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Project 3.3

BLAST EFFECTS ON TREE STAND

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OPERATION CASTLE

Project 3.3

BLAST EFFECTS ON TREE STAND

REPORT TO THE TEST DIRECTOR

by

W. L. Fons
Theodore G. Storey

March 1955

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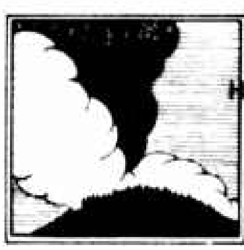

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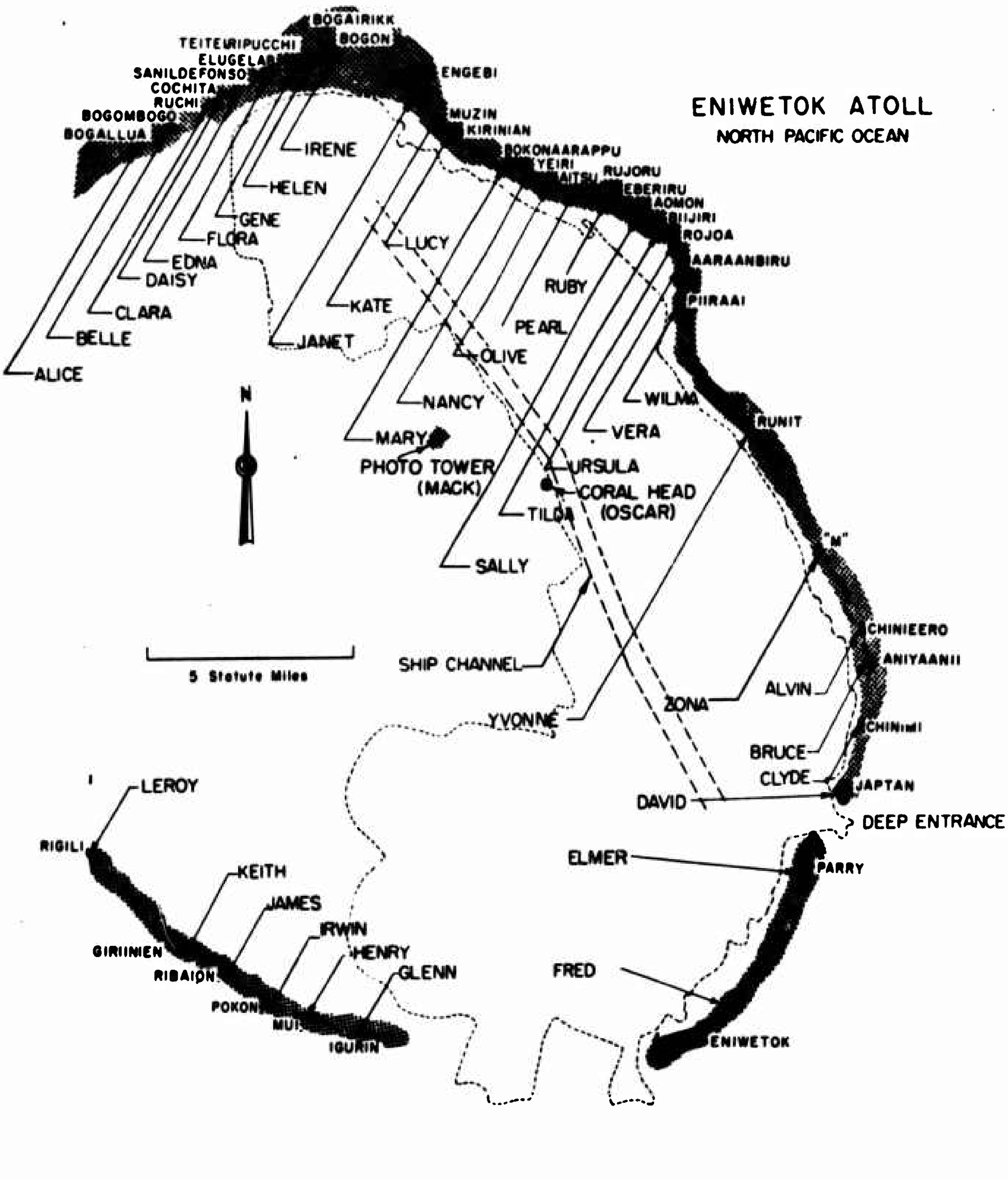

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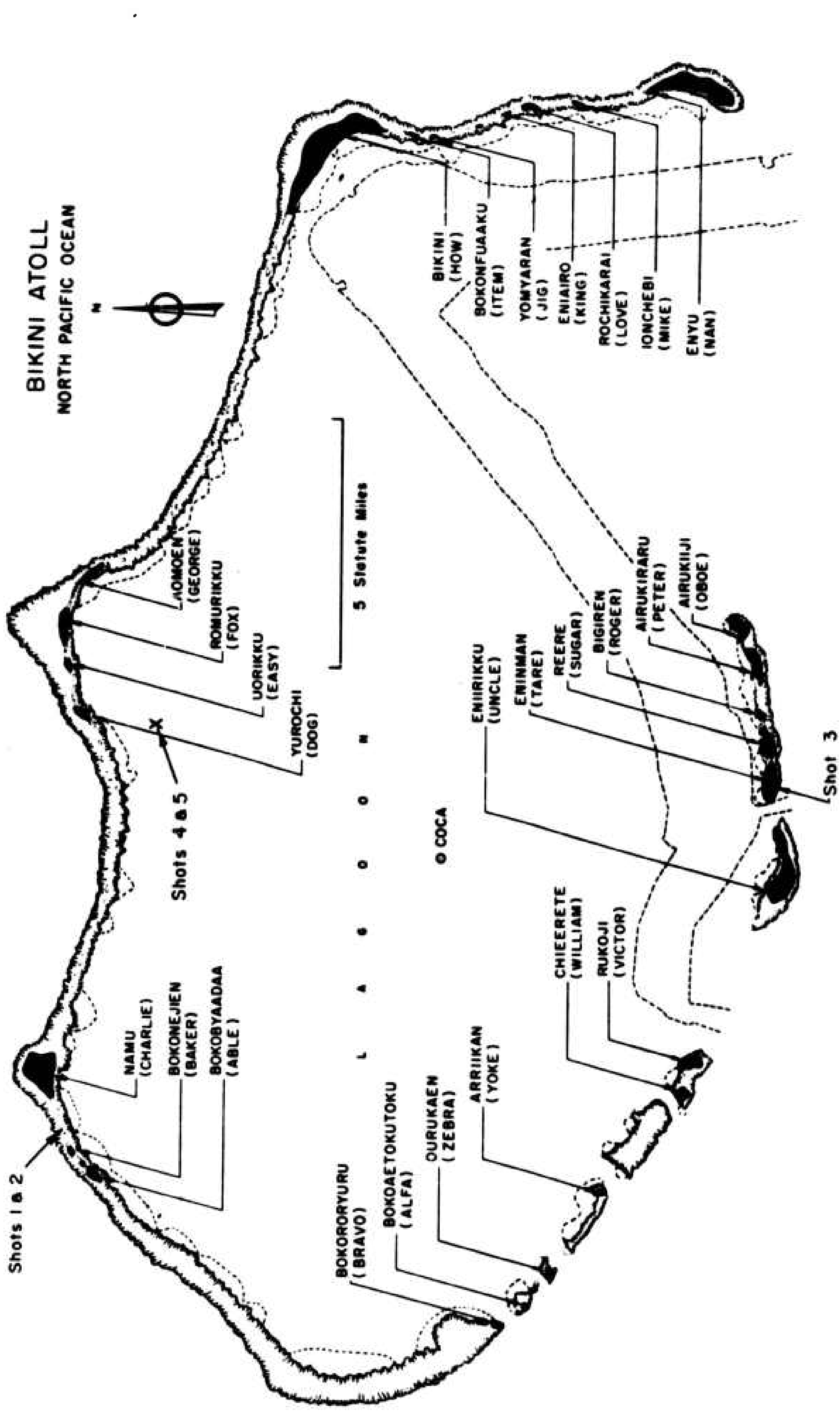

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GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen)		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800.27	N 161,424.43 E 116,688,15	N 147,750.00 E 67,790.00

* APPROXIMATE

SECRET – RESTRICTED DATA

ABSTRACT

Project 3.3 obtained experimental data on three natural tree stands in support of studies in predicting blast damage to forested areas. Primary objectives were: 1) to determine blast damage to trees in terms of stem breakage, limb breakage, and defoliation where effects are influenced by their location in a natural tree stand; 2) to determine the effect of natural forest cover on the shock wave in terms of its peak static overpressure and peak dynamic pressure attenuation; 3) to provide individual tree deflection data in the region of long positive phase duration times in order to support the theoretical basis for breakage prediction.

