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May 5, 1948

To: Joseph G. Hamilton

From: Kenneth G. Scott

Subject: Fission Product Warfare

A consideration of the probable effects of fission products as such, or those resulting from an atomic bomb explosion upon the population in an area such as the San Francisco Bay region leads one to examine the data collected during and after the Baker burst at Bikini. Because of similarities in physical size between San Francisco Bay and Bikini lagoon, a great many facts resulting from the Baker studies can be applied to that area as well as other areas near large bodies of water.

The data collected at Bikini relavent to the fission product content of the lagoon water is of especial interest. During the time of the test very little of the contaminated water left the lagoon. This is substantiated by data presented in Table I in which the total beta activity from the fission products has been calculated. In addition, the active water diffused away from the explosion rather slowly. For the above reasons, the radiation levels achieved at Bikini represent what may be considered as the maximum to be expected if a bomb of the same size as that used in test Baker were exploded below the surface in an area such as the San Francisco bay. An estimation of the geophysical characteristics of such an explosion as well as the radiation in roentgens which might be expected are offered in Table II. The radiation levels presented are calculated from the fission product activity in the water itself and not radiation resulting from surrounding objects contaminated from the intensely radioactive spray from the bomb. However, the radiation levels to be expected from such a spray-contaminated structure are given in Table II as well. As an example, LCI-332 is used. This ship was equipped with a telemeter device for measuring the radiation in r per day. LCI-332 was placed approximately 1.3 miles from the burst. Some ships such as the LCT-874 were further away from the blast (1.4 mi.) but were even more active. The distribution of fission products in spray can be rather capricious. The activity deposited in any one area is subject to chance as well as the prevailing meteorological conditions.

An examination of Table II shows that the initial patch of contaminated water from Baker covered an area of about 16 square miles with a mean diameter of about 5 miles. This slowly increased until at the 8th day after the blast, the active area was 160 square miles with

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a virtual diameter of 14 miles. The amount of surface radiation is small owing to the incorporation of the fission products produced by the bomb in such a large volume of water.

The r per day values were obtained at Bikini lagoon by direct measurement of the contaminated surface. These were correlated with the absolute quantity of fission products present in the same water. The data is presented in Table IV. The value obtained was that 1 microcurie of fission product activity per liter would result in a radiation level of .032 r per day. The maximum radiation rate in r per day from the water 4 hours after Baker is therefore calculated to be 37 r per day. Owing to decay and dilution this was reduced to 1.8 r per day 38 hours after the explosion. The radiation level dropped to accepted tolerance levels 130 hours after the bomb burst.

The me n relative rates of radiation intensities to be encountered are also presented in Table II. It can be seen that these are not impressive. In summary, contamination of water areas by fission products with the intent of tying up shipping or transport facilities in a bay would not be successful from an atomic bomb explosion of this type. However, the geophysical characteristics of any one area should be considered before a final conclusion relative to that area is reached.

In case an atomic bomb were exploded in a bay, some fission products would be deposited upon the bottom of the bay in addition to the activity in the water. The fate of this material might well be similar to that which is now remaining upon the bottom of Bikini lagoon. Although the amount of activity in this case appears to be large, the residue, after several thousand hours of decay, offers no real hazard when viewed upon a geophysical scale. The story of the activity on the bottom of the Bikini lagoon is offered as a reference point. This information is included as an Appendix to this communication.

Decay factors of fission products produced at the Baker test are also available for about 10,000 hours after the burst. These were compiled from several sources such as data received from the LCI-332, from sea water collected by the drone boats in operation on Baker day, and from active bottom samples collected between Baker plus 7 and 16 days. The rate of decay of all of these materials is similar. Decay factors as well as r per hour from LCT-332 are presented up to 2400 hours after the burst in Table III. A person entering such a blast area in an uncontaminated vessel four hours after the blast would receive less than 20 r during the first day. This would drop to relatively negligible amounts of radiation on the succeeding days. Table III shows that after 100 days, the initial radioactivity has been reduced by a factor of about 50,000. Similarly, the exposure to personnel 4 hours after a blast on contaminated objects between 1 and 2 miles from the center of the explosion would not be excessive. The following 24 hours of exposure on the LCI-332, after Baker plus 4 hours, would have been less than 40 r per day.

