is given in tables 1 - 5. One should recall that all the doses and risks shown herein are representative of free space, outside the earth's magnetosphere. As can be seen, the BFO limit is exceeded until 10 g/cm^2, table 1, for the August 1972 flare, and this does not take into account the GCR contribution. Tables 6 - 25 show the organ-, age-, and sex-specific cancer and mortality risks for the different flares behind 1 and 10 g/cm^2 of Al shielding. It should be noted that due to the lack of a suitable female model at the time this study was conducted, the risk from the breasts was left out for the female. This is significant in that the breasts generally represent the greatest single organ cancer risk to the female and the exposure is expected to be relatively high (Shavers et al., 1991). Upon completion of a female model, currently being worked on, risks will be calculated and documented. The risk contribution from secondary particles can be seen in tables 26 - 29 and average approximately 33% of the total risk at 10 g/cm^2 of Al shielding. Tables 30 - 34 show the doses and associated risks at dosimeter locations (DLOC) #1 and #2 on the current Space Shuttle in free space for the August 1972 event.

5. CONCLUSIONS

This study investigated organ doses from many different perspectives. The current NASA limits were compared with the BFO, skin, and eye computed doses. It can be seen that for each of the SPE's, the BFO doses exceeded the current 30-day limit of 25 rem using 10 g/cm^2 of aluminum shielding. It should be stated that the limits for Space Exploration Initiative (SEI) class missions could vary from current limits depending on other nominal risks associated with these flights and the feasibility of staying below a predetermined dose limit. The annual limit, 50 rem, was surpassed by the August 1972, October 1989, and the three 1989 events combined behind 5 g/cm^2 of aluminum. Graphs of doses and dose equivalents for other organs vs. shield thickness are shown in figures 1 - 10. These figures give a representation of where more shielding yields small changes in dose for each event. This appears to be between 10 and 15 g/cm^2 on average for the flares used in this study. Tables 6 - 25 display age- and sex-specific risks based on the organ doses from each SPE. These risks were calculated behind 1 and 10 g/cm^2 of shielding. The risks are displayed as excess cancers and cancer mortalities per 1000 people. For the three combined

1989 events behind 10 g/cm^2 of shielding, a 25 year old male would have approximately a 2.5% risk of obtaining a fatal cancer. This doesn't take into account the GCR contribution which would add to this risk. To show the contribution of secondary particles, tables 26 - 29 show excess cancers and cancer mortalities for a 25 year old male due to both primary protons and secondary particles. The secondary particle contribution is approximately 1/3 of the total risk at 10 g/cm^2. The last set of tables, 30 - 34, show organ doses and their respective risks at two representative dosimeter locations on the current Space Shuttle for the August 1972 event in free space. It can be seen that the annual limit of 50 rem for the BFO was surpassed at DLOC #2 and was approached at DLOC #1. It should be noted that these two dosimeter locations are historically the highest (#2) and lowest (#1) dose points recorded during flights. The measured crewmember exposures have historically averaged approximately 110% of the DLOC #1 dose.

The flare doses behind varying depths of Al obtained with BRYNTRN correlated well with previously published values. As a reminder, these doses and risks do not include the additional exposure from GCR's which would be significant on an SEI mission. The results of this study give a detailed assessment of risks associated with major SPE's. The question of how much shielding is required for a "storm shelter" will be based on an amount equal to or greater than that shielding required to keep all doses at or below a level such that the mortality risk to the crewmembers stays below a predetermined value (e.g., 3-5%). The total radiation risk would require evaluations of contributions from the GCR as well as any onboard sources such as nuclear power. This does not exclude the As Low As is Reasonably Achievable (ALARA) principle, however; and it should be stressed that radiation limits of any kind, risk, or dose are established as maximums and not quotas.

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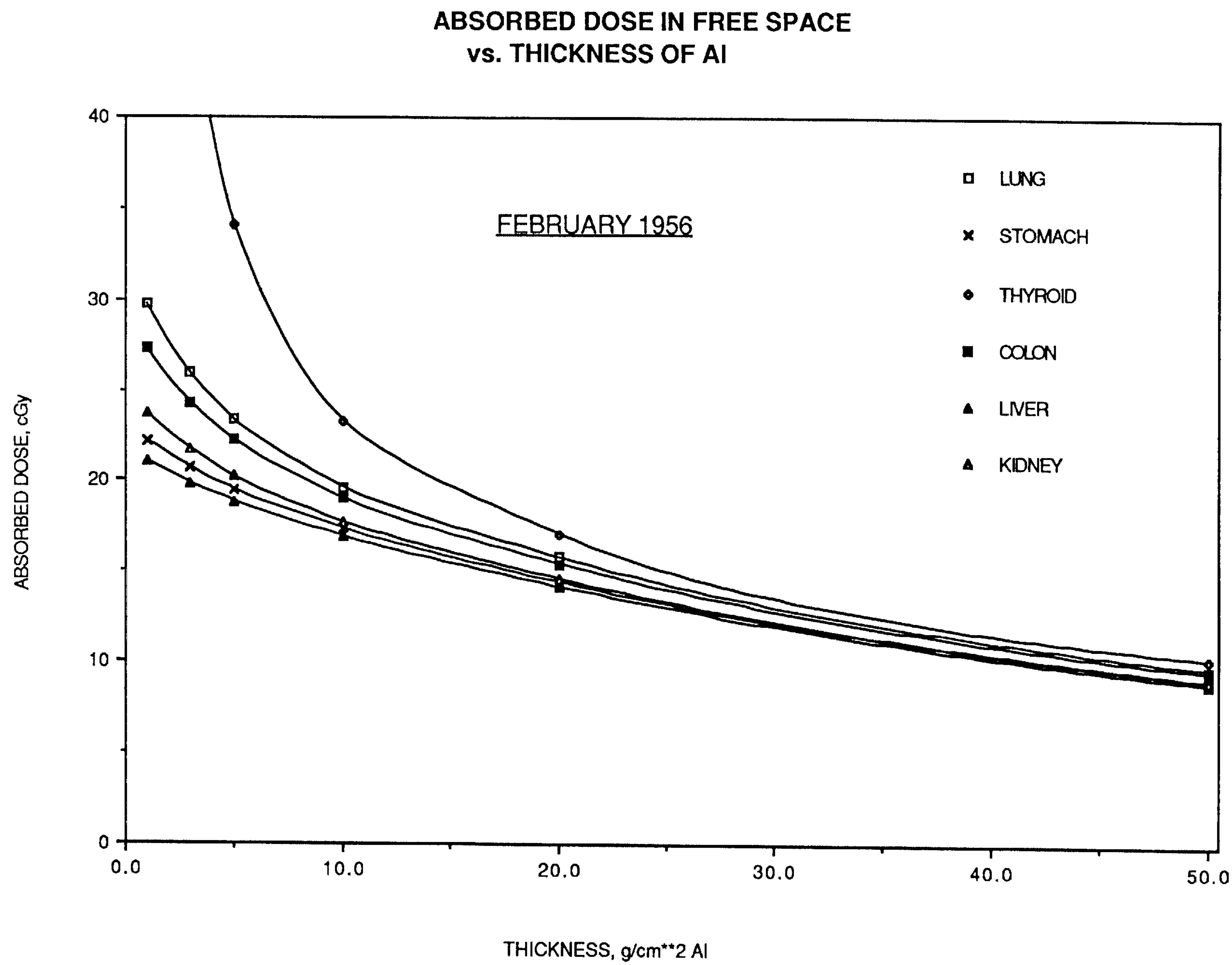
ABSORBED DOSE IN FREE SPACE
vs. THICKNESS OF Al
FEBRUARY 1956
LUNG
STOMACH
THYROID
COLON
LIVER
KIDNEY
ABSORBED DOSE, cGy
0
10
20
30
40
0.0
10.0
20.0
30.0
40.0
50.0
THICKNESS, g/cm**2 Al

