Potential Effects of Project Chariot on Local Water Supplies Northwestern Alaska

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POTENTIAL EFFECTS OF PROJECT CHARIOT ON LOCAL WATER SUPPLIES NORTHWESTERN ALASKA

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ABSTRACT

Project Chariot—once planned under the auspices of the Atomic Energy Commission as a nuclear-excavation test in northwestern Alaska—presumably might introduce some radioactive nuclides into local water supplies. This report develops an order-of-magnitude appraisal of the expectable concentrations of such nuclides in streams and other water sources. The appraisal is reported in full because it is unique in scope and because its results are applicable generally to preliminary evaluations of other proposals for nuclear excavation.

Project Chariot would involve simultaneous detonation of one 200-kiloton and four 20-kiloton nuclear explosives, all emplaced below the land surface. Expectable vented radioactivity would be 1,500 megacuries due to mixed fission products, including 3,000 curies due to Sr^{90}, 3,000 curies due to Cs^{137}, and 100,000 curies due to I^{131}. This radioactivity would be dispersed downwind as fallout; about 50 percent within a distance of 2 miles from ground zero, 75 percent within 10 miles, and 90 percent within 30 miles. The area receiving fallout (radioactivity more than 0.005 megacurie per square statute mile) would be some 1,500 square miles and would have a maximum downwind reach of about 125 miles. (These amounts of radioactivity and their dispersal were projected by the Lawrence Radiation Lab.; they are stated for the standard reference time of 1 hour after detonation.)

Subsequent redispersal of the fallout in and by water of the area is analyzed for four hypothetical cases, which together span the yearly range in hydrologic conditions. The four cases assume: (case I) detonation 30 days prior to breakup in the spring, ordinarily in April, fallout being on continuous snow cover; negligible redistribution of fallout by the wind; snowmelt runoff of 1 inch over the area, within 30 days following breakup; snowmelt detained in microponds (minute pools), 0.3 inch over the area; (case II) detonation at the close of melt-water runoff, ordinarily in early June; within the 30 days following detonation, a precipitation total of 0.5 inch but not more than 0.1 inch in any one storm; runoff averaging 0.03 inch but none generated by rain during the 30-day period; (case III) detonation in early August, following 2 months of minimum precipitation and an accumulated soil-water deficiency of 1 inch; within the 30 days following detonation, rainfall of 2.5 inches generating runoff of 0.7 inch; (case IV) detonation in late September, 10 days prior to freezeup, fallout being on saturated tundra; in the 10-day interim, no precipitation and 0.1 inch of runoff.

In each case the vented fission-product radioactivity, appropriately decayed, would be distributed as follows: (1) Dissolved in streams running off from the fallout area or in the water of microponds within the area, (2) suspended in the streams, (3) adsorbed on land-surface materials and so virtually immobilized, (4) infiltrated to soil water and so momentarily immobilized, but subject to later uptake by growing plants, to slow percolation through the soil, and to adsorption on soil particles, and (5) remaining on the land surface or on vegetation near the place of fall, subject to later redispersal by water or wind and to ingestion by grazing animals.

Among the four hypothetical cases, the radioactivity interjected in streams owing to dissolved nuclides would be by far the least in case III, as detonation in early August would be followed by heavy rains. For the more distant parts of the fallout area this activity would be less than the lifelong drinking-water standard.

Activity in the streams due to suspended fallout particles would be nearly zero in case II, as detonation ordinarily in early June would be followed by light rainfall and minimum runoff. In the other cases, this activity would depend largely on an unknown factor—the proportional part of the fallout particles that would be moved in competition with natural soil particles, by water flowing overland. Inferentially, this proportion would be greatest under case I.

Total stream burden would be greatest in case III, which encompasses an interval of high momentary streamflow but moderate average flow. Under these conditions, activity once in the streams, either dissolved or suspended, would pass in very large part to the Chukchi Sea within a few days. This being so, no unmanageable situation, involving continuing hazard to residents of the area, is foreseen.

Activity that does not reach the streams soon after detonation would of course remain in the area—adsorbed on land-surface materials, infiltrated to soil water or ground water, or dispersed over the land surface as insoluble particulate matter. In the aggregate, this remaining activity would include the greater part of that vented. Insoluble particles on the land surface would probably move to the streams over a period of years, ordinarily in concentrations progressively less with each passing year. For most of the area, the management problems should vanish within a few years.

SCOPE OF THE REPORT

This report develops an order-of-magnitude appraisal of concentrations of radioactive nuclides that likely would be introduced into local water supplies by Project Chariot, once planned as a nuclear-excavation test under the auspices of the Atomic Energy Commission. The site is in northwestern Alaska, near Cape Thompson. Project Chariot has been postponed indefinitely, but the appraisal is reported in full because it is unique in scope and because its results are applicable generally to preliminary evaluations of other proposals for nuclear excavation.

The investigation here reported was wholly a hypothetical-case study which was carried out in two stages, in 1961 and 1962 respectively. For the first stage, the writer visited the area from July 7 to 14, 1961, for ground and air reconnaissance with Reuben Kachadoorian of the Geological Survey. At that time a preliminary small suite of samples was collected to typify the vegetation, soils, and rocks of the area. Subsequently, to derive so-called distribution coefficients, these samples were equilibrated in the laboratory with nine solutions synthesized to simulate chemical composition of stream and pond waters of the area; to the nine solutions had been added carrier-free Sr^{85}, I^{131}, or Cs^{137}. Findings from this first-stage work were stated in a preliminary report (Piper, 1961).

In the second stage, in 1962, more comprehensive information as to distribution coefficients was derived from field tests at the site by W. A. Beetem, V. J. Janzer, and Reuben Kachadoorian of the Geological Survey. Also, the initial input assumptions were reconsidered and in certain respects were adjusted to more definitive information that had become available.

INPUT ASSUMPTIONS[1]

The 10 assumptions that are basic to this appraisal are as follows:

1. The array and emplacement of nuclear explosives would be that described in "Project Chariot, Technical Director's Operation Plan, 28 October 1960, revised 1 February 1961." In brief, this plan contemplated one 200-kiloton nuclear explosive emplaced 800 feet below the land surface, and four 20-kiloton nuclear explosives each emplaced 400 feet below the land surface. In the array, the most remote two emplacements would be 2,400 feet apart. The five explosives would be detonated simultaneously.
2. The radioactivity of all vented fission products would be 1,500 Mc (megacuries) 1 hour after detonation. Included would be 3,000 curies due to Sr^{90}, 3,000 curies due to Cs^{137}, and 100,000 curies due to I^{131}. Owing to decay, these activities would diminish with time, of course. Table 1 indicates the several rates of diminution.

TABLE 1.—*Decay of mixed fission products and certain radionuclides*

Time lapse after detonation	Activity relative to a value of 1.00 for 1 hour after detonation[1]			
	Mixed fission products	Sr^{90}	I^{131}	Cs^{137}
1 hour	1.00	1.00	1.00	1.00
1 day	2.21×10^{-2}	------	2.04	------
5 days	3.20×10^{-3}	------	1.60	------
10 days	1.39×10^{-3}	------	1.06	------
15 days	8.56×10^{-4}	9.99×10^{-1}	4.43×10^{-1}	9.99×10^{-1}
30 days	3.73×10^{-4}	9.98×10^{-1}	1.89×10^{-1}	9.98×10^{-1}
45 days	2.29×10^{-4}	9.97×10^{-1}	5.19×10^{-2}	9.97×10^{-1}
60 days	1.62×10^{-4}	9.96×10^{-1}	1.43×10^{-2}	9.96×10^{-1}
90 days	9.97×10^{-5}	9.94×10^{-1}	1.08×10^{-3}	9.94×10^{-1}
6 months	4.27×10^{-5}	9.88×10^{-1}	3.74×10^{-7}	9.88×10^{-1}
8 months	3.03×10^{-5}	9.84×10^{-1}	2.00×10^{-9}	9.85×10^{-1}
9 months	2.62×10^{-5}	9.82×10^{-1}	1.44×10^{-10}	9.83×10^{-1}
1 year	1.86×10^{-5}	9.76×10^{-1}	5.63×10^{-14}	9.77×10^{-1}
2 years	8.09×10^{-6}	9.52×10^{-1}	------	9.55×10^{-1}
3 years	4.97×10^{-6}	9.28×10^{-1}	------	9.33×10^{-1}
5 years	------	8.84×10^{-1}	------	8.91×10^{-1}
10 years	------	7.81×10^{-1}	------	7.94×10^{-1}
25 years	------	5.39×10^{-1}	------	5.61×10^{-1}
50 years	------	2.90×10^{-1}	------	3.15×10^{-1}

[1] For mixed fission products $R_t/R_1=t^{-1.2}$. For Sr^{90}, I^{131}, and Cs^{137} $R_t/R_0=(\frac{1}{2})^n$ where *n* is the number of half lives; for these three radionuclides the respective half lives are taken as 28 years, 8.05 days, and 30 years. In the presence of its precursors and daughters, the abundance of I^{131} reaches a maximum about 1 day after detonation and only after 15 days does it diminish at a rate approaching that indicated by the half life of 8.05 days.

3. The expected reach and distribution of fission-product activity would be as shown on plate 1, based on the preceding assumption and on winds experienced at Kotzebue, Alaska, on April 4, 1959. Plate 1 shows the activity in megacuries per square statute mile. From its original mathematical model, Lawrence Radiation Laboratory computed total fission-product activity within each of the isopleths on its fallout diagram of 1961 (G. H. Higgins, written commun., May 1962 and May 1963.) Converted to fit plate 1, these computed activities are as follows:

Isopleth (Mc per sq mi)	Radioactivity within the isopleth (Mc at 1 hr)	Percent of total radioactivity
50	745	49.7
10	1,005	67.0
5	1,110	74.0
1	1,332	88.0
.5	1,398	93.2
.1	1,446	96.4
.05	1,458	97.2
.01	1,485	99.0
.005	1,496	99.7
0	1,500	100.0

4. The fallout sector would lie between azimuths of 40° and 110°, clockwise from true north—that is, it would have an angular spread of 70°. Because the fallout pattern on plate 1 has an angular spread of approximately 85°, this assumption could not be fulfilled literally. In this appraisal, two fallout patterns and two sectors are considered: (1) the pattern of plate 1, oriented between azimuths of 40° and 125°, and (2) a mirror image of the

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[1] Assumptions delineated in or derived from three memorandums: (1) Mr. John F. Philip, Director, Spec. Proj. Div., San Francisco Operations Office, Atomic Energy Comm., to Dr. Gerald W. Johnson, Associate Director, Lawrence Radiation Lab., Mar. 21, 1961; (2) Dr. Johnson to Mr. Philip, Mar. 31, 1961; and (3) Mr. Philip to Mr. V. E. McKelvey, U.S. Geol. Survey, Apr. 13, 1961.

pattern of plate 1, rotated to orient between azimuths of 25° and 110°. Limits of the two sectors are shown on plate 1. Table 2 breaks down these two fallout patterns according to activity in each of the stream basins outlined on plate 1.

5. Standards for drinking water would be one-tenth of the "maximum permissible concentrations" of radionuclides, as recommended in the National Bureau of Standards Handbook 69 (U.S. Department of Commerce, 1959) for occupational exposure of 168 hours per week.
6. In the fallout from Project Chariot, fission products would in large part be attached to disaggregated but chemically unaltered fragments of the mudstone of the Ogotoruk Formation, in which the explosives would be detonated. Theoretical consideration by W. A. Beetem and J. H. Baker (written commun., July 1961) concludes that the vented fission products would attach to the mudstone fragments largely by cation exchange or by adsorption, and that nearly all the vented products would be so attached. Since the opportunities for cation exchange and adsorption would be about proportional to the surface area of the mudstone fragments, it follows that, per unit weight of fallout, the activity of attached fission products would vary about inversely to the mean diameter of fragments. In other words, the smaller fallout particles would be the more radioactive.
7. Size distribution of fallout particles could be scaled from results of the high-explosive test of November 1960, by K. H. Larson and others (K. H. Larson and F. J. Berta, written commun., May 19, 1961). Specifically, for particle sizes less than 2 millimeters (2,000 microns), the distribution found by the test would apply approximately to Project Chariot, if distances from ground zero are increased by a factor of 10^3. Table 3 shows this estimated size distribution and the corresponding estimated radioactivity.
8. Solubility of fission products in water would be 10 percent for products having mass numbers that range from 88 to 92 and from 131 to 140; solubility would be 1 percent for all other products. The 10-percent solubility factor would apply chiefly to isotopes of strontium, yttrium, iodine, cesium, barium, and lanthanum. Table 2 shows the soluble and insoluble fractions of fission-product activity in each of the stream basins outlined on plate 1.
9. The appraisal should derive probable rather than maximum-credible concentrations of fission-product activity in the streams and water-supply sources of the area and should give due consideration to the fraction of activity that would become fixed on vegetation or earth materials. The potential for fixation by dynamic ion exchange is treated on pages 25–27. Concentrations are derived for all fission products and separately for Sr^{90}, I^{131}, and Cs^{137}.
10. Detonation would occur at various seasons, so that the several consequent appraisals span the natural yearly range of hydrologic conditions. Separate appraisals are developed for: (case I) detonation 30 days prior to breakup in the spring, usually in April, fallout being on continuous snow cover; (case II) detonation in early June, at the end of snowmelt runoff; within the 30 days following detonation, 0.5 inch of precipitation but not more than 0.1 inch in any one storm; (case III) detonation in early August, following 2 months of minimum precipitation; concurrent soil-water deficiency of 1 inch; precipitation of 2.5 inches within the next 30 days; (case IV) detonation in late September, fallout being on saturated tundra 10 days before freezeup; no precipitation between detonation and freezeup.

SELECTED CHARACTERISTICS OF THE AREA

WIND MOVEMENT

Plate 1 shows downwind movement at the Chariot site in the spring and summer of 1960. The dominant movement shown is from the north and north-northeast and is characteristic throughout the year. There was wind in this sector for 62 percent of the daily observations in the 13 months ending with September 1960, and for 75 percent of the observations through December 1959 (Allen and others, 1960). In this sector, observed maximum velocities were 48.5 knots for daily averages and 73 knots for gusts. Velocities exceeding 20 knots are common in the north and north-northeast sectors, but uncommon in other sectors.

Allen pointed out that this so-called Ogotoruk wind from the north and north-northeast is peculiar to the vicinity of the Chariot site. His explanation was as follows: (1) High barometric pressure is dominant over the Arctic icepack to the north, especially in winter. (2) Most low-pressure centers pass to the south; consequently, air movement ordinarily would spiral toward these centers. (3) A pronounced temperature inversion exists in the Arctic most of the year and locally prevents air movement over major topographic barriers such as the Brooks Range. (4) Low-level air movement is deflected westward by the Brooks Range and channeled southward through the lowland of the central-Kukpuk and Ogotoruk valleys, at substantially increased velocities.

TABLE 2.—*Assumed distribution of fission-product activity from Project Chariot, after 1 hour*

	Basin or area														
	Offshore, Chukchi Sea	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek *to* Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas [1]	Total
No. on pl. 1	-----------	0	1	2	3	4	5	6	7	8	9	10	11	-----------	-----------
FALLOUT BETWEEN AZIMUTHS 40° AND 125°															
Area receiving fallout,[2] in *square miles*	184	39	6	60	639	291	371	274	345	121	470	0	225	-----------	3,025
Gross activity															
Total on basin, in curies	4.09×10^8	5.74×10^8	7.19×10^6	3.10×10^8	1.49×10^8	9.10×10^6	1.88×10^7	3.61×10^6	6.36×10^6	1.24×10^6	5.53×10^6	-----------	3.67×10^6	4.00×10^6	1.50×10^9
Percent of total	27.3	38.3	.48	20.7	9.9	.61	1.2	.24	.42	.08	.37	-----------	.24	.27	100.0
Curies per square mile:															
Average	2.22×10^6	1.47×10^7	1.20×10^6	5.17×10^6	2.33×10^5	3.13×10^4	5.07×10^4	1.32×10^4	1.84×10^4	1.02×10^4	1.18×10^4	-----------	1.63×10^4	-----------	-----------
Maximum	$>1.0\times10^8$	2.7×10^8	5.0×10^6	$>1.0\times10^8$	5.0×10^6	2.0×10^5	5.0×10^5	3.0×10^4	5.0×10^4	1.2×10^4	2.0×10^4	-----------	2.5×10^4	5.00×10^3	-----------
Minimum	$<5.0\times10^3$	$<5.0\times10^3$	5.0×10^4	1.5×10^5	$<5.0\times10^3$	$<8.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	-----------	$<5.0\times10^3$	-----------	-----------
Soluble products, in curies															
Sr^{90} and Cs^{137}, each	8.18×10^1	1.15×10^2	1.44×10^0	6.20×10^1	2.98×10^1	1.82×10^0	3.76×10^0	7.22×10^{-1}	1.27×10^0	2.48×10^{-1}	1.11×10^0	-----------	7.34×10^{-1}	8.00×10^{-1}	3.00×10^2
I^{131}	2.73×10^3	3.83×10^3	4.79×10^1	2.07×10^3	9.93×10^2	6.07×10^1	1.25×10^2	2.41×10^1	4.24×10^1	8.27×10^0	3.69×10^1	-----------	2.45×10^1	2.67×10^1	1.00×10^4
Other nuclides	2.79×10^7	3.92×10^7	4.91×10^5	2.12×10^7	1.02×10^7	6.21×10^5	1.28×10^6	2.46×10^5	4.34×10^5	8.46×10^4	3.78×10^5	-----------	2.51×10^5	2.73×10^5	1.024×10^8
Subtotal, soluble	2.79×10^7	3.92×10^7	4.91×10^5	2.12×10^7	1.02×10^7	6.21×10^5	1.28×10^6	2.46×10^5	4.34×10^5	8.46×10^4	3.78×10^5	-----------	2.51×10^5	2.73×10^5	1.024×10^8
Insoluble products, in curies															
Sr^{90} and Cs^{137}, each	7.36×10^2	1.03×10^3	1.29×10^1	5.58×10^2	2.68×10^2	1.64×10^1	3.38×10^1	6.50×10^0	1.14×10^1	2.23×10^0	9.95×10^0	-----------	6.61×10^0	7.20×10^0	2.70×10^3
I^{131}	2.45×10^4	3.44×10^4	4.31×10^2	1.86×10^4	8.94×10^3	5.46×10^2	1.13×10^3	2.17×10^2	3.82×10^2	7.44×10^1	3.32×10^2	-----------	2.20×10^2	2.40×10^2	9.00×10^4
Other nuclides	3.81×10^8	5.35×10^8	6.70×10^6	2.89×10^8	1.39×10^8	8.48×10^6	1.75×10^7	3.36×10^6	5.93×10^6	1.16×10^6	5.15×10^6	-----------	3.42×10^6	3.73×10^6	1.398×10^9
Subtotal, insoluble	3.81×10^8	5.35×10^8	6.70×10^6	2.89×10^8	1.39×10^8	8.48×10^6	1.75×10^7	3.36×10^6	5.93×10^6	1.16×10^6	5.15×10^6	-----------	3.42×10^6	3.73×10^6	1.398×10^9
FALLOUT BETWEEN AZIMUTHS 25° AND 110°															
Area receiving fallout,[2] in square miles	56	39	6	56	666	162	495	430	0	331	0	784	0	-----------	3,025
Gross Activity															
Total on basin, in curies	2.93×10^8	5.90×10^8	9.75×10^6	4.33×10^8	8.86×10^7	4.48×10^7	8.72×10^6	1.13×10^7	-----------	6.85×10^6	-----------	1.06×10^7	-----------	4.00×10^6	1.50×10^9
Percent of *total*	19.5	39.3	.65	28.9	5.9	3.0	.58	.75	-----------	.46	-----------	.71	-----------	.27	100.0
Curies per square mile:															
Average	5.23×10^6	1.51×10^7	1.62×10^6	7.73×10^6	1.33×10^5	2.77×10^5	1.76×10^4	2.63×10^4	-----------	2.07×10^4	-----------	1.35×10^4	-----------	-----------	-----------
Maximum	$>5.0\times10^8$	2.7×10^8	1.0×10^7	$>1.0\times10^8$	2.0×10^6	1.2×10^6	1.0×10^5	1.3×10^5	-----------	6.5×14^4	-----------	2.5×10^4	-----------	5.00×10^3	-----------
Minimum	$<5.0\times10^3$	8.0×10^5	3.0×10^5	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	$<5.0\times10^3$	-----------	$<5.0\times10^3$	-----------	$<5.0\times10^3$	-----------	-----------	-----------

Soluble products, in curies

Sr^{90} and Cs^{137}, each	5.86×10^{1}	1.18×10^{2}	1.95×10^{0}	8.66×10^{1}	1.77×10^{1}	8.96×10^{0}	1.74×10^{0}	2.26×10^{0}	------------	1.37×10^{0}	------------	2.12×10^{0}	------------	8.00×10^{-1}	3.00 ×10^{2}
I^{131}	1.95×10^{3}	3.93×10^{3}	6.50×10^{1}	2.89×10^{3}	5.91×10^{2}	2.99×10^{2}	5.81×10^{1}	7.53×10^{1}	------------	4.57×10^{1}	------------	7.07×10^{1}	------------	2.67×10^{1}	1.00 ×10^{4}
Other nuclides	2.00×10^{7}	4.03×10^{7}	6.66×10^{5}	2.96×10^{7}	6.05×10^{6}	3.06×10^{6}	5.95×10^{5}	7.71×10^{5}	------------	4.68×10^{5}	------------	7.24×10^{5}	------------	2.73×10^{5}	1.024×10^{8}
Subtotal, soluble	2.00×10^{7}	4.03×10^{7}	6.66×10^{5}	2.96×10^{7}	6.05×10^{6}	3.06×10^{6}	5.95×10^{5}	7.71×10^{5}	------------	4.68×10^{5}	------------	7.24×10^{5}	------------	2.73×10^{5}	1.024×10^{8}

Insoluble products, in curies

Sr^{90} and Cs^{137}, each	5.27×10^{2}	1.06×10^{3}	1.76×10^{1}	7.79×10^{2}	1.59×10^{2}	8.06×10^{1}	1.57×10^{1}	2.03×10^{1}	------------	1.23×10^{1}	------------	1.91×10^{1}	------------	7.20×10^{0}	2.70 ×10^{3}
I^{131}	1.76×10^{4}	3.54×10^{4}	5.85×10^{2}	2.60×10^{4}	5.32×10^{3}	2.69×10^{3}	5.23×10^{2}	6.78×10^{2}	------------	4.11×10^{2}	------------	6.36×10^{2}	------------	2.40×10^{2}	9.00 ×10^{4}
Other nuclides	2.73×10^{8}	5.50×10^{8}	9.09×10^{6}	4.04×10^{8}	8.26×10^{7}	4.18×10^{7}	8.13×10^{6}	1.05×10^{7}	------------	6.38×10^{6}	------------	9.88×10^{6}	------------	3.73×10^{6}	1.398×10^{9}
Subtotal, insoluble	2.73×10^{8}	5.50×10^{8}	9.09×10^{6}	4.04×10^{8}	8.26×10^{7}	4.18×10^{7}	8.13×10^{6}	1.05×10^{7}	------------	6.38×10^{6}	------------	9.88×10^{6}	------------	3.73×10^{6}	1.398×10^{9}

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[1] Activity <5×10^{3} curies (0.005 Mc) per sq mi.

[2] Activity >5×10^{3} curies per sq mi.

TABLE 3.—*Estimated characteristics of fallout, Project Chariot*

Particle size (mm)	Size distribution of particles [1] (Percent by weight, at given distance)							Radioactivity [2] (Percent of gross activity at given distance)						
	Downwind distance from ground zero (miles)													
	10	25	50	75	100	125	150	10	25	50	75	100	125	150
2.00 -1.00	32.8	22.8	11.7	1.5	1.0	0	0	8.2	3.8	1.2	0.1	0.1	0	0
1.00 - .500	22.6	24.6	21.4	12.8	6.9	3.2	1.2	11.3	8.2	4.4	1.8	.7	.3	.1
.500- .350	11.3	11.9	13.0	10.6	7.1	4.8	3.4	10.0	7.0	4.7	2.6	1.4	.8	.5
.350- .297	6.9	8.4	8.2	9.9	9.2	6.8	3.7	8.0	6.5	3.9	3.2	2.4	1.5	.7
.297- .250	5.5	6.2	6.6	8.7	7.8	6.6	4.5	7.5	5.7	3.7	3.3	2.4	1.7	.9
.250- .210	5.0	5.1	5.9	7.9	8.2	7.1	5.5	8.2	5.6	4.0	3.6	3.0	2.2	1.5
.210- .177	4.0	4.4	6.3	7.4	8.0	8.2	7.7	7.8	5.7	5.0	4.0	3.5	3.0	2.5
.177- .149	3.7	4.2	5.8	7.3	7.8	8.3	8.3	8.5	6.5	5.5	4.7	4.0	3.6	3.2
.149- .125	3.5	4.1	5.5	7.1	7.3	9.3	12.3	9.5	7.5	6.2	5.4	4.5	4.8	5.6
.125- .088	2.8	3.6	4.8	8.1	11.0	13.9	16.5	10.0	8.5	7.0	7.9	8.7	9.3	9.7
.088- .044	1.9	2.4	4.6	8.0	11.4	13.9	15.6	11.0	9.0	10.8	12.7	14.5	14.9	14.8
<.044	0	2.3	6.2	10.7	14.3	17.9	21.3	0	26.0	43.6	50.7	54.8	57.9	60.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Adapted from results of 256-lb high-explosive test in Nov. 1960, after K. H. Larson and F. J. Berta, (written commun., May 19, 1961). It is assumed that all particles larger than 2 mm would fall within less than 10 miles and that all particles smaller than 0.044 mm would fall more than 10 miles from ground zero.

[2] Activity assumed proportional to surface area of particles, derived from size distribution in percent by weight.

The local belt of Ogotoruk wind is about 25 miles wide at the coast, from Cape Thompson on the northwest to Cape Seppings on the southeast (pl. 1). South of Cape Seppings, the prevailing wind is approximately from the northwest, and commonly of less velocity.

Information is not at hand for a summary of high-level wind movement, or of low-level movement over the outlying parts of the area shown on plate 1.

AIR TEMPERATURE AND PERMAFROST

Mean maximum air temperature is below freezing from about October through May. The zone of thawing in summer is thin—extensively no more than 3 feet thick and generally less than 10 feet thick over most of the land area. Beneath this zone, permafrost generally extends to several hundred feet below the land surface. On the Chukchi Sea, shore ice and pack ice form extensively each winter.

PRECIPITATION

As interpolated by the U.S. Weather Bureau, yearly precipitation at the Chariot site averages about 8 inches and may be expected to range between 6 and 13 inches—that is, between 75 and 160 percent of average. Precipitation measured at the Chariot site in the water year 1959–60 was near the interpolated average.

About 60 percent of the yearly precipitation at the site, or roughly 5 inches on the average, falls as rain from June through September. Kachadoorian and others familiar with the area have reported (oral commun.) that the summer rainfall is ordinarily sufficient to have saturated much of the extensive tundra at the time of freezeup.

From October through May precipitation ordinarily is in the form of snow, its water equivalent being about 40 percent of the total yearly precipitation, or somewhat more than 3 inches on the average. At the Chariot site in 1959–60, the water equivalent of measured snowfall was less than this average.

Owing to the persistent strong winds, snow commonly is blown extraordinary distances and its original flakes or crystals are abraded to granules. Newly wind-packed snow commonly is sufficiently dense to bear the weight of a man or a dogsled. Kachadoorian (oral commun.) has observed snowdrifts as much as 30 feet thick in the lee of low ridges that lie athwart the prevailing wind, the drifts being packed to a density of 1-inch-water equivalent in 3½ to 4 inches of the snow. Considerable silt may be incorporated in the wind-transported snow; silt content is estimated to be as much as 10 percent, by weight.

The short climatologic record at the Chariot site, beginning in late August 1960, suggests that monthly precipitation and the frequency and magnitude of storms are about the same as at Kotzebue, 120 miles to the southeast. Tables 4 and 5 summarize the 20-year record at Kotzebue. It is assumed that the data of these two tables apply to all the area of concern in this appraisal.

TABLE 4.—*Minimum, average, and maximum monthly precipitation, in inches, at Kotzebue, Alaska, 1940–60*

[Based on records published by the U.S. Weather Bureau]

Month	Minimum	Average	Maximum
January	0.01	0.30	0.68
February	.01	.33	1.13
March	.00	.32	1.23
April	.00	.29	1.34
May	.03	.40	.80
June	.01	.53	1.37
July	.54	1.59	2.84
August	1.29	2.59	5.18
September	.35	1.46	2.85
October	.00	.68	1.53
November	.05	.40	.98
December	.01	.31	.76
Year	----------	9.20	----------

TABLE 5.—*Number of storms of various magnitudes at Kotzebue, Alaska, over a 20-year term*

[Each storm encompasses consecutive days having measurable precipitation, and each is terminated by one or more calendar days without measurable precipitation. Based on records published by the U.S. Weather Bureau, 1940–60]

Month	Magnitude of storm, in inches precipitated								
	<0.05	0.05–0.09	0.10–0.24	0.25–0.49	0.50–0.74	0.75–0.99	1.00–1.24	1.25–1.50	>1.50
January	32	18	16	3	1	----------	----------	----------	----------
February	24	16	26	1	1	----------	----------	----------	----------
March	28	20	18	1	1	1	----------	----------	----------
April	26	8	12	5	1	----------	----------	----------	----------
May	26	22	14	5	1	----------	----------	----------	----------
June	24	16	20	10	2	1	----------	----------	----------
July	12	16	16	19	12	4	2	1	4
August	26	6	20	15	11	10	5	4	6
September	18	16	20	14	10	5	2	2	2
October	28	18	14	7	5	3	----------	----------	----------
November	34	22	20	8	----------	----------	----------	----------	----------
December	40	14	16	5	1	----------	----------	----------	----------

STREAMFLOW

Specific information on the flow of streams in the area of plate 1 is available only for Ogotoruk Creek (near whose mouth the Chariot site is located). A gaging station was established on this stream in August 1958, 1.2 miles upstream from the mouth. Table 6 summarizes the available records of measured flow.

TABLE 6.—*Monthly discharge of Ogotoruk Creek, 1959–60*

Month	Acre-feet		Inches on drainage area	
	1959	1960	1959	1960
May	1,000±	1,580	0.48	0.75
June	12,660	3,260	6.03	1.55
July	7,080	946	3.38	.45
August	1,580	3,020	.75	1.43
September	787	468	.38	.22
October	1,110	----------	.53	----------
Total period	24,200	9,270	11.52	4.41

Both in Ogotoruk Creek and in other streams of the area covered by plate 1, two periods of principal flow are characteristic. The earlier, usually in June, is generated by melting snow; it may be the longer in duration but its peak flows are the smaller. The later period, ordinarily in August, is generated by rainstorms; commonly it encompasses several short intervals of peak flow and its major peak is the extreme of the year.

In winter, streamflow is generally small or zero. In Ogotoruk Creek in 1959, R. M. Waller (written commun.) of the Geological Survey observed a small flow in mid-November, beneath ice cover. He reasoned, however, that flow probably ceased and the stream froze to the bottom about mid-December. In that year, snow cover was thin so that freezing may have penetrated to greater than usual depth below the land surface, and earlier in the season. It is conceivable, therefore, that in some years a small flow continues long into, or even throughout the winter. Prolonged winter flow is more likely along the main stems of the larger streams, such as the Kukpuk River.

