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by

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ABSTRACT

A deterministic estimate of the nuclear radiation fields from the Hiroshima and Nagasaki nuclear weapon explosions requires the yields of these explosions. The yield of the Nagasaki explosion is rather well established by both fireball and radiochemical data from other tests as 21 kt. There are no equivalent data for the Hiroshima explosion. Equating thermal radiation and blast effects observed at the two cities subsequent to the explosions gives a yield of about 15 kt. The pressure-vs-time data, obtained by dropped, parachute-retarded canisters and reevaluated using 2-D hydrodynamic calculations, give a yield between 16 and 17 kt. Scaling the gamma-ray dose data and calculations gives a yield of about 15 kt. Sulfur neutron activation data give a yield of about 15 kt. The current best estimates for the yield of these explosions are the following:

Hiroshima	15 kt
Nagasaki	21 kt

The outside limits of uncertainties in these values are believed to be 20 percent for Hiroshima and 10 percent for Nagasaki.

I. INTRODUCTION

The Manhattan Project culminated in the design and fabrication of two types of nuclear weapons--Little Boy and Fat Man. The first type was exploded over Hiroshima, the second over Nagasaki. Estimates of radiation exposures depend in part on explosive yields, and much of the evaluation of radiation effects upon man depends on data from the Hiroshima and Nagasaki explosions. The yield of the Fat Man has been determined rather well, being given variously from 19-24 kt. (Present official yield is 23 kt.[1]) Estimates[2-7] for the Little Boy have ranged from 6-23 kt. (The current official yield is 13 kt.[1]) The data from which estimates may be made are fragmentary, and the parameters needed for evaluation have been either missing, inconsistent, or erroneous. Part of the problem arises from President Truman's edict that the yields of both explosions were 20 000 tons of TNT; another part of the problem arises from the inadequate and faulty documentation of the combat missions by the Army Air Corps 509th Composite Group and the US Air Force historians.

Many well-researched books,[8-21] particularly Ref. 16, are useful in resolving inconsistencies. There is also documentation by the US Strategic Bombing Survey (USSBS),[22] the Manhattan Engineering District,[8,15] and the Japanese.[21] These sources are not particularly useful for yield evaluation; however, they contain clues.

II. TRINITY TEST

The purposes of the Trinity Test of July 16, 1945, were to determine the performance of the Fat Man; to determine the explosion's physical effects, particularly blast; and to evaluate methods of determining the yield of the weapons to be used against Japan. Yield was measured on the combat missions by determining the fireball's rate of growth and the time dependence of the overpressure of the blast wave at altitude. Data were to be obtained on the combat missions from instrumentation aircraft accompanying the strike aircraft. The growth of the fireball was to be recorded with a Fastax™ camera mounted on the gyrostabilizer of the Norden™ bomb sight of the photographic aircraft; the camera was to be operated on the first mission by B. Waldman and by R. Serber on the second. Overpressure-vs-time data were to be obtained from gages in parachute-retarded canisters dropped by and telemetered to another instrumented aircraft in formation with the strike aircraft; this program was executed by a group headed by L. Alvarez, which included H. Agnew and L. Johnston.

During the Trinity Test, excellent photographic records were obtained of the fireball and the aftermath. Weather conditions and/or safety considerations prevented collecting overpressure-vs-time data, although the aircraft was in the area and observed the explosion.

III. HIROSHIMA MISSION

The mission against Hiroshima has been described as textbook with all aircraft and equipment operating as planned. The bomb was dropped within 15 s of plan. Waldman believed he obtained good Fastax™ records from a point some

19 miles out, and good overpressure-vs-time data were obtained by telemetry from the dropped parachute-retarded canisters. Because the film developing equipment malfunctioned, the Fastax™ film was torn, the emulsion was blistered or was scraped off, and the film came out clear where emulsion did exist; no image was visible. The equipment had earlier successfully processed the films from the cameras recording the canister data.[23] The overpressure-vs-time records[24-25] were good.

The locations of the canisters relative to the burst have been elusive data. The historical records[26] of the mission by the 509th Composite Group of the Army Air Corps, the operational group formed to deliver the weapons, are both incomplete and inconsistent. For example, the crew members' logs, in particular those of the bombardiers, and the debriefing notes are not included. A crucial fact, the aircraft altitude, is given for the Hiroshima mission in the strike report[26] as 30 200 ft, in the historical narrative[26] as 31 600 ft, and in Parsons' log[10] as 32 700 ft. Upon discovery of the navigator's log on the inside covers of Marx's book,[16] many of the inconsistencies were resolved: the true altitude is given there as 31 060 ft, possibly a transposition. Correction of the indicated pressure altitude gives a value of 32 200 ft, in reasonable agreement with Parsons' log or the 31 600 ft. An interview by J. A. Auxier and L. J. Deal with General Sweeney (then Major), who piloted the instrumentation aircraft from which the canisters were dropped, resolved the problem of the aircraft spacing in the formation.* Uncertainties which still remain include the time from "bomb away" or release tone to parachute deployment, the true altitude, and the gage calibrations. A summary of the missions is given in Tables I and II.

IV. NAGASAKI MISSION

The plans for the second mission, with the primary target of Kokura, were similar to those for Hiroshima, but the execution did not go as planned.[9] The problems started before takeoff--a fuel transfer valve was inoperative and fuel in one bomb-bay tank was unavailable; further, R. Serber, who was to have operated the Fastax™ camera in the photographic plane, when drawing equipment

* Lord Penney[27] said he questioned the bombardier of the canister aircraft after the mission as to the spacing. He was "completely sure he was very close -- 100 yd." Beahan, the bombardier, confirmed this.

TABLE I

MISSION SUMMARIES FOR STRIKE AIRCRAFT

	Hiroshima	Nagasaki
Bomb designation	L-11, Little Boy	F-31, Fat Man
Mission number	13	16
Strike aircraft	V-82, Enola Gay	V-77, Bock's Car
Aircraft commander	Col. P. W. Tibbets	Maj. C. W. Sweeney
Pilot	Capt. R. A. Lewis	1st Lt. C. D. Albury
Navigator	Capt. T. T. Van Kirk	Capt. J. F. Van Plet
Bombardier	Maj. T. W. Ferebee	Capt. K. K. Beahan
Weaponeer	Capt. W. S. Parsons (USN)	Cdr. F. L. Ashworth (USN)
Time of detonation	0815, August 6, 1945	1102, August 9, 1945
Indicated air speed	200 mph	200 mph
True air speed	328 mph	315 mph
Wind	8 knots at 170°	1-knot head wind
True heading	262°	
True course	265°	
Indicated altitude	30 200 ft	28 000 ft
True altitude	31 600 ft (34 640 ft)[a]	28 900 ft
Temperature	Ind. -22°C, True -33°C	
Height of burst[28]	580 ± 15 m	503 ± 3 m
Time of fall	44.4 s (46.9 s)	47.0

[a] Quantities in parenthesis have been derived from canister pressure-time records and test drop data.