Figure 1

ABSORBED DOSE IN FREE SPACE vs. THICKNESS OF Al

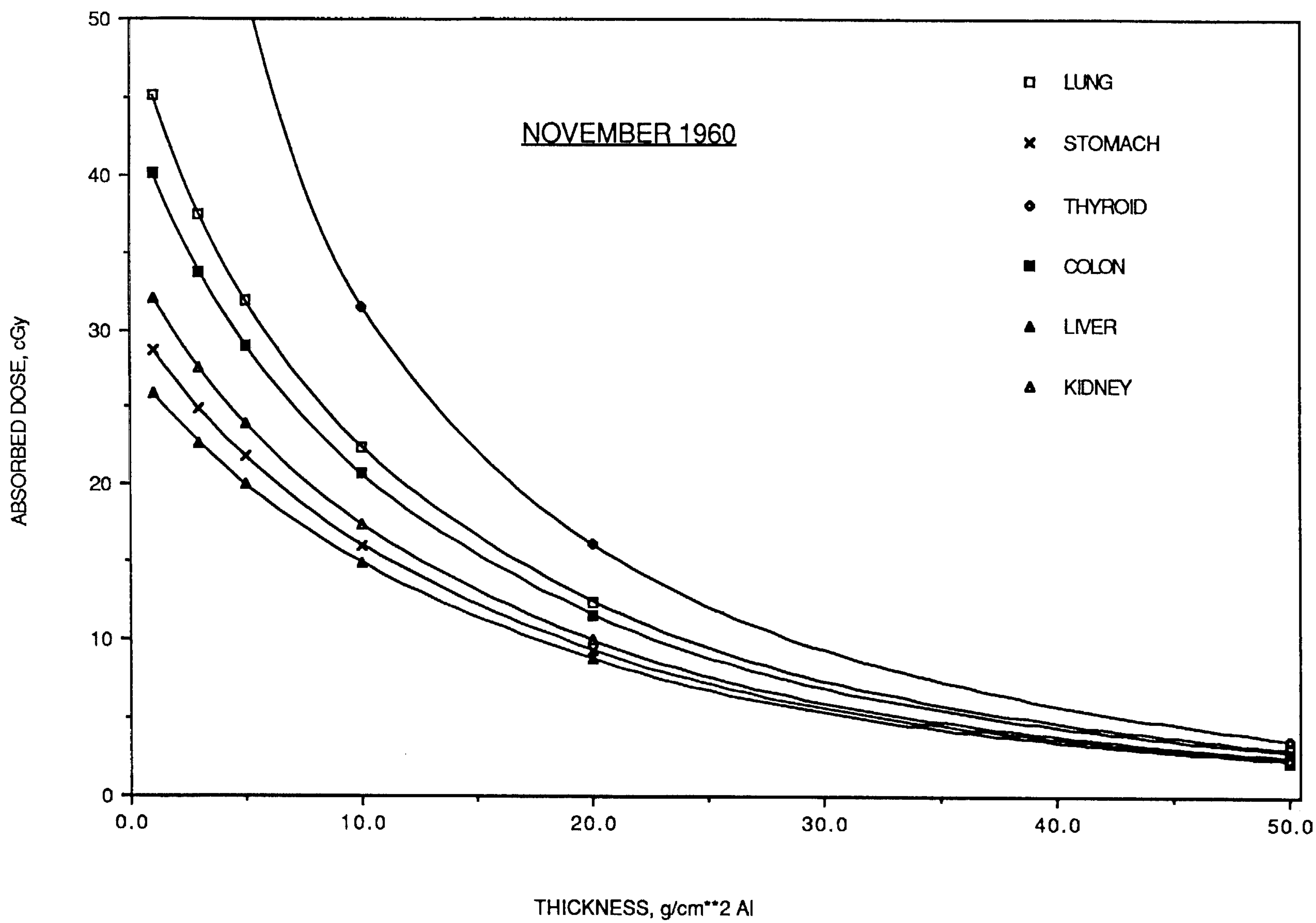

Figure 2

ABSORBED DOSE IN FREE SPACE vs. THICKNESS OF Al

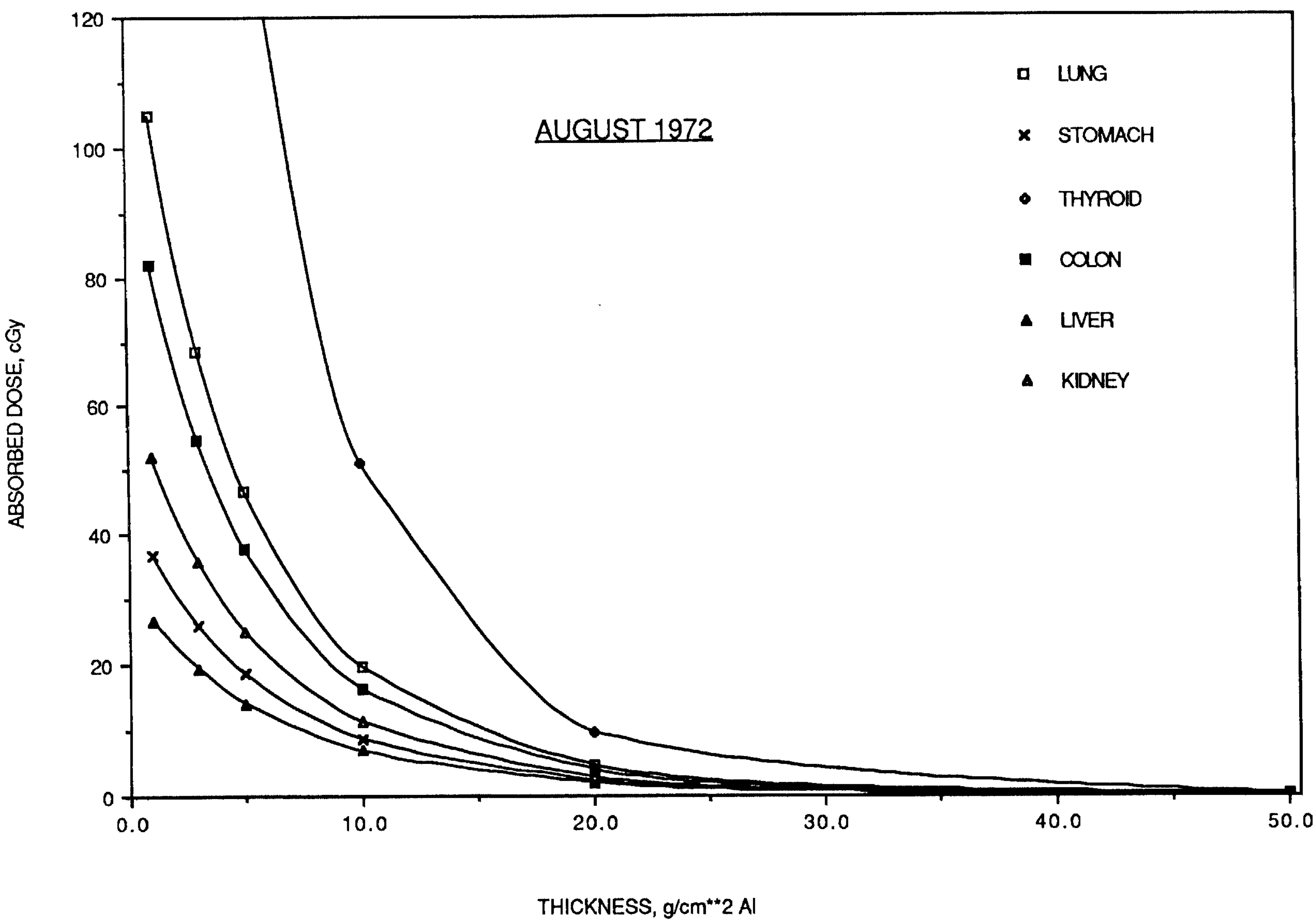

Figure 3

ABSORBED DOSE IN FREE SPACE vs. THICKNESS OF Al

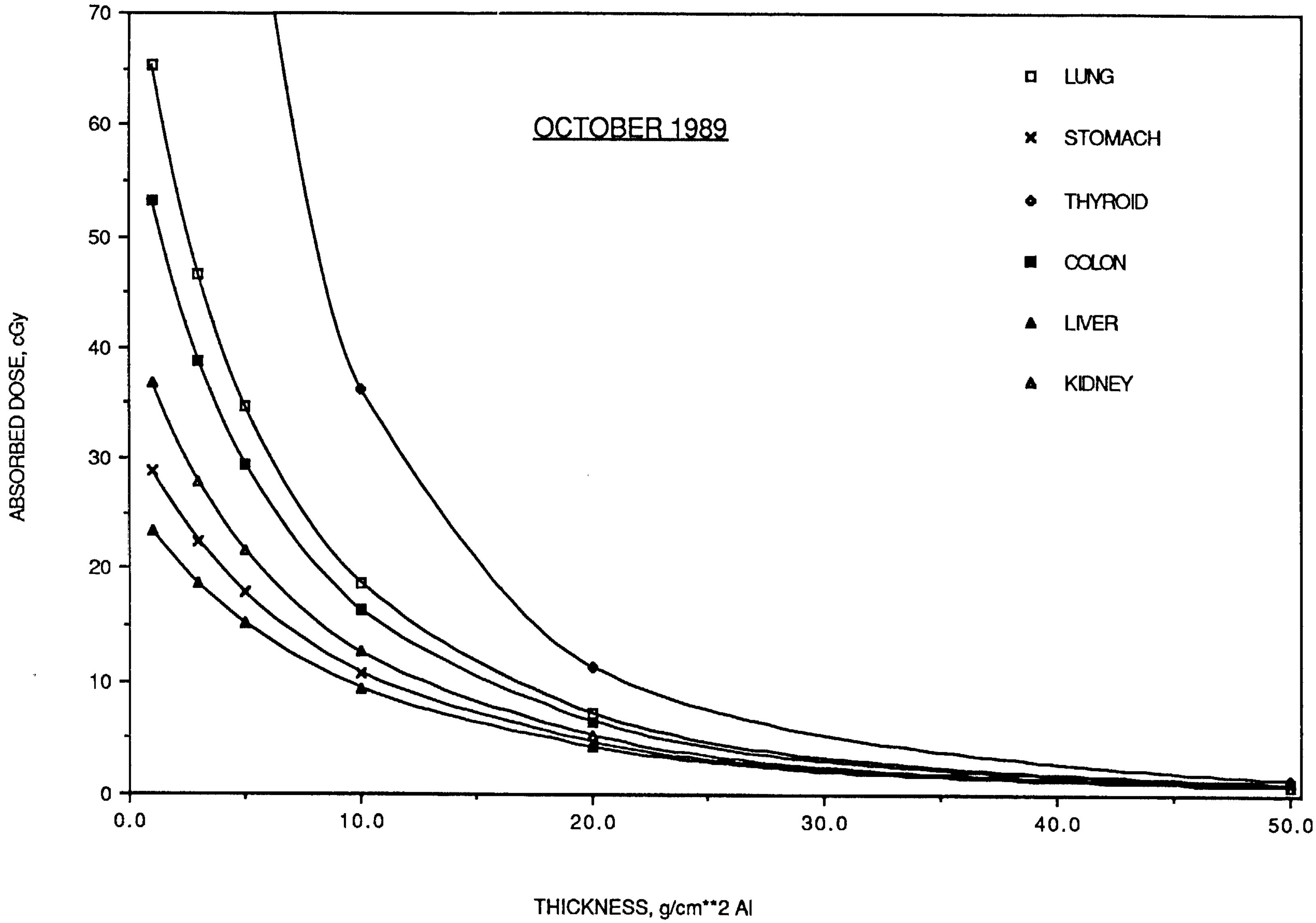

Figure 4

ABSORBED DOSE IN FREE SPACE vs. THICKNESS OF Al

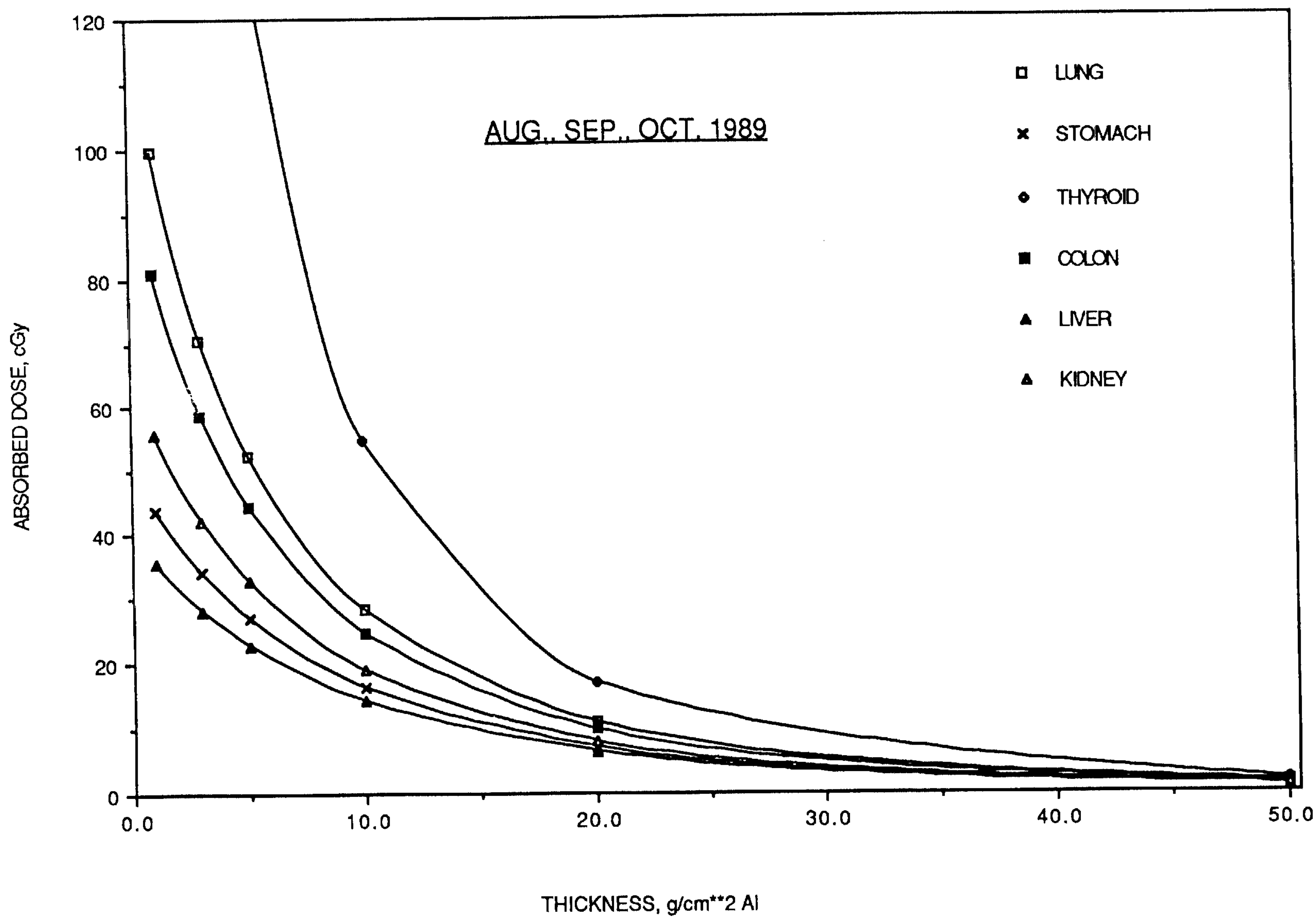

Figure 5

DOSE EQUIVALENT IN FREE SPACE vs. THICKNESS OF Al

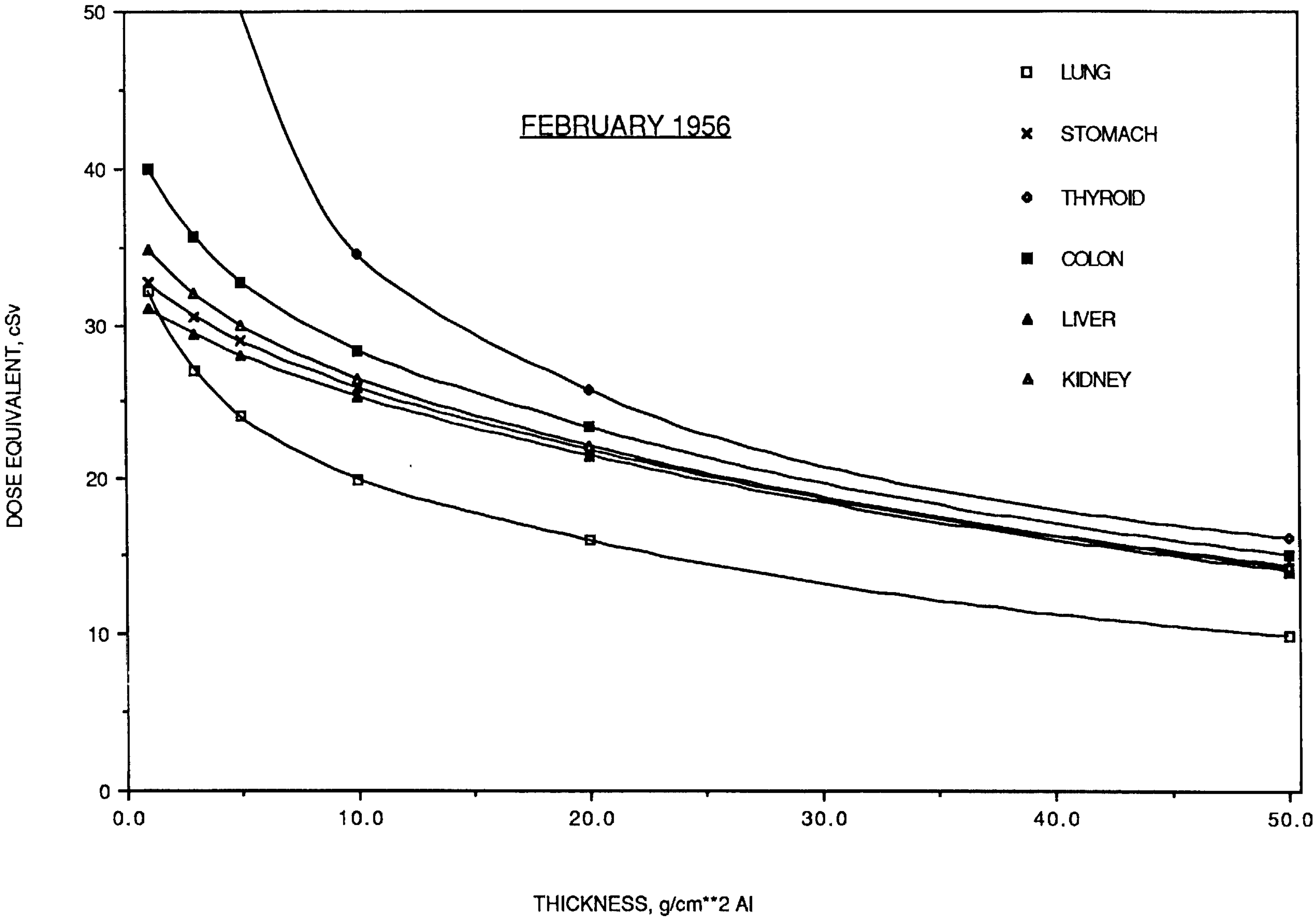

Figure 6

DOSE EQUIVALENT IN FREE SPACE vs. THICKNESS OF Al

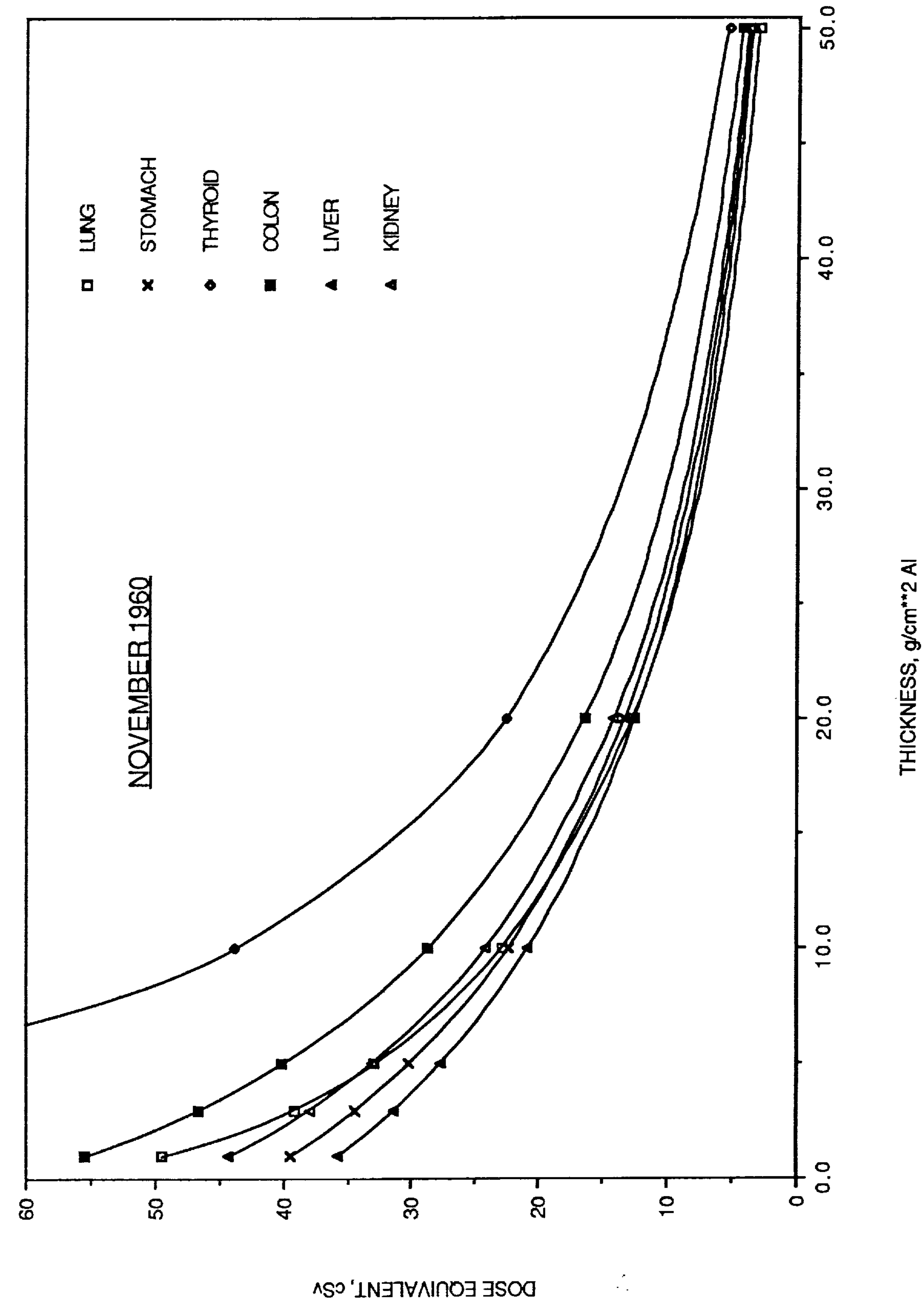

Figure 7

DOSE EQUIVALENT IN FREE SPACE vs. THICKNESS OF Al

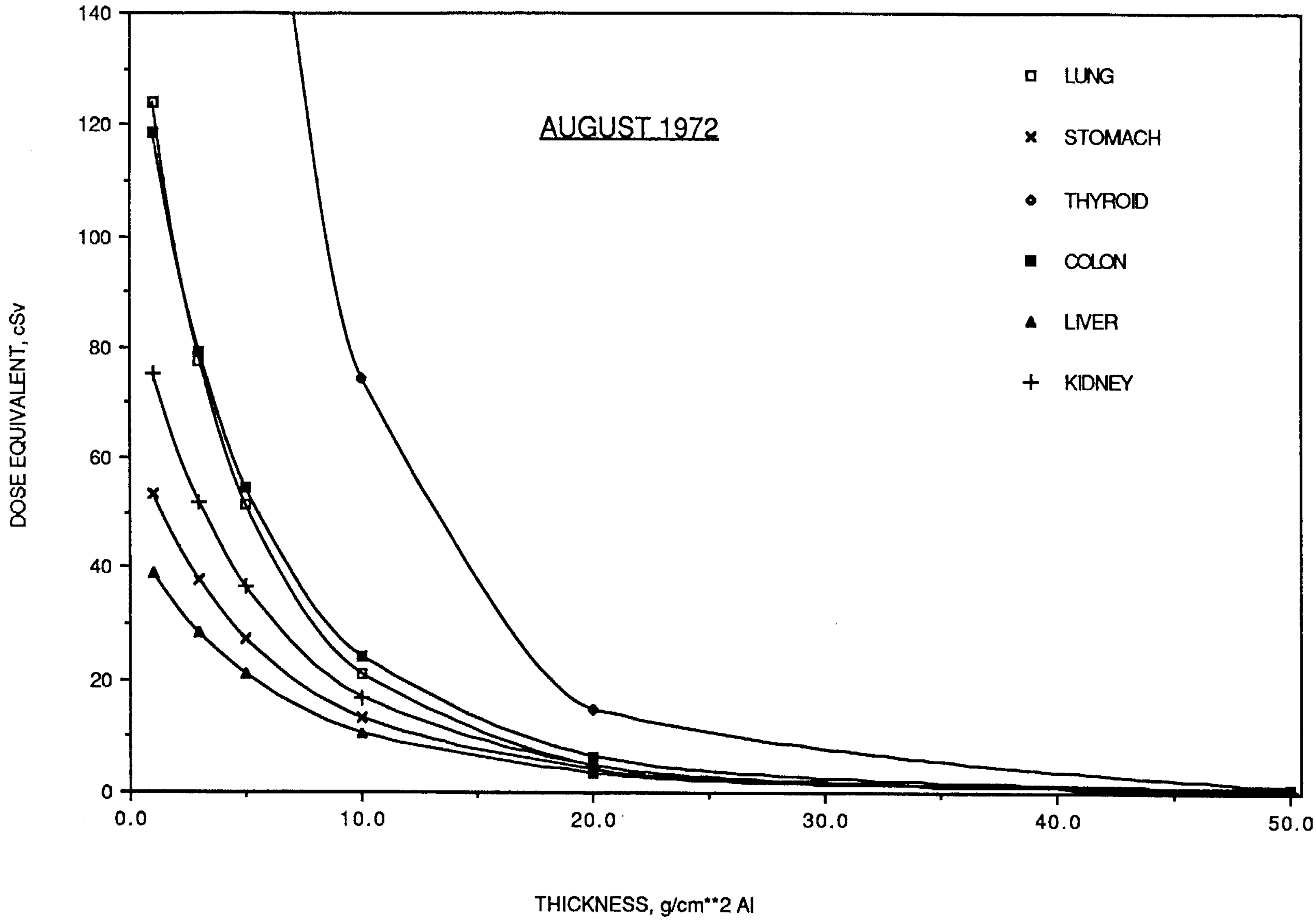

Figure 8

DOSE EQUIVALENT IN FREE SPACE vs. THICKNESS OF Al

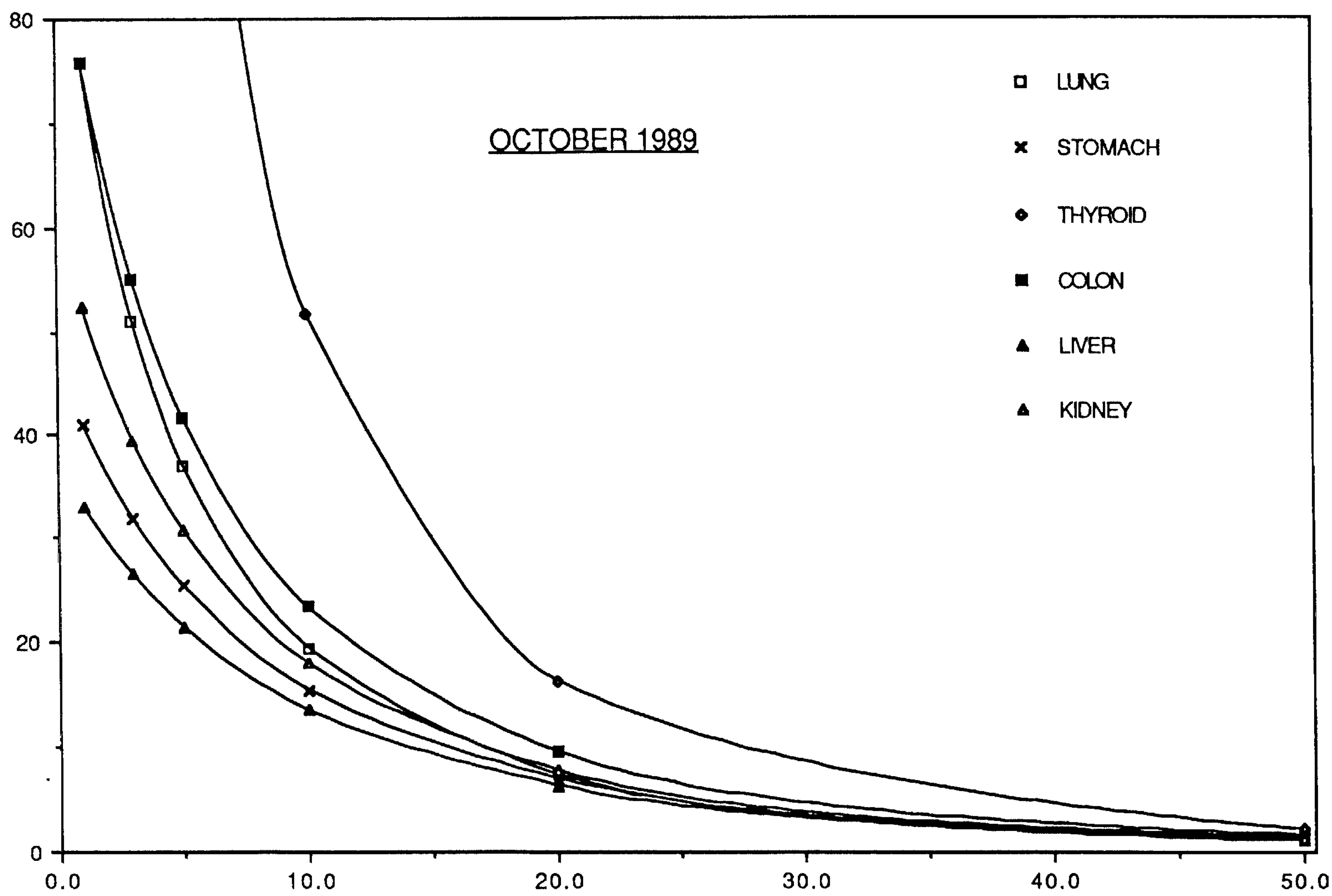