EVAPOTRANSPIRATION AND SOIL WATER

Figure 1 shows the approximate runoff-depletion characteristic of the Ogotoruk Creek basin—that is, the rate at which runoff would diminish were there no interim addition of water to the basin by snowmelt or by precipitation. On this and on the available records of runoff and precipitation are based the following conclusions for the Ogotoruk Creek basin: (1) At the end of snowmelt, all the tundra is ordinarily saturated. (2) During the season of principal vegetal growth, about June through August and possibly into September, loss of water due to evaporation and transpiration is about 0.8 inch per month or 3.25 inches in the season. During the remainder of the year the additional loss is

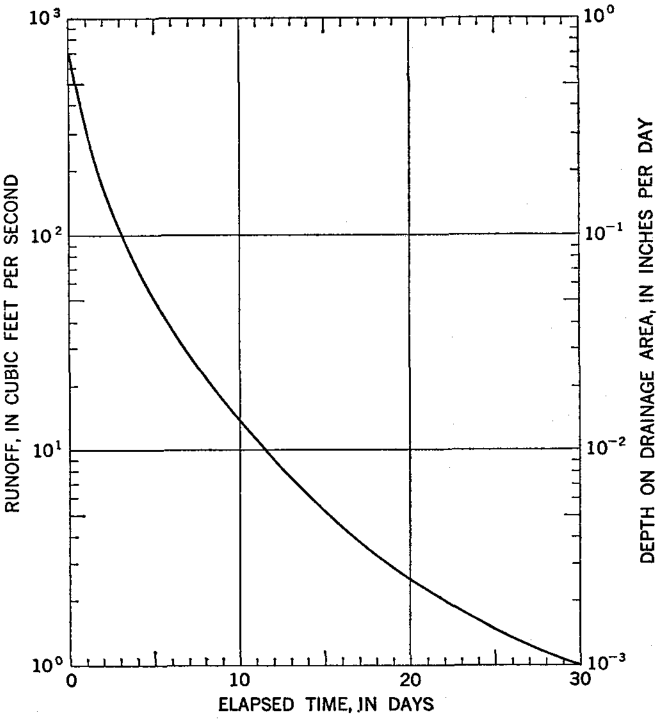

FIGURE 1.—Approximate runoff-depletion characteristic of the Ogotoruk Creek basin.

about 0.75 inch. (3) Also during the season of vegetal growth, soil water is depleted rather continually by evaporation and transpiration but is replenished intermittently by rain. Soil-water deficiency is zero at the end of snowmelt and reaches a maximum in August or September. In 1960, a dry year, the maximum soil-water deficiency was about 1.2 inches. (4) Owing to the relatively heavy precipitation in August and September (table 4) all the tundra is ordinarily resaturated prior to freezeup, by about the end of September. These characteristics of the Ogotoruk Creek basin are assumed to apply to all the area of concern in this appraisal.

At the end of snowmelt and just prior to freezeup, the saturated tundra holds an appreciable amount of water trapped in minute pools, or microponds, on the uneven land surface. In a sense this is akin to soil water in that it is depleted by evaporation and transpiration and is replenished intermittently by rainfall. From reconnaissance observation, the writer estimates that aggregate volume of such water is equivalent to a depth of about 0.3 inch over the area. Whatever its amount, this water is included in foregoing estimates of seasonal and yearly loss by evaporation and transpiration.

GROUND-WATER MOVEMENT

Over substantially all the area of concern, shallow ground-water movement can occur only intermittently, in the relatively thin zone of annual thawing, between the land surface and the zone of permafrost. As has been described by Waller, permeable deposits beneath flood plains and streambeds probably afford the principal paths of such movement. Recharge of these deposits is presumably by infiltration from the steams during intervals of high flow. Discharge from these deposits presumably maintains the base flow of streams during the summer and the small flow that may persist after freezeup, beneath ice cover.

A few perennial springs exist within the reach of plate 1; these imply fairly deep ground-water movement. Principal among them is Kavrorak Spring near Cape Seppings, 27 miles southeast of the Chariot site. Its discharge is reported to vary substantially—30 cfs (cubic feet per second), August 15, 1959; 22.7 cfs, September 9, 1959; 6.17 cfs, early April 1960; and 12.3 cfs, August 6, 1960. As estimated by the writer from air reconnaissance in July 1961, the orifice is several tens of feet above the level of the Chukchi Sea and is at the base of an extensive outcrop of limestone.

The specific area of recharge to Kavrorak Spring and the route of water movement to the orifice bear on the potential for introduction of radionuclides into the spring water by Project Chariot. For this spring in particular, however, these features are largely speculative because relevant evidence, which is summarized as follows, is conflicting. (1) At least in part on the basis of the chemical character of the water, Waller has postulated deep movement from a remote area of recharge, in bedrock and through or under the zone of permafrost. However, the chemical makeup of the water from Kavrorak Spring can be duplicated approximately by a mixture of local surface water with Chukchi Sea water. (2) The relatively large reported discharge, as much as 30 cfs, indicates an aquifer having greater than ordinary transmissibility. The requisite transmissibility could be afforded by a cavernous zone in the limestone that crops out near the orifice. However, if such a zone exists and extends to a remote area of recharge, the volume of water in ground storage would be so large that the spring discharge should be fairly uniform. Instead, based on the four values cited previously, maximum discharge is at least fivefold greater than minimum discharge. (3) This variability in discharge implies a local rather than a remote source. A local source would not be precluded by the existence of permafrost in the vicinity; however it may have been established, an aquifer having the requisite transmissibility and a small or moderate cross-sectional area would have a heat budget such that it probably would remain unfrozen.

On the basis of similarity in chemical makeup of the water, Waller and W. L. Lamar (written commun.) have implied that Nasorak Creek, 3 miles northwest of the site, is fed by springs analogous to Kavrorak Spring. As observed by the writer in mid-July 1961, the discharge of Nasorak Creek was a few tens of gallons a minute at a point about 200 yards upstream from the shore of the Chukchi Sea. This discharge evidently was the aggregate of numerous trickles issuing from limestone talus within a reach of about one-fourth mile along the creek, terminating no more than one-half mile from the shore of the Chukchi Sea. No major orifice such as that of Kavrorak Spring was evident.

Elsewhere within the reach of plate 1, only one other perennial-spring area is reported—in the Igichuk Hills that lie athwart the Noatak River valley near its mouth, about 100 miles southeast of the Chariot site (Waller, written commun., 1960). The water has a "noticeable sulfur odor."

SEDIMENT MOVEMENT

As shown in table 2, most of the fallout from Project Chariot would probably be insoluble. It would exist on the land surface as particulate matter subject to overland transport by flowing water in competition with natural earth particles.

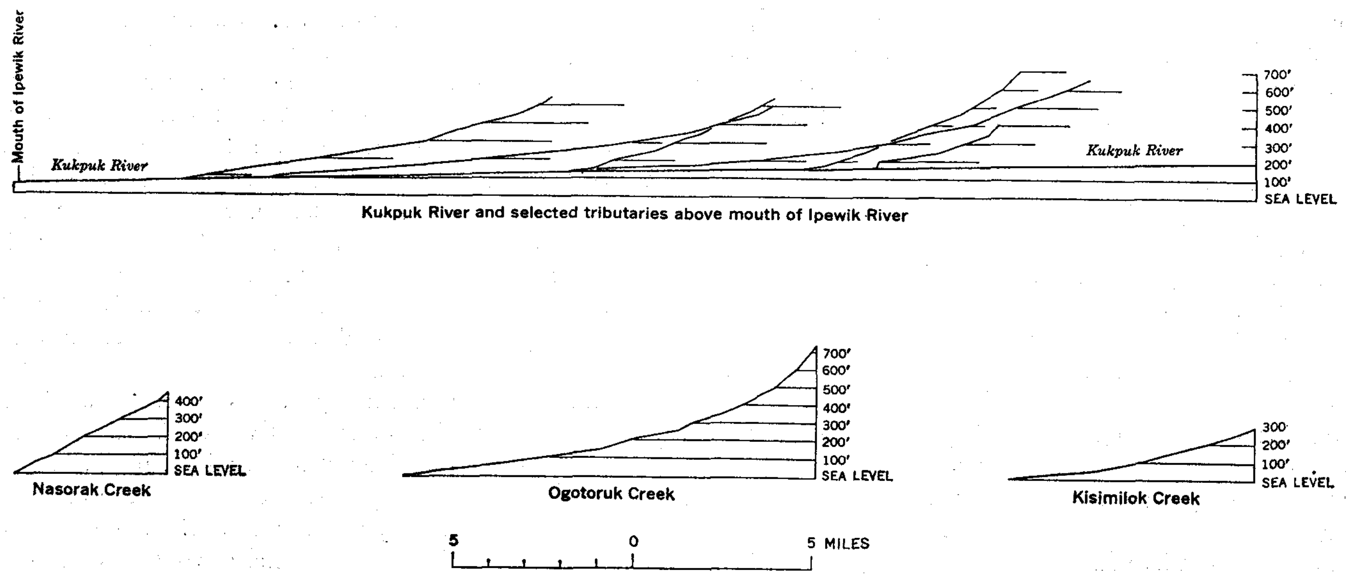

FIGURE 2.—Profiles of representative streams, Chariot-site vicinity.

Potential mobility of fallout and earth particles depends on range in particle size and on land-surface and stream gradients. Figure 2 shows representative stream gradients of the area. A rough measure of potential mobility is afforded also by the particle-size distribution of materials handled by the streams as suspended sediment and as bedload.

Table 7, samples 1 to 4 and 6 to 8, shows particle-size distribution of gravel-bar deposits along a 50-mile reach of the Ipewik River (pl. 1). Presumably these deposits are of material that was derived originally from land surfaces, and that now moves largely as bedload during the intermittent periods of high streamflow. As shown by the seven samples, median particle size differs from place to place over the streambed, and ranges about from 20 mm (pebble gravel) to 0.125 mm (fine sand). However, no progressive change in median size is evident within the 50-mile reach.

As observed by the writer, streambed materials in the lower 5-mile reach of Ogotoruk Creek are poorly sorted sand, grit, and pebble-to-cobble gravel. The common maximum particle size is about 100 mm (4 in.). Most of the larger particles are tabular and subrounded. On the riffles, little sand is evident and the finer particles commonly are granules or small pebbles, 5 to 10 mm in size. Within the 5-mile reach, no progressive change in

TABLE 7.—*Particle-size distribution of stream deposits and of sediment, Chariot-site vicinity*

[Particles larger than 0.125 mm analyzed by sieve; smaller particles analyzed by standard pipette procedure. Samples 1 through 8 collected for the writer by I. L. Tailleur, U.S. Geol. Survey, June to July 1961. The three sediment samples at site 9 collected by George Porterfield, U.S. Geol. Survey, Aug. 1958]

Sample (pl. 1)	Percent by weight of total particles finer than the indicated size in millimeters														
	32.0	16.0	8.0	4.0	2.0	1.0	0.50	0.25	0.125	0.0625	0.0312	0.0156	0.0078	0.0039	0.00195
S.1	74.8	47.0	30.8	22.6	18.0	14.2	10.4	6.9	4.0						
2			68.5	63.4	57.3	44.8	24.6	16.5	7.1	4.2					
3	91.5	62.2	43.9	30.1	21.3	14.9	10.6	6.9	3.9						
4		91.5	83.8	77.2	73.8	70.2	65.1	54.5	22.6	10.4	4.2	2.5	1.7	1.2	0.8
6		88.8	76.9	69.4	65.4	63.8	63.3	61.5	49.1	23.8	9.5	6.2	3.7	2.7	1.7
7			91.0	78.1	67.9	58.9	51.1	35.7	11.5	4.5					
8	77.9	43.3	28.8	20.9	16.6	13.9	11.1	5.3	2.2						
9.1							100	83	57	39	30	20	12	8	6
9.2						100	98	95	86	71	53	40	27	19	14
9.3							100	99	96	90	82	66	53	40	37
10					99.9	99.4	94.1	66.9	25.4	12.6	5.6	3.7	2.2	1.1	.5

S.1. East Fork of Ipewik River, gravel bar, about 51 river miles upstream from confluence with North Fork and 52 miles northeast of Chariot site.

S.2. East Fork of Ipewik River, high-water stream deposit at base of willow clump, about 47 river miles upstream from confluence with North Fork.

S.3. Tributary to East Fork of Ipewik River from the south, top of gravel bar, about 26 river miles upstream from confluence with North Fork.

S.4. East Fork of Ipewik River, gravel bar, about 20 river miles upstream from confluence with North Fork.

S.6. East Fork Ipewik River, top of gravel bar, about 4 river miles upstream from confluence with North Fork.

S.7. North Fork of Ipewik River, island in mouth, gravel bar.

S.8. Ipewik River, stream deposit, about ¾ mile downstream from mouth of North Fork and 31 miles north-northeast of Chariot site.

S.9. Ogotoruk Creek, suspended sediment at gaging station about 1 mile nearly north of Chariot site.

S.9.1. Depth-integrated sample on rising stage, concentration 448 ppm (parts per million), 4:00 p.m. Aug. 10, 1958.

S.9.2. Dipped sample on falling stage, probably exaggerates the amount of finer particles in the full cross section, concentration 1,530 ppm, 5:10 p.m. Aug. 11, 1958.

S.9.3. Dipped sample on falling stage, probably exaggerates finer particles, concentration 428 ppm, 10:00 a.m. Aug. 12, 1958.

S.10. Flood plain of Ogotoruk Creek, high-water stream deposit, about ¼ mile north of camp at Chariot site. Sampled by the writer, July 9, 1961.

median particle size is evident. In general, bed materials of Ogotoruk Creek appear to have about the same size distribution as those of the Ipewik River, even though the creek gradient is substantially the steeper.

The suspended-sediment load of Ogotoruk Creek was determined by George Porterfield of the Geological Survey in July to August 1958 and July to August 1959. (See table 7, samples 9.1 to 9.3.) Maximum determined concentration was 1,530 ppm (parts per million) on August 11, 1958, during rain-generated high flow. Seventeen hours later, on August 12, the concentration had diminished to 428 ppm. Size of median particle was 0.125 mm on August 10 and 0.031 mm on August 11. Maximum concentration determined in 1959 was 142 ppm on July 9; concurrent streamflow was 700 cfs. Generally, the sediment concentration diminished to 10 ppm within five days following a rain-generated peak flow. Presumably other streams of the area behave similarly during the summer—that is, suspended-sediment loads generally are nominal, except during periods of rain-generated runoff.

Table 7, sample 10, is inferred by the writer to represent the coarser fraction of sediment in suspension during rain-generated flash runoff of Ogotoruk Creek in late June 1961. Size distribution is compatible with this interpretation and with the size distribution of suspended sediment determined by Porterfield in 1958.

Sediment loads of the melt-water runoff in June and July have not been determined. Presumably they are at least moderately large and relatively prolonged.

Under the basic assumptions of this appraisal—as shown by table 2 and plate 1—about 20 percent of the fission-product activity that would likely be vented by Project Chariot would fall on land more than 10 miles from the center of detonation. Substantially all this activity would be expected on fallout particles smaller than 2 mm in size (table 3)—in other words, on particles that would be moved readily over the land surface by flowing water and that, once in a trunk stream, would move as suspended sediment during periods of high water. Similarly, about 25 percent of the vented activity would fall on land between 10 miles and 5 miles from the center of detonation. Expected particle sizes are such that much of this fraction of the activity would not readily move overland, and in a trunk stream would move only as bedload.

Fallout and throwout particles so large as to be virtually immobile—unresponsive both to overland transport and to bedload transport in trunk streams—would be expected only within 5 miles of the center of detonation, and largely within half that distance or less. In other words, immobile particles would be expected over only about a third of the Ogotoruk Creek basin and small adjacent areas.

LAND-SURFACE TYPES

Table 8 classifies the vicinity of the Chariot site by major land-surface types: rock outcrops, rubble (talus and colluvium), tundra vegetation, bare soil, and longshore lagoons. The classification was made on vertical aerial photographs by Kachadoorian of the Geological Survey and, for planimetry of the respective areas, was transferred to topographic maps at scales of 1:48,000 and 1:50,000, chiefly by the Army Map Service. Brief descriptions of the types follow.

ROCK OUTCROPS

Bedrock crops out in sea cliffs, high on the ridges where commonly it is moderately extensive, and in scattered streamcuts. Principal types are mudstone,

TABLE 8.—*Classification of land surface, Chariot-site vicinity*

[Rock types: Conglomerate (Cgl), limestone (Ls), mudstone (Ms), shale and siltstone (Sh), and sandstone (Ss). Quantities in percent of basin area. Determinations by Reuben Kachadoorian, U.S. Geol. Survey, Aug. 1961]

	Basin or area											
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Minor basins, Pitmegea River to Kukpowruk River	Total
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	11	-------
Rock types and percent of each if known	Ms & Ss 90, Ls 10	Ls	Ms	Ms 80, Ls 20	Ss	Sh 80, Ls 20	Ss & Ls	Cgl, Ss, Sh	Ls & Ss	Cgl, Ss, Sh	Cgl, Ss, Sh	-------
Rock outcrops	4.4	12.9	3.7	0.2	0.4	0.6	5.7	0.3	2.2	2.4	<0.1	1.6
Rubble (talus and colluvium)	39.6	51.9	33.4	21.1	9.3	16.2	7.7	9.6	23.7	28.2	2.9	16.1
Grasses, mosses, and other tundra plants	23.8	21.2	37.0	56.6	70.0	59.9	71.6	66.6	43.4	38.8	77.7	60.0
Bare soil [1]	32.2	14.1	25.0	22.1	19.2	23.3	14.0	23.9	30.6	30.5	19.4	22.0
Lagoon	0	0	.9	0	1.1	0	1.0	0	.1	0	0	.3
Conspicuously rill marked	-------	-------	-------	-------	-------	-------	20	25	10	20	30	-------
Drainage characteristic	Fair	Excellent	Good	Poor to good	Good	Fair, local ponding	Poor to good	Good	Poor to good	Good	Good	-------

[1] Largely in "frost boils" interspersed among tundra plants; generally residual from local rocks but in part windblown; commonly gritty to pebbly owing to actions of frost and wind.

siltstone, sandstone, shale, limestone, and conglomerate. Except in sea cliffs, streamcuts, and the more rugged parts of the area, outcrops commonly are shattered from frost action and mantled by a few inches of rubble.

RUBBLE (TALUS AND COLLUVIUM)

Talus is not extensive in the area, occurs only locally on steep slopes, and in the Ogotoruk Creek valley occurs commonly below outcrops of limestone. It comprises angular blocks of the parent rock as much as 5 feet in maximum dimension, but generally from 2 feet to 6 inches. Locally, talus is intermingled with the coarser colluvium and may have a matrix of grit, sand, and silt. Among most talus deposits, thickness probably does not exceed 10 feet, porosity and infiltration capacity are large, and drainage is doubtless rapid and nearly complete. Also, it is inferred that in talus the top of the permafrost zone commonly is deeper than in other deposits of the area.

Land areas here classified as colluvium are parts of slopes of intermediate steepness and are practically devoid of vegetation. The colluvium is generally a wind-winnowed assemblage of sand, grit, and rock chips in all sizes up to about 4 inches in maximum dimension. Locally it grades into talus and may include boulders as much as 2 feet across. The colluvium is generally no more than a few feet thick, has small to moderate porosity and infiltration capacity, and drains more slowly and less completely than the talus. Being thin, it may thaw to its bottom each summer.

As a land-forming material rather than a land-surface type, colluvium is much more extensive than indicated by table 7; this is discussed below.

TUNDRA VEGETATION AND BARE SOIL

Among the several basins discriminated in table 8 and on plate 1, vegetation mantles from 21 to 78 percent of the land surface. At one extreme it constitutes lush wet meadow of grass, small sedge, and moss. Such areas have low surface gradient and are poorly drained. Here the vegetation canopy is dense and, except for a few scattered ponds, covers practically 100 percent of the surface. At the other extreme, the vegetal cover is sparse, although some is everywhere except on the steepest and driest slopes. The dominant type of sparse vegetal cover is tussock grass; numerous other genera and species are interspersed. Over most of the area, height of the vegetation generally is no more than 12 inches. Coverage ranges from dense to sparse, about from 90 to 35 percent of the land, from one place to another.

In the Ogotoruk Creek basin and certain coastal valleys to the south there are scattered stands of willow along streambanks; locally this growth is diminutive. In the extreme southeast part of the area shown on plate 1, the Noatak River lowland has local stands of spruce.

The bare-soil type comprises "frost boils" and "frost scars" interspersed with the tundra vegetation. The component material is sandy to pebbly, and is in part residual from local rocks and in part windborne from distant sources. Commonly the exposed surface has been wind winnowed to a residuum of grit and small pebbles.

Together, the vegetated and bare-soil areas are coextensive with a mantle of unconsolidated materials, colluvial in origin, which on the higher and steeper slopes feathers out or grades into the nonvegetated colluvium described previously. According to Kachadoorian (oral commun.), this mantle commonly is no more than about 15 feet thick but locally, several miles east of Ogotoruk Creek, is as much as 60 feet thick. In the mantle, the zone of yearly thawing generally reaches no more than 3 feet below the land surface; much of the mantle extends into the zone of permafrost.

Hydrologic characteristics of this mantle, and in particular of its zone of yearly thawing, would influence strongly the dispersal of fission products from Project Chariot. In gross scale, most of its exposed surface slopes substantially; ordinarily it would be considered well drained. In small to minute scale, however, much of that surface is hummocky, lacks a network of integrated rill marks, and does not drain completely. For example, the Ogotoruk Creek basin is classed in table 8 as having fair drainage. Yet it has been estimated that water to an average depth of about 0.3 inch is detained intermittently on the surface of that basin. Only a minor fraction of the detained water is contained in the few perennial ponds. In other basins, however, especially in the northern and eastern parts of the area shown on plate 1, networks of integrated rill marks are locally conspicuous and moderately extensive. By inference, drainage there is virtually complete.

Water can infiltrate the mantle only as soil water is depleted by the transpiration of plants during the summer. In other seasons the mantle generally is saturated or frozen, and infiltration is virtually zero. For the Ogotoruk Creek basin, it has been concluded that the soil-water deficit—that is, the potential for infiltration—reaches a maximum of about 1.2 inches late in a dry summer. For other basins of the area, no basis exists for estimating potential infiltration; it is postulated to be the same as for the Ogotoruk Creek basin.

Finally, over much of, if not all, the area, water does not percolate through the mantle to substantial depth below the land surface. Deep percolation is precluded by the relatively shallow permafrost.

LAGOONS

Both large and small lagoons, generally shallow, are numerous along the coast southeastward from Point Hope (pl. 1). Certain of the smaller lagoons are closed by permanent barrier beaches. Those fed by the larger streams, however, are commonly closed only intermittently, whenever the surf generated by an onshore wind builds ephemeral barrier beaches across their outlets. Although these ephemeral barriers are breached during periods of calm, the lagoons generally do not drain completely. In respect to dispersal of fission products from Project Chariot, the lagoons are approximate counterparts of the inland ponds described on page 32.

USES OF WATER

The basic concern of this appraisal is with the sources of water ingested by humans, and with the anticipated effects of Project Chariot on those sources. The native Eskimo population lives in widely spaced permanent villages and subsists largely on game. Its hunting parties move through virtually all the land area of plate 1 and several miles offshore on the Chukchi Sea, by boat and on the winter ice by sled.

In order of distance from the Chariot site, the principal villages of concern are Point Hope, native population 290, 32 miles to the northwest, on a barrier beach; Kivalina, native population 135, 41 miles to the southeast, on a barrier beach; Cape Lisburne (a military base), 55 miles to the north, on the shore; Noatak, native population about 350, 80 miles to the southeast, on the Noatak River some 50 miles above the mouth of that stream; and Kotzebue, native population about 900, 120 miles to the southeast, on a barrier beach.

At Point Hope the summer source of water is a dug well on the barrier beach, about 600 yards southeast of the village and 250 yards from the shore of the Chukchi Sea. The well is concrete curbed, 6 feet square, and approximately 6 feet deep below the natural land surface. When inspected by the writer on July 10, 1961, the water level in the well was 1.3 feet below the top of the concrete curb and about 8 feet above sea level. A sample of the water taken in July 1960 contained 221 ppm of dissolved solids. In reacting values, calcium, magnesium, and bicarbonate were 51 percent of the total; sodium and chloride, 42 percent. From this meager information it is inferred that the well taps a thin body of fresh water—either in "Ghyben-Herzberg" balance with water of the Chukchi Sea to the south and the Kukpuk River lagoon to the north, or perched above permafrost. Recharge presumably is by local infiltration of rain and melt water.

The winter source of water for Point Hope is ice, cut on one of two small land-locked lagoons about 6 miles east-southeast of the village. Ordinarily none of the village supply is taken from Marryatt Inlet, into which the Kukpuk River discharges (pl. 1), nor from any of the stream-fed ponds and lagoons of the vicinity.

At Kivalina, water is taken (1) in the winter, from ice of the Wulik River or the adjacent lagoon, about 1 mile east of the village, (2) in spring, from snow on shore ice or from the Wulik River about 5 miles above its mouth, and (3) in summer, from the Wulik River between ¼ and 2 miles above its mouth, according to the amount of flow. No wells are used currently, but formerly there were two wells about 5 feet deep on the lagoon side of the spit. These were used for late-autumn water whenever the river was extremely low. Water from these wells was considered undesirable because commonly it was noticeably salty and turbid.

At Cape Lisburne, the summer source is reported to be ground water (Waller, oral commun., 1961). The winter source is not known to the writer.

At Noatak, water ordinarily is taken from the Noatak River throughout the year—in summer, immediately upstream from the village; in winter, from river ice or from a swiftly flowing reach of the river that does not freeze, on the eastern or distant side of the flood plain. At times during breakup, the river is excessively turbid and water is obtained by melting snow. According to report, the snow is nearly free from windborne silt.

At least half of the residents of Noatak live during the summer at a fishing camp on Sheshalik Spit at the northern extremity of Kotzebue Sound, 9 miles northwest of Kotzebue, 41 miles south of Noatak, and 110 miles southeast of the site. For this camp, water is taken from a few wells at the axis of the spit or transported by boat from the Noatak River about 1 mile upstream from its mouth. The well water is boiled before use.

At Kotzebue, in summer, drinking water is hauled either by tank truck from June Creek (Stubby's Creek) about 2 miles to the southeast or by barge from the Noatak River. The creek water has noticeable color derived from tundra vegetation; the river water commonly is turbid. The winter source is ice from a few miles to the east. Water for washing and flushing is drawn from numerous wells in the town; these wells are reported to be no more than 25 feet deep.

Hunting parties take water from any source momentarily available—in summer from the streams, ponds, and shallow-seated springs; in winter from snow scooped up at trailside and melted in the mouth for drinking water, by men and sled dogs alike. Winter night-camp supplies also are melted, from ice in preference to snow. Thus, water sources are anywhere along the traditional trail routes. The routes here of principal concern are along the shore, offshore on sea ice, along the Ogotoruk Creek valley, and widely in the lowland of the Kukpuk-Ipewik River valley.

Ingestion of water by game and other wild animals is a significant "use" to the extent that flesh of these animals enters the local food chain. This use encompasses not only the perennial streams, ponds, and springs, but also—especially for birds and the smaller animals—the countless rills and microponds that are generated intermittently by the melting of snow and by the heavier rainfall.

Such are the diverse and scattered water sources here of concern.

STANDARDS FOR DRINKING WATER

The National Bureau of Standards Handbook 69 (U.S. Department of Commerce, 1959) lists "maximum permissible concentrations" of radionuclides in water, both for occupational exposure of 40 hours per week and for continuous exposure of 168 hours per week. The listed values apply to workers in the radiation industry, where adequate "rad-safe" (radiation-safety) precautions are taken; for other situations, one-tenth the listed values would apply.

Several aspects of these drinking-water standards are stressed, as follows: The listed "permissible concentrations" assume that a person ingests the nuclide-bearing water continually over a period of 50 years in an average amount of 2,200 grams, or 0.58 gallon, a day. In this figure is included the water content of foodstuffs.

> The maximum permissible average body burden of radionuclides in persons outside of the controlled area and attributable to the operations within the controlled area shall not exceed one-tenth of that for radiation workers (based on continuous occupational exposure for a 168-hour week). This will generally entail control of the average concentrations in * * * water at the point of intake, or of the rate of intake to the body in foodstuffs, to levels not exceeding one-tenth of the maximum permissible concentrations allowed in * * * water and foodstuffs for continuous occupational exposure. *The body burden and concentrations of radionuclides may be averaged over periods up to one year* [italics by the writer].
>
> The maximum permissible dose and the maximum permissible concentrations of radionuclides * * * are primarily for the purpose of keeping the average dose to the whole population as low as reasonably possible, *and not because of the likelihood of specific injury to the individual* [italics by the writer].
>
> A 50-year exposure period is assumed in deriving [the "maximum permissible concentrations"], and the exposure level is assumed to be constant. Thus a transient situation (e.g., fallout shortly after a nuclear detonation or a major reactor accident where the level of activity is rapidly decreasing, and even the relative abundance of different radionuclides will be changing) presents a hazard widely different from the constant level 50-year occupational exposure which is assumed. The measure of difference is here so large that to attempt to correct it amounts to a new calculation.

With these qualifications, the following "maximum permissible concentrations" are cited only as a basis for numerical comparison with concentrations of fission-product nuclides expected to result from Project Chariot. Including the one-tenth factor, they are:

	Soluble (*μc per ml*)	*Insoluble* (*μc per ml*)
Mixed fission products [1]	1×10^{-7}	5×10^{-6}
Sr^{90}	1×10^{-7}	4×10^{-5}
I^{131}	2×10^{-6}	6×10^{-5}
Cs^{137}	2×10^{-5}	4×10^{-5}

[1] No isotopes of radium present.

Execution of Project Chariot would create a "transient situation," in which a human could tolerate greater concentrations of radionuclides in water than the "maximum permissible" values just cited. It is not within the writer's competence to suggest how great the acceptable concentrations might be. However, gamma or beta activity acceptable in an emergency has been set at 9×10^{-2} μc per ml (microcuries per milliliter) for a 10-day period of ingestion, and 3×10^{-2} μc per ml for a 30-day period (U.S. Atomic Energy Commission, 1957, p. 535). This 30-day standard is 3×10^{5} greater than the life-long standard for mixed fission products.

POTENTIALS FOR ADSORPTION (DISTRIBUTION COEFFICIENTS)

GENERAL ASPECTS

A fraction of the fission products that would likely be vented by Project Chariot would be soluble in water; specifics have been given on page 3 and in table 2. In turn, a fraction of the dissolved nuclides would become attached to earth materials or vegetation—by adsorption onto the solid phase or exchange of ions between liquid and solid phase. The fraction so attached would be determined by dynamic ionic equilibrium among (1) the particular nuclide, (2) the amount and kind of solutes in the environmental water, and (3) the particular solid-phase material. Higgins (1959a, p. 27) stated the basic equation for such equilibrium in a form analogous to:

$$K_d=\frac{K_s}{A_l}\cdot\frac{M_l}{M_s}$$

in which: K_d is a so-called distribution coefficient characterizing the particular nuclide-water-solid system;

A_s and A_l are the radioactivities of the particular solid and liquid phases, respectively, at equilibrium;

M_l and M_s are the masses of the liquid and solid phases, respectively, that react with each other.

Higgins pointed out also that in general K_d values (1) diminish logarithmically as other solutes in the water increase, but (2) in ionized solutions do not vary greatly between pH concentrations of 2 and about 9. It is presumed that K_d values are affected little by differences in temperature.

For common pairs of nuclide and earth material, in ordinary environmental water, values of K_d range generally from *1 to 100,000. In other words, the solid* phase generally sorbs from at least one-half to nearly all the radioactivity of the environment. Figure 3 shows the distribution of radioactivity between solid and liquid phases for values of K_d ranging between 0.01 and 100; the ratio M_l/M_s is assumed to be unity.

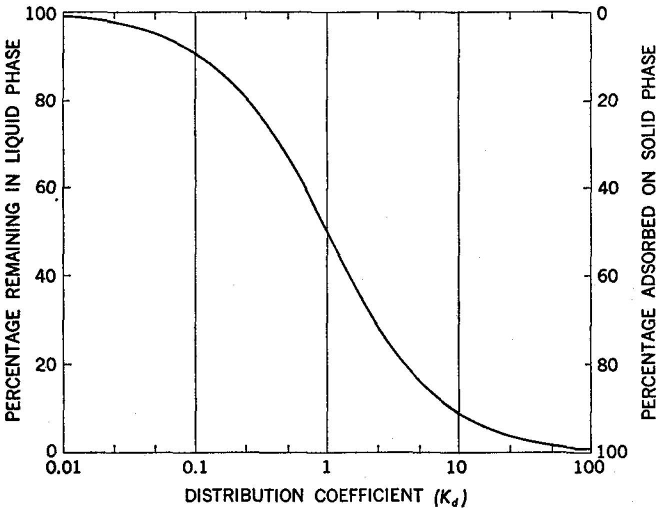

FIGURE 3.—Distribution of soluble nuclides between liquid and solid phases in an adsorption environment.

In field situations it is difficult to evaluate M_l/M_s, which is a ratio of the masses reacting with each other. Of itself, the reaction is essentially between ions in solution and exchangeable ions exposed on the surfaces of solid-phase particles. Hence, it can be presumed that all the mass of a solid-phase earth material can react only if that material is finely comminuted. Also, for an earth material of density 2.7 grams per cubic centimeter, so comminuted into spherical particles, a M_l/M_s ratio of unity would require interstitial space of 73 percent. Thus, for a nuclide-bearing ground water in a fine-textured aquifer of medium porosity, say 20 percent, the ratio would be about 0.1; radioactive nuclides adsorbed on the aquifer materials would be tenfold greater than "normal"—that is, tenfold greater than if the M_l/M_s ratio were unity. For nuclide-bearing sediment suspended in a stream and for nuclide-bearing water flowing over massive rock or coarse gravel, the ratio would be greater than unity, possibly by several orders of magnitude. Under these conditions radioactivity on the solid phase at equilibrium would be substantially less than "normal." All these extreme conditions would be represented in adsorption reactions associated with Project Chariot.