TABLE II

MISSION SUMMARIES: INSTRUMENT AND PHOTOGRAPHIC AIRCRAFT

	Hiroshima	Nagasaki
Instrument aircraft	V-89, Great Artiste	V-89, Great Artiste
Position	300 ft behind V-82	300 ft behind V-77
Aircraft commander	Maj. C. W. Sweeney	Capt. F. Bock
Bombardier	Capt. K. K. Beahan	1st Lt. C. Levy
Scientists, observers	L. W. Alvarez	L. Johnston
	H. M. Agnew	W. Goodman
	L. Johnston	J. Kupferberg
		W. Laurence (The New York Times)
Photo aircraft	V-91, Strange Cargo	V-90, Full House
Aircraft commander	Capt. Marquardt	Maj. J. Hopkins
Scientists, observers	B. Waldman	Dr. W. G. Penney
		Gr. Capt. G. L. Cheshire

for the mission, was given two life rafts instead of a raft and a parachute. When this was discovered before takeoff, he attempted to obtain a ´chute; however, the plane took off without him.[29] Instead of three aircraft rendezvousing over Yakoshima Island before proceeding to Japan, the photographic plane circled the wrong island and never joined the formation; the strike and the instrumentation aircraft, after a 45-minute wait, proceeded to the primary target. Kokura was obscured by smoke and after three aborted bombing runs without seeing the target, the two aircraft proceeded to the secondary target: Nagasaki. The target was obscured by clouds; the bombing run was made by radar with a late decision to drop by radar even though the operation order specified only visual bombing; however, a hole through the clouds opened and the drop was made visually. The strike aircraft barely made Okinawa with the remaining fuel (an excess of seven gallons).[9,14,16,20] The photographic plane not only was not near Nagasaki at detonation time, but it did not have an operator for the Fastax™ camera.[9] There were no fireball pictures. An overpressure-vs-time record was obtained from the dropped canisters, but that record was off-scale.[24]

The position parameters for the second mission are even more uncertain than for the first mission. For example, the altitude is given as 28 000 ft in the strike report, as 28 900 ft in the final report, and as 31 600 ft (the same as the Hiroshima mission) in the summary report.[26] Admiral Ashworth (then Commander), the weaponeer of the mission, states that the aircraft were on a glide from Kokura to Nagasaki to conserve fuel and that the altitude was under 28 000 ft. It seems clear that the 31 600 ft altitude used by previous evaluators is incorrect. Because the crew members´ logs have not been found, there are no wind data. However, one source[26] states that there was a 1-knot head wind. Similarly, the aircraft separation is unknown. Laurence[14] states the separation was one-half mile, but it probably was about that of the Hiroshima mission. Tables I and II present a summary of the mission.

V. THE OVERPRESSURE-VS-TIME DATA

The evaluation of the pressure-vs-time data obtained from the condenser gages mounted in the parachute-retarded canisters dropped from instrumentation aircraft, the Great Artiste, requires at least the following data: 1) distance of canister from the explosion, 2) altitude of canister, 3) definition of the atmosphere, 4) calibration of the gages, and 5) calculations of the overpressure expected at the gage altitude with yield as a parameter.

As implied earlier, the aircraft altitude is a necessary parameter; it may have been resolved adequately for the Nagasaki mission but is uncertain for Hiroshima. Three values are given: 31 600 ft from the AF historical records,[26] 32 700 ft from Parsons' log,[10] and 35 000 ft from Alvarez' letter to McCrae[25] and from working backward from the timing of the Hiroshima p(t) record. These and the other assumed parameters for the two missions are given in Table III. The estimated bomb ballistics are derived from drop test data at Site M (Muroc) (Appendix), and projectile calculations using the classical solution assuming the projectile drag is proportional to the square of its speed.[30] (The test data for Thin Man, an earlier longer gun device with cross-sectional area and weight similar to the Little Boy, were used for the Little Boy; test data for Little Boy have not been located.) Calculations for the test drop conditions determined the drag (terminal speed), which was then used for the combat conditions. A summary of these data and calculations is given in Table IV. The summary of the data and calculations giving the canister position is given in Table V.

The time of fall of the Little Boy is based on test data of tests at Muroc plus trajectory calculations for other altitudes using the test data to derive a drag coefficient. The calculations are very well fit by the free-fall equation with g reduced to 30.1 $\pm$ 0.1 ft/s^2 from the perfect bomb case of 32.16. This good fit and the 1.72-s difference that the S-Cubed calculations* show between the acoustic and shock arrival times as a result of their 2-D hydrodynamic calculation permit a parameter study. To simplify calculations, I have used an average sound velocity derived from a fit to the 1945 Japanese meteorological observations used by ORNL and S-Cubed. That value is 1.087 kft/s.

There are two possible evaluations of canister position using the timing from the canister record: 1) one based on the time difference between the direct and reflected shocks as well as the arrival time of the direct shock and 2) another using only the time of arrival of the direct shock. With the first, there is agreement with the record timing if the canister altitude was about 34 kft in agreement with the S-Cubed calculations by Penney, and my previous work. As the reflected shock traverses previously shocked air, the acoustic reflection time is longer than for the reflected shock (2.55 s). To

* Information from L. W. Kennedy of S-Cubed. April 25, 1984.

TABLE III

MISSION PARAMETERS

	Hiroshima	Nagasaki
Height-of-burst (ft)	1 903 (Ref. 28)	1 650 (Ref. 28)
Aircraft altitude (ft)	31 600 (Ref. 26) 32 700 (Ref. 10) 35 000 (Ref. 25)	28 900 (Ref. 26)
Ground speed (mph)	328 (Ref. 26,16)	315 (Ref. 26)
Head wind speed (mph)	0 (Ref. 10)	1 (Ref. 26)
Aircraft separation (ft)	300 (Ref. 27)	300[a]
Time delay from bomb to canister release[a] and start of record[25] (s)	1	1
Parachute opening time (s)[a]	1	1
Canister drop speed (ft/s)(?)	16	16

[a] Estimates.

TABLE IV

TRAJECTORY PARAMETERS

	Hiroshima		Nagasaki	
Height-of-burst (ft)	1 903 (Ref. 28)		1 650 (Ref. 28)	
Aircraft altitude (ft)	31 600 (Ref. 26)		28 900 (Ref. 26)	
Ground speed (mph)	328 (Ref. 26)		315 (Ref. 26)	
	Data[a]	Calc[30]	Data[a]	Calc[30]
Site M test				
Altitude (ft)	28 065		28 026	
Air speed (mph)	315		300	
Time of fall (s)	43.11	43.4	47.70	47.71
Vertical speed (fps)	1 138	1 116	901	
Terminal speed (fps)		2 030		1 005
Angle at impact	12°	17°	10°	11.5°
Trail (ft)	1 441	1 449	5 005	5 068
Combat conditions				
Time of fall (s)		44.4		47.0
Angle from vertical at explosion		17°		12°
Trail (ft)		1 330		5 200

Vacuum time-of-fall (TOF) = 43.0 s

Tone signal switched on by Ferebee at -15 s (Ref. 20, p. 256).

Tone break at release.

[a] Appendix Table A-I.

TABLE V

CANISTER LOCATION SUMMARY

Canister locations for Hiroshima and Nagasaki as estimated from "historical" records for the aircraft altitudes, ground speeds, and drop test data. Aircraft altitudes are based on shock arrival times at the canisters taken from the pressure-time records (together with aircraft ground speed from "historical" records, drop test data, and Tokyo pressure-temperature soundings for August 6, 1945).

	Hiroshima		Nagasaki	
	Historical	p(t)	Historical	p(t)
ac altitude (kft)	31.6	34.6	28.9	28.7
ac separation (kft)	0.3		0.3	
ground speed (kft/s)	0.481		0.462	
time-of-fall (s)	44.4	46.9	47.0	46.7
canister altitude[a] (kft)	30.5	33.8	27.65	27.78
vertical separation[a] (kft)	28.4	31.9	26.0	26.1
horizontal separation[a] (kft)	20.3	21.5	16.7	16.0
slant distance[a] (kft)	35.1	38.4	30.9	30.6
$\bar{c}$ (kft/s)	1.087		1.087	
acoustic reflection t (s)				
shock arrival time (s)	80.6		72.9	
height of burst (kft)	1.903		1.65	
trail (kft)	1.33	1.45	5.2	

[a] Canister location relative to burst at shock arrival. Location assumes 2 s from bomb release to parachute opening and 16 ft/s canister fall speed.

Canisters found 12.5 m north of ground zero at Hiroshima.[22]
Canisters found 12 km east of ground zero at Nagasaki.[21]

obtain a reasonable trail (lag over that for a perfect bomb), the acoustic time is about 3.0 s. To bring agreement with the 30.5 kft altitude requires an average sound speed of about 0.91 kft/s or a time of arrival of the shock about 5.5 s less than given by the record. Using the second method there is again agreement with the record if the higher altitudes or a reduced shock time-of-arrival are used.

