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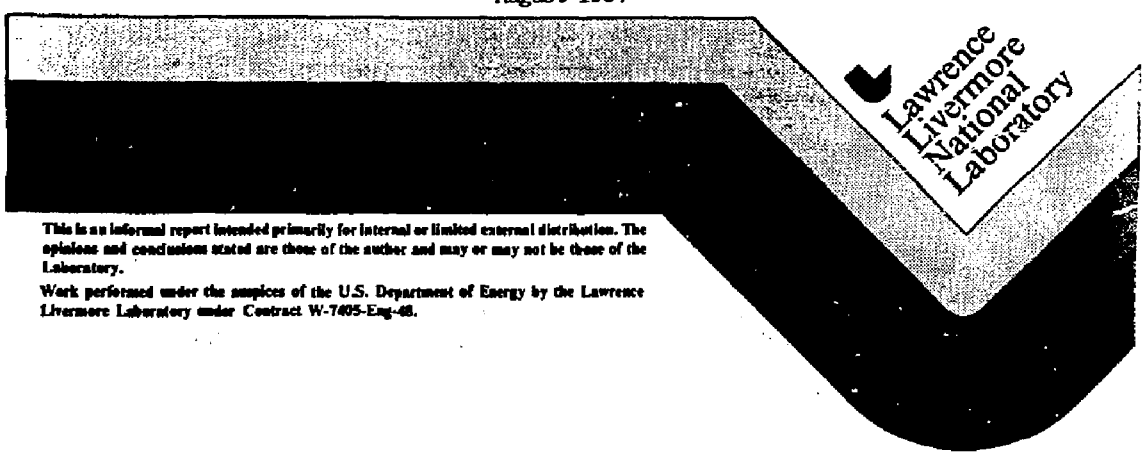

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DISCLAIMER

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Abstract

1. A new tropospheric deposition model raises the dose from the troposphere by more than a factor of 2.

2. For the 5310 megaton baseline scenario, the 50 year dose in the 30-50°N latitude band is increased from 23 to 33 rads. The global population dose is 6.7 x 10^{10} man-rads.

3. For all of the scenarios studied, the percent increase above the current level in the incidence of cancer, leukemia, and genetic mutations are of the order of a few percent. We utilize the global population dose in man-rads as an index of the biological impact of varying scenarios.

4. The shift to smaller yield warheads in the nuclear arsenal can result in significant increases in population-averaged radiation doses.

5. For the baseline scenario that includes present USA nuclear facilities, the 50 year dose in the 20 50°N band is increased from 84 rads made in the 1983 calculations, to 95 rads. By vaporizing the U.S.A. nuclear facilities with smaller yield devices, the above dose increases from 95 to 124 rads. A major exchange also involving the vaporization of European and Asian nuclear facilities would lead to comparable increases (a factor of about 3) and would have severe radiological consequences to the global population.

6. By shifting the 5310 megaton baseline scenarios to the equatorial zone (detonations at 20°N), the global population dose increases dramatically from 6.7 to 22 x 10^{10} man-rads.

7. We have used GLODEP2 to develop a simple method of estimating latitude dose that is useful to researchers who do not have a GLODEP2 code available.

Introduction

We have utilized the GLODEP2[1] computer code to determine biological impact to humans on a global scale using up-to-date estimates of biological risk. These risk factors use varied biological damage models for assessing effects. We draw mainly upon the work of the BEIR committee (1980),[2] the UNSCEAR committee (1982),[3] and the publications of Feinendegen and Booz in West Germany.[4] [5] Our work focuses on the long term chronic dose effects that result in an increased incidence of cancer, leukemia and genetic mutations in the live born. All the doses reported here are the unsheltered, unweathered, smooth terrain, external gamma dose. We do not include sources internal to the body that contribute to the dose. We assume the unperturbed atmosphere in determining injection and deposition. Effects due to "nuclear winter" may invalidate this assumption. We expect to investigate the validitiy of this assumption within the next two years by coupling radioisotopes with the 3 dimensional GRANTOUR code.

We have altered the tropospheric deposition model in GLODEP2 to reflect a deposition that is exponential in time with a variable time constant. We utilize time constants that have been reported by Michael MacCracken and John Walton based on results using GRANTOUR in 2-D calculations conducted in 1983. We also have excluded the contribution to the dose from the first day, as this can be considered part of the early or local fallout. This new, and we believe more realistic, tropospheric deposition algorithm produces significantly different predictions of radiation dose than the earlier algorithm, and so we have repeated a number of the scenarios that were previously reported in the 1983 Erice conference paper by Joe Knox.[6]

Our calculations also include scenarios that attempt to assess the impact of the changing nature of the nuclear stockpile. In particular, the shift from larger to smaller yield nuclear devices significantly changes the injection pattern into the atmosphere, and hence significantly affects the radiation doses that ensue. We have also looked at injections into the equatorial atmosphere*. In total, we report here the results for 8 scenarios all of which will be described later.

* We adopt here the nomenclature used in the GLODEP2[1] report and use the term "equatorial" to refer to the areas with latitude less than 30°, and "polar" to the areas with latitude greater than 30°.

We have incorporated into the code the global distribution by latitude band (20° widths) of human population and birth rate. Utilizing these, we are able to calculate damage predictions in absolute as well as relative terms. We calculate the number of man-rads for each latitude band, as well as the global total of man-rads for each scenario. The latter we believe is a useful index to assess biological impact of varying scenarios. Parameter studies of biological impact as a function of yield of individual nuclear explosions have also been initiated. We recognize that the dose distribution around latitude circles is not uniform, and local precipitation patterns can produce hot spots where the dose is perhaps 10 times the average for that latitude band.

We have studied the approach utilized by Prof. Arthur Broyles (internal LLNL report dated July 27, 1983) that is useful for obtaining quick and easy estimates of doses, and have extended the Broyles' approach by utilizing GLODEP2 to provide the parameters used in estimating radiation dose as a function of latitude band. These estimates can be especially useful to researchers who do not have a GLODEP2 available.

Biological Effects of Radiation

Biological effects on humans from exposure to ionizing radiations are generally divided into two categories: acute and chronic. The acute effects can produce lethal injury to cells resulting in sickness and possibly death to the exposed individual. Acute effects are generally due to short-term, high dose, and high dose rate irradiations whose effects manifest in time periods of days, weeks or months. Chronic effects are generally due to long term, low dose, and low dose rate irradiations, and can induce most of the known forms of cancers, as well as leukemia, and genetic mutations. The latency period for the appearance of cancer is normally 15 to 30 years, while for leukemia it can be of the order of a few years. Genetic mutations appear in the live born of the first generation, and then to a smaller extent in succeeding generations (for a single exposure). For chronic exposure that continues through many generations (e.g. natural background radiation), the number of mutations per generation increases until an equilibrium level is achieved.