DATA FROM EARTH-MATERIAL SAMPLES, 1961

As a basis for estimating potential adsorption under Project Chariot, distribution coefficients were determined in the laboratory in 1961 for (1) a suite of 18 samples representing the vegetation, soil, and rocks near the Chariot site paired with (2) nine solutions intended to simulate the chemical composition of stream and pond waters of the area; to the nine solutions had been added carrier-free Sr^{85}, I^{131}, or Cs^{137}. Laboratory procedures have been outlined by J. H. Baker and W. A. Beetem (written commun., 1961). Table 9 identifies the surface materials sampled near the site. Tables 10 and 11 show, respectively, the composition of (1) stream and pond waters of the area and (2) the solutions simulating the natural waters. Tables 12 to 14 list the distribution coefficients determined after 1-day and 6-day equilibration with the several isotopes.

TABLE 9.—*Materials from Chariot-site vicinity, equilibrated with solutions containing* Sr^{85}, I^{131}, *or* Cs^{137}, *per tables 12 to 14*

[Samples collected by Reuben Kachadoorian and A. M. Piper, U.S. Geol. Survey, July 1961. Moisture content: In grams per 100 grams, as received in laboratory; determinations by J. H. Baker and W. A. Beetem, U.S. Geol. Survey, Aug. 1961]

Sample	Description	Moisture content	Location
AKd 1	Limestone fragments	------	Crest of Crowbill Point, 1.5 miles west-northwest of site.
2	Limestone talus	------	Do.
3	Residual soil from limestone.	22.2	Do.
4	Live moss on limestone colluvium.	------	Do.
5	Dead moss on limestone colluvium.	------	Do.
6	Mixed vegetation, live and dead, on limestone colluvium.	------	Do.
7	Live moss from tundra	------	Slope southeast of Ikaknak Pond, 6.5 miles north of site.
8	Tussock grass, crown and roots, from tundra.	------	Do.
9	Windblown silt (possibly deposited from melted snow).	49.8	Do.
10	Soil from frost boil	37.5	Do.
11	Organic bottom sludge from perennial pond.	83.2	Ikaknak Pond.
112	Mudstone fragments, fresh, Ogotoruk Formation.	------	2,200 ft nearly east of site.
113	Soil from frost boil	19.7	Vicinity of test hole D, which is *2,150 ft* east-northeast of site.
114	do	11.0	Do.
115	do	12.7	Do.
116	do	23.5	Do.
117	do	21.1	Do.
118	Windblown silt from frost boil.	43.7	Do.

TABLE 10.—*Composition of stream and pond waters, in equivalents per million, from Chariot-site vicinity*

[Analyses by U.S. Geol. Survey]

Sample (pl. 1)	Source	Date sampled	Ca+Mg	Na+K	Total cations	$\frac{Ca+Mg}{Na+K}$	HCO_3	SO_4	Cl	$\frac{HCO_3}{SO_4}$	pH
C. 1	Ipewik River, East Branch	9- 7-59	3.232	0.433	3.665	7.4	2.573	1.062	0.028	2.4	8.0
2	Ipewik River	9- 1-59	1.814	.285	2.109	6.4	1.393	.645	.056	2.2	7.7
3	Kukpuk River	9- 1-59	2.395	.263	2.658	9.1	1.721	.874	.028	2.0	7.7
4	Kukpuk River	8-29-59	2.114	.302	2.416	7.0	1.541	.770	.113	2.0	7.7
		5-30-60	.637	.155	.792	4.2	.475	.181	.141	2.6	6.9
5	Angayukak Creek	8-25-59	3.835	.132	3.967	29	3.229	.625	.113	5.3	7.8
6	Ikaknak Pond	8- 4-59	.060	.184	.244	.33	.098	.025	.113	3.9	5.7
7	Pumakak Pond	8- 4-59	.722	.586	1.308	1.2	.279	.958	.056	.29	6.4
8	Ogotoruk Creek	8-10-58	.436	.199	.635	2.2	.295	.208	.113	1.4	6.5
		8-12-58	.391	.195	.586	2.0	.295	.156	.099	1.9	6.5
		8-17-58	.436	.224	.660	1.9	.295	.229	.113	1.3	6.7
		8- 6-59	.476	.206	.682	2.4	.262	.333	.085	.79	6.6
		8-28-59	.581	.259	.840	2.2	.311	.416	.113	.75	6.9
9	Kisimilok Creek	8-15-59	.199	.267	.466	.74	.197	.154	.113	1.3	6.4
10	Kivalina River	11- 5-60	3.130	.657	3.787	4.7	2.852	.291	.705	9.8	7.9
11	Wulik River	8- 7-59	2.656	.271	2.927	9.4	2.082	.500	.310	4.2	7.8
12	Noatak River	9- 9-59	2.546	.062	2.608	41	2.147	.548	.028	4.7	7.9
Minimum			.060	.062	.244	.33	.197	.025	.028	.29	5.7
Maximum			3.835	.657	3.967	41	3.229	1.062	.705	9.8	8.0

C.1. About 51 miles east-northeast of Point Hope and 39 miles northeast of Chariot site.

C.2. One-fourth mile upstream from confluence with Kukpuk River, 17 miles north of site.

C.3. About 14 miles northeast of site.

C.4. About 16 miles east-northeast of Point Hope and 24 miles northwest of site.

C.5. About 22 miles east-southeast of Point Hope and 11 miles northwest of site.

C.6. Near divide between Ogotoruk Creek and Kukpuk River, 7 miles north of site.

C.7. About 1 mile east of No. 6, 7 miles north of site.

C.8. About 1.2 miles upstream from mouth and from site.

C.9. About ½ mile upstream from mouth, 7 miles east-southeast of site and 11 miles northwest of Cape Seppings.

C.10. About 7 miles north-northeast of Kivalina and 39 miles east-southeast of site.

C.11. About 4 miles east-northeast of Kivalina and 42 miles east-southeast of site.

C.12. At confluence with Kelly River, about 75 miles north of Kotzebue and 90 miles nearly east of site.

TABLE 11.—*Composition of solutions, in equivalents per million, equilibrated with materials from Chariot-site vicinity*

[pH of solutions, about 7.2; Sr^{85}, I^{131}, or Cs^{137} added to each solution. Determinations by J. H. Baker and W. A. Beetem, U.S. Geol. Survey, Aug. 1961]

No.	Ca	Mg	Na	Total cations	$\frac{Ca+Mg}{Na}$	HCO_3	SO_4	$\frac{HCO_3}{SO_4}$
1	0.111	0.054	0.033	0.2	5	0.033	0.166	0.2
2	.089	.044	.067	.2	2	.067	.133	.5
3	.044	.022	.133	.2	.5	.133	.067	2.0
4	.545	.278	.167	1.0	5	.167	.823	.2
5	.445	.222	.333	1.0	2	.333	.667	.5
6	.222	.111	.667	1.0	.5	.667	.333	2.0
7	2.22	1.11	.667	4.0	5	.667	3.33	.2
8	1.78	.890	1.33	4.0	2	1.33	2.67	.5
9	.890	.445	2.67	4.0	.5	2.67	1.33	2.0

DATA FROM SAMPLES OF SNOW, STREAMS, AND MICROPONDS

In June to August 1962, an effort was made to determine distribution coefficients under field conditions at the Chariot site. To that end, it was presumed that snow and rain in the vicinity of the site in mid-1962 would bring down long-lived fission products from antecedent test detonations of nuclear devices in the atmosphere, principally by Russia. Accordingly, two suites of samples were collected and handled as follows:

1. V. J. Janzer and Reuben Kachadoorian of the Geological Survey sampled snow on the ground at several places and at several depths below the snow surface. Each sample of snow, plus contained foreign matter, was collected in a polyethylene bag, melted, and taken to the Survey laboratory at Denver, Colo. Volume of each melted sample was at least 7.5 liters. In the laboratory, solid and liquid fractions were separated by centrifuging, and the radioactivity of each fraction was determined. Presumably, each solid fraction comprised particulate fission products scavenged from the atmosphere by falling snow plus particles of wind-transported silt derived from areas of bare soil at and near the site.
2. W. A. Beetem and V. J. Janzer, of the Geological Survey subsequently sampled three microponds in the tundra, also the soil or organic matter forming the bottom or margin of each pond. Each of the soil fractions was scraped from the pond bottom, to a depth of about 5 mm. Volume of each fluid sample was about 8 liters. Mass of each soil sample was about 500 grams; mass of the single sample of organic matter was about 100 grams. Radiometric determinations were made in the Denver laboratory on the liquid and solid fractions.
3. Concurrently with the samples from snow and from microponds, several 8-liter samples were taken from streams, of the flowing water plus any contained sediment. In the laboratory, liquid and solid fractions were separated by centrifuging, and radiometric determinations were run on each fraction.

TABLE 12.—*Distribution coefficients for 1- and 6-day adsorption of* Sr^{85} *on materials from Chariot-site vicinity*

[1-day values, upper figures; 6-day values, lower figures. Determinations by J. H. Baker and W. A. Beetem, U.S. Geol. Survey, Aug. 1961]

Sample	Material	Solution No. (table 11)								
		1	2	3	4	5	6	7	8	9
	Tundra vegetation									
AKd 4	Live moss on limestone colluvium	1,260 450	--- ---	3,720 1,600	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
5	Dead moss on limestone colluvium	696 560	--- ---	940 930	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
6	Mixed species, live and dead, on limestone colluvium	495 380	--- ---	631 440	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
7	Live moss	713 348	--- ---	2,620 670	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
8a	Tussock-grass crown	--- ---	53 43	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
8b	Tussock-grass root mat	--- ---	86 98	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
11	Organic bottom sludge, Ikaknak Pond	1,980 992	2,210 948	5,360 1,190	364 369	616 452	12,210 4,180	73 73	131 127	7,320 10,700
	Soil mantle									
3	Residual soil from limestone	577 585	697 620	757 914	166 245	222 385	440 730	47 60	55 65	155 3,400
9	Windblown silt (possibly from melted snow)	207 222	496 222	1,407 482	91 101	141 124	285 507	22 22	33 39	666 4,940
10	Frost boil in tundra	141 128	305 142	1,230 341	55 60	104 107	859 710	14 21	26 32	1,980 4,130
113	do	249 150	425 205	1,260 550	66 68	131 115	2,150 1,480	15 16	26 26	1,100 3,100
114	do	333 236	586 300	1,980 702	80 85	130 153	3,650 2,700	20 27	27 37	624 2,440
115	do	216 136	371 178	1,420 480	54 54	104 91	1,450 3,480	12 13	23 22	1,750 2,700
116	do	221 131	407 190	1,060 630	64 70	118 118	2,170 1,900	14 18	31 28	1,210 4,100
117	do	282 230	493 300	1,480 855	76 80	139 132	2,410 2,100	16 16	31 32	918 3,200
118	Windblown silt from frost boil	227 150	377 144	1,100 300	88 75	131 107	1,040 875	19 22	29 36	888 2,200
	Rocks									
1	Limestone fragments	.85 .80	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
2	Limestone talus	2.8 3.1	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
112	Mudstone fragments, fresh, Ogotoruk Formation	38. 75.	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---

4. Four samples of rainfall at the Chariot campsite, collected by the caretaker, were analyzed likewise. Their volumes ranged from 1 to 8 liters. No solid fraction was separable.

In the laboratory, Co^{60}, Zn^{65}, $Zr\text{-}Nb^{95}$, Cs^{137}, Ru^{106}, and Ce^{144} ordinarily were determined from the gamma spectrum, using a 400-channel pulse-height analyzer (Radiation Instrument Devel. Lab., model 34–12, transistorized). For a few samples, radionuclides were separated chemically and the separates were determined in a 2π flowing-gas counter. Determinations of Sr^{90} and of gross beta activity were made by the techniques described by J. O. Johnson and F. B. Barker (unpub. data) and by Barker and Robinson (1963), using a low-background 2π flowing-gas beta detector (Tracerlab, model CE–14).

Tables 15 and 16 identify the several samples and present the analytical data.

From the data in tables 15 and 16, table 17 derives so-called activity ratios for the environmental samples, as if all the mass of the solid phase entered into sorption or base-exchange reaction with all the liquid phase. These ratios are analogous to distribution coefficients but, in a strict sense, may differ from such coefficients by a few orders of magnitude.

Thus, for the snowmelt samples, the solid fraction presumably is a mixture of fission-product nuclides scavenged from the atmosphere by falling snow plus wind-carried earth particles derived from areas of bare soil. In such a mixture, only the water-soluble part of the fission product reacts with the earth particles; accordingly, the radioactivity of only that part should be considered in computing a model distribution coefficient. But each of the values of solid-fraction radioactivity listed in table 16 presumably is a sum of (1) activity of the insoluble part of the fission-product nuclides plus (2) activity of the soluble part that is adsorbed or otherwise attached to the earth particles. Also, the mass of fission products in the solid fraction probably is negligibly small in comparison with the mass of earth particles. Consequently, to derive model distribution coefficients from the snowmelt samples, their activity ratios in table 17 should, in principle, be multiplied by percentage solubility of the several radionuclides involved. Under input assumption 8 of this report (p. 3), this multiplier would be 0.1 for Cs^{137} and Sr^{90} and would have a mean value of 0.01 for the

TABLE 13.—*Distribution coefficients for 1- and 6-day adsorption of* I^{131} *on materials from Chariot-site vicinity*

[1-day values, upper figures; 6-day values, lower figures. Determinations by J. H. Baker and W. A. Beetem, U.S. Geol. Survey, Aug. 1961]

Sample	Material	Solution No. (table 11)								
		1	2	3	4	5	6	7	8	9
	Tundra vegetation									
AKd 4	Live moss on limestone colluvium	68 282	-------- --------	26 267	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
5	Dead moss on limestone colluvium	67 540	-------- --------	64 568	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
6	Mixed species, live and dead, on limestone colluvium	40 288	-------- --------	23 233	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
7	Live moss	26 728	-------- --------	21 905	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
8a	Tussock-grass crown	-------- --------	8.4 23	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
8b	Tussock-grass root mat	-------- --------	2.7 4.1	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
11	Organic bottom sludge, Ikaknak Pond	235 3,970	71 1,900	150 2,450	97 3,440	122 3,100	188 2,070	31 1,100	240 4,050	66 1,950
	Soil mantle									
3	Residual soil from limestone	4.5 51	12 216	7.2 216	14 232	7.0 60	12 75	2.8 12	6.5 52	4.7 11
9	Windblown silt (possibly from melted snow)	95 1,090	22 345	12 976	30 448	45 1,090	53 862	20 58	42 881	56 630
10	Frost boil in tundra	16 159	11 92	16 277	11 1,040	12 139	24 274	8.5 60	14 133	11 53
113	do	6.4 50	10 80	3.4 73	16 100	7.8 34	7.1 58	5.6 12	3.6 20	5.5 86
114	do	1.9 14	3.3 26	.9 16	5.6 28	3.4 24	1.2 7.2	2.6 12	1.5 12	1.6 14
115	do	1.9 14	10 32	.9 19	5.8 23	3.5 16	2.8 19	2.4 6.4	1.6 9.0	2.0 26
116	do	7.6 40	12 126	4.1 56	13 90	6.8 38	11 54	6.0 12	4.6 30	7.2 93
117	do	3.6 29	9.4 113	4.1 38	12 94	4.4 40	5.4 40	4.4 10	2.2 13	3.2 19
118	Windblown silt from frost boil	22 273	8.1 218	10 175	21 260	14 20	47 115	18 198	8.1 175	9.4 89
	Rocks									
1	Limestone fragments	.29 .60	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
2	Limestone talus	.12 1.2	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
112	Mudstone fragments, fresh, Ogotoruk Formation	.04 .017	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------

TABLE 14.—*Distribution coefficients for 1- and 6-day adsorption of* Cs^{137} *on materials from Chariot-site vicinity*

[1-day values, upper figures; 6-day values, lower figures. Determinations by J. H. Baker and W. A. Beetem, U.S. Geol. Survey, Aug. 1961]

Sample	Material	Solution No. (table 11)								
		1	2	3	4	5	6	7	8	9
	Tundra vegetation									
AKd 4	Live moss on limestone colluvium	594 1,820	-------- --------	4,040 5,540	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
5	Dead moss on limestone colluvium	1,520 4,160	-------- --------	1,650 2,640	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
6	Mixed species, live and dead, on limestone colluvium	1,780 2,200	-------- --------	1,240 3,380	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
7	Live moss	99 1,370	-------- --------	168 4,150	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
8a	Tussock-grass crown	-------- --------	8.3 13	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
8b	Tussock-grass root mat	-------- --------	164 138	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------	-------- --------
11	Organic bottom sludge, Ikaknak Pond	3,980 4,320	3,570 4,300	6,440 5,790	1,630 3,170	3,620 5,480	5,300 14,730	2,400 4,140	2,750 4,940	2,250 2,590
	Soil mantle									
3	Residual soil from limestone	6,590 12,800	13,000 10,560	14,950 27,460	1,320 5,060	4,320 14,130	5,280 40,160	2,760 11,900	3,350 21,900	1,880 8,200
9	Windblown silt (possibly from melted snow)	2,000 3,970	2,620 5,420	31,740 16,550	3,320 5,070	2,620 7,380	10,460 53,130	1,620 8,320	3,750 8,370	4,500 17,300
116	Frost boil in tundra	1,640 2,120	2,340 3,980	4,170 8,620	1,730 5,660	2,560 9,000	2,630 49,130	2,150 6,990	2,320 9,070	3,000 11,180
	Rocks									
1	Limestone fragments	[1] 3.0	--------	--------	--------	--------	--------	--------	--------	--------
2	Limestone talus	[1] 6.7	--------	--------	--------	--------	--------	--------	--------	--------
112	Mudstone fragments, fresh, Ogotoruk Formation	[1] 26.4	--------	--------	--------	--------	--------	--------	--------	--------

[1] 1-day value. Solution with which the rock sample was equilibrated had a pH of 3.

TABLE 15.—*Environmental samples from Chariot-site vicinity, 1962*

[Samples in the AKd series, by V. J. Janzer and Reuben Kachadoorian; those in the ABJ series, by W. A. Beetem and V. J. Janzer]

Sample	Date	Location	Description
		Snowdrifts	
AKd 4.1	June 11	Between weather stations 4 and 5.	Depth 6 in. Snow granular.
4.2	do	do	Depth 12 to 18 in. Icy layer.
4.3	do	do	Depth 36 in. Slush.
5	do	At weather station 3	Depth about 12 in.
6	do	At weather station 1	Do.
7	June 12	On west bank Kisimilok Creek, about ⅜ mile from mouth and 7 miles south of base camp.	Do.
8	June 13	On west flank of Crowbill Point, about ¾ mile inland.	Depth about 6 in. Drift overlies limestone talus.
9	do	Flank of Crowbill Point, about 50 yd southeast of AKd 8.	Depth about 33 to 36 in.
10	do	Foot of Crowbill Point, about 150 yd from the shore.	Depth 6 in. Drift overlies sandstone and mudstone of Ogotoruk Formation.
11	do	do	Depth 36 to 42 in.
		Microponds	
ABJ 131	Aug. 26	50 ft south of test hole D, north of the long airstrip.	Water.
131.a	do	do	Soil from bottom.
132	do	About 100 ft north of west end of the long airstrip.	Water.
132.a	do	do	Soil from bottom.
133	do	About 220 yd west of base camp.	Water.
133.a	do	do	Organic material, principally moss, from bottom and margin.
		Streams	
AKd 6.a	June 12	Kisimilok Creek, about ⅜ mile from mouth and 7 miles south of base camp.	
12	June 13	Ogotoruk Creek at base camp.	
ABJ 130	Aug. 26	Ogotoruk Creek at gaging station, about 1 mile upstream from base camp.	
134	Aug. 29	Tributary "three" of Snowbank Creek, about 1.7 miles north-northeast from base camp.	
135	do	Tributary "two" of Snowbank Creek, about 1.7 miles north-northeast from base camp.	
		Rainfall	
136	July 8	At Chariot base camp	
137	July 22	do	
138	Aug. 1	do	
139	Aug. 12	do	

remaining nuclides covered by table 17; for mixed fission products it would be about 0.06 according to calculation by the writer.

A contrary relation applies to the samples of water and soil from microponds. Again, here the solid fraction presumably includes the insoluble part of the fission-product nuclides plus some fraction of the soluble part adsorbed onto earth particles. But probably a major part of the solid-fraction sample had not naturally been in contact with the micropond water. Therefore, in deriving model distribution coefficients the activity ratios of table 17 should in theory be increased by an unknown factor to compensate for nonreactive soil in the solid-fraction sample. This factor might well be one order of magnitude, or more.

Even beyond these uncertainties as to what part of the solid fraction was reactive, the total mass of this fraction being so very small made rigorous measurements of radioactivity impossible for most samples. Accordingly, the writer feels that meaningful distribution coefficients cannot be derived from the activity ratios of table 17.

DATA FROM OVERLAND-TRANSPORT MEASUREMENTS

FIELD EXPERIMENTS

To elucidate and, hopefully, to confirm earlier determinations and estimates of distribution coefficients applicable to the Chariot site, W. A. Beetem and V. J. Janzer (written commun., Sept. 1963 and Feb. 1964) measured the overland transport of certain radioactive tracers at the site on August 20 to 25, 1962. These measurements were on 10 plots which represented a variety of microdrainage patterns; all 10 plots were adjacent to the headwater forks of Snowbank Creek, about 1.6 miles north-northwest from the Chariot site. Plate 2 shows essential features of the overland-transport plots. Experimental technique involved the following steps:

1. Each of the plots was enclosed with 1- by 6-inch boards that were wrapped in polyethylene sheet, set edgewise, and buried sufficiently deep to cut off both surface flow and shallow seepage through the soil.
2. A single tracer was distributed uniformly on each plot, generally over all the plot but over only one-third of plots 106 and 113 (pl. 2). Two of the tracers, Cs^{137} and Sr^{85}, had been acquired in soluble form, in HCl. In the Denver laboratory of the Geological Survey, these had been buffered and diluted with Na_2CO_3 to a pH of about 5.6 and a concentration of about 0.05 normal, and exchanged onto a local sandy soil that contained very little organic matter. The soil then had been oven dried for transport to the Chariot site. At the site these two tracers were further diluted (manyfold) with a tundra soil that had been dried and screened and that had fairly large exchange capacity and content of organic matter. The twice-diluted Cs^{137} tracer was applied to plots in concentrations about from 3×10^{-3} to 6×10^{-3} Mc per mi^2 (megacuries per square mile); roughly, these concentrations are from sixfold to elevenfold greater than the maximum concentration of Cs^{137} that would be expected in fallout from Project Chariot. Concentrations of the Sr^{85} tracer were about 4×10^{-3} and 9×10^{-3} Mc per mi^2, or roughly sevenfold and seventeenfold greater than

TABLE 16.—*Radioactivity of certain nuclides in environmental samples from Chariot-site vicinity, 1962*

[Upper values, solid fraction, in microcuries per gram. Lower values, liquid fraction, in microcuries per milliliter. Less than (<) values indicate minimum activity detectable in the particular instance; plus or minus (±) values indicate relative reliability of counting statistics. Determinations by C. G. Angelo, M. C. Goldberg, and V. J. Janzer]

Sample	Co^{60}	Zn^{65}	$Zr\text{-}Nb^{95}$	Cs^{137}	Ru^{106}	Ce^{144}	Sr^{90}	Gross beta activity (as Sr^{90})
Snowmelt								
AKd4.1	51±34	<60	1,930±50	752±34	456±101	---	---	06,670±1,00
	<0.004	<0.007	0.007±0.005	0.005±0.003	<11	0.075±0.012	[1] 0.0029±0.0005	0.080±0.012
4.2	267±133	700±233	8,100±130	1,730±130	3,300±400	11,400±400	100±15	21,300±3,195
	0.020±0.004	0.059±0.008	0.022±0.006	0.022±0.003	0.104±0.013	0.031±0.013	[1] 0.0029±0.0005	0.076±0.011
4.3	<272	<476	8,500±210	1,360±210	4,560±750	6,260±750	1,290±194	9,590±1,439
	0.006±0.004	0.018±0.008	<0.003	0.009±0.003	0.028±0.013	<0.013	[1] 0.0029±0.005	0.076±0.011
5	173±26	173±51	4,780±40	743±26	1,250±90	7,600±110	164±25	8,970±1,346
	<0.004	0.020±0.008	<0.003	0.010±0.003	0.027±0.012	0.042±0.012	<0.0004	0.074±0.011
6	248±52	313±91	4,410±70	900±52	1,410±170	8,690±180	---	15,700±2,355
	0.008±0.006	<0.008	<0.004	0.015±0.004	<0.016	<0.014	0.0013±0.0004	0.074±0.011
7	355±35	<62	6,530±40	470±35	2,010±124	9,830±124	103±15	20,400±3,060
	<0.005	<0.009	<0.004	---	0.022±0.014	0.085±0.017	<0.0004	---
8 [3]	274±36	493±82	9,960±90	905±37	2,010±140	13,720±180	74±11	27,300±4,100
9	103±69	377±137	4,300±120	549±51	1,530±220	8,060±240	---	13,900±2,100
	<0.004	0.008±0.007	<0.003	0.039±0.003	<0.011	<0.011	0.0015±0.0004	0.093±0.014
10 [3]	80±25	252±49	5,930±61	730±25	1,780±90	10,730±110	18±3	4,490±670
	<0.004	0.019±0.008	<0.003	0.007±0.003	0.049±0.012	<0.012	0.0014±0.0004	0.042±0.006
11 [3]	67±30	141±59	4,130±60	379±30	891±104	6,120±120	36±5	3,560±530
	<0.004	0.019±0.008	<0.003	0.007±0.003	0.049±0.012	<0.012	0.0014±0.0004	0.042±0.006
Microponds								
ABJ 131	<4	<7	<5	<3	<12	<13	---	88±13
	0.017±0.004	<0.008	<0.005	0.004±0.003	<0.012	<0.012	<0.0004	0.028±0.0042
132	<4	<7	<5	<3	<12	<13	---	101±15
	0.017±0.004	0.036±0.008	<0.005	0.010±0.003	0.116±0.012	<0.012	0.0009±0.0004	0.219±0.033
133	<4	<7	23±8	12±4	22±15	48±14	---	82±12
	0.012±0.004	0.038±0.008	<0.005	0.011±0.003	0.034±0.012	<0.012	0.0010±0.0004	0.150±0.022
Streams								
AKd 6a [4]	205±146	---	2,940±124	2,200±57	404±58	958±6	90±14	487±73
	<0.006	<0.011	<0.004	---	0.066±0.015	0.032±0.015	0.0007±0.0004	0.503±0.076
12	44±35	186±71	486±44	150±27	362±106	460±106	11±2	442±66
	<0.004	0.022±0.008	<0.006	<0.003	0.065±0.013	0.083±0.013	0.0019±0.0004	0.056±0.008
130 [5]	0.007±0.004	0.009±0.008	0.007±0.004	<0.003	0.112±0.012	<0.012	<0.0004	0.073±0.011
134 [5]	0.040±0.004	0.021±0.009	<0.005	<0.003	0.110±0.013	<0.013	<0.0004	0.560±0.084
135 [5]	<0.004	<0.008	<0.003	<0.005	<0.012	<0.012	0.0004±0.0004	0.030±0.005
Rainfall								
(6)	0.009±0.004	0.021±0.008	0.031±0.006	0.027±0.003	0.127±0.013	0.028±0.013	0.0060±0.002	0.170±0.028

[1] Composite of equal parts of AKd 4.1, 4.2, and 4.3.
[2] Solid fraction.
[3] Liquid fraction is composite of equal parts of AKd 10 and 11.
[4] Chemical separations involved in determinations of Co^{60}, $Zr\text{-}Nb^{95}$, Cs^{137}, Ru^{106}, and Ce^{144}.
[5] Liquid fraction.
[6] Liquid fraction; composite of equal parts of ABJ 136, 137, 138, and 139.

expected maximum concentration of Sr^{90} in Project Chariot fallout.

A third tracer, I^{131}, was handled in much the same way except that the dilution with sandy soil at Denver was by wetting and drying rather than by exchange. The second-stage dilution at the Chariot site was with the same tundra soil as that which diluted the Cs and Sr tracers. The twice-diluted I^{131} tracer was applied to plots 109 and 110 in concentrations of about 7×10^{-3} and 1.4×10^{-2} Mc per mi^2—that is, respectively, about 0.4 and 0.8 times the maximum 1-hour concentration of I^{131} expected in fallout from Project Chariot, or 7.5- and 15-fold greater than the maximum 45-day concentration.

Presumably these three tracers—Cs^{137}, Sr^{85}, and I^{131}—were completely soluble and, under the experimental conditions, entered fully into sorption and base-exchange reactions with soils of the several plots.

The fourth and final tracer was fallout that had been collected about 1 mile from ground zero of the Sedan detonation at the Nevada Test Site. This tracer was from 45 to 50 days old at the time of the experiments here described. It comprised diverse fission and activation products, largely attached to particles of Nevada Test Site alluvium. It was not diluted at the Chariot site. Of this fallout tracer, about 7×10^1 μc was applied to each of three plots (Nos. 113, 114, and 115)—in other words, at concentrations from about 3×10^{-5} to 2.5×10^{-4} Mc per mi^2. These are less than the minimum 1-hour concentration of the fallout pattern projected for Project Chariot (pl. 1), but are roughly equal to the

TABLE 17.—*Activity ratios for certain radionuclides in environmental samples from Chariot-site vicinity, 1962*

Sample	Co^{60}	Zn^{65}	$Zr\text{-}Nb^{95}$	Cs^{137}	Ru^{106}	Ce^{144}	Sr^{90}	Gross beta activity (as Sr^{90})
Snowmelt								
AKd 4.1	>4,200	----------	>150,000	>90,000	>32,000	----------	----------	83,400
4.2	13,400	11,900	368,000	78,600	31,700	368,000	240,000	280,000
4.3	----------	<26,000	>2,700,000	151,000	163,000	>420,000	240,000	126,000
5	>37,000	8,650	>1,600,000	74,300	46,300	181,000	>350,000	121,000
6	>14,000	>28,000	>1,100,000	60,000	>80,000	>610,000	----------	212,000
7	>64,000	----------	>1,600,000	----------	>86,000	116,000	>220,000	----------
9	>8,000	>16,000	>1,400,000	14,000	>120,000	>710,000	----------	149,000
10 11	>11,000	10,300	>1,600,000	79,200	27,300	>700,000	19,300	95,800
Mean	>22,000	>17,000	>1,300,000	78,200	>73,000	>440,000	>210,000	152,000
Microponds								
ABJ 131	<300	----------	----------	<3,000	----------	----------	----------	3,130
132	<300	<250	----------	<430	<120	----------	----------	460
133	<500	<250	>3,000	1,090	<1,100	>4,000	----------	550
Mean	<370	<250	>3,000	<1,500	<600	>4,000	----------	1,380
Streams								
AKd 6a	>9,800	----------	>700,000	----------	6,120	29,900	>69,000	968
12	>2,200	8,450	>74,000	>41,000	5,570	5,540	5,790	7,900
Mean	>6,000	8,450	>387,000	>41,000	5,840	17,700	>37,400	4,430

projected 45-day concentrations between 8 and 35 miles from ground zero.

Presumably only the soluble fraction of this fallout tracer entered into sorption and base-exchange reactions with soil of the experimental plots. From table 2, mean solubility of radioactive nuclides in the fallout would be about 6.8 percent.

3. Water drawn from Snowbank Creek by a portable gasoline-powered pump was applied to the plots through hose and spray nozzle, to simulate rain. Among the 10 plots, 4 received one such application, 4 received two applications each, and 2 received seven applications in succession. Each application was sufficient to transiently saturate the surface soil of the plot and to generate ephemeral runoff. The amount of simulated rain was measured in several gages (50-ml beakers) placed as shown on plate 2; the range was between 0.64 and 4.95 centimeters per application (0.25 and 2.0 in.) and, in total, between 3.53 and 14.69 cm per test (1.4 and 5.8 in.). Intensity of the simulated rainfall doubtless was substantially greater than would be expected to occur naturally. The amount per test exceeded natural monthly rainfall measured at Kotzebue, Alaska, in most months of the period 1940–60 (see table 4). The simulated rain contained but little suspended or dissolved solids; its chemical reactivity probably did not differ greatly from that of natural water that would be involved in the dispersal of fallout nuclides from Project Chariot.
4. Runoff having been generated, samples of it were taken in 100-ml polyethylene bottles for transport to the laboratory at Denver to determine its radioactivity. Also, samples of soil on the several plots were taken to a depth of 1 cm, for determinations of bulk density and radioactivity. On the plots to which simulated rain was applied more than once, runoff was intermittent and was regenerated by each application; each generation of runoff was sampled separately. In the runoff, radioactivity due to Sr^{85} or I^{131} was determined by appropriate counting on 2-ml aliquots; that due to Cs^{137} or to mixed products from Sedan fallout was first counted on 2-ml aliquots and later recounted on all the residual sample.

