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GLOBAL DOSE TO MAN FROM
PROPOSED NNTRP HIGH
ALTITUDE NUCLEAR TESTS

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INTRODUCTION

The National Nuclear Test Readiness Program (NNTRP) is charged with the responsibility of maintaining a state of readiness for prompt resumption of atmospheric nuclear testing in the unlikely, but possible, change in international relations that would make such a move vital to our national defense. One such change might be Soviet abrogation of the Limited Test Ban Treaty.

According to the National Environmental Policy Act of 1970, the NNTRP might be required to prepare an environmental assessment prior to resumption of atmospheric nuclear testing. In order to meet their responsibility regarding promptness, an environmental statement for typical tests is being prepared. If the need arises, this statement will form the basis of a final assessment, based on the actual test schedule.

The first part of our contribution to this environmental assessment covered the proposed surface and tropospheric nuclear bursts in the Pacific Test Area (1). This report, our second contribution, provides world-wide individual and population doses from proposed high altitude tests in the same area. These tests, typical of what might be included in a final assessment, would place about 400 kt of fission products into the high atmosphere above 50 km.

PRIOR HIGH ALTITUDE TESTS

Prior high altitude nuclear testing has produced unique radioactive tracers that were subsequently measured for several years in the lower stratosphere and as surface deposition at several places around the world. In the summer of 1958, a nuclear-tipped rocket burst at 43 km contained ^{102}Rh . The cloud rose to 100-150 km before stabilizing (2). Kalkstein (2) speculated that the rhodium descended to 80 km in a matter of months and then to 55 km in weeks to months. He further speculated that debris clouds injected at greater heights, but within the earth's gravitational field, would settle very rapidly to a height of a few hundred kilometers and then behave like the 1958 ^{102}Rh debris. In the summer of 1962 a U. S. rocket test at 17°N detonated a nuclear device containing ^{109}Cd at 400 km.⁽³⁾ The stabilization height of the debris cloud is unknown, but it is believed that only a fraction of the cadmium may have been lost to outer space. An accidental re-entry burn-up at 11°S of a SNAP-9A space vehicle containing ^{238}Pu provided another tracer.(3).

These data revealed that, although the radionuclides were injected at equatorial latitudes, the eventual concentration distribution in the lower stratosphere and the total deposition on the surface closely resembled the pattern observed following Soviet surface and low tropospheric airbursts. The exception to this, as described by List and Telegadas (4), is that the maximum deposition occurs in the winter hemisphere at the time of the burst. For example, a high altitude burst at 17°N in July will

produce the largest total deposition in the middle latitudes of the Southern Hemisphere. The first measurable surface deposition occurs about the second spring following the detonation. The maximum deposition appears in the third spring, while the first half of the total deposition occurs by about 3.5 years. The ratio of partitioning between hemispheres is estimated as 2.5:1 (see Ref. 5).

GLOBAL DEPOSITION MODEL

Using the high altitude data described above, and data from other tracers injected during 1958 at lower altitudes, Peterson (5) developed an empirical global deposition model (GDEP) to estimate ^{90}Sr deposition by 20 degree latitude bands. Code inputs are total yield, fission fraction, height of burst, and latitude, season and year of the burst. Using these input data, GDEP places the ^{90}Sr generated by each burst (at 90 Curies per kiloton of gross fission products) into one or more of six stratospheric and high atmosphere compartments. The vertical distribution of this debris is based on that proposed by Ferber (6). For bursts near the equator, stabilized cloud bases and tops are based on past U.S. atmospheric nuclear testing experience. For the high altitude tests all of the debris would initially be placed into the high equatorial atmosphere compartment whose base is at 50 km.

RESULTS

About 90% of the world's population resides in the Northern Hemisphere and, as mentioned, the maximum deposition occurs in the winter hemisphere at the time of injection. Therefore in order to maximize the population dose, all high altitude tests were assumed to occur in winter, viz., September to February. Also since GDEP treats all bursts above 50 km alike, all proposed tests were treated as a single detonation with a fission yield of 400 kt. This assumption seems reasonable in view of Kalkstein's (2) hypothesis of ^{102}Rh transport mentioned earlier.