Figure 9

DOSE EQUIVALENT IN FREE SPACE vs. THICKNESS OF Al

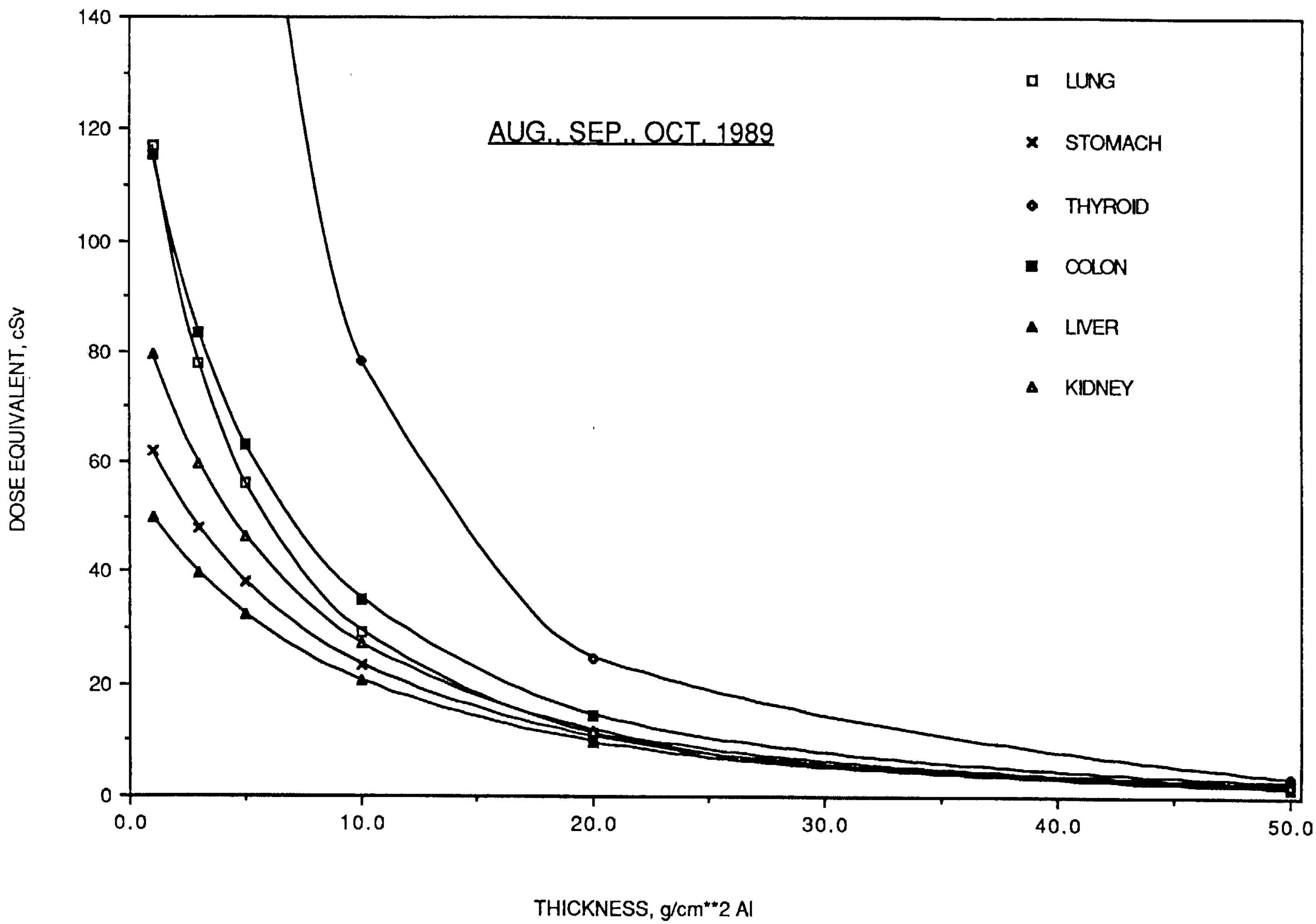

Figure 10

Table 1 DOSE EQUIVALENTS (REM) FROM THE AUGUST 1972 SPE IN FREE SPACE

ORGAN	ALUMINUM SHIELD THICKNESS, g/cm**2					30 DAY LIMIT (REM)	ANNUAL LIMIT (REM)
	1	3	5	10	20		
BFO	183.2	113.5	74.80	30.86	7.713	25	50
SKIN	1095	347.6	194.4	63.67	13.37	150	300
EYE	1461	617.0	336.3	105.3	19.83	100	200

Table 2 DOSE EQUIVALENTS (REM) FROM THE FEBRUARY 1956 SPE IN FREE SPACE

ORGAN	ALUMINUM SHIELD THICKNESS, g/cm**2					30 DAY LIMIT (REM)	ANNUAL LIMIT (REM)
	1	3	5	10	20		
BFO	47.34	39.73	35.39	29.62	24.10	25	50
SKIN	264.2	91.19	61.60	37.51	26.86	150	300
EYE	207.3	98.60	65.59	39.75	28.07	100	200

Table 3 DOSE EQUIVALENTS (REM) FROM THE NOVEMBER 1960 SPE IN FREE SPACE

