UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

POTENTIAL EFFECTS OF PROJECT CHARIOT ON LOCAL WATER SUPPLIES*

By

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Trace Elements Investigations Report 810.

This report has not been edited for conformity with Geological Survey format and nomenclature

*Prepared on behalf of the San Francisco Operations Office, United States Atomic Energy Commission

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ON LOCAL WATER SUPPLIES

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SCOPE OF THE REPORT

This report covers an order-of-magnitude appraisal of the concentrations of radioactive nuclides that might be introduced into local water supplies by execution of Project Chariot, near Cape Thompson, Alaska. (See Plate 1.) It is wholly a hypothetical case study, based on a single set of assumptions that will be outlined. Those assumptions, and the conclusions derived from them, may or may not be sustained in the final design of the project.

A first stage of the appraisal was outlined in a memorandum dated February 28, 1961, from Dr. John Wolfe, Chairman, Committee on Environmental Studies for Project Chariot, to Mr. E. C. Shute, Manager, SAN. It was authorized by a memorandum dated April 13, 1961, from Mr. John F. Philip, Director, Special Projects Division, SAN to Mr. Vincent E. McKelvey, Assistant Chief Geologist, Geological Survey. A second stage of the appraisal was authorized subsequently.

ANTECEDENT WORK

The writer visited the area July 7-14, 1961, for ground and air reconnaissance in company with Reuben Kachadoorian of the Geological Survey. However, much of the appraisal is based on information supplied by colleagues in the Geological Survey, or contained in the reports listed below. All these sources are drawn on freely, commonly without specific citations.

Allen, P. W., Van Der Hoven, I., and Weedfall, R. O., December 1960, Microclimatology of Ogotoruk Valley, Preliminary Report No. 1: U. S. Weather Bureau Research Station, Las Vegas, Nevada.

Kachadoorian, Reuben, and others, October 1958, Geology of the Ogotoruk Creek area, northwestern Alaska (with sections on surface water and quality of water): U. S. Geological Survey, Trace Elements Memorandum Report 976.

Kachadoorian, Reuben, and others, January 1960, 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, Trace Elements Investigations Report 753.

Kachadoorian, Reuben, and others, June 1960, Supplementary report on geologic investigations in support of Phase II, Project Chariot in the vicinity of Cape Thompson, northwestern Alaska: U. S. Geol. Survey, Trace Elements Investigations Report 764.

Kachadoorian, Reuben, and others, January 1961, Geologic investigations in support of Project Chariot, Phase III, in the vicinity of Cape Thompson, northwestern Alaska--Preliminary report: U. S. Geol. Survey, Trace Elements Investigation Report 779.

BASIC ASSUMPTIONS

Certain assumptions that are basic to this appraisal are delineated in three memorandums: (1) Mr. John F. Philip, Director, Special Projects Division, SAN, to Dr. Gerald W. Johnson, Associate Director, Lawrence Radiation Laboratory, March 21, 1961; (2) Dr. Johnson to Mr. Philip, March 31, 1961; and (3) the previously cited memorandum from Mr. Philip to Mr. V. E. McKelvey of the Geological Survey, April 13, 1961. These assumptions are:

1. The array and emplacement of nuclear explosives will by that described in "Project Chariot, Technical Director's Operation Plan, 28 October 1960, revised 1 February 1961." In brief, this plan contemplates one 200-kt nuclear explosive emplaced 800 feet below the land surface, and four 20-kt 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 will be 1,500 megacuries (Mc) one hour after detonation. Included will be 3,000 curies due to Sr^{90}, 3,000 curies due to Cs^{137}, and 2,250,000 curies due to I^{131}. [Owing to decay, these activities will 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 since detonation	Relative activity[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}	. . .	9.21×10^{-1}	. . .
5 days	3.20×10^{-3}	. . .	6.53×10^{-1}	. . .
10 days	1.39×10^{-3}	. . .	4.24×10^{-1}	. . .
15 days	8.56×10^{-4}	9.99×10^{-1}	2.76×10^{-1}	9.99×10^{-1}
30 days	3.73×10^{-4}	9.98×10^{-1}	7.58×10^{-2}	9.98×10^{-1}
45 days	2.29×10^{-4}	9.97×10^{-1}	2.09×10^{-2}	9.97×10^{-1}
60 days	1.62×10^{-4}	9.96×10^{-1}	5.73×10^{-3}	9.96×10^{-1}
90 days	9.97×10^{-5}	9.94×10^{-1}	4.33×10^{-4}	9.94×10^{-1}
6 months	4.27×10^{-5}	9.88×10^{-1}	1.51×10^{-7}	9.88×10^{-1}
8 months	3.03×10^{-5}	9.84×10^{-1}	8.21×10^{-10}	9.85×10^{-1}
9 months	2.62×10^{-5}	9.82×10^{-1}	5.82×10^{-11}	9.83×10^{-1}
1 year	1.86×10^{-5}	9.76×10^{-1}	2.25×10^{-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} $R_t / R_o = (1/2)^n$ 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.

3. The expected reach and distribution of fission-product activity will be as shown on Plate 2, based on the preceding assumption and on winds experienced at Kotzebue, Alaska, on April 4, 1959. [Plate 2 "contours" the activity in megacuries per square statute mile; the corresponding model by Lawrence Radiation Laboratory scales the activity in megacuries per square nautical mile.]

4. The fallout sector will lie between azimuths of 40° and 110°, clockwise from true north--that is, it will have an angular spread of 70°. [Because the fallout pattern on Plate 2 has an angular spread of approximately 85°, this assumption cannot be fulfilled literally. In this appraisal, two fallout patterns and two sectors are considered--(1) the pattern of Plate 2, oriented between azimuths of 40° and 125°; and (2) a mirror image of the pattern of Plate 2, rotated to orient between azimuths 25° and 110°. Limits of the two sectors are shown on Plate 1. Table 2 breaks down these two fallout patterns according to activities in each of the stream basins outlined on on Plate 1.]

5. Standards for drinking water will be one-tenth of the "maximum permissible concentrations" of radionuclides, as recommended in Handbook 69 of the National Bureau of Standards, for occupational exposure of 168 hours per week. (See p. 54.)

Further assumptions and instructions were prescribed for the second-stage appraisal, as follows:

6. In the fallout from Project Chariot, fission products will in large part be attached to disaggregated but chemically unaltered fragments of the mudstone, the Tiglukpuk formation, in which the "devices" will be detonated. [Theoretical consideration by Beetem and Baker[1/] concludes that very little of the fragmented mudstone will fuse and entrap fission products in a resulting glass. Rather, that the fission products will attach to the mudstone fragments largely by cation exchange or by adsorption; also, that essentially all fission products will be so attached. Since the opportunities for cation exchange and adsorption will be about proportional to surface area of the mudstone fragments, it follows that, per unit weight of fallout, the activity of attached fission products will vary about inversely to the mean diameter of fragments. In other words, the smaller fallout particles will be the more radioactive.]

1/ Beetem, W. A., and Baker, J. H., U. S. Geological Survey, written communication, July 1961.

7. Size distribution of fallout particles may be scaled from results of the high-explosive test of November 1960, by K. H. Larson and others[2]. Specifically, for particle sizes

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2/ Larson, K. H., University of California at Los Angeles, written communication, May 1961.

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less than 2 milimeters (2,000 microns), the distribution found by the test will 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. Table 4 shows the corresponding estimated distribution of radioactivity.]

8. Solubility of fission products in water will be taken as 10 percent for products having mass numbers that range from 88 to 92 and from 131 to 140; solubility will be taken as 1 percent for all other products. [Excluding those products whose abundance is too small to be of consequence in this appraisal, the 10-percent solubility factor applies chiefly to isotopes of strontium, yttrium, iodine, cesium, barium, and lanthanum. Preceding Table 2 estimates the soluble and insoluble fractions of fission-product activity in each of the stream basins outlined on Plate 1.]