The primary GDEP code output is ^{90}Sr deposition in mCi/km^2 for 20 degree latitude bands. Calculations are made by quarter-years out to six years after detonation. As an example of the global deposition pattern, Fig. 1 presents quarter-year ^{90}Sr values in $\mu\text{Ci}/\text{km}^2$ for a Northern Hemisphere winter injection of 400 kt of fission products into the high atmosphere above 50 km. It is evident that for winter detonations, the Northern Hemisphere experiences the first arrival and the greater deposition of ^{90}Sr from the high altitude tests. The occurrence of spring maxima in both hemispheres is apparent. Had the bursts occurred in summer, the deposition pattern would approximate a mirror image of that shown in Fig. 1. After 6 years, GDEP calculations indicate that about 70% of the radioactivity has been deposited. Since neither shielding nor weathering are accounted for in the calculations, it is reasonable to neglect the 30% not accounted for in the subsequent dose estimates.

Although a host of radionuclides would be produced by the high altitude tests, most of them have short half-lives, are produced in relatively small amounts, or have small dose conversion constants. Nuclides were ranked by forming the product of

$$[\text{Source (Ci/kt)}] \cdot [\text{Dose Conversion Constant } (\frac{R_m^2}{C_i})] \cdot [t^{-1.2} \text{ or } \exp(-\Delta t)]$$

where external gamma, forage-cow-milk, and pasture-meat pathways were considered. For external gamma, the decay term assumed the $t^{-1.2}$ law at two years, while for the food pathways $\exp(-\Delta t)$, where $t = 2$ years, was used. This analysis revealed that in addition to gross-fission product doses, ^{90}Sr and ^{137}Cs were the more important nuclides for dose to man calculations; ^{106}Ru came in a poor fourth, but is shown in subsequent tables. Table 1 presents the relevant data that went into these calculations.

Since the GDEP code output is ^{90}Sr deposition in mCi/km^2 , deposition values for ^{106}Ru , ^{137}Cs , and gross fission products were obtained by ratioing the source terms; this assumes that transport and settling speeds of these nuclides are similar to the behavior of ^{90}Sr . Each quarter-year deposition value was transformed into integrated 30-year individual dose; these were accumulated out to six years for each dose pathway and latitude band.

The deposition pattern for ^{90}Sr , shown in Figure 1, may be used to depict quarter-year ^{90}Sr thirty-year doses and ^{137}Cs concentrations and doses by multiplying the Figure 1 contours by the factors given in Table 2.

Due to its short half-life (about one year) ^{106}Ru has not been included. A factor for gross fission product doses has also been excluded because of the different decay scheme; instead, Figure 2 has been prepared and shows the external gamma dose pattern in millirem, as opposed to microrem for the conversion constants in Table 2. The pattern is similar to the Figure 1 pattern for ^{90}Sr deposition. This is because from two to six years the $t^{-1.2}$ curve is extremely flat and is nearly equivalent to ^{90}Sr decay.

Population doses were obtained by multiplying the total whole body individual dose (from the two food pathways and for external gamma) by the estimated 1974 population (7) for each latitude band. Figure 3 is a histogram of the world's population. Note that about 90% of the people live in the Northern Hemisphere, while some 75% reside between 10° - 50°N latitude.

Table 3 presents 30-year individual and population doses for the proposed high altitude tests, arranged by 20-degree latitude bands and pathways. This table shows that gross fission products are the largest contributor to the individual dose with 0.01 rem to the whole body at 30° - 50°N . The ^{90}Sr forage-cow-milk bone doses and the ^{137}Cs pasture-meat whole body and bone doses are both about 1/5 the doses from gross fission products. The smallest doses are contributed by ^{106}Ru .