The relation of 0.03 roentgens per day to 1 microcurie of

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fission products is also a useful value in the consideration of the possibilities of contaminating a large land area. One such example would be the city of San Francisco which might be the object of radioactive warfare. This area could be contaminated either by a reflected water burst from an atomic bomb or the distribution of fission products in grain size evenly over the area. Calculations have been made which indicate that 33 millicuries of fission products per square meter of a plane area would result in enough gamma activity to deliver 10 r per day to occupants of that area. The basis of these calculations is the 1 microcurie per liter ratio to 0.03 r per day measured at Bikini as on Baker plus 6 and presented in Table IV. In these calculations each liter of sea water was considered to occupy a plane area of 100 square centimeters ten centimeters in depth. Since inclusion of fission products into the materials presenting the area by a city are variable, a certain percentage of them are going to be absorbed to some depth of material or otherwise shielded.

The value of 33 millicuries of fission products per square meter being equivalent to 10 r per day agrees well with those for radium. In this case, it was calculated that 50 milligrams of radium would be necessary on an infinite plane surface to deliver 10 r per day.

However, if the activity were delivered to a city by the atomic bomb spray method, it would be subject to rather rapid decay. The initial radiation rate would be about 15,000 r one hour after a bomb explosion if all of the fission product activity from an atomic bomb were delivered to an area the size of San Francisco by the spray method. The total gamma activity of the fission products produced have been estimated to be 6 x 10^9 curies one hour after the blast. Calculations have been made of the radiation rate in r in such an area up to 100 days after such a blast from the decay data available. These are presented in Table V along with the calculated radiation rates for the inclusion of the same activity in an area 1/30th as small as San Francisco or 1 square mile. Since it would be difficult indeed to deliver all of the activity from an atomic bomb burst uniformly over a city, the data obtained from LCT-874 is presented as indicative of the radiation levels which might be achieved were such a thing attempted. It is fairly obvious from an examination of this data that lethal or near lethal levels of radiation are approached during the first ten hours of an area contaminated to the same extent as that of LCT-874. However, the contamination may well be primarily of a surface nature rather than internal. Rather than attempting a mass exodus of the general population from such an area via contaminated streets, it would probably be much safer for a population to seek areas which could be used as shelters from the

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gamma rays for about 30 hours. At this point, the fission products would have decayed to much lower intensities of radiation. Displacement of a population could be attempted one or two days after a blast much more safely than immediately following such an incident. However, in order to execute such a plan, almost each individual would have to have available for himself some rapid means of estimating his radiation rate in some particular area. The simplest thing which occurred to me would be the employment of self-developing strip film supplied with standards of darkening in order to estimate r along with a shielded case to prevent the film from being exposed before the measurement. At relatively high radiation levels (about .1 r per minute) darkening could be accomplished in a very short time and the answer could be obtained almost immediately. A procedure such as this lends itself to mass production on an enormous scale readily. It offers no service problem such as that presented by large numbers of electronic devices used in the detection of radiation.

In addition to the contamination of an area directly with an atomic bomb, the use of fission products from the pile as a radioactive embarrassment to an urban population is undoubtedly being considered in several quarters. For this reason, the data available from Bikini have been used in order to calculate how much fission product activity would be needed to subject an area as large as San Francisco to a radiation level of 10 r per day. Since the plane area of San Francisco is at least 1.2×10^8 square meters and the deposition of 33 millicuries of fission product activity would produce 10 r per day, it is calculated that about 4×10^6 curies of activity would have to be uniformly distributed over such an area. If the fission products were about 100 days old, the radiation levels would be of a rather permanent nature unless successful methods of decontamination were available.

An examination of Table V shows that the activity produced from one atomic bomb, decayed for 100 days, would produce a relatively permanent radiation level of about 10 r per day per square mile. From our calculations of the bomb efficiency, a 10^6 kw pile could produce enough long-lived fission products each day to contaminate one square mile to a 10 r per day level making it an untenable area to occupy.