ORGAN	ALUMINUM SHIELD THICKNESS, g/cm**2					30 DAY LIMIT (REM)	ANNUAL LIMIT (REM)
	1	3	5	10	20		
BFO	69.78	54.44	45.48	31.86	17.91	25	50
SKIN	4368	234.7	95.60	45.53	23.26	150	300
EYE	689.1	177.8	101.9	54.85	27.37	100	200

Table 4 DOSE EQUIVALENTS (REM) FROM THE OCTOBER 1989 SPE IN FREE SPACE

ORGAN	ALUMINUM SHIELD THICKNESS, g/cm**2					30 DAY LIMIT (REM)	ANNUAL LIMIT (REM)
	1	3	5	10	20		
BFO	110.4	73.29	52.76	27.70	10.84	25	50
SKIN	1312	243.6	129.0	49.83	16.26	150	300
EYE	997.0	352.1	190.8	70.51	20.89	100	200

Table 5 DOSE EQUIVALENTS (REM) FROM THE AUGUST, SEPTEMBER, & OCTOBER 1989 SPE'S IN FREE SPACE

ORGAN	ALUMINUM SHIELD THICKNESS, g/cm**2					30 DAY LIMIT (REM)	ANNUAL LIMIT (REM)
	1	3	5	10	20		
BFO	171.3	112.1	80.15	41.92	16.54	25	50
SKIN	2287	383.3	198.8	75.38	24.69	150	300
EYE	1725	546.6	297.2	107.0	31.65	100	200

Table 6
FEBRUARY 1956 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	3.812	0.390	2.043	2.181	1.666	1.228
M	35	2.567	0.167	1.041	0.991	0.543	0.575
M	45	1.849	0.111	0.655	0.545	0.254	0.345
M	55	1.359	0.167	0.617	0.545	0.145	0.384
F	25	3.020	0.446	2.891	2.578	1.956	1.880
F	35	2.491	0.223	1.696	1.289	0.833	0.806
F	45	2.265	0.167	1.041	0.793	0.398	0.499
F	55	1.925	0.223	0.887	0.744	0.217	0.499

SEX, AGE @ EXP		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	1.411	3.002	2.867	4.541		23.14
M	35	1.534	1.647	1.864	2.025		12.96
M	45	1.657	1.065	1.234	1.105		8.822
M	55	1.657	0.775	0.733	0.859		7.240
F	25	0.921	3.584	8.872	2.884		29.03
F	35	1.043	2.131	6.429	1.657		18.60
F	45	1.289	1.453	4.680	1.227		13.81
F	55	1.411	1.162	3.137	1.227		11.43