The 30-year population doses to the whole body show that over 98% of the global dose is received in the Northern Hemisphere, with about 75% of the global total occurring at 30° - 50°N . Note that the 30-year

natural background population dose, assuming that everyone receives 0.1 rem/y, is 300 times the estimated dose from the proposed high altitude tests. Should such tests be conducted in summer (March-August) instead of winter, as has been assumed in Table 3, the Northern Hemisphere doses would be decreased by a factor of 3 to 4; the Southern Hemisphere doses would be increased by a similar amount. Hence, the world total person-rem would be about one-third the value for a winter high altitude test series, or 1×10^7 person-rem.

ERROR ESTIMATE

The GDEP code was verified against four years of deposition observations from the 1961-62 Soviet and U.S. test series (5). The annual ^{90}Sr calculated deposition agreed with measurements well within a factor of two for all latitude bands, except $10^\circ\text{N} - 10^\circ\text{S}$ where calculations were about a factor of three too low. These series included a multitude of yields for bursts within the troposphere and a few tests that placed debris in the high atmosphere. In this report, we are calculating deposition from only high altitude tests. Therefore, the expected errors would be largest for quarterly deposition calculations. Annual estimates should have a smaller error, but probably greater than a factor of ten in some years. However, the total 6-year deposition calculations should be within a factor of ten of measurements should a test series be executed. Also note that the calculations give average depositions for 20-degree latitude bands.

Order-of-magnitude variations have been observed within the same latitude band. Volchok (8) has speculated that the relative maximum of radioactive deposition in the west-central United States is due to a "preferred area of stratospheric-troposphere communication", i.e. a region where stratospheric material can more readily pass into the troposphere. Rainout of radionuclides in such regions when lower stratospheric concentrations are highest could cause local "hot spots" that would deviate from the calculated average deposition by factors of 10 to 100. To date, the climatology of stratospheric extrusions is not well-known and it is not possible to determine longitudinal variations in deposition any more closely than order of magnitude estimates.

SUMMARY

Radionuclide measurements from past high altitude nuclear testing have enabled development of a model (5) to estimate surface deposition and doses from 400 kt of fission products injected in winter within the Pacific Test Area at altitudes in excess of 50 km. The largest 30-year average dose to man is about 10 millirem and occurs at 30°-50°N latitude. The principal contributor to this dose is external gamma radiation from gross fission products. Individual doses from ^{90}Sr via the forage-cow-milk pathway and ^{137}Cs via the pasture-meat pathway are about 1/5 the gross fission product doses.

The global 30-year population dose is 3×10^7 person-rem, which compares with a 30-year natural background population dose of 1×10^{10} person-rem. Due in large part to the global distribution of population, over 98% of the

global person-rem from the proposed high altitude tests is received in the Northern Hemisphere, while about 75% of the total population dose occurs within the 30°-50°N latitude belt. Detonations in summer would decrease the global dose by about a factor of three.

Table 1. Data Used in Ranking the More Important Radionuclides for High Altitude Tests

Nuclide	Source Ci/kt	Dose Conversion Constants ^a					Half-Life
		External Gamma	Forage-Cow-Milk Pathway		Pasture-Meat Pathway		
		Whole Body	Whole Body	Bone	Whole Body	Bone	
Sr-90	9x10 ¹	ø	1.2x10 ⁶	9.5x10 ⁶	4.0x10 ⁵	3.3x10 ⁶	28 y
Ru-106	2x10 ³	-	3.5x10 ¹	7.1x10 ¹	4.2x10 ⁴	1.0x10 ⁵	1.01 y
Cs-137 ^b	2x10 ²	1.0x10 ¹	4.5x10 ⁵	4.5x10 ⁵	3.9x10 ⁶	3.9x10 ⁶	30 y
Gross F.P. ^c	4.4x10 ⁸	1.7x10 ¹	-	-	-	-	c

a. Units are $\text{Rem-m}^2/\text{Ci-hr}$ for Ext. Gamma; others are $\text{Rem-m}^2/\text{Ci}$.

b. Cs-137 whole body external gamma dose is from Ba-137 daughter.

c. Source term is at H+1 h; decay is by $t^{-1.2}$.