Many researchers have found that radiation damage has a dose rate dependence and distinguish between low dose rate and high dose rate. A recent study by the National Council on Radiation Protection[7] reviewed the knowledge of the dose-rate effect for carcinogenic and genetic effects in humans from low-LET (linear energy transfer) radiations (sparsely ionizing x-rays, gamma rays, and electrons). They indicate that the induction of cell killing, chromosome aberrations, mutations, teratogenic effects, shortening of life, and tumor formation in experimental systems has been consistently observed to depend upon the temporal distribution of dose. They define a factor DREF (Dose Rate Effectiveness Factor) as the ratio of the effectiveness per unit dose of high vs. low dose rate exposures. Experiments with mice indicate a DREF of about 3 for mutagenic effects. Other studies with mammals for carcinogenesis and life shortening yields DREF values of from 2 to 10.

We have adopted here the definition of low dose rate given by L. E. Feinendegen[4] which is based on his theoretical and experimental work on radiation damage. He defines the low dose rate limit as 6 rads per day. Below this rate, Feinendegen finds that repair mechanism for damaged cells are at their most efficient level, and damage per unit radiation exposure is one-third that of an equivalent high dose rate exposure. This factor of 3 has been largely accepted by others for the ratio of dose from protracted (low dose rate) exposure to dose from acute (high dose rate) exposure to give the same degree of genetic effect. For somatic effects, we shall also use the factor of 3 suggested by Feinendegen as it is certainly in the range suggested by the NCRP Report. Feinendegen also suggests 48 rads per day as the dose rate that defines the lower threshold for acute exposure. We have used a linear interpolation between these two values in our calculations of effects when we calculate the "Feinendegen" risk factors. For all the scenarios reported here, the dose rates as determined by GLODEP2 are always in the low dose rate regime, and so our "Feinendegen" casualties are all a factor of three below what we call the "linear" casualties. By "linear" here, we mean that the risk estimates were made by using the linear hypothesis, i.e. by extrapolating the experimental data linearly into the low dose area. This was the approach used by the BEIR and the UNSCEAR committees.

The risk factors for estimating radiation damage have been estimated by a number of authoritative groups. We principally use here the 1980 B.E.I.R. report,[2] the 1982 U.N.S.C.E.A.R. report,[3] and the paper by Feinendegen[4] presented at the Erice Conference in 1983.

Feinendegen uses these sources and suggests that one may expect approximately 150 to 200 fatal cancers will be produced per rad to a million individuals for low linear energy transfer (L.E.T.) radiation. Fallout radiation is of this type. For our study, we use 175 cancer fatalities per rad per million people, or an absolute risk factor for cancer [R_{ab} (cancer)] of 1.75×10^{-4} per rad per person. The lifetime current cancer mortality rate (R_{cur} (cancer)) for the United States is about 165,000 per million people, i.e. 0.165 per person. We see then that each rad of low LET radiation produces an increase of about 0.1 percent above the current level. This is called the relative risk; i.e. the risk relative to the current rate. We use this figure in our work, and assume also that the U.S. current rate applies throughout the globe. Using the Feinendegen approach, the appropriate figure for low dose rate exposure would be one third as much, or 0.033% per rad above the current level.

To summarize, for calculating absolute values for global fatal cancer induction, we use.

$$N_{ab}(\text{cancer}) = R_{ab} \sum_{b=1}^{9} P_{op}(b) D(b)$$

where $R_{ab} \equiv 1.75 \times 10^{-4}$ cancers per rad per person

$P_{op}(b) \equiv$ population in latitude band b

$D(b) \equiv$ 50 year dose in latitude band b.

and the index b denotes the nine latitude bands of width 20° that divide the earth in the GLODEP-II code.

The increase relative to the current level is

$$\frac{N_{ab}}{R_{cur} \sum P_{op}(b)} = \frac{R_{ab}}{R_{cur}} \frac{\sum P_{op}(b) D(b)}{\sum P_{op}(b)} = \frac{R_{ab}}{R_{cur}} \bar{D}_{pop}$$

where $\bar{D}_{pop}$ is the population averaged dose. The % increase relative to the current level is

$$\% \text{ increase} = 100 \frac{R_{ab}}{R_{cur}} \bar{D}_{pop} = \frac{100(1.75 \times 10^{-4})}{0.165} \bar{D}_{pop}$$

$$\% \text{ increase (cancer)} = 0.106 \bar{D}_{pop} \quad \% = 0.1 \bar{D}_{pop} \quad \%$$

For genetic damage, we examine Table 1, which is reproduced from the 1982 UNSCEAR report. It is stated in that report that there is general agreement between the values presented in the 1977 UNSCEAR study and the 1980 BEIR report, even though some of the methods of analysis used were not the same. We see that the current mutation rate that results in genetic diseases, handicaps and disabilities amongst the live born is 106,000 per million live births, or about 10% of live births. For a discussion of the seriousness of these genetic conditions, we refer the reader to the UNSCEAR report[3] (pgs. 514-519). There attempts are made to establish quantitative indices of harm for these conditions, such as mortality, years of life lost, economic cost, and quality of life detriment.

Table 1 shows that the effect of 1 gray (100 rads) per generation is to produce at equilibrium an additional 14,900 mutant births per million live births. Many of these mutations will disappear from the ensuing generations because of negative selection processes. It can be shown that the figure for equilibrium (after repeated exposures for many generations) is numerically equal to the total over all future generations that results from a single exposure. We see then that there is an increase of 14,900 mutant births over all future generations per million live births, from a single exposure of 100 rads to the parental population. This represents a relative radiation-induced risk (increase as a percentage of the current rate) of 0.14% per live birth per rad. This is the figure we adopt for this study. In absolute terms, for each rad of low LET radiation, there is an increase of 149 mutant births per million live births. We use the 1982 UNSCEAR figure of 15% as the number of these that appear in the first generation (the 1980 BEIR report suggested 20%).

Table 1

Estimated effect of 1 Gy per generation of low dose or low dose rate, low-LET irradiation on a population of one million liveborn according to the doubling dose method

Assumed doubling dose: 1 Gy

Disease classification a/	Current incidence b/	Effect of 1 Gy per generation	
		First generation c/	Equilibrium
Autosomal dominant and X-linked diseases	10000 d/	1500	10000
Recessive diseases	2500 e/	slight	slow increase
Chromosomal diseases			
Structural	400 f/	240	400
Numerical	3000 g/	probably very small	probably very small
Congenital anomalies, anomalies expressed later and constitutional and degenerative diseases	90000 h/	450	4500 i/
Total	105900	2190	14900

a/ Follows that given in the BEIR report [1860], except that chromosomal diseases are divided into those with a structural and those with a numerical basis.
b/ Based on the results of the British Columbia survey and other studies. For details, see [U1] and Table 2 of the present Annex.
c/ The first generation incidence is assumed to be about 15 % of the equilibrium incidence for autosomal dominant and X-linked diseases (see text for details), about 3/5 of the equilibrium incidence for structural anomalies and about 10 % of the equilibrium incidence for diseases of complex inheritance.
d/ Includes diseases with both early and late onset.
e/ Also includes diseases maintained by heterozygous advantage.
f/ Based on the pooled values of Table 2 but excluding euploid structural rearrangements, Robertsonian translocations and "others" (mainly mosaics). See text for details.
g/ Excluding mosaics; see text.
h/ Includes an unknown proportion of numerical (other than Down's syndrome) and structural chromosomal anomalies.
i/ Based on the assumption of a 5 % mutational component; see [U1] for details.

