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DEPARTMENT OF DEFENSE 410270

ARMED FORCES SPECIAL WEAPONS PROJECT

WASHINGTON 25, D. C.

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ADDRESS REPLY TO:
THE CHIEF, ARMED FORCES
SPECIAL WEAPONS PROJECT

SWPEF-5.1 920 18 APR 1957

DELETED VERSION ONLY

Brigadier General Alfred D. Starbird
Director, Division of Military Application
Atomic Energy Commission
1901 Constitution Avenue, N. W.
Washington 25, D. C.

Dear General Starbird:

In reference to your letter, MAT:KFM, dated 19 November 1956, much of the information relating to a briefing of the Commission, the feasibility of a fall-out symposium, and other subjects has been supplied by personal meeting and telephone conversations. The information requested in the second paragraph is now available and the answers are as follows:

Part a is included in inclosure 1 in a series of tables that show the role of fractionation of certain radionuclides. These tables compare the ratio of strontium-90 to total fission, and zirconium-95 to total fission, at each collection station.

Parts b and c, dealing with the problem of estimating the magnitude of local vs. world-wide fall-out by measuring crater volume are included in inclosures 2 and 3.

The analysis of radioactive particles collected at the REDWING series in the Pacific Proving Ground was reported by letter to the Chief, Armed Forces Special Weapons Project. Specifically, the results of the megaton weapons were studied to show effects of land surface, water surface, and variation of depth under the water surface vs. distance from ground zero. The stations where the radioactive fall-out particles were collected consisted of barges (YFNB 13 and 29), an atoll island of Bikini (HOW Island), laboratory ships (YAG 39 and 40), and a floating platform (LST 611). The collection stations were identical, being tubs with the same array of collectors and instruments at each station.

The results of analysis of the chemical data are treated for the purpose of providing this information to you in inclosure 1.

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SWPLF-5.1 920
Brigadier General Alfred D. Starbird

TEWA shot was a water surface detonation over shallow water (maximum depth of water 60 feet under the detonation barge), had a yield of 5 MT [redacted] As can be seen in the TEWA table of inclosure 1, there is a strong indication of an increased strontium-90 content collected at stations distant from ground zero. There is an exception, a high reading at "HOW" collection station only 10 miles from ground zero. This station is well within the area covered by the original growth of the mushroom. Diffusion had probably not yet exerted any effect upon the mushroom and purely local phenomenon could have biased the collection at this station. Certainly no clear-cut picture of large-scale fractionation in favor of strontium-90 was observed at the distant stations. If one can ignore "HOW" station, not more than twice the amount was found at any station beyond 10 miles. There was no evident fractionation, with distance, for zirconium-95. See inclosure 1, table 1.

NAVAJO was a water surface shot detonated over moderately deep water (215-foot depth), [redacted] fission. This shot, as shown in inclosure 1, resulted in no apparent fractionation of strontium-90, with distances as great as 42 miles from ground zero. The increase of strontium-90, although slight, was found in close at collection stations about 7 miles from ground zero. There was no fractionation of zirconium-95 apparent with distance. See inclosure 1, table II.

ZUNI was a land surface shot with a yield of 3.5 MT. [redacted] was documented at stations ranging from 8.5 to 89 miles from ground zero. The results (inclosure 1) of this land surface burst indicate fractionation of strontium-90. Approximately 4 to 8 times the quantity of strontium-90 was observed at the distant stations as was observed at the close-in stations. The preceding comparison is based on an average value of strontium-90 for the close-in stations. This fractionation was not apparent at ZUNI for another radionuclide zirconium-95 studied in the same manner. See inclosure 1, table III.