Table 3 .- Estimated size distribution of fallout particles, Project Chariot [1/]

[Quantities in percent by weight]

Downwind distance from ground zero, miles	10	25	50	75	100	125	150
Particle size, mm:							
2.00 - 1.00	32.8	22.8	11.7	1.5	1.0	0	0
1.00 - .500	22.6*	24.6	21.4	12.8	6.9	3.2	1.2
.500 - .350	11.3	11.9*	13.0	10.6	7.1	4.8	3.4
.350 - .297	6.9	8.4	8.2*	9.9	9.2	6.8	3.7
.297 - .250	5.5	6.2	6.6	8.7	7.8	6.6	4.5
.250 - .210	5.0	5.1	5.9	7.9*	8.2	7.1	5.5
.210 - .177	4.0	4.4	6.3	7.4	8.0	8.2	7.7
.177 - .149	3.7	4.2	5.8	7.3	7.8*	8.3	8.3
.149 - .125	3.5	4.1	5.5	7.1	7.3	9.3*	12.3
.125 - .088	2.8	3.6	4.8	8.1	11.0	13.9	16.5*
.088 - .044	1.9	2.4	4.6	8.0	11.4	13.9	15.6
< .044	0	2.3	6.2	10.7	14.3	17.9	21.3
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Adapted from results of 256-pound high-explosive test in November 1960, after K. H. Larson and F. J. Berta, May 19, 1961. It is assumed that all particles larger than 2 mm. fall within less than 10 miles, and that all smaller than 0.044 mm. fall more than 10 miles from ground zero.

* Median weight.

Table 4 .- Estimated distribution of radioactivity according to size of fallout particles, Project Chariot 1/

[Quantities in percent of gross activity at given downwind distances from ground zero.]

Downwind distance from ground zero, miles	10	25	50	75	100	125	150
Particle size, mm:							
2.00 - 1.00	8.2	3.8	1.2	0.1	0.1	0	0
1.00 - .500	11.3	8.2	4.4	1.8	.7	.3	.1
.500 - .350	10.0	7.0	4.7	2.6	1.4	.8	.5
.350 - .297	8.0	6.5	3.9	3.2	2.4	1.5	.7
.297 - .250	7.5	5.7	3.7	3.3	2.4	1.7	.9
.250 - .210	8.2*	5.6	4.0	3.6	3.0	2.2	1.5
.210 - .177	7.8	5.7	5.0	4.0	3.5	3.0	2.5
.177 - .149	8.5	6.5	5.5	4.7	4.0	3.6	3.2
.149 - .125	9.5	7.5*	6.2	5.4	4.5	4.8	5.6
.125 - .088	10.0	8.5	7.0	7.9	8.7	9.3	9.7
.088 - .044	11.0	9.0	10.8*	12.7	14.5	14.9	14.8
< .044	0	26.0	43.6	50.7*	54.8*	57.9*	60.5*
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Activity assumed proportional to surface area of particles, derived from size distribution in percent by weight.

* Median activity.

9. The appraisal will derive probable rather than maximum-credible concentrations of fission-product activity in the streams and water-supply sources of the area, giving due consideration to the fraction of activity that becomes fixed on vegetation or earth materials. [The potential for fixation by dynamic ion exchange is covered on pages 34 to 50. Concentrations are derived for all fission products and separately for Sr^{90}, I^{131}, and Cs^{137}.]

10. Detonation will be assumed to occur at various seasons, such that the several consequent appraisals span the natural yearly range of hydrologic conditions. [Separate appraisals are developed subsequently for: (1) Detonation about in April, with fallout on continuous snow cover 30 days prior to breakup. (2) Detonation in early June, at the end of snowmelt runoff; in the 30 days following detonation, 0.5 inch precipitation with not more than 0.1 inch in any one storm. (3) Detonation in early August following two months of minimum precipitation; concurrent soil-water deficiency 1 inch, precipitation 2.5 inches in the next 30 days.
(4) Detonation in late September, with fallout on saturated tundra 10 days before freezeup; no precipitation between detonation and freezeup.]

SELECTED CHARACTERISTICS OF THE AREA

Certain environmental characteristics of the area bear directly on this appraisal. Brief summaries of these follow.

Wind movement

Plate 2 includes "roses" of downwind movement at the Chariot site in the spring and summer of 1960. The dominant movement there shown, from the north and north-northeast, is characteristic throughout the year. Wind was in this sector 62 percent of the daily observations in the 13 months ending with September 1960, and 75 percent in December 1959 (Allen, 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 other sectors, velocities exceeding 20 knots are uncommon.

Allen points out that this "Ogotoruk wind" out of the north and north-northeast is peculiar to the near vicinity of the Chariot site. Elements of his explanation are as follows: (1) High barometric pressure is dominant over the Arctic ice pack 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.

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 (see Plate 1). South of Cape Seppings, the prevailing wind is about out of the northwest, and commonly of less velocity.

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

Air temperature and permafrost

Mean maximum air temperature is below freezing about from 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 report that this summer rainfall is sufficient that much of the extensive tundra ordinarily is saturated at the time of freezeup.

About from October through May precipitation is in the form of snow, with a water content equivalent to about 40 percent of the yearly total, or somewhat more than 3 inches on the average. At the Chariot site in 1959-60, the water content of measured snowfall was less than this average.

Owing to persistent strong winds, which have been described, 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 dog sled. In the lee of low ridges that lie athwart the prevailing wind, Kachadoorian has observed snowdrifts as much as 30 feet thick, 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; estimates of silt content range up to 10 percent, by weight.

The short climatologic record at the Chariot site, beginning in late August 1960, suggests that monthly precipitation, also the frequency and magnitude of storms, are about the same as at Kotzebue, 120 miles to the southeast. Tables 5 and 6 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 5.- Minimum, average, and maximum monthly precipitation at Kotzebue, Alaska, 1940-1960

[Quantities in inches]

	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

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

Table 6 .- Number of storms of various magnitudes at at Kotzebue, Alaska, over a 20-year term 1/

Month	Magnitude of storm, in inches precipitated								
	< .05	.05-.09	.10-.24	.25-.49	.50-.74	.75-.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	0			
May	26	22	14	5	1	0			
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	0				
December	40	14	16	5	1				

1/ Based on records published by the U. S. Weather Bureau, 1940-1960. Here, each "storm" encompasses consecutive days having measurable precipitation; each is terminated by one or more calendar days without measurable precipitation.

Streamflow

Concerning the flow of streams in the area of Plate 1, specific information 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 7 summarizes the available records of measured flow.

Table 7.- Monthly discharge of Ogotoruk Creek, 1959-1960

	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
Aug.	1,580	3,020	.75	1.43
Sept.	787	468	.38	.22
Oct.	1,110	. . .	.53	. . .
The 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 the smaller. The later period, about in August, is generated by rain storms; commonly it encompasses several short intervals of peak flow and its major peak is the extreme of the year.

In winter, streamflow generally is small or zero. In Ogotoruk Creek in 1959, Waller 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. From this, and from the available records of runoff and of precipitation it is concluded that, in the Ogotoruk Creek basin:
(1) At the end of snowmelt, all the tundra ordinarily is saturated.
(2) During the season of principal vegetal growth, about June through August and possibly into September, loss of water owing 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 about 0.75 inch. (3) Also during the season of vegetal growth, soil water is depleted fairly 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 about in August or September. In 1960, a dry year, the maximum soil-water deficiency was about 1.2 inches.