The tree stands on three separate islands varied from 29 to 170 acres in area with vegetation composed of broadleaf trees up to 80 ft tall and coconut palms about 40 ft tall. Several palms on the three islands were equipped with snubber wire arrangement for measuring maximum deflection. The large stand was instrumented with 16 self-recording ground-level static overpressure gages at eight locations and two self-recording dynamic pressure gages at two locations; the two smaller stands were instrumented with two static overpressure gages each. Sample plots were established on two islands for assessing stem and limb breakage in more detail.

Ground-level pressure measurements lengthwise of a large stand showed no attenuation in peak static overpressure. It was not possible to evaluate the degree of peak dynamic pressure attenuation because gages both in front of and inside the tree stand measured unrealistically high peak dynamic pressure compared to values calculated from corresponding peak static overpressure measurements. Nonuniform character of stands prohibited evaluation of shock attenuation from observations of tree damage with distance. The damage to the broadleaf trees was principally crown damage with occasional stem breakage or uprooting. The type of damage experienced was similar for moderate and high yield weapons. Observed damage from two weapons of different yields compare favorably with isodamage curves prepared for broadleaf stands.

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FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the Military Effects Tests Program of Operation CASTLE, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT-934, Summary Report of the Commander, Task Unit 13, Programs 1-9, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots.
b. Discussion of all project results.
c. A summary of each project, including objectives and results.
d. A complete listing of all reports covering the Military Effects Tests Program.

ACKNOWLEDGMENTS

Planning of Project 3.3 for Operation CASTLE was done by A. A. Brown, Division Chief, Fred M. Sauer, Theodore G. Storey, and W. L. Fons, Project Officer. Stenographic work during the planning of the project and in preparation of the report was performed by Flora M. Doyle.

The authors wish to acknowledge the assistance rendered by personnel of the Department of Defense, the Director of Program 3, and others at the Pacific Proving Grounds for their help to achieve the objectives of the project. Pressure measurements in the tree stands were made by Ballistic Research Laboratories. Preshot and postshot documentary still photography was made by Task Unit 8.

CONTENTS

TABLES

ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

Project 3.3, Operation CASTLE, was part of a research program sponsored by the Armed Forces Special Weapons Project (AFSWP) aimed at prediction of blast damage to forested areas from atomic explosions. A knowledge of blast damage to forested areas provides a means of assessing the degree of damage to material and personnel and/or the amount of cover the forest affords. Degree of blowdown to the forest stand will also impede troop movements through or out of the area.

The objectives of this project were:

1. To determine blast damage to trees in terms of stem breakage, branch breakage, and defoliation where effects are influenced by their location in a natural tree stand.
2. To determine the effect of natural forest cover on the shock wave in terms of its peak static overpressure and peak dynamic pressure attenuation.
3. To provide individual tree breakage data in the region of long positive phase duration times in order to substantiate the basis for breakage predictions.

The degree of momentum exchange between the shock wave and obstacles, such as trees in a stand, capable of absorbing substantial amounts of energy is not well known. There is no immediate theoretical or scaled model method of analyzing the interaction of shock wave and trees in a natural tree stand; therefore it was necessary to achieve stated objectives experimentally.

CASTLE presented an opportunity to make measurements on a natural stand several times larger than the Operation UPSHOT-KNOTHOLE[1] experimental stand. Even though the natural stand was composed of tropical trees, breakage data were desirable since continental tests in forested areas are not imminent.

1/ AFSWP, UPSHOT-KNOTHOLE, Project 3.19, Blast Damage to Coniferous Tree Stands by Atomic Explosions, WT-731, January 1954. CONFIDENTIAL--Restricted Data.

1.2 BACKGROUND

Previous analytical and experimental work[2,3] on isolated coniferous trees established that aerodynamic drag of tree crowns due to the action of particle velocity is a factor causing stem and branch breakage. The impulse given the tree crowns by the peak static overpressure is small since static pressure equalizes around individual components of the crown with the shock velocity. Structures having natural periods substantially longer than the time required for pressure equalization respond to the drag impulse of the dynamic pressure $1/2\rho u^2$ where ρ is the air density following the shock and u the particle velocity. The dynamic pressure pulse is characterized by its peak value, the positive phase duration, and the wave form factor.[4] Crown characteristics and drag measurements,[2,5,6] combined with breakage deflection and breakage force measurements,[7] resulted in an analytical prediction system for breakage of isolated trees. Breakage force-deflection measurements for static loading of ponderosa pines show that force and deflection at breakage vary approximately 300 per cent between the extremes.

On UPSHOT-KNOTHOLE an artificial stand of coniferous trees 320 ft long by 160 ft wide, composed of 145 ponderosa pine trees averaging 51 ft in height, was exposed at 4.5 psi peak static overpressure. The stand was instrumented along and across the stand with ground level static pressure gages and pitot-type dynamic pressure gages at three elevations 250 ft from front of stand. Ground-level pressure measurements showed no significant attenuation in peak static pressure or increase in rise times.

UPSHOT-KNOTHOLE results indicate that the prediction system for isolated trees was conservative when applied to small coniferous stands. However, in view of the unknown degree of attenuation for stands of large extent and the tenuous nature of the specification of military damage with respect to tree damage, isolated tree damage predictions were assumed representative of damage to tree stands. On the basis of analysis of all available data, a general breakage prediction system was developed which represents various levels of probability of breakage

2/ Operations Research Office, Preliminary Study of the Consequences of an Atomic Explosion Over a Forest, ORO-T-108, 1950, CONFIDENTIAL.
3/ AFSWP, SNAPPER, Project 3.3, Blast Damage to Trees--Isolated Conifers, WT-509, January, 1953, CONFIDENTIAL--Restricted Data.
4/ AFSWP, UPSHOT-KNOTHOLE, Project 3.19.
5/ U. S. Dept. of Agriculture, Forest Service, Div. of Fire Research, Experimental Investigation of Aerodynamic Drag in Tree Crowns Exposed to Steady Wind--Conifers, Phase Report for Operations Research Office, December, 1951, CONFIDENTIAL.
6/ U. S. Dept. of Agriculture, Forest Service, Div. of Fire Research, Crown Characteristics of Several Coniferous Tree Species, AFSWP Interim Tech. Report 416, February, 1955.
7/ U. S. Dept. of Agriculture, Forest Service, Div. of Fire Research, Tree Breakage Characteristics Under Static Loading, AFSWP Interim Tech. Report 406, January, 1953, CONFIDENTIAL.

for tree stands. The prediction system was applied to idealized tree stands to determine damage by various size weapons, using height of burst curves modified to include wave form and where damage criteria were based on length of stems down per acre. For three general stand types isodamage curves giving light and heavy damage have been prepared for inclusion in the Capabilities Handbook.[8]

8/ AFSWP, Capabilities of Atomic Weapons, TM 23-200, October, 1952, SECRET.

CHAPTER 2

EXPERIMENT DESIGN

2.1 GENERAL

The experiment design consisted of sample plots and pressure measurements on three small naturally forested islands (Uncle, Victor, and William) spaced along a radius bearing approximately 280° from Shot 3. These islands spanned a desirable predicted overpressure region for the expected yield ranging from heavy damage to light or no damage. It was essential to the success of the experiment that a substantial portion of the trees as a group remain intact, giving a graded series of damage in order to secure data in substantiation of previously developed breakage prediction systems.[1/]

The size of the stands and the range covered were dictated by the adequacy of vegetation and the radial, periodic orientation of the few available islands adjacent to Shot 3 island. Because of expected contamination by Shots 1 and 2 all project work for Shot 3 on the three islands except arming of the various gages was completed prior to Shot 1.

2.2 TREE STANDS

2.2.1 Uncle Island

Uncle Island, largest of the three islands, west of the tidal inlet is 170 acres in area, and bore a dense cover consisting of coconut palm, Pisonia (a broadleaf tree), and several shrub species. Openings among the trees were covered with the grass Lepturus and the prostrate Ipomoea vine while the fringing trees were adorned with the liane-type vine Cassytha. Table 2.1 gives common and botanical names of the important tree and shrub species on all islands and their relative abundance. Figure 2.1 shows the Uncle Island stand from the air prior to Shot 1. Figure 3.5 is a view inside the palm portion of the same stand, and Fig. 3.4 shows the interior of the broadleaf portion of Uncle Island stand.

1/ AFSWP, UPSHOT-KNOTHOLE, Project 3.19.