However, the rather dreary prospect of having rather large and useful areas contaminated for long periods of time need not be a forgone conclusion. During August and September after the Bikini tests, solutions which had been used in this laboratory for decontaminating purposes for several years, were tested with respect to their ability

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to remove fission products from ships' structures. During these tests, new solutions were developed which were able to remove fission product activity 60 to 100 days old from such contaminated materials as copper nickle pipe, steel pipe, encrusted with marine scale, and other odd items which are necessary to a ship. At least 99.9% of the fission product activity was removed in four hours of treatment in controlled laboratory tests. The solutions used were composed of organic complexing agents such as citric acid in combination with varying amounts of dilute mineral acids. They are easily made and inexpensive. They are non-toxic and could be easily applied to urban areas by expanding the facilities of the average fire department. Successful use of such decontaminating agents would rescue for any group a war potential otherwise lost. Since the contaminated waste solutions used must have some place to go in order to finally remove the offending activity, it may well be that the capacity and completeness of a waste disposal system of a city would remain the last factor in the successful decontamination of a vital area. For this reason, the successful participant in radioactive warfare may insome measure owe that success to an adequate public works system begun many years earlier.

In conclusion, it would appear to me that the use of fission products to tie up water areas permanently has rather poor prospects. On the other hand, the capacity of a 10^6 Kw pile could be used effectively to immobilize for limited periods of time in a humane manner large areas. The permanence of such an act need not be related to the radioactive decay of the materials used but more to successful decontaminating methods.

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TABLE I

A CALCULATION OF THE TOTAL AMOUNT OF FISSION PRODUCT ACTIVITY PRESENT IN BIKINI LAGOON AFTER TEST BAKER
Corrections Have Been Made for Decay - The Activity Measured is Primarily Beta Activity.*

Date Sample Collected	Total Radioactivity in Lagoon Water Decay Corrected to 4 Hours After Explosion	
Baker + 1	4.8×10^8	Curies
Baker + 2	3.0×10^9	Curies
Baker + 3	2.1×10^9	Curies
Baker + 4	1.3×10^9	Curies
Baker + 5	1.7×10^9	Curies
Baker + 8	1.7×10^7	Curies

* The Geiger-Müller tubes used on these studies had a geometry for fission product Beta rays of 10%, for Gamma rays ~2%

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TABLE II

A COMPARISON OF THE MAGNITUDE OF THE CONTAMINATED AREA OF THE WATER BURST AFTER BAKER AND THE RELATIVE RADIATION INTENSITIES FROM THE CONTAMINATED WATER IN MOST ACTIVE REGIONS, THE MEAN RELATIVE ACTIVITY, AND THAT FROM ONE STRUCTURE EXPOSED TO RADIOACTIVE SPRAY

Time After Burst Days	Hours	Contaminated Area Square Miles	Virtual Diameter Contaminated Area	Maximum r/Day Most Active Area	r/Day From LCT-332 Telemeter	Mean Relative r/Day over Entire Area
1	4	16.6	4.6	27.2	70.0	
1-2	38	18.4	4.8	1.8	3.1	1.8
2-3	62	48.6	7.9	0.54	1.5	0.19
3-4	86	61.8	8.9	0.48	1.0	0.09
4-5	100	70.6	9.5	0.18	0.82	0.04
5-6	130	107.0	11.7	0.08	0.55	0.026
8-9	200	160.0	14.3	0.0004	0.31	0.0004

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TABLE III

DECAY FACTORS OBTAINED FROM DECAY DATA AFTER BAKER BURST. DATA FROM TELEMETER ON LCT-332, SEA WATER COLLECTED BY DRONE BOATS, CORES COLLECTED FROM BOTTOM OF BIKINI LAGOON NEAR CENTER OF BURST

Hours After Burst	Activity Reduced by a Factor of	r/Hour LCT-332 1.3 miles from blast
1	0	450.0
10	22.5	20
20	58.6	7.7
30	100.0	4.5
60	281.0	1.6
100	563.0	0.8
500	5300.0	0.085
1000	13600.0	0.033
2400	50000.0	0.009

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TABLE IV

COMPARISON OF RADIATION LEVELS IN ROENTGENS WITH FISSION PRODUCT ACTIVITY IN SEA WATER IN MICRO-CURIES PER LITER. Samples Collected 6 Days After Test Baker

Position Bikini Grid No.	Observed Roentgens	Microcuries Per Liter of Water	Roentgens / Day / μc / Liter Measured from an LCPL Craft
1013	.5 r	14.1 μc	.035
1404	.17 r	16.8 μc	.010
1508	.024 r	0.316 μc	.076 *
1902	.15 r	6.4 μc	.023
LCT 1013	.20 r	6.6 μc	.030
Near Prinz Eugen	.30 r	13.3 μc	.023
YOG 83	.40 r	16.0 μc	.025

* Low activities were difficult to estimate becuae of the contamination of the LCPL used in these measurements.