TABLE 2. Genetic Effects of an Average Population Exposure of 1 Rem per 30-Yr Generation

Type of Genetic Disorder[a]	Current Incidence, per Million Liveborn Offspring	Effect per Million Liveborn Offspring, Rem per Generation	
		First Generation[b]	Equilibrium[c]
Autosomal dominant and X-linked	10,000	5-65[d]	40-200
Irregularly inherited	90,000		20-900[e]
Recessive	1,100	Very few; effects in heterozygotes accounted for in top row	Very slow increase
Chromosomal aberrations[f]	6,000	Fewer than 10[g]	Increases only slightly

[a] Includes disorders and traits that cause serious handicap at some time during lifetime.
[b] Estimated directly from measured phenotypic damage or from observed cytogenetic effects.
[c] Estimated by the relative-mutation-risk method.
[d] No first-generation estimate available for X-linked disorders: the expectation is that it would be relatively small.
[e] Some estimates have been rounded off to eliminate impression of considerable precision.
[f] Includes only aberrations expressed as congenital malformations, resulting from unbalanced segregation products of transiocations and from numerical aberration.
[g] Majority of Subcommittee feels that it is considerably closer to zero, but one member feels that it could be as much as 20.

A further word of explanation about Table 2 may be in order. It indicates that the doubling dose for genetic mutations assumed in the calculations is 1 Gray, or 100 rads. This implies a relative increase above the current level of 1% per rad. And yet we use the figure 149 cases per rad per million live births, which when considered next to the current level of 106,000 per million implies a figure for the relative risk of 0.14% per live birth per rad. The explanation for this seeming discrepancy is that the radiation sensitivity varies for each of the disease classifications listed in the Table. The UNSCEAR committee assumes that the component that is sensitive to radiation in the largest listed category of current incidence (congenital anomalies, anomalies expressed later, and constitutional and degenerative diseases; 90,000) has only a 5% mutational component. If one looks at the other principal categories (autosomal dominant and x-linked diseases, and structural chromosomal diseases), we see that the risk there relative to the current level is 1% per rad.

To summarize, we calculate the increase in the incidence of observable genetic effects or disease amongst the live born per year created in all future generations as

$$N_{ab}\,(\text{mutations}) = R_{ab} \Sigma\, P_{op}(b) BR(b) D(b)$$

where $R_{ab} = 1.49 \times 10^{-4}$ per live birth per rad, and BR(b) is the birth rate in latitude band b. The number of these that appears in the first generation is 15%.

The percent increase relative to the current level of the globe is

$$\%\ \text{increase} = \frac{N_{ab} \cdot 100}{R_{cur}\ \Sigma\, P_{op}(b) BR(b)} = \frac{100\, R_{ab}}{R_{cur}} \frac{\Sigma\, P_{op}(b) BR(b) D(b)}{\Sigma\, P_{op}(b) BR(b)}$$

where $R_{ab} = 1.49 \times 10^{-4}$ observable genetic effects or disease per live born per rad, and $R_{cur} = 0.106$ per live birth.

The percent increase in any latitude band is

% increase (b) = 0.14D(b)

We can illustrate the large uncertainties in these genetic risk factors by examining Table 2, which is reproducted from the 1980 BEIR report. There, we see for the autosomal category a spread of 40 to 200 for the incidence at equilibrium per rad per generation per million live births. The UNSCEAR figure for this is 100. For the irregularly inherited category, we see in Table 2B a spread of 20 to 900. The UNSCEAR figure for this is 45. One can conclude from this that our calculations of genetic effects have large uncertainties (a factor of 10) due to the uncertainties in the risk estimates.

Regarding the dose rate dependence of the risk estimates, GLODEP2 determines the average dose rate per quarter year, and calculates the average dose rate over 20° latitude bands. For all our scenarios, all the dose rates encountered so far have been well below the upper limit of the low dose rate region. That is why we have focused on chronic effects here. We do however, recognize that hot spot regions as predicted by GRANTOUR may have dose rates approximately an order of magnitude higher,[6] and the resulting doses are certainly in the acute and lethal effects range for many in the population. Also, high dose rates may be encountered in the first days of the 1st quarter but be missed when we average the dose rate over the first quarter. We shall reserve an attempt to assess acute effects for a later study, perhaps after 3-D GRANTOUR simulations are made.

Population and Birth Rate Distribution by Latitude Band

In order to calculate quantities like population averaged dose, total global population dose, and the absolute values for the biological effects examined here, it was necessary to generate figures for the population and birth rate distribution averaged over the 20° latitude bands used in GLODEP2. In Table 3, we present our estimates. These figures were determined by taking the population of each country as reported in the U.N. Demographic Yearbook of 1982,[8] and putting these into latitude bands by examining a world atlas. Interpolations were necessary as many

countries straddled two latitude bands. While our estimates are approximate, they should suffice for the purposes of our study here. It is of interest to note that about 90% of the world's population resides in the northern hemisphere. Indeed, over 80% of the world's population resides in the three latitude bands between 10°N and 70°N.

Table 3

Population and Birth Rate by Latitude Band(a)

Band Number	Latitude Range	Population in Millions	Birth Rate (per year)	
1	70°-90°N	0	--	
2	50°-70°N	262	.016	
3	30°-50°N	1380	.017	Total population = 4.59×10^9
4	10°-30°N	2080	.033	
5	10°S-10°N	620	.043	average birth rate = .029/year
6	30°-10°S	194	.040	
7	50°-30°S	60	.021	
8	70°-50°S	0	--	
9	90°-70°S	0	--	

(a) Estimates based on 1982 U.N. Demographic Yearbook data.(7)

Description of Scenarios Studied

(All are winter injections except where noted)

1. Baseline 5300 megaton strategic exchange as described in GLODEP2[1] (τ = 8.2 days) τ is the e-folding time for deposition from the troposphere. These value of τ were obtained from MacCracken and Walton[9] using GRANTOUR in 2 dimensional calculations conducted in 1983, and are at best good to $\pm$ 50%.

2. Scenario 1, summer injection (τ = 1&2 days).

3. Scenario 1 plus U.S.A. nuclear power facilities as described in GLODEP2.

4. Same as 3 except nuclear facilities are vaporized and lofted by devices of yield 0.2 megaton instead of the 0.9 megaton yields used in 3.

5. Scenario 1, but with a shift from larger to smaller yield weapons while keeping the total yield at 5300 megatons. More specifically, in Scenario 1 we change 1000 devices at 0.9 megaton into 4500 devices at 0.2 megaton. Also 450 devices at 1.5 megatons into 3966 devices at 0.17 megaton. This increases the number of devices from 6,235 to 13,250.