Table 7
FEBRUARY 1956 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	3.020	0.334	1.426	1.140	1.594	1.151
M	35	2.038	0.167	0.732	0.545	0.543	0.537
M	45	1.472	0.111	0.463	0.297	0.254	0.345
M	55	1.057	0.111	0.463	0.297	0.145	0.345
F	25	2.151	0.334	2.159	1.289	1.920	1.765
F	35	1.812	0.167	1.272	0.644	0.797	0.767
F	45	1.623	0.111	0.771	0.397	0.362	0.460
F	55	1.397	0.167	0.655	0.347	0.181	0.460

SEX, AGE @ EXP		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	1.105	0.969	0.463	1.780		12.98
M	35	1.227	0.581	0.296	0.798		7.466
M	45	1.350	0.387	0.193	0.430		5.302
M	55	1.350	0.291	0.116	0.368		4.543
F	25	0.675	1.259	0.810	1.166		13.53
F	35	0.798	0.775	0.591	0.675		8.299
F	45	0.921	0.484	0.424	0.491		6.045
F	55	1.043	0.387	0.283	0.491		5.412

Table 8
FEBRUARY 1956 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.175	0.229	1.547	1.426	1.308	0.933
M	35	1.465	0.098	0.788	0.648	0.426	0.437
M	45	1.055	0.065	0.496	0.357	0.199	0.262
M	55	0.775	0.098	0.467	0.357	0.114	0.291
F	25	1.723	0.262	2.190	1.685	1.535	1.428
F	35	1.421	0.131	1.285	0.843	0.654	0.612
F	45	1.292	0.098	0.788	0.519	0.313	0.379
F	55	1.098	0.131	0.671	0.486	0.171	0.379
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	0.787	2.137	0.855	2.533		13.93
M	35	0.856	1.172	0.556	1.130		7.576
M	45	0.924	0.758	0.368	0.616		5.102
M	55	0.924	0.552	0.219	0.479		4.276
F	25	0.513	2.551	2.645	1.609		16.14
F	35	0.582	1.517	1.917	0.924		9.885
F	45	0.719	1.034	1.395	0.685		7.222
F	55	0.787	0.827	0.935	0.685		6.171

Table 9
FEBRUARY 1956 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	1.723	0.196	1.080	0.745	1.251	0.874
M	35	1.163	0.098	0.555	0.357	0.426	0.408
M	45	0.840	0.065	0.350	0.194	0.199	0.262
M	55	0.603	0.065	0.350	0.194	0.114	0.262
F	25	1.228	0.196	1.635	0.843	1.507	1.341
F	35	1.034	0.098	0.963	0.421	0.625	0.583
F	45	0.926	0.065	0.584	0.259	0.284	0.350
F	55	0.797	0.098	0.496	0.227	0.142	0.350
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	0.616	0.689	0.138	0.993		8.306
M	35	0.685	0.414	0.088	0.445		4.638
M	45	0.753	0.276	0.058	0.240		3.237
M	55	0.753	0.207	0.035	0.205		2.789
F	25	0.377	0.896	0.241	0.650		8.913
F	35	0.445	0.552	0.176	0.377		5.274
F	45	0.513	0.345	0.127	0.274		3.727
F	55	0.582	0.276	0.084	0.274		3.326

Table 10
NOVEMBER 1960 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	6.558	0.618	2.585	3.319	1.980	1.543
M	35	4.415	0.265	1.317	1.509	0.646	0.723
M	45	3.182	0.176	0.829	0.830	0.301	0.434
M	55	2.338	0.265	0.780	0.830	0.172	0.482
F	25	5.195	0.706	3.658	3.923	2.324	2.362
F	35	4.286	0.353	2.146	1.961	0.990	1.012
F	45	3.896	0.265	1.317	1.207	0.473	0.627
F	55	3.312	0.353	1.122	1.132	0.258	0.627
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	2.366	3.961	6.116	7.614		36.66
M	35	2.572	2.172	3.977	3.395		20.99
M	45	2.778	1.405	2.633	1.852		14.42
M	55	2.778	1.022	1.563	1.440		11.67
F	25	1.543	4.727	18.92	4.836		48.20
F	35	1.749	2.811	13.71	2.778		31.80
F	45	2.161	1.917	9.982	2.058		23.90
F	55	2.366	1.533	6.692	2.058		19.45

Table 11
NOVEMBER 1960 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	5.195	0.529	1.805	1.735	1.894	1.446
M	35	3.506	0.265	0.927	0.830	0.646	0.675
M	45	2.532	0.176	0.585	0.453	0.301	0.434
M	55	1.818	0.176	0.585	0.453	0.172	0.434
F	25	3.701	0.529	2.732	1.961	2.281	2.218
F	35	3.117	0.265	1.610	0.981	0.947	0.964
F	45	2.792	0.176	0.976	0.603	0.430	0.578
F	55	2.403	0.265	0.829	0.528	0.215	0.578
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	1.852	1.278	0.987	2.984		19.71
M	35	2.058	0.767	0.631	1.338		11.64
M	45	2.264	0.511	0.411	0.720		8.383
M	55	2.264	0.383	0.247	0.617		7.150
F	25	1.132	1.661	1.728	1.955		19.90
F	35	1.338	1.022	1.262	1.132		12.64
F	45	1.543	0.639	0.905	0.823		9.467
F	55	1.749	0.511	0.603	0.823		8.505

Table 12
NOVEMBER 1960 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.559	0.240	1.307	1.453	1.042	0.782
M	35	1.723	0.103	0.666	0.661	0.340	0.367
M	45	1.241	0.069	0.419	0.363	0.159	0.220
M	55	0.912	0.103	0.394	0.363	0.091	0.245
F	25	2.027	0.275	1.849	1.717	1.223	1.198
F	35	1.672	0.137	1.085	0.859	0.521	0.513
F	45	1.520	0.103	0.666	0.528	0.249	0.318
F	55	1.292	0.137	0.567	0.495	0.136	0.318
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	0.860	1.797	1.084	2.767		13.89
M	35	0.935	0.985	0.705	1.234		7.717
M	45	1.009	0.638	0.466	0.673		5.258
M	55	1.009	0.464	0.277	0.523		4.381
F	25	0.561	2.144	3.353	1.757		16.10
F	35	0.636	1.275	2.429	1.009		10.14
F	45	0.785	0.869	1.769	0.748		7.555
F	55	0.860	0.696	1.186	0.748		6.434

Table 13
NOVEMBER 1960 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.027	0.206	0.912	0.760	0.996	0.734
M	35	1.368	0.103	0.468	0.363	0.340	0.342
M	45	0.988	0.069	0.296	0.198	0.159	0.220
M	55	0.709	0.069	0.296	0.198	0.091	0.220
F	25	1.444	0.206	1.381	0.859	1.200	1.125
F	35	1.216	0.103	0.814	0.429	0.498	0.489
F	45	1.089	0.069	0.493	0.264	0.226	0.293
F	55	0.937	0.103	0.419	0.231	0.113	0.293
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	0.673	0.580	0.175	1.084		8.146
M	35	0.748	0.348	0.112	0.486		4.678
M	45	0.823	0.232	0.073	0.262		3.318
M	55	0.823	0.174	0.044	0.224		2.847
F	25	0.411	0.753	0.306	0.710		8.396
F	35	0.486	0.464	0.224	0.411		5.134
F	45	0.561	0.290	0.160	0.299		3.745
F	55	0.636	0.232	0.107	0.299		3.371

Table 14
AUGUST 1972 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	23.90	2.414	3.798	9.727	2.202	2.227
M	35	16.09	1.034	1.935	4.421	0.718	1.044
M	45	11.60	0.690	1.218	2.432	0.335	0.626
M	55	8.520	1.034	1.147	2.432	0.191	0.696
F	25	18.93	2.759	5.375	11.50	2.585	3.410
F	35	15.62	1.379	3.153	5.748	1.101	1.462
F	45	14.20	1.034	1.935	3.537	0.527	0.905
F	55	12.07	1.379	1.648	3.316	0.287	0.905
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	10.01	7.508	19.74	32.20		113.7
M	35	10.88	4.117	12.83	14.36		67.43
M	45	11.75	2.664	8.496	7.832		47.64
M	55	11.75	1.938	5.044	6.091		38.84
F	25	6.527	8.962	61.07	20.45		141.56
F	35	7.397	5.328	44.25	11.75		97.19
F	45	9.137	3.633	32.21	8.702		75.82
F	55	10.01	2.906	21.59	8.702		62.82

Table 15
AUGUST 1972 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	18.93	2.069	2.652	5.085	2.106	2.088
M	35	12.78	1.034	1.362	2.432	0.718	0.974
M	45	9.229	0.690	0.860	1.326	0.335	0.626
M	55	6.626	0.690	0.860	1.326	0.191	0.626
F	25	13.49	2.069	4.013	5.748	2.537	3.201
F	35	11.36	1.034	2.365	2.874	1.053	1.392
F	45	10.18	0.690	1.433	1.769	0.479	0.835
F	55	8.756	1.034	1.218	1.548	0.239	0.835
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	7.832	2.422	3.186	12.62		58.99
M	35	8.702	1.453	2.035	5.656		37.15
M	45	9.572	0.969	1.327	3.046		27.98
M	55	9.572	0.727	0.797	2.611		24.03
F	25	4.786	3.149	5.576	8.267		52.84
F	35	5.656	1.938	4.071	4.786		36.53
F	45	6.527	1.211	2.921	3.481		29.52
F	55	7.397	0.969	1.947	3.481		27.42