- Not calculated.

Table 2. Factors for Obtaining ^{90}Sr Dose Patterns and ^{137}Cs Deposition and Dose Patterns

Nuclide	Deposition Pattern ($\mu\text{Ci}/\text{km}^2$)	30 y Dose Pattern (Units in μrem)			
		<u>Forage-Cow-Milk</u>		<u>Pasture-Meat</u>	
		Whole Body	Bone	Whole Body	Bone
Sr-90	1.0	1.2	9.5	0.40	3.3
Cs-137	2.2	1.0	1.0	8.7	8.7

TABLE 3. Estimated 30 year global doses from debris placed into the stratosphere by proposed high altitude tests occurring in winter

Latitude and Pathway	Sr-90 (Rem)	Ru-106 (Rem)	Cs-137 (Rem)	Gross FP (Rem)	Total Individual Dose (Rem)	Est. 1974 Population ^b	Population Dose (Person-Rem)	30y Natural Background Pop. Dose ^d (Person-Rem)
70 - 90 N						^c	-	-
FCM WB	3×10^{-5}	a	3×10^{-5}	-	6×10^{-5}		-	-
Bone	3×10^{-4}	a	3×10^{-5}	-	3×10^{-4}		-	-
PM WB	1×10^{-5}	4×10^{-6}	2×10^{-4}	-	2×10^{-4}		-	-
Bone	9×10^{-5}	9×10^{-6}	2×10^{-4}	-	3×10^{-4}		-	-
Ext. Dose (WB)	0	a'	1×10^{-5}	2×10^{-3}	2×10^{-3}		-	-
50 - 70 N						3.3×10^8		
FCM WB	2×10^{-4}	a	1×10^{-4}	-	3×10^{-4}		1×10^5	-
Bone	1×10^{-3}	a	1×10^{-4}	-	1×10^{-3}		3×10^5	-
PM WB	6×10^{-5}	2×10^{-5}	1×10^{-3}	-	1×10^{-3}		3×10^5	-
Bone	5×10^{-4}	5×10^{-5}	1×10^{-3}	-	2×10^{-3}		7×10^5	-
Ext. Dose (WB)	0	a	6×10^{-5}	8×10^{-3}	8×10^{-3}		3×10^6	1×10^9
30 - 50 N						1.5×10^9		
FCM WB	2×10^{-4}	a	2×10^{-4}	-	4×10^{-4}		6×10^5	-
Bone	2×10^{-3}	a	2×10^{-4}	-	2×10^{-3}		3×10^6	-
PM WB	7×10^{-5}	3×10^{-5}	2×10^{-3}	-	2×10^{-3}		3×10^6	-
Bone	6×10^{-4}	6×10^{-5}	2×10^{-3}	-	3×10^{-3}		5×10^6	-
Ext. Dose (WB)	0	a	8×10^{-5}	1×10^{-2}	1×10^{-2}		2×10^7	5×10^9
10 - 30 N						1.4×10^9		
FCM WB	7×10^{-5}	a	6×10^{-5}	-	1×10^{-4}		1×10^5	-
Bone	5×10^{-4}	a	6×10^{-5}	-	6×10^{-4}		8×10^5	-
PM WB	2×10^{-5}	8×10^{-6}	5×10^{-4}	-	5×10^{-4}		7×10^5	-
Bone	2×10^{-4}	2×10^{-5}	5×10^{-4}	-	7×10^{-4}		1×10^6	-
Ext. Dose (WB)	0	a	3×10^{-5}	3×10^{-3}	3×10^{-3}		4×10^6	4×10^9
10 S - 10 N						4.2×10^8		
FCM WB	5×10^{-6}	a	4×10^{-6}	-	9×10^{-6}		4×10^3	-
Bone	4×10^{-5}	a	4×10^{-6}	-	4×10^{-5}		2×10^4	-
PM WB	2×10^{-6}	5×10^{-7}	4×10^{-5}	-	4×10^{-5}		2×10^4	-