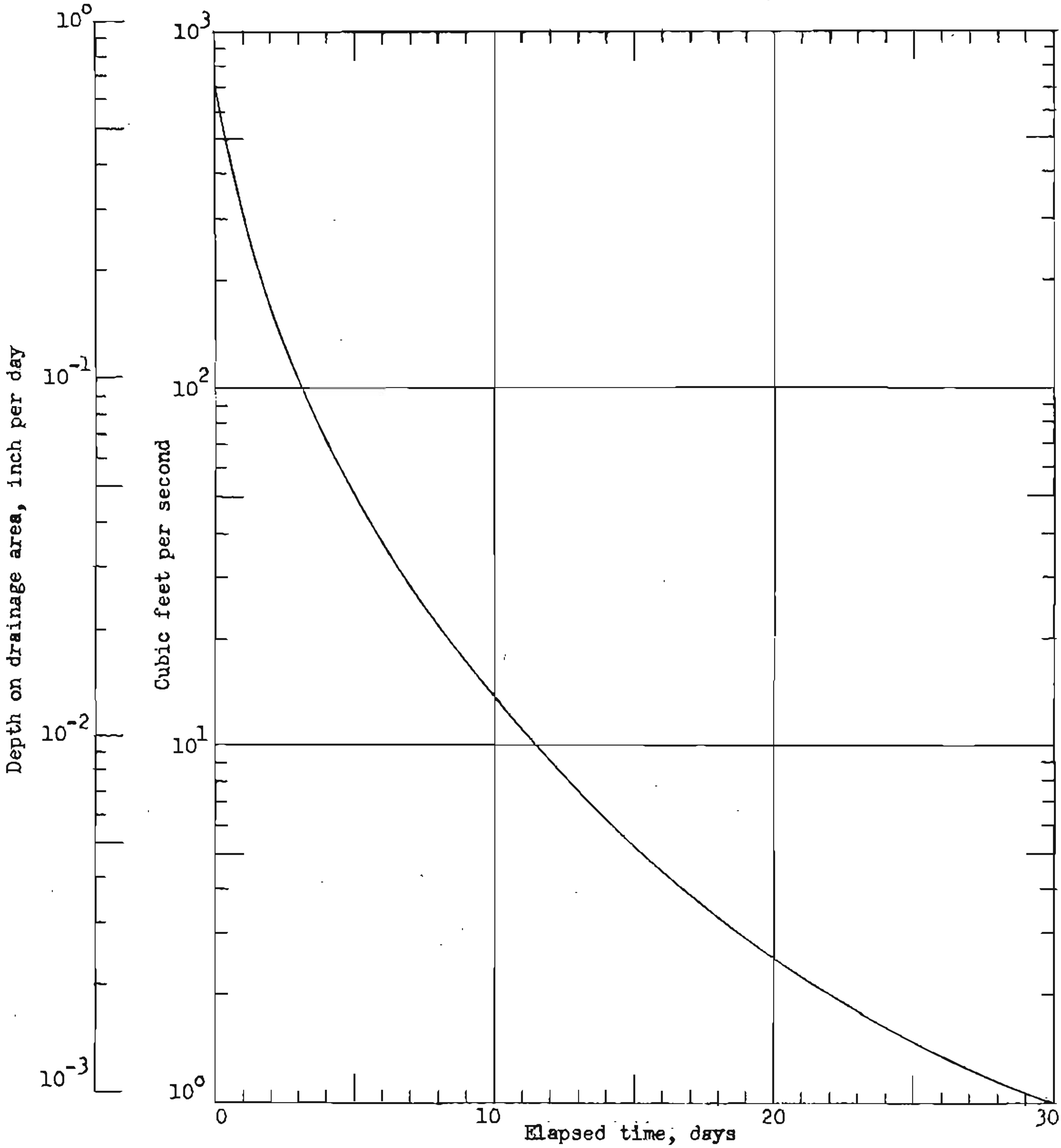

Figure 1.- Approximate runoff-depletion characteristic of the Ogotoruk Creek basin

To follow page 19

(4) Owing to the relatively heavy precipitation in August and September (see Table 5), all the tundra ordinarily is re-saturated prior to freezeup--that is, about by the end of September. It is postulated that these characteristics of the Ogotoruk Creek basin 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 "micro-ponds," 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 the aggregate volume of such water to be 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 here 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 (see p. 14). As has been described by Waller, permeable deposits beneath flood plains and stream beds probably afford the principal paths of such movement. Recharge of these deposits presumably is by infiltration from the streams 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 relatively deep ground-water movement. Principal among them is Covroeruk Spring near Cape Seppings, 27 miles southeast of the Chariot site. Its discharge is reported to range substantially--30 cfs (cubic feet per second) on August 15, 1959; 22.7 cfs on September 9, 1959; 6.17 cfs in early April 1960; and 12.3 cfs on 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.

For this spring in particular, the specific area of recharge and the route of water movement to the orifice are largely speculative, even though these features bear on the potential for introduction of radionuclides into the spring water by Project Chariot. Relevant evidence, which is summarized below, is conflicting. (1) At least in part on the basis of the chemical character of the water, Waller postulates deep movement from a remote area of recharge, in bedrock and through or under the zone of permafrost. However, the chemical make-up of the water from Covroeruk 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 discharge, the volume of water in ground storage would be so large that the spring discharge should be more nearly uniform. Based on the four values cited above, maximum discharge is at least five-fold greater than minimum discharge. (3) This variability in discharge implies a local rather than a remote source. This would not be precluded by the existence of permafrost in the vicinity. Thus, 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 probably it would remain unfrozen.

Based on similarity in chemical make-up of the waters, Waller and Lamar have implied that Nusoaruk Creek, 3 miles northwest of the site, is fed by springs analogous to Covroeruk Spring. As observed by the writer in mid-July 1961, the discharge of Nusoaruk 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 half a mile from the shore of the Chukchi Sea. No major orifice such as that of Covroeruk 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, 1960). The water has a "noticeable sulfur odor."

Sediment movement

As Table 2 has shown, most of the fallout from Project Chariot is expected to 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.

Potential mobility of fallout and earth particles depends on range in particle size and on land-surface and stream gradients. Plate 3 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 8, 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. 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 varies from place to place over the streambed, and ranges about from 20 millimeters (pebble gravel) to 0.125 millimeter (fine sand). However, no progressive change in median size is evident within the 50-mile reach.

As observed by the writer, stream-bed 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 millimeters (4 inches). Most of the larger particles are tabular and ill-rounded. On the riffles, little sand is evident and the finer particles commonly are granules or small pebbles, 5 to 10 millimeters in size. Within the 5-mile reach, no progressive change in median particle size was evident to the eye. 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 gradiant is substantially the steeper.

Table 8, notes.- Continued

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

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

   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. August 11, 1958.

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

10. Flood plain of Ogotoruk Creek, high-water stream deposit, about 1/4 mile north of camp at Chariot site. Sampled by the writer, July 9, 1961.

The suspended-sediment load of Ogotoruk Creek has been determined by Porterfield of the Geological Survey in July-August 1958 and July-August 1959 (see Table 8, 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 (millimeter) on August 11, and 0.031 mm on August 12. Maximum concentration determined in 1959 was 142 ppm on July 9; concurrent streamflow was 700 cfs (cubic feet per second). 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 "direct" runoff from rain.

Table 8, 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-July have not been determined. Presumably they are at least moderately large and relatively prolonged.

Under basic assumptions of this appraisal--as shown by Table 2 and Plates 1 and 2--about 20 percent of the fission-product activity vented by Project Chariot would fall on land more than 10 miles from the center of detonation. Substantially all this activity is expected to be on fallout particles smaller than 2 mm in size (see 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 move overland less readily, and in a trunk stream, would move only as bedload.

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

Land-surface types

Table 9 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. [Most of these maps are in process of publication; manuscript copies were made available for the classification, 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 stream cuts. Principal types are mudstone, siltstone, sandstone, shale, limestone, and conglomerate. Except in sea cliffs, stream cuts, 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 usually 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 is estimated not to exceed 10 feet, porosity and infiltration capacity are large, and drainage is doubtless rapid and nearly complete. It is inferred that in talus the top of the permafrost zone commonly is deeper than in other parts of the area.

Land areas here classified as colluvium are those that occur on slopes of intermediate steepness and that are essentially devoid of vegetation. In such areas the colluvium generally is 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. In such areas, also, 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 8; this is developed below.

Tundra vegetation and bare soil.- Among the several basins discriminated in Table 9 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 are of low surface gradient and poorly drained. Here the vegetation canopy is dense and, excepting a few scattered ponds, covers essentially 100 percent of the surface. At the other extreme, the vegetal cover is sparse and occupies all but the steepest and driest slopes. Here the dominant vegetal type 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 of the coastal valleys to the south there are scattered stands of willow along stream banks; 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 wind-borne 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 non-vegetated colluvium described previously. According to Kachadoorian, 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 9 as having "fair" drainage. Yet it has been estimated (p. 20) 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 accounted for 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 is there essentially 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 infiltrations is essentially zero. For the Ogotoruk Creek basin, it has been concluded (p. 19) 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 in 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.- Lagoons, both large and small, generally shallow, are numerous along the coast southeastward from Point Hope (see Plate 1). Certain of the smaller lagoons are closed by permanent barrier beaches. Those fed by the larger streams, however, commonly are closed only intermittently, whenever the surf generated by an on-shore 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 pages 70-72.