TABLE 2.1 - Principal Stand Components on Uncle, Victor, and William Islands

Common Name	Botanical Name	Growth Form	Abundance		
			Uncle Island (%)	Victor Island (%)	William Island (%)
Pisonia	Pisonia grandis R. Brown	large tree	40.0	70.0	20.0
Coconut palm	Cocos nucifera Linn.	large tree	20.0	0.1	5.0
Scaevola	Scaevola frutescens Mill.	large shrub	20.0	20.0	35.0
Tournefortia	Tournefortia argentea Linn.	lg. shrub or small tree	10.0	5.0	15.0
Guettarda	Guettarda speciosa Linn.	lg. shrub or small tree	5.0	3.0	15.0
Cordia	Cordia subcordata Lam.	small tree	3.0	1.3	7.0
Pandanus	Pandanus sp.	medium size tree	1.0	0.5	1.0
Pemphis	Pemphis acidula For.	lg. shrub or small tree	1.0	0.1	2.0
		Total	100.0	100.0	100.0

Taller, dominant coconut palms, averaging 45 ft in height and 14 in. in diameter at 5 ft above ground, fringed the central lagoon side of the island to a depth of about 800 ft. Several brush species composed a dense understory of a uniform 20 ft height that extended over the remainder of the island, broken only on the east and west ends by taller clumps of the broadleaf Pisonia averaging 50 ft in height and 24 in. in diameter at the base. Figure 2.2 shows the location of the principal Uncle stand components and their relation to ground zero.

Excluding the somewhat heavier tropical undergrowth found on Uncle Island, the Pisonia clumps bore a marked resemblance to an American beech forest by the deliquescent branching and leaf size. Also superficial examination showed the root systems to be similar. With on-the-ground study it became increasingly apparent that this similarity to the beech forest would make the Pisonia portions of the stands the most useful for verification of breakage prediction system developed.

Palm, on the other hand, a monocotyledon, is unlike either the coniferous or broadleaf trees (both dicotyledons) that comprise the bulk of the earth's sizable temperate vegetation. The stem of palm does not exhibit the characteristic ring-type growth but has a hard outer

Fig. 2.1 Aerial View of Uncle Island Prior to Shot 1, Looking Away from Ground Zero. Victor and William Islands in distance.

shell becoming softer toward the center. In addition the concentration of the pliable crown at the apex of the single stem is unique as is the extensive, fibrous root system emanating from the swollen lower stem. Two other factors, unrelated to the structure of the tree or to inherent wood strength but which rendered most palm trees on these three islands unsuitable for study, were axe damage and fire scar. Nearly all trees bore some foothold notches and the cross sectional areas of many were seriously reduced, predisposing such trees to breakage. Fire damage to root crowns from past ground fires had reduced the bearing surface of many palms, again predisposing them to breakage at the ground line. All palms studied were carefully selected and were relatively free of these defects.

Topography was uniformly flat with a maximum elevation of 12 ft above mean low water springs. Nowhere was topography sufficient to cause shielding of pressure gages.

2.2.2 Victor Island

The uncleared portion of Victor Island, 36 acres in area, was covered with a dense, nearly pure stand of large Pisonia trees. From a fringe of pioneer Tournefortia and Scaevola scrub along the top of the beach the trees increased in height to the center of the island. This effect, known as "wind shear" or "spray shear," was most pronounced from north to south, the direction of the prevailing wind. Over the years the mechanical breakage action of hurricane winds and the growth-retarding effect of impinging salt had imparted this domed appearance to the

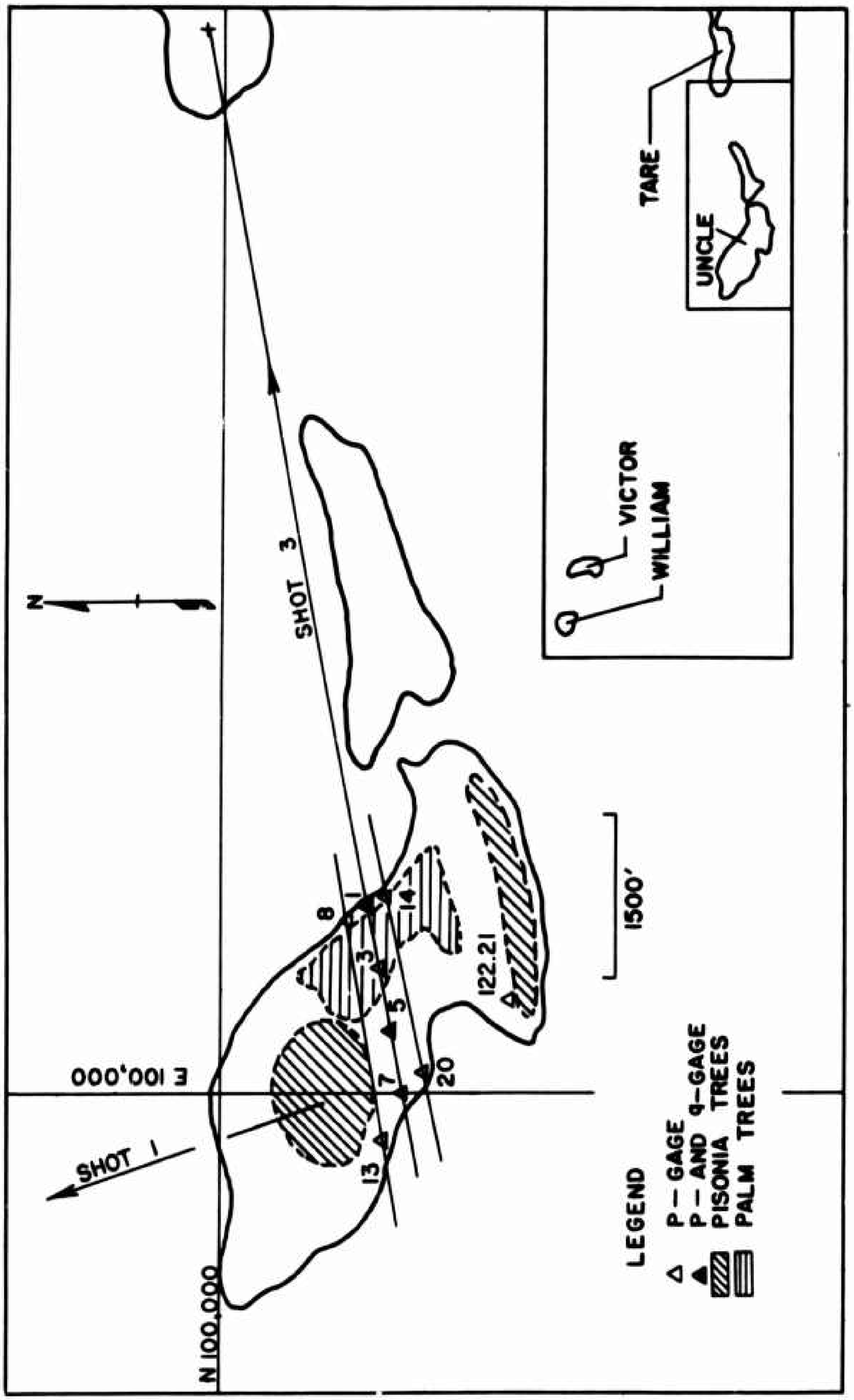

Fig. 2.2 Uncle Island Showing Orientation, Pressure Gage Locations, and Principal Stand Components

stand that centered on the southern third of the island. Trees in the main portion of the stand averaged 80 ft in height, with many individual specime s up to 42 in. in diameter at 5 ft above ground. The shorter trees to windward of the stand center were thicker for their height and therefore stronger. Branches were thick and short with gnarled ends.

Undergrowth was quite scanty in the stand center due to the deep shade cast by the crowns of the close-growing trees. Underbrush increased toward the beach on all sides as shading decreased. Although Pisonia as well as all other species are evergreens, there is considerable leaf fall in the dry season. CASTLE fell in this period, and no doubt foliage was somewhat deficient although there was full shading in the stand center. Figure 2.3 shows the orientation of the stand on Victor with respect to the other two islands and Tare. An exterior view of the Pisonia stand on the southern third of Victor prior to Shot 1 is shown in Fig. 2.4, and Fig. 3.2 gives the interior stand appearance.

Topography was uniformly flat above the beach slope, reaching a maximum elevation of only 10 ft.

2.2.3 William Island

William Island, 29 acres in area, supported a uniformly dense cover of low broadleaf brush species broken only by a small colony of palm trees on the southern tip and a 5 acre stand of large Pisonia in the center of the island. The palms averaged 40 ft tall and 13 in. in diameter, while the Pisonia averaged 50 ft in height with trees up to 24 in. diameter at breast height (d.b.h.). The Pisonia stand exterior view closely resembled the Victor Island stand shown in Fig. 2.4 although trees were not quite as tall. An aerial view of William Island is presented in Fig. 2.5. Figure 2.3 gives the orientation of the stand components and their relation to ground zero. The interior stand appearance is shown in Fig. 3.1.

2.3 INSTRUMENTATION

To assess the effects of the Uncle Island stand on shock overpressure, both static and dynamic, in terms of horizontal attenuation the stand was instrumented at eight locations with twin ground-level static pressure gages and at two locations with single dynamic pressure gages at 3 ft elevation (see Fig. 2.2 for locations). Twin static pressure gage installations were also made in the cleared areas of Victor and William Islands, and a dynamic pressure gage, at 3 ft elevation, was placed on Victor Island (see Fig. 2.3 for locations). Table 3.1 gives ground ranges for all pressure gages. Gage installations and pressure measurements were provided by the Ballistic Research Laboratories (BRL), Project 1.2b,2/ which also had pressure gage installations along a radial blast line cleared of vegetation adjacent to the Uncle Island tree stand (Fig. 2.1).