Bone	1×10^{-5}	1×10^{-6}	4×10^{-5}	-	5×10^{-5}		2×10^4	-
Ext. Dose (WB)	0	a	2×10^{-6}	2×10^{-4}	2×10^{-4}		8×10^4	1×10^9
10 - 30 S						1.4×10^8		
FCM WB	2×10^{-5}	a	2×10^{-5}	-	4×10^{-5}		6×10^3	-
Bone	2×10^{-4}	a	2×10^{-5}	-	2×10^{-4}		3×10^4	-
PM WB	7×10^{-6}	2×10^{-6}	2×10^{-4}	-	2×10^{-4}		3×10^4	-
Bone	6×10^{-5}	5×10^{-6}	2×10^{-4}	-	3×10^{-4}		4×10^4	-
Ext. Dose (WB)	0	a	8×10^{-6}	9×10^{-4}	9×10^{-4}		1×10^5	4×10^8
30 - 50 S						5.3×10^7		
FCM WB	7×10^{-5}	a	6×10^{-5}	-	1×10^{-4}		5×10^3	-
Bone	5×10^{-4}	a	6×10^{-5}	-	6×10^{-4}		3×10^4	-
PM WB	2×10^{-5}	6×10^{-6}	5×10^{-4}	-	5×10^{-4}		3×10^4	-
Bone	2×10^{-4}	1×10^{-5}	5×10^{-4}	-	7×10^{-4}		4×10^4	-
Ext. Dose (WB)	0	a	3×10^{-5}	3×10^{-3}	3×10^{-3}		2×10^5	2×10^8
50 - 70 S						^c	-	-
FCM WB	5×10^{-5}	a	4×10^{-5}	-	9×10^{-5}		-	-
Bone	4×10^{-4}	a	4×10^{-5}	-	4×10^{-4}		-	-
PM WB	2×10^{-5}	5×10^{-6}	4×10^{-4}	-	4×10^{-4}		-	-
Bone	1×10^{-4}	1×10^{-5}	4×10^{-4}	-	6×10^{-4}		-	-
Ext. Dose (WB)	0	a	2×10^{-5}	2×10^{-3}	2×10^{-3}		-	-
70 - 90 S						^c	-	-
FCM WB	1×10^{-5}	a	9×10^{-6}	-	2×10^{-5}		-	-
Bone	8×10^{-5}	a	9×10^{-6}	-	9×10^{-5}		-	-
PM WB	3×10^{-6}	9×10^{-7}	8×10^{-5}	-	8×10^{-5}		-	-
Bone	3×10^{-5}	2×10^{-6}	8×10^{-5}	-	1×10^{-4}		-	-
Ext. Dose (WB)	0	a	4×10^{-6}	5×10^{-4}	5×10^{-4}		-	-
World Total ^e Unit						3.9×10^9 People	3×10^7 (Person-Rem)	1×10^{10} (Person-Rem)

a Dose $< 10^{-7}$ Rem

b Source - 1975 Information Please Almanac

c Population $< 10^5$

d Assumes 0.1 Rem/y in each latitude band

e Doses are to whole body only

- Not calculated

FCM = Forage-cow-milk pathway

PM = Pasture-meat pathway

WB = Whole Body

Figure 1. Sr-90 deposition in $\mu\text{Ci}/\text{km}^2$ for a winter injection within the Pacific Test Area of 400 kt of gross fission products at altitudes above 50 km.

Figure 2. 30-year external gamma doses in mrem from 400 kt of gross fission products injected in winter within the Pacific Test Area at altitudes above 50 km.

Figure 3. World population by 20 degree latitude bands in units of millions of people.

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