6. Scenario 5, but instead of increasing the number of devices to keep the total yield at 5300 megatons, we keep the number of targets (and devices) the same and decrease the total yield from 5300 to 4011 megatons. More specifically, we change 1000 devices at 0.9 megaton into 1000 devices at 0.2 megaton, and also we change 450 devices at 1.5 megatons into 450 at 0.17 megaton while keeping everything else in Scenario 1 the same.

7. Scenario 1 but all devices are detonated at 20°N latitude. Our motivation in running this very unrealistic scenario was to obtain a GLODEP2 run with an equatorial injection in order to obtain the dose conversion factors for use in the modification of Art Broyles' approach. The global doses obtained here are very much larger than in Scenario 1 because the equatorial (low latitude) troposphere is much higher than in the polar regions. This results in a much larger fractional injection into the troposphere, hence larger doses.

8. European theater exchange as described in the J. Knox Erice paper (1983).[6]

The various quantitative characteristics of the above scenarios are summarized in Table 4. Included are the weapons fission product injections that we shall be referring to frequently in our discussion of results.

Discussion of Results

In the discussions of the results about each scenario that follows, we shall make extensive use of Tables 5, 6, & 7, as well as Figures 1 through 6.

Table 4. Scenario Characteristics.

Scenario Number	Injection Season	Tropospheric time decay Constant (days)	Total Explosive Yield (Megatons)	Total # Nuclear explosions	Tropospheric Injection (Megatons)	Lower Stratospheric Injection (Megatons)	Upper Stratospheric Injection (Megatons)	Total Fission Injection (Megatons)(b)
1	Winter	8.2	5,310	6,235	225.6	1,239	571.4	2,036
2	Summer	18.2	"	"	"	"	"	"
3	Winter	8.2	"	"	225.6 +.019 n.f.(c)	1,239+ .481 n.f.	571.4	2,036 +.5 n.f.
4	"	"	"	"	225.6 .35 n.f.	1,239 +.15 n.f.	"	2,036 +.5 n.f.
5	"	"	"	13,250	655.0	848.5	533.1	2,036
6	"	"	4,011	6,235	287.9	697.6	533.1	1,519
7(a)	"	"	5,310	"	1,002(a)	674.1(a)	359.2(a)	2,036(a)
8	"	"	387.6	1,751	54.54	103.3	0.36	158.2

(a) In this scenario, all the detonations are at 20°N and the injections are into the equatorial atmosphere. All the others are polar injections.

(b) There are no injections into either the high polar or high equatorial atmosphere. One needs very large yield explosions for this to occur.

(c) Pluses here mean the injected fraction contributed by the destroyed nuclear facilities (n.f.).

Table 5 lists the 50 year dose assessments for each scenario for each of the three most populous latitude bands (10°N to 70°N). We isolate here the contributions from the troposphere, lower stratosphere, and upper stratospheric compartment. Also listed is the total population dose for each band in man-rads, a useful measure of biological impact.

Table 6 presents our results for Global Somatic Assessments. Here we present for each scenario the projections of cancer and leukemia induction in absolute as well as relative terms. Also presented is the global population dose in man-rads, the area-averaged dose, and the population averaged dose. The latter is more significant for assessing biological impact, which is a function of population as well as dose distribution. The "Feinendegen" figures here are always a factor of three lower than the "linear" results.

Table 7 presents our results for Long Term Genetic Effects. We have used here the risk estimates for low L.E.T. and low dose rate radiation. Again, we present the assessments in both absolute as well as relative terms.

Figures 1 through 6 illustrate the accumulated dose calculated as a function of time for the Baseline Scenario (# 1) as well as the scenarios that include the nuclear facilities.

One can make a few general comments about these results before discussing each scenario separately. We see that the % increase in somatic and genetic effects above the current levels are of the order of a few percent; always less than 10% even if one adopts the "linear" figures and looks at the biologically most severe scenario. These biological assessments, while serious by themselves, will be completely swamped by casualty estimates from other aspects of a major nuclear war that are not treated here (blast, fire, early fallout, lack of food supplies, "nuclear winter," etc.).

Table 5
Dose Assessments[a] in Latitude Bands from 10°N to 70°N.
Relative Contributions from the Troposphere, Lower Stratosphere and Upper Stratosphere

Scenario Number	Latitude Band	Troposphere Dose (rads) Contribution	Lower Stratosphere Dose Contri.	Upper Stratosphere Dose Contri.	Total Dose (rads)	#Man-rads ($\times 10^{10}$)
1	10° to 30°N	2.15	4.08	.684	6.91	1.43
2	"	1.69	3.15	.776	5.62	1.16
3	"	3.00	24.52	.684	28.2	5.85
4	"	18.28	10.45	.684	29.4	6.10
5	"	7.35	2.79	.638	10.8	2.24
6	"	3.05	2.29	.638	5.98	1.24
7	"	79.51	1.39	.367	81.3	16.9
8	"	0.674	0.340	.0004	1.01	0.21
1	30° to 50°N	17.89	12.81	2.20	32.9	4.53
2	"	14.08	10.72	2.63	27.4	3.77
3	"	21.77	70.71	2.20	94.7	13.0
4	"	91.16	30.85	2.20	124.2	17.1
5	"	53.58	8.78	2.05	64.4	8.86
6	"	23.28	7.21	2.05	32.5	4.48
7	"	22.42	3.15	.798	26.4	3.63
8	"	4.55	1.07	.001	5.62	.77
1	50° to 70°N	16.79	8.80	1.76	27.3	0.72
2	"	13.21	6.74	1.72	21.7	0.57
3	"	17.95	52.29	1.76	72.0	1.89
4	"	38.76	22.35	1.76	62.9	1.65
5	"	44.44	6.03	1.64	52.1	1.37
6	"	20.26	4.96	1.64	26.9	0.70
7	"	.215	2.21	.557	2.98	0.08
8	"	3.46	0.734	.0011	4.20	0.11

a) These are 50 year unsheltered, unweathered, smooth terrain external gamma doses.

Table 6
Global Chronic (Long Term) Somatic Assessments
Induction of Latent[a] Cancers and Leukemias (C&L)

Scenario Number	Global Population Dose (Man-rads) x 10^{10}	Global Area Averaged Dose/rads	Population Averaged Dose/rads	C&L percent increase above current rate (linear)[b]	C&L percent increase above current rate (Feinendegen[c])	C&L Absolute Number (Linear) x 10^7	C&L Absolute Number (Feinendegen) x 10^7
1	6.74	8.40	14.7	1.47	0.49	1.18	.393
2	5.55	6.82	12.1	1.21	0.40	.971	.323
3	21.1	25.7	46.1	4.61	1.54	3.69	1.23
4	25.0	27.9	54.5	5.45	1.82	4.38	1.46
5	12.5	15.4	27.3	2.73	0.91	2.19	0.73
6	6.46	8.02	14.1	1.41	0.47	1.13	.376
7	21.8	21.0	47.5	4.75	1.58	3.81	1.27
8	1.10	1.32	2.40	0.24	0.08	0.19	.064

(a) These figures are for fatal cancers.