Table 18 summarizes the experimental data and results which, with supplementary laboratory tests to be described, better demonstrate some phenomena by which radionuclides become dispersed between water and soil in a natural environment.

The distribution coefficients of table 18 are derivable from the overland-transport experiments after assigning a thickness, and a consequent mass, to the layer of soil entering into sorption and base-exchange reactions with the tracers. To this end it is assumed that, at the time of experiment, soil-water deficiency was uniformly 25 percent by volume; in other words, the simulated rain infiltrated the soil to four times the equivalent depth of

TABLE 18.—*Summary of tracer tests on overland-transport plots at the Chariot site, 1962*

[Data by W. A. Beetem and V. J. Janzer]

Plot No. (ser. 62B ABJ)	Plot area (cm²)	Weight of soil per centimeter of depth (g)	Diluted tracer applied			Water applied		Radioactivity in runoff water		Distribution coefficient, *Kd* [1]
			Weight (g)	Specific activity (μc/g)	Total activity (μc)	Depth (cm)	Accumulated volume (ml)	Concentration (μc/ml)	Total (μc)	
				Cs^{137}						
105	11,700	31,000	1,800	8.21×10^{-1}	1.48×10^{3}	5.44	63,600	8.90×10^{-7}	5.66×10^{-2}	2,460
106	10,900	29,000	1,800	4.74×10^{-1}	8.53×10^{2}	3.33	36,300	9.80×10^{-7}	3.56×10^{-2}	2,250
						1.70	54,800	1.48×10^{-6}	8.11×10^{-2}	987
						5.03				
107	6,250	16,500	1,800	5.22×10^{-1}	9.40×10^{2}	3.38	21,100	2.70×10^{-7}	5.70×10^{-3}	15,600
						2.90	39,200	7.50×10^{-7}	2.94×10^{-2}	3,020
						6.28				
				I^{131}						
109	3,720	10,000	900	1.12×10^{0}	1.01×10^{3}	3.71	13,800	1.32×10^{-4}	1.82×10^{0}	51
110	3,720	10,000	1,800	1.12×10^{0}	2.02×10^{3}	3.53	13,100	1.92×10^{-4}	2.52×10^{0}	74
				Sr^{85}						
111	4,520	12,000	1,800	8.71×10^{-1}	1.57×10^{3}	4.95	22,400	6.44×10^{-4}	1.44×10^{1}	10
112	6,600	17,500	1,500	6.22×10^{-1}	9.33×10^{2}	2.49	16,400			
						2.46	32,600	6.74×10^{-4}	2.20×10^{1}	4.0
						4.95				
				Sedan fallout						
113	31,200	83,000	1,350	5.29×10^{-2}	7.14×10^{1}	2.59	80,800	2.82×10^{-5}	2.28×10^{0}	41
						2.26	151,300	3.12×10^{-6}	4.72×10^{-1}	205
						2.08	216,200	1.20×10^{-7}	2.59×10^{-2}	3,810
						2.21	285,100	7.0×10^{-8}	1.97×10^{-2}	4,980
						1.88	343,800	7.2×10^{-8}	2.48×10^{-2}	3,960
						1.73	397,800	$<2\times10^{-8}$	$<8.0\times10^{-3}$	>12,000
						1.63	448,700	$<2\times10^{-8}$	$<9.0\times10^{-3}$	>11,000
						14.38				
114	22,100	58,500	1,350	5.29×10^{-2}	7.14×10^{1}	2.16	47,700	2.60×10^{-6}	1.24×10^{-1}	790
						2.24	97,200			
						2.67	156,200	3.67×10^{-6}	5.73×10^{-1}	176
						1.73	194,400	3.74×10^{-6}	7.27×10^{-1}	135
						1.32	223,600	2.74×10^{-6}	6.13×10^{-1}	160
						1.93	266,300	1.45×10^{-6}	3.86×10^{-1}	249
						2.64	324,600	6.20×10^{-7}	2.01×10^{-1}	483
						14.69				
115	2,790	7,500	1,350	5.29×10^{-2}	7.14×10^{1}	3.33	9,290	2.46×10^{-5}	2.28×10^{-1}	425
						.64	11,080	5.12×10^{-5}	5.67×10^{-1}	176
						3.97				

[1] Assuming equilibrium among all the tracer, all the accumulation of water applied, and all the soil to a depth four times that of water applied. See discussion in text.

that rain. A deficiency of this magnitude is compatible with the runoff-depletion characteristics of the Ogotoruk Creek basin, at least in respect to the topmost part of the soil. Under this assumption, depth of infiltration would have ranged about from 9 cm (3.4 in.), by the smallest of the initial applications of rain, to 59 cm (23 in.), by the seven-stage application to plot 114.

It is assumed further, following each application of simulated rain: (1) fully reversible reactions of sorption and base exchange approached equilibrium among (a) all the soluble nuclides of the tracer, (b) all the accumulation of water applied, and (c) all the soil to the assumed depth of infiltration; also, (2) the runoff water represented the liquid phase of this equilibrium.

The distribution coefficients so derived (table 18) are subject to error from several causes, probably substantial error under certain circumstances. Included are the following causes of error:

1. The reacting mass of water should, in principle, include not only the applied simulated rain but also the preexisting soil water within the zone of infiltration. In the experiments here reviewed, antecedent soil water was not considered; accordingly, both the presumed reacting mass of water

and the resulting distribution coefficient would tend to be too small. Error from this cause is presumed to be of minor consequence.

2. The applications of simulated rain probably were at intensities, and at least for plots 113 and 114 were in total amounts, that transiently exceeded infiltration capacity of the soil. Thus, the term of experiment probably was too short for the applied water to have become dispersed fully in the soil, especially if the soil beneath any of the plots was distinctly stratified. To the extent that actual depth of infiltration may have been less than assumed, reacting mass of soil would tend to be too large and distribution coefficient too small.
3. Water that infiltrates into soil does not circulate freely throughout the zone infiltrated; thus, even at equilibrium, sorption and base-exchange reactions do not distribute their products uniformly in either the liquid phase or the solid phase. Rather, the infiltrating water moves largely by *displacement downward and horizontally.* Reacting constituents of the water tend to be sorbed or exchanged onto the solid-phase particles first contacted, until the sorption and exchange capacities there are saturated. There, local equilibrium is achieved at relatively high specific concentrations of the reacting constituents. As the infiltration front displaces into solid-phase material whose sorption and exchange capacities *are not saturated,* equilibrium is achieved in the new locale at lower specific concentrations. Thus, the reacting constituents tend to attenuate, and in effect the infiltrating water outreaches the sorption and exchange reactions. In the zone of saturation, reacting constituents in moving ground water attenuate in the same general way (Higgins, 1959b).

In the experiments here reviewed, the runoff which was sampled to determine transported radionuclides doubtless was a mixture, in indeterminate proportions, of (1) water applied at a rate exceeding infiltration capacity of the land surface, which therefore was rejected at the land surface with only a minimal opportunity to dissolve tracer material, and (2) water returned to the land surface after infiltrating the soil some unknown distance and having its reacting constituents attenuated in some unknown degree. Thus, this runoff doubtless was more dilute than the mean concentration of interstitial water at equilibrium with the soil and tracer. To the extent that this is so, the distribution coefficients of table 18 are too large. In general, error from this cause probably is substantially greater than that due to uncertain reacting masses of water and soil. It may be expected to increase as duration and intensity of rainfall increase; for example, it well may be considerable in the coefficients derived from the later applications of water to plots 113 and 114.

LABORATORY TESTS

In the Denver laboratory, two series of supplementary tests were made to amplify data from the overland-transport plots. The first series involved portions of (1) the twice-diluted Cs^{137} tracer that had been prepared for application to plot 107, (2) the Cs^{137} tracer plus soil from plot 106 after that transport experiment had been completed, (3) the Sr^{85} tracer as prepared for plots 111 and 112, (4) the postexperiment Sr^{85} tracer plus soil from plot 111, and (5) the I^{131} tracer as prepared for plots 109 and 110. About a 1-gram portion from each of these materials was equilibrated (in triplicate) with water from Snowbank Creek; after centrifuging, the liquid phase was decanted and its radioactivity was counted on a 2-ml aliquot; the equilibration, separation, and counting were repeated four more times with successive new volumes of water. In these equilibrations the M_l/M_s ratio was between 50 and 226. Indicated distribution coefficients differ substantially for each of the tracers; they are shown in figure 4. Values from the two tests with Cs^{137} tracer have a rather wide scatter and, for a reason not known, are ill-matched with values from a later test with Cs^{137} tracer in the second series.

The second series of supplementary tests involved (1) twice-diluted Cs^{137} tracer and (2) Sedan fallout. Each of these was equilibrated with Snowbank Creek water in ten successive steps, the procedure being modified from that of the first series in that (1) approximately 1 gram of the tracer and 10 ml of the water were enclosed in a cellulose sausage casing and (2) immersed in another 90 ml of the water in a polyethylene bottle; (3) each equilibration was continued two days, after which a 60-ml portion of the water was decanted from the bottle for counting its radioactivity; then (4) a fresh 60-ml portion of the water was added for the next equilibration. The indicated distribution coefficients are shown in figure 4, those for Sedan fallout based on only 6.8 percent of that material being soluble and free to react with the water. (This is the solubility estimated, from table 2, for fallout from Project Chariot.)

In these two series of multiple-equilibration tests, especially the second series, the indicated distribution coefficients increase progressively through the successive equilibrations. Evidently this increase is real, at least for the tracers tested—Sr^{85}, I^{131}, Cs^{137}, and Sedan fallout. Stated in other words, specific activity of the liquid phase evidently diminishes progressively with time, by an order of magnitude or more; conversely,

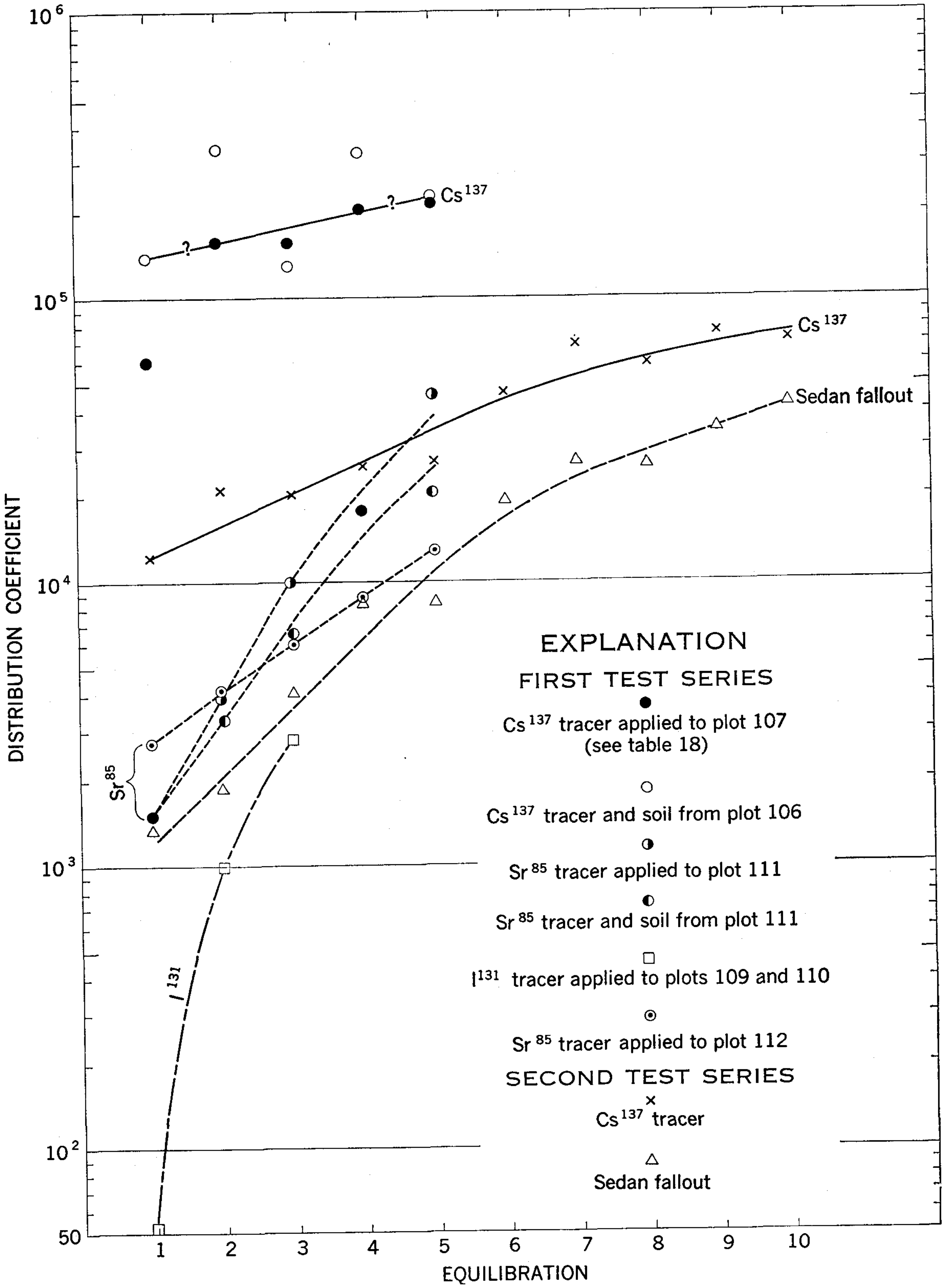

Figure 4.—Distribution coefficients determined from overland-transport plots.

specific activity of the solid phase increases, but percentagewise the increase commonly is of little consequence.

For the 10-stage equilibration of Cs^{137} tracer, the indicated distribution coefficient increased from 12,000 to 74,000, or about sixfold. Activity in the liquid phase diminished about from 9×10^{-5} to 1.5×10^{-5} times total activity in the system (M_l/M_s ratio, 111).

For Sedan fallout, the indicated distribution coefficient (adjusted for presumed solubility of the fallout) increased 36-fold, from 1,200 to 43,000, and liquid-phase activity diminished about from 7×10^{-2} to 2.3×10^{-3} times system total (M_l/M_s ratio, 100).

In tentative explanation of such changes in liquid-phase activity, W. A. Beetem (oral commun., 1963) has suggested that a progressively increasing fraction of the tracer nuclide reacts nonreversibly with some particular constituent of the solid phase (in this experiment soil or another earth material) and so becomes "fixed," or nonreactive. In effect, this implies two concurrent reactions among the tracer nuclides, Snowbank Creek water, and Chariot-site soil—(1) a prompt reversible reaction and (2) a slower nonreversible reaction whose products are all insoluble. Assuming this to be so and that the prompt reaction is characterized by a distribution coefficient approximating that from the 1st equilibration, then by the 10th equilibration about 84 percent of the Cs^{137} tracer and 97 percent of the once-soluble Sedan-fallout nuclides are fixed in the solid phase.

PERCOLATION TEST

Underground transport of nuclides was appraised by a simple 18-hour percolation test in August 1962 on a hillside above Snowbank Creek (plot 62 ABJ 116). Here a small pit was dug through a surface layer of humus-rich soil 15 cm (6 in.) thick, and about 10 cm into underlying silt and clay. The pit was charged to within 2 inches of its rim with 3 pounds of Sedan fallout mixed into a slurry with creek water, and recharged three times with additional water. As was determined later, water that percolated from the pit moved in part through the porous humus-rich soil, but moved largely along the contact between that soil and the underlying humus-poor silt and clay. This percolate was sampled in a trench dug 84 cm (33 in.) downslope from the pit, samples being taken in polyethylene bottles at 15-minute intervals during the first 4 hours and then once after 18 hours. At the end of the test, soil samples were taken from a subsidiary trench dug from the pit to the percolate trench. Figure 5 shows the pit and trenches in profile and plan, also radioactivity of soil samples taken from the wall of the subsidiary trench. Figure 6 shows radioactivity of the percolate.

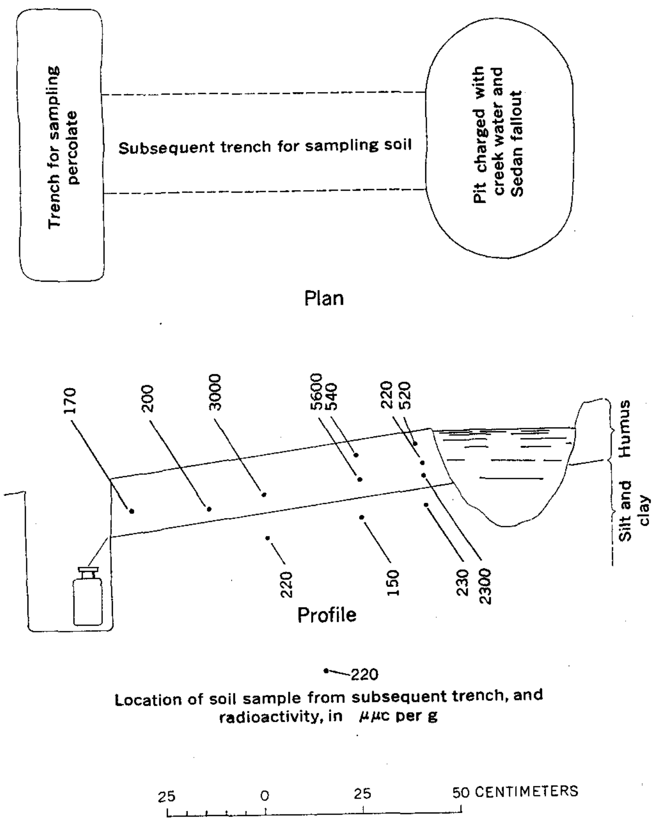

FIGURE 5.—Plan and profile of plot 116, percolation pit and sampling trenches.

Specific activity of the fallout material before charging the pit was 5.29×10^{-2} μc per g; that of dried slurry from the pit at the end of the test, including some soil dislodged from the sides of the pit as the slurry was stirred, was 2.60×10^{-2} μc per g. This residual activity of the slurry could be accounted for by assuming that (1) solubility of nuclides in the Sedan fallout was the same as that derived for table 2, or 6.8 percent, (2) all soluble nuclides were transported from the pit in percolate, and (3) soil dislodged from the sides of the pit and mixed in the residual slurry weighed slightly less than the charge of fallout material. All these assumptions are acceptable as first approximations.

Figure 6 shows four pulsations in specific activity of the percolate as sampled. Each of these occurred shortly after the pit had been filled or refilled with water; evidently each filling accelerated the rate of percolation and transport of nuclides, as would be expected.

It may be presumed that specific activity of the percolate (fig. 6) reached equilibrium, at least approximately, with that of the soil percolated (fig. 5). If so, distribution coefficients range from 150 to 520; these are in the same order of magnitude as those derived from overland-transport plots 114 and 115 and from

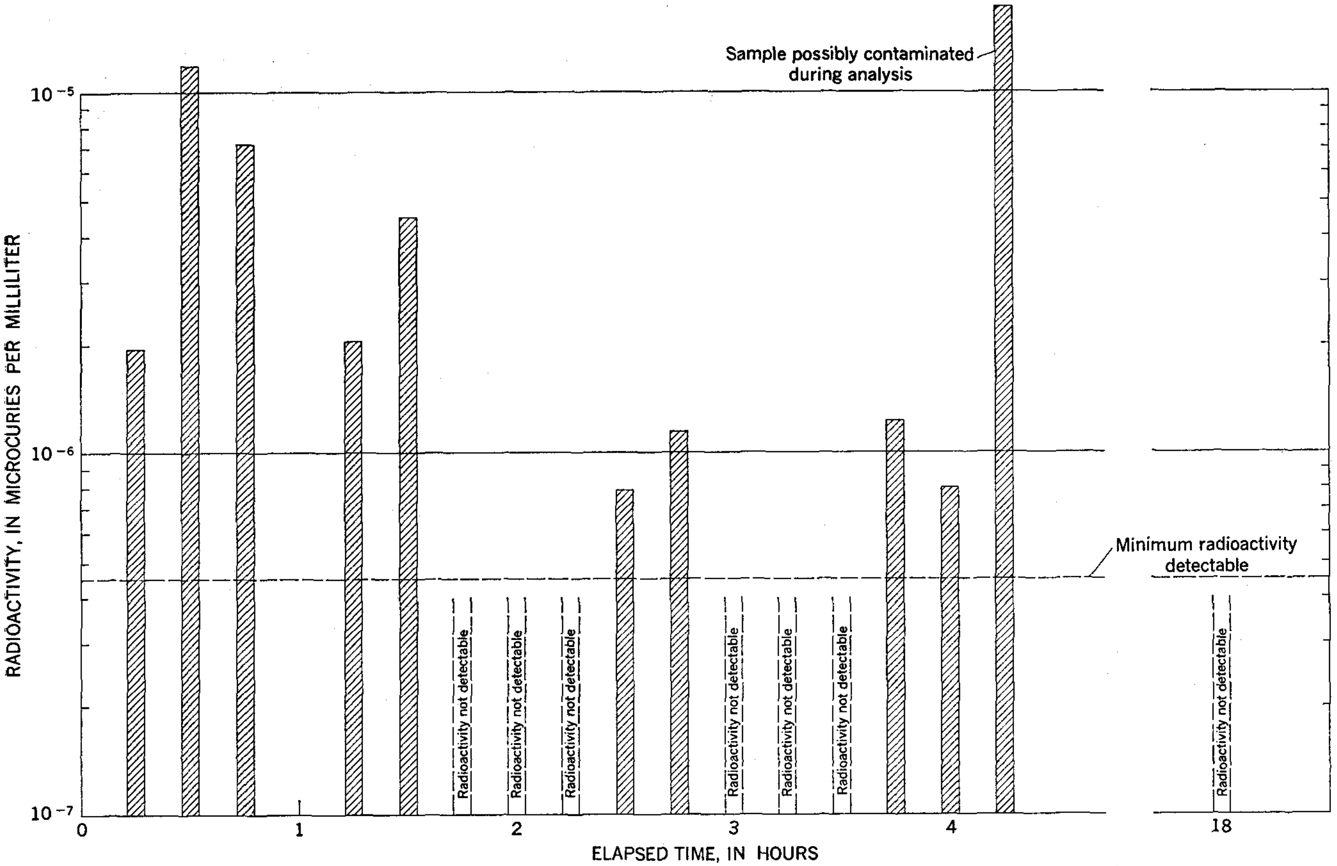

FIGURE 6.—Specific radioactivity of percolate from plot 116.

the second application of simulated rain to plot 113 (table 18).

This test discloses, rudely, the attenuation of nuclides adsorbed or exchanged from percolating or infiltrating water, as already summarized.

MEAN BASINWIDE DISTRIBUTION COEFFICIENTS

The overland-transport, percolation, and laboratory tests in 1962 afford a much deeper insight into variation of distribution coefficients in relation to environmental factors. However, neither the results from these tests in 1962 nor from the tests in 1961 are fully definitive; some deviate greatly from the seeming norm. The preponderance of evidence appears to support the following tentative generalizations and weighted-mean distribution coefficients.

RELATION TO NATURE OF EARTH MATERIALS

Magnitude of the distribution coefficient for any particular radionuclide differs substantially according to chemical and physical nature of earth materials with which the nuclides may enter sorption or base-exchange reactions. Thus, from the tests in 1961, the largest value of the distribution coefficient for Sr^{85}—among the several samples of vegetation and soil, with other conditions of reaction the same—is commonly from 5 to 10 times the smallest value; in the extreme set of values, the largest is about 50 times the smallest. For I^{131}, the ratio of largest to smallest value is commonly from 100 to 500, with an extreme minimum of 10. For Cs^{137}, the ratio is commonly from 2 to 10, with an extreme maximum exceeding 1,000. The comparable range for mixed fission and activation products is not known.

In spite of this considerable variation, it is presumed that the purpose of this report (an order-of-magnitude appraisal) can be achieved on the basis of mean distribution coefficients for each of three principal land-surface classes—vegetated area, bare soil, and rock outcrops and rubble (table 8). To the end of deriving suitable mean values for vegetated and bare-soil areas, the coefficients of 1961 (tables 12 to 14) are taken to have equal weight and collectively to represent all the area of concern. Coefficients from the overland-transport plots of 1962 are assigned according to general character of the plot surface—plots 107, 109, 113, and 114 as vegetated; the other plots as bare soil with no more than sparse vegetation.

Only a very few coefficients applicable to rock outcrops and rubble were determined in the tests of 1961.

Somewhat arbitrarily, mean coefficients are taken to be 1 percent of the respective bare-soil values.

RELATION TO SOLUTES IN THE REACTING WATERS

Magnitude of the distribution coefficient differs also according to kind and concentration of solutes in the reacting waters. For example, the tests of 1961 were not run with waters native to the Project Chariot area, but rather with nine synthesized solutions whose chemical makeup and concentration differed moderately. Among resulting distribution coefficients for Sr^{85}, the largest is commonly from 50 to 250 times the smallest, the conditions of reaction being the same except for kind and concentration of solutes. For I^{131} and Cs^{137} this ratio of largest to smallest value generally is between 2 and 20.

Two of the synthesized solutions, Nos. 5 and 8, conform reasonably to the range in concentration and to the average makeup of waters native to the Project Chariot area. A third solution, No. 2, conforms in makeup but is more dilute. Only the distribution coefficients determined with these three are considered further. Those determined with solution 2 are assigned a weight of one; those with solutions 5 and 8, a weight of two.

All the tests of 1962 were with native water from Snowbank Creek. Nonetheless, distribution coefficients from these tests are assigned a weight of one only, owing to factors other than nature of the reacting fluid.

RELATION TO ELAPSED TIME OF REACTION

The tests of 1961 imply, and the laboratory tests of 1962 confirm, that the specific radioactivity of solid and liquid phases may change progressively with time, the solid-phase radioactivity generally increasing. Specifically, in the tests of 1961, distribution coefficients for I^{131} after 6 days of equilibration were consistently greater than those after 1 day, as much as twentyfold. Those for Sr^{85} were somewhat greater in certain of the tests; those for Cs^{137} averaged twofold to threefold greater. Presumably the 6-day coefficients more nearly typify the dispersal of fission and activation products in the hydrologic environment, should Project Chariot be executed. Accordingly, the 6-day coefficients are assigned a weight of two; the 1-day coefficients, a weight of one.

In the multiple-equilibration tests of 1962, the ratio of specific radioactivities, solid to liquid, increased as much as 25-fold from the 1st to the 5th equilibration of Sr^{85} tracers, at least 50-fold from the 1st to the 3d equilibration of I^{131} tracer, 6-fold from the 1st to the 10th equilibration of one particular Cs^{137} tracer, and 35-fold from the 1st to the 10th equilibration of Sedan fallout (fig. 4). These increases may be time dependent, in part if not in whole. However, they can neither be explained fully at this time nor correlated with any particular stage of the nuclide dispersal that would follow Project Chariot detonation. In view of these major uncertainties, only the first equilibration in each of the series is considered in deriving the mean distribution coefficients for bare-soil areas; this first equilibration is assigned a weight of one.

The overland-transport test on plot 113 involved seven applications of simulated rain and, seemingly, a progressively increasing distribution coefficient (table 18). There is, however, major uncertainty as to the masses of solid and liquid that reacted, the uncertainty growing with each of the successive simulated rains. This being so, it is postulated that the overland-transport tests did not generate any time-dependent shift of distribution coefficient; also, that coefficients derived from the third and subsequent simulated rains are unreliable. One selected coefficient from each plot—in multiple applications, the coefficient derived from the second simulated rain; otherwise, that derived from the single application—is considered in the mean basinwide value. The selected coefficient is given a weight of one.

THE MEAN COEFFICIENTS

Table 19 assembles mean basinwide distribution coefficients, modified from the values of 1961 according to generalizations and criteria just discussed. From the mean coefficients and the distribution of land-surface classes (table 8), table 20 derives the fractions of fission- and activation-product radioactivity that accordingly would be sorbed or exchanged onto land-surface materials, basin by basin. Values in these two tables are approximate at the best, but presumably are in the correct order of magnitude. To the extent that they may be biased, they are inferred to be small rather than large, and therefore resulting estimates of the concentrations of radionuclides in local water sup-

TABLE 19.—*Mean distribution coefficients and mean basinwide sorption or exchange of radionuclides, Project Chariot*

Nuclide	Land-surface type		
	Vegetated area	Bare soil	Rock, talus, and colluvium
Distribution coefficient, *Kd*:			
Sr^{90}	390	170	1.7
I^{131}	1,500	95	1.0
Cs^{137}	3,200	8,100	32
All fission products, collectively	600	690	6.9
Fraction of activity sorbed or exchanged onto land-surface materials: [1]			
Sr^{90}	.9974	.9942	.6296
I^{131}	.9993	.9896	.5000
Cs^{137}	.9997	.9999	.9697
All fission products, collectively	.9983	.9986	.8734

[1] Assuming the M_l/M_s ratio to be unity.

TABLE 20.—*Fraction of radioactivity presumed to be sorbed or exchanged onto land-surface materials, Project Chariot*

Nuclide	M_l/M_s ratio	Basin or area												
		Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River[1]	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas[1]
No. on pl. 1	----------	0	1	2	3	4	5	6	7	8	9	10	11	----------
Sr^{90}	1	0.8345	0.7590	0.8512	0.9184	0.9502	0.9349	0.9377	0.9602	0.9002	0.8839	0.9286	0.9861	0.9286
	10	.6001	.4339	.6508	.7915	.8779	.8285	.8498	.8856	.7498	.7118	.8185	.9450	.8185
	100	.3995	.2683	.4581	.5932	.6796	.6263	.6603	.6792	.5424	.5068	.6190	.7410	.6190
	1,000	.1143	.0811	.1408	.1913	.2245	.2022	.2215	.2208	.1667	.1540	.2006	.2462	.2006
I^{131}	1	.7765	.6749	.8026	.8908	.9380	.9132	.9211	.9476	.8660	.8436	.9058	.9830	.9058
	10	.5678	.3970	.6275	.7816	.8779	.8211	.8501	.8829	.7315	.6902	.8112	.9500	.8112
	100	.3844	.2738	.4724	.6404	.7508	.6767	.7408	.7385	.5585	.5163	.6714	.8232	.6714
	1,000	.1712	.1401	.2441	.3590	.4368	.3798	.4419	.4185	.2872	.2602	.3793	.4831	.3793
Cs^{137}	1	.9866	.9803	.9796	.9933	.9858	.9947	.9857	.9968	.9910	.9906	.9914	.9989	.9914
	10	.8941	.8451	.9012	.9472	.9635	.9578	.9557	.9741	.9356	.9256	.9537	.9904	.9537
	100	.6555	.5017	.6957	.8188	.8920	.8517	.8651	.9020	.7859	.7527	.8420	.9521	.8420
	1,000	.4816	.3071	.5159	.6346	.7072	.6690	.6743	.7201	.6111	.5774	.6584	.7656	.6548
All fission products	1	.9434	.9176	.9431	.9718	.9753	.9774	.9716	.9860	.9651	.9602	.9733	.9948	.9733
	10	.7311	.6117	.7618	.8615	.9174	.8874	.8970	.9272	.8343	.8082	.8793	.9673	.8793
	100	.5136	.3466	.5594	.6919	.7740	.7278	.7446	.7825	.6560	.6196	.7179	.8373	.7179
	1,000	.2237	.1415	.2434	.3039	.3416	.3209	.3266	.3465	.2894	.2725	.3160	.3708	.3160

[1] Interpolated mean values, basinwide.

plies, caused by Project Chariot, are large rather than small.

The adsorption-potential values of tables 19 and 20 apply, of course, only to the soluble fraction of the fission products that would be vented by Project Chariot (table 2). It is assumed that, in the mixed fission products, the adsorption potentials of the several nuclides are not diminished by interference one with another—in other words, that adsorption does not follow a preferential exclusive sequence of nuclides. Although this assumption is not strictly true, it is considered acceptable for the order-of-magnitude appraisal here reported and for the small concentration of radionuclides expected in the waters.

EXPECTED DISPERSAL OF FISSION PRODUCTS FROM PROJECT CHARIOT

Within the framework of general assumptions thus far presented and certain specific assumptions and simplifications to be explained, tables 21 to 25 show expected dispersals of fission products in fallout from Project Chariot, generally in the first few weeks following detonation. These dispersals cover four hypothetical cases, each of which postulates a distinct climatic and hydrologic setting, but which together span the yearly range of hydrologic conditions in the vicinity. Under each case, a dispersal is traced out for the fallout pattern of plate 1 in each of the two orientations outlined on pages 2–3. Under each case and fallout pattern, the vented fission-product activities of table 2, appropriately decayed, are distributed among five categories, as follows: (1) Dissolved in streams running off from the fallout area or in the water of microponds within the area, (2) suspended in the streams, (3) adsorbed on land-surface materials and so virtually immobilized, (4) infiltrated to soil water and so momentarily immobilized, but subject to later uptake by growing plants, to slow percolation through the soil, and to adsorption on soil particles, (5) remaining on the land surface or on vegetation near the place of fall, subject to later redispersal by water or wind, also to ingestion by grazing animals.