The delay between bomb release and canister release is not known but was estimated by Alvarez as about 1 s.[25] The time separation between the three canisters was also probably less than 1 s. The time between release and opening of the parachutes is also not known but Wieboldt states that the expected g-loading during parachute opening at these altitudes and air speeds was in the range of 20 to 50 g.* Assuming uniform deceleration, the opening time must have been about 1 s. To minimize parachute opening time but avoid having it open in the bomb bay, the lanyards were short and looped around bomb-bay shackles low in the bomb bay. Thus, the time delay between bomb release and parachute deployment must have been in the range of 2 to 3 s. The parachutes were standard personnel 'chutes; for Crossroads, the parachutes were "baseball" parachutes, 24 ft in diameter with 40-ft shrouds and stopped with no more than one oscillation. The measured fall rate on that operation was 16 ft/s at 30 000 ft. Hirschfelder used 15 ft/s in his May 1945 memo to Alvarez on the evaluation of the canister method. Subsequently, the transmitter power and hence battery weight were increased with probable increase in fall rate. For Crossroads the transmitter power was reduced from about 20 W to 3 W with reduced weight. Sixteen to twenty-eight ft/s seem to be possible fall rates.

The system was based on the Firing Error Indicator (FEI) developed for the Navy by the California Institute of Technology (CIT) (W. Panofsky's group). It used a condenser microphone as the capacitor of a radio-frequency oscillator providing a very simple frequency-modulated system in which the frequency was proportional to the pressure. The receivers were units supplied by CIT. The transmitters and packaging were built at Los Alamos. The gage itself was modified at Los Alamos to provide a slow vent to equalize pressures for changes in altitude (this was nominally 30 s but the Hiroshima gage had a

* This and much of what follows are extracts from a Crossroads handbook and the notebooks of participants on the combat missions. These remain classified.

18 s e-folding time).[24] Also added were two spring-actuated pistons (snappers) to provide known volume changes and provide a direct calibration of the gage after deployment. One piston rotated inward, the other outward to restore the original volume; they were set to trip at 30 and 40 s. The motions had some overshoot, and extrapolation to zero time was necessary to determine the volume changes. The operating frequencies of the units were 52, 54, and 56 MHz; the receiver output was expected to be about 10 V with about a 60-kHz frequency deviation.

The recorders were Kodak Cine E cameras modified for strip film use photographing a cathode ray oscilloscope. The time scale was by blanking markers derived from pip sharpening of the output of a Wien bridge oscillator; calibration was in terms of a model 200C Hewlett-Packard signal generator, which had an accuracy of about 1 percent. Johnston states the calibration was "quite adequate." There were two checks on the timing accuracy--film speed and the settings of the snappers.

A. Calibration

Three independent methods of calibration of the gage were provided: Luis´ weight plus volt-box, snappers, and the Firing Error Indicator (FEI) or Agnew box.[24]

For the Luis´ weight plus volt-box calibration, small weights were placed on the gage diaphragm and the resultant voltage output of the receiver was measured. The volt-box introduced voltages, in steps, into the recorder and the resultant deflections on the film gave the conversion of deflection to voltage. For the Hiroshima mission, the weight used was equivalent to 10.0 cm of water or 0.142 psi at 30 kft to produce 9.0 V from the receiver. The volt-box data were:

Volts	Deflection, V/mm	
16.0	2.44	
12.0	2.15	
8.0	2.07	2.13
4.0	2.16	

It was noted the calibration using the 16-V step indicated the system was not linear at the largest step. As the voltage produced by the shock was about 4.5 V, it seemed appropriate to discard this value and use the three lower steps. Full-scale deflection was 10 V. The average was 2.13 V/mm. The combination yields 0.0336 psi/mm.

For the Hiroshima mission the snappers were set to trip at about 30 s and 40 s. Only the first snapper worked on the record analyzed. The resulting calibration was 0.0336 psi/mm,[24] the same as the weight plus volt-box value.

Another voltage calibration used the FEI or Agnew box supplied by CIT. This unit was developed at CIT as the field calibration unit for the Navy. This unit injected a signal with a known frequency deviation into the receiver. The unit was used on the mission though now no one on the mission remembers the unit. The calibrations were not used in the field analysis of the data, nor were they used on the Crossroads measurements. The calibration using this unit disagreed by a large factor (3.1 V/mm vs 2.13 V/mm)[24] from that of the other two techniques. The problem probably was the large temperature difference (greater than 60°C) between the setup conditions on Tinian and the operating altitude. The relative linear contraction would have been about 10^{-3}. As inductance of a coil is proportional to about the square of the diameter, and the frequency is proportional to the inverse square root of the inductance, the frequency shift would be about 10^{-3} of the operating frequency, which was 54 MHz; a frequency shift of 0.5 MHz could have occurred. The bandwidth of the system was about 0.1 MHz and the receiver was retuned on the mission to match the transmitter frequency, whereas the FEI box was probably not, therefore the FEI calibration box may not have been at the receiver frequency. This is conjecture but it seems plausible; the value is in the right direction.

B. Zero-Time Signal

It has been conjectured by some that an electromagnetic signal (the EMP) may have been recorded to provide a zero-time indicator. Such was not noted by those, including both Alvarez and Penney, who examined the records on Tinian. Nor would it be expected. The systems had narrow-band, frequency-modulated 50+ MHz receivers inherently insensitive to amplitude-modulated signals such as EMP. Further, the frequency components of the EMP from such weapons, particularly the Little Boy, would lie well below the frequency band of the receivers. In any case, the complete records have not been found.

C. The Canister Data

The original films from the missions have not been located; reproductions exist in LAMS-377.[24] The films have been read at least twice--by the original team with the readings contained in W. Goodman's notebook and a reevaluation by Wieboldt summarized by LAMS-377.[24] A copy of the original plot of the data from the Hiroshima mission was attached to Alvarez' letter to McCrae[25] and reproduced in Brode.[2]

I have used the LAMS-377 readings but have been guided in choosing calibration factors by notes made by the original team. I have made a correction for the gage leak and, following a suggestion by Reed and Bannister, made a correction for the time resolution of the gage of the form given by Reed.[31] The readings and corrections to the data are given in Figs. 1 and 2. The time scale on the figures is the time from canister release. Alvarez[25] suggests adding 1 s for the time from weapon release. With this time scale it is possible to get both the slant distance to the gage from the direct pulse time and the altitude of the gage above ground from the reflected pulse using the known height-of-burst (HOB). The reflected pulse, however, must traverse previously shocked air, requiring a two-dimensional hydrodynamics calculation.

Penney, in his evaluation of the canister data on Tinian after the mission, took the canister release altitude as 35 kft, probably based upon the time-of-arrival of the direct shock. (Alvarez, on the plot of the data made on Tinian, gives the canister altitude as 30.5 kft).[25] Based upon the data, the canister altitude must have been about 34 kft, putting the aircraft at an altitude of about 35 kft, an improbable altitude for a B-29 with that fuel and bomb load.

VI. POSTSHOT SURVEYS

Estimates of an explosion's yield can also be made from observations of its effects. Direct comparison of equal effects under similar detonation conditions from two explosions will give an estimate of one explosion, if the yield of the other is known. The conditions of the Hiroshima and Nagasaki explosions were indeed similar, and a few such direct comparisons exist because of ground surveys conducted after the two explosions. One survey, headed by W. G. Penney, was on a time scale of a few days, and surveys by a British mission and the USSBS were on a time scale of a few months. The Japanese also made observations, and there were surveys by the Manhattan Engineering District.[8,15,21] All of these surveys form the basic data for evaluation of the yield of the Hiroshima explosion scaled to the rather well-known yield of the Nagasaki explosion. The Fat Man was tested not only at Trinity with excellent photographic coverage and radiochemistry, but also