2/ Ground Surface Air Pressure vs Distance from High Yield Detonations, Operation CASTLE, Project 1.2b, WT-905.

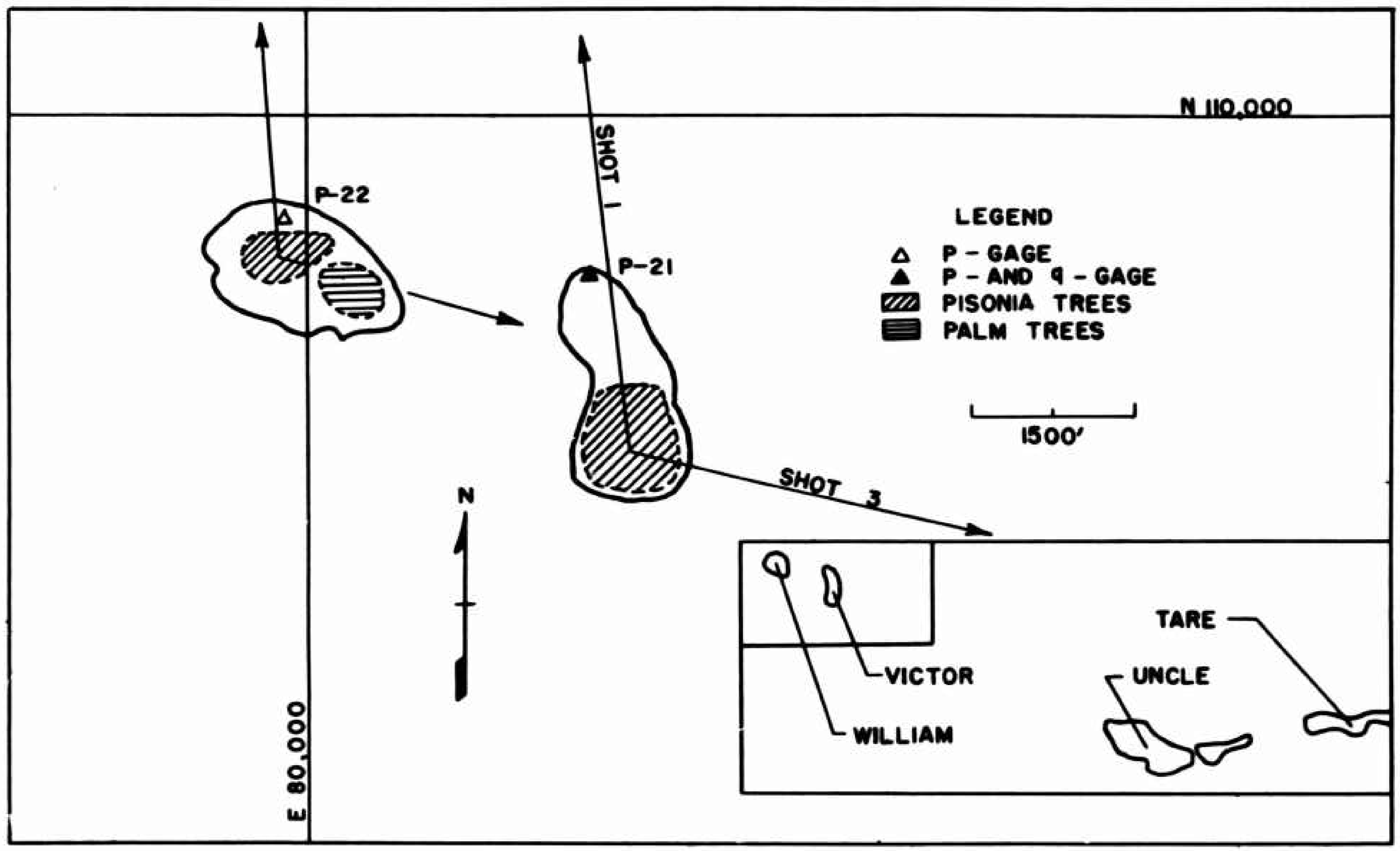

Fig. 2.3 Victor and William Islands Showing Orientation, Pressure Gage Locations, and Principal Stand Components

Fig. 2.4 Exterior View of Pisonia Stand on Southern Third of Victor Island Prior to Shot 1

Fig. 2.5 Aerial View of William Island Stand Prior to Shot 1 Looking Away from Shot 3 Ground Zero

Sound palm trees of various heights were selected across Uncle Island stand, and were provided with a snubber wire arrangement to measure maximum deflection of the center of pressure of the tree crowns under shock loading. Similar snubber wires were installed on palm trees on Victor and William Islands. Snubber wire arrangement consisted of two lengths of piano wire attached to the tree at the center of pressure of the tree crown and led down through friction grips on stakes driven into the ground, each a different known distance from the base of the tree on a radius toward ground zero. Sufficient tail was provided each, and measurements pre- and post-Shot 1 permitted calculations of the maximum movement of centers of pressure under shock loading.

2.4 SAMPLE PLOTS

To assess damage in detail to tree stands from shock-wave winds accompanying Shot 3 in terms of stem and branch breakage and defoliation, and to demonstrate how damage to individual trees is influenced by their location in the stand, sample plots were established on Uncle and Victor Islands. Plots were photographed and tree characteristics were measured prior to Shot 1.

On Uncle Island one Pisonia and three palm sample plots were selected along a radius spanning the center of the island. Sample plots for tree measurement were about 1/5-acre in area and contained from six to eight large trees with an understory of brush. Sample plot tree data are presented in Table 3.3. Figure 3.4 gives the pre-Shot 1 appearance of the Uncle Island Pisonia sample plot looking away from ground zero.

Only one sample plot was studied in the pure Pisonia stand on Victor Island as the island was considered too narrow to detect differences in individual tree breakage with position in the stand. A 100 per cent cruise of the trees on this 1/4-acre plot was made recording diameters and heights. These data are given in Table 3.2. A ground photograph of the sample plot taken prior to Shot 1 is presented in Fig. 3.2.

2.5 STATIC BREAKAGE TESTS

2.5.1 Field Tests

Prior to Shot 1 static bending tests similar to those conducted for ponderosa pine[3] were applied to 10 naturally rooted coconut palms in the Uncle Island stand to determine the force and deflection necessary for breakage. Static deflection measurements were necessary for calculating predicted deflection for breakage.

Table 2.2 gives physical characteristics and static breakage data for all test specimens. Palms on the three test islands were considered one population for application of bending strength test data.

2.5.2 Standard Tests

As the standard strength parameters for green palm and Pisonia wood had not been determined previously, arrangements were made for

3/ U. S. Dept. of Agriculture, Forest Service, Div. of Fire Research, Tree Breakage Characteristics Under Static Loading.

TABLE 2.2 - Experimental Stem Breakage Data for Palm Trees on Uncle Island [a]

Tree No.	H_b (ft)	d_b [b] (in.)	H_r (ft)	d_r [b] (in.)	H_c (ft)	d_c [b] (in.)	H_{br} (ft)	τ_t (sec)	τ_s (sec)	W_{dc} (lb)	R_b (lb)	y_b (ft)
1	40.7	11.0	33.7	6.6	35.7	6.6	7.5	2.47	1.18	68	1,658	30.1
2	43.5	12.5	35.0	6.8	38.5	5.9	0.0	--	1.34	80	2,677	33.0
3	35.5	12.0	27.7	7.2	30.5	6.5	0.8	1.76	0.90	71	960	5.7
4	39.0	10.5	31.0	7.7	34.0	7.1	8.0	2.39	--	102	3,040	20.6
5	48.0	17.2	39.0	8.9	43.0	8.4	15.3	2.61	0.94	108	4,496	18.9
6	32.5	12.5	21.5	9.0	25.5	8.8	0.0	1.78	0.50	108	4,148	12.3
7	33.5	10.7	26.5	6.4	30.5	6.2	9.5	1.78	0.75	86	2,340	19.6
8	30.5	11.2	24.5	8.2	27.5	7.8	0.0	1.97	0.61	96	1,891	11.2
9	48.5	11.6	40.0	6.8	43.5	6.4	0.5	2.27	1.35	77	1,342	18.0
10	25.8	10.8	18.3	7.2	20.8	7.8	5.0	1.35	0.50	80	2,582	12.2

[a] For Nomenclature see page 46.
[b] Coconut palm has no bark.

static bending tests at the proving grounds. Following ASTM standards small clears were cut and subjected to tests in the materials testing laboratory on Elmer Island (Eniwetok Atoll). From force-deflection data, strength characteristics were calculated.