(b) Here we use the BEIR-UNSCEAR risk estimate of 1.75×10^{-4} per rad per person. We assume for the entire globe the U.S. current cancer rate of 165 thousand per million.

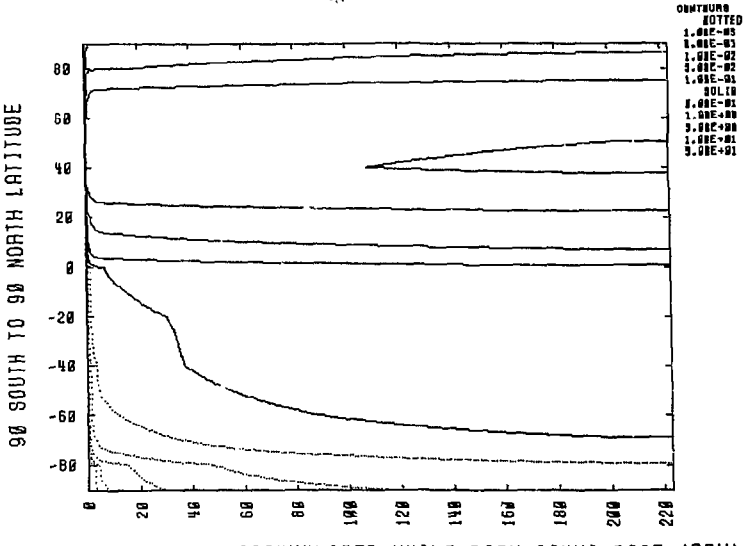
(c) This uses the Feinendegen repair algorithms.

Table 7
Global Long Term Genetic Assessments
Increase of Genetic Mutations in the Live Born

Scenario Number	Global Population Dose (Man-Rads) x 10^{10}	Population Averaged Dose (rads)	Percent Increase in Mutations above current rate(a)	Increase in Absolute number of mutations in 1st generation per year x 10^5	Increase in Absolute number of mutations over all time; per year x 10^5
1	6.74	14.7	1.5	0.31	2.1
2	5.55	12.1	1.2	0.25	1.7
3	21.1	46.1	4.9	1.0	6.9
4	25.0	54.5	5.5	1.2	7.8
5	12.5	27.3	2.6	0.55	3.7
6	6.46	14.1	1.3	0.29	1.9
7	21.8	47.5	7.1	1.5	10.0
8	1.10	2.40	0.23	0.049	0.33

a) We use the BEIR-UNSCEAR figures for the current rate. See Table 2.