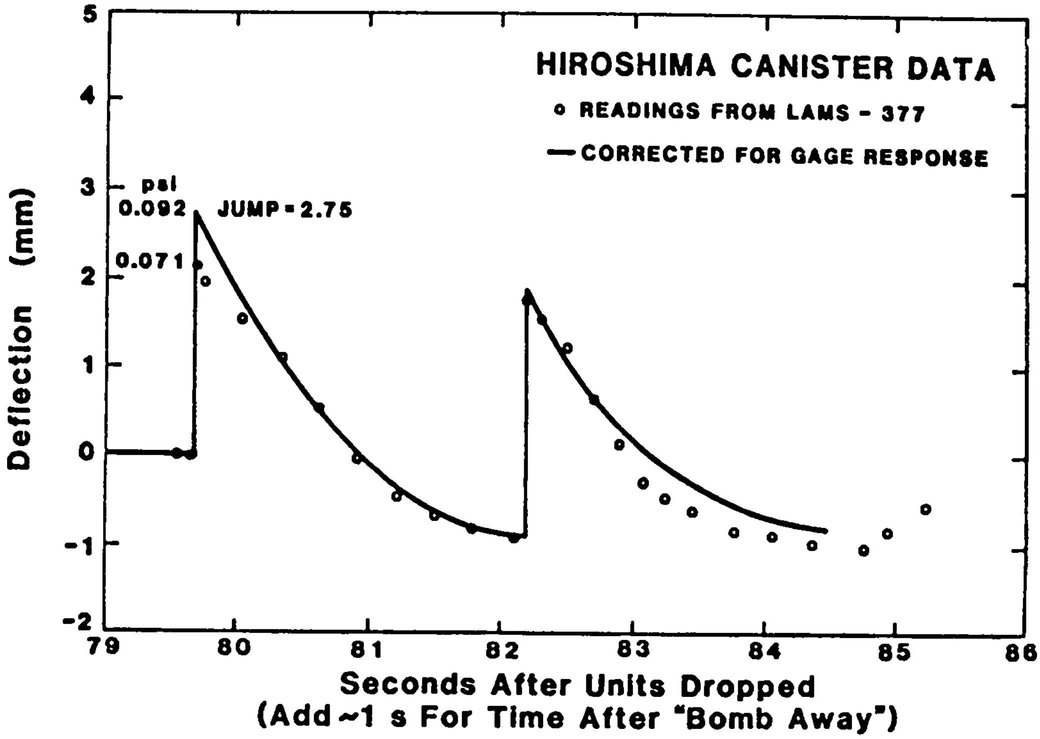

Fig. 1. Hiroshima canister pressure data.

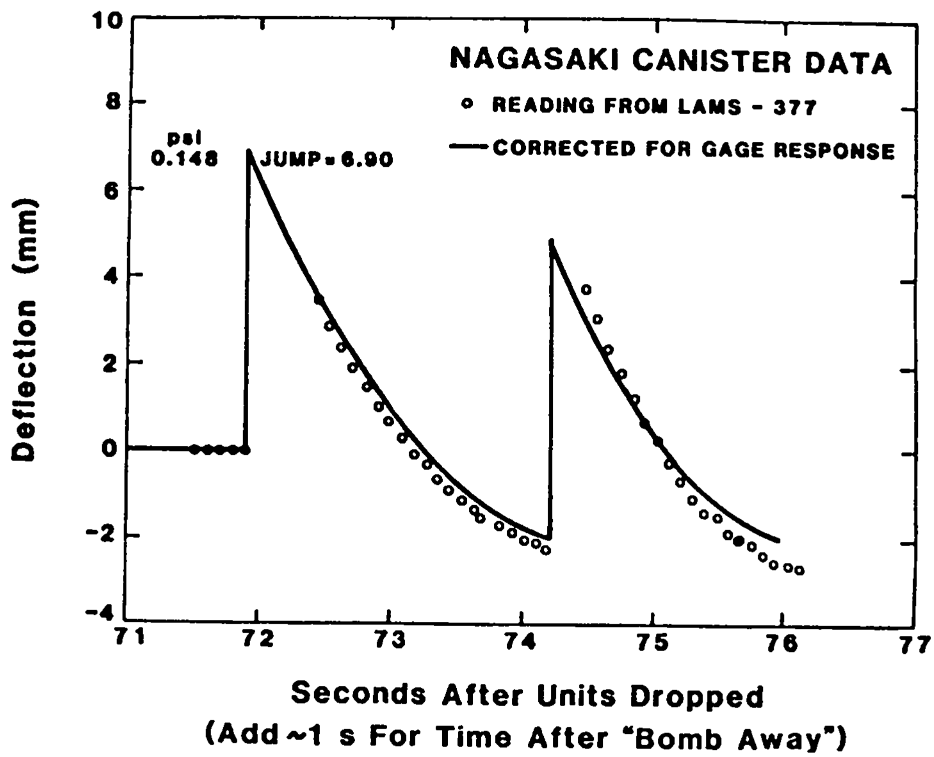

Fig. 2. Nagasaki canister pressure data.

during Crossroads, where radiochemical debris was collected and fireball radius-vs-time data were obtained. (Unfortunately, the large bombing error of Able, the air burst, put the burst outside the prime fireball cameras' field of view; only a streak camera record was obtained, however those data are very good.) Table VI summarizes the data relative to the measurements of the yield of Fat Man.

VII. LITTLE BOY YIELD FROM BLAST DATA (HIROSHIMA)

A. Canister pressure-vs-time measurements

The shock overpressure-vs-time measurement used gages in parachute-retarded canisters dropped from an aircraft flying in formation with the strike aircraft.[24] The three canisters were toggled by the bombardier upon noting "first motion" of the bomb.

One good record was obtained on each mission (the signal went off-scale on the Nagasaki); the record shows both the direct and reflected shock as timed from the start of the recorder (about 1 s after bomb release).[2,25] In principle there is enough information on the records to determine the canister range and altitude. For the Hiroshima mission, historical records give the bomb drop altitude as 31.6 kft[26] and the canister altitude at shock arrival time (?) as 30.5 kft,[24,25] consistent values. Values obtained from the record give the drop altitude as about 35 kft and the canister altitude as about 34 kft. The difference has not been resolved. These data have recently been reanalyzed by Kennedy et al.[32], who used meteorological data taken over Japan in August 1945 to describe the atmosphere and used a combination of two- and one-dimensional hydrodynamic calculations to attempt to match the timing of the record and the shock magnitudes. They put most reliance upon the positive phase duration and the impulse. For these slant ranges and low overpressures, the method should not be sensitive to the canister location. Their yield estimate is 16.6 $\pm$ 0.3 kt where the error quoted is the precision of the calculation and not the overall error, which must be greater than 10 percent. As their slant range to the canister is greater than the probable range, this yield is probably an upper limit.

B. Equivalent blast effects scaling

Surveys after the explosions noted distances from ground zero of similar effects due to the blast wave. The data set for comparison is limited but a few comparisons by the same observers and with documentation exist. Damage

TABLE VI

YIELD OF THE FAT MAN

Radiochemical yield (kt)	
Trinity	20.3
Crossroads A	20.4
Crossroads B	21.7
Fireball yield (kt)	
Trinity	20.8
Crossroads A	21.4
Calculated yield (kt)[a]	22
Recommended yield	21

[a] By R. Osborne, Los Alamos National Laboratory Group X-4.

due to drag effects has been excluded; only those comparisons of damage due to overpressure with a significant number of objects observed were retained. The ground surfaces were far from "ideal;" thermal effects would have produced a precursor to the blast wave and added both smoke and dust loads. In addition, mechanical effects due to the many buildings would have absorbed energy from the wave as well as providing debris to further load the blast wave.[33] The summary of blast data and the comment by Brode[34] suggest simpler models of the height-of-burst effect may be more appropriate. Two such models have been suggested: using scaled ground ranges and using scaled slant ranges. Scaling by ground range allows for some HOB effects but is independent of HOB. Scaling by slant range implies that the effect of the direct shock results in more damage than does the reflected shock. Both postulations have the same yield dependence. Brode prefers the first but the second appears to be more appropriate. These relations are

$$W_H/W_N = (X_H/X_N)^3$$

or

$$(R_H/R_N)^3 \quad ,$$

where the subscripts refer to Hiroshima and Nagasaki, W to the yield, X to the ground range (GR), and R to the slant range (SR). Taking the Nagasaki explosion yield at 21 kt, Table VII gives the data set and the derived yields for Hiroshima. The average for the Hiroshima yield is about 14.3 kt using ground range scaling and 14.9 using slant range scaling. The average of these is about 15 kt when rounded.