In the cited tables, activities are expressed in curies per square statute mile or in microcuries per milliliter of water. For interconversion of these two units, 1 c per mi^2 dissolved in water 1 inch deep over the area would result in a concentration of 1.52×10^{-5} μc per ml.

CASE I: DETONATION ORDINARILY IN APRIL

GENERAL ASPECTS

Case I (table 21) assumes: (1) Detonation 30 days prior to breakup in the spring, ordinarily in April, fallout being on continuous snow cover. (2) Negligible redistribution of fallout by the wind. This assumption is unrealistic but is a necessary simplification (p. 3 and 31). (3) Snowmelt runoff of 1 inch over the area within 30 days following breakup, the average being 35 cfs in Ogotoruk Creek. This is the runoff of Ogotoruk Creek in a fairly dry year. In other years, runoff might be several fold greater; if so, the concentration of nuclides in the streams would be less, approximately in an inverse ratio. (4) Snowmelt detained in microponds, 0.3 inch over the area, as has been estimated.

During the breakup, or thaw, melting would occur at the upper surface of the snow layer, with the latent heat of melting derived from solar energy and not from ground heat. Melt water first would percolate downward in the snow until intercepted by an ice layer, the frozen land, or some other impermeable surface. Once intercepted, it would move laterally toward and into stream channels. Each day in this cycle, probably some of the melt would refreeze at night.

NUCLIDES DISSOLVED IN RUNOFF AND IN MICROPONDS

It is assumed that all the soluble fission products would be dissolved by the melt water and, except for the fractions detained in microponds or adsorbed by land-surface materials (to be appraised), would flow to the Chukchi Sea and so would pass rather quickly from the area. In table 21, maximum values among the several basins are given for the expected concentration in microponds, rills, and small streams at place of origin in melting snow; it is assumed that (1) "hot spots" would have activities tenfold greater than those indicated by the generalized pattern of plate 1, and (2) there would be no depletion of activity by adsorption. Among the basins, these maximum concentrations are roughly from 10- to 200-fold greater than the average concentrations.

Average concentrations are for the 30-day period of melt-water runoff, in streams or in the many microponds within the area of measurable fallout (pl. 1). In trunk streams, these concentrations may be diluted outside the fallout pattern by runoff from outlying areas, either upstream or downstream, or both. No such dilution would occur in the basins of Ogotoruk and Nasorak Creeks or in most of the small basins between Ogotoruk Creek and Cape Seppings (basins 0, 1, and 2 on pl. 1). In other basins of the area, dilution probably would be less than fivefold and almost certainly less than tenfold.

NUCLIDES SUSPENDED IN RUNOFF

Except within a few miles of the Chariot site, insoluble fallout particles presumably would be of such size (table 3) as to move readily with melt water and, unless trapped by irregularities of the snow-ice-land surface, would become suspended sediment in the streams. The fraction so becoming sediment cannot be reasoned from information at hand. For purposes of this appraisal, table 21 postulates values ranging from 5 percent for basins within 10 miles of the site to 50 percent for those more than about 35 miles distant. So postulated, activity in the trunk streams due to suspended fallout particles likely would be from about the same as, to tenfold greater than, that due to dissolved nuclides. The smaller ratio would apply to basins close to the site; the larger ratio, to the most remote basins.

TOTAL STREAM BURDEN

The total computed stream burden, dissolved and suspended, would range from 4.0×10^{-3} to 1.3×10^{-5} μc per ml. Thus, total stream burden would be greater than the lifelong standard for drinking water, but less than the 30-day emergency standard. In part because the activity would pass to the Chukchi Sea within a few days after it reaches a trunk stream, the implied hazard apparently would be readily manageable.

NUCLIDES ADSORBED

Under the assumed conditions of case I, the opportunity for dissolved activity to be depleted by adsorption is not readily evaluated. Thus, in passing from the area, much of the early melt water would not contact mineral particles other than windblown silt contained in the snow (p. 6), nor vegetation other than that which protrudes through the snow. Only the later part of the melt-water period would expose a large fraction of the land surface and its vegetal mantle. In these curcumstances, a mean M_l/M_s ratio of 10^3 is postulated, or a reduction in the distribution coefficients by a factor of 10^{-3}. Even so, appreciable percentages of Sr^{90} and I^{131} and substantial percentages of Cs^{137} and other nuclides would be immobilized by adsorption on land-surface materials (table 20).

NUCLIDES INFILTRATED TO SOIL WATER

During the snowmelt period of case I, the zone of soil water would be saturated continuously and frozen at least part of the time; consequently, opportunity for infiltration would be nearly zero. Weeks or months later, however, a substantial or even a major fraction of the melt water that previously had been detained in microponds might infiltrate (p. 11 and 32).

PRODUCTS REMAINING NEAR PLACE OF FALL

In case I, 50 to 95 percent of the vented insoluble fission products would probably remain near their place of fall—lodged in or around vegetation or dispersed over the nonvegetated areas. As has been stated, part of this fraction of the fission products may be ingested by grazing animals and so enter the local food chain. The greater part, however, would be subject to later redispersal by the wind or by runoff, either rain generated or melt-water generated, over ensuing months or even years. Being insoluble, the part redispersed by runoff could pass from the area only as suspended sediment or bedload in the streams. The residual remaining in the area can be expressed by a general equation:

$$C_n=C_0(1-f)^n$$

in which: C_n=concentration of residual nuclides n years after detonation (decay of activity not considered).

C_0=initial concentration, and
f =a fraction of the nuclides removed from the area each year.

A specific value for f of the preceding equation is conjectural. By inference, however, f would be relatively large for the outlying parts of the fallout pattern, where the residual nuclides would diminish to nominal concentrations relatively quickly. For the close-in parts of the pattern, f would be smaller, and the residual concentration would dissipate more slowly. Within a few miles of the site, much of the throwout and some of the fallout particles presumably would not be moveable by water.

Whatever the rate at which insoluble nuclides are redispersed, the concentration in streams, as suspended sediment and bedload, ordinarily would be substantially less than during the period of melt-water runoff covered by table 21. Concentrations equaling or exceeding those of the melt-water runoff might be experienced, however, in the event of unusually intense rainfall in the June or July following detonation.

CASE II: DETONATION IN EARLY JUNE

Case II (table 22) assumes: (1) Detonation at the close of melt-water runoff, ordinarily in early June. (2) Within the 30 days following detonation, a precipitation total of 0.5 inch but not more than 0.1 inch in any one storm. There appears to be about an even chance that such a precipitation sequence would occur (tables 4 and 5). (3) Runoff averaging 0.03 inch (1 cfs from Ogotoruk Creek basin) but none generated by rain during the 30-day period.

The following generalizations and simplifications have been introduced in regard to case II dispersal of soluble nuclides: (1) All the soluble nuclides would dissolve in the assumed 0.5 inch of rain plus any water in antecedent microponds. (2) Interim evapotranspiration would be about 0.8 inch, so that all the dissolved nuclides would infiltrate the soil, but none would percolate to ground water and contribute to base flow in streams. (3) In such an adsorption environment, the M_l/M_s ratio would probably be somewhat less than unity; accordingly, unmodified K_d values would apply. (4) Of concurrent runoff, 90 percent would be derived from base flow—that is, from effluent ground water—and 10 percent from interim rainfall. The base-flow component would be nuclide free, on the basis of generalization 2. In the interim-rainfall component, concentration of nuclides would be that which would result if all the solubles dispersed uniformly in all the rainfall. (5) In table 22, values for nuclides infiltrated to soil water are the residual solubles that would not be adsorbed and that would not reach the streams.

In contrast with case I it is expected that: (1) Concentration of soluble nuclides in Ogotoruk and Nasorak Creeks would be about an order of magnitude less; in other streams the contrast would be even greater. (2) Virtually no nuclides would reach the streams as suspended sediment; in other words, substantially all insoluble nuclides would remain near their place of fall. (3) Nuclides adsorbed on land-surface materials would be greater by one or two orders of magnitude. (4) Whereas in case I dissolved nuclides would not infiltrate to soil water during the period of snowmelt, in case II such infiltration not only would be substantial in amount but also would take place during the assumed 30 days of initial fission-product dispersal.

CASE III: DETONATION IN EARLY AUGUST

Case III (table 23) assumes: (1) Detonation in early August, following 2 months of minimum precipitation and an accumulated soil-water deficiency of 1 inch. (2) Within the 30 days following detonation, rainfall of 2.5 inches generating runoff of 0.7 inch (approximate average in Ogotoruk Creek, 25 cfs). There is about an even chance that these antecedent conditions would be realized.

The dispersal of soluble nuclides under case III is derived from the following specific assumptions or generalizations: (1) All the solubles would dissolve in the first 1 inch of rain, of which all would infiltrate to replenish antecedent soil-water deficiency. Thus, all the solubles would be dispersed in soil water before any microponds would be generated by the subsequent rainfall. (2) As in case II, the adsorption environment would involve unmodified K_d values. (3) After the first inch of rain, further infiltration would just compensate the 30-day evapotranspiration of 0.8 inch. Accordingly, nuclide concentration in the soil water would change only by sorption and exchange reaction with soil particles (4) Of the concurrent runoff, 20 percent or 0.14 inch would be base flow derived from ground water—that is, from soil-water excess. In other words, 20 percent of all nonadsorbed solubles would reach the streams and 80 percent would remain in the soil water. (5) The solubles that would reach the streams would be diluted by nuclide-free overland runoff in the ratio of 1 to 4—that is, in the depth of 0.56 inch.

Results may be generalized as follows: (1) Concentration of soluble nuclides in the runoff would be very small; 35 miles or more from the project site, it would be less than the lifelong drinking-water standards previously cited. (2) Insoluble nuclides reaching the streams as suspended sediment would constitute most of the total stream burden. Their expected concentration would be about 3- to 3.5-fold greater than in case I. (3) Nuclides adsorbed, those infiltrated to soil water, and the insolubles remaining near their place of fall would be in substantially the same concentration as in case II.

CASE IV: DETONATION IN LATE SEPTEMBER

Case IV assumes: (1) Detonation in late September, 10 days prior to freezeup, fallout being on saturated tundra. (2) In the 10-day interim, no precipitation and 0.1 inch of runoff—that is, an average of 10 cfs in Ogotoruk Creek, due to antecedent rain. Dispersal of nuclides must be considered in two periods—an initial dispersal prior to freezeup (table 24) and a redispersal during the next ensuing snowmelt period (table 25). Thus, in a sense case IV is roughly analogous to case II combined with case I, with an intervening decay period of about 8 months.

Case IV also involves these supplemental assumptions: (1) Soluble nuclides would dissolve in water detained by the microrelief of the saturated tundra. (2) Adsorption would take place only during the initial 10-day dispersal, in an environment having a M_l/M_s ratio of about 10^2. At this ratio, the quantities adsorbed would be only slightly less than under the model environment (table 20). (3) The soil zone being saturated or frozen, none of the soluble nuclides would infiltrate. (4) Of the nonadsorbed solubles, one-third would reach the streams during the initial 10-day period; the remaining two-thirds would be detained in microponds, would be immobilized over winter in ice, and would reach the streams during the later half of the ensuing melt-water period, in one-fourth of the melt-water runoff. (5) Insolubles would reach the streams only during the period of redispersal, in the percentage amounts previously assumed for case III.

Briefly, during the initial 10-day dispersal, concentration of I^{131} dissolved in runoff of the Ogotoruk Creek basin would be roughly three orders of magnitude greater than the previously cited lifelong standard for drinking water. Concentration would diminish with distance from the project site; beyond about 30 miles it would be between 2.5 and 0.5 times the standard. Soluble Sr^{90} would be from three orders greater than standard in the Ogotoruk Creek basin to half the standard at the outer margin of the fallout pattern; Cs^{137} would be less than the lifelong standard except in the basins of Ogotoruk and Nasorak Creeks and small basins to the southeast. In the final dispersal, after 8 months decay: (1) stream-borne soluble Sr^{90} and Cs^{137} would be moderately less than in the initial dispersal; and (2) I^{131} would be at least six orders of magnitude less than the lifelong standard.

Among insolubles reaching the streams as suspended sediment, (1) Sr^{90} and Cs^{137} would be about one order of magnitude less than in case III but twofold or threefold greater than in case I; they would be less than the lifelong standard (for insolubles) in all the area except the basin of Ogotoruk Creek and its immediate vicinity; (2) I^{131} would be at least six orders of magnitude less than the lifelong standard, and (3) other nuclides would be about one order less than in case III but would exceed the lifelong standard in all except outlying parts of the fallout pattern.

Nuclides adsorbed in the initial 10-day period would be one or two orders of magnitude less concentrated than in cases II and III, but as much as threefold more concentrated than in case I.

THE FOUR CASES IN SUMMARY

Among the four hypothetical cases, the radioactivity in streams due to dissolved nuclides would be by far the least in case III—that is, with detonation in early August, followed by heavy rains. For the more distant parts of the fallout area, this activity would be less than the lifelong drinking-water standard.

Activity in the streams due to suspended fallout particles would be nearly zero in case II—that is, with detonation ordinarily in early June, followed by light rainfall and minimum runoff. In all the other cases, this activity would depend largely on an unknown factor—the proportional part of the fallout particles that would be moved in competition with natural soil particles, by water flowing overland. Whatever this proportion might prove to be, inferentially it would be greatest under case I and nearly as great under case III and the redispersal stage of case IV.

Among the four cases as presented, total stream burden would be greatest in case III. However, this case encompasses an interval of high momentary streamflow but moderate average flow. Under these conditions, activity once in the streams, either dissolved or suspended, would pass in very large part to the Chukchi Sea within a few days. This being so, no unmanageable situation, involving continuing hazard to residents of the area, is foreseen.

Activity that would not reach the streams soon after detonation would of course remain in the area—adsorbed on land-surface materials, infiltrated to soil water or ground water, or dispersed over the land surface as insoluble particulate matter. In the aggregate, this remaining activity would include the greater part of that vented. Insolubles on the land surface probably would move to the streams over a period of years, but ordinarily in concentrations progressively less with each passing year. For most of the area, the relevant problems of management should vanish within a few years.

SPECIAL ASPECTS OF FISSION-PRODUCT DISPERSAL

RELATION OF COMPUTED STREAM BURDENS TO DRINKING-WATER STANDARDS

As computed in tables 21 to 25, the burden of radionuclides to be expected in streams and ponds following execution of Project Chariot would be less than the 30-day emergency drinking-water standard (p. 13) except in the basin of Ogotoruk Creek, and in that basin except during the initial-dispersal stage of case IV. In certain of the hypothetical cases and over extensive parts of the area expected to receive fallout, stream burdens would be less than the lifelong standard as well as the emergency standard.

Total stream burdens would be least under case II—that is, with detonation at the end of snowmelt runoff in early June and with minimal rainfall during the next 30 days. In that situation, virtually all the stream burdens would result from dissolved nuclides. They would range from a maxium of 2.4×10^{-4} μc per ml over the Ogotoruk Creek basin to as little as 2.4×10^{-8} μc per ml at the outer margin of the fallout pattern. In this case, the burden of all nuclides would be less than the lifelong drinking-water standard except in the basin of Ogotoruk Creek and adjacent areas within a radius of about 12 miles from the center of detonation. The burden of Cs^{137} alone would be less than the lifelong standard (for that particular nuclide) in all the area of concern, including the basin of Ogotoruk Creek.

Stream burdens due to dissolved nuclides alone would be even less under case III. However, that case encompasses the greatest burdens due to particulate suspended nuclides and the next-to-greatest total burdens. Under that case, (1) burdens of suspended Sr^{90} and Cs^{137} would be less than the lifelong standard over all the area of concern, (2) burdens of suspended I^{131} would be less than the lifelong standard except in the basin of Ogotoruk Creek, but (3) burdens of other nuclides would exceed the lifelong standard in all the area of concern, even its most remote parts. Over the area, suspended burden would range from 6.5×10^{-3} μc per ml in the basin of Ogotoruk Creek to as little as 2.2×10^{-5} μc per ml at the outer margin of the fallout pattern. These two extremes would be, respectively, 1,300 and 4 times the lifelong standard, and about 100 and 2,000 times the corresponding dissolved burdens.

DISPERSAL BY WIND AND AS WATER-BORNE SEDIMENT

From the dispersals derived in tables 21 to 25 it is implicit—not only for Project Chariot in particular but also for other such applications of nuclear explosives in general—that only a minor fraction of fission-product radioactivity is removed in solution, by streams. Except as it dissipates by decay, in place, radioactivity vanishes from the area of fallout largely as undissolved particulate matter, owing to overland transport by either wind or water.

Transport by wind can be highly effectual. An instance in point is postshot experience at the Nevada Test Site in the vicinity of the Project Sedan crater. There, over about 18 months, where the sparse desert vegetation had been destroyed, the wind has winnowed away much of the fine particles of fallout. Total yearly wind movement there doubtless is substantially less than at the site of Project Chariot; transport by water has been nil.

At the Chariot site in particular, each of the four hypothetical cases assumes that fallout remains in the pattern of plate 1 or its mirror image, and within the prescribed fallout sectors, until transported by water or adsorbed by land-surface materials. Such an assumption is not warranted, especially with fallout on antecedent snow, as in case I.

Specifically, an "Ogotoruk wind" such as described on page 3 could, within a single day, redistribute fission products from a large part of the area and carry them far downwind mingled with snow. Such redistribution would be largely southward and generally between azimuths 125° and 215° (pl. 1, wind roses). The potential reach is presumed to be at least 20 miles, or to the vicinity of Cape Seppings; farther south, winter winds are reported to be of moderate velocity and in various azimuths. Climatic records from the site suggest at least 9 chances in 10 that the fallout pattern of plate 1 would be drastically modified in this way, if detonation precedes breakup by 30 days or more. However, there is no established basis from which rate, quantity, or geographic reach of such redistribution can be estimated specifically or with reasonable certainty.

Notable "hot spots" of radioactivity might be created. For example, assume a snowdrift 30 feet deep, such as occurs locally in the lee of minor ridges athwart the dominant wind from the north (p. 6). Assume further that the drift resulted from wind erosion of outlying snow surfaces to a depth of 1 inch and that all fission products in the eroded areas were removed with the snow. The drift, therefore, would contain fission products from an area 360 times greater than its own extent, uniform snow density being assumed. On breakup, the radioactivity of insoluble fission products remaining in the drift area would be about 2½ orders of magnitude greater than it would have been in the area from which the drift was accumulated. If a 1-inch water equivalent is assumed in 4 inches of the drifted snow (p. 6), the activity of fission products dissolved in the melt water would be increased fourfold over that of case I.

Redistribution of fission products by wind might take place in any month of the year, but probably to the greatest degree under conditions of case I. The potential for redistribution would be progressively less in case II, the fallout being on relatively dry tundra; case III, the fallout being on tundra saturated and flushed by heavy subsequent rain; and case IV, the fallout being largely immobilized by freezeup soon after detonation.

Any dispersal of fission products as water-borne sediment obviously would add to the hazard that water-supply sources may be contaminated. In general, the potential for such dispersal depends chiefly on the intensity and duration of rainfall or snowmelt; gradient and smoothness of the land surface and of its rills and channels; and the size, assortment, and cohesiveness of natural land-surface particles in competition with fallout particles and throwout particles. Means have not been devised to express these and related parameters in terms of consequent production of sediment, basinwide.

In regard to Project Chariot, dispersal of fission products as sediment has been presumed under the conditions of case I, case III, and the delayed phase of case IV (tables 21, 23, and 25). In these cases, the percentages of insoluble particulate fission products taken into suspension in the several basins are wholly conjectural. Hopefully they are reasonable first approximations.

FISSION PRODUCTS IN PONDS

Like nearly all arctic terranes, the land surface of the area here considered does not drain completely. There are several perennial ponds in the Kukpuk River lowland, immediately northeast of the Ogotoruk Creek basin. In their vicinity, the approximate 1-hour activity of fallout would be between 1 and 5 Mc per sq mi. Other ponds probably would exist transiently during breakup and following heavy rain, widely over the tundra. These ponds would influence locally the dispersal of fission products from Project Chariot.

Fallout on the water surface would be trapped within the pond area, perennially if the pond does not overflow. Some of the larger ponds drain moderately extensive land areas, the runoff from which would carry additional fission products into the ponds under the conditions of cases I and III and the redispersal phase of case IV. Data are lacking as to pond volumes and drainage areas, from which the resulting concentrations of soluble products might be estimated. In certain ponds, however, the concentration might be severalfold greater than the average concentration in adjacent streams as shown in tables 21 to 25.

For a pond with no overflow, water volume would diminish in summer by evaporation, by the transpiration draft of adjacent vegetation, and possibly by infiltration of the pond's bed. In perennial ponds, fission-product concentration would increase accordingly (in terms of weight rather than of radioactivity). Many small sag ponds and their trapped fission products would dessicate. In succeeding years, the ponds would refill.

In numerous ponds it is expected that the initial influx of fission products would be constrained permanently, the total radioactivity diminishing largely or wholly by decay (table 1). A major fraction of the soluble products probably would be adsorbed on particles of pond-bottom ooze or on sedges. The concentration of nonadsorbed and insoluble products would fluctuate seasonally—in the perennial ponds, probably less than an order of magnitude—owing to successive dilutions by rain and melt water. Some of the pond activity might enter the local food chain, through aquatic or grazing animals.

The numerous intermittent microponds on the tundra constitute a special and critical consideration. At the height of melt-water runoff and during intense rainfall, many of these doubtless overflow one into another. In the waning stages of snowmelt or heavy rainfall, however, they separate into discrete units analogous to the larger ponds just described. Most of these discrete minute pools desiccate one or more times each summer —in part by evaporation and in part, probably in major part, by infiltration to replenish the soil water that is transpired by surrounding vegetation (p. 11).

These microponds doubtless would trap a substantial fraction of insoluble fission-product particles. In the aggregate, their water volume doubtless would be sufficient to dissolve all the soluble nuclides.

FISSION PRODUCTS IN SOIL WATER AND GROUND WATER

As has been shown, soils of the area are wet to their capacities most of the year, and a soil-water deficiency exists only intermittently during summer. Thus, recharge of soil water is very largely from rain; probably no more than a nominal part of the recharge is from melt water that may be retained in microponds until the growing season has progressed substantially. Accordingly, it is expected that (1) dissolved fission products from Project Chariot would infiltrate the soil only under the conditions of cases II and III, and (2) substantially all the products dissolved in discrete microponds would infiltrate during the first summer following detonation. In the soil, all but a small fraction of the dissolved fission products would be adsorbed onto earth particles—the M_l/M_s ratio would be somewhat less than unity (table 20). Subsequently, some unknown fraction of them might be taken into the tissue of sedges and other tundra vegetation, and eventually enter the local food chain through grazing and browzing animals.

Most ground-water bodies of the area—at shallow depth beneath the streams and above permafrost, and possibly at depth in or beneath the permafrost—inferentially are recharged from the streams, in part by melt-water runoff and in part by rain-generated runoff. The shallow bodies discharge to their companion streams, as the flow of those streams recedes after breakup and between summer rains.

Ground-water bodies of the area probably would be infused extensively by soluble fission products from Project Chariot, especially under the conditions of cases II and III. Any such infusion would advance slowly in its aquifer, generally no more than a few hundred feet a year. It would advance into an undepleted adsorption environment—in net effect, the M_l/M_s ratio would become vanishingly small, and adsorption would be substantially complete within a fairly short distance from the area of recharge. Therefore, most discharging ground water of the area—chiefly the base flow of streams and the issue of small springs—would likely contain only nominal amounts of radioactive fission products.

One possible exception to this generalization exists—Kovrorak Spring, 27 miles southeast of the site. There, the hydrologic setting is not known fully (p. 8). Some ultimate effect on this spring by Project Chariot would be conceivable.

EFFECTS ON LOCAL WATER SUPPLIES

All villages of the area are outside the fallout sectors of the foregoing appraisal; accordingly, their established water sources (p. 12) would be exposed only to stream-transported or wind-transported fission products from Project Chariot. Two of the villages, Kivalina and Noatak, definitely would be so exposed.

At Kivalina and Noatak, water is taken from the Wulik and Noatak Rivers, respectively—seasonally at Kivalina and perennially at Noatak. If fallout were between azimuths of 25° and 110°, both these streams presumably would receive fission products upstream from the two villages (tables 21 to 25). As has been pointed out, however, the concentration of streamborne products would likely be neither high nor persistent—the basins of the two streams encroach on only the fringe of the assumed fallout pattern and the concentrations of activity would be relatively low; also, flow time for passage of activity to the Chukchi Sea would be a few days only. The implied hazard would probably be readily manageable, although neither stream should be assumed to satisfy an appropriate drinking-water standard until so proven by radiochemical analysis.

Even though closest to the site, the village of Point Hope would likely be exposed only to wind-transported fission products, not to products transported by the Kukpuk River, dissolved or suspended. This stream discharges into Marryatt Inlet about 9 miles east-northeast of the village (pl. 1). At the time of melt-water runoff (case I), the inlet ordinarily is still frozen and shore ice persists on the Chukchi Sea. The river discharges beneath this ice (Reuben Kachadoorian, oral commun., 1961). During the summer (cases II and III), fission-product activity carried by the river would be diluted at least severalfold in the inlet. At no time is the water of the river or of the inlet believed to recharge the ground-water body tapped by the village well.

Trail-side water sources used by hunting parties might not satisfy an appropriate drinking-water standard in the first weeks or months after detonation. Under case I, in water melted from snow or ice, or taken from a pond or small stream, it is expected that concentration of fission products would vary according to the maximum values outlined on page 28—that is, would be as much as two orders of magnitude greater than the basin averages of table 21. However, the implied hazard would be of short term; the aggregate stay time of any trail party within the prospective fallout area probably has been no more than a week or two during any year. Over a period so short, a relatively high nuclide intake could be tolerated. However trail-side water sources should be considered "off limits" until proven otherwise by adequate radiochemical analysis, especially in the basins of Ogotoruk Creek, Nasorak Creek, and the several small streams southeastward to Cape Seppings.

RECOMMENDATIONS

Relatively little specific hydrologic knowledge was available as the basis for this appraisal, and that little pertained chiefly to the immediate vicinity of the Chariot site. However, it is felt that the basic purpose has been served—an order-of-magnitude appraisal of the concentrations of radioactive nuclides that might be introduced into local water supplies, under the particular input assumptions outlined on pages 2 and 3. Also, to refine the appraisal substantially would require much more knowledge of new kinds, obtainable only by intensive investigation over a term of several years.

Project Chariot was planned as a prototype for other possible nuclear excavations. This appraisal suggests that, for some such excavations, effects on the hydrologic environment could be substantial and could seriously handicap man's subsequent activities. Accordingly, until experience has been gained, it is considered advisable that each proposal for nuclear excavation provide for an appraisal such as is presented by this report, and that postshot phenomena be studied in sufficient scope to verify the preshot appraisal—in particular, to determine the actual fallout pattern and the actual dispersal and ultimate disposition of fission products relative to interception by vegetation, adsorption, infiltration, overland transport (both water and wind), and stream transport. Presumably the postshot schedule would provide for monitoring activity levels in local water sources, springs, and streams and at other critical points.

In preparation for such postshot studies, antecedent radioactivity of the stream waters would need to be determined as little before shot time as is practical.

SELECTED REFERENCES

Allen, P. W., Van Der Hoven, I., and Weedfall, R. O., 1960, Microclimatology of Ogotoruk Valley: Las Vegas, Nev., U.S. Weather Bur. Research Sta. Prelim. Rept. 1.

Barker, F. B., and Robinson, B. P., 1963, Determination of beta activity in water: U.S. Geol. Survey Water-Supply Paper 1696-A, 32 p.

Higgins, G. H., 1959a, Evaluation of the ground-water contamination hazard from underground nuclear explosions: California Univ., Lawrence Radiation Lab. Rept. UCRL 5678, 102 p.

Higgins, G. H., 1959b, Evaluation of the ground-water contamination hazard from underground nuclear explosions: Jour. Geophys. Research, v. 64, p. 1509-1519.

Kachadoorian, Reuben, and others, 1958, Geology of the Ogotoruk Creek area, northwestern Alaska, *with sections on* Surface water and quality of water: U.S. Geol. Survey TEM-976, 43 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1960a, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska—Preliminary report, *with sections on* Ground-water conditions, quality of water, and surface-water discharge: U.S. Geol. Survey TEI-753, 94 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1960b. Supplementary report on geologic investigations in support of Phase II, Project Chariot in the vicinity of Cape Thompson, northwestern Alaska: U.S. Geol. Survey TEI-764, 30 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1961, Geologic investigations in support of Project Chariot, Phase III, in the vicinity of Cape Thompson, northwestern Alaska—Preliminary report: U.S. Geol. Survey TEI-779, 104 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Piper, A. M., 1961, Potential effects of Project Chariot on local water supplies: U.S. Geol. Survey TEI-810, 76 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

U.S. Atomic Energy Commission, 1957, The effects of nuclear weapons: 579 p.

U.S. Department of Commerce, 1959, Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and in water for occupational exposure: Natl. Bur. Standards Handb. 69, 95 p.