Potentials for adsorption

General aspects.- A fraction of the fission products vented by Project Chariot will be soluble in water; specifics have been given on page 9 and in Table 2. In turn, a fraction of the dissolved nuclides will 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 is determined by dynamic ionic equilibrium among (1) the particular nuclide in solution, (2) the amount and kind of other solutes in solution, and (3) the particular solid-phase material. Higgins[3/] has stated the basic

3/ Higgins, G. H., 1959, Evaluation of the ground-water contamination hazard from underground nuclear explosions: University of California, Lawrence Radiation Laboratory, Plowshare Series, Part IV, UCRL 5678, p. 27.

equation for such equilibrium in a form analogous to:

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

in which: K_d is a "distribution coefficient" characterizing the particular nuclide in solution;

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 one with the other.

Obviously, the preceding equation describes any one of an infinite number of adsorption environments. For a particular nuclide paired with a particular solid-phase material, the ratio A_s / A_l approaches the "normal" value of K_d only as the ratio M_l / M_s approaches unity.

Higgins points 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 not known to the writer whether K_d values range appreciably with differences in temperature.

For common pairs of nuclide and earth material, "normal" values of K_d range generally from 1 or less to at least 100,000. In other words, the radioactivity adsorbed by the solid phase generally ranges from at least one-half to nearly all the radioactivity of the environment. Figure 2 shows the distribution of radioactivity between solid and liquid phases for values of K_d ranging between 0.01 and 100, assuming the ratio M_l / M_s to be unity.

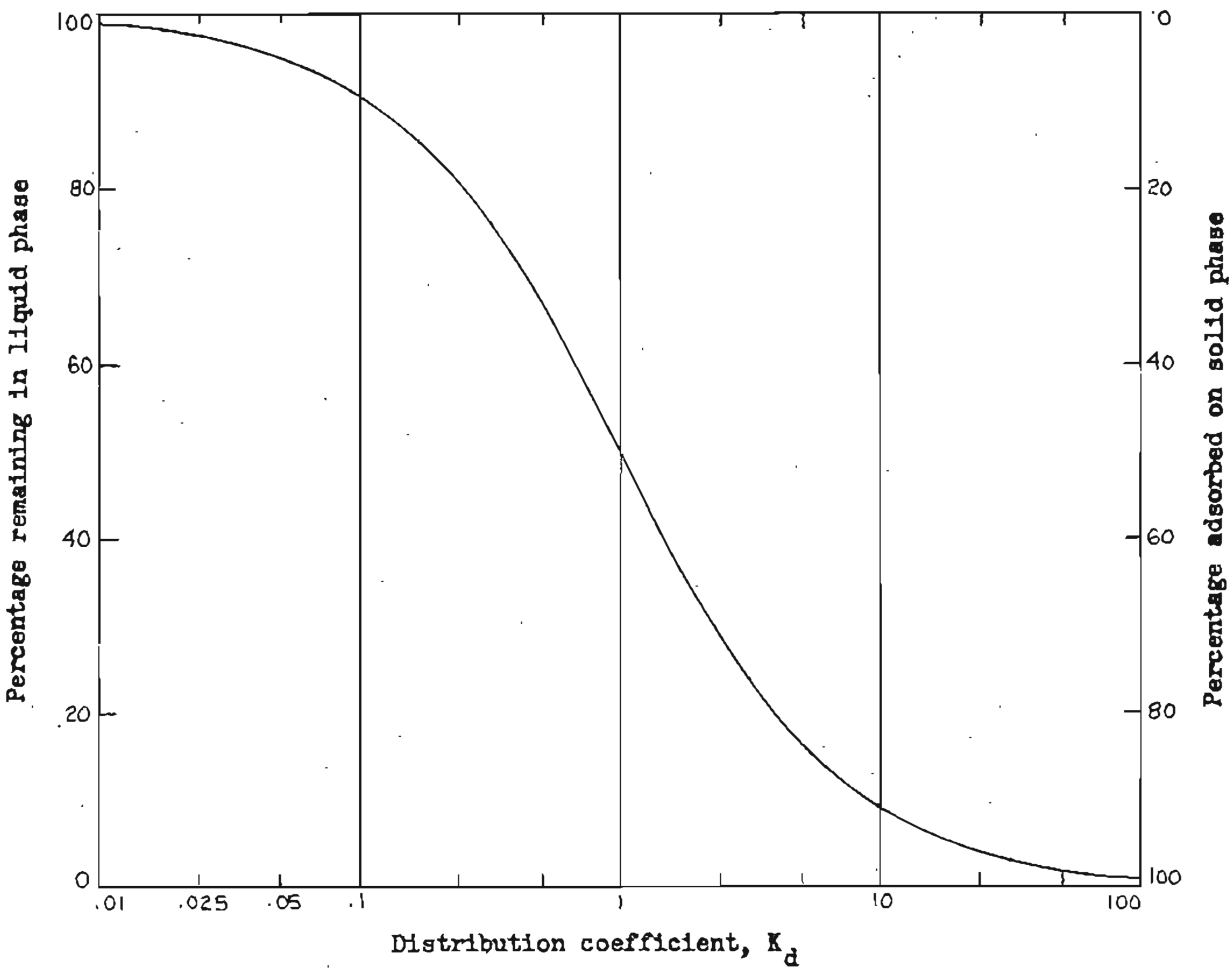

Figure 2.- Distribution of soluble nuclides between liquid and solid phases in an adsorption environment

In field situations it is difficult to evaluate the ratio M_l / M_s, which is a ratio of the masses reacting one with the 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 of a solid-phase earth material can react only if that material is finely comminuted. Also, assuming an earth material of density 2.7, 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 an aquifer of medium porosity, say 15 to 20 percent, the ratio would be about 0.25; radioactive nuclides adsorbed on the aquifer materials would be somewhat greater than "normal." In the cases of nuclide-bearing sediment suspended in a stream, and of nuclide-bearing water flowing over massive rock or coarse gravel, the ratio would be greater than unity, possibly by several orders of magnitude. In these cases radioactivity on the solid phase at equilibrium would be substantially less than "normal." All these extreme cases would be represented in adsorption reactions associated with Project Chariot.

Distribution coefficients for typical materials and particular nuclides.- As a basis for estimating potential adsorption under Project Chariot, distribution coefficients have been determined in the laboratory for (1) a suite of 18 samples representing the vegetation, soil, and rocks near the Chariot site paired with (2) nine solutions simulating the chemical composition of stream and pond waters of the area, to which solutions had been added carrier-free Sr^{85}, I^{131}, and Cs^{137}. Laboratory procedures are outlined by Baker and Beetem[4/]. Table 10

4/ Baker, J. H., and Beetem, W. A., September 1961, Distribution coefficients for adsorption of carrier-free cesium, strontium, and iodine by samples from the vicinity of Cape Thompson, northwestern Alaska: U. S. Geological Survey, Technical Letter Chariot-1, duplicated, 19 p.

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identifies the surface materials sampled near the site. Tables 11 and 12 show, respectively, the composition of (1) stream and pond waters of the area and (2) the solutions simulating those natural waters. Tables 13-15 list the distribution coefficients determined after 1-day and 6-day equilibration with the several isotopes.

Table 10.- Materials from vicinity of Chariot site, equilibrated with solutions containing Sr^{85}, I^{131}, or Cs^{137}, per Tables 12 to 14.

[Samples collected by R. Kachadoorian and A. M. Piper, July 1961]

Field Number	Description	Moisture content 1/	Location
AKd 1	Limestone fragments	. . .	Crest of Point Crowbill, 1.5 miles WNW of site.
AKd 2	Limestone talus	. . .	
AKd 3	Residual soil from limestone.	22.2	
AKd 4	Live moss on limestone colluvium.	. . .	
AKd 5	Dead moss on limestone colluvium.	. . .	
AKd 6	Mixed vegetation, live and dead, on limestone colluvium.	. . .	
AKd 7	Live moss from tundra	. . .	Slope southeast of West Pond, 6.5 miles north of site.
AKd 8	Tussock grass, crown and roots, from tundra.	. . .	
AKd 9	Windblown silt (deposited from melted snow?).	49.8	
AKd 10	Soil from frost boil	37.5	
AKd 11	Organic bottom sludge from perennial pond.	83.2	West Pond (no. 6)
AKd 112	Mudstone fragments, fresh, Tiglukpuk formation.	. . .	2,200 feet nearly east of site.
AKd 113	Soil from frost boil	19.7	Vicinity of test hole "Dog," which is 2,150 feet ENE of site.
AKd 114	Do.	11.0	
AKd 115	Do.	12.7	
AKd 116	Do.	23.5	
AKd 117	Do.	21.1	
AKd 118	Windblown silt from frost boil.	43.7	

1/ Grams per 100 grams, as received in laboratory. Determinations by J. H. Baker and W. A. Beetem, U. S. Geological Survey, August 1961.