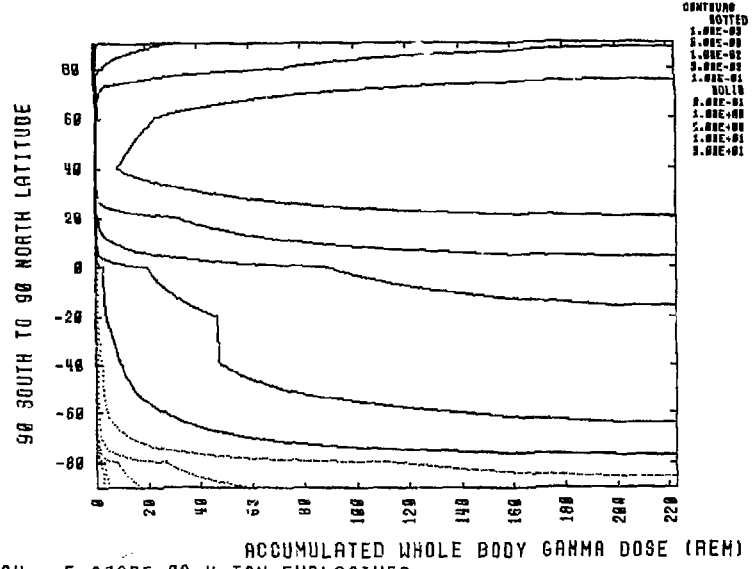
Figure 1



FROM 5.3097E+03 M-TON EXPLOSIVES
5310MT BASE CASE, 1ST QTR, 6 DAY TROP

Scenario 1

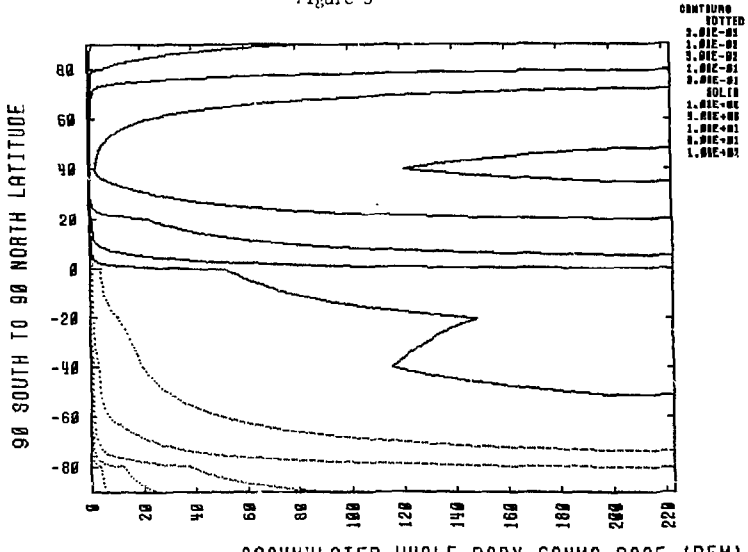
Figure 2



FROM 5.3097E+03 M-TON EXPLOSIVES
5310MT 1ST QTR, .9MT EACH ON NUCLEAR FACILITIES

Scenario 3

Figure 3



FROM 5.3097E+03 M-TON EXPLOSIVES
5310MT 1ST QTR. .2MT EACH NUCLEAR FACILITY

Scenario 4

Figure 4

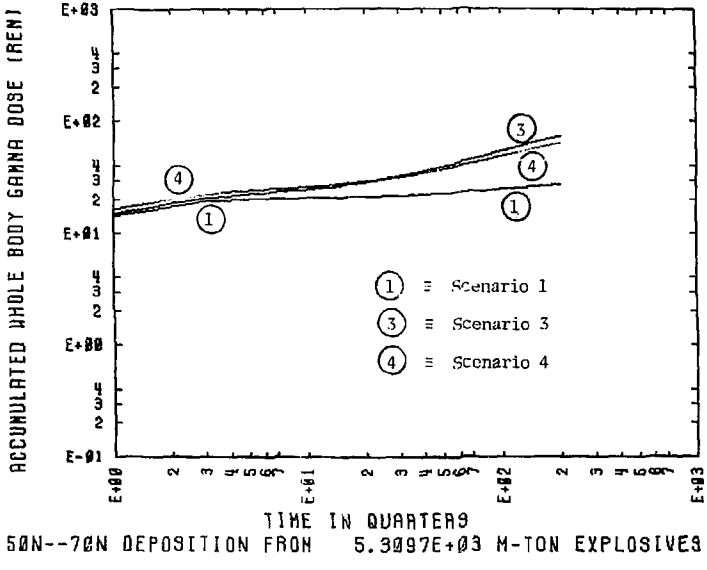
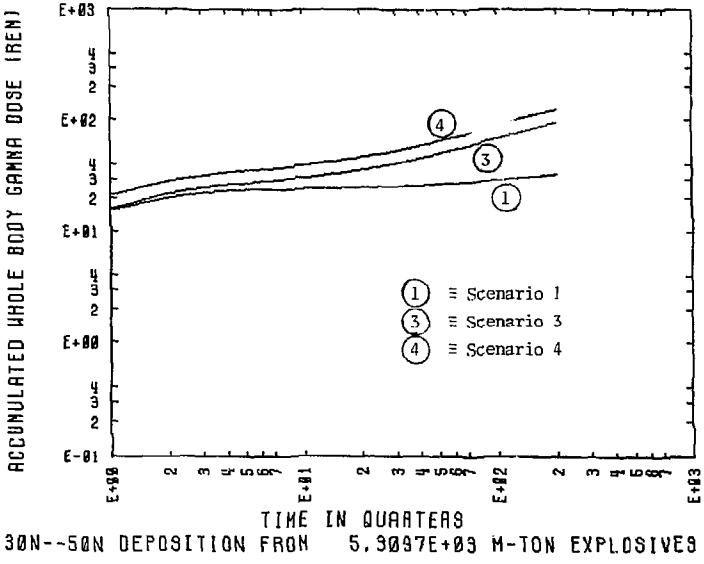
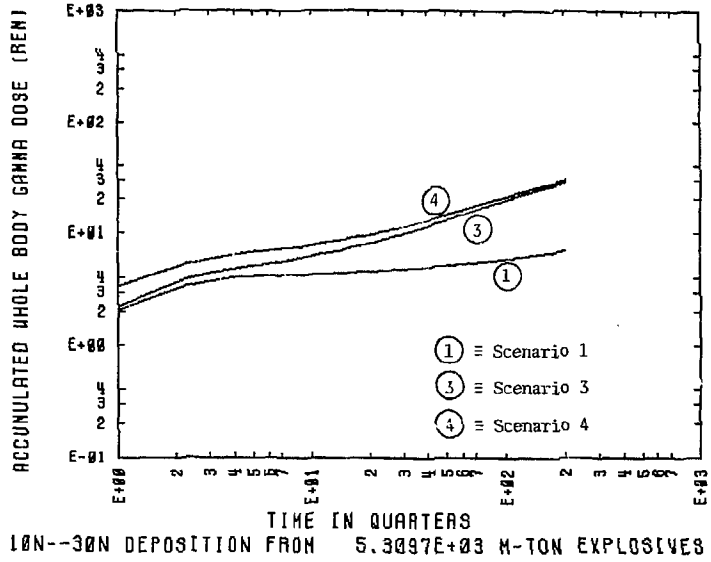

ACCUMULATED WHOLE BODY GAMMA DOSE (REM)
E+03
2
E+02
2
E+01
2
E+00
2
E-01
E+00
2
3
4
5
6
7
E+01
2
3
4
5
6
7
E+02
2
3
4
5
6
7
E+03
TIME IN QUARTERS
50N--70N DEPOSITION FROM 5.3097E+03 M-TON EXPLOSIVES
1 ≡ Scenario 1
3 ≡ Scenario 3
4 ≡ Scenario 4

Figure 5



30N--50N DEPOSITION FROM 5.3097E+03 M-TON EXPLOSIVES

Figure 6


ACCUNULATED WHOLE BODY GAMMA DOSE (REM)
E+03
E+02
E+01
E+00
E-01
E+00
E+01
E+02
E+03
TIME IN QUARTERS
1 ≡ Scenario 1
3 ≡ Scenario 3
4 ≡ Scenario 4
10N--30N DEPOSITION FROM 5.3097E+03 M-TON EXPLOSIVES

Acute effects generally become apparent above 50 rads. When one takes into account hot spots, it is clear that a significant number of people will have exposures in the acute range. Arthur Broyles and I have begun working on this problem, and plan to continue to study this in the near future.

In the following, we shall discuss the results of each scenario separately.

A. Tropospheric deposition model: The new experimental tropospheric deposition model has raised the contribution of the tropospheric injections to the 50 year dose by more than a factor of two above those predicted in the 1983 GLODEP2 model. For example, the dose from the tropospheric injections in the 30°-50° latitude band was 8 rads for the 5310 megaton baseline case as reported in Erice in 1983. The contributions from the lower polar stratosphere and upper polar stratosphere were 12.81 and 2.20 rads respectively, giving a total dose of 23 rads. Those calculations assumed a delta function deposition at 30 days after injection. The exponential deposition model with a time constant τ of 8.2 days for the same scenario yields a dose from the troposphere of 19.16 rads. By eliminating the contribution to the dose from the first day, we reduce the tropospheric dose to 17.89 rads. The dose contributions from the stratosphere are unchanged. Hence our new figure for the 50 year unweathered, unsheltered, smooth terrain dose in the 30-50°N latitude band is 32.9 rads. Indeed, the relative importance of the troposphere in dose assessments for all our scenarios has increased significantly. Table 5 displays the dose contributions for all the scenarios from the various compartments of the atmosphere, in the three latitude bands where most of the worlds population resides. We see that the troposphere accounts for a major share of the dose in most of our scenarios. Figure 1 illustrates the dose distribution over the globe as a function of time for scenario 1.

B. Baseline scenario - Winter vs. Summer injection. The summer injection transfer coefficients of Peterson for the stratosphere differ somewhat than for winter. We assume that the tropospheric deposition is slower in summer and use τ = 8.2 days for winter and τ = 18.2 days for summer. A comparison of the two runs yields 27.4 rads for summer vs. 32.9 rads for winter in the 30-50°N band. The corresponding figures for the global population dose in man-rads is 5.55×10^{10} (summer) and 6.7×10^{10} (winter). The population averaged dose

per person is 12.1 rads (summer) and 14.7 rads (winter). The doses from the troposphere and lower polar stratosphere are reduced somewhat in summer vis-a-vis winter, while the upper stratospheric contribution is increased (Table 5). We see the differences between summer/winter are not large.

In comparing the winter and summer injections, we can get a sense of the uncertainty in the dose that arises from the 50% uncertainties in the values of τ alluded to earlier. It is seen that the dose commitments are not very sensitive to τ and that other sources of uncertainty would predominate.