TABLES 21–25

TABLE 21.—*Expected dispersal of fission products in fallout from Project Chariot, case I*

[Maximum and minimum concentrations excepted, quantities are mean values for the respective areas, assuming 45 days decay. For maximum concentration, 30 days decay; for minimum, 60 days. Dissolved products infiltrated to soil water, values are zero or nominal in all basins]

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kuk-powruk River	Noatak River	Minor basins, Pitmegea River to Kuk-powruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	----------
FALLOUT BETWEEN AZIMUTHS 40° AND 125° (CASE I.a)													
Products dissolved in runoff and in microponds													
Maximum concentration, all products (μc per ml)	8.0×10^{-1}	1.5×10^{-2}	$>3.0\times10^{-1}$	1.5×10^{-3}	6.0×10^{-4}	1.5×10^{-3}	9.0×10^{-5}	1.5×10^{-4}	3.6×10^{-5}	6.0×10^{-5}	(1)	7.4×10^{-5}	1.5×10^{-5}
Minimum concentration, all products (μc per ml)	$<6.5\times10^{-7}$	7.2×10^{-6}	1.9×10^{-5}	$<5.9\times10^{-7}$	$<8.9\times10^{-7}$	$<5.7\times10^{-7}$	$<5.7\times10^{-7}$	$<5.5\times10^{-7}$	$<6.0\times10^{-7}$	$<6.1\times10^{-7}$	(1)	$<5.3\times10^{-7}$	$<5.7\times10^{-7}$
Average concentration [2] (μc per ml):													
Sr^{90}	3.0×10^{-5}	2.6×10^{-6}	1.0×10^{-5}	4.4×10^{-7}	5.7×10^{-8}	9.4×10^{-8}	2.4×10^{-8}	3.3×10^{-8}	2.0×10^{-8}	2.3×10^{-8}	(1)	2.9×10^{-8}	$<9.3\times10^{-9}$
I^{131}	2.0×10^{-5}	1.7×10^{-6}	6.4×10^{-6}	2.4×10^{-7}	2.9×10^{-8}	5.1×10^{-8}	1.2×10^{-8}	1.7×10^{-8}	1.2×10^{-8}	1.4×10^{-8}	(1)	1.4×10^{-8}	$<5.1\times10^{-9}$
Cs^{137}	1.8×10^{-5}	1.9×10^{-6}	5.8×10^{-6}	2.0×10^{-7}	2.1×10^{-8}	3.9×10^{-8}	1.0×10^{-8}	1.2×10^{-8}	9.2×10^{-9}	1.2×10^{-8}	(1)	8.9×10^{-9}	$<4.0\times10^{-9}$
Other nuclides	2.0×10^{-3}	1.8×10^{-4}	7.0×10^{-4}	2.9×10^{-5}	3.7×10^{-6}	6.1×10^{-6}	1.6×10^{-6}	2.1×10^{-6}	1.3×10^{-6}	1.6×10^{-6}	(1)	1.9×10^{-6}	$<6.1\times10^{-7}$
All products	2.1×10^{-3}	1.9×10^{-4}	7.2×10^{-4}	3.0×10^{-5}	3.8×10^{-6}	6.3×10^{-6}	1.6×10^{-6}	2.2×10^{-6}	1.3×10^{-6}	1.6×10^{-6}	(1)	1.9×10^{-6}	$<6.3\times10^{-7}$
Insoluble particulate products suspended in runoff													
Percent assumed transported	5	5	10	25	35	35	35	50	50	50	--------	50	50
Average concentration [2] (μc per ml):													
Sr^{90} and Cs^{137}, each	1.5×10^{-5}	1.3×10^{-6}	1.1×10^{-5}	1.2×10^{-6}	2.3×10^{-7}	3.7×10^{-7}	9.7×10^{-8}	1.9×10^{-7}	1.1×10^{-7}	1.2×10^{-7}	(1)	1.7×10^{-7}	$<5.2\times10^{-8}$
I^{131}	1.1×10^{-5}	8.8×10^{-7}	7.6×10^{-6}	8.5×10^{-7}	1.6×10^{-7}	2.6×10^{-7}	6.8×10^{-8}	1.3×10^{-7}	7.5×10^{-8}	8.6×10^{-8}	(1)	1.2×10^{-7}	$<3.7\times10^{-8}$
Other nuclides	1.8×10^{-3}	1.5×10^{-4}	1.3×10^{-3}	1.5×10^{-4}	2.6×10^{-5}	4.3×10^{-5}	1.2×10^{-5}	2.2×10^{-5}	1.3×10^{-5}	1.5×10^{-5}	(1)	2.0×10^{-5}	$<6.1\times10^{-6}$
All products	1.8×10^{-3}	1.5×10^{-4}	1.3×10^{-3}	1.5×10^{-4}	2.7×10^{-5}	4.4×10^{-5}	1.2×10^{-5}	2.3×10^{-5}	1.3×10^{-5}	1.5×10^{-5}	(1)	2.0×10^{-5}	$<6.2\times10^{-6}$
Total stream burden													
Dissolved and suspended products [2] (average μc per ml):													
Sr^{90}	4.5×10^{-5}	3.9×10^{-6}	2.1×10^{-5}	1.6×10^{-6}	2.9×10^{-7}	4.6×10^{-7}	1.2×10^{-7}	2.2×10^{-7}	1.3×10^{-7}	1.4×10^{-7}	(1)	2.0×10^{-7}	$<6.1\times10^{-8}$
I^{131}	3.1×10^{-5}	2.6×10^{-6}	1.4×10^{-5}	1.1×10^{-6}	1.9×10^{-7}	3.1×10^{-7}	8.0×10^{-8}	1.5×10^{-7}	8.7×10^{-8}	1.0×10^{-7}	(1)	1.3×10^{-7}	$<4.2\times10^{-8}$
Cs^{137}	3.3×10^{-5}	3.2×10^{-6}	1.7×10^{-5}	1.4×10^{-6}	2.5×10^{-7}	4.1×10^{-7}	1.1×10^{-7}	2.0×10^{-7}	1.2×10^{-7}	1.3×10^{-7}	(1)	1.8×10^{-7}	$<5.6\times10^{-8}$
Other nuclides	3.8×10^{-3}	2.8×10^{-4}	1.9×10^{-3}	1.8×10^{-4}	3.0×10^{-5}	4.9×10^{-5}	1.3×10^{-5}	2.5×10^{-5}	1.4×10^{-5}	1.6×10^{-5}	(1)	2.1×10^{-5}	$<6.6\times10^{-6}$
All products	3.9×10^{-3}	2.9×10^{-4}	2.0×10^{-3}	1.8×10^{-4}	3.1×10^{-5}	5.0×10^{-5}	1.4×10^{-5}	2.5×10^{-5}	1.4×10^{-5}	1.7×10^{-5}	(1)	2.2×10^{-5}	$<6.8\times10^{-6}$
Products adsorbed [3]													
Products on vegetation (c per mi^2):													
Sr^{90}	8.2×10^{-1}	6.7×10^{-2}	2.9×10^{-1}	1.3×10^{-2}	1.8×10^{-3}	2.8×10^{-3}	7.4×10^{-4}	1.0×10^{-3}	5.7×10^{-4}	6.6×10^{-4}	(1)	9.1×10^{-4}	$<2.8\times10^{-4}$
I^{131}	1.2×10^{0}	1.0×10^{-1}	4.3×10^{-1}	1.9×10^{-2}	2.6×10^{-3}	4.2×10^{-3}	1.1×10^{-3}	1.5×10^{-3}	8.5×10^{-4}	9.9×10^{-4}	(1)	1.4×10^{-3}	$<4.2\times10^{-4}$
Cs^{137}	2.2×10^{0}	1.8×10^{-1}	7.9×10^{-1}	3.5×10^{-2}	4.8×10^{-3}	7.7×10^{-3}	2.0×10^{-3}	2.8×10^{-3}	1.5×10^{-3}	1.8×10^{-3}	(1)	2.5×10^{-3}	$<7.6\times10^{-4}$
Other nuclides	8.2×10^{1}	6.7×10^{0}	2.8×10^{1}	1.3×10^{0}	1.7×10^{-1}	2.9×10^{-1}	7.3×10^{-2}	1.0×10^{-1}	5.7×10^{-2}	6.6×10^{-2}	(1)	9.1×10^{-2}	$<2.8\times10^{-2}$
All products	8.6×10^{1}	7.0×10^{0}	3.0×10^{1}	1.4×10^{0}	1.8×10^{-1}	3.0×10^{-1}	7.7×10^{-2}	1.1×10^{-1}	6.0×10^{-2}	6.9×10^{-2}	(1)	9.6×10^{-2}	$<2.9\times10^{-2}$
Products on soil (c per mi^2):													
Sr^{90}	4.3×10^{-1}	3.5×10^{-2}	1.5×10^{-1}	6.8×10^{-3}	9.1×10^{-4}	1.5×10^{-3}	3.8×10^{-4}	5.3×10^{-4}	3.0×10^{-4}	3.4×10^{-4}	(1)	4.7×10^{-4}	$<1.4\times10^{-4}$
I^{131}	1.8×10^{-1}	1.4×10^{-2}	6.2×10^{-2}	2.8×10^{-3}	3.8×10^{-4}	6.1×10^{-4}	1.6×10^{-4}	2.2×10^{-4}	1.2×10^{-4}	1.4×10^{-4}	(1)	2.0×10^{-4}	$<6.0\times10^{-5}$
Cs^{137}	2.6×10^{0}	2.1×10^{-1}	9.2×10^{-1}	4.1×10^{-2}	5.6×10^{-3}	9.0×10^{-3}	2.3×10^{-3}	3.3×10^{-3}	1.8×10^{-3}	2.1×10^{-3}	(1)	2.9×10^{-3}	$<8.9\times10^{-4}$
Other nuclides	9.1×10^{1}	7.4×10^{0}	3.2×10^{1}	1.4×10^{0}	1.9×10^{-1}	3.1×10^{-1}	8.1×10^{-2}	1.2×10^{-1}	6.3×10^{-2}	7.2×10^{-2}	(1)	9.6×10^{-2}	$<3.1\times10^{-2}$
All products	9.4×10^{1}	7.7×10^{0}	3.3×10^{1}	1.5×10^{0}	2.0×10^{-1}	3.2×10^{-1}	8.4×10^{-2}	1.2×10^{-1}	6.5×10^{-2}	7.5×10^{-2}	(1)	1.0×10^{-1}	$<3.2\times10^{-2}$
Products on rock, talus, and colluvium (c per mi^2):													
Sr^{90}	5.0×10^{-3}	4.1×10^{-4}	1.7×10^{-3}	7.9×10^{-5}	1.1×10^{-5}	1.7×10^{-5}	4.5×10^{-6}	6.2×10^{-6}	3.5×10^{-6}	4.0×10^{-6}	(1)	5.5×10^{-6}	$<1.7\times10^{-6}$
I^{131}	2.0×10^{-3}	1.7×10^{-4}	7.2×10^{-4}	3.2×10^{-5}	4.4×10^{-6}	7.1×10^{-6}	1.8×10^{-6}	2.6×10^{-6}	1.4×10^{-6}	1.6×10^{-6}	(1)	2.3×10^{-6}	$<7.0\times10^{-7}$
Cs^{137}	9.1×10^{-2}	7.4×10^{-3}	3.2×10^{-2}	1.4×10^{-3}	1.9×10^{-4}	3.1×10^{-4}	8.2×10^{-5}	1.1×10^{-4}	6.3×10^{-5}	7.3×10^{-5}	(1)	1.0×10^{-4}	$<3.1\times10^{-5}$
Other nuclides	1.5×10^{0}	1.2×10^{-1}	5.2×10^{-1}	2.3×10^{-2}	3.2×10^{-3}	5.0×10^{-3}	1.3×10^{-3}	1.9×10^{-3}	1.0×10^{-3}	1.2×10^{-3}	(1)	1.6×10^{-3}	$<5.1\times10^{-4}$
All products	1.6×10^{0}	1.3×10^{-1}	5.5×10^{-1}	2.5×10^{-2}	3.4×10^{-3}	5.4×10^{-3}	1.4×10^{-3}	2.0×10^{-3}	1.1×10^{-3}	1.3×10^{-3}	(1)	1.7×10^{-3}	$<5.4\times10^{-4}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.5×10^{1}	2.0×10^{0}	8.4×10^{0}	3.1×10^{-1}	3.7×10^{-2}	5.9×10^{-2}	1.5×10^{-2}	1.7×10^{-2}	9.2×10^{-3}	1.1×10^{-2}	(1)	1.5×10^{-2}	$<4.5\times10^{-3}$
I^{131}	1.8×10^{1}	1.4×10^{0}	5.8×10^{0}	2.2×10^{-1}	2.6×10^{-2}	4.1×10^{-2}	1.1×10^{-2}	1.2×10^{-2}	6.4×10^{-3}	7.4×10^{-3}	(1)	1.0×10^{-2}	$<3.1\times10^{-3}$
Other nuclides	2.9×10^{3}	2.3×10^{2}	9.7×10^{2}	3.6×10^{1}	4.2×10^{0}	6.8×10^{0}	1.8×10^{0}	2.0×10^{0}	1.1×10^{0}	1.3×10^{0}	(1)	1.7×10^{0}	$<5.2\times10^{-1}$
All products	3.0×10^{3}	2.4×10^{2}	9.9×10^{2}	3.7×10^{1}	4.3×10^{0}	7.0×10^{0}	1.8×10^{0}	2.0×10^{0}	1.1×10^{0}	1.3×10^{0}	(1)	1.7×10^{0}	$<5.3\times10^{-1}$

See footnotes at end of table.

TABLE 21.—*Expected dispersal of fission products in fallout from Project Chariot, case I*—Continued

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	----------
FALLOUT BETWEEN AZIMUTHS 25° AND 110° (CASE I.b)													
Products dissolved in runoff and in microponds													
Maximum concentration, all products (μc per ml)	8.0×10^{-1}	3.0×10^{-2}	$>3.0\times10^{-1}$	6.0×10^{-3}	3.6×10^{-3}	3.0×10^{-4}	3.9×10^{-4}	(1)	1.9×10^{-4}	(1)	7.4×10^{-4}	(1)	1.5×10^{-5}
Minimum concentration, all products (μc per ml)	1.0×10^{-4}	4.3×10^{-5}	$<6.4\times10^{-7}$	$<5.9\times10^{-7}$	$<5.5\times10^{-7}$	$<5.7\times10^{-7}$	$<5.7\times10^{-7}$	(1)	$<6.0\times10^{-7}$	(1)	$<5.7\times10^{-7}$	(1)	$<5.7\times10^{-7}$
Average concentration [2] (μc per ml):													
Sr^{90}	3.1×10^{-5}	3.5×10^{-6}	1.5×10^{-5}	2.5×10^{-7}	5.0×10^{-7}	3.3×10^{-8}	4.8×10^{-8}	(1)	4.0×10^{-8}	(1)	2.5×10^{-8}	(1)	$<9.3\times10^{-9}$
I^{131}	2.0×10^{-5}	2.3×10^{-6}	9.5×10^{-6}	1.4×10^{-7}	2.5×10^{-7}	1.8×10^{-8}	2.4×10^{-8}	(1)	2.4×10^{-8}	(1)	1.4×10^{-8}	(1)	$<5.1\times10^{-9}$
Cs^{137}	1.8×10^{-5}	2.6×10^{-6}	8.7×10^{-6}	1.1×10^{-7}	1.9×10^{-7}	1.4×10^{-8}	2.0×10^{-8}	(1)	1.9×10^{-8}	(1)	1.1×10^{-8}	(1)	$<4.0\times10^{-9}$
Other nuclides	2.0×10^{-3}	2.4×10^{-4}	1.1×10^{-3}	1.7×10^{-5}	3.2×10^{-5}	2.1×10^{-6}	3.1×10^{-6}	(1)	2.6×10^{-6}	(1)	1.7×10^{-6}	(1)	$<6.1\times10^{-7}$
All products	2.1×10^{-3}	2.5×10^{-4}	1.1×10^{-3}	1.7×10^{-5}	3.3×10^{-5}	2.2×10^{-6}	3.2×10^{-6}	(1)	2.7×10^{-6}	(1)	1.7×10^{-6}	(1)	$<6.2\times10^{-7}$
Insoluble particulate products suspended in runoff													
Percent assumed transported	5	5	10	25	35	35	35	--------	50	--------	50	----------	50
Average concentration [2] (μc per ml):													
Sr^{90} and Cs^{137}, each	1.6×10^{-5}	1.7×10^{-6}	1.6×10^{-5}	7.0×10^{-7}	2.0×10^{-6}	1.3×10^{-7}	1.9×10^{-7}	(1)	2.2×10^{-7}	(1)	1.4×10^{-7}	(1)	$<5.2\times10^{-8}$
I^{131}	1.1×10^{-5}	1.2×10^{-6}	1.1×10^{-5}	4.9×10^{-7}	1.4×10^{-6}	9.0×10^{-8}	1.3×10^{-7}	(1)	1.5×10^{-7}	(1)	9.9×10^{-8}	(1)	$<3.7\times10^{-8}$
Other nuclides	1.9×10^{-3}	2.0×10^{-4}	1.9×10^{-3}	8.1×10^{-5}	2.3×10^{-4}	1.5×10^{-5}	2.2×10^{-5}	(1)	2.5×10^{-5}	(1)	1.7×10^{-5}	(1)	$<6.1\times10^{-6}$
All products	1.9×10^{-3}	2.0×10^{-4}	1.9×10^{-3}	8.3×10^{-5}	2.4×10^{-4}	1.5×10^{-5}	2.3×10^{-5}	(1)	2.6×10^{-5}	(1)	1.7×10^{-5}	(1)	$<6.2\times10^{-6}$
Total stream burden													
Dissolved and suspended products [2] (average μc per ml).													
Sr^{90}	4.7×10^{-5}	5.2×10^{-6}	3.1×10^{-5}	9.5×10^{-7}	2.5×10^{-6}	1.6×10^{-7}	2.4×10^{-7}	(1)	2.6×10^{-7}	(1)	1.6×10^{-7}	(1)	$<6.1\times10^{-8}$
I^{131}	3.1×10^{-5}	3.5×10^{-6}	2.0×10^{-5}	6.3×10^{-7}	1.6×10^{-6}	1.1×10^{-7}	1.5×10^{-7}	(1)	1.7×10^{-7}	(1)	1.1×10^{-7}	(1)	$<4.2\times10^{-8}$
Cs^{137}	3.4×10^{-5}	4.3×10^{-6}	2.5×10^{-5}	8.1×10^{-7}	2.2×10^{-6}	1.4×10^{-7}	2.1×10^{-7}	(1)	2.4×10^{-7}	(1)	1.5×10^{-7}	(1)	$<5.6\times10^{-8}$
Other nuclides	3.9×10^{-3}	4.4×10^{-4}	2.9×10^{-3}	1.0×10^{-4}	2.6×10^{-4}	1.7×10^{-5}	2.5×10^{-5}	(1)	2.8×10^{-5}	(1)	1.9×10^{-5}	(1)	$<6.6\times10^{-6}$
All products	4.0×10^{-3}	4.5×10^{-4}	3.0×10^{-3}	1.0×10^{-4}	2.7×10^{-4}	1.7×10^{-5}	2.6×10^{-5}	(1)	2.9×10^{-5}	(1)	1.9×10^{-5}	(1)	$<6.8\times10^{-6}$
Products adsorbed [3]													
Products on vegetation (c per mi^2):													
Sr^{90}	8.4×10^{-1}	9.1×10^{-2}	4.3×10^{-1}	7.4×10^{-3}	1.5×10^{-2}	9.8×10^{-4}	1.5×10^{-3}	(1)	1.2×10^{-3}	(1)	7.6×10^{-4}	(1)	$<2.8\times10^{-4}$
I^{131}	1.3×10^{0}	1.4×10^{-1}	6.5×10^{-1}	1.1×10^{-2}	2.3×10^{-2}	1.5×10^{-3}	2.2×10^{-3}	(1)	1.7×10^{-3}	(1)	1.1×10^{-3}	(1)	$<4.2\times10^{-4}$
Cs^{137}	2.3×10^{0}	2.5×10^{-1}	1.2×10^{0}	2.0×10^{-2}	4.2×10^{-2}	2.7×10^{-3}	4.0×10^{-3}	(1)	3.1×10^{-3}	(1)	2.1×10^{-3}	(1)	$<7.6\times10^{-4}$
Other nuclides	8.4×10^{1}	9.0×10^{0}	4.3×10^{1}	7.4×10^{-1}	1.5×10^{0}	9.5×10^{-2}	1.4×10^{-1}	(1)	1.1×10^{-1}	(1)	7.5×10^{-2}	(1)	$<2.8\times10^{-2}$
All products	8.8×10^{1}	9.5×10^{0}	4.5×10^{1}	7.8×10^{-1}	1.6×10^{0}	1.0×10^{-1}	1.5×10^{-1}	(1)	1.2×10^{-1}	(1)	7.9×10^{-2}	(1)	$<2.9\times10^{-2}$
Products on soil (c per mi^2):													
Sr^{90}	4.4×10^{-1}	4.7×10^{-2}	2.2×10^{-1}	3.9×10^{-3}	8.0×10^{-3}	5.1×10^{-4}	7.6×10^{-4}	(1)	6.0×10^{-4}	(1)	3.9×10^{-4}	(1)	$<1.4\times10^{-4}$
I^{131}	1.8×10^{-1}	2.0×10^{-2}	9.3×10^{-2}	1.6×10^{-3}	3.3×10^{-3}	2.1×10^{-4}	3.2×10^{-4}	(1)	2.5×10^{-4}	(1)	1.6×10^{-4}	(1)	$<6.0\times10^{-5}$
Cs^{137}	2.7×10^{0}	2.9×10^{-1}	1.4×10^{0}	2.4×10^{-2}	4.9×10^{-2}	3.1×10^{-3}	4.7×10^{-3}	(1)	3.7×10^{-3}	(1)	2.4×10^{-3}	(1)	$<8.9\times10^{-4}$
Other nuclides	9.3×10^{1}	9.6×10^{0}	4.7×10^{1}	8.2×10^{-1}	1.7×10^{0}	1.1×10^{-1}	1.6×10^{-1}	(1)	1.3×10^{-1}	(1)	8.3×10^{-2}	(1)	$<3.1\times10^{-2}$
All products	9.6×10^{1}	1.0×10^{1}	4.9×10^{1}	8.5×10^{-1}	1.8×10^{0}	1.1×10^{-1}	1.7×10^{-1}	(1)	1.3×10^{-1}	(1)	8.6×10^{-2}	(1)	$<3.2\times10^{-2}$
Products on rock, talus, and and colluvium (c per mi^2):													
Sr^{90}	5.1×10^{-3}	5.5×10^{-4}	2.6×10^{-3}	4.5×10^{-5}	9.4×10^{-5}	6.0×10^{-6}	8.9×10^{-6}	(1)	7.0×10^{-6}	(1)	4.6×10^{-6}	(1)	$<1.7\times10^{-6}$
I^{131}	2.1×10^{-3}	2.3×10^{-4}	1.1×10^{-3}	1.9×10^{-5}	3.9×10^{-5}	2.4×10^{-6}	3.7×10^{-6}	(1)	2.9×10^{-6}	(1)	1.9×10^{-6}	(1)	$<7.0\times10^{-7}$
Cs^{137}	9.3×10^{-2}	1.0×10^{-2}	4.8×10^{-2}	8.2×10^{-4}	1.7×10^{-3}	1.1×10^{-4}	1.6×10^{-4}	(1)	1.3×10^{-4}	(1)	8.3×10^{-5}	(1)	$<3.1\times10^{-5}$
Other nuclides	1.5×10^{0}	1.6×10^{-1}	7.8×10^{-1}	1.3×10^{-2}	2.8×10^{-2}	1.8×10^{-3}	2.6×10^{-3}	(1)	2.1×10^{-3}	(1)	1.3×10^{-3}	(1)	$<5.1\times10^{-4}$
All products	1.6×10^{0}	1.7×10^{-1}	8.3×10^{-1}	1.4×10^{-2}	3.0×10^{-2}	1.9×10^{-3}	2.8×10^{-3}	(1)	2.2×10^{-3}	(1)	1.4×10^{-3}	(1)	$<5.4\times10^{-4}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.8×10^{0}	1.2×10^{1}	1.8×10^{-1}	3.2×10^{-1}	2.1×10^{-2}	3.1×10^{-2}	(1)	1.9×10^{-2}	(1)	1.2×10^{-2}	(1)	$<4.5\times10^{-3}$
I^{131}	1.8×10^{1}	1.9×10^{0}	8.7×10^{0}	1.3×10^{-1}	2.3×10^{-1}	1.4×10^{-2}	2.1×10^{-2}	(1)	1.3×10^{-2}	(1)	8.5×10^{-3}	(1)	$<3.1\times10^{-3}$
Other nuclides	3.0×10^{3}	3.2×10^{2}	1.5×10^{3}	2.1×10^{1}	3.7×10^{1}	2.3×10^{0}	3.5×10^{0}	(1)	2.1×10^{0}	(1)	1.4×10^{0}	(1)	$<5.2\times10^{-1}$
All products	3.1×10^{3}	3.3×10^{2}	1.5×10^{3}	2.1×10^{1}	3.8×10^{1}	2.4×10^{0}	3.6×10^{0}	(1)	2.2×10^{0}	(1)	1.4×10^{0}	(1)	$<5.3\times10^{-1}$

[1] Zero or nominal.

[2] Average during the 30 days of snowmelt runoff, in trunk streams at outer margin of the area of measurable fallout: also in microponds within the area of fallout. It is expected that throwout would dam Ogotoruk Creek and pond the runoff in the lower part of that basin, at least temporarily.

[3] Adsorption scaled to mean K_d's times 10^{-3}, as explained in text (p. 28).

TABLE 22.—*Expected dispersal of fission products in fallout from Project Chariot, case II*

[Quantities are mean values for the respective areas, assuming 15 days decay. Insoluble particulate products suspended in runoff, values are zero or nominal in all basins; in consequence, values for total stream burden are the same as those for products dissolved in runoff]

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	----------
FALLOUT BETWEEN AZIMUTHS 40° AND 125° (CASE II.a)													
Products dissolved in runoff													
Average concentration [1] (μc per ml):													
Sr^{90}	2.4×10^{-6}	2.8×10^{-7}	7.5×10^{-7}	1.8×10^{-8}	1.5×10^{-9}	3.2×10^{-9}	8.0×10^{-10}	7.1×10^{-10}	9.9×10^{-10}	1.3×10^{-9}	(2)	2.2×10^{-10}	$<3.5\times10^{-10}$
I^{131}	2.9×10^{-5}	3.5×10^{-6}	9.1×10^{-6}	2.3×10^{-7}	1.7×10^{-8}	3.9×10^{-8}	9.3×10^{-9}	8.6×10^{-9}	1.2×10^{-8}	1.7×10^{-8}	(2)	2.5×10^{-9}	$<4.2\times10^{-9}$
Cs^{137}	1.9×10^{-7}	2.3×10^{-8}	1.0×10^{-7}	1.5×10^{-9}	4.3×10^{-10}	2.6×10^{-10}	1.8×10^{-10}	5.7×10^{-11}	8.9×10^{-11}	1.1×10^{-10}	(2)	1.7×10^{-11}	$<4.2\times10^{-11}$
Other nuclides	2.1×10^{-4}	2.4×10^{-5}	7.4×10^{-5}	1.7×10^{-6}	2.0×10^{-7}	2.9×10^{-7}	1.0×10^{-7}	6.4×10^{-8}	8.7×10^{-8}	1.1×10^{-7}	(2)	2.1×10^{-8}	$<3.3\times10^{-8}$
All products	2.4×10^{-4}	2.8×10^{-5}	8.4×10^{-5}	1.9×10^{-6}	2.2×10^{-7}	3.3×10^{-7}	1.1×10^{-7}	7.3×10^{-8}	1.0×10^{-7}	1.3×10^{-7}	(2)	2.4×10^{-8}	$<3.8\times10^{-8}$
Products adsorbed [3]													
Products on vegetation (c per mi [2]):													
Sr^{90}	2.9×10^{0}	2.4×10^{-1}	1.0×10^{0}	4.6×10^{-2}	6.2×10^{-3}	1.0×10^{-2}	2.6×10^{-3}	3.7×10^{-3}	2.0×10^{-3}	2.4×10^{-3}	(2)	3.2×10^{-3}	$<1.0\times10^{-3}$
I^{131}	2.7×10^{1}	2.2×10^{0}	9.5×10^{0}	4.3×10^{-1}	5.8×10^{-2}	9.3×10^{-2}	2.4×10^{-2}	3.4×10^{-2}	1.9×10^{-2}	2.2×10^{-2}	(2)	3.0×10^{-2}	$<9.2\times10^{-3}$
Cs^{137}	2.9×10^{0}	2.4×10^{-1}	1.0×10^{0}	4.7×10^{-2}	6.3×10^{-3}	1.0×10^{-2}	2.6×10^{-3}	3.7×10^{-3}	2.0×10^{-3}	2.4×10^{-3}	(2)	3.3×10^{-3}	$<1.0\times10^{-3}$
Other nuclides	8.3×10^{2}	6.7×10^{1}	2.9×10^{2}	1.3×10^{1}	1.7×10^{0}	2.9×10^{0}	7.4×10^{-1}	1.1×10^{0}	5.8×10^{-1}	6.6×10^{-1}	(2)	9.1×10^{-1}	$<2.8\times10^{-1}$
All products	8.6×10^{2}	7.0×10^{1}	3.0×10^{2}	1.4×10^{1}	1.8×10^{0}	3.0×10^{0}	7.7×10^{-1}	1.1×10^{0}	6.0×10^{-1}	6.9×10^{-1}	(2)	9.5×10^{-1}	$<2.9\times10^{-1}$
Products on soil (c per mi [2]):													
Sr^{90}	2.9×10^{0}	2.4×10^{-1}	1.0×10^{0}	4.6×10^{-2}	6.2×10^{-3}	1.0×10^{-2}	2.6×10^{-3}	3.7×10^{-3}	2.0×10^{-3}	2.3×10^{-3}	(2)	3.2×10^{-3}	$<9.9\times10^{-4}$
I^{131}	2.7×10^{1}	2.2×10^{0}	9.4×10^{0}	4.2×10^{-1}	5.7×10^{-2}	9.2×10^{-2}	2.4×10^{-2}	3.4×10^{-2}	1.9×10^{-2}	2.1×10^{-2}	(2)	3.0×10^{-2}	$<9.1\times10^{-3}$
Cs^{137}	2.9×10^{0}	2.4×10^{-1}	1.0×10^{0}	4.7×10^{-2}	6.3×10^{-3}	1.0×10^{-2}	2.6×10^{-3}	3.7×10^{-3}	2.0×10^{-3}	2.4×10^{-3}	(2)	3.3×10^{-3}	$<1.0\times10^{-3}$
Other nuclides	8.3×10^{2}	6.7×10^{1}	2.9×10^{2}	1.3×10^{1}	1.7×10^{0}	2.9×10^{0}	7.4×10^{-1}	1.1×10^{0}	5.8×10^{-1}	6.6×10^{-1}	(2)	9.1×10^{-1}	$<2.8\times10^{-1}$
All products	8.6×10^{2}	7.0×10^{1}	3.0×10^{2}	1.4×10^{1}	1.8×10^{0}	3.0×10^{0}	7.7×10^{-1}	1.1×10^{0}	6.0×10^{-1}	6.9×10^{-1}	(2)	9.5×10^{-1}	$<2.9\times10^{-1}$
Products on rock, talus, and colluvium (c per mi [2]):													
Sr^{90}	1.8×10^{0}	1.5×10^{-1}	6.5×10^{-1}	2.9×10^{-2}	3.9×10^{-3}	6.4×10^{-3}	1.7×10^{-3}	2.3×10^{-3}	1.3×10^{-3}	1.5×10^{-3}	(2)	2.1×10^{-3}	$<6.3\times10^{-4}$
I^{131}	1.4×10^{1}	1.1×10^{0}	4.8×10^{0}	2.1×10^{-1}	2.9×10^{-2}	4.7×10^{-2}	1.2×10^{-2}	1.7×10^{-2}	9.4×10^{-3}	1.1×10^{-2}	(2)	1.5×10^{-2}	$<4.6\times10^{-3}$
Cs^{137}	2.8×10^{0}	2.3×10^{-1}	1.0×10^{0}	4.5×10^{-2}	6.1×10^{-3}	9.8×10^{-3}	2.6×10^{-3}	3.6×10^{-3}	2.0×10^{-3}	2.3×10^{-3}	(2)	3.2×10^{-3}	$<9.7\times10^{-4}$
Other nuclides	7.3×10^{2}	6.0×10^{1}	2.5×10^{2}	1.2×10^{1}	1.6×10^{0}	2.5×10^{0}	6.5×10^{-1}	9.2×10^{-1}	5.1×10^{-1}	5.9×10^{-1}	(2)	8.1×10^{-1}	$<2.5\times10^{-1}$
All products	7.5×10^{2}	6.1×10^{1}	2.6×10^{2}	1.2×10^{1}	1.6×10^{0}	2.6×10^{0}	6.7×10^{-1}	9.4×10^{-1}	5.2×10^{-1}	6.0×10^{-1}	(2)	8.3×10^{-1}	$<2.6\times10^{-1}$
Dissolved products infiltrated to soil water													
Products (c per mi [2]):													
Sr^{90}	4.8×10^{-1}	5.7×10^{-2}	1.5×10^{-1}	3.8×10^{-3}	3.1×10^{-4}	6.5×10^{-4}	1.6×10^{-4}	1.4×10^{-4}	2.0×10^{-4}	2.7×10^{-4}	(2)	4.5×10^{-5}	$<7.1\times10^{-5}$
I^{131}	6.0×10^{0}	7.1×10^{-1}	1.9×10^{0}	4.6×10^{-2}	3.5×10^{-3}	8.0×10^{-3}	1.9×10^{-3}	1.8×10^{-3}	2.5×10^{-3}	3.4×10^{-3}	(2)	5.0×10^{-4}	$<8.6\times10^{-4}$
Cs^{137}	3.9×10^{-2}	4.7×10^{-3}	2.1×10^{-2}	3.1×10^{-4}	8.8×10^{-5}	5.3×10^{-5}	3.7×10^{-5}	1.2×10^{-5}	1.8×10^{-5}	2.2×10^{-5}	(2)	3.5×10^{-6}	$<8.5\times10^{-6}$
Other nuclides	4.1×10^{1}	4.9×10^{0}	1.5×10^{1}	3.3×10^{-1}	4.1×10^{-2}	5.7×10^{-2}	2.0×10^{-2}	1.3×10^{-2}	1.8×10^{-2}	2.3×10^{-2}	(2)	4.4×10^{-3}	$<6.8\times10^{-3}$
All products	4.8×10^{1}	5.7×10^{0}	1.7×10^{1}	3.8×10^{-1}	4.5×10^{-2}	6.6×10^{-2}	2.2×10^{-2}	1.5×10^{-2}	2.1×10^{-2}	2.7×10^{-2}	(2)	4.9×10^{-3}	$<7.7\times10^{-3}$
Insoluble particulate products remaining near place of fall													
Products (c per mi [2]):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.2×10^{0}	9.3×10^{0}	4.2×10^{-1}	5.6×10^{-2}	9.1×10^{-2}	2.4×10^{-2}	3.3×10^{-2}	1.8×10^{-2}	2.1×10^{-2}	(2)	2.9×10^{-2}	$<9.0\times10^{-3}$
I^{131}	2.4×10^{2}	2.0×10^{1}	8.6×10^{1}	3.9×10^{0}	5.2×10^{-1}	8.4×10^{-1}	2.2×10^{-1}	3.0×10^{-1}	1.7×10^{-1}	2.0×10^{-1}	(2)	2.7×10^{-1}	$<8.3\times10^{-2}$
Other nuclides	1.2×10^{4}	9.4×10^{2}	4.0×10^{3}	1.9×10^{2}	2.4×10^{1}	3.9×10^{1}	1.1×10^{1}	1.5×10^{1}	7.9×10^{0}	9.2×10^{0}	(2)	1.3×10^{1}	$<3.9\times10^{0}$
All products	1.2×10^{4}	9.6×10^{2}	4.1×10^{3}	1.9×10^{2}	2.5×10^{1}	4.0×10^{1}	1.1×10^{1}	1.5×10^{1}	8.1×10^{0}	9.4×10^{0}	(2)	1.3×10^{1}	$<4.0\times10^{0}$

See footnotes at end of table.

