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PRELIMINARY BLAST SUMMARY - OPERATION IVY

F. B. Porzel, Program 6 (Nov. 22, 1952)

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US ATOMIC ENERGY

PURPOSE OF TESTS

With due regard for the preliminary nature of tests results to date, it is useful and probably justified to draw some tentative conclusions. The interest in blast on Operation Ivy falls into three phases, which formed the framework of Program 6.

First, because of the large size of the weapon, the earth's atmosphere can no longer be considered homogeneous in studying its blast hydrodynamics. On the scale of these bombs, particularly MIKE, at pressures of practical interest, the bomb was literally burst in a relatively thin layer of air at the earth's surface; most of the blast wave propagated in a near vacuum at high altitude where sound velocities are low and winds are high and variable. In addition, large scale afterwinds from the rise of the MIKE fireball were expected because of the size and because it was a surface burst. It was anticipated that these atmospheric effects of inhomogeneity, refraction and afterwinds would markedly affect the pressures patterns measured at the surface, but no theory is available at present for predicting the effects quantitatively.

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Second, the Operation Ivy blast program was part of a logical sequence, Buster-Tumbler-Ivy, designed to study the effect of ground surface in altering the shock hydrodynamics at the ground. Buster and Tumbler were largely concerned with measurements over essentially poor surfaces, with high heights of burst, where the thermal effect on blast was expected and found to be serious. Both Ivy shots were fired essentially over water, and at low heights of burst.

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The reduction in pressures from surface effects on MIKE were not expected to be serious, and to approach ideal pressures and wave forms. On KING, separate blast lines were established to compare wave forms and pressures over both land and water surfaces.

A third phase of Program 6 involved studies of phenomena such as water waves produced by the explosion, crater size, energy absorption by ground and ground accelerations, which were of considerable interest because of the large change in scale of the MIKE weapon.

It is of interest to note that energy-wise MIKE Shot involved a change of scaling in the same ratio to nominal atomic weapons, as those weapons stood to the large high explosive bombs used in World War II, and again as these stand to "small charges", i.e., there is the one thousand-fold change of scale in

12 MT: 12 KT: 12 tons (TNT): 24 lbs. (TNT)

Despite this change of scale, no doubt was cast upon the basic validity of the $W^{1/3}$ scaling law, as it applied to the basic framework of the blast wave. The questions of scaling are concerned only with the failure of its perturbations to scale. As such, the data from MIKE or KING Shots cannot be scaled directly in a simple fasion without considering the causes for failure of scaling listed above in the three types of perturbations.

I - MIKE SHOT

Fireball Measurements

Discussion of preliminary fireball analysis is presented in preliminary reports of Program 3, from which the yield is estimated as 12 ±1 MT. The fireball analysis is of interest here because it shows that there is little which is unusual during the early history of the blast wave, and because it is fundamentally a blast measurement. The rate of growth curve is itself diagnostic; it shows a predominance of the radiative phase over mass effect during the early growth, and is characteristic of a bomb of very high yield to mass ratio; this was expected because 600 tons of structure around MIKE, compares to only 1200 lbs. around a 12 KT weapon. As expected, the energy transfer to the ground was very small, no large abnormalities were introduced because of proximity to the surface. The shock wave was clean and essentially symmetrical. There is no reason to suspect scaling does not apply, because, for the first time on any operation, the "fireball yield" was determined on an absolute, instead of relative, basis, using an analytic solution only recently developed. The same solution had given good agreement with radiochemistry when applied to bombs of previous operations.

As shown below, the fireball yield is consistent with the interpretation of hydrodynamic data appearing below, so that even if the fireball yield is in eventual disagreement with radiochemistry yields, the fireball yield will still be necessary for interpretation of hydrodynamic data.

Refraction, Inhomogeneity, Afterwinds

Pertinent measurements were made by Sandia Corporation in Project 6.1 - "Pressure Time", and 6.3 - "Shock Winds and Afterwinds"; by Los Alamos Scientific Laboratory in Project 6.2 - "Air Mass Motion Studies", and Project 6.3 - "Afterwinds"; by Wright Air Development Center in Project 6.10 - "Free Air Pressure, Manned Aircraft"; and by Air Force Cambridge Research Center in Project 6.11 - "Free Air Pressure, Parachute Cannisters". Preliminary conclusions drawn here from test results are based on comparison with the predictions under ideal conditions, in Annex A, J-12372, "Report of Evacuation Plans Conference".