FLATHEAD was a device detonated on a barge on the surface of the Bikini Lagoon. The depth of water under the weapon was 114 feet. The [redacted] A large amount of iron and coral were incorporated in the barge, sufficient amounts to confuse the expected fall-out results. This shot was documented at stations from 5.1 to 45 miles from ground zero (inclosure 1). A very apparent fractionation of strontium-90 at the 37 mile station did not hold true at another station farther out. This most distant station did show some fractionation of strontium-90, however, very much-less pronounced than the 37 mile station. No indication of fractionation with distance is

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evidenced for the radionuclide zirconium-95. See inclosure 1, table IV.

The results of the REDWING series fail to disclose any real evidence that the phenomenon of fractionation operated to minimize world-wide distribution of strontium-90. It has been postulated that the percentage of strontium-90 deposited locally would be greater, because of fractionation, than other radionuclides formed in the same detonation. The result of the deposit of a larger percentage locally would be a denial of that extra fraction for world-wide contamination. The failure to demonstrate fractionation in the fall-out samples collected at REDWING, could have several reasons. The collection stations might have been too few; the collection stations, although positioned at intervals along the predicted "hot line," may in actuality have been poorly positioned and collected biased samples. The alternative would be, of course, that fractionation does not play a decisive role in bringing a large percentage of strontium-90 down locally.

Weapons Effects Division of this headquarters undertook to assess the amounts of water and coral "taken up" by comparison of a shallow water shot and the deep water shots. The comparison lacks clear-cut basic data upon which to make an assessment. As is shown in inclosure 4, figure 1, many of the craters overlapped or were superimposed, so the area representing the contribution of any one detonation cannot be fixed. The sequence of underwater crater formation is likewise not known with a preciseness that would permit a theoretical "refilling the hole" as a means of determining what was thrown into the air as salt or solid particles for radioactive particle formation. A value arrived at by measuring existing craters, assigning their formation to a particular detonation, permits an estimate of the maximum value for water and coral available. This maximum value is then simply the water and coral that are inclosed in a paraboloid including the crater and extending the lips to the lagoon surface. The minimum value would, of course, be that amount of water and coral that occupied that portion of the lagoon actually displaced by the fireball. Values for the maximum and minimum amount of material available for fall-out particle formation are given in inclosure 2, table 1. The compilation of these data lend little support to the concept of the use of crater volume, from post shot data, as a basis of fall-out prediction. Its usefulness at the PLUMBBOB series will be negative because of the proposed positioning of the weapons during detonation.

In part c of paragraph two information is desired in addition to matter already covered, specifically the pickup of coral in deep water shots. Since the deepest water shot of the REDWING series was on the

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surface over 215 feet of water, the description of the particles collected there is of interest. They are described as salt-laden slurry when collected on the YAG 40 at 32 miles from ground zero. The close-in stations were described as having 80 to 90 percent of the particulate as fine salt crystals. There was some $CaCO_3$ material among the remaining material. No iron was detected.

The information given here should be regarded as intermediate between the preliminary reports and the not yet available final reports of the REDWING series.

Sincerely,

A. R. LUEDECKE
Major General, USAF
Chief, AFSWP

3 Incl
1. Tables I, II, III, IV, Cy 1A
2. "Take-up of Solid Particulate and Water," Cy 1A
3. "Crater Volume," Cy 1A
4. Chart of Bikini Atoll, Cy 1B

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Table I

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Table II

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Table III

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Table IV

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TAKE-UP OF SOLID PARTICULATE AND WATER

1. In discussing this phenomena it is convenient to separate the events of interest into types depending on their burst environment. These types are:

a. Shots Fired from Barges Over Relatively Deep Water in the Lagoon:

CASTLE

Union - 6.5 MT
Yankee - 13.5 MT

REDWING

Flathead
Dakota
Navajo DELETED

b. Shots Fired Over Relatively Shallow Water:

IVY

Mike - 10.5 MT

CASTLE

Bravo - 14.5 MT

REDWING

Tewa - 5 MT

c. Shots Fired on Land Surfaces:

[redacted]

CASTLE

DELETED 110 KT

REDWING

Zuni - 3.5 MT

2. Limitations of the Data. Some underwater crater data from Pacific Proving Ground are available; however, under no circumstances can it be assured that the amount of material lost (as represented by crater value) has been taken up into the atmosphere. This difficulty arises from several sources:

Incl 2.