Table 16
AUGUST 1972 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.309	0.223	0.715	1.178	0.488	0.424
M	35	1.554	0.095	0.364	0.536	0.159	0.199
M	45	1.120	0.064	0.229	0.295	0.074	0.119
M	55	0.823	0.095	0.216	0.295	0.042	0.133
F	25	1.829	0.254	1.012	1.393	0.573	0.649
F	35	1.509	0.127	0.594	0.696	0.244	0.278
F	45	1.372	0.095	0.364	0.429	0.117	0.172
F	55	1.166	0.127	0.310	0.402	0.064	0.172
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	0.827	1.032	1.844	2.662		11.70
M	35	0.899	0.566	1.199	1.187		6.759
M	45	0.971	0.366	0.794	0.647		4.680
M	55	0.971	0.266	0.471	0.504		3.816
F	25	0.540	1.231	5.707	1.691		14.88
F	35	0.611	0.732	4.136	0.971		9.898
F	45	0.755	0.499	3.011	0.719		7.533
F	55	0.827	0.399	2.018	0.719		6.205

Table 17
AUGUST 1972 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	1.829	0.191	0.499	0.616	0.467	0.398
M	35	1.234	0.095	0.256	0.295	0.159	0.186
M	45	0.891	0.064	0.162	0.161	0.074	0.119
M	55	0.640	0.064	0.162	0.161	0.042	0.119
F	25	1.303	0.191	0.755	0.696	0.562	0.610
F	35	1.097	0.095	0.445	0.348	0.233	0.265
F	45	0.983	0.064	0.270	0.214	0.106	0.159
F	55	0.846	0.095	0.229	0.187	0.053	0.159
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	0.647	0.333	0.298	1.043		6.320
M	35	0.719	0.200	0.190	0.468		3.802
M	45	0.791	0.133	0.124	0.252		2.771
M	55	0.791	0.100	0.074	0.216		2.369
F	25	0.396	0.433	0.521	0.683		6.150
F	35	0.468	0.266	0.380	0.396		3.994
F	45	0.540	0.166	0.273	0.288		3.062
F	55	0.611	0.133	0.182	0.288		2.784

Table 18
OCTOBER 1989 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	11.65	1.131	2.700	5.076	1.800	1.596
M	35	7.845	0.485	1.376	2.307	0.587	0.748
M	45	5.653	0.323	0.866	1.269	0.274	0.449
M	55	4.153	0.485	0.815	1.269	0.157	0.499
F	25	9.229	1.292	3.821	5.999	2.114	2.444
F	35	7.614	0.646	2.242	2.999	0.900	1.048
F	45	6.922	0.485	1.376	1.846	0.431	0.648
F	55	5.884	0.646	1.172	1.730	0.235	0.648
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	4.562	4.632	11.72	14.68		59.55
M	35	4.959	2.540	7.622	6.545		35.01
M	45	5.355	1.644	5.047	3.570		24.45
M	55	5.355	1.195	2.996	2.777		19.70
F	25	2.975	5.529	36.27	9.322		79.00
F	35	3.372	3.287	26.28	5.355		53.75
F	45	4.165	2.241	19.14	3.967		41.22
F	55	4.562	1.793	12.83	3.967		33.46

Table 19
OCTOBER 1989 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	9.229	0.969	1.885	2.653	1.722	1.496
M	35	6.230	0.485	0.968	1.269	0.587	0.698
M	45	4.499	0.323	0.611	0.692	0.274	0.449
M	55	3.230	0.323	0.611	0.692	0.157	0.449
F	25	6.576	0.969	2.853	2.999	2.074	2.295
F	35	5.537	0.485	1.681	1.500	0.861	0.998
F	45	4.961	0.323	1.019	0.923	0.391	0.599
F	55	4.268	0.485	0.866	0.808	0.196	0.599
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	3.570	1.494	1.892	5.752		30.66
M	35	3.967	0.897	1.209	2.578		18.89
M	45	4.364	0.598	0.789	1.388		13.99
M	55	4.364	0.448	0.473	1.190		11.94
F	25	2.182	1.943	3.312	3.769		28.97
F	35	2.578	1.195	2.418	2.182		19.44
F	45	2.975	0.747	1.735	1.587		15.26
F	55	3.372	0.598	1.156	1.587		13.93

Table 20
OCTOBER 1989 SPE, EXCESS CANCERS PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.116	0.199	0.855	1.135	0.640	0.510
M	35	1.424	0.085	0.436	0.516	0.209	0.239
M	45	1.026	0.057	0.274	0.284	0.097	0.143
M	55	0.754	0.085	0.258	0.284	0.056	0.159
F	25	1.676	0.228	1.210	1.342	0.752	0.781
F	35	1.382	0.114	0.710	0.671	0.320	0.335
F	45	1.257	0.085	0.436	0.413	0.153	0.207
F	55	1.068	0.114	0.371	0.387	0.084	0.207
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	0.727	1.177	1.282	2.338		10.98
M	35	0.790	0.646	0.833	1.043		6.220
M	45	0.853	0.418	0.552	0.569		4.273
M	55	0.853	0.304	0.328	0.442		3.523
F	25	0.474	1.405	3.966	1.485		13.32
F	35	0.537	0.835	2.874	0.853		8.631
F	45	0.663	0.570	2.092	0.632		6.508
F	55	0.727	0.456	1.402	0.632		5.447

Table 21
OCTOBER 1989 SPE, EXCESS CANCER MORTALITIES PER 1000 PEOPLE BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	1.676	0.171	0.597	0.593	0.612	0.478
M	35	1.131	0.085	0.306	0.284	0.209	0.223
M	45	0.817	0.057	0.194	0.155	0.097	0.143
M	55	0.586	0.057	0.194	0.155	0.056	0.143
F	25	1.194	0.171	0.903	0.671	0.738	0.733
F	35	1.005	0.085	0.532	0.335	0.306	0.319
F	45	0.901	0.057	0.323	0.206	0.139	0.191
F	55	0.775	0.085	0.274	0.181	0.070	0.191
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	0.569	0.380	0.207	0.916		6.199
M	35	0.632	0.228	0.132	0.411		3.641
M	45	0.695	0.152	0.086	0.221		2.617
M	55	0.695	0.114	0.052	0.190		2.241
F	25	0.348	0.494	0.362	0.600		6.213
F	35	0.411	0.304	0.264	0.348		3.910
F	45	0.474	0.190	0.190	0.253		2.923
F	55	0.537	0.152	0.126	0.253		2.644

Table 22
AUG., SEP., & OCT. 1989 SPE'S, EXCESS CANCERS PER 1000 PEOPLE
BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	21.88	2.174	4.636	9.337	3.029	2.735
M	35	14.73	0.932	2.362	4.244	0.988	1.282
M	45	10.62	0.621	1.487	2.334	0.461	0.769
M	55	7.800	0.932	1.400	2.334	0.263	0.855
F	25	17.33	2.484	6.560	11.04	3.556	4.189
F	35	14.30	1.242	3.849	5.517	1.515	1.795
F	45	13.00	0.932	2.362	3.395	0.724	1.111
F	55	11.05	1.242	2.012	3.183	0.395	1.111
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	8.986	8.638	19.51	28.91		109.8
M	35	9.768	4.737	12.68	12.89		64.62
M	45	10.55	3.065	8.397	7.033		45.33
M	55	10.55	2.229	4.986	5.470		36.82
F	25	5.861	10.31	60.35	18.36		140.0
F	35	6.642	6.130	43.73	10.55		95.27
F	45	8.205	4.180	31.84	7.814		73.56
F	55	8.986	3.344	21.34	7.814		60.48

Table 23
AUG., SEP., & OCT. 1989 SPE'S, EXCESS CANCER MORTALITIES PER 1000 PEOPLE
BEHIND 1 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	17.33	1.863	3.237	4.881	2.898	2.564
M	35	11.70	0.932	1.662	2.334	0.988	1.197
M	45	8.450	0.621	1.050	1.273	0.461	0.769
M	55	6.067	0.621	1.050	1.273	0.263	0.769
F	25	12.35	1.863	4.898	5.517	3.490	3.932
F	35	10.40	0.932	2.887	2.759	1.449	1.710
F	45	9.317	0.621	1.749	1.698	0.659	1.026
F	55	8.017	0.932	1.487	1.485	0.329	1.026
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	7.033	2.787	3.149	11.33		57.07
M	35	7.814	1.672	2.012	5.079		35.39
M	45	8.595	1.115	1.312	2.735		26.38
M	55	8.595	0.836	0.787	2.344		22.61
F	25	4.298	3.623	5.510	7.423		52.91
F	35	5.079	2.229	4.024	4.298		35.77
F	45	5.861	1.393	2.886	3.126		28.34
F	55	6.642	1.115	1.924	3.126		26.08

Table 24
AUG., SEP., & OCT. 1989 SPE'S, EXCESS CANCERS PER 1000 PEOPLE
BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	3.431	0.329	1.377	1.864	1.026	0.821
M	35	2.310	0.141	0.701	0.847	0.335	0.385
M	45	1.664	0.094	0.442	0.466	0.156	0.231
M	55	1.223	0.141	0.416	0.466	0.089	0.256
F	25	2.717	0.377	1.948	2.203	1.205	1.257
F	35	2.242	0.188	1.143	1.102	0.513	0.539
F	45	2.038	0.141	0.701	0.678	0.245	0.333
F	55	1.732	0.188	0.598	0.636	0.134	0.333
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	1.208	1.987	1.944	3.888		17.88
M	35	1.313	1.090	1.264	1.734		10.12
M	45	1.419	0.705	0.837	0.946		6.959
M	55	1.419	0.513	0.497	0.736		5.755
F	25	0.788	2.372	6.014	2.469		21.35
F	35	0.893	1.410	4.358	1.419		13.81
F	45	1.103	0.961	3.173	1.051		10.43
F	55	1.208	0.769	2.127	1.051		8.776