Peak pressures measured by Sandia Corporation are shown in Table I, in comparison with the predicted pressures from 12 MT for an ideal surface and homogeneous atmosphere. Pressure is essentially up to the ideal value at the closest distances, but are markedly reduced at long distances. On the basis of peak pressure, the apparent yield diminishes from about 10.5 MT at Engebi to less than 1 MT on Parry. Also, Sandia Corporation reports fast rise times in the pressure wave at the 23.6 psi level on Engebi; fast rise times as far out as Aomon (2.75 psi). Successively longer rise times occur at long distances.

TABLE I

Island	Distance From Zero - Feet	Theoretical Pressure Ideal Surface - Homogeneous Medium - Psi	Measured Peak Psi	Apparent Yield MT
Engebi	16,000	26	23.6	10.3
Muzin	21,500	14	12	9.3
Aitsu	36,500	5.4	3.7	6.8
Aomon	47,500	3.5	2.75	6.8
Runit	75,000	1.85	1.32	5.7
Parry	114,000	1.1	.36	0.6
Estee	188,000	.62	.28	1.0

As expected, these results are distinctly different from Buster-Tumbler results, which generally had slow rise times and pressures, which were a factor of 2 or more below ideal at high pressures, but which had sharp rise times and close to ideal values at low pressures. The results on MIKE are reasonable; at high pressures and over a good surface, the pressures and wave forms are in fact ideal. At longer distances, the atmospheric effects apparently do result in a marked attenuation of peak pressures. Further, at long distances, one perhaps observed a different type of degradation, as the blast wave passed from "shock" to sonic amplitudes. When the shock wave becomes very weak, its velocity as well as sound velocity behind it approaches ambient sound velocity. If the wave form is perturbed, because of either surface or atmospheric effects, it is virtually impossible for the wave to "shock up" again, hence the long rise times which appear at Runit and Parry.

Further data will be available from mass motion studies, afterwind studies and cannister results.

Time of Arrival

Times of arrival are available from Sandia Corporation's measurements in Project 6.1, and from measurements aboard the Estes by Cowan and Reines (altimeter and stop-watch) and by England (Wiancko gauge with brush recorder). The difference in time between shock arrival and the computed arrival of a sound wave furnish a rough estimate of yield and some insight into the hydrodynamics involved.

A theoretical time of arrival curve consistent with the theoretical peak pressure - distance curve of Table I is available from a machine calculation of the blast wave. This shows small, if at all, significant differences from the time of arrival curve of Figure 7, J-12372, which was calculated originally from early tests of atomic weapons. Based on the theoretical curve and computed sound velocity at the surface, the apparent yields are:

Location	Distance (Feet)	Sound Velocity (FPS)	Shock Arrival (Seconds)	Time Differences	W (MT)
Estes	184,000	1130	144.9	18.0	10.3
Parry	114,200	1128	85.3	16.0	9.1
Runit	74,900	1125	51.2	15.3	10.4
Aomon	47,600	1124	28.76	13.3	10.0
Aitsu	36,700	1124	19.35	13.3	12.5
Musin	21,400	1124	8.7	10.35	9.6
Engebi	15,900	1125	9.3	8.83	8.5

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The results are of interest because they tend to confirm the high yield shown by the fireball. However, it is a reasonable question what the effective sound velocity really is; at ground distances like 100,000 feet the velocity at the "surface" is a microscopic detail, the shock propagation is controlled by sound velocities at many thousands of feet. At altitude, the temperatures and wind velocities were such as to decrease the apparent sound velocity, increase the time difference and therefore apparent yield. For example, if at the Estes (184,000 feet) sound velocity is taken as 1124 feet instead of 1130, to compensate for a 17 knot wind which was present from altitudes of 2000 feet to 9000 feet, the acoustic time raises from 162.9 to 163.8 seconds, the time difference raises to 18.9 seconds, and the apparent yield to about 12 MT. The same value of sound velocity occurs for an ambient temperature of 23°C, compared with 27°C as measured at the surface, or 18.8°C as measured at 5000 feet. Sound velocity at the surface has meaning, only as related to the peak pressure as measured at the surface. At the high pressures and velocity, the interactions behind the shock wave and very rapid and a low "average ambient" sound velocity say at 5000 feet, may quickly affect the shock velocities at distances like 15,000 feet, where pressures and velocities are still high. At large distances the peak pressures measured at the surface are already low, presumably because of atmospheric effects, the shock arrival times will be later, the apparent yield still somewhat consistently small. Here again, the atmospheric effect is probably the significant factor. In all this, the theoretical curves may be in error, of course, but if so, the close-in values of pressures would be anomalously high.