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a. Accuracy of Crater Measurement Techniques. Techniques of underwater crater measurement do not permit precision. Thus, material removed from the crater and deposited in thin layers over wide areas cannot be detected. It is conceivable that a large portion of the lost material of the crater can be accounted for by this process.

b. Compressibility of Bottom Materials. Bottom materials have an extremely high water content. It is conceivable that a substantial portion of the crater volume results from compression of the bottom materials.

c. Suspension of Finely Divided Materials. Inspection of photos taken soon after shots reveals large areas of finely divided material in water suspension being moved quite long distances from the burst point. It is conceivable that this process could account for a considerable portion of the crater volume. Re-deposition of this material has not and probably cannot be detected by current techniques.

d. Mechanisms of Crater Formation. Craters are formed due to complex inter-related mechanisms. The mechanisms include vaporization of the material, hydrodynamic throw-out for underground bursts, dynamic failure of the material and subsequent upward motion due to convective air currents, and finally failure of the material due to shear with the classical rotational mass motion. These mechanisms act together in an unknown manner and it is not possible to assess a portion of the resulting crater volume to each mechanism. The situation is further complicated in the Pacific Proving Ground cases when large volumes of salt water are present.

3. In view of the limitations noted above, any calculations on the amount of particulate take-up must be considered as rough order of magnitude estimates. The following paragraphs will consider past events by the categories listed in paragraph 1.

4. Shots fired from Barges Over Relatively Deep Water in the Lagoon:

a. Further limitations occur since all of the deep water large shots of Operation CASTLE and REDWING were fired from essentially the same point, later shots being of smaller yield than earlier shots.

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which before and after bottom profiles were taken.

b. Castle Shot 4 (Union) Estimates. As noted, a crater survey was performed for the Union Shot. Results are documented in WT-920. The calculated crater volume indicates an apparent volume of 300 x 10^6 cu ft. There is, however, no evidence that this amount of material, or any portion thereof, was taken up in the cloud to contribute to the fall-out. It is the opinion of AFSWP that essentially no coral particulate was taken up in this shot and that the apparent crater volume can be accounted for by one or more of the processes indicated in paragraphs 2a, b, and c. The volume of water vaporized by Union was 12 x 10^6 cu feet containing 100,000 tons of salt (NaCl).

c. REDWING Flathead and Navajo. As noted in paragraph 4a no crater volume data is available for these shots. It is the opinion of AFSWP, however, that essentially no coral particulate was taken up on these shots.

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5. Shots Fired Over Relatively Shallow Water.

a. In general, crater data from shots of this type also suffer the limitations noted in paragraph 2. This case is perhaps more straightforward however because of the shallower water. Also fall-out samples from shots of this type indicate considerable take up of solid particulate. In this case IVY-MIKE and CASTLE-BRAVO are included with REDWING-TEWA since the former two shots, although fired on small reef islands, produced craters breaching considerable distances into the lagoon. However, since basic communication requests data only on TEWA, calculations are presented for this single case.

b. Crater Volume. Only rough crater data are available at the moment since the results of a detailed survey are not yet available. The apparent value of TEWA crater is 600 x 10^6 cu ft. The volume of water in and above the crater projected to the water surface, assuming the crater to be a paraboloid, is 500 x 10^6 cu ft and contains 425,000 tons of salt (NaCl). Estimates of the amount of material taken up can be established to limits. The above quantities represent the upper limits. A lower limit may be established by estimating the volume of vaporized coral. In the case of TEWA this would account for only 0.04 x 10^6 cu ft of coral and 0.15 x 10^6 cu ft of water which contains 130 tons of salt (NaCl). This fraction of coral and salt would account for that fall-out which is found to be globular and which is reformed from condensed vapor. There is no possible way of estimating the quantity of the major fraction of the fall-out which is the flaky, finely divided material which has been mechanically removed and which

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is detected in fall-out samples from this shot type.