Table 2.3 presents average values of fiber stress at proportional limit, modulus of rupture, and modulus of elasticity for the three palm and Pisonia test specimens. Similar values for typical American woods are given for comparison purposes.

2.6 PHOTOGRAPHY

To fix the undamaged appearance of sample plots, snubber trees, and the tree stands as a whole, extensive still ground photography was made prior to Shot 1. Low oblique aerial photographs were taken at intervals along the center pressure gage radial across Uncle Island stand. These views when repeated post-Shot 3 allowed assessing damage in terms of stem and branch breakage and defoliation, and the effect of tree position in the stand.

TABLE 2.3 - Comparative Strength Properties of Palm and Pisonia with Typical American Woods

Common and Botanical Name of Species	Moisture (%)	Specific Gravity	Fiber Stress at Proportional Limit (lb/sq in.)	Modulus of Rupture (lb/sq in.)	Modulus of Elasticity (10^3 lb/sq in.)
Coconut palm [a] (Cocos nucifera)	209	.35	1,800	3,600	370
Pisonia [a] (Pisonia grandis)	243	.25	1,700	2,300	305
American beech [b] (Fagus grandifolia)	54	.56	4,300	8,600	1,380
Douglas-fir [b] (Pseudotsuga taxifolia)	36	.45	4,800	7,600	1,550
Ponderosa pine [b] (Pinus ponderosa)	91	.38	3,100	5,000	970
Silver maple [b] (Acer saccharinum)	66	.44	3,100	5,800	940

[a] Average of three specimens.
[b] Wood Handbook, Forest Products Laboratory, Forest Service, USDA. June, 1940.

CHAPTER 3

RESULTS

3.1 GENERAL

The unexpectedly large yield of Shot 1 incident from the opposite direction of Shot 3 caused heavy damage to the tree stands on William and Victor Islands, and light damage to the upper portion of the stand on Uncle Island. Shot 2, coming from the same direction as Shot 1, caused no additional damage.

Shot 1 proved to be rather fortuitous, especially in light of the unexpectedly low yield of Shot 3, for which heavy damage extended to just beyond the light damage region of Shot 1. Thus, two sets of graded general damage data were secured instead of one, namely, data on damage from a high yield weapon of long positive phase duration time, and damage from a medium yield weapon with shorter positive phase duration time.

3.2 OVERPRESSURE AND POSITIVE PHASE DURATION

3.2.1 Shot 1

Ground ranges and estimates of overpressures and positive phase duration for Shot 1 are given in Table 3.1. Ground ranges were calculated from established coordinates, and are distances to BRL gages used for reference points. Free field overpressure and positive phase duration time data were furnished by Program 1[1/] and were used in correlating damage with distance of natural tree stands.

3.2.2 Shot 3

Table 3.1 gives ground ranges and overpressure and positive phase duration time estimates used in reducing test data. Peak static overpressure records from Shot 3 were satisfactory as generally one gage in each twin installation was operative. Positive phase duration time data

1/ Summary Report of the Commander Task Unit 13, Operation CASTLE Programs 1-9, WT-934. SECRET--Restricted Data.

TABLE 3.1 - Pressures and Positive Phase Duration Times at Project 3.3 Stations, Shots 1 and 3

Station Number [a]	Ground Range (ft)	Peak Static Overpressure (psi)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)
		Shot 1		
P-22	61,710	2.5 [b]	10.0 [b]	--
P-21	62,500	2.4 [b]	10.0 [b]	--
P-13	75,400	1.7 [b]	12.0 [b]	--
		Shot 3		
P-14	8,040	4.70 [c]	1.46 [c]	--
P-1	8,200	4.50	1.16	0.9
P-8	8,340	4.52	1.47	--
P-3	8,800	NR [d]	--	--
122.21 [e]	9,380	4.12	1.61	--
P-5	9,400	4.19 [f]	--	2.3
P-20	9,840	3.98	--	--
P-7	10,000	4.07	--	--
P-13	10,440	3.20	--	--
P-21	28,430	0.79 [f]	--	0.5
P-22	31,310	--	--	--

[a] See Figs. 2.2 and 2.3 for gage locations.
[b] Values furnished by Program 1, gages not activated.
[c] Average of two gages.
[d] No record obtained.
[e] BRL free field measurements, adjacent to tree stand. Average of 5 gages.
[f] From dynamic pressure gage.

were incomplete. All dynamic pressure gages were operable and records were satisfactory. A peak static overpressure measurement taken in the cleared area of BRL gage line on Uncle Island, which was at a ground range about equal to the center of the tree stand, is given for comparison with measurements taken within the stand.

3.3 MAXIMUM DEFLECTION MEASUREMENTS

Shot 3 maximum deflection data from snubber trees on Uncle Island were unsatisfactory due to breakage of instrumented trees or fouling of wires by falling trees and branches. Deflections of instrumented trees on Victor and William Islands were negligible although all snubbers were operative.

As no usable deflection data were obtained the physical characteristics of snubber trees are not reported.

3.4 SHOT 1 DAMAGE

The William Island Pisonia stand near Station P-22 at a ground range of 61,710 ft, 2.5 psi peak static overpressure, was heavily damaged. Before and after interior views of the stand are given in Fig. 3.1. Damage was primarily in the form of branch breakage with some uprooting and main stem breakage. All uprooted trees fell away from ground zero. All broadleaf species were completely defoliated. Only two defective palms were broken, others suffered only occasional loss of fronds.

The Victor Island Pisonia stand near Station P-21, including the sample plot, at a ground range of 62,500 ft, 2.4 psi peak overpressure, were heavily damaged. Figure 3.2 shows the plot interior before and after Shot 1. Figure 3.3 gives an exterior postshot view for comparison with preshot view shown in Fig. 2.4. Damage was quite similar in appearance to that on William Island as the two small islands were practically contiguous. Table 3.2 presents number, size, and damage distribution for the trees on the sample 1/4-acre plot.

There was 30 per cent branch breakage, considered as light damage, in the Pisonia clump on the northwest end of Uncle Island near Station P-13 at 75,400 ft ground range, 1.7 psi peak static overpressure, and 12 sec positive phase duration time. Damage also was primarily in the form of branch breakage and heavy defoliation with occasional trunk failure and uprooting of smaller trees. Figure 3.4 shows the Uncle Island Pisonia sample plot before and after Shot 1.

3.5 SHOT 3 DAMAGE

Physical characteristics of trees on the four Uncle Island sample plots and corresponding breakage data are presented in Table 3.3. Fifteen of the 26 trees in the 4 plots or 58 per cent were damaged at an average ground range of 8800 ft, 4.2 psi peak static overpressure. This degree of damage is borne out by the appearance of the stand as a whole and was considered heavy damage.

Fig. 3.1 William Island Pisonia Stand Near Station P-22, Before and After Shot 1, Looking Away from Ground Zero.

Ground Range, Station P-22: 61,710 ft

Peak Static Overpressure: 2.5 psi

Fig. 3.2 Victor Island Pisonia Stand Near Station P-21, Before and After Shot 1, Looking Away from Ground Zero.

Ground Range, Station P-21: 62,500 ft
Peak Static Overpressure: 2.4 psi

Fig. 3.3 Exterior View of Pisonia Stand on Southern Third of Victor Island Near Station P-21, Following Shot 1, at Right Angles to Blast Line, With Ground Zero to Left. (Preshot view, Fig. 2.4.)
Ground Range, Station P-21: 62,500 ft
Peak Static Overpressure: 2.4 psi

Figures 3.5 and 3.6 show the appearance of the palm portion of Uncle Island tree stand prior to and following Shot 3 at 8340 ft and 8600 ft ground ranges, respectively. Figure 3.5 shows the nearly complete destruction of smaller broadleaf species and light damage to the palm. Figures 3.7 and 3.8 at successively greater distances show damage in the predominantly broadleaf portion of Uncle Island stand.

Damage to Pisonia trees was primarily in the form of branch breakage and complete defoliation with some uprooting and main stem failure. Figure 3.9, which repeats Fig. 3.4, shows additional damage to the Pisonia sample plot resulting from Shot 3.

No additional damage resulted to either Victor Island or William Island tree stands from Shot 3.

TABLE 3.2 - Tree Characteristics and Damage, Shot 1--Victor Island 1/4-acre Pisonia Sample Plot [a]

Diameter Class (in.)	Average Height (ft)	Total Trees in Sample Plot (no.)	Trees with Crown Damage (no.)	Trees Uprooted (no.)	Tree Damage by Diameter Class (%)
4	23	3	2	0	66
6	25	5	3	0	60
8	40	3	3	0	100
10	37	5	4	1	100
12	40	1	1	0	100
14	48	3	3	0	100
16	48	2	0	1	50
18	75	3	0	1	33
20	68	2	0	0	0
22	64	5	1	0	20
24	70	8	4	1	62
26	70	3	2	0	66
28	75	3	2	0	66
32 [b]	75	2	0	0	0
48	80	1	1	0	100
Total		49	28	4	65.2

[a] Estimated peak static overpressure of 2.4 psi at sample plot.
[b] No trees in 30 in. or 34 to 46 in. class.