TABLE 22.—*Expected dispersal of fission products in fallout from Project Chariot, case II*—Continued

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	------------
FALLOUT BETWEEN AZIMUTHS 25° AND 110° (CASE II.b)													
Products dissolved in runoff													
Average concentration [1] (μc per ml):													
Sr^{90}	2.4×10^{-6}	3.8×10^{-7}	1.1×10^{-6}	1.1×10^{-8}	1.3×10^{-8}	1.1×10^{-9}	1.6×10^{-9}	(2)	2.0×10^{-9}	(2)	9.4×10^{-10}	(2)	$<3.5\times10^{-10}$
I^{131}	3.0×10^{-5}	4.7×10^{-6}	1.4×10^{-5}	1.3×10^{-7}	1.5×10^{-7}	1.4×10^{-8}	1.9×10^{-8}	(2)	2.5×10^{-8}	(2)	1.1×10^{-8}	(2)	$<4.2\times10^{-9}$
Cs^{137}	2.0×10^{-7}	3.1×10^{-8}	1.5×10^{-7}	8.7×10^{-10}	3.8×10^{-9}	9.1×10^{-11}	3.7×10^{-10}	(2)	1.8×10^{-10}	(2)	1.1×10^{-10}	(2)	$<4.2\times10^{-11}$
Other nuclides	2.1×10^{-4}	3.3×10^{-5}	1.0×10^{-4}	9.6×10^{-7}	1.7×10^{-6}	9.5×10^{-8}	1.9×10^{-7}	(2)	1.8×10^{-7}	(2)	8.8×10^{-8}	(2)	$<3.3\times10^{-8}$
All products	2.4×10^{-4}	3.8×10^{-5}	1.2×10^{-4}	1.1×10^{-6}	1.9×10^{-6}	1.1×10^{-7}	2.1×10^{-7}	(2)	2.1×10^{-7}	(2)	1.0×10^{-7}	(2)	$<3.8\times10^{-8}$
Products adsorbed [3]													
Products on vegetation (c per mi^2):													
Sr^{90}	3.0×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.5×10^{-2}	3.5×10^{-3}	5.2×10^{-3}	(2)	4.1×10^{-3}	(2)	2.7×10^{-3}	(2)	$<1.0\times10^{-3}$
I^{131}	2.8×10^{1}	3.0×10^{0}	1.4×10^{1}	2.4×10^{-1}	5.1×10^{-1}	3.2×10^{-2}	4.8×10^{-2}	(2)	3.8×10^{-2}	(2)	2.5×10^{-2}	(2)	$<9.2\times10^{-3}$
Cs^{137}	3.0×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.7×10^{-2}	5.5×10^{-2}	3.5×10^{-3}	5.3×10^{-3}	(2)	4.1×10^{-3}	(2)	2.7×10^{-3}	(2)	$<1.0\times10^{-3}$
Other nuclides	8.6×10^{2}	9.1×10^{1}	4.3×10^{2}	7.5×10^{0}	1.5×10^{1}	9.6×10^{-1}	1.4×10^{0}	(2)	1.2×10^{0}	(2)	7.6×10^{-1}	(2)	$<2.8\times10^{-1}$
All products	8.9×10^{2}	9.5×10^{1}	4.5×10^{2}	7.8×10^{0}	1.6×10^{1}	1.0×10^{0}	1.5×10^{0}	(2)	1.2×10^{0}	(2)	7.9×10^{-1}	(2)	$<2.9\times10^{-1}$
Products on soil (c per mi^2):													
Sr^{90}	3.0×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.5×10^{-2}	3.5×10^{-3}	5.2×10^{-3}	(2)	4.1×10^{-3}	(2)	2.7×10^{-3}	(2)	$<9.9\times10^{-4}$
I^{131}	2.7×10^{1}	3.0×10^{0}	1.4×10^{1}	2.4×10^{-1}	5.0×10^{-1}	3.2×10^{-2}	4.8×10^{-2}	(2)	3.8×10^{-2}	(2)	2.5×10^{-2}	(1)	$<9.1\times10^{-3}$
Cs^{137}	3.0×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.7×10^{-2}	5.5×10^{-2}	3.5×10^{-3}	5.3×10^{-3}	(2)	4.1×10^{-3}	(2)	2.7×10^{-3}	(2)	$<1.0\times10^{-3}$
Other nuclides	8.5×10^{2}	9.1×10^{1}	4.3×10^{2}	7.5×10^{0}	1.5×10^{1}	9.6×10^{-1}	1.4×10^{0}	(2)	1.2×10^{0}	(2)	7.6×10^{-1}	(2)	$<2.8\times10^{-1}$
All products	8.8×10^{2}	9.5×10^{1}	4.5×10^{2}	7.8×10^{0}	1.6×10^{0}	1.0×10^{0}	1.5×10^{0}	(2)	1.2×10^{0}	(2)	7.9×10^{-1}	(2)	$<2.9\times10^{-1}$
Products on rock, talus, and colluvium (c per mi^2):													
Sr^{90}	1.9×10^{0}	2.0×10^{-1}	9.7×10^{-1}	1.7×10^{-2}	3.5×10^{-2}	2.2×10^{-3}	3.3×10^{-3}	(2)	2.6×10^{-3}	(2)	1.7×10^{-3}	(2)	$<6.3\times10^{-4}$
I^{131}	1.4×10^{1}	1.5×10^{0}	7.1×10^{0}	1.2×10^{-1}	2.5×10^{-1}	1.6×10^{-2}	2.4×10^{-2}	(2)	1.9×10^{-2}	(2)	1.2×10^{-2}	(2)	$<4.6\times10^{-3}$
Cs^{137}	2.9×10^{0}	3.1×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.4×10^{-2}	3.4×10^{-3}	5.1×10^{-3}	(2)	4.0×10^{-3}	(2)	2.6×10^{-3}	(2)	$<9.7\times10^{-4}$
Other nuclides	7.5×10^{2}	8.1×10^{1}	3.8×10^{2}	6.6×10^{0}	1.4×10^{1}	8.8×10^{-1}	1.3×10^{0}	(2)	1.1×10^{0}	(2)	6.7×10^{-1}	(2)	$<2.5\times10^{-1}$
All products	7.7×10^{2}	8.3×10^{1}	3.9×10^{2}	6.8×10^{0}	1.4×10^{1}	9.0×10^{-1}	1.3×10^{0}	(2)	1.1×10^{0}	(2)	6.9×10^{-1}	(2)	$<2.6\times10^{-1}$
Dissolved products infiltrated to soil water													
Products (c per mi^2):													
Sr^{90}	4.9×10^{-1}	7.7×10^{-2}	2.3×10^{-1}	2.1×10^{-3}	2.7×10^{-3}	2.3×10^{-4}	3.2×10^{-4}	(2)	4.1×10^{-4}	(2)	1.9×10^{-4}	(2)	$<7.1\times10^{-5}$
I^{131}	6.2×10^{0}	9.6×10^{-1}	2.8×10^{0}	2.6×10^{-2}	3.1×10^{-2}	2.8×10^{-3}	3.8×10^{-3}	(2)	5.1×10^{-3}	(2)	2.3×10^{-3}	(2)	$<8.6\times10^{-4}$
Cs^{137}	4.0×10^{-2}	6.3×10^{-3}	3.1×10^{-2}	1.8×10^{-4}	7.8×10^{-4}	1.8×10^{-5}	7.4×10^{-5}	(2)	3.7×10^{-5}	(2)	2.3×10^{-5}	(2)	$<8.5\times10^{-6}$
Other nuclides	4.2×10^{1}	6.7×10^{0}	2.2×10^{1}	1.9×10^{-1}	3.7×10^{-1}	2.0×10^{-2}	3.9×10^{-2}	(2)	3.6×10^{-2}	(2)	1.8×10^{-2}	(2)	$<6.8\times10^{-3}$
All products	4.9×10^{1}	7.7×10^{0}	2.5×10^{1}	2.2×10^{-1}	4.0×10^{-1}	2.3×10^{-2}	4.3×10^{-2}	(2)	4.2×10^{-2}	(2)	2.1×10^{-2}	(2)	$<7.7\times10^{-3}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.7×10^{1}	2.9×10^{0}	1.4×10^{1}	2.4×10^{-1}	5.0×10^{-1}	3.2×10^{-2}	4.7×10^{-2}	(2)	3.7×10^{-2}	(2)	2.4×10^{-2}	(2)	$<9.0\times10^{-3}$
I^{131}	2.5×10^{2}	2.7×10^{1}	1.3×10^{2}	2.2×10^{0}	4.6×10^{0}	2.9×10^{-1}	4.4×10^{-1}	(2)	3.4×10^{-1}	(2)	2.2×10^{-1}	(2)	$<8.3\times10^{-2}$
Other nuclides	1.2×10^{4}	1.3×10^{3}	6.0×10^{3}	1.1×10^{2}	2.1×10^{2}	1.4×10^{1}	2.0×10^{1}	(2)	1.6×10^{1}	(2)	1.1×10^{1}	(2)	$<3.9\times10^{0}$
All products	1.2×10^{4}	1.3×10^{3}	6.2×10^{3}	1.1×10^{2}	2.2×10^{2}	1.4×10^{1}	2.1×10^{1}	(2)	1.7×10^{1}	(2)	1.1×10^{1}	(2)	$<4.0\times10^{0}$

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[1] Average during the 30 days following detonation, in trunk streams at outer margin of the area of measurable fallout. It is expected that throwout would dam Ogotoruk Creek and pond the runoff in the lower part of that basin, at least temporarily.

[2] Zero or nominal.

[3] Adsorption scaled to mean K_d's as explained in text (p. 29).

TABLE 23.—*Expected dispersal of fission products in fallout from Project Chariot, case III*

[Quantities are mean values for the respective areas, assuming 15 days decay. In all basins, concentration of products dissolved in streams being inconsequential, values for total stream burden are nearly the same as those for insoluble particulate products suspended in runoff. Also in all basins, values for products adsorbed are nearly the same as those for case II, as given in table 22]

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	------------
FALLOUT BETWEEN AZIMUTHS 40° AND 125° (CASE III.a)													
Products dissolved in runoff													
Average concentration [1] (μc per ml):													
Sr^{90}	7.4×10^{-7}	8.8×10^{-8}	2.3×10^{-7}	5.8×10^{-9}	4.7×10^{-10}	1.0×10^{-9}	2.5×10^{-10}	2.2×10^{-10}	3.1×10^{-10}	4.2×10^{-10}	(2)	6.9×10^{-11}	$<1.1\times10^{-10}$
I^{131}	9.2×10^{-6}	1.1×10^{-6}	2.9×10^{-6}	7.1×10^{-8}	5.4×10^{-9}	1.2×10^{-8}	2.9×10^{-9}	2.7×10^{-9}	3.8×10^{-9}	5.2×10^{-9}	(2)	7.8×10^{-10}	$<1.3\times10^{-9}$
Cs^{137}	6.0×10^{-8}	7.2×10^{-9}	3.4×10^{-8}	4.7×10^{-10}	1.3×10^{-10}	8.2×10^{-11}	5.7×10^{-11}	1.8×10^{-11}	2.8×10^{-11}	3.4×10^{-11}	(2)	5.4×10^{-12}	$<1.3\times10^{-11}$
Other nuclides	6.4×10^{-5}	7.6×10^{-6}	2.3×10^{-5}	5.0×10^{-7}	6.3×10^{-8}	8.7×10^{-8}	3.0×10^{-8}	2.0×10^{-8}	2.8×10^{-8}	3.6×10^{-8}	(2)	6.6×10^{-9}	$<1.1\times10^{-8}$
All products	7.4×10^{-5}	8.8×10^{-6}	2.6×10^{-5}	5.8×10^{-7}	6.9×10^{-8}	1.0×10^{-7}	3.3×10^{-8}	2.3×10^{-8}	3.2×10^{-8}	4.2×10^{-8}	(2)	7.5×10^{-9}	$<1.2\times10^{-8}$
Insoluble particulate products suspended in runoff													
Percentage assumed transported	2.5	2.5	5	12.5	17.5	17.5	17.5	25	25	25	------------	25	25
Average concentration [1] (μc per ml):													
Sr^{90} and Cs^{137}, each	1.4×10^{-5}	1.2×10^{-6}	1.0×10^{-5}	1.1×10^{-6}	2.1×10^{-7}	3.5×10^{-7}	9.0×10^{-8}	1.8×10^{-7}	1.0×10^{-7}	1.2×10^{-7}	(2)	1.6×10^{-7}	$<4.9\times10^{-8}$
I^{131}	1.3×10^{-4}	1.1×10^{-5}	9.3×10^{-5}	1.0×10^{-5}	2.0×10^{-6}	3.2×10^{-6}	8.3×10^{-7}	1.7×10^{-6}	9.2×10^{-7}	1.1×10^{-6}	(2)	1.5×10^{-6}	$<4.5\times10^{-7}$
Other nuclides	6.2×10^{-3}	5.1×10^{-4}	4.4×10^{-3}	4.9×10^{-4}	9.3×10^{-5}	1.5×10^{-4}	3.9×10^{-5}	7.8×10^{-5}	4.3×10^{-5}	5.0×10^{-5}	(2)	6.9×10^{-5}	$<2.1\times10^{-5}$
All products	6.4×10^{-3}	5.2×10^{-4}	4.5×10^{-3}	5.0×10^{-4}	9.5×10^{-5}	1.5×10^{-4}	4.0×10^{-5}	8.0×10^{-5}	4.4×10^{-5}	5.1×10^{-5}	(2)	7.1×10^{-5}	$<2.2\times10^{-5}$
Dissolved products infiltrated to soil water													
Products (c per mi^2):													
Sr^{90}	4.5×10^{-1}	5.4×10^{-2}	1.4×10^{-1}	3.5×10^{-3}	2.9×10^{-4}	6.1×10^{-4}	1.5×10^{-4}	1.4×10^{-4}	1.9×10^{-4}	2.5×10^{-4}	(2)	4.2×10^{-5}	$<6.6\times10^{-5}$
I^{131}	5.6×10^{0}	6.7×10^{-1}	1.7×10^{0}	4.4×10^{-2}	3.3×10^{-3}	7.5×10^{-3}	1.8×10^{-3}	1.6×10^{-3}	2.3×10^{-3}	3.2×10^{-3}	(2)	4.7×10^{-4}	$<8.1\times10^{-4}$
Cs^{137}	3.7×10^{-2}	4.4×10^{-3}	2.0×10^{-2}	2.9×10^{-4}	8.3×10^{-5}	5.0×10^{-5}	3.5×10^{-5}	1.1×10^{-5}	1.7×10^{-5}	2.1×10^{-5}	(2)	3.3×10^{-6}	$<8.0\times10^{-6}$
Other nuclides	3.9×10^{1}	4.7×10^{0}	1.4×10^{1}	3.1×10^{-1}	3.8×10^{-2}	5.4×10^{-2}	1.8×10^{-2}	1.2×10^{-2}	1.6×10^{-2}	2.3×10^{-2}	(2)	4.1×10^{-3}	$<6.4\times10^{-3}$
All products	4.5×10^{1}	5.4×10^{0}	1.6×10^{1}	3.6×10^{-1}	4.2×10^{-2}	6.2×10^{-2}	2.0×10^{-2}	1.4×10^{-2}	1.9×10^{-2}	2.6×10^{-2}	(2)	4.6×10^{-3}	$<7.3\times10^{-3}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.1×10^{0}	8.8×10^{0}	3.7×10^{-1}	4.6×10^{-2}	7.5×10^{-2}	2.0×10^{-2}	2.5×10^{-2}	1.4×10^{-2}	1.6×10^{-2}	(2)	2.2×10^{-2}	$<6.7\times10^{-3}$
I^{131}	2.4×10^{2}	1.9×10^{1}	8.1×10^{1}	3.4×10^{0}	4.3×10^{-1}	6.9×10^{-1}	1.8×10^{-1}	2.3×10^{-1}	1.3×10^{-1}	1.5×10^{-1}	(2)	2.0×10^{-1}	$<6.2\times10^{-2}$
Other nuclides	1.1×10^{4}	9.1×10^{2}	3.8×10^{3}	1.6×10^{2}	2.0×10^{1}	3.2×10^{1}	8.5×10^{0}	1.1×10^{1}	5.9×10^{0}	6.9×10^{0}	(2)	9.6×10^{0}	$<2.9\times10^{0}$
All products	1.1×10^{4}	9.3×10^{2}	3.9×10^{3}	1.6×10^{2}	2.1×10^{1}	3.3×10^{1}	8.7×10^{0}	1.1×10^{1}	6.1×10^{0}	7.1×10^{0}	(2)	9.8×10^{0}	$<3.0\times10^{0}$

See footnotes at end of table.

TABLE 23.—*Expected dispersal of fission products in fallout from Project Chariot, case III*—Continued

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kuk-powruk River	Noatak River	Minor basins, Pitmegea River to Kuk-powruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	------------
FALLOUT BETWEEN AZIMUTHS 25° AND 110° (Case III.b)													
Products dissolved in runoff													
Average concentration[1] (μc per ml):													
Sr^{90}	7.6×10^{-7}	1.2×10^{-7}	3.5×10^{-7}	3.3×10^{-9}	4.2×10^{-9}	3.5×10^{-10}	5.0×10^{-10}	(2)	6.3×10^{-10}	(2)	2.9×10^{-10}	(2)	$<1.1\times10^{-10}$
I^{131}	9.4×10^{-6}	1.5×10^{-6}	4.3×10^{-6}	4.1×10^{-8}	4.8×10^{-8}	4.3×10^{-9}	5.8×10^{-9}	(2)	7.8×10^{-9}	(2)	3.6×10^{-9}	(2)	$<1.3\times10^{-9}$
Cs^{137}	6.1×10^{-8}	9.7×10^{-9}	4.8×10^{-8}	2.7×10^{-10}	1.2×10^{-9}	2.8×10^{-11}	1.1×10^{-10}	(2)	5.7×10^{-11}	(2)	3.5×10^{-11}	(2)	$<1.3\times10^{-11}$
Other nuclides	6.6×10^{-5}	1.0×10^{-5}	3.4×10^{-5}	2.9×10^{-7}	5.6×10^{-7}	3.0×10^{-8}	6.0×10^{-8}	(2)	5.6×10^{-8}	(2)	2.8×10^{-8}	(2)	$<1.1\times10^{-8}$
All products	7.6×10^{-5}	1.2×10^{-5}	3.9×10^{-5}	3.3×10^{-7}	6.1×10^{-7}	3.5×10^{-8}	6.6×10^{-8}	(2)	6.4×10^{-8}	(2)	3.2×10^{-8}	(2)	$<1.2\times10^{-8}$
Insoluble particulate products suspended in runoff													
Percent assumed transported	2.5	2.5	5	12.5	17.5	17.5	17.5	------------	25	------------	25	------------	25
Average concentration[1] (μc per ml):													
Sr^{90} and Cs^{137}, each	1.5×10^{-5}	1.6×10^{-6}	1.5×10^{-5}	6.5×10^{-7}	1.9×10^{-6}	1.2×10^{-7}	1.8×10^{-7}	(2)	2.0×10^{-7}	(2)	1.3×10^{-7}	(2)	$<4.9\times10^{-8}$
I^{131}	1.4×10^{-4}	1.5×10^{-5}	1.4×10^{-4}	6.0×10^{-6}	1.7×10^{-5}	1.1×10^{-6}	1.7×10^{-6}	(2)	1.9×10^{-6}	(2)	1.2×10^{-6}	(2)	$<4.5\times10^{-7}$
Other nuclides	6.3×10^{-3}	6.8×10^{-4}	6.5×10^{-3}	2.8×10^{-4}	8.2×10^{-4}	5.2×10^{-5}	7.8×10^{-5}	(2)	8.8×10^{-5}	(2)	5.7×10^{-5}	(2)	$<2.1\times10^{-5}$
All products	6.5×10^{-3}	7.0×10^{-4}	6.7×10^{-3}	2.9×10^{-4}	8.4×10^{-4}	5.3×10^{-5}	8.0×10^{-5}	(2)	9.0×10^{-5}	(2)	5.8×10^{-5}	(2)	$<2.2\times10^{-5}$
Dissolved products infiltrated to soil water													
Products (c per mi^2):													
Sr^{90}	4.6×10^{-1}	7.3×10^{-2}	2.1×10^{-1}	2.0×10^{-3}	2.6×10^{-3}	2.1×10^{-4}	3.0×10^{-4}	(2)	3.8×10^{-4}	(2)	1.8×10^{-4}	(2)	$<6.6\times10^{-5}$
I^{131}	5.8×10^{0}	9.0×10^{-1}	2.6×10^{0}	2.5×10^{-2}	2.9×10^{-2}	2.6×10^{-3}	3.6×10^{-3}	(2)	4.7×10^{-3}	(2)	2.2×10^{-3}	(2)	$<8.1\times10^{-4}$
Cs^{137}	3.8×10^{-2}	5.9×10^{-3}	2.9×10^{-2}	1.7×10^{-4}	7.3×10^{-4}	1.7×10^{-5}	7.0×10^{-5}	(2)	3.5×10^{-5}	(2)	2.2×10^{-5}	(2)	$<8.0\times10^{-6}$
Other nuclides	4.0×10^{1}	6.3×10^{0}	2.1×10^{1}	1.7×10^{-1}	3.4×10^{-1}	1.9×10^{-2}	3.7×10^{-2}	(2)	3.4×10^{-2}	(2)	1.8×10^{-2}	(2)	$<6.4\times10^{-3}$
All products	4.6×10^{1}	7.3×10^{0}	2.4×10^{1}	2.0×10^{-1}	3.7×10^{-1}	2.2×10^{-2}	4.1×10^{-2}	(2)	3.9×10^{-2}	(2)	2.0×10^{-2}	(2)	$<7.3\times10^{-3}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.8×10^{0}	1.3×10^{1}	2.1×10^{-1}	4.1×10^{-1}	2.6×10^{-2}	3.9×10^{-2}	(2)	2.8×10^{-2}	(2)	1.8×10^{-2}	(2)	$<6.7\times10^{-3}$
I^{131}	2.4×10^{2}	2.6×10^{1}	1.2×10^{2}	1.9×10^{0}	3.8×10^{0}	2.4×10^{-1}	3.6×10^{-1}	(2)	2.6×10^{-1}	(2)	1.7×10^{-1}	(2)	$<6.2\times10^{-2}$
Other nuclides	1.2×10^{4}	1.3×10^{3}	5.8×10^{3}	9.1×10^{1}	1.8×10^{2}	1.2×10^{1}	1.7×10^{1}	(2)	1.2×10^{1}	(2)	7.9×10^{0}	(2)	$<2.9\times10^{0}$
All products	1.2×10^{4}	1.3×10^{3}	5.9×10^{3}	9.3×10^{1}	1.8×10^{2}	1.2×10^{1}	1.7×10^{1}	(2)	1.2×10^{1}	(2)	8.1×10^{0}	(2)	$<3.0\times10^{0}$

[1] Average during the 30 days following detonation, in trunk streams at outer margin of the area of measurable fallout. It is expected that throwout would dam Ogotoruk Creek and pond the runoff in the lower part of that basin, at least temporarily.

[2] Zero or nominal.

TABLE 24.—*Expected initial dispersal of fission products in fallout from Project Chariot, case IV*

[Quantities are mean values for the respective areas, assuming 5 days decay. See table 25 for expected redispersal during ensuing snowmelt season. In all basins, values for insoluble particulate products suspended in runoff are zero or nominal; in consequence, values for total stream burden are the same as those for products dissolved in runoff and microponds. Also in all basins, values for dissolved products infiltrated to soil water are zero or nominal]

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	----------
FALLOUT BETWEEN AZIMUTHS 40° AND 125° (CASE IV.a.1)													
Products dissolved in runoff and in microponds													
Average concentration [1] (μc per ml):													
Sr^{90}	8.9×10^{-5}	8.9×10^{-6}	2.8×10^{-5}	9.6×10^{-7}	1.0×10^{-7}	1.9×10^{-7}	4.5×10^{-8}	6.0×10^{-8}	4.7×10^{-8}	5.9×10^{-8}	(2)	4.3×10^{-8}	$<1.9\times10^{-8}$
I^{131}	4.9×10^{-3}	4.7×10^{-4}	1.5×10^{-3}	4.5×10^{-5}	4.2×10^{-6}	8.9×10^{-6}	1.8×10^{-6}	2.6×10^{-6}	2.4×10^{-6}	3.1×10^{-6}	(2)	1.6×10^{-6}	$<8.9\times10^{-7}$
Cs^{137}	2.0×10^{-4}	2.0×10^{-5}	5.0×10^{-5}	4.3×10^{-7}	3.4×10^{-8}	7.6×10^{-8}	1.8×10^{-8}	1.8×10^{-8}	2.2×10^{-8}	3.0×10^{-8}	(2)	7.9×10^{-9}	$<8.0\times10^{-9}$
Other nuclides	7.4×10^{-2}	8.2×10^{-3}	2.3×10^{-2}	7.4×10^{-4}	7.4×10^{-5}	1.4×10^{-4}	3.5×10^{-5}	4.1×10^{-5}	3.7×10^{-5}	4.7×10^{-5}	(2)	2.7×10^{-5}	$<1.5\times10^{-5}$
All products	7.9×10^{-2}	8.7×10^{-3}	2.5×10^{-2}	7.9×10^{-4}	7.8×10^{-5}	1.5×10^{-4}	3.7×10^{-5}	4.4×10^{-5}	3.9×10^{-5}	5.0×10^{-5}	(2)	2.9×10^{-5}	$<1.6\times10^{-5}$
Products adsorbed [3]													
Products on vegetation (c per mi²):													
Sr^{90}	2.3×10^{0}	1.9×10^{-1}	8.2×10^{-1}	3.7×10^{-2}	5.0×10^{-3}	8.1×10^{-3}	2.1×10^{-3}	2.9×10^{-3}	1.6×10^{-3}	1.9×10^{-3}	(2)	2.6×10^{-3}	$<8.0\times10^{-4}$
I^{131}	1.5×10^{2}	1.2×10^{1}	5.2×10^{1}	2.3×10^{0}	3.1×10^{-1}	5.1×10^{-1}	1.3×10^{-1}	1.8×10^{-1}	1.0×10^{-1}	1.2×10^{-1}	(2)	1.6×10^{-1}	$<5.0\times10^{-2}$
Cs^{137}	2.9×10^{0}	2.3×10^{-1}	1.0×10^{0}	4.5×10^{-2}	6.1×10^{-3}	9.8×10^{-3}	2.6×10^{-3}	3.6×10^{-3}	2.0×10^{-3}	2.3×10^{-3}	(2)	3.2×10^{-3}	$<9.7\times10^{-4}$
Other nuclides	2.6×10^{3}	2.1×10^{2}	9.2×10^{2}	4.2×10^{1}	5.6×10^{0}	9.0×10^{0}	2.4×10^{0}	3.2×10^{0}	1.8×10^{0}	2.1×10^{0}	(2)	2.9×10^{0}	$<8.9\times10^{-1}$
All products	2.8×10^{3}	2.2×10^{2}	9.7×10^{2}	4.4×10^{1}	5.9×10^{0}	9.5×10^{0}	2.5×10^{0}	3.4×10^{0}	1.9×10^{0}	2.2×10^{0}	(2)	3.1×10^{0}	$<9.4\times10^{-1}$
Products on soil (c per mi²):													
Sr^{90}	1.9×10^{0}	1.5×10^{-1}	6.5×10^{-1}	2.9×10^{-2}	3.9×10^{-3}	6.4×10^{-3}	1.7×10^{-3}	2.3×10^{-3}	1.3×10^{-3}	1.5×10^{-3}	(2)	2.1×10^{-3}	$<6.3\times10^{-4}$
I^{131}	7.6×10^{1}	6.2×10^{0}	2.7×10^{1}	1.2×10^{0}	1.6×10^{-1}	2.6×10^{-1}	6.9×10^{-2}	9.6×10^{-2}	5.3×10^{-2}	6.1×10^{-2}	(2)	8.5×10^{-2}	$<2.6\times10^{-2}$
Cs^{137}	2.9×10^{0}	2.4×10^{-1}	1.0×10^{0}	4.6×10^{-2}	6.2×10^{-3}	1.0×10^{-2}	2.6×10^{-3}	3.6×10^{-3}	2.0×10^{-3}	2.3×10^{-3}	(2)	3.2×10^{-3}	$<9.9\times10^{-4}$
Other nuclides	2.7×10^{3}	2.2×10^{2}	9.6×10^{2}	4.3×10^{1}	5.8×10^{0}	9.4×10^{0}	2.4×10^{0}	3.4×10^{0}	1.8×10^{0}	2.2×10^{0}	(2)	3.0×10^{0}	$<9.2\times10^{-1}$
All products	2.8×10^{3}	2.3×10^{2}	9.9×10^{2}	4.4×10^{1}	6.0×10^{0}	9.7×10^{0}	2.5×10^{0}	3.5×10^{0}	1.9×10^{0}	2.3×10^{0}	(2)	3.1×10^{0}	$<9.5\times10^{-1}$
Products on rock, talus, and colluvium (c per mi²):													
Sr^{90}	4.9×10^{-2}	4.0×10^{-3}	1.7×10^{-2}	7.8×10^{-4}	1.0×10^{-4}	1.7×10^{-4}	4.4×10^{-5}	6.2×10^{-5}	3.4×10^{-5}	3.9×10^{-5}	(2)	5.5×10^{-5}	$<1.7\times10^{-5}$
I^{131}	1.5×10^{0}	1.3×10^{-1}	5.4×10^{-1}	2.5×10^{-2}	3.3×10^{-3}	5.4×10^{-3}	1.4×10^{-3}	1.9×10^{-3}	1.1×10^{-3}	1.2×10^{-3}	(2)	1.7×10^{-3}	$<5.3\times10^{-4}$
Cs^{137}	7.1×10^{-1}	5.8×10^{-2}	2.5×10^{-1}	1.1×10^{-2}	1.5×10^{-3}	2.5×10^{-3}	6.4×10^{-4}	8.9×10^{-4}	4.9×10^{-4}	5.7×10^{-4}	(2)	7.9×10^{-4}	$<2.4\times10^{-4}$
Other nuclides	2.1×10^{2}	1.7×10^{1}	7.2×10^{1}	3.3×10^{0}	4.4×10^{-1}	7.0×10^{-1}	1.9×10^{-1}	2.6×10^{-1}	1.4×10^{-1}	1.7×10^{-1}	(2)	2.3×10^{-1}	$<6.9\times10^{-2}$
All products	2.1×10^{2}	1.7×10^{1}	7.3×10^{1}	3.3×10^{0}	4.4×10^{-1}	7.1×10^{-1}	1.9×10^{-1}	2.6×10^{-1}	1.4×10^{-1}	1.7×10^{-1}	(2)	2.3×10^{-1}	$<7.0\times10^{-2}$
Insoluble particulate products remaining near place of fall													
Products (c per mi²):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.2×10^{0}	9.3×10^{0}	4.2×10^{-1}	5.6×10^{-2}	9.1×10^{-2}	2.4×10^{-2}	3.3×10^{-2}	1.8×10^{-2}	2.1×10^{-2}	(2)	2.9×10^{-2}	$<9.0\times10^{-3}$
I^{131}	1.4×10^{3}	1.2×10^{2}	5.0×10^{2}	2.2×10^{1}	3.0×10^{0}	4.9×10^{0}	1.3×10^{0}	1.8×10^{0}	9.8×10^{-1}	1.1×10^{0}	(2)	1.6×10^{0}	$<4.8\times10^{-1}$
Other nuclides	4.3×10^{4}	3.5×10^{3}	1.4×10^{4}	6.7×10^{2}	9.0×10^{1}	1.4×10^{2}	3.8×10^{1}	5.3×10^{1}	2.9×10^{1}	3.4×10^{1}	(2)	4.7×10^{1}	$<1.5\times10^{1}$
All products	4.4×10^{4}	3.6×10^{3}	1.5×10^{4}	6.9×10^{2}	9.3×10^{1}	1.5×10^{2}	3.9×10^{1}	5.5×10^{1}	3.0×10^{1}	3.5×10^{1}	(2)	4.9×10^{1}	$<1.5\times10^{1}$

See footnotes at end of table.