Table 11.- Composition of stream and pond waters, in equivalents per million, from vicinity of the Chariot site

[Analyses by U. S. Geological Survey]

Number on Plate 4	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
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	Agahyoukuk Creek	8/25/59	3.835	.132	3.967	29	3.229	.625	.113	5.3	7.8
6	West Pond (No. 6)	8/ 4/59	.060	.184	.244	.33	.098	.025	.113	3.9	5.7
7	East Pond (GE No. 1)	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	Kisimulowk 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	.458	.028	4.7	7.9
Extremes			.060	.062	.244	.33	.197	.025	.028	.29	5.7
			3.835	.657	3.967	41	3.229	1.062	.705	9.8	8.0

Table 11.- Continued.

Notes.- 1. About 51 miles ENE of Point Hope and 39 miles NE of Chariot site.

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

3. About 14 miles NE of site.

4. About 16 miles ENE of Point Hope and 24 miles NW of site.

5. About 22 miles ESE of Point Hope and 11 miles NW of site.

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

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

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

9. About one-half mile upstream from mouth, 7 miles ESE of site and 11 miles NW of Cape Seppings.

10. About 7 miles NNE of Kivalina and 39 miles ESE of site.

11. About 4 miles ENE of Kivalina and 42 miles ESE of site.

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

Table 12.- Composition of solutions, in equivalents per million, equilibrated with materials from vicinity of the Chariot site

[pH of solutions about 7.2; Sr^{85}, I^{131}, or Cs^{137} added to each solution. After Baker and Beetem, 1961]

Number	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		5	0.033	0.166	0.2
2	.089	.044	.067	0.2	2	.067	.133	.5
3	.044	.022	.133		.5	.133	.067	2.0
4	.545	.278	.167		5	.167	.823	.2
5	.445	.222	.333	1.0	2	.333	.667	.5
6	.222	.111	.667		.5	.667	.333	2.0
7	2.22	1.11	.667		5	.667	3.33	.2
8	1.78	.890	1.33	4.0	2	1.33	2.67	.5
9	.890	.445	2.67		.5	2.67	1.33	2.0

Table 13.- Distribution coefficients for 1-day and 6-day adsorption of Sr^{85} on materials from vicinity of Chariot site

[Determinations by J. H. Baker and W. A. Beetem, U. S. Geological Survey, August 1961]

Sample number	Material		Solution number (see Table 12) 1	2	3	4	5	6	7	8	9
	Tundra vegetation										
AKd 4	Live moss on limestone colluvium.	1-day	1,260	. . .	3,720						
		6-day	450	. . .	1,600						
AKd 5	Dead moss on limestone colluvium.	1-day	696	. . .	940						
		6-day	560	. . .	930						
AKd 6	Mixed species, live and dead, on limestone colluvium.	1-day	495	. . .	631						
		6-day	380	. . .	440						
AKd 7	Live moss	1-day	713	. . .	2,620						
		6-day	348	. . .	670						
AKd 8a	Tussock-grass crown	1-day	. . .	53	. . .						
		6-day	. . .	43	. . .						
AKd 8b	Tussock-grass root mat	1-day	. . .	86	. . .						
		6-day	. . .	98	. . .						
AKd 11	Organic bottom sludge, West Pond.	1-day	1,980	2,210	5,360	364	616	12,210	73	131	7,320
		6-day	992	948	1,190	369	452	4,180	73	127	10,700
	Soil mantle										
AKd 3	Residual soil from limestone.	1-day	577	697	757	166	222	440	47	55	155
		6-day	585	620	914	245	385	730	60	65	3,400
AKd 9	Windblown silt (from melted snow?).	1-day	207	496	1,407	91	141	285	22	33	666
		6-day	222	222	482	101	124	507	22	39	4,940

Table 13.-Sr^{85}, continued.

Sample number	Material		Solution number (see Table 12) 1	2	3	4	5	6	7	8	9
	Soil mantle.-Continued.										
AKd 10	Frost boil in tundra	1-day	141	305	1,230	55	104	859	14	26	1,980
		6-day	128	142	341	60	107	710	21	32	4,130
AKd 113	Do.	1-day	249	425	1,260	66	131	2,150	15	26	1,100
		6-day	150	205	550	68	115	1,480	16	26	3,100
AKd 114	Do.	1-day	333	586	1,980	80	130	3,650	20	27	624
		6-day	236	300	702	85	153	2,700	27	37	2,440
AKd 115	Do.	1-day	216	371	1,420	54	104	1,450	12	23	1,750
		6-day	136	178	480	54	91	3,480	13	22	2,700
AKd 116	Do.	1-day	221	407	1,060	64	118	2,170	14	31	1,210
		6-day	131	190	630	70	118	1,900	18	28	4,100
AKd 117	Do.	1-day	282	493	1,480	76	139	2,410	16	31	918
		6-day	230	300	855	80	132	2,100	16	32	3,200
AKd 118	Windblown silt from frost boil.	1-day	227	377	1,100	88	131	1,040	19	29	888
		6-day	150	144	300	75	107	875	22	36	2,200
	Rocks										
AKd 1	Limestone fragments	1-day	.85								
		6-day	.80								
AKd 2	Limestone talus	1-day	2.8								
		6-day	3.1								
AKd 112	Mudstone fragments, fresh, Tiglukpuk formation.	1-day	38.								
		6-day	75.								

Table 14.- Distribution coefficients for 1-day and 6-day adsorption of I^{131} on materials from vicinity of Chariot site

[Determinations by J. H. Baker and W. A. Beetem, U. S. Geological Survey, August 1961]

Sample number	Material		Solution number (see Table 12)								
			1	2	3	4	5	6	7	8	9
	Tundra vegetation										
AKd 4	Live moss on limestone colluvium.	1-day	68	. . .	26						
		6-day	282	. . .	267						
AKd 5	Dead moss on limestone colluvium.	1-day	67	. . .	64						
		6-day	540	. . .	568						
AKd 6	Mixed species, live and dead, on limestone colluvium.	1-day	40	. . .	23						
		6-day	288	. . .	233						
AKd 7	Live moss	1-day	26	. . .	21						
		6-day	728	. . .	905						
AKd 8a	Tussock-grass crown	1-day	. . .	8.4	. . .						
		6-day	. . .	23	. . .						
AKd 8b	Tussock-grass root mat	1-day	. . .	2.7	. . .						
		6-day	. . .	4.1	. . .						
AKd 11	Organic bottom sludge, West Pond.	1-day	235	71	150	97	122	188	31	240	66
		6-day	3,970	1,900	2,450	3,440	3,100	2,070	1,100	4,050	1,950
	Soil mantle										
AKd 3	Residual soil from limestone.	1-day	4.5	12	7.2	14	7.0	12	2.8	6.5	4.7
		6-day	51	216	216	232	60	75	12	52	11
AKd 9	Windblown silt (from melted snow?).	1-day	95	22	12	30	45	53	20	42	56
		6-day	1,090	345	976	448	1,090	862	58	881	630

Table 14.- I^{131}, continued.