6. Shots Fired on Land Surface. This category is not strictly correct since the relative area available for MT shots at the Pacific Proving Ground is small. Crater data from shots of this type also suffer the limitations of paragraph 2, however, probably to a lesser degree. Fall-out samples indicate both flaky and globular materials. Upper and lower limits of the take up can be established as in paragraph 5 above. The shot of interest in this type is REDWING-ZUNI and is summarized in paragraph 7. In this case the real value is probably closer to the upper limit than in the case of the shallow water shot, however, AFSWP has no recommendation as to the appropriate value.

7. A summary of solid particulate and water taken up for the shots discussed in paragraphs 4, 5, and 6 follows:

TABLE 1 - SOLID PARTICULATE AND WATER TAKE UP

Shot	Yield (MT)	Water Upper limit (cu ft)	Water Lower limit (cu ft)	Salt (NaCl) Upper limit (tons)	Salt (NaCl) Lower limit (tons)	Coral Upper limit (cu ft)	Coral Lower limit (cu ft)
CASTLE 4	6.5	—	0.22×10^6	—	190	0	0
FLATHEAD				DELETED			
NAVAJO							
TEWA	5.	500×10^6	0.15×10^6	425,000	130	600×10^6	$.04 \times 10^6$
ZUNI	3.5	97×10^6	0.05×10^6	82,000	40	200×10^6	$.09 \times 10^6$

8. Calculations to support paragraphs 4, 5, and 6 are provided in Inclosure 2.

[redacted]

~~ENCLOSURE 2~~

1. CASTLE 4 (UNION) Yield 6.5 MT

a. Volume vaporized water, V_{VW}

Radius of dissociated steam scaled to 1 KT, WIGWAM 9.25 ft.

Assume portion of work done on water below the burst is 1% of yield.

To compute the radius of the hemisphere of vaporized water and coral under the shot determine the radius of a sphere of vaporized water for twice the energy.

$$\text{Radius} = 9.25 \times \left(\frac{6500 \times 2}{100}\right)^{1/3} = 47 \text{ feet}$$

$$V_{VW} = 2/3 \pi r^3$$

$$= 2/3 \cdot \pi \cdot 47^3$$

$$= \underline{\underline{0.22 \times 10^6 \text{ cubic feet}}}$$

b. Weight of vaporized salt, W_{VS} in the vaporized water.

Assume salt content is 3.5% of sea water weighing 64 lb/cu ft and that 77% of the salt is NaCl.

∴ Assume 1.7 lbs NaCl per cu ft salt water

$$W_{VS} = 1.7 \times 0.22 \times 10^6 \div 2000$$

$$= \underline{\underline{190 \text{ tons}}}$$

2. FLATHEAD Yield DELETED

a.

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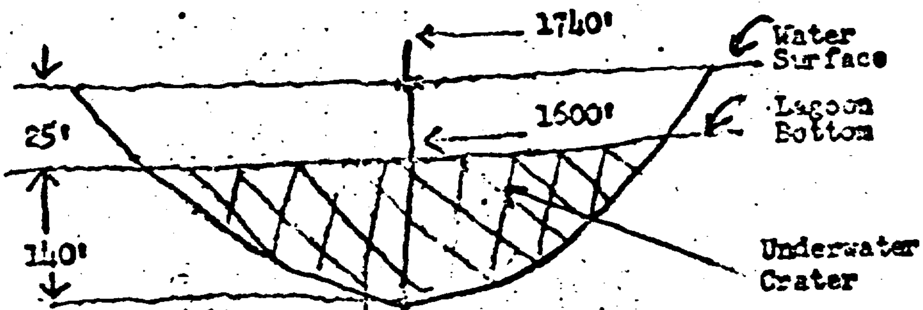
3. NAVAJO

DELETED

4.a. TEWA

Yield 5 MT



(1) Volume Underwater Crater, V_{ucr}

$V_{ucr} = 1/2\ r^2 \pi h = 1/2 \cdot 1600^2 \cdot \pi \cdot 140$

$\cong$ 600 x 10^6 cubic feet

(2) Volume of Water, V_w in and above underwater crater

(Assume coral contains water equal to 50% of coral volume)

$V_w = V_t - 1/2\ V_{ucr}$

where V_t = total volume of underwater crater projected to water surface assuming crater to be a paraboloid.