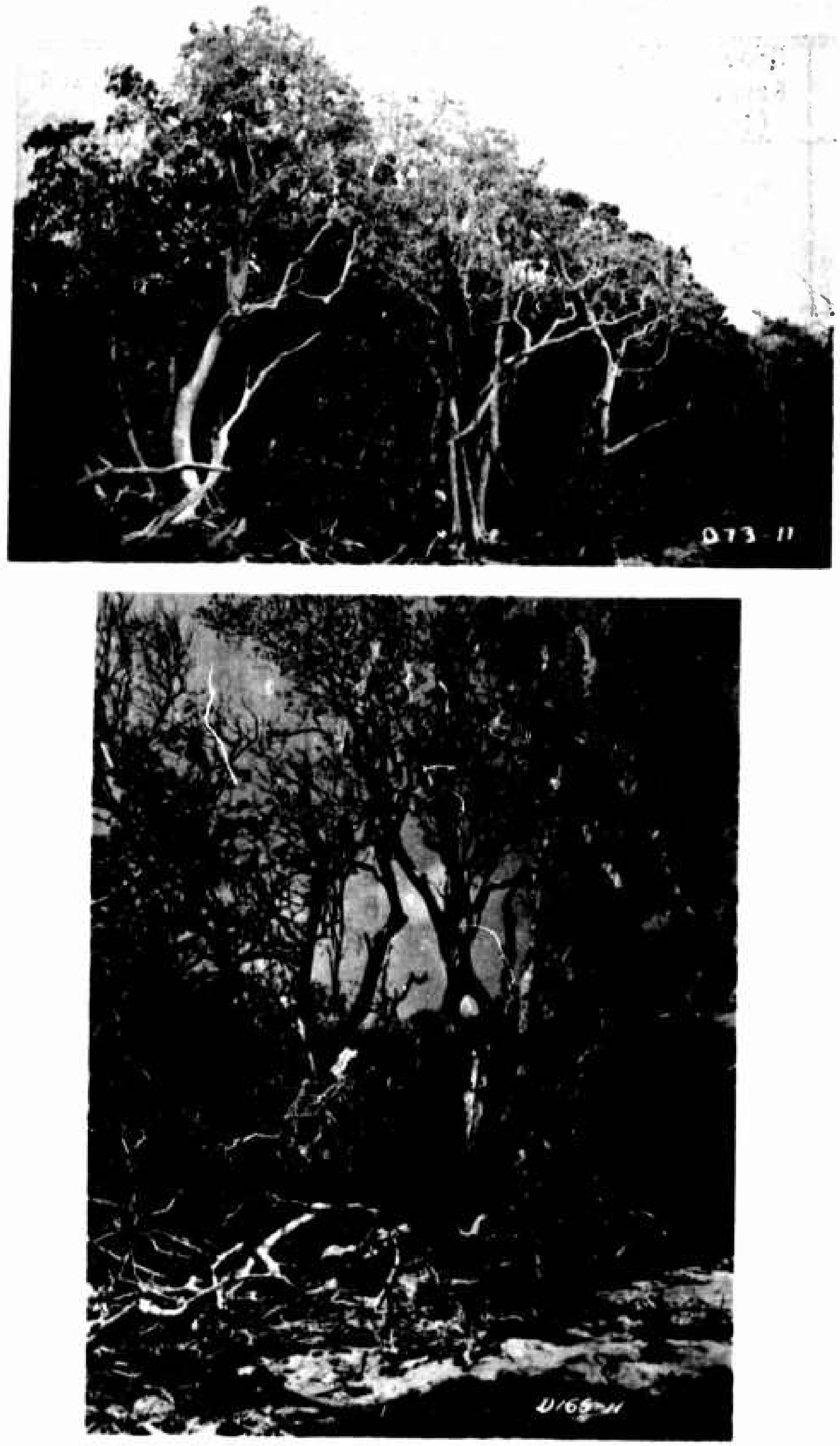

Fig. 3.4 Uncle Island Pisonia Sample Plot D Near Station P-13, Before and After Shot 1, Looking Toward Ground Zero.
Ground Range, Station P-13: 75,400 ft
Peak Static Overpressure: 1.7 psi

TABLE 3.3 - Tree Characteristics and Damage, Shot 3-- Uncle Island Sample Plots

Plot [a] and Tree No.	Ground Range (ft)	Stem Diameter at Base [b] (in.)	Total Height (ft)	Crown Height (ft)	Period (sec)	Height of Break (ft)
A-1	8,340	11.4	31	14	1.64	0
A-2	"	17.6	59	10	3.00	8
A-3	"	12.7	52	12	2.51	-- [d]
A-4	"	14.1	57	12	3.09	6
A-5	"	13.7	42	12	2.18	10
A-6	"	12.5	52	10	2.55	-- [d]
A-7	"	14.1	51	12	2.60	9
B-1	8,610	11.4	27	10	1.34	-- [d]
B-2	"	11.7	25	10	1.90	-- [d]
B-3	"	14.3	32	12	2.18	-- [d]
B-4	"	11.8	43	10	2.52	-- [d]
B-5	"	14.1	44	10	2.74	-- [d]
B-6	"	12.0	36	10	2.17	-- [d]
B-7	"	11.2	39	10	2.67	-- [d]
B-8	"	10.7	36	10	2.29	5
C-1	9,000	13.2	34	10	1.98	4 [e]
C-2	"	13.0	36	10	1.96	16
C-3	"	12.6	38	10	2.32	21
C-4	"	12.2	38	10	2.58	-- [d]
C-5	"	14.5	32	12	1.58	-- [d]
C-6	"	13.1	48	12	1.75	28
D-1 [c]	10,140	10.6	35	10	2.22	20
D-2	"	11.0	40	15	2.42	0
D-3	"	13.9	45	20	2.00	-- [f]
D-4	"	15.2	40	15	1.92	-- [f]
D-5	"	12.3	42	17	2.14	-- [f]
D-6	"	10.6	35	10	2.48	-- [f]

[a] Plots A, B, and C, coconut palm; Plot D, Pisonia.
[b] Diameter at 5 ft above ground level.
[c] On Plot D some defoliation and small branch breakage resulted from Shot 1.
[d] No damage.
[e] Broken by Shot 1.
[f] Branch breakage.

Fig. 3.5 Uncle Island Palm Sample Plot A, Before and After Shot 3, Looking Away from Ground Zero.
Ground Range: 8,340 ft
Peak Static Overpressure (from Fig. 4.1): 4.6 psi