C. <u>UK Yield Evaluation</u>

A group from the Manhattan District, composed of W. G. Penney, R. Serber, and G. T. Reynolds, was sent to both Hiroshima and Nagasaki soon after the explosions to report on physical effects. These surveys have provided much of the information upon which to make estimates of the yields of the two explosions. The results of the survey and samples of damaged objects from the blast wave were analyzed by Lord Penney et al.,[5] who concluded that the yield of the Hiroshima explosion was 12 ± 1 kt and that of the Nagasaki explosion was 22 ± 2 kt. They used data from objects damaged from the pressure pulse

TABLE VII

SCALING EQUIVALENT BLAST DAMAGE

$$W_H = W_N\left(\frac{X_H}{X_N}\right)^3, \text{ or } W_N\left(\frac{R_N}{R_N}\right)^3$$

	Ground Distance (km)		W_H/W_N	
	H	N	GR	SR
Collapse or complete destruction of wooden-frame buildings[35]	2.0	2.4	0.579	0.612
Severe structural damage to homes:				
Ref. 15	1.98	2.44	0.562	0.568
Ref. 36	2.41	2.62	0.778	0.802
Damage to buildings (Ref. 36)[a]				
One story brick	2.19	2.55	0.633	0.662
Wooden buildings (except residences)	2.61	2.82	0.793	0.813
Wooden residences	2.19	2.46	0.706	0.735
10 to 20% of empty 4-gal. petrol cans undamaged (Ref. 5)[b]	1.74	1.95	0.710	0.755
Average			0.68	0.71
Best estimate, based on W_N = 21 kt:			15 kt	

[a] The damaged area was observed to be more elliptical than the implied circular area.

[b] The petrol can data are believed to be the more credible with damage to buildings as next best.

and by drag.* Calibration was in terms of scale models in high-explosive tests. Unfortunately, the scale used was for a full-scale explosion at the Hiroshima height-of-burst but at 9 kt, requiring an extrapolation for both explosions. They also assumed ideal surfaces in the two cities. Lord Penney has recently reevaluated the data of Reference 5 using US blast data and finds the same results. He also suggests that the vertical velocity gradient can produce turbulence and this may in part explain the nonideal shape of recorded pressure-time records in addition to the distortion produced by thermal effects on the surface.

He suggests that a measure of the angle of the sector of the scorched area on the telegraph poles may be a better way to determine limiting distances of thermal effects. Better photographs of the poles may yield better information. He notes the distances quoted in the USSBS may be reversed for the two cities (assuming they are reversed, then scaling in the manner of Sec. VIII.A below gives 14.3 kt for the Hiroshima explosion yield).

He has added to information needed for evaluation of the canister data for Sec. VII.A; he confirms the spacing of the two aircraft. He also conjectures that shock reflection from the parachute may alter the time dependence of the record. (The method of correcting the record should have removed the effect.)

VIII. LITTLE BOY YIELD FROM THERMAL DATA (HIROSHIMA)

A. Equivalent thermal effects scaling

Surveys subsequent to the explosions noted distances from ground zero of similar effects due to thermal radiation in the two cities. The data set is limited, but four comparisons by the same observers and with the documentation have been selected by Kerr.[37] The same set is used here. Scaling is on the basis that the thermal fluence at slant range R is proportional to

$$\frac{W \cos i \; e^{-\varepsilon R}}{R^2} ,$$

where W is the yield, i the angle of incidence, and ε the extinction

* An evaluation of the Hiroshima yield using the observation of damage of drag-sensitive objects--lightning rods, flagpoles, etc.--was made at Sandia Corp. in the early 1950s by Shelton. Calibration was by scaled models exposed in a supersonic wind tunnel. Documentation has not been located but the value of yield obtained was 16 kt. F. Shelton, Kaman Sciences, Jan.10, 1984.

coefficient. The extinction coefficient may be obtained from the measured visibility by the relation $\varepsilon = (\ln 50)/V$ used by meteorologists, where V is the visibility, given as greater than 20 km in both cities.[21] For the data set used and when all surfaces are taken as vertical except for the roof tiles, the ratio of the yields in the two cities W_H/W_N is given in Table VIII, resulting in an average of 0.64. Taking the Nagasaki explosion yield as 21 kt, this scaling gives a yield for the Hiroshima explosion of about 13.4 kt. If a 30-km visibility is used, the derived yield is about 13.7 kt. If observations of the exfoliation of granite observations are omitted as suggested by Tajima because of the paucity of these data, the yield ratio is 0.68, or a yield scaled to Nagasaki of 14.3 kt.

TABLE VIII

SCALING EQUIVALENT THERMAL EFFECTS

	Ground Range (m)		W_H/W_N[a]
	H	N	
Watanabe et al.[38]			
Melting of roof tiles[b]	600	950 - 1000	0.575 - 0.526
Exfoliation of granite[38c]	1000 - 1100	1600	0.473 - 0.545
British Mission[39]			
Charring of poles	2740	3050	0.782
Lord Penney[5,39,40]			
Charring of poles	2900	3350	0.707
Average			0.64[d]

[a] W_H/W_N, ratio of the explosion yield at Hiroshima to that at Nagasaki.

[b] Ridge tiles: normal incidence.

[c] The quantitative (and qualitative) data for this effect are of lower value compared with that of the roof tile data. This entry has low weight; omitting it results in an average of 0.68.

[d] With 30-km visibility $W_H/W_N = 0.65$.

B. Charring of Cypress on Chugoku Electric Power Building

Charring of cypress wood on a shrine atop the Chugoku Electric Power Building, reported by Kimura, Akutsu, and Tajima[41] and again by Tajima,[42] offers an evaluation of the Hiroshima explosion yield in absolute terms. It was observed that there were two charred layers, one a completely carbonized layer 0.10 mm thick (1.38 mg/cm^2) and a brown incompletely carbonized layer 0.35 mm thick. To produce the completely charred layer required 3.3 s of exposure from a 1200°C electric hot plate. This is a thermal fluence of 21.1 cal/cm^2 assuming block body radiation at this temperature. The thickness of the second layer was observed to be dependent upon the intensity of the radiation and not on the exposure time from a carbon arc furnace. To obtain the 0.35-mm thickness of the incompletely charred layer required a fluence rate of 14 cal/cm^2 per s; with this fluence rate it required 1.4 s to produce the 0.10-mm-thick completely carbonized layer. This is a fluence of 19.6 cal/cm^2.

The distance to the Chugoku Electric Building from ground zero (hypocenter) was about 676 m. The height of the building (and shrine) was 21 m, giving a slant range of about 877 m. The transmission using a visibility of 20 km (Ref. 21) was about 0.84. The measured angle between the burst and the normal to the surface was given as 62°36′. The fraction of the explosion energy allotted to thermal energy is generally taken as 0.35.[33] With these values, the yield of the Hiroshima explosion must have been about 15.1 kt using the first calibration method or 14.0 kt using the second.

The evaluations neglect conduction and reflection effects. It was noted in the original article[41] that with the longer irradiation times from the calibrating sources as compared with the weapon thermal pulse (time of maximum t_{max} is about 0.14 s; at 10 times this value or 1.4 s, 0.80 of the total is delivered), more heat is lost into the wood by conductance, and the fluences obtained are upper values. Reflection from the surface is an opposing effect and would be greater from the bomb thermal fluence; the reflection coefficient probably varied from 0.7 to 0.05 during the irradiation. In an attempt to examine conduction, a calculation was made of temperature and flux into the material, using reasonable values for the thermal parameters (conductivity K = $2.8 \cdot 10^{-3}$ $cal/cm^2\ s/°C/cm$, density ρ = 0.46 g/cm^3, specific heat c = 0.40 $cal/g°C$, and diffusivity $k = K/c\rho$ = 0.015 cm^2/s).[43] The fluence rate peaks at about 1 t_{max} and the temperature at about 2 t_{max}. Penetration at 10 $_{max}$ is about 4 mm. The calculation assumed constant values and no phase changes (no equation-of-state was found). For a constant fluence rate as from the calibrating source at a time of 1.4 s and a distance of 4 mm, the fluence rate is down to 0.05 of the fluence rate at the surface versus about 0.01 for the bomb thermal pulse. Reflection from the surface opposes the conduction effect, but no estimates have been made.