C. Baseline plus Nuclear Facilities. We have repeated this scenario and compare our new results for this scenario with those reported at Erice in 1983. Calling the previous results "1983" and the present results "1984", we find the 50 year dose for the 30-50°N band is increased from 84.6 to 94.7 rads. We can well understand the source of this increase by examining Table 8. Here we have isolated the dose from the nuclear facilities by subtracting the contribution of the weapons alone (scenario 1).

Table 8

		Scenario 3 - 30-50°N doses (in rads) "1983"	"1984"
Tropospheric Dose		11.8	21.8
lps & ups		72.8	72.9
Total Dose		84.6	94.7
Nuclear	tropospheric	3.8	3.9
Facilities	lps & ups	57.8	57.9
alone	total dose	61.6	61.8

We see from this table that the principal difference between our new calculation and the previous one is due to the increase we saw earlier in the tropospheric dose contributions from the weapons alone. The contribution from the nuclear facilities hardly changes. The reason for this is clear, namely that the time decay in the first months of the nuclear facility activity is very much slower than that of the weapons. Hence changing the tropospheric deposition model as we have by altering the time behavior of the deposition in the first month after injection does not change the contribution from the nuclear facilities appreciably vis-a-vis that of the weapons.

Figure 2 illustrates the dose distribution over the globe as a function of time.

The data on the biological impact of Scenario 3 is presented with the usual caveat that this is hopefully an unrealistic scenario and the assumptions are perhaps a hint of "worst case." We find the global population dose is 2.1 x 10^{11} man-rads, which is equivalent to a global population averaged dose of 46.1 rads per person. When one considers that hot spots could have doses an order of magnitude higher than these, we see that many in the population will suffer severe acute and lethal doses.

The situation would be even more serious if one alters this scenario by including worldwide nuclear facilities (Scenario 3 contains only present USA facilities). We also point out that GLODEP2 calculates 50 year doses, and that nuclear facilities, unlike the weapons, will continue to yield appreciable doses far beyond that time period. We can conjecture that a major exchange involving all the worldwide nuclear power facilities would have very serious radiological consequences for the global population.

D. Baseline + 0.2 megatons on nuclear facilities: In Scenario 3, the USA nuclear facilities are targeted with 0.9 megaton Soviet warheads. Here, in Scenario 4, we examine the consequences of using lower yield warheads knowing that this would inject more radioactivity from the nuclear facilities into the troposphere vis-a-vis the lower polar stratosphere, resulting in an earlier deposition and higher doses. We recognize that vaporizing and lofting the nuclear debris from the nuclear facilities is harder to do with smaller yield warheads. One finds in comparing Scenarios 3 and 4 that the 30-50°N band dose increases from 94.7 to 124.2 Rads. One can see by examining Tables 4 and 5 that this increase is indeed due to the shift in radioactivity from the stratosphere to the troposphere. The tropospheric dose goes from 21.8 to 91.2 rads, while the lps dose decreases from 70.7 to 30.9 rads. The global population dose increases from 2.1 to 2.5 x 10^{11} man-rads. The remarks made above on the biological significance of Scenario 3 apply even more so here.

Figure 3 displays the global distribution of dose as a function of time for this Scenario (4). Figures 4 through 6 compare the time behavior of the dose for Scenarios 1, 3 and 4, in the three most populous latitude bands between 10°N and

70°N. We can see that the contribution to the dose from the nuclear facilities becomes more pronounced as time progresses. We can also see that the rate of buildup of dose from the nuclear facilities is still considerable after 50 years vis-a-vis the dose from the weapons alone. This is due to the slower rate of decay of the radiation from the nuclear facilities. It would be of interest to extend our calculations here well beyond 50 years.

When we compare the early time behaviors in Figs. 4, 5 and 6, it appears that the dose due to the nuclear facilities in Scenarios 3 and 4 have different time behaviors. This appearance is primarily due to the fact that as we shift injections from the stratosphere into the troposphere, we also shift the depositions between the 3 latitude bands examined. The differences we see in the early time behavior in these figures would diminish if we integrated over the 3 bands.

Fetter and Tsipis[10] have examined the consequences of vaporizing a nuclear reactor with a one megaton device. They conclude that the radiological contributions of the reactor to the doses in that scenario are very much more severe than that due to a major reactor accident without the weapon explosion, and much more severe than that due to the weapon alone. The reason for this is that the weapon serves as a very efficient way to distribute the reactor radioisotopes over an extended area whereas the reactor accident alone is mostly local in effect. This argument for a single warhead on a reactor applies even more so to our scenarios 3 and 4 where we have considered the <u>global</u> distribution of the radioisotopes from many nuclear facilities, thereby exposing the entire population of the globe.

E. Scenarios 5 and 6 were motivated by the attempt to assess the long-term consequences of the shift in the nuclear arsenals from larger to smaller yield devices. This shift has been going on for about 2 decades now, and continues apace. The principal variables that affect the radiological consequences of this shift are, on the one hand, smaller yield devices produce correspondingly smaller amounts of fission products, while, on the other hand, the amount of fission products is proportional to the number of these devices. The third, and the significant variable examined particularly in this work, is that a smaller yield injects a proportionally larger portion of its fission products into the troposphere. This results, as we have seen, in a higher dose on the ground.

In Scenario 5, we have increased the number of devices in the Baseline situation from 6,235 to 13,250 while keeping the total yield at 5,310 megatons. In Scenario 6, we have used smaller yields but have kept the number of devices constant at 6,235. The total yield consequently is reduced 25% from 5,310 to 4,011 megatons. In Table 9 we present some comparative figures for the 50 year dose.

Table 9

Scenario	30-50°N Dose (rads)	Global Population Averaged Dose (rads)	Global Population Dose (man-rads) ($\times 10^{10}$)
1	32.9	14.7	6.74
5	64.4	27.3	12.5
6	32.5	14.1	6.46

We see that a shift to smaller weapons in our baseline scenario has approximately doubled the dose, even for the same total yield (Scenario 5). We also see in 6 that the dose remains about the same even with a 25% drop in total scenario yield. Based on these results, it would seem prudent to keep a constant alert on the changing nature of the nuclear stockpile to insure that we are aware of the potential radiological consequences of any proposed shifts in weapons yield, type, and numbers.

F. Baseline Equatorial Scenario: In order to generate dose conversion constants to use in the simple method of approximating doses described elsewhere in this report, we undertook a GLODEP2 run with the baseline scenario except that all detonations were located at 20°N latitude (Scenario 7). Our purpose here was to achieve injections into the equatorial atmosphere. We find the results very interesting, with calculated doses considerably higher than those in our baseline polar injection (Scenario 1). When we compare the doses in the 10°-30°N band in Scenario 7 with the 30°-50° and 50°-70°N bands in Scenario 1 (Table 5), we see 81.3 compared to 32.9 and 27.3 rads respectively. The impact on the global population dose is even more pronounced because of the larger population of the 10-30°N band (principally India and Southern China). We find 21.8 x 10^{10} as compared to 6.74 x 10^{10} man-rads, a dramatic increase. We assumed in 7 a tropospheric time constant of 8.2 days. By using 18.2 days, the number of man-rads would be reduced by about 20%.