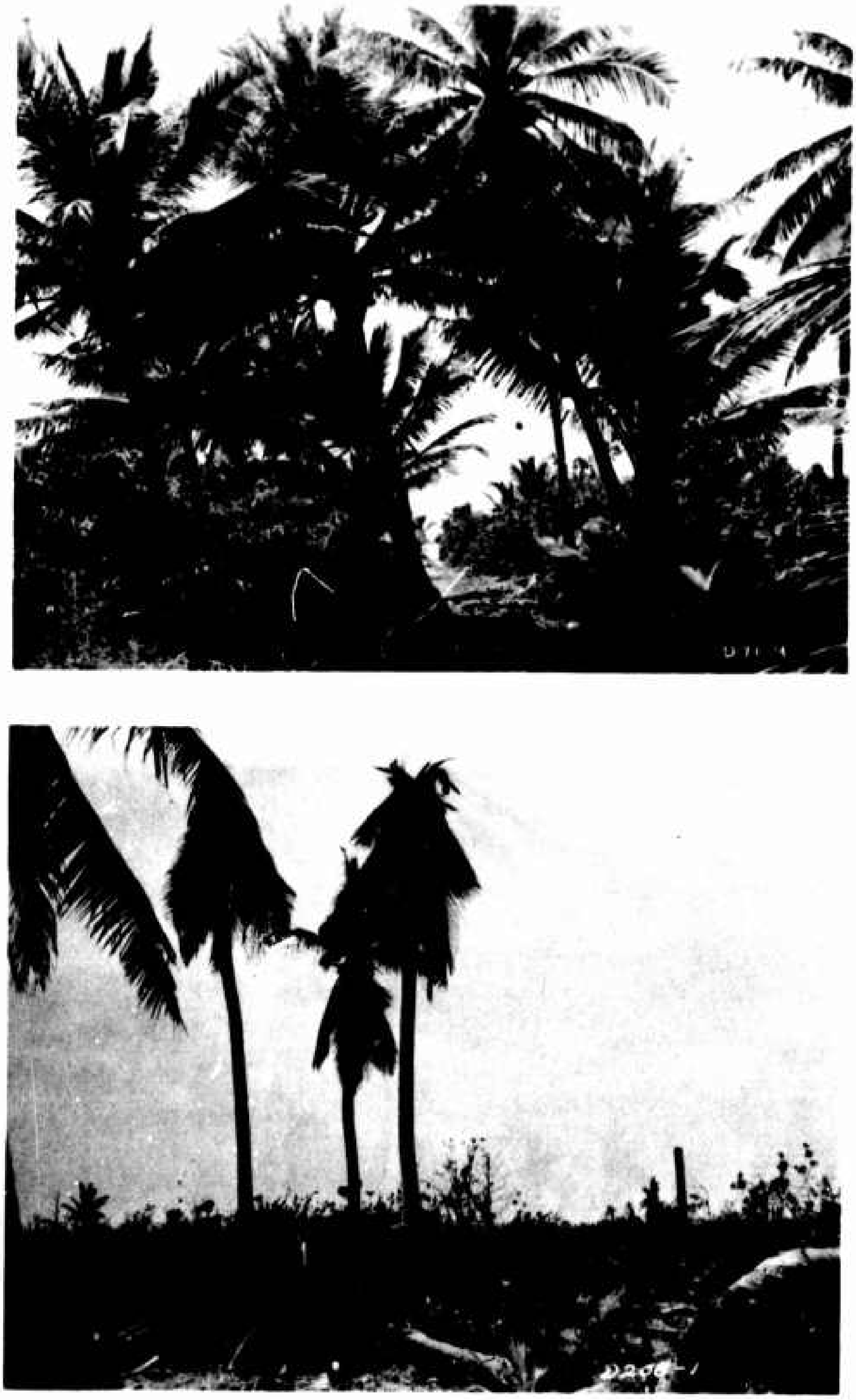

Fig. 3.6 Uncle Island Palm Sample Plot B, Before and After Shot 3.

Ground Range: 8610 ft

Peak Static Overpressure (from Fig. 4 1): 4.4 psi

Fig. 3.7 Uncle Island Tree Stand, Before and After Shot 3, Looking Away from Ground Zero.
Ground Range: 8800 ft
Peak Static Overpressure (from Fig. 4.1): 4.2 psi

Fig. 3.8 Uncle Island Tree Stand, Before and After Shot 3, Looking Away from Ground Zero.

Ground Range:	9300 ft
Peak Static Overpressure (from Fig. 4.1):	3.8 psi

Fig. 3.9 Uncle Island Pisonia Sample Plot D, After Shot 3, Looking Away from Ground Zero. (Preshot view, Fig. 3.4.)

Ground Range:	10,150 ft
Peak Static Overpressure (from Fig. 4.1):	3.3 psi

CHAPTER 4

DISCUSSION

All experiment objectives were partially met in spite of unexpected deviation from the predicted yields of Shots 1 and 3. Shot 1 yield was much larger than expected which resulted in heavy damage to stands on William and Victor Islands and light damage to a portion of Uncle Island stand. The yield of Shot 3, for which the experiment was designed, was much lower than predicted; however, the entire Uncle Island stand was heavily damaged. This heavy damage overlapped the Shot 1 light damage region on the upper end of Uncle Island. Negligible deflection of snubber trees on Victor and William Islands for Shot 3 placed these islands in a no-damage region. Thus two graded series of damage were secured--one from a high yield weapon, and one from a medium yield weapon.

Measured peak static overpressure values for Shot 3 through the mixed palm-broadleaf Uncle Island stand (Fig. 4.1) are in general within -5 and +15 per cent of curve values prepared from free field measurements adjacent to the stand. Results of these measurements taken at stations over a distance of 2000 ft into the stand do not indicate any peak static overpressure attenuation.

For Shot 3, the three dynamic pressure gages, one outside and one inside Uncle Island tree stand and one outside the stand on Victor Island, recorded peak dynamic pressures respectively 1.9, 5.6, and 33 times greater than values calculated from corresponding peak static overpressure measurements. The single free field measurement along the blast line, at 6500 ft, adjacent to the Uncle Island stand was greater than the calculated value by 10 per cent. In light of these unreasonably high peak dynamic pressure measurements, both outside and inside Uncle Island stand, the amount of attenuation of the peak dynamic pressure in an extensive tree stand remains an open question.

Isodamage curves presented in Fig. 4.2 are one of a set of curves prepared for inclusion in Capabilities Handbook[1] and are the results of theoretical analysis of dynamic breakage due to shock loading. The

1/ AFSWP, Capabilities of Atomic Weapons, TM 23-200.

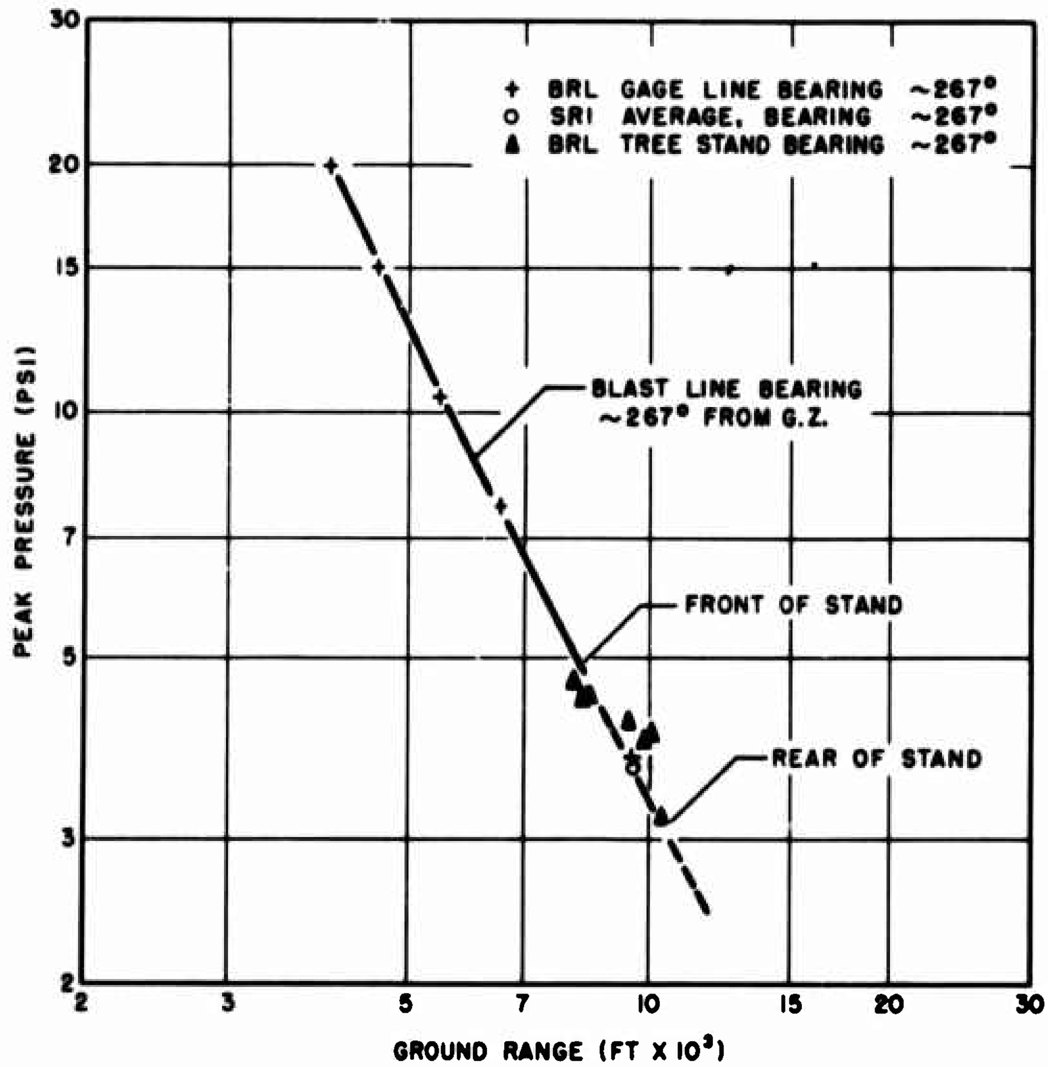

Fig. 4.1 Comparison of Uncle Island Tree Stand and Free Field Peak Static Overpressure Measurements--Shot 3

procedure leading to prediction of breakage has been outlined in detail in a previous report.2/

Breakage calculations have been carried out for a range of 1KT to 10MT. Positive phase duration was static overpressure scaled.3/ In each case a curve of damage vs peak dynamic pressure was obtained for a number of dynamic pressure wave form factors. By choosing a specific degree of damage (i.e., light or heavy) a corresponding peak dynamic pressure was obtained for each wave form factor. Plotting these calculated points on a composite HOB-dynamic pressure-wave form factor curve4/ results in isodamage curves similar to Figure 4.2 for each yield investigated.

2/ AFSWP, UPSHOT-KNOTHOLE, Project 3.19.