The average yield obtained by the two calibrations is 14 kt or 15 kt if the more reliable value from the completely charred layer is used. Repeat calibration using more modern thermal sources with approximately the proper time dependence would likely produce a better estimate from these data.

IX. GAMMA-RAY DOSE SCALING

Scaling integrated gamma-ray dose at ranges where hydrodynamic shock enhancement and cloud rise effects are small has long been used by Los Alamos as one method of determining the yield of a nuclear explosion. The methodology was to scale at a range at which these effects are small (2.5 to 3.0 km), correct for the difference in atmospheric conditions, and simply scale the measured dose linearly with yield. Better agreement was obtained if the reference data were from a similar device. It has worked well for yields less than about 40 kt using similar film badges housed in similar packages.

Methods have been developed at Science Applications International Corporation (SAIC) for calculating the dose from fission devices for the nitrogen capture and fission product components, the latter considering the three main fissionable materials.[44,45]

The data on thermoluminescence of roof tiles reported by Ichikawa[46] provides a useful set of measurements for estimating a yield. In particular, the tiles from the Hiroshima University Building HU-2 are of known orientation and distances. SAIC has calculated the TLD dose considering orientation (horizontal) with an assumed yield of 15 kt. The results of their preliminary evaluation* are given in Table IX. The calculated dose will scale nearly directly with yield for the same bomb and atmospheric condition. The data are better fit by calculations with an assumed yield of 16.6 kt.

---

* W. A. Woolson, Science Applications International Corporation, October 18, 1984.

TABLE IX

CALCULATED AND MEASURED TLD DOSE

AT HIROSHIMA UNIVERSITY

Ground Range (m)	TLD Dose (rad(Si))		
	Calculated[a]	Measured[b]	W[c]
1377	75	83	-0.11
1382	77	84	-0.09
1411	65	69	-0.05
1439	68	68	-0.14

[a] Yield: 15 kt, March 1985 calculation; the calculated dose at these ranges ought to scale linearly with yield.

[b] Ichikawa,[46] horizontal samples from building HU-2 rad (silicon) = 0.87 roentgen.

[c] (Calc-meas) / meas.
Note: To bring the average of the deviations[c] values to zero requires that 16.6 kt be used in the calculations.

X. SULFUR NEUTRON FLUENCE EVALUATION

For similar bombs the fluence of high-energy neutrons (that is, those above the sulfur threshold), corrected for atmospheric transmission effects, has been used to scale measured fluences to reference data from a similar device to determine the yield of a nuclear explosion.

A yield determination may be made using data from the activation of sulfur by high-energy neutrons in the reaction $^{32}S(n,p)^{32}P$. Revision of Yamasaki's[47] data have been reported by Hamada.[48] Calculations of the activity at Hiroshima have been made by SAIC, including the geometric corrections for tilt angle (TA) of the weapon and bomber heading (BH) of the drop aircraft.* The data and calculations are summarized in Fig. 3. The weapon yield was assumed to be 15 kt in the calculations.

* D. C. Kaul, Science Applications International Corporation, March 13, 1985.

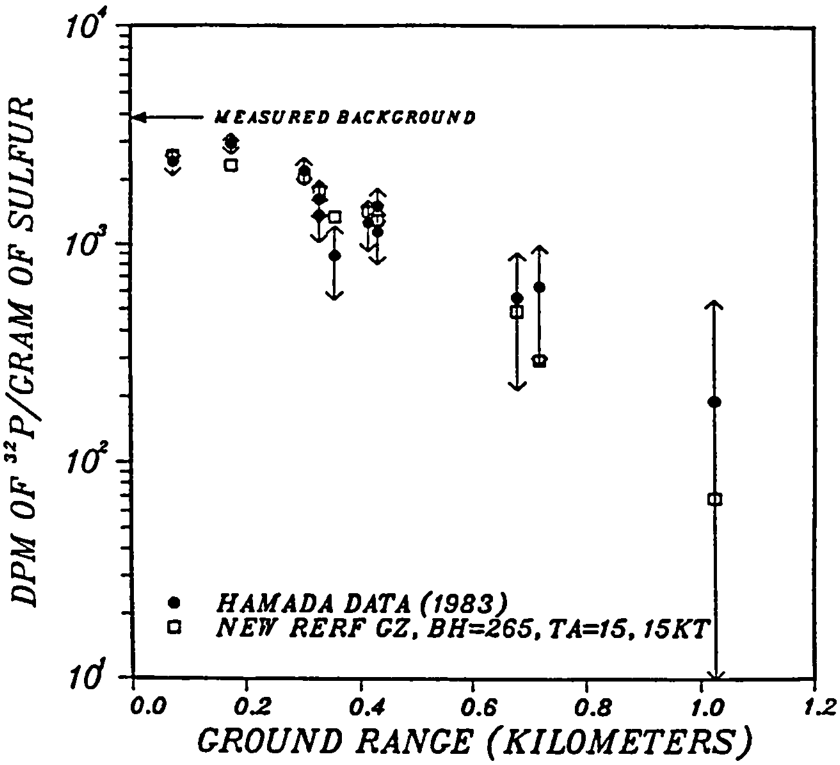

Fig. 3. Sulfur activations at Hiroshima.

XI. CONCLUSIONS

The yields for the Little Boy used on Hiroshima, as derived from the various methods, are summarized in Table X. From these evaluations, the value of 15 kt is estimated with a 20-percent uncertainty. This is twice the uncertainty applied to radiochemical and fireball yield evaluations with good data and seems appropriate for the indirect methods required to estimate the yield of the Hiroshima explosion.

The recommended yields for the two explosions are as follows:

Hiroshima	15 kt
Nagasaki	21 kt ,

where the value is believed to have an outside limit of 20 percent for Hiroshima and 10 percent for Nagasaki.

TABLE X

YIELD EVALUATIONS FOR LITTLE BOY (HIROSHIMA)

Method	Yield (kt)
Canister P(T) Data	16
Equivalent Thermal	14
Cypress Charring	15
Equivalent Blast	15
Lord Penney, et al.	12
Thermoluminescence of Roof Tile	17
Sulfur Activation	15
Design Predictions (Schiff)	15

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REFERENCES

1. DOE Nevada Operations Office, Announced United States Nuclear Tests, NVO-209 Rev. 4 (1984).

2. H. L. Brode, "Yield of the Hiroshima Bomb Derived from Pressure Record," Rand Corporation report RM-4193-PR (1964).

3. Kenneth F. Caudle, "Yield of the Hiroshima Weapon," US Naval Ordnance Laboratory report NOLTR 65-143 (1966).

4. J. O. Hirschfelder, Manhattan Engineering District Extract in Appendix File, Los Alamos Scientific Laboratory microfilm, MF-SF-SL-969.

5. Lord Penney, D. E. J. Samuels, and G. C. Scorgie, "The Nuclear Explosive Yields at Hiroshima and Nagasaki," Philos. Trans. Roy. Soc. London, 266, 357-424 (1970).

6. F. Reines, "Yield of the Hiroshima Bomb," Los Alamos National Laboratory report LA-1398 (1952).

7. John A. Auxier, "Ichiban: Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki," Oak Ridge National Laboratory report TID-17080 (1977).

8. Anthony Cave Brown and Charles B. McDonald, The Secret History of the Atomic Bomb (Dial Press/James Wade, New York, 1977).

9. Frank W. Chinnock, Nagasaki: The Forgotten Bomb (World Publishing Co., New York, 1969).

10. Stephane Groueff, Manhattan Project (Little, Brown, and Co., Boston, 1967).

11. Leslie R. Groves, Now It Can Be Told (Harper and Bros, New York, 1962).

12. James W. Kunetka, City of Fire (University of New Mexico Press, Albuquerque, 1979).

13. Lansing Lamont, Day of Trinity (Atheneum, New York, 1965).

14. William Laurence, Dawn Over Zero (Alfred A. Knopf, New York, 1946).

15. Manhattan Engineering District, "The Atomic Bombings of Hiroshima & Nagasaki." Los Alamos Archives.

16. Joseph L. Marx, Seven Hours to Zero (G. P. Putnam's Sons, New York, 1967).

17. The New York Times, July 11 through August 10, 1945.

18. The New York Times, Hiroshima Plus 20 (Delacorte Press, New York, 1965).

19. Rafael Steinberg, Postscript from Hiroshima (Random House, New York, 1977).

20. Gordon Thomas and Max Morgan Witts, Enola Gay (Stein and Day, New York, 1977).

21. The Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, Hiroshima and Nagasaki -- The Physical, Medical, and Social Effects of the Atomic Bombings, (American Basic Books Inc., translation, New York 1982).