TABLE 24.—*Expected initial dispersal of fission products in fallout from Project Chariot, case IV*—Continued

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	
FALLOUT BETWEEN AZIMUTHS 25° AND 110° (CASE IV.b.l)													
Products dissolved in runoff and microponds													
Average concentration [1] (μc per ml):													
Sr^{90}	9.2×10^{-5}	1.2×10^{-5}	4.2×10^{-5}	5.5×10^{-7}	9.0×10^{-7}	6.7×10^{-8}	9.1×10^{-8}	(2)	9.6×10^{-8}	(2)	5.2×10^{-8}	(2)	$<1.9\times10^{-8}$
I^{131}	5.0×10^{-3}	6.4×10^{-4}	2.2×10^{-3}	2.6×10^{-5}	3.7×10^{-5}	3.1×10^{-6}	3.7×10^{-6}	(2)	4.9×10^{-6}	(2)	2.4×10^{-6}	(2)	$<8.9\times10^{-7}$
Cs^{137}	5.3×10^{-5}	8.2×10^{-6}	2.4×10^{-5}	2.4×10^{-7}	3.0×10^{-7}	2.6×10^{-8}	3.6×10^{-8}	(2)	4.5×10^{-8}	(2)	2.2×10^{-8}	(2)	$<8.0\times10^{-9}$
Other nuclides	7.6×10^{-2}	1.1×10^{-2}	3.6×10^{-2}	4.2×10^{-4}	6.5×10^{-4}	5.0×10^{-5}	7.0×10^{-5}	(2)	7.4×10^{-5}	(2)	4.0×10^{-5}	(2)	$<1.5\times10^{-5}$
All products	8.1×10^{-2}	1.2×10^{-2}	3.8×10^{-2}	4.5×10^{-4}	6.9×10^{-4}	5.3×10^{-5}	7.4×10^{-5}	(2)	7.9×10^{-5}	(2)	4.2×10^{-5}	(2)	$<1.6\times10^{-5}$
Products adsorbed [3]													
Products on vegetation (c per mi²):													
Sr^{90}	2.4×10^{0}	2.6×10^{-1}	1.2×10^{0}	2.1×10^{-2}	4.4×10^{-2}	2.8×10^{-3}	4.2×10^{-3}	(2)	3.3×10^{-3}	(2)	2.1×10^{-3}	(2)	$<8.0\times10^{-4}$
I^{131}	1.5×10^{2}	1.6×10^{1}	7.7×10^{1}	1.3×10^{0}	2.8×10^{0}	1.8×10^{-1}	2.6×10^{-1}	(2)	2.1×10^{-1}	(2)	1.4×10^{-1}	(2)	$<5.0\times10^{-2}$
Cs^{137}	2.9×10^{0}	3.1×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.4×10^{-2}	3.4×10^{-3}	5.1×10^{-3}	(2)	4.0×10^{-3}	(2)	2.6×10^{-3}	(2)	$<9.7\times10^{-4}$
Other nuclides	2.6×10^{3}	2.8×10^{2}	1.3×10^{3}	2.4×10^{1}	4.9×10^{1}	3.1×10^{0}	4.6×10^{0}	(2)	3.7×10^{0}	(2)	2.4×10^{0}	(2)	$<8.9\times10^{-1}$
All products	2.8×10^{3}	3.0×10^{2}	1.4×10^{3}	2.5×10^{1}	5.2×10^{1}	3.3×10^{0}	4.9×10^{0}	(2)	3.9×10^{0}	(2)	2.5×10^{0}	(2)	$<9.4\times10^{-1}$
Products on soil (c per mi²):													
Sr^{90}	1.9×10^{0}	2.0×10^{-1}	9.7×10^{-1}	1.7×10^{-2}	3.5×10^{-2}	2.2×10^{-3}	3.3×10^{-3}	(2)	2.6×10^{-3}	(2)	1.7×10^{-3}	(2)	$<6.3\times10^{-4}$
I^{131}	7.8×10^{1}	8.4×10^{0}	4.0×10^{1}	6.9×10^{-1}	1.4×10^{0}	9.1×10^{-2}	1.4×10^{-1}	(2)	1.1×10^{-1}	(2)	7.0×10^{-2}	(2)	$<2.6\times10^{-2}$
Cs^{137}	3.0×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.5×10^{-2}	3.5×10^{-3}	5.2×10^{-3}	(2)	4.1×10^{-3}	(2)	2.7×10^{-3}	(2)	$<9.9\times10^{-4}$
Other nuclides	2.8×10^{3}	3.0×10^{2}	1.5×10^{3}	2.4×10^{1}	5.2×10^{1}	3.3×10^{0}	4.9×10^{0}	(2)	3.8×10^{0}	(2)	2.5×10^{0}	(2)	$<9.2\times10^{-1}$
All products	2.9×10^{3}	3.1×10^{2}	1.5×10^{3}	2.5×10^{1}	5.3×10^{1}	3.4×10^{0}	5.0×10^{0}	(2)	3.9×10^{0}	(2)	2.6×10^{0}	(2)	$<9.5\times10^{-1}$
Products on rock, talus, and colluvium (c per mi²):													
Sr^{90}	5.0×10^{-2}	5.4×10^{-3}	2.6×10^{-2}	4.4×10^{-4}	9.3×10^{-4}	5.9×10^{-5}	8.8×10^{-5}	(2)	6.9×10^{-5}	(2)	4.5×10^{-5}	(2)	$<1.7\times10^{-5}$
I^{131}	1.6×10^{0}	1.7×10^{-1}	8.2×10^{-1}	1.4×10^{-2}	2.9×10^{-2}	1.9×10^{-3}	2.8×10^{-3}	(2)	2.2×10^{-3}	(2)	1.4×10^{-3}	(2)	$<5.3\times10^{-4}$
Cs^{137}	7.3×10^{-1}	7.9×10^{-2}	3.7×10^{-1}	6.4×10^{-3}	1.3×10^{-2}	8.5×10^{-4}	1.3×10^{-3}	(2)	1.0×10^{-3}	(2)	6.5×10^{-4}	(2)	$<2.4\times10^{-4}$
Other nuclides	2.1×10^{2}	2.3×10^{1}	1.1×10^{2}	1.9×10^{0}	3.9×10^{0}	2.5×10^{-1}	3.7×10^{-1}	(2)	2.9×10^{-1}	(2)	1.9×10^{-1}	(2)	$<6.9\times10^{-2}$
All products	2.1×10^{2}	2.3×10^{1}	1.1×10^{2}	1.9×10^{0}	3.9×10^{0}	2.5×10^{-1}	3.7×10^{-1}	(2)	2.9×10^{-1}	(2)	1.9×10^{-1}	(2)	$<7.0\times10^{-2}$
Insoluble particulate products remaining near place of fall													
Products (c per mi²):													
Sr^{90} and Cs^{137}, each	2.7×10^{1}	2.9×10^{0}	1.4×10^{1}	2.4×10^{-1}	5.0×10^{-1}	3.2×10^{-2}	4.7×10^{-2}	(2)	3.7×10^{-2}	(2)	2.4×10^{-2}	(2)	$<9.0\times10^{-3}$
I^{131}	1.4×10^{3}	1.6×10^{2}	7.4×10^{2}	1.3×10^{1}	2.7×10^{1}	1.7×10^{0}	2.5×10^{0}	(2)	2.0×10^{0}	(2)	1.3×10^{0}	(2)	$<4.8\times10^{-1}$
Other nuclides	4.4×10^{4}	4.6×10^{3}	2.2×10^{4}	3.9×10^{2}	8.0×10^{2}	5.0×10^{1}	7.5×10^{1}	(2)	6.0×10^{1}	(2)	3.9×10^{1}	(2)	$<1.5\times10^{1}$
All products	4.5×10^{4}	4.8×10^{3}	2.3×10^{4}	4.0×10^{2}	8.3×10^{2}	5.2×10^{1}	7.8×10^{1}	(2)	6.2×10^{1}	(2)	4.0×10^{1}	(2)	$<1.5\times10^{1}$

[1] Average during the 10 days between detonation and freezeup, in trunk streams at outer margin of the area of measurable fallout; also in microponds within the area of fallout. It is expected that throwout would dam Ogotoruk Creek and pond the runoff in the lower part of that basin, at least temporarily.

[2] Zero or nominal.

[3] Adsorption scaled to mean K_d's times 10^{-2}, as explained in text (p. 30).

TABLE 25.—*Expected redispersal of fission products in fallout from Project Chariot, case IV*

[Quantities are mean values for the respective areas, assuming 8 months decay. See table 24 for expected dispersal at time of antecedent freezeup. In all basins, values for dissolved products infiltrated to soil water are zero or nominal. Assumptions: (1) Detonation as assumed in table 24; this table covers the partial redispersal of products during the next ensuing snowmelt season, also the interim decay of products not redispersed. (2) Snowmelt runoff of 1 inch over the area, within 30 days following breakup. (3) Mobile products would reach the streams during the later half of the snowmelt season, in one-fourth of the snowmelt runoff (see supplemental assumption 4 in text, p. 30)]

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	----------
FALLOUT BETWEEN AZIMUTHS 40° AND 125° (CASE IV.a.2)													
Products dissolved in runoff and in microponds													
Average concentration [1] (μc per ml):													
Sr^{90}	3.2×10^{-5}	3.2×10^{-6}	1.0×10^{-5}	3.4×10^{-7}	3.6×10^{-8}	6.9×10^{-8}	1.6×10^{-8}	2.1×10^{-8}	1.7×10^{-8}	2.1×10^{-8}	(2)	1.5×10^{-8}	$<6.9\times10^{-9}$
I^{131}	2.2×10^{-12}	2.1×10^{-13}	6.7×10^{-13}	2.1×10^{-14}	1.9×10^{-16}	4.0×10^{-15}	8.4×10^{-16}	1.2×10^{-15}	1.1×10^{-15}	1.4×10^{-15}	(2)	7.1×10^{-16}	$<4.0\times10^{-16}$
Cs^{137}	1.8×10^{-5}	2.2×10^{-6}	5.7×10^{-6}	1.5×10^{-7}	1.2×10^{-8}	2.7×10^{-8}	6.5×10^{-9}	6.5×10^{-9}	7.9×10^{-9}	1.1×10^{-8}	(2)	2.8×10^{-9}	$<2.9\times10^{-9}$
Other nuclides	2.2×10^{-4}	2.5×10^{-5}	7.1×10^{-5}	2.2×10^{-6}	2.2×10^{-7}	4.3×10^{-7}	1.1×10^{-7}	1.2×10^{-7}	1.1×10^{-7}	1.4×10^{-7}	(2)	8.2×10^{-8}	$<4.4\times10^{-8}$
All products	2.7×10^{-4}	3.0×10^{-5}	8.7×10^{-5}	2.7×10^{-6}	2.7×10^{-7}	5.3×10^{-7}	1.3×10^{-7}	1.5×10^{-7}	1.3×10^{-7}	1.7×10^{-7}	(2)	1.0×10^{-7}	$<5.4\times10^{-8}$
Insoluble particulate products suspended in runoff													
Percentage assumed transported	2.5	2.5	5	12.5	17.5	17.5	17.5	25	25	25	--------	25	25
Average concentration [1] (μc per ml):													
Sr^{90} and Cs^{137}, each	4.0×10^{-5}	3.2×10^{-6}	2.8×10^{-5}	3.1×10^{-6}	5.9×10^{-7}	9.6×10^{-7}	2.5×10^{-7}	5.0×10^{-7}	2.7×10^{-7}	3.2×10^{-7}	(2)	4.4×10^{-7}	$<1.3\times10^{-7}$
I^{131}	2.7×10^{-12}	2.2×10^{-13}	1.9×10^{-12}	2.1×10^{-13}	4.0×10^{-14}	6.5×10^{-14}	1.7×10^{-14}	3.4×10^{-14}	1.9×10^{-14}	2.2×10^{-14}	(2)	3.0×10^{-14}	$<9.1\times10^{-15}$
Other nuclides	5.5×10^{-4}	4.5×10^{-5}	3.8×10^{-4}	4.4×10^{-5}	8.2×10^{-6}	1.3×10^{-5}	3.5×10^{-6}	6.9×10^{-6}	3.9×10^{-6}	4.5×10^{-6}	(2)	6.1×10^{-6}	$<1.8\times10^{-6}$
All products	6.3×10^{-4}	5.1×10^{-5}	4.4×10^{-4}	5.0×10^{-5}	9.4×10^{-6}	1.5×10^{-5}	4.0×10^{-6}	7.9×10^{-6}	4.4×10^{-6}	5.1×10^{-6}	(2)	7.0×10^{-6}	$<2.1\times10^{-6}$
Total stream burden													
Dissolved and suspended [1] (average μc per ml):													
Sr^{90}	7.2×10^{-5}	6.4×10^{-6}	3.8×10^{-5}	3.4×10^{-6}	6.3×10^{-7}	1.0×10^{-6}	2.7×10^{-7}	5.2×10^{-7}	2.9×10^{-7}	3.4×10^{-7}	(2)	4.6×10^{-7}	$<1.4\times10^{-7}$
I^{131}	4.9×10^{-12}	4.3×10^{-13}	2.6×10^{-12}	2.3×10^{-13}	4.2×10^{-14}	6.9×10^{-14}	1.8×10^{-14}	3.5×10^{-14}	2.0×10^{-14}	2.3×10^{-14}	(2)	3.1×10^{-14}	$<9.5\times10^{-15}$
Cs^{137}	5.8×10^{-5}	5.4×10^{-6}	3.4×10^{-5}	3.2×10^{-6}	6.0×10^{-7}	9.9×10^{-7}	2.6×10^{-7}	5.2×10^{-7}	2.8×10^{-7}	3.3×10^{-7}	(2)	4.4×10^{-7}	$<1.3\times10^{-7}$
Other nuclides	7.7×10^{-4}	6.9×10^{-5}	4.6×10^{-4}	4.6×10^{-5}	8.5×10^{-6}	1.4×10^{-5}	3.6×10^{-6}	7.0×10^{-6}	3.9×10^{-6}	4.6×10^{-6}	(2)	6.2×10^{-6}	$<1.9\times10^{-6}$
All products	9.0×10^{-4}	8.1×10^{-5}	5.3×10^{-4}	5.3×10^{-5}	9.7×10^{-6}	1.6×10^{-5}	4.1×10^{-6}	8.0×10^{-6}	4.5×10^{-6}	5.3×10^{-6}	(2)	7.1×10^{-6}	$<2.2\times10^{-6}$
Products adsorbed													
Products on vegetation (c per mi^2):													
Sr^{90}	2.3×10^{0}	1.9×10^{-1}	8.1×10^{-1}	3.6×10^{-2}	4.9×10^{-3}	7.9×10^{-3}	2.1×10^{-3}	2.9×10^{-3}	1.6×10^{-3}	1.8×10^{-3}	(2)	2.6×10^{-3}	$<7.8\times10^{-4}$
I^{131}	1.8×10^{-7}	1.5×10^{-8}	6.5×10^{-8}	2.9×10^{-9}	3.9×10^{-10}	6.3×10^{-10}	1.6×10^{-10}	2.3×10^{-10}	1.3×10^{-10}	1.5×10^{-10}	(2)	2.0×10^{-10}	$<6.2\times10^{-11}$
Cs^{137}	2.8×10^{0}	2.3×10^{-1}	9.9×10^{-1}	4.5×10^{-2}	6.0×10^{-3}	9.7×10^{-3}	2.5×10^{-3}	3.5×10^{-3}	1.9×10^{-3}	2.3×10^{-3}	(2)	3.1×10^{-3}	$<9.6\times10^{-4}$
Other nuclides	2.1×10^{1}	1.7×10^{-1}	7.4×10^{0}	3.3×10^{-1}	4.4×10^{-2}	7.2×10^{-2}	1.8×10^{-2}	2.7×10^{-2}	1.4×10^{-2}	1.7×10^{-2}	(2)	2.3×10^{-2}	$<7.2\times10^{-3}$
All products	2.6×10^{1}	2.1×10^{0}	9.2×10^{0}	4.1×10^{-1}	5.5×10^{-2}	9.0×10^{-2}	2.3×10^{-2}	3.3×10^{-2}	1.8×10^{-2}	2.1×10^{-2}	(2)	2.9×10^{-2}	$<8.9\times10^{-3}$
Products on soil (c per mi^2):													
Sr^{90}	1.8×10^{0}	1.5×10^{-1}	6.4×10^{-1}	2.9×10^{-2}	3.9×10^{-3}	6.3×10^{-3}	1.6×10^{-3}	2.3×10^{-3}	1.3×10^{-3}	1.5×10^{-3}	(2)	2.0×10^{-3}	$<6.2\times10^{-4}$
I^{131}	9.5×10^{-8}	7.8×10^{-9}	3.3×10^{-8}	1.5×10^{-9}	2.0×10^{-10}	3.3×10^{-10}	8.6×10^{-11}	1.2×10^{-10}	6.6×10^{-11}	7.7×10^{-11}	(2)	1.1×10^{-10}	$<3.2\times10^{-1}$
Cs^{137}	2.9×10^{0}	2.3×10^{-1}	1.0×10^{0}	4.5×10^{-2}	6.1×10^{-3}	9.9×10^{-3}	2.6×10^{-3}	3.6×10^{-3}	2.0×10^{-3}	2.3×10^{-3}	(2)	3.2×10^{-3}	$<9.7\times10^{-4}$
Other nuclides	2.2×10^{1}	1.8×10^{0}	7.7×10^{0}	3.5×10^{-1}	4.7×10^{-2}	7.6×10^{-2}	2.0×10^{-2}	2.7×10^{-2}	1.5×10^{-2}	1.7×10^{-2}	(2)	2.4×10^{-2}	$<7.4\times10^{-3}$
All products	2.7×10^{1}	2.2×10^{0}	9.3×10^{0}	4.2×10^{-1}	5.7×10^{-2}	9.2×10^{-2}	2.4×10^{-2}	3.3×10^{-2}	1.8×10^{-2}	2.1×10^{-2}	(2)	2.9×10^{-2}	$<9.0\times10^{-3}$
Products on rock, talus, and colluvium (c per mi^2):													
Sr^{90}	4.8×10^{-2}	3.9×10^{-3}	1.7×10^{-2}	7.7×10^{-4}	1.0×10^{-4}	1.7×10^{-4}	4.3×10^{-5}	6.1×10^{-5}	3.4×10^{-5}	3.9×10^{-5}	(2)	5.4×10^{-5}	$<1.6\times10^{-5}$
I^{131}	1.9×10^{-9}	1.6×10^{-10}	6.8×10^{-10}	3.1×10^{-11}	4.1×10^{-12}	6.7×10^{-12}	1.7×10^{-12}	2.4×10^{-12}	1.3×10^{-12}	1.6×10^{-12}	(2)	2.1×10^{-12}	$<6.6\times10^{-13}$
Cs^{137}	7.0×10^{-1}	5.7×10^{-2}	2.5×10^{-1}	1.1×10^{-2}	1.5×10^{-3}	2.4×10^{-3}	6.3×10^{-4}	8.8×10^{-4}	4.9×10^{-4}	5.6×10^{-4}	(2)	7.8×10^{-4}	$<2.4\times10^{-4}$
Other nuclides	1.3×10^{0}	9.9×10^{-2}	4.2×10^{-1}	1.9×10^{-2}	2.6×10^{-3}	4.2×10^{-3}	1.1×10^{-3}	1.6×10^{-3}	8.8×10^{-4}	1.0×10^{-3}	(2)	1.4×10^{-3}	$<4.1\times10^{-4}$
All products	2.0×10^{0}	1.6×10^{-1}	6.9×10^{-1}	3.1×10^{-2}	4.2×10^{-3}	6.8×10^{-3}	1.8×10^{-3}	2.5×10^{-3}	1.4×10^{-3}	1.6×10^{-3}	(2)	2.2×10^{-3}	$<6.7\times10^{-4}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.5×10^{1}	2.1×10^{0}	8.7×10^{0}	3.6×10^{-1}	4.6×10^{-2}	7.4×10^{-2}	1.9×10^{-2}	2.4×10^{-2}	1.4×10^{-2}	1.6×10^{-2}	(2)	2.2×10^{-2}	$<6.6\times10^{-3}$
I^{131}	1.7×10^{-6}	1.4×10^{-7}	5.9×10^{-7}	2.4×10^{-8}	3.1×10^{-9}	5.0×10^{-9}	1.3×10^{-9}	1.7×10^{-9}	9.2×10^{-10}	1.1×10^{-9}	(2)	1.5×10^{-9}	$<4.5\times10^{-10}$
Other nuclides	3.5×10^{2}	2.9×10^{1}	1.2×10^{2}	5.1×10^{0}	6.4×10^{-1}	1.1×10^{0}	2.7×10^{-1}	3.4×10^{-1}	1.9×10^{-1}	2.2×10^{-1}	(2)	3.1×10^{-1}	$<9.7\times10^{-2}$
All products	4.0×10^{2}	3.3×10^{1}	1.4×10^{2}	5.8×10^{0}	7.3×10^{-1}	1.2×10^{0}	3.1×10^{-1}	3.9×10^{-1}	2.2×10^{-1}	2.5×10^{-1}	(2)	3.5×10^{-1}	$<1.1\times10^{-1}$

See footnotes at end of table.

TABLE 25.—*Expected redispersal of fission products in fallout from Project Chariot, case IV*—Continued

	Basin or area												
	Ogotoruk Creek	Nasorak Creek	Minor basins, Ogotoruk Creek to Cape Seppings	Kukpuk River above Ipewik River	Minor basins, Cape Seppings to Kivalina River	Ipewik River	Kivalina River	Pitmegea River	Wulik River	Kukpowruk River	Noatak River	Minor basins, Pitmegea River to Kukpowruk River	Outlying areas
No. on pl. 1	0	1	2	3	4	5	6	7	8	9	10	11	------------
FALLOUT BETWEEN AZIMUTHS 25° AND 110° (CASE IV.b.2)													
Products dissolved in runoff and in microponds.													
Average concentration [1] (μc per ml):													
Sr^{90}	3.3×10^{-5}	4.3×10^{-6}	1.5×10^{-5}	2.0×10^{-7}	3.2×10^{-7}	2.4×10^{-8}	3.2×10^{-8}	(2)	3.4×10^{-8}	(2)	1.9×10^{-8}	(2)	$<6.9\times10^{-9}$
I^{131}	2.3×10^{-12}	2.9×10^{-13}	1.0×10^{-12}	1.2×10^{-14}	1.7×10^{-14}	1.4×10^{-15}	1.7×10^{-15}	(2)	2.2×10^{-15}	(2)	1.1×10^{-15}	(2)	$<4.0\times10^{-16}$
Cs^{137}	1.9×10^{-5}	2.9×10^{-6}	8.5×10^{-6}	8.7×10^{-8}	1.1×10^{-7}	9.5×10^{-9}	1.3×10^{-8}	(2)	1.6×10^{-8}	(2)	7.7×10^{-9}	(2)	$<2.9\times10^{-9}$
Other nuclides	2.3×10^{-4}	3.3×10^{-5}	1.1×10^{-4}	1.3×10^{-6}	2.0×10^{-6}	1.5×10^{-7}	2.2×10^{-7}	(2)	2.2×10^{-7}	(2)	1.2×10^{-7}	(2)	$<4.4\times10^{-8}$
All products	2.8×10^{-4}	4.0×10^{-5}	1.3×10^{-4}	1.6×10^{-6}	2.4×10^{-6}	1.8×10^{-7}	2.6×10^{-7}	(2)	2.7×10^{-7}	(2)	1.5×10^{-7}	(2)	$<5.4\times10^{-8}$
Insoluble particulate products suspended in runoff													
Percentage assumed transported	2.5	2.5	5	12.5	17.5	17.5	17.5	--------	25	--------	25	----------	25
Average concentration [1] (μc per ml):													
Sr^{90} and Cs^{137}, each	4.1×10^{-5}	4.4×10^{-6}	4.2×10^{-5}	1.8×10^{-6}	5.2×10^{-6}	3.3×10^{-7}	5.0×10^{-7}	(2)	5.6×10^{-7}	(2)	3.6×10^{-7}	(2)	$<1.3\times10^{-7}$
I^{131}	2.8×10^{-12}	3.0×10^{-13}	2.8×10^{-12}	1.2×10^{-13}	3.5×10^{-13}	2.2×10^{-14}	3.4×10^{-14}	(2)	3.8×10^{-14}	(2)	2.5×10^{-14}	(2)	$<9.1\times10^{-15}$
Other nuclides	5.7×10^{-4}	6.0×10^{-5}	5.8×10^{-4}	2.5×10^{-5}	7.3×10^{-5}	4.6×10^{-6}	6.9×10^{-6}	(2)	7.8×10^{-6}	(2)	5.1×10^{-6}	(2)	$<1.8\times10^{-6}$
All products	6.5×10^{-4}	6.9×10^{-5}	6.6×10^{-4}	2.9×10^{-5}	8.3×10^{-5}	5.3×10^{-6}	7.9×10^{-6}	(2)	8.9×10^{-6}	(2)	5.8×10^{-6}	(2)	$<2.1\times10^{-6}$
Total stream burden													
Dissolved and suspended [1] (average μc per ml):													
Sr^{90}	7.4×10^{-5}	8.7×10^{-6}	5.7×10^{-5}	2.0×10^{-6}	5.5×10^{-6}	3.5×10^{-7}	5.3×10^{-7}	(2)	5.9×10^{-7}	(2)	3.8×10^{-7}	(2)	$<1.4\times10^{-7}$
I^{131}	5.1×10^{-12}	5.9×10^{-13}	3.8×10^{-12}	1.3×10^{-13}	3.7×10^{-13}	2.3×10^{-14}	3.5×10^{-14}	(2)	4.0×10^{-14}	(2)	2.6×10^{-14}	(2)	$<9.5\times10^{-15}$
Cs^{137}	6.0×10^{-5}	7.3×10^{-6}	5.0×10^{-5}	1.9×10^{-6}	5.3×10^{-6}	3.4×10^{-7}	5.1×10^{-7}	(2)	5.8×10^{-7}	(2)	3.7×10^{-7}	(2)	$<1.3\times10^{-7}$
Other nuclides	8.0×10^{-4}	9.4×10^{-5}	6.8×10^{-4}	2.7×10^{-5}	7.4×10^{-5}	4.8×10^{-6}	7.2×10^{-6}	(2)	8.0×10^{-6}	(2)	5.2×10^{-6}	(2)	$<1.9\times10^{-6}$
All products	9.3×10^{-4}	1.1×10^{-4}	7.9×10^{-4}	3.1×10^{-5}	8.5×10^{-5}	5.5×10^{-6}	8.2×10^{-6}	(2)	9.2×10^{-6}	(2)	6.0×10^{-6}	(2)	$<2.2\times10^{-6}$
Products adsorbed													
Products on vegetation (c per mi^2):													
Sr^{90}	2.4×10^{0}	2.5×10^{-1}	1.2×10^{0}	2.1×10^{-2}	4.3×10^{-2}	2.8×10^{-3}	4.1×10^{-3}	(2)	3.2×10^{-3}	(2)	2.1×10^{-3}	(2)	$<7.8\times10^{-4}$
I^{131}	1.9×10^{-7}	2.0×10^{-8}	9.7×10^{-8}	1.7×10^{-9}	3.5×10^{-9}	2.2×10^{-10}	3.3×10^{-10}	(2)	2.6×10^{-10}	(2)	1.7×10^{-10}	(2)	$<6.2\times10^{-11}$
Cs^{137}	2.9×10^{0}	3.1×10^{-1}	1.5×10^{0}	2.5×10^{-2}	5.3×10^{-2}	3.4×10^{-3}	5.0×10^{-3}	(2)	4.0×10^{-3}	(2)	2.6×10^{-3}	(2)	$<9.6\times10^{-4}$
Other nuclides	2.2×10^{1}	2.3×10^{0}	1.1×10^{1}	1.9×10^{-1}	3.9×10^{-1}	2.5×10^{-2}	3.8×10^{-2}	(2)	3.0×10^{-2}	(2)	1.9×10^{-2}	(2)	$<7.2\times10^{-3}$
All products	2.7×10^{1}	2.9×10^{0}	1.4×10^{1}	2.4×10^{-1}	4.9×10^{-1}	3.1×10^{-2}	4.7×10^{-2}	(2)	3.7×10^{-2}	(2)	2.4×10^{-2}	(2)	$<8.9\times10^{-3}$
Products on soil (c per mi^2):													
Sr^{90}	1.9×10^{0}	2.0×10^{-1}	9.6×10^{-1}	1.6×10^{-2}	3.4×10^{-2}	2.2×10^{-3}	3.3×10^{-3}	(2)	2.6×10^{-3}	(2)	1.7×10^{-3}	(2)	$<6.2\times10^{-4}$
I^{131}	9.8×10^{-8}	1.0×10^{-8}	5.0×10^{-8}	8.6×10^{-10}	1.8×10^{-9}	1.1×10^{-10}	1.7×10^{-10}	(2)	1.3×10^{-10}	(2)	8.8×10^{-11}	(2)	$<3.2\times10^{-11}$
Cs^{137}	2.9×10^{0}	3.2×10^{-1}	1.5×10^{0}	2.6×10^{-2}	5.4×10^{-2}	3.4×10^{-3}	5.1×10^{-3}	(2)	4.0×10^{-3}	(2)	2.6×10^{-3}	(2)	$<9.7\times10^{-4}$
Other nuclides	2.2×10^{1}	2.4×10^{0}	1.2×10^{1}	2.0×10^{-1}	4.1×10^{-1}	2.6×10^{-2}	4.0×10^{-2}	(2)	3.0×10^{-2}	(2)	2.0×10^{-2}	(2)	$<7.4\times10^{-3}$
All products	2.7×10^{1}	2.9×10^{0}	1.4×10^{1}	2.4×10^{-1}	5.0×10^{-1}	3.2×10^{-2}	4.8×10^{-2}	(2)	3.7×10^{-2}	(2)	2.4×10^{-2}	(2)	$<9.0\times10^{-3}$
Products on rock, talus, and colluvium (c per mi^2):													
Sr^{90}	5.0×10^{-2}	5.3×10^{-3}	2.5×10^{-2}	4.4×10^{-4}	9.1×10^{-4}	5.8×10^{-5}	8.7×10^{-5}	(2)	6.8×10^{-5}	(2)	4.4×10^{-5}	(2)	$<1.6\times10^{-5}$
I^{131}	2.0×10^{-9}	2.1×10^{-10}	1.0×10^{-9}	1.8×10^{-11}	3.7×10^{-11}	2.3×10^{-12}	3.5×10^{-12}	(2)	2.7×10^{-12}	(2)	1.8×10^{-12}	(2)	$<6.6\times10^{-13}$
Cs^{137}	7.2×10^{-1}	7.7×10^{-2}	3.7×10^{-1}	6.4×10^{-3}	1.3×10^{-2}	8.4×10^{-4}	1.3×10^{-3}	(2)	9.9×10^{-4}	(2)	6.4×10^{-4}	(2)	$<2.4\times10^{-4}$
Other nuclides	1.2×10^{0}	1.4×10^{-1}	6.0×10^{-1}	1.1×10^{-2}	2.3×10^{-2}	1.4×10^{-3}	2.1×10^{-3}	(2)	1.7×10^{-3}	(2)	1.1×10^{-3}	(2)	$<4.1\times10^{-4}$
All products	2.0×10^{0}	2.2×10^{-1}	1.0×10^{0}	1.8×10^{-2}	3.7×10^{-2}	2.3×10^{-3}	3.5×10^{-3}	(2)	2.8×10^{-3}	(2)	1.8×10^{-3}	(2)	$<6.7\times10^{-4}$
Insoluble particulate products remaining near place of fall													
Products (c per mi^2):													
Sr^{90} and Cs^{137}, each	2.6×10^{1}	2.8×10^{0}	1.3×10^{1}	2.1×10^{-1}	4.0×10^{-1}	2.6×10^{-2}	3.8×10^{-2}	(2)	2.8×10^{-2}	(2)	1.8×10^{-2}	(2)	$<6.6\times10^{-3}$
I^{131}	1.8×10^{-6}	1.9×10^{-7}	8.8×10^{-7}	1.4×10^{-8}	2.7×10^{-8}	1.7×10^{-9}	2.6×10^{-9}	(2)	1.9×10^{-9}	(2)	1.2×10^{-9}	(2)	$<4.5\times10^{-10}$
Other nuclides	3.7×10^{2}	3.9×10^{1}	1.8×10^{2}	2.9×10^{0}	5.7×10^{0}	3.6×10^{-1}	5.3×10^{-1}	(2)	3.8×10^{-1}	(2)	2.5×10^{-1}	(2)	$<9.7\times10^{-2}$
All products	4.2×10^{2}	4.5×10^{1}	2.1×10^{2}	3.3×10^{0}	6.5×10^{0}	4.1×10^{-1}	6.1×10^{-1}	(2)	4.4×10^{-1}	(2)	2.9×10^{-1}	(2)	$<1.1\times10^{-1}$

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[1] Average over 15 days, in trunk streams at outer margin of the area of measurable fallout. Although it is expected that throwout would dam Ogotoruk Creek at the time of detonation, this dam well may be breached by the snowmelt runoff.

[2] Zero or nominal.

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