An explanation for this dramatic increase is that the equatorial troposphere is much higher than the polar troposphere. Hence a larger proportion of the injection goes into the equatorial troposphere, resulting in the tripling of the dose. The tropospheric injection in Scenario 1 of 225.6 megatons, is increased to 1,002 megatons in Scenario 7 (Table 4). We think these results are of interest, especially to the countries of the equatorial regions of the globe.

7. European Theater Scenario: The final scenario reported here (Scenario 8) is a re-run of the European Theater War reported by J. Knox in Erice (1983)[6]. The resulting figures are presented in the Tables. This 387.6 megaton exchange produces a 50 year dose in the 30-50°N band of 5.62 rads. Over 80% of this comes from the tropospheric injections. The global population averaged dose is 2.40 rads. Local variations (e.g. hotspots) from the average are likely to be greater here than as for a major exchange. When we compare this with Scenario 1, we see that with only 7.3% of the total yield of Scenario 1, Scenario 8 produces a dose that is 16.3% of that of Scenario 1. Again, we see the importance of smaller yield weapons and their injections into the troposphere.

A Fast and Convenient Method to Estimate Latitude Dose

Using an approach suggested by Art Broyles paper, we have developed a fast and convenient method of calculating dose assessments by latitude band that does not require the use of GLODEP2. This method can be useful to researchers who do not have a GLODEP2 code available for their use.

Our approach is based upon the observation that the dose assessment problem in GLODEP2 is conveniently split into two parts; injection (easy) and deposition and dose integration (harder). Injection is made into the eight compartments that divide up the atmosphere (e.t., l.e.s., u.e.s., h.e.a., p.t., l.p.s., u.p.s., h.p.a.). Once injection is made, the code then calculates the time-dependent deposition and resulting 50 year doses. The principle point here, is that for all the compartments other than the troposphere, the fission products have no memory of their source. The GLODEP2 code calculates a unique value of the doses in each of the

latitude bands. The troposphere has a memory, but only a weak one. This is because the code distributes the tropospheric fission products from each burst location into the latitude bands by using a Gaussian spatial distribution around the burst latitude. So the doses in individual latitude bands due to the tropospheric injections are weakly dependent on the burst latitude. This means our fast method predicts these tropospheric doses only approximately (within 10% in most cases tried). However, global averages of area doses are predicted accurately as these average over the latitude bands and hence the memory of burst location is averaged out.

Our method uses GLODEP2 to calculate the dose conversion constants used to estimate dose. We define C_{et} as the constant used for converting injections into the equatorial troposphere into latitude doses. The units of C_{et} are rads per megaton of fission product injected. We similarly define C_{les}, C_{ues}, C_{hea}, $C_{p.t.}$, C_{lps}, C_{ups}, C_{hpa}. Each of these constants is a function of latitude band, and also depends weakly on the tropospheric time decay constant and season of injection. Our equation for calculating the dose in latitude band b is

$$D(b) = C_{et} I_{et} + C_{les} I_{les} + C_{ues} I_{ues} + C_{hea} I_{hea} + C_{pt} I_{pt} + C_{lps} I_{lps} + C_{nps} + C_{hpa} I_{hpa}$$

Here, the I^S are the injections into their respective atmospheric compartments. The values of the dose constants for a winter injection with τ = 8.2 days are presented in Table 10. These constants are for a nuclear weapon distribution of fission products. The C^S for nuclear power facilities would be different, but easily generated from our data.

As an example of how one would utilize this approach, we have used it to predict doses for Scenario 8 (the European Theater War), and compared it with the GLODEP2 run. This scenario has only polar injections. We illustrate the calculation of the dose in the 30-50°N band. The values for I (in megatons) for this scenario are: I_{pt} = 54.54, I_{lps} = 103.3; and I_{ups} = 0.36. All the other I^S are zero. Hence

$$D(30\text{-}50°N) = 54.54\,(7.9 \times 10^{-2}) + 103.3\,(1.03 \times 10^{-2}) + 0.36\,(3.8 \times 10^{-3}) = 5.37 \text{ rads (50 years)}$$

The values of the C_i^{Σ} are given in Table 10.

In Table 11, we present the results for other latitude zones and compare them to those calculated by GLODEP2. We also calculate the latitude area times the dose (area-dose). One can see, as expected, the small variations of the approximate method from the GLODEP2 values, and also the excellent agreement in the sum of the area-doses over all five relevant latitude bands.

Table 10

Constants for Calculating Latitude Doses Using Broyles' Approach.

January Northern Hemisphere Injections
τ = 8.2 days
Units: Rads per megaton fission yield injected of nuclear weapon debris

Zone Injection Latitude	Polar Troposphere p.t.	Lower Polar Stratosphere l.p.s.	Upper Polar Stratosphere u.p.s.	Equatorial Troposphere e.t.	Lower Equatorial Stratosphere l.e.s.	Upper Equatorial Stratosphere u.e.s.
70°-90°N	6.8 (-3)	2.01 (-3)	8.33 (-4)	0	8.02 (-4)	3.85 (-4)
50°-70°N	7.4 (-2)	7.10 (-3)	3.07 (-3)	2.11 (-4)	3.28 (-3)	1.55 (-3)
30°-50°N	7.9 (-2)	1.03 (-2)	3.84 (-3)	2.2 (-2)	4.68 (-3)	2.22 (-3)
10°-30°N	9.5 (-3)	3.29 (-3)	1.20 (-3)	7.9 (-2)	2.06 (-3)	1.02 (-3)
10°S-10°N	5.5 (-5)	5.54 (-4)	1.12 (-4)	1.7 (-2)	2.19 (-3)	7.62 (-4)
30°-10°S	0	3.28 (-4)	2.55 (-4)	1.2 (-4)	1.68 (-3)	1.04 (-3)
50°-30°S	0	2.50 (-4)	8.15 (-4)	0	2.13 (-3)	2.38 (-3)
70°-50°S	0	1.16 (-4)	5.65 (-4)	0	1.62 (-3)	1.71 (-3)
90°-70°S	0	6.89 (-6)	1.33 (-4)	0	5.42 (-6)	4.46 (-4)

Table 11

Comparison of Approximate Method With GLODEP2

		GLODEP2		Approximate Method	
Band Number	Latitude Band	Dose (Rads)	Area x Dose (Rads-M_i^2) x 10^7	Dose (Rads)	Area x Dose (Rads-M_i^2 x 10^7
1	70-90°N	0.494	0.30	0.579	0.35
2	50-70°N	4.20	7.31	4.77	8.30
3	30-50°N	5.62	14.94	5.37	14.28
4	10-30°N	1.01	3.32	0.86	2.83
5	10°S-10°N	.061	0.21	.087	0.30
Total Area x Dose			26.08		26.06

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(10) S. A. Fetter and K. Tsipis "Catastropic Releases of Radioactivity," Scientific American, 244, No. 4, (April, 1981).

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