Positive durations reported by Sandia Corporation are much longer than predicted, and would indicate abnormally high yields. This result again may be due to the low sound velocity at high altitudes, where the pressure wave may lay behind its corresponding part at the surface, and tend to support the interior of the wave, near the end of the positive phase. The normal lapse rate of temperature with altitudes on MIKE, is not unlike the thermal effect observed for high heights of burst; in a sense it results in similar precursor action at the surface, which also tends to lengthen the positive phase.

Surface Effects

Pertinent measurements were made by the projectalisted above, and in particular, by Sandia Corporation in Projects 6.3, and by LASL in the photography for 6.2, in 6.3, and in Project 6.9 - "Beta Densitometer".

The fast rise time obtained by Sandia Corporation at Engebi is remarkable because it may be the sharpest rise time ever observed at this pressure level on an atomic bomb. One recalls that the sharp rise time at high pressures over ideal surfaces is a theoretical prediction, despite Greenhouse-Buster-Tumbler results. This gauge was near the shore on Engebi, with a considerable run of water between it and the bomb. Another gauge in ground baffle, placed by Sandia near the OCE structure on Engebi, several thousand feet inland, gave only 9 psi and a poor wave form, to be compared with 16 psi obtained by interpolation between their measurements at Engebi and Muzin, or 18 psi as predicted for ideal surface and homogeneous atmosphere. Reflected pressures measured on the structure were about 36 psi, a reasonably small reduction below 45 psi expected from normal reflection of a 16 psi shock, or 52 psi as expected from normal reflection of an 18 psi shock. From these results one infers that a surface effect was probably present inland on Engebi, but not near the shore.

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Photography on the mass motion cameras showed pronounced pre-shock dust on Engebi, about four miles distance from zero. This is a reasonable thermal effect; despite the initially zero height of burst, the radius of the fireball was in the order of 1 mile at this time; it probably had already risen to sufficient height to provide an appreciable angle of incidence for thermal radiation on the ground.

A beta densitometer trace from Kirinion shows enormous dust-loading of the shock wave, but no pre-shock dust-loading. By itself, the shock wave density would be about 1.40 times normal air density at this pressure level; this record shows that the density reached a maximum of 8.0 times normal several seconds after shock arrival. It suggests even worse dust-loading than usually observed on atom bombs, perhaps due to the failure of gravity to scale in such long duration blast waves.

Cambridge Research Center reports fast rise times in free air. This is again consistent with the theory of surface effects, which predicted that the rise times should be fast in the absence of a surface perturbation.

Wave Action

Pertinent measurements were made by LASL in 6.4a - "Water Waves, Shallow" and Scripps Institute Project 6.4b - "Sea Waves"; by Bureau of Ships, Project 6.7a - "Underwater Pressures, Deep", and Sandia Corporation in Project 6.7b - "Underwater Pressures on Reef". No quantitative results are yet available. Predictions for wave heights are contained in J-9543 by George White, "Scaling For Surface Explosions in Shallow Water", (LASL).

Baker of LASL reports a perceptible wave in the order of a foot near Parry, and a few feet near Runit. These results are in reasonable agreement with the predictions by White. Due to damage to the camera no record was obtained on Engebi.

Visual inspection suggests that an appreciable wave washed over Engebi, closer islands were surely inundated, and it is even possible that parts of Kirinian were washed. During a damage survey on M + 2, I was forcibly struck by the peculiar absence of burned vegetation on Engebi, Surely the thermal charring was very severe, as in the case of a wooden raft just off shore. Nonetheless, no blackened vegetation was visible on Engebi; the upper brush was scorched, but grass was visibly green at its base. This seems most reasonable if one assumes the charred material had been completely removed by wave action, long after the blast and thermal effects. More direct evidence was obtained later on during another inspection trip. Project 6.2 had 10 AA guns on the east end of Engebi, just off shore, where the island is unusually high, about 7 feet, above the lagoon. Here driftwood was found lodged in the gun mechanisms, some 7 feet above ground. Also, one gun had been smashed from several feet above ground by a large boulder, several feet across; broken parts of this boulder were lying on the gun platform. It seems that only a large wave, greater than 15 feet high, could have produced these effects. On the far end of Engebi, away from the bomb, gravel was deposited around test installations, and ground wires were pulled in a way typical of wave action. The most striking evidence of waves on Engebi was present on the OCE structure; one section of this, facing the blast, was made of corrugated iron, with the channels running horizontally. Deposited on these ledges and plastered on the wall, was a mixture of flotsam, sand and fine organic debris, which certainly looks like wave work. This material was deposited to within several feet of the top of this 30 foot structure. It would be very difficult to ascribe all these effects to blast wind; Ogle makes a reasonable alternative suggestion that a base surge phenomena could have plastered the structure.