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$V_t = 1/2 \cdot 1740^2 \cdot \pi \cdot 165$

$\cong 800 \times 10^6$ cu. ft.

$V_w = 800 \times 10^6 - 300 \times 10^6$

$= \underline{\underline{500 \times 10^6 \text{ cubic feet}}}$

(3) Weight of Salt, W_s in volume of water

$W_s = 500 \times 10^6 \times 1.7 \div 2000$

$= \underline{\underline{425,000 \text{ tons}}}$

3 [redacted]

[redacted]

4b(1) Volume of TEWA vaporized coral, V_{vc}, and vaporized water, V_{vw}

Radius (vaporized water and coral) $= 9.25 \times \left(\frac{5000 \times 2}{100}\right)^{1/3}$

$= 43$ feet

TEWA was fired in 25 feet of water

$$\therefore V_{vc} = \pi h^2 \left(r - \frac{h}{3}\right)$$

$$= \pi \times 18^2 \left(43 - \frac{18}{3}\right)$$

$$= \underline{0.04 \times 10^6 \text{ cubic feet}}$$

$$V_{vw} = V_{vt} - 1/2\, V_{vc}$$

where V_{vt} = volume, vaporized total of coral and water

$$V_{vt} = 2/3\, \pi r^3$$

$$= 2/3 \cdot \pi \cdot 43^3$$

$$\simeq .17 \times 10^6 \text{ cu ft}$$

$$V_{vw} = 0.17 \times 10^6 - 0.02 \times 10^6 \text{ cu ft}$$

$$= \underline{0.15 \times 10^6 \text{ cubic feet}}$$

4b.(2) Weight of Salt, W_s, in water

$$W_s = 0.15 \times 10^6 \times 1.7 \div 2000$$

$$= \underline{130 \text{ tons}}$$

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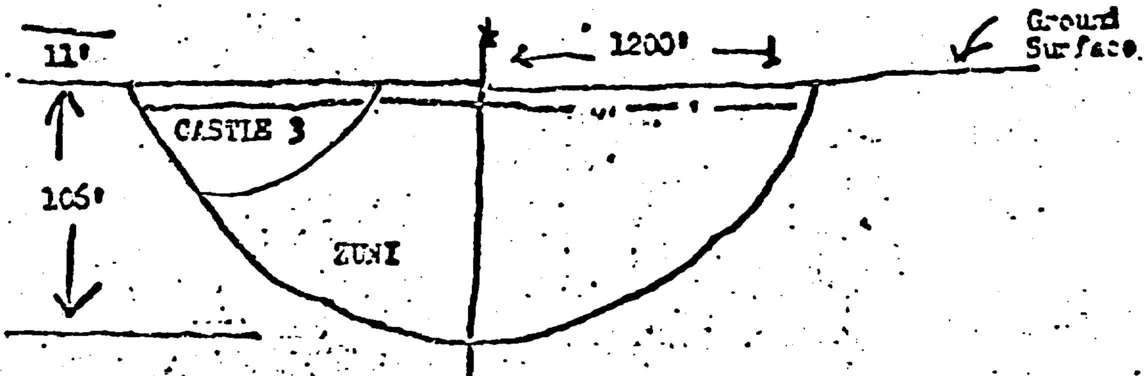
5.a. ZUNI Yield 3.5 MT