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TABLE V

RADIATION RATE IN ROENTGEN'S PER DAY FROM THE ENTIRE FISSION PRODUCT ACTIVITY OF ONE ATOMIC BOMB USED AS A SPRAY EXPLOSION. Bomb Calculated to Produce 6×10^9 Curies Gamma Activity at 1 Hour.

Time Elapsed			Area Size San Francisco 30 Square Miles	Area of 1 sq. Mile	Observed r on LCT-874 During Baker Test approx. 1.4 mi. from Blast
Days	Hours	Decay Factor			
	1		15,000.	450,000	1,200.
	10	22.5	666.	19,980	62.0
	20	58.6	256.	7,680	25.0
	30	100.0	150.	4,500	12.0
	60	281.0	53.4	1,600	5.0
4.15	100	563.0	26.7	800	2.6
20.8	500	5300.0	2.83	85.	
42.0	1000	13600.0	1.10	33.	
100.0	2400	50000.0	0.30	9.0	

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APPENDIX

A calculation of the fission products remaining on the bottom of Bikini Lagoon has been made from samples collected 7 to 16 days after test Baker. These calculations indicate that the active material is now tied up primarily in 1.5×10^2 grid squares near the area of the blast, the major percentage of the activity being contained in the first 30 cm. of bottom material. One square on the grid chart is, according to the map I have, about 9.5×10^5 square meters. The total contaminated area is 1.5×10^8 square meters with a mass of 1.4×10^{11} kilograms of material present in the lagoon bottom containing the major portion of the activity from the Baker blast.

A compilation of activity on the bottom from complete assays made upon samples collected upon Baker +7, +8, +9, +15, +16 days shows a total activity of 2×10^6 curies on the bottom on Baker plus 7. This represents approximately 2×10^9 curies at B + 1 hour or a major part of the activity from the bomb.

The activity remaining from B + 7 or 2×10^6 curies has decayed after about 10,000 hours to 1/50 of 2×10^6 or 4×10^4 curies. No appreciable loss in activity was lost between samples taken on B + 7 and those collected in December of 1946, a matter of ten months later. For this reason, it does not appear likely that the resurvey will reveal a great deal of change in deposition. In view of the fact that this material is incorporated into about 1.4×10^{11} kilograms of material, a major transfer of activity elsewhere is unlikely, and the deposition of this activity in this material is of a permanent nature.

Although the activity remaining appears to be great, the mass is great also so that the r delivered per unit of mass is small, turning out to be of the order of .03 r per day on the average. The hottest part would hardly be greater than .3 r per day. The amount of radiation delivered to an object in close proximity to one of these areas would receive less radiation naturally. It is estimated to be between .03 and .003 r per day for the first two centimeters of tissue depending upon the actual activity on the bottom.

It would seem that although 2×10^4 curies of residual activity is an impressive figure when considered in relation to the mass involved, the values are below tolerance levels eighteen months after the blast.

It may be of interest for medical legal reasons to consider the amount of radioactivity existing in Bikini lagoon prior to any

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atom bomb tests so that things might be viewed in their proper perspective. The volume of Bikini lagoon has been estimated to be 2.8 x 10^{13} liters of sea water at low tide. The activity from the natural radioactive isotope of potassium, K^{40} in all potassium, can be calculated as follows.

There are about .4 grams of potassium per liter of any sea water. It follows then that every liter of sea water contains 48 micrograms of radio-active potassium 40, since .012 % of all potassium regardless of source is K^{40}. In Bikini lagoon then there are 1.4 x 10^9 grams of K^{40}. This would result in 2.1 x 10^{31} atoms. The mean life of K^{40} is 1.8 x 10^{16} seconds taking the value of the half-life for 4 x 10^8 years; the total disintegrations per second from K^{40} in Bikini lagoon is 1.15 x 10^{15} or 3.1 x 10^4 curies of K^{40}. This is an amount of activity comparable to the residue of the Baker blast after eighteen months of decay. One liter of sea water absorbs the ionization from 42 disintegrations per second from K^{40} continuously without untoward effects upon biological mechanisms present.

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