Sample number	Material		Solution number (see Table 12) 1	2	3	4	5	6	7	8	9
	Soil mantle.-Continued										
AKd 10	Frost boil in tundra	1-day	16	11	16	11	12	24	8.5	14	11
		6-day	159	92	277	1,040	139	274	60	133	53
AKd 113	Do.	1-day	6.4	10	3.4	16	7.8	7.1	5.6	3.6	5.5
		6-day	50	80	73	100	34	58	12	20	86
AKd 114	Do.	1-day	1.9	3.3	.9	5.6	3.4	1.2	2.6	1.5	1.6
		6-day	14	26	16	28	24	7.2	12	12	14
AKd 115	Do.	1-day	1.9	10	.9	5.8	3.5	2.8	2.4	1.6	2.0
		6-day	14	32	19	23	16	19	6.4	9.0	26
AKd 116	Do.	1-day	7.6	12	4.1	13	6.8	11	6.0	4.6	7.2
		6-day	40	126	56	90	38	54	12	30	93
AKd 117	Do.	1-day	3.6	9.4	4.1	12	4.4	5.4	4.4	2.2	3.2
		6-day	29	113	38	94	40	40	10	13	19
AKd 118	Windblown silt from frost boil.	1-day	22	8.1	10	21	14	47	18	8.1	9.4
		6-day	273	218	175	260	20	115	198	175	89
	Rocks										
AKd 1	Limestone fragments	1-day	.29								
		6-day	.60								
AKd 2	Limestone talus	1-day	.12								
		6-day	1.2								
AKd 112	Mudstone fragments, fresh, Tiglukpuk formation.	1-day	.04								
		6-day	.017								

Table 15.- Distribution coefficients for 1-day and 6-day adsorption of Cs^{137} on materials from vicinity of Chariot site

[Determinations by J. H. Baker and W. A. Beetem, U. S. Geological Survey, August 1961]

Sample number	Material		Solution number (see Table 12) 1	2	3	4	5	6	7	8	9
	Tundra vegetation										
AKd 4	Live moss on limestone colluvium.	1-day	594	. . .	4,040						
		6-day	1,820	. . .	5,540						
AKd 5	Dead moss on limestone colluvium.	1-day	1,520	. . .	1,650						
		6-day	4,160	. . .	2,640						
AKd 6	Mixed species, live and dead, on limestone colluvium.	1-day	1,780	. . .	1,240						
		6-day	2,200	. . .	3,380						
AKd 7	Live moss	1-day	99	. . .	168						
		6-day	1,370	. . .	4,150						
AKd 8a	Tussock-grass crown	1-day	. . .	8.3	. . .						
		6-day	. . .	13	. . .						
AKd 8b	Tussock-grass root mat	1-day	. . .	164	. . .						
		6-day	. . .	138	. . .						
AKd 11	Organic bottom sludge, West Pond.	1-day	3,980	3,570	6,440	1,630	3,620	5,300	2,400	2,750	2,250
		6-day	4,320	4,300	5,790	3,170	5,480	14,730	4,140	4,940	2,590
	Soil mantle										
AKd 3	Residual soil from limestone.	1-day	6,590	13,000	14,950	1,320	4,320	5,280	2,760	3,350	1,880
		6-day	12,800	10,560	27,460	5,060	14,130	40,160	11,900	21,900	8,200
AKd 9	Windblown silt (from melted snow?).	1-day	2,000	2,620	31,740	3,320	2,620	10,460	1,620	3,750	4,500
		6-day	3,970	5,420	16,550	5,070	7,380	53,130	8,320	8,370	17,300
AKd 116	Frost boil in tundra	1-day	1,640	2,340	4,170	1,730	2,560	2,630	2,150	2,320	3,000
		6-day	2,120	3,980	8,620	5,660	9,000	49,130	6,990	9,070	11,180

Table 15.- Cs^{137}, continued.

Sample number	Material		Solution number (see Table 12) 1	2	3	4	5	6	7	8	9
	Rocks										
AKd 1	Limestone fragments	1-day	* 3.0								
AKd 2	Limestone talus	1-day	* 6.9								
AKd 112	Mudstone fragments, fresh, Tiglukpuk formation.	1-day	*26.4								

* Solution with which the rock samples were equilibrated had a pH of 3.

Mean distribution coefficients and mean basin-wide adsorption.-- The numerous distribution coefficients determined by Baker and Beetem must be generalized for purposes of this report. The generalization involves three steps: (1) Mean distribution coefficients are interpolated for the several land-surface types of Table 9, paired with each of the three nuclides tested by Baker and Beetem, also with other fission-product nuclides collectively. (2) Corresponding to these mean coefficients, values are calculated for the fractions of total radioactivity adsorbed by the solid phase ("A_s" of the equation on p. 34). (3) In turn these mean fractions of radioactivity adsorbed by each land-surface type are applied to the percentage areas of Table 9 to derive, by summation of partial products, a mean value for the fraction of radioactivity adsorbed within each of the basins discriminated on Plate 1. For purposes of this report, the available data have been so generalized for M_l / M_s ratios of 1, 100, and 1,000--that is, for mean distribution coefficients multiplied by factors of 10^0, 10^{-2}, and 10^{-3}, respectively. Tables 16 and 17 summarize the generalized data.

The adsorption-potential values of Tables 16 and 17 apply, of course, only to the soluble fraction of the fission products vented by Project Chariot (see 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.

Table 16.- Mean distribution coefficients and percentages of activity adsorbed by land-surface materials, Project Chariot

Nuclide	Land-surface type: Vegetated	Bare soil	Rock, talus, and colluvium
	Distribution coefficient, K_d		
Sr^{90}	126	142	23.5
I^{131}	31.3	29.5	.5
Cs^{137}	156	7,400	40
Other 1/	325	400	60
	Fraction of activity adsorbed 2/		
Sr^{90}	.9921	.9888	.9592
I^{131}	.9690	.9672	.3333
Cs^{137}	.9936	.9999	.9756
Other	.9969	.9975	.9836

1/ Other fission-product nuclides collectively; values estimated.

2/ Assuming the ratio M_l / M_s to be unity.

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. However, it 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 by sled on the winter ice.

In order of distance from the Chariot site, the principal villages of concern are Point Hope, native population 290, on a barrier beach, 32 miles to the northwest; Kivalina, native population 135, also on a barrier beach, 41 miles to the southeast; Cape Lisburne (a military base), on the shore 55 miles to the north; 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, on a barrier beach, 120 miles to the southeast.

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, 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, Ca, Mg, and HCO_3 were 51 percent of the total; Na and Cl, 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 (see Plate 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 1/4 mile and 2 miles above its mouth, according to the amount of flow. No wells are used currently, but formerly there were two 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, summer source is reported to be ground water (Waller, 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 essentially free from wind-borne silt.

At least half the residents of Noatak live during the summer at a fishing camp on Sheshalik Spit at the north 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 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 trail-side and melted in the mouth for drinking water, 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. The previously cited papers by Foote trace these routes specifically.

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 in the case of birds and the smaller animals--the countless rills and micro-ponds that are generated intermittently by melting of snow and by the heavier rainfall.

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

STANDARDS FOR DRINKING WATER

National Bureau of Standards Handbook 69 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" precautions are taken; for other situations, one-tenth the listed values is to be applied.

Several aspects of these drinking-water standards are stressed, as follows:[5]

5/ Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and in water for occupational exposure: U. S. Dept. Commerce, National Bureau of Standards Handbook 69, pp. 6, 21 (1959).

> 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. Here 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 by averaged over periods up to one year [underscore 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 [underscore 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, "maximum permissible concentrations" are cited below, 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:

	$\mu c/ml$	
	Soluble	Insoluble
Mixed fission products*	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}

*No isotopes of radium present

Execution of Project Chariot would have only transient effects on local water supplies, in the sense of the foregoing quotation from Handbook 69. In this transient situation, 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. It is noted, however, that gamma or beta activity acceptable in an emergency has been set at 9×10^{-2} $\mu c/ml$ for a 10-day period of ingestion, and 3×10^{-2} $\mu c/ml$ for a 30-day period.[6/] This 30-day standard is 3×10^5 greater than the life-long standard for mixed fission products.

6/ The effects of nuclear weapons: U. S. Atomic Energy Commission, paragraph 12.101, p. 535 (1957).

EXPECTED DISPERSAL OF FISSION PRODUCTS FROM PROJECT CHARIOT

Within the framework of general assumptions thus far presented, and certain specific assumptions and simplifications that will be explained, Tables 18-22 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 2 in each of the two orientations outlined on page 5. 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 micro-ponds within the area; (2) suspended in the streams; (3) adsorbed on land-surface materials and so essentially 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 re-dispersal by water or wind, also to ingestion by grazing animals.

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

Case I: Detonation about in April (Table 18)

General aspects.- Case I assumes: (1) Detonation about in April, with fallout on continuous snow cover 30 days prior to breakup.
(2) Negligible redistribution of fallout by the wind. This assumption is unrealistic but is a necessary simplification (see pp. 13 and 68-69).
(3) Snowmelt runoff of 1 inch over the area, in 30 days following breakup. This is the runoff of Ogotoruk Creek in a "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 micro-ponds, 0.3 inch over the area, as estimated on page 20.