Table 25
AUG., SEP., & OCT. 1989 SPE'S, EXCESS CANCER MORTALITIES PER 1000 PEOPLE
BEHIND 10 g/cm**2 OF Al

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	2.717	0.282	0.961	0.975	0.982	0.769
M	35	1.834	0.141	0.494	0.466	0.335	0.359
M	45	1.325	0.094	0.312	0.254	0.156	0.231
M	55	0.951	0.094	0.312	0.254	0.089	0.231
F	25	1.936	0.282	1.455	1.102	1.182	1.180
F	35	1.630	0.141	0.857	0.551	0.491	0.513
F	45	1.461	0.094	0.520	0.339	0.223	0.308
F	55	1.257	0.141	0.442	0.297	0.112	0.308
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	0.946	0.641	0.314	1.524		10.11
M	35	1.051	0.385	0.200	0.683		5.948
M	45	1.156	0.256	0.131	0.368		4.283
M	55	1.156	0.192	0.078	0.315		3.673
F	25	0.578	0.833	0.549	0.998		10.10
F	35	0.683	0.513	0.401	0.578		6.358
F	45	0.788	0.320	0.288	0.420		4.761
F	55	0.893	0.256	0.192	0.420		4.317

Table 26
Excess Cancers per 1000 25 yr. old Males Behind 1 g/cm**2 of Al
(Aug. 72 Flare, Rem data)

Organ	Primary Protons	Secondaries & Recoils	Total
Lung	22	2	24
Colon	8	2	10
Kidney & Bladder	6	2	8
Total Cancers	98	16	114

Table 27
Excess Cancer Mortalities per 1000 25 yr. old Males Behind 1 g/cm**2 of Al
(Aug. 72 Flare, Rem data)

Organ	Primary Protons	Secondaries & Recoils	Total
Lung	18	1	19
Colon	4	1	5
Kidney & Bladder	2	0.5	2.5
Total Cancers	51	8	59

Table 28
Excess Cancers per 1000 25 yr. old Males Behind 10 g/cm**2 of Al
(Aug. 72 Flare, Rem data)

Organ	Primary Protons	Secondaries & Recoils	Total
Lung	2.1	0.2	2.3
Colon	0.9	0.3	1.2
Kidney & Bladder	0.8	0.2	1
Total Cancers	10	2	12

Table 29
Excess Cancer Mortalities per 1000 25 yr. old Males Behind 10 g/cm**2 of Al
(Aug. 72 Flare, Rem data)

Organ	Primary Protons	Secondaries & Recoils	Total
Lung	1.7	0.1	1.8
Colon	0.5	0.1	0.6
Kidney & Bladder	0.3	0.05	0.35
Total Cancers	5	1	6

Table 31
EXCESS CANCERS PER 1000 PEOPLE AT STS DLOC 1

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	5.469	0.382	0.930	1.797	0.596	0.550
M	35	3.682	0.164	0.474	0.817	0.194	0.258
M	45	2.653	0.109	0.298	0.449	0.091	0.155
M	55	1.949	0.164	0.281	0.449	0.052	0.172
F	25	4.332	0.436	1.316	2.124	0.700	0.842
F	35	3.574	0.218	0.772	1.062	0.298	0.361
F	45	3.249	0.164	0.474	0.653	0.143	0.223
F	55	2.762	0.218	0.404	0.613	0.078	0.223
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	1.477	1.450	4.287	4.753		21.69
M	35	1.606	0.795	2.787	2.120		12.90
M	45	1.734	0.514	1.845	1.156		9.006
M	55	1.734	0.374	1.096	0.899		7.170
F	25	0.964	1.730	13.26	3.019		28.73
F	35	1.092	1.029	9.611	1.734		19.75
F	45	1.349	0.701	6.997	1.285		15.24
F	55	1.477	0.561	4.690	1.285		12.31

Table 32
EXCESS CANCER MORTALITIES PER 1000 PEOPLE AT STS DLOC 1

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	4.332	0.327	0.649	0.939	0.570	0.515
M	35	2.924	0.164	0.333	0.449	0.194	0.240
M	45	2.112	0.109	0.211	0.245	0.091	0.155
M	55	1.516	0.109	0.211	0.245	0.052	0.155
F	25	3.087	0.327	0.983	1.062	0.687	0.790
F	35	2.599	0.164	0.579	0.531	0.285	0.343
F	45	2.328	0.109	0.351	0.327	0.130	0.206
F	55	2.004	0.164	0.298	0.286	0.065	0.206
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	1.156	0.468	0.692	1.863		11.51
M	35	1.285	0.281	0.442	0.835		7.148
M	45	1.413	0.187	0.288	0.450		5.260
M	55	1.413	0.140	0.173	0.385		4.399
F	25	0.707	0.608	1.211	1.220		10.68
F	35	0.835	0.374	0.884	0.707		7.301
F	45	0.964	0.234	0.634	0.514		5.796
F	55	1.092	0.187	0.423	0.514		5.238

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Table 33
EXCESS CANCERS PER 1000 PEOPLE AT STS DLOC 2

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	12.60	0.893	1.819	3.958	1.117	1.071
M	35	8.485	0.383	0.927	1.799	0.364	0.502
M	45	6.114	0.255	0.583	0.990	0.170	0.301
M	55	4.492	0.383	0.549	0.990	0.097	0.335
F	25	9.982	1.020	2.574	4.678	1.311	1.640
F	35	8.235	0.510	1.510	2.339	0.559	0.703
F	45	7.486	0.383	0.927	1.439	0.267	0.435
F	55	6.363	0.510	0.789	1.349	0.146	0.435
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL CANCERS**
M	25	3.552	3.136	8.707	11.43		48.29
M	35	3.861	1.720	5.661	5.097		28.80
M	45	4.170	1.113	3.748	2.780		20.23
M	55	4.170	0.809	2.226	2.162		16.21
F	25	2.317	3.743	26.94	7.259		61.47
F	35	2.626	2.226	19.52	4.170		42.40
F	45	3.244	1.518	14.21	3.089		33.00
F	55	3.552	1.214	9.527	3.089		26.98

Table 34
EXCESS CANCER MORTALITIES PER 1000 PEOPLE AT STS DLOC 2

SEX, AGE @ EXP		LUNG	ESOPHAGUS	STOMACH	COLON	LIVER	PANCREAS
M	25	9.982	0.765	1.270	2.069	1.069	1.004
M	35	6.738	0.383	0.652	0.990	0.364	0.469
M	45	4.866	0.255	0.412	0.540	0.170	0.301
M	55	3.494	0.255	0.412	0.540	0.097	0.301
F	25	7.112	0.765	1.922	2.339	1.287	1.540
F	35	5.989	0.383	1.132	1.169	0.534	0.669
F	45	5.365	0.255	0.686	0.720	0.243	0.402
F	55	4.617	0.383	0.583	0.630	0.121	0.402
		SUM (NON-CL) LEUKEMIA	KIDNEY & BLADDER	THYROID	ALL OTHER CANCERS		**TOTAL MORTALITIES**
M	25	2.780	1.012	1.406	4.479		25.84
M	35	3.089	0.607	0.898	2.008		16.20
M	45	3.398	0.405	0.586	1.081		12.01
M	55	3.398	0.304	0.351	0.927		10.08
F	25	1.699	1.315	2.460	2.935		23.37
F	35	2.008	0.809	1.796	1.699		16.19
F	45	2.317	0.506	1.288	1.236		13.02
F	55	2.626	0.405	0.859	1.236		11.86

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13. ABSTRACT *(Maximum 200 words)* This study investigated radiation exposures and cancer induction/mortality risks for several major solar particle events (SPEs). The SPEs included in this study are February 1956, November 1960, August 1972, October 1989, and September, August, and October 1989 (combined). The three 1989 events were treated as one since all three could affect a single lunar or Mars mission. A baryon transport code was used to propagate particles through aluminum and tissue shield materials. This study used a free space environment for all calculations. Results show the 30-day blood forming organs (BFO) limit of 25 rem was surpassed by all five events using 10 g/cm^2 of shielding. The BFO limit is based on a depth dose of 5 cm of tissue, while this study used a more detailed shield distribution of the BFO. A comparison between the 5 cm depth dose and the dose found using the BFO shield distribution shows the 5 cm depth value slightly higher than the BFO dose. The annual limit of 50 rem was exceeded by the August 1972, October 1989, and three combined 1989 events with 5 g/cm^2 of shielding. Cancer mortality risks ranged from 1.5 to 17% at 1 g/cm^2 and 0.5 to 1.1% behind 10 g/cm^2 of shielding for the five events. These ranges correspond to those for a 45-year old male. It is shown that secondary particles comprise about 1/3 of the total risk at 10 g/cm^2 of shielding. Using a computerized Space Shuttle shielding model to represent a typical spacecraft configuration in free space at the August 1972 SPE, average crew doses exceeded the BFO limit.

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