(1) Volume coral in crater, V_{ce}

$$V_{ce} = V_{ZUNI\ Crater} - V_{CASTLE\ 3\ crater}$$

$$V_{ZUNI\ crater} = 1/2\ r^2 \pi h = 1/2 \cdot 1200^2 \cdot \pi \cdot 106$$

$$\cong 120 \times 10^6 \text{ cu ft}$$

$$V_{CASTLE\ 3\ crater} = 1/2 \cdot 400^2 \cdot \pi \cdot 40$$

$$\cong 10 \times 10^5 \text{ cu ft}$$

$$\therefore V_{ce} = 210 \times 10^6 - 10 \times 10^6 = \underline{200 \times 10^6 \text{ cubic feet}}$$

(2) Volume water in crater, V_{wc}

Assume saturated coral exists five feet below ground level.

Assume saturated coral contains 50% of water by volume.

$$V_{top\ layer\ coral} \cong 1200^2 \frac{\pi}{4} \times 5 - 400^2 \frac{\pi}{4} \times 5$$

$$= 24.4 \times 10^6 - 2.5 \times 10^6 = 22 \times 10^6 \text{ cu ft}$$

$$V_{wc} = 1/2\ (V_{ce} - V_{top\ layer\ coral})$$

$$+ V_{CASTLE\ 3\ Crater} - \text{Air space above water in Castle 3 crater}$$

$$= 1/2 \times (200 \times 10^6 - 22 \times 10^5)$$

$$+ 10 \times 10^6 - 2.5 \times 10^6$$

[redacted] 2 5

[redacted]

$= (89 + 10 - 2.5) \times 10^6$

$= \underline{96.5 \times 10^6 \text{ cubic feet}}$

(3) Weight of Salt, W_s, in volume of water

Assume salt content is 1.7 lbs per cubic foot, neglect effect of rain water dilution of salt content.

$W_s = 1.7 \times 96.5 \times 10^6$

$= 164 \times 10^6$ lbs.

$= \underline{82,000 \text{ tons}}$

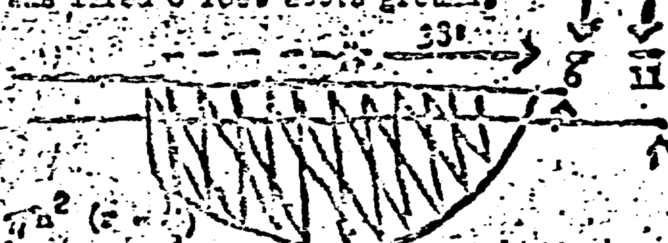
f.b. (1) Volume of ZUNI vaporized coral V_{vc}

Assume portion of work done on saturated coral below the burst is 1% of the yield.

$$\text{Radius (vaporized saturated coral)} = 9.25 \times \left(\frac{3500 \times 2}{100}\right)^{1/3}$$

$= 38$ feet

To partially compensate for the fact ZUNI was fired 11 feet above ground. Assume material surrounding Zuni is equivalent to five feet of material or that ZUNI was fired 6 feet above ground.



$V = \pi h^2 (r - \frac{h}{3})$

$= \pi 32^2 (38 - \frac{32}{3})$

$= 27$

$= \underline{.09 \times 10^6 \text{ cubic feet}}$

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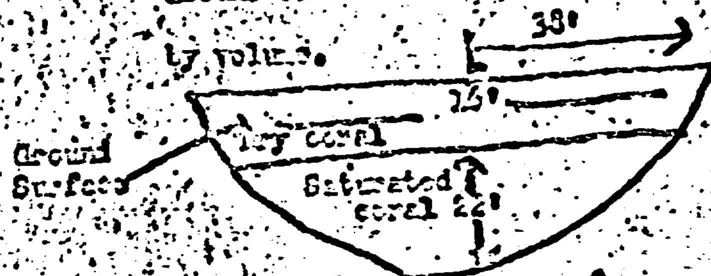
5.b. (2) Volume of vaporized water, V_{vw}, in ZUNI vaporized coral.

Assume saturated coral exists five feet below ground level.