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 re-freeze at night.

Nuclides dissolved in runoff and in micro-ponds.- It is assumed that all the soluble fission products will be dissolved by the melt water and, excepting the fractions detained in micro-ponds or adsorbed by land-surface materials (to be appraised), will flow to the Chukchi Sea and so will pass rather quickly from the area. In Table 18, maximum values among the several basins are for the expected concentration in micro-ponds, rills, and small streams at place of origin in melting snow, assuming (1) "hot spots" having activities 10-fold greater than according to the generalized pattern of Plate 2, and (2) 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 micro-ponds within the area of measurable fallout (Plate 2). 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 Kusoaruk Creeks, or in most of the small basins between Ogotoruk Creek and Cape Seppings (basins 0, 1, and 2 on Plate 1). In other basins of the area, dilution probably would be less than five-fold and almost certainly less than ten-fold.

Nuclides suspended in runoff.- Except within a few miles of the Chariot site, insoluble fallout particles are presumed to be of such size (Table 3) as to move readily with the melt water and, unless trapped by irregularities of the snow-ice-land surface to become suspended sediment in the streams. The fraction so becoming sediment cannot be reasoned from information at hand. For purposes of this appraisal, Table 18 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. As so postulated, activity in the trunk streams due to suspended fallout particles is expected to be about from 3- to 35-fold greater than that due to dissolved nuclides. The smaller ratio applies 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, ranges from 4.5×10^{-3} to 2.0×10^{-5} $\mu c/ml$. Thus, total stream burden is 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 appears to 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. 15), 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 circumstances, a mean M_l / M_s ratio of 10^3 is postulated--in other words, that "normal" distribution coefficients are reduced by a factor of 10^{-3}. Even so, substantial percentages of Cs^{137} and "other" nuclides, and appreciable percentages of Sr^{90} and I^{131} would be immobilized by adsorption on land-surface materials (see Table 17).

Nuclides infiltrated to soil water.- During the snow-melt 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 essentially zero. Weeks or months later, however, a substantial or even a major fraction of the melt water that previously had been detained in micro-ponds might infiltrate (see pp. 33 and 72).

Products remaining near place of fall.- Case I assumes that from 50 to 95 percent of the vented insoluble fission products would remain near their place of fall--lodged in or around vegetation, or dispersed over the non-vegetated 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 re-dispersal by the wind or by runoff, either rain-generated or melt water-generated, over ensuing months or even years. Being insoluble, the part re-dispersed 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:

$$C_n = C_o \, (1-f)^n$$

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

C_o = initial concentration

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 re-dispersed, 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 18. 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 (Table 19)

Case II assumes: (1) Detonation at the close of melt-water runoff, about in early June. (2) In 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 (see Tables 5 and 6). (3) Runoff averaging 0.03 inch (1 cfs from Ogotoruk Creek basin) with none generated by rain during the 30-day period.

The following generalizations and simplifications were introduced in regard to Case II dispersal of soluble nuclides. (1) All the soluble nuclides dissolve in the assumed 0.5 inch of rain plus any water in antecedent micro-ponds. (2) Interim evapotranspiration is about 0.8 inch, so that all the dissolved nuclides infiltrate the soil. (3) In such an adsorption environment, the M_1 / M_s ratio probably is somewhat less than unity; accordingly, "normal" K_d values apply. (4) Concentration of radioactivity in the soil water increases in the ratio of rainfall to interim evapotranspiration--that is, in the ratio of 5 to 8. (5) Concurrent runoff is base flow derived from soil water concentrated in that ratio. Runoff at that concentration and at the assumed average rate (1 cfs in Ogotoruk Creek) removes 9.1 percent of the activity not adsorbed. So derived, the Table 19 values for activity of nuclides dissolved in the streams probably approach the credible maximum. (6) Table 19 values for nuclides infiltrated to soil water are the residual solubles that are not adsorbed and that do not reach the streams.

In contrast with Case I it is expected that: (1) Concentration of soluble nuclides in the streams will be somewhat greater in Ogotoruk and Nusoaruk Creeks, but slightly less in other streams. (2) Essentially no nuclides will reach the streams as suspended sediment; in other words, substantially all insoluble nuclides will remain near their place of fall. (3) Nuclides adsorbed on land-surface materials will 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 snow melt, in Case II such infiltration not only will be substantial in amount but also will take place during the assumed 30 days of initial fission-product dispersal.

Case III: Detonation in early August (Table 20)

Case III assumes: (1) Detonation in early August, following two months of minimum precipitation with an accumulated soil-water deficiency of 1.0 inch. (2) In 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 dissolve in the first 1.0 inch of rain, of which all infiltrates to replenish antecedent soil-water deficiency. Thus, all the solubles are dispersed before any micro-ponds are generated by the subsequent rainfall. (2) As in Case II, the adsorption environment involves "normal" K_d values. (3) Of the concurrent runoff, 20 percent is base flow derived from soil water concentrated in the fashion outlined in the preceding case. On this basis, 18 percent of the non-adsorbed solubles reaches the streams and 82 percent remains in the soil water. (4) The solubles that reach the streams are diluted by nuclide-free overland runoff in the ratio of 1 to 4.

Results may be generalized as follows: (1) Concentration of soluble nuclides in the streams is very small and, excepting Ogotoruk Creek and adjacent small streams to the southeast, is less than the lifelong drinking-water standards previously cited. (2) Insoluble nuclides reaching the streams as suspended sediment constitute most of the total stream burden. Their expected concentration is about 3- or 4-fold greater than in Case I. (3) Nuclides adsorbed, those infiltrated to soil water, and the insolubles remaining near their place of fall are in substantially the same concentration as in Case II.

Case IV: Detonation in late September (Tables 21 and 22)

Case IV assumes: (1) Detonation in late September, 10 days prior to freezeup, with fallout on saturated tundra. (2) In the 10-day interim, no precipitation and runoff scaled to an average of 10 cfs in Ogotoruk Creek. Dispersal of nuclides must be considered in two periods--an initial dispersal prior to freezeup (Table 21) and a re-dispersal during the next ensuing snowmelt period (Table 22). Thus, in a sense Case IV is roughly analogous to Case II combined with Case I, with an intervening decay period of about eight months.

Case IV also involves these supplemental assumptions: (1) Soluble nuclides dissolve in water detained by the micro-relief of the saturated tundra. (2) Adsorption takes 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 are only slightly less than under a "normal" environment (see Table 17). (3) The soil zone being saturated or frozen, none of the soluble nuclides infiltrate. (4) Of the non-adsorbed solubles, one-third reaches the streams during the initial 10-day period; the remaining two-thirds is detained in micro-ponds, is immobilized over winter in ice, and reaches the streams during the later half of the ensuing melt-water period, in one-fourth of the melt-water runoff. (5) Insolubles reach the streams only during the period of re-dispersal, in the percentage amounts previously assumed for Case III.

Briefly, I^{131} dissolved in runoff during the initial 10-day dispersal is roughly from one to four orders of magnitude greater than the previously cited lifelong standard for drinking water. Soluble Sr^{90} is from two orders greater to one order less than that standard; Cs^{137} is less than the lifelong standard in all basins. In the final dispersal, after eight months decay: (1) stream-borne soluble Sr^{90} and Cs^{137} are moderately less than in the initial dispersal; (2) I^{131} is at least five orders of magnitude less than the lifelong standard; and (3) "other" nuclides are less than the lifelong standard except within about 10 miles of the Chariot site.

Among insolubles reaching the streams as suspended sediment, (1) Sr^{90} and Cs^{137} are about three-fold greater than in Case III and two-fold greater than in Case I, but are less than the lifelong standard in all basins except that of Ogotoruk Creek; (2) I^{131} is at least six orders of magnitude less than the lifelong standard; and (3) "other" nuclides are about one order less than in Case III but exceed the lifelong standard in all except the outlying parts of the fallout pattern.

Nuclides adsorbed in the initial 10-day period are somewhat less concentrated than in Cases II and III, but roughly two orders of magnitude more concentrated than in Case I.

The four cases in summary

Among the four hypothetical cases, the radioactivities in streams due to dissolved nuclides are 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, these activities are less than the lifelong drinking-water standards.