22. United States Strategic Bombing Survey, USSBS, Vol. 1, "Hiroshima."

23. L. F. Fussell, letter to J. A. Auxier (December 18, 1954),Los Alamos Archives.

24. W. G. Stroud, B. Waldman, and J. Wieboldt, "Pressure Gage Data: Hiroshima and Nagasaki Explosions," Los Alamos National Laboratory report LAMS-377 (1946).

25. L. Alvarez, letter to V. V. McRae, April 19, 1963 (reproduced in reference 2.)

26. Historical Records of the 509th Composite Bomb Group, USAF Microfilm A7741, B0678, B0679.

27. Lord Penney, letter to W. Ellett (September 8, 1983), Los Alamos Archives.

28. H. H. Hubbel, T. D. Jones, and J. S. Cheka, "The Epicenters of the Atomic Bomb," Atomic Bomb Casualty Commission report ABCC-TR-3-69 (1969).

29. L. W. Alvarez, letter to Lt. Gen. L. E. Groves (May 5, 1965), Los Alamos Archives.

30. Theodore von Kármán and Maurice A. Biot, Mathematical Methods in Engineering (McGraw-Hill Book Co., New York, 1940), pp. 139-143.

31. J. W. Reed, "Atmospheric Attenuation of Explosion Waves," J. Acoust. Soc. Amer. 61, 39 (January 1977).

32. Lynn W. Kennedy, Louis A. Roth, Charles E. Needham, "Calculations to Assist in a New Hiroshima Yield Estimate," S-Cubed report 84-6629 (March 31, 1984).

33. Samuel Glasstone, P. J. Dolan, eds., Effects of Nuclear Weapons, 3d Edition (US Government Printing Office, Washington, DC, 1977).

34. H. L. Brode, "Review of Nuclear Test Peak Overpressure Height-of-Burst Data," Pacific Sierra Research Corp. note 353, (November 1981).

35. Report of the British Mission to Japan, "The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki," Home Office of the Air Ministry, His Majesty's Stationary Office, London (1946); DOE Technical Information Center, NP-1156, p. 8 (1946).

36. The Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, Hiroshima and Nagasaki..., p. 54 (Basic Books, Inc., New York 1978, 1981).

37. G. D. Kerr, "Estimates of Hiroshima Bomb Yield," Second US-Japan Joint Workshop, Radiation Effects Research Foundation (November 1983).

38. T. Watanabe, M. Yamasaki, G. Kojima, S. Nagaska, K. Hirayama, "Geological Study of Damages Caused by Atomic Bombs in Hiroshima and Nagasaki," Japan J. Geol. Geogr. 24, 161 (1954).

39. US Strategic Bombing Survey, Medical Division, "The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki," (US Government Printing Office, Washington, DC, 1947).

40. A. C. Brown and C. B. McDonald, The Secret History of the Atomic Bomb (Dial Press/James Wade, New York, 1977).

41. K. Kimura, H. Akutsu, and E. Tajima, "Determination of Intensity of Radiant Heat Rays and Duration of Flash in the Hiroshima Atomic Bomb," paper 24, p. 88. Collection of Investigative Reports on Atomic Bomb Disaster, Vol. 1, Radiation Effects Research Foundation. (no date; 1947 or 1949?)

42. E. Tajima, "Estimation of the Hiroshima Bomb Yield and Weather Conditions at the Time of the Bomb." Second US-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Radiation Effects Research Foundation, p. 1, 8-9 November 1983.

43. CRC Handbook of Chemistry and Physics, 64th ed. 1983-1984, p. E-5.

44. W. H. Scott, "Delayed Radiation at Hiroshima and Nagasaki, Reevaluations of Dosimetric Factors: Hiroshima and Nagasaki," DOE Symposium Series 55, CONF-810928 (V. P. Bond and J. W. Thiessen, Eds.) pp. 159-178 (1982).

45. W. H. Scott, "Delayed Radiation at Hiroshima and Nagasaki," Trans. Amer. Nucl. Soc. 41, 472 (1982).

46. Y. Ichikawa and T. Nagatomo, "Measurement of Gamma Ray Dose from the Atomic Bomb by the Quartz Inclusion Technique." Second US-Japan Joint Workshop for Reassessment of Atomic Bomb Dosimetry in Hiroshima and Nagasaki, Radiation Effects Research Foundation, pp. 30-31 (November 1983).

47. F. Yamasaki and A. Sugimoto, "Radioactive ^{32}P Produced in Sulfur in Hiroshima," paper No. 5, pp. 46-48, Collection of Investigative Reports on Atomic Bomb Disaster, Vol. 1, Radiation Effects Research Foundation.

48. T. Hamada, "^{32}P Activity Induced in Sulfur in Hiroshima: Reevaluation of Data by Yamasaki and Sugimoto," Second US-Japan Joint Workshop for Reassessment of Atomic Bomb Dosimetry in Hiroshima and Nagasaki, Radiation Effects Research Foundation, p. 52 (8-9 November 1983).

APPENDIX
EXTRACTS FROM LOS ALAMOS HISTORICAL FILES

INTER-OFFICE MEMORANDUM

TO: R. J. Oppenheimer

FROM: Hirschfelder and Magee

SUBJECT: ENERGY OF HIROSHIMA SHOT, 6000 TONS TNT

The parachute gauge was supposed to be located at an altitude of 30,000 feet above the ground and 23,000 feet in a horizontal direction away from the point of explosion. We used the formulae of Hirschfelder, Littler, and Sheard (LA-316) to interpret the experimental record. According to the record, the reflected shock had not caught up to the primary shock (and never would, since the reflected shock was traveling in the suction phase wake of the primary shock).

From the primary shock we find (realizing that the primary shock has not been compounded with the reflected wave):

Energy estimated from maximum pressure	3526 tons TNT
" " " positive impulse	6233
" " " energy left in blast	4635

Similarly from the reflected shock we find:

Energy estimated from maximum pressure	6030 tons TNT
" " " positive impulse	9409
" " " energy left in blast	7310

It is difficult to know how much credence to place on the reflected shock wave results. However, it would seem that our best estimate of the blast energy would come from combining the energy left in the positive phase of the primary shock with the energy left in the positive phase of the reflected blast. This leads to:

Energy blast Hiroshima shot 5970 tons TNT

J. O. Hirschfelder
J. Magee

jsh

cc - Bethe
Larkin
Parsons

INTER-OFFICE MEMORANDUM

TO: J. R. Oppenheimer DATE 13 August 1945

FROM W. S. Parsons

SUBJECT: Paraphrased Teletype Reference NR-302 dated 13 August

To Larkin, for Oppenheimer, from Manley

Estimates of tonnage have been made by Penney for the two units. However, they should not be circulated. The relative values give much more meaning than the absolute values. This information comprises all that has been forwarded from Destination.

On the first unit, the ground equivalent value was 15,000 tons, and on the second, was 30,000 tons. The peak pressure on the first unit was 0.076# per square inch from a blast pressure at 39,000 ft. from detonation at an altitude of 30,500 ft.

On unit No. 2, the peak pressure was 0.055 lbs. per square inch positive pressure, for a duration of 1.44 seconds. This blast pressure was taken at 32,000 ft. from detonation, and an altitude of 29,000 ft., and was a free air wave. The reflected wave gave 0.178 lbs. per square inch as peak pressure on the second unit.