Assume saturated coral contains 50% of water by volume.



$$V_{vw} = h^2 \left(r - \frac{h}{3}\right) = 22^2 \left(38 - \frac{22}{3}\right)$$

$$= .05 \times 10^6 \text{ cubic feet.}$$

(3) Weight of vaporized salt, W_{vs}

$$= .05 \times 10^6 \times 1.7$$

$$= .08 \times 10^6 \text{ lbs.}$$

$$= \underline{10 \text{ tons}}$$

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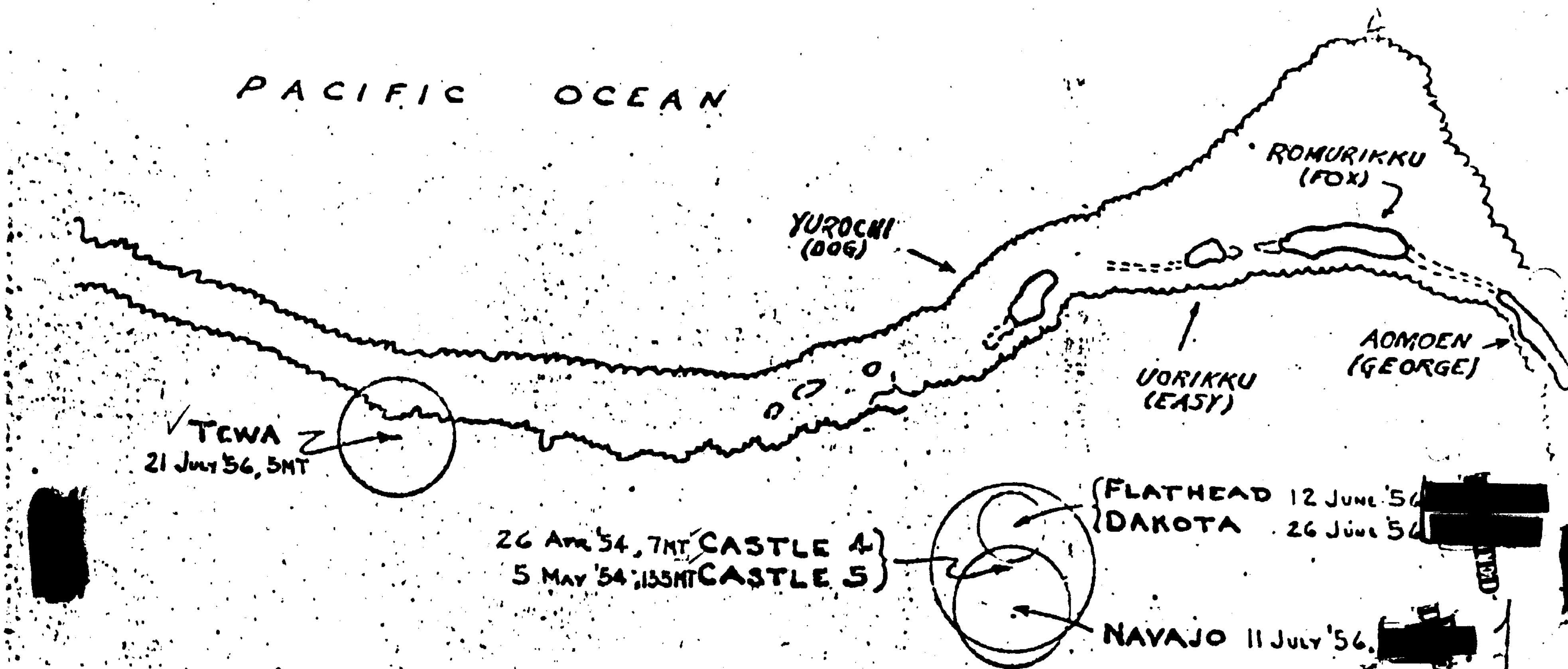

BIKINI ATOLL

fig. 1

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