Activities in the streams due to suspended fallout particles are essentially zero in Case II--that is, with detonation about in early June, followed by light rainfall and minimum runoff. In all the other cases, these activities depend largely on an unknown factor--the proportional part of the fallout particles that will 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 possibly, but not certainly, nearly as great under Case III.

Among the four cases as presented, total stream burden is 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 does not reach the streams soon after detonation will 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 will include the greater part of that vented.

Insolubles on the land surface probably will 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

Re-distribution by the wind

Each of the preceding four hypothetical cases has assumed that fallout remains in the pattern of Plate 2 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 13 could, within a single day, re-distribute the fission products over a large part of the area and carry them far downwind mingled with snow. Such re-distribution would be largely southward and generally between azimuths 125° and 215° (see Plate 2, 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 2 will be drastically modified in this way, if detonation precedes breakup by 30 days or more.

Notable "hot spots" of radioactivity might be created. For example, assume a snowdrift 30 feet deep, such as occur locally in the lee of minor ridges athwart the dominant wind from the north (p. 13). 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, assuming uniform density of the snow. On breakup, the radioactivity of insoluble fission products remaining in the drift area would be about two and a half orders of magnitude greater than it would have been in the area from which the drift was accumulated. Assuming a 1-inch water equivalent in 4 inches of the drifted snow (see p. 15), the activity of fission products dissolved in the melt water would be increased four-fold over those of Case I.

Re-distribution of fission products by wind might take place in any month of the year, but probably to a smaller degree than under conditions of Case I. The potential for re-distribution would be progressively less in Case II, with the fallout on relatively dry tundra; Case III, with fallout on tundra saturated and flushed by heavy subsequent rain; to Case IV, with fallout largely immobilized by freezeup soon after detonation.

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 expected 1-hour activity of fallout ranges about between 1 and 5 megacuries per square mile. Other ponds probably exist transiently during breakup and following heavy rain, widely over the tundra. These ponds will 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 has no 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 re-dispersal 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. It is inferred, however, that in certain ponds the concentration might be several-fold greater than the average concentration in adjacent streams as shown in Tables 18 to 22.

In the case of 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 re-fill.

In numerous ponds it is expected that the initial influx of fission products would be constrained permanently, with total radioactivity diminishing largely or wholly by decay (see Table 1). A major fraction of the soluble products probably would be adorbed on particles of pond-bottom ooze or on sedges. The concentration of non-adsorbed 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 micro-ponds on the tundra constitute a special and critical case. At the height of melt-water runoff and during intense rainfall, many of these doubtless overflow one into another. In the waning stages of snow melt and of heavy rainfall, however, they separate into discrete units analogous to the larger ponds just described. Most of these discrete, minute pools dessicate 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 (see p. 33).

These micro-ponds doubtless would trap a substantial fraction of the insoluble fission-product particles. In the aggregate, their water volume doubtless is sufficient to dissolve all the soluble nuclides (see p. 20).

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 micro-ponds until the growing season has progressed substantially. Accordingly, it is expected that (1) dissolved fission products from Project Chariot will infiltrate the soil only under the conditions of Cases II and III, and (2) substantially all the products dissolved in discrete micro-ponds will 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. (See Table 17.) 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 "spiked" extensively by soluble fission products from Project Chariot, especially under the conditions of Cases II and III. Any such "spike" advances slowly in its aquifer, generally less than a mile per year. It advances into an undepleted adsorption environment--in net effect, the M_l / M_s ratio becomes vanishingly small, and adsorption is substantially complete within a relatively short distance from the area of recharge. It is expected, therefore, that most discharging ground waters of the area--chiefly the base flow of streams and the issue of small springs--will contain only inconsequential amounts of radioactive fission products.

One possible exception to this generalization exists--Covroeruk Spring, 27 miles southeast of the site. There, the hydrologic setting is not known fully (see p. 22). Some ultimate effect on this spring by Project Chariot is conceivable.

EFFECTS OF PROJECT CHARIOT ON LOCAL WATER SUPPLIES

All villages of the area are outside the fallout sectors of the foregoing appraisal; accordingly, their established water sources (pp. 51-53) are exposed only to stream-transported or wind-transported fission products. Two of the villages, Kivalina and Noatak, definitely are 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 is between azimuths of 25° and 110°, both these streams presumably would receive fission products upstream from the two villages (see Tables 18-22). As has been pointed out, however, the concentration of stream-borne products is expected to 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 are relatively low; also, flow time for passage of activity to the Chukchi Sea is a few days only. The implied hazard seems 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 seems 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 (see Plate 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.[7] During the summer (Cases II and III),

7/ Kachadoorian, Reuben, personal communication.

fission-product activity carried by the river would be diluted at least several fold 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 (see p. 51).

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 58--that is, to be as much as two orders of magnitude greater than the basin averages of Table 18. 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-limit" until proven otherwise by adequate radiochemical analysis, especially in the basins of Ogotoruk Creek, Nusoaruk 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 by execution of Project Chariot, under the particular imput assumptions outlined on pages 3-12. Also that, to refine the appraisal substantially would require much more knowledge of new kinds, obtainable only by intensive investigation over a term of several years.

If and when executed, Project Chariot will be a prototype for other possible applications of nuclear energy. Under some situations, effects on the hydrologic environment could be substantial and a serious handicap to man's activities. Accordingly, it is considered advisable and is recommended that post-shot phenomena be studied in sufficient scope to verify the analysis here reported. In particular, to determine the actual fallout pattern and the actual dispersal and ultimate disposition of fission products among interception by vegetation, adsorption, infiltration, overland transport (both water and wind), and stream transport. Presumably the post-shot schedule will provide for monitoring activity levels in village water sources, springs, and at other critical points. These would logically be programmed after the actual fallout pattern has been established.

In preparation for these recommended post-shot studies, antecedent radioactivity of the stream waters would need be determined as little before shot time as is practical. At least one station for such determination (and for post-shot sampling and measurement of streamflow) is desirable in each of the basins outlined on Plate 1. It is recommended that the pre-shot operation schedule include reconnaissance for selecting station sites, and for the antecedent sampling.

Table 8.- Particle-size distribution of stream deposits and of sediment, vicinity of the Chariot site

[Quantities are percent of total weight in particles finer than the size indicated.]

Number on Plate 4	1	2	3	4	6	7	8	9.1	9.2	9.3	10
Size, millimeters											
32.0	78.4	. . .	91.5	. . .	. . .	. . .	77.9				
16.0	47.0	. . .	62.2	91.5	88.8	. . .	43.3				
8.0	30.8	68.5	43.9	83.8	76.9	91.0	28.8				
4.0	22.6	63.4	30.1	77.2	69.4	78.1	20.9				
2.0	18.0	57.3	21.3	73.8	65.4	67.9	16.6	. . .	. . .	. . .	99.9
1.0	14.2	44.8	14.9	70.2	63.8	58.9	13.9	. . .	100	. . .	99.4
.50	10.4	24.6	10.6	65.1	63.3	51.1	11.1	100	98	100	94.1
.25	6.9	16.5	6.9	54.5	61.5	35.7	5.3	83	95	99	66.9
.125	4.0	7.1	3.9	22.6	49.1	11.5	2.2	57	86	96	25.4
.0625	. . .	4.2	. . .	10.4	23.8	4.5	. . .	39	71	90	12.6
.0312	. . .	. . .	. . .	4.2	9.5	. . .	. . .	30	53	82	5.6
.0156	. . .	. . .	. . .	2.5	6.2	. . .	. . .	20	40	66	3.7
.0078	. . .	. . .	. . .	1.7	3.7	. . .	. . .	12	27	53	2.2
.0039	. . .	. . .	. . .	1.2	2.7	. . .	. . .	8	19	40	1.1
.00195	. . .	. . .	. . .	.8	1.7	. . .	. . .	6	14	37	.5

Notes.- Samples 1 through 8 collected for the writer by I. L. Tailleur, U. S. Geological Survey, June-July 1961. The three sediment samples at site 9, by George Porterfield, U. S. Geological Survey, August 1958.

All analyses by U. S. Geological Survey. Particles larger than 0.125 millimeter, by sieve; smaller, by standard pipette procedure.

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

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.

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.

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

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

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

8. Ipewik River, stream deposit, about 3/4 mile downstream from mouth of North Fork and 31 miles NNE of Chariot site.