3/ Sandia Corporation, Methods for Estimating Blast Loading on Simple Structures, September, 1953, SECRET--Restricted Data.

4/ U. S. Dept. of Agriculture, Forest Service, Div. of Fire Research, Dynamic Pressure Wave Form-Height of Burst Curves, Interim Tech. Report AFSWP-419, February 10, 1955, SECRET.

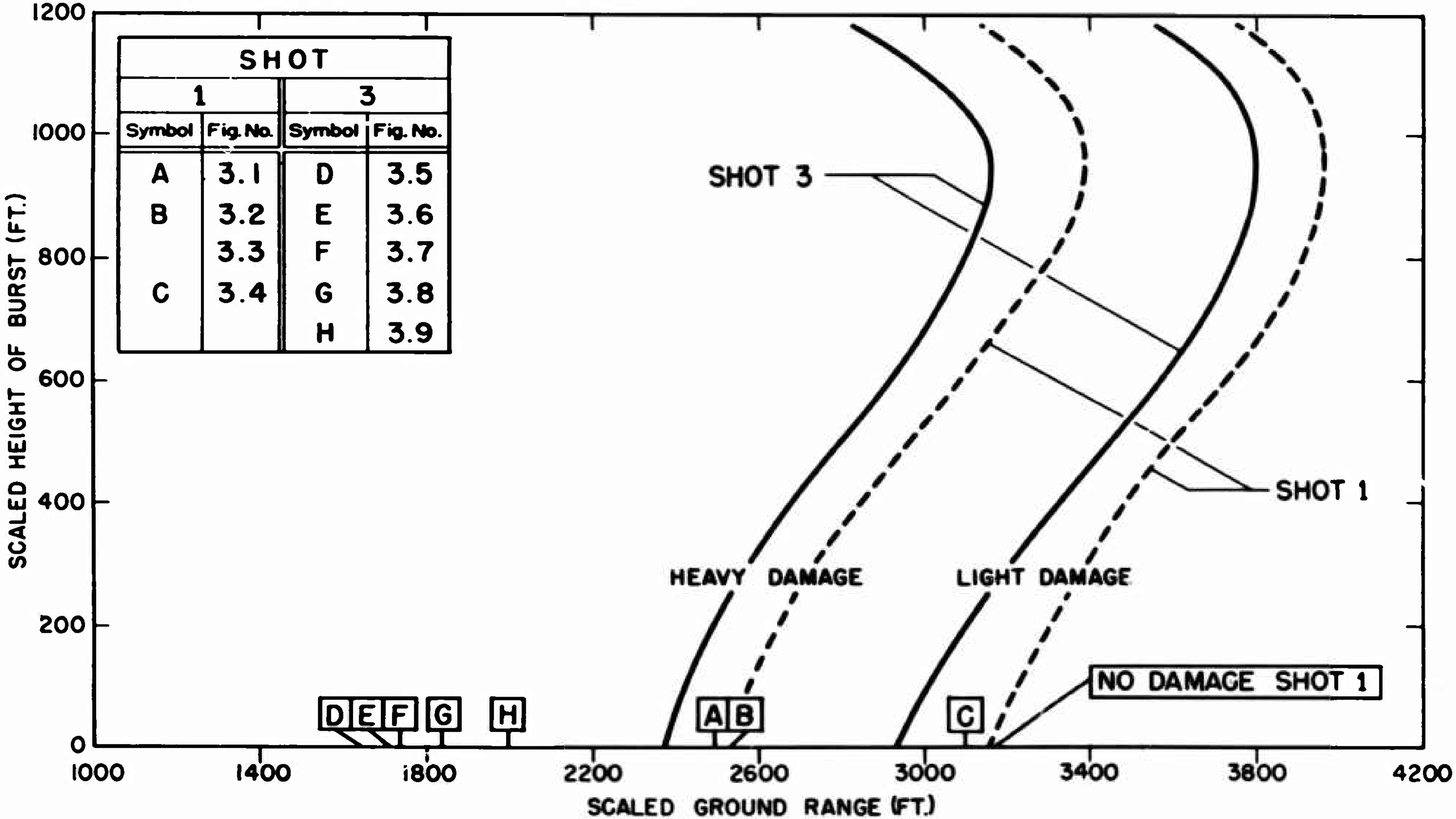

Fig. 4.2 Comparison of Damage from Shots 1 and 3 with Predicted Isodamage Curves for Broadleaf Tree Stand

Differences due to weapon yield are the results of variation of positive phase duration with respect to tree natural period, i.e., the period modulus. Since the period modulus for 110KT is already sufficiently small the reduction in period modulus due to the larger yield (14.5MT) does not lead to a corresponding decrease in dynamic pressure modulus.[5]

Isodamage curves shown delineate light and heavy damage to broadleaf tree stands resulting from 15MT and 130KT weapons. The criteria for light and heavy damage given in Table 4.1 are based on total length of stems and limbs on the ground, and are estimates of two degrees of damage in impeding movement of military personnel and vehicles. It should be pointed out here that the criteria used in arriving at the two degrees of damage have no experimental basis.

The degree of damage to William Island and Victor Island Pisonia stands from Shot 1 was considered as heavy. Scaled distances of William Island and Victor Island locations from Shot 1 are shown on Fig. 4.2 by symbols "A" and "B," respectively. The damage based on trees damaged on Victor Island Pisonia plot (Fig. 3.2) by Shot 1 was assessed as 65 per cent. The damage consisted of stem and limb breakage with some uprooting. The 65 per cent damage value was consistent with observations of the stand as a whole.

TABLE 4.1 - Criteria for Two Degrees of Damage--
Broadleaf Stands, Stocking 196 Trees/Acre

Degree of Damage	Trees Damaged (%)	Length of Stems and Limbs Down on the Ground (ft/acre)
Light	10	1500
Heavy	60	9000

The degree of damage from Shot 1 to trees on Uncle Island Pisonia plot (Fig. 3.4) was assessed as 30 per cent or light damage. Scaled ground range of this plot is shown by symbol "C" on Fig. 4.2. For Shot 1, no damage resulted to Uncle Island stand beyond a scaled ground range of 3180 ft. The nearness of light damage and no damage might suggest shock attenuation by the stand. However, the area of no damage consisted mostly of palm and small broadleaf trees as contrasted with the light damage region where inherently weaker Pisonia trees predominated. This change in the Uncle Island stand composition did not permit estimation of the amount of shock attenuation from observations of degree of damage with distance.

The degree of damage by Shot 3 to Uncle Island stand as a whole was assessed as heavy. Scaled distances of locations illustrated by Figs. 3.5 through 3.9 are shown on Fig. 4.2 by symbols "D" to "H," inclusive. The tallied stem breakage of trees on the sample plots, excluding small diameter broadleaf trees, was 58 per cent. According to Table 4.1,

5/ AFSWP, UPSHOT-KNOTHOLE, Project 3.19, Fig. 1.3.

percentage of damage falls close to the percentage necessary for heavy damage. However, heavy damage to the small broadleaf trees throughout the stand area indicated that had the sample plots been fully stocked with larger broadleaf trees the percentage breakage would have exceeded this value.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. Ground level pressure measurements 2000 ft into a tree stand substantiate UPSHOT-KNOTHOLE conclusion of no attenuation in peak static overpressure; therefore, for this purpose further measurements of overpressure in tree stands should not be necessary.

2. It was not possible to assess the stand influence by observation of damage because of non-uniformity of stand composition; nor was it possible to determine the peak dynamic pressure attenuation because the three gages in or near the stands showed large unexplained variation.

3. Observed damage from two weapons of different yields compare favorably with isodamage curves prepared for broadleaf stands.

4. Damage in broadleaf stands is principally limb breakage and defoliation with occasional breakage of the main stem or uprooting.

5. Snubber wire arrangement for measurement of maximum deflection of tree stem is not feasible in a forested area composed of broadleaf trees and brush species where limb breakage is the principal form of damage.

5.2 RECOMMENDATIONS

In future operations, where a detonation (preferably an air burst) is near or over forested areas, projects should be programed to obtain additional damage data on tree stands, and to secure needed peak dynamic pressure data for assessing the amount of attenuation. In that event duplicate gage installation at all stations is advisable.

In about two years, growth of vegetation on Uncle, Victor, and William Islands should be sufficient in amount to provide areas for studying attenuation of dynamic pressure. However, it will take many years before the growth will be sufficient to study tree damage.

NOMENCLATURE

H_b = height of tree above 5-ft mark, ft

d_b = stem diameter at 5-ft above ground level, in.

H_r = height above ground at which deflection measurements were made, ft

d_r = stem diameter at deflection measurement point, in.

H_c = height of crown base above ground, ft

d_c = stem diameter of crown base, in.

H_{br} = height of break above ground, ft

τ_t = tree natural period, sec

τ_s = bare stem natural period, sec

W_{dc} = weight of dry crown, lb

R_b = horizontal applied force at breakage, lb

y_b = arc deflection at breakage, ft