Between direct and reflected wave, the time interval was 2.55 seconds for both units. The equivalent at the point of detonation was 8,000 and 16,000 tons for units one and two, respectively.

ja
cc: File

28 September 1945

Norman F. Ramsey

R. B. Brode

Units L-11 and F-31 — Height of Operation

The estimated altitude of operation of Unit L-11 was 1885 feet, plus or minus 50 feet.

The estimated height of operation of F-31 was 1650 feet, plus or minus 50 feet.

These height estimates are made on the basis of data obtained both at Destination and at Kingman. These values may differ slightly from previous estimates due to the fact that we have included here more recent data than was available to the crew at Destination.

R. B. Brode

cc: Bradbury NFR

Find out if TWX was sent to Parsons on this. Also include damage radius.

NFR

TABLE A-1

SUMMARY OF SITE M TEST DATA

Serial No. of Test	Type & Serial	Date of Test	Description	Altitude (ft)	True Air Speed (mph)	Standard Ground Speed (mph)	Measured Range (ft)	Effect of D.B.W. (ft)	Earth Rotation & Rack Lag (ft)	Standard Range (ft)	Vacuum Time (s)	Time Lag (s)	Standard T_f (s)	Vert. Comp. Strike Velocity (ft/s)	Angle of Yaw (deg)	Diff. Ball. Range Wind (mph)	Angle of Impact (deg)	C_x	C_t	
M-13	Thin	3-06-44	Standard Thin Man	19300	280	228	11300	- 63	22	11260	34.65	0.65	35.30	----	----	19	----	6.55	8.43	
M-15	Fat	3-14-44	Standard Round Tail	19300	278	196	8720	-139	32	8549	34.65	2.92	37.57	785	15.5	20	9.	1.64	1.30	
M-16	Fat	3-14-44	Standard Round Tail	19300	278	206	-----	----	--	-----	34.65	3.37	38.02	766	19.	--	10.	----	1.10	
M-20	Thin"M"	6-14-44	Test of Flanged Lug	27700	300	230	13210	- 45	44	13209	41.73	0.83	42.56	1361	0.	52	14.	4.95	9.58	
M-21	Fat #5	6-15-44	Standard Box Tail	28075	300	192	9415	-397	42	9060	41.79	5.26	47.05	859	9.	26	6.	1.23	1.08	(3)
M-22	Fat #13	6-16-44	Standard Box Tail	-----	---	---	-----	----	--	-----	41.73	5.72	47.45	859	9.5	—	5.	----	----	(3)
M-23	Fat #15	6-17-44	Standard Box Tail	28050	300	238	12685	-424	42	12300	41.77	6.03	47.80	792	14.	22	8.5	1.48	1.02	(3)
M-24	Fat #8	6-19-44	External Drag Fins	28000	300	215	8985	-708	34	8310	41.73	8.85	50.58	797	2.	30	3.	0.64	0.64	(2)
M-25	Fat #11	6-20-44	Internal Parachute Tail	27960	300	206	9930	-317	30	9640	41.70	5.76	47.46	891	1.	13	8.25	1.35	1.07	(1)
M-26	Thin"O"	6-21-44	75° C.G.	27975	300	184	10590	-163	41	10470	41.72	1.37	43.09	1149	0.	39	10.	5.29	5.77	
M-27	Thin"H"	6-21-44	77° C.G.	28065	315	220	13005	-101	41	12945	41.78	1.33	43.11	1136	0.	24	12.	7.90	5.95	
M-28	Fat #7	6-23-44	Lengthened Box Tail	28070	300	230	12290	-385	34	11940	41.79	6.01	47.80	779	18.	23	9.	1.46	0.96	
M-29	Fat #9	6-24-44	External Drag Fins	27930	300	242	12340	-683	37	11695	41.68	9.74	51.42	779	3.5	27	8.	0.90	0.55	(2)
M-30	Fat #12	6-27-44	Internal Parachute Tail	28010	300	260	13995	-443	42	13590	41.73	5.71	47.44	897	1.5	17	8.5	1.27	1.01	(1)
M-31	Fat #6	6-27-44	Internal Parachute Tail	28025	300	260	13700	-425	42	13315	41.75	5.95	47.70	901	2.	18	10.	1.12	1.01	(1)

(1) Similar Units with Internal Drag Fins

(2) Similar Units with External Drag Fins

(3) Similar Units with Standard Box Tail

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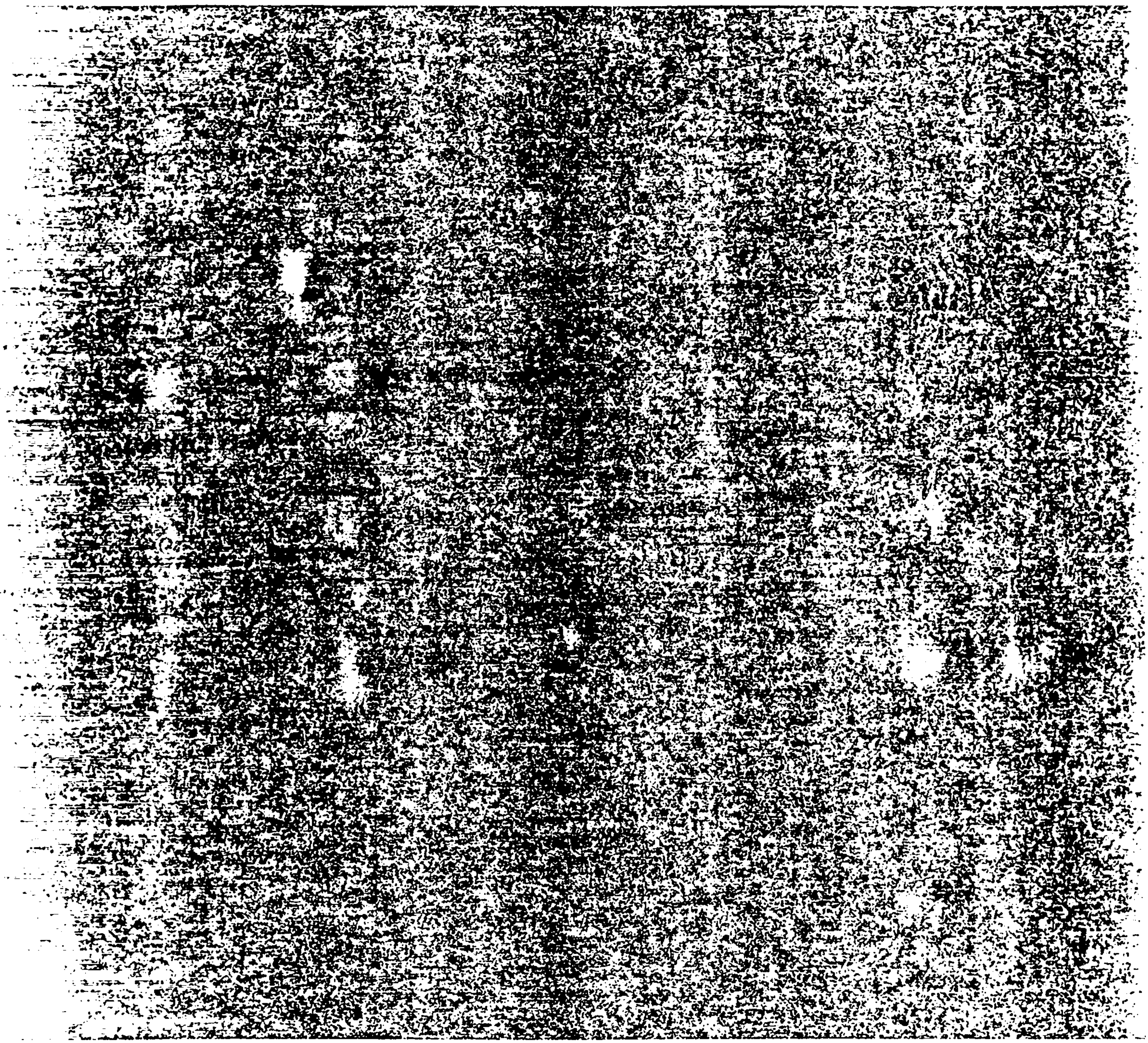

Los Alamos