Crater, Ground Accelerations

Pertinent measurements were taken by Sandia Corporation, Project 6.5 - "Ground Motion, Seismic", and later through measurements of the crater. Cox of Sandia reports only small earth accelerations at Engebi.

Considerable conjecture arose from the possibility of a structural collapse of the atoll on MIKE shot, because geologic investigations by LASL (H.K. Stephenson) and Scripps Institute had shown the rock structure to be weak; a structural collapse might have resulted in a tsunama of destructive magnitude. A rough quantitative prediction was contained in a memorandum, "Soil Pressures and Energy Transfer on Mike Shot", October 10, 1952, Porzel to William E. Ogle, from which one expected a crater approximately 10 meters deep for 5 MT or about 14 meters for a 12 MT explosion, assuming a geologic structure as strong as the shot island for George shot during Greenhouse. It also showed the small possibility of breaking the rock structure to depths like 300 meters, which might then subside into the ocean, but not of serious consequence.

No large scale failure of the atoll occurred. A preliminary aerial survey was made by Ogle just after shot time; he reports isolated turbid regions of water at distances great enough to suggest the "squeezing out" of sand through fissures in the coral sheath of the atoll. An aerial survey two days later by Porzel and Raines suggested that the crater was still shifting because sharp demarcations of turbid water were still visible, which long since should have diffused away if they had started at zero time. The crater appeared to be 4500 feet across. On the ocean side, the original reef had extended about 4000 feet from the shot island; no channel was broken through between ocean and lagoon. The reef material is markedly different now than before the shot, as in the lip of a ground crater, but here it has been broken up by wave action.

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About H/4 Cowan reached the water above the submerged crater and obtained soundings showing a depth of 14 fathoms, or approximately 25 meters. Several weeks after shot time, the crater was surveyed by Holmes and Narver, but the data were not worked up at the time of writing. The crater width was substantially as mentioned above, but a maximum depth of 180 feet was recorded near the zero point.

It seems a reasonable conjecture that the crater depth does scale within the gross uncertainties of geologic structure which, in themselves, probably affect the depth by factors of 3 or more. The rock structure was somewhat weaker on Elugelab than on Ebiriru, and was broken to a considerable depth, which may not stabilize for sometime - perhaps weeks or months.

II - KING SHOT

Fireball Measurements

The analytic solution was applied to data from an early Eastman film taken by EG&G; based on Fussel's measurements, the yield was computed as 580 KT. Details of the fireball measurements are given in Ogle's preliminary report, under Program 3.

The KING weapon will provide an ideal case for study of fireball growth, superior even to Buster-Easy and Tumbler No. 4. As predicted in LA-1214, and subsequent papers, this rate of growth involves considerable amount of fine structure, due to the early radiative phase, the mass effect of the bomb and variations in gamma. On most weapons, the mass effect surface irregularities of the fireball result in measured scatter, which tends to obscure the fine structures. Early inspection of the KING fireball curve indicates that, because of the very high yield to mass ratio, the fireball is extremely regular, and scatter of measurements sufficiently small, that fine details in the rate of growth may be readily apparent. As such, it can greatly aid in establishing the basic hydrodynamics of the blast wave on a firm empirical basis.

Quick Hydrodynamic Yields

Some quick estimates of yield were made on K-Day using hydrodynamic measurements from Parry, which are reported in Appendix B of the KING Shot Cursory Report. These results are of interest here because of their hydrodynamic implications.

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Based on the theoretical predicted values for homogeneous media, and time of arrival measurements at the Parry Compound and Sandia Corporation's station, the indicated tonnages from KING were in the order of 520 KT and 500 KT. This low value, as compared with the fireball yield, is reasonable and consistent with the experiences on MIKE. It is probably the result of long range atmospheric inhomogeneity of the atmosphere.

Based again on the theoretical curves, and Sandia's measurement of the blast wave at Parry, the indicated yield is about 850 KT; this is to be compared with a predicted value of 3.9 seconds for 580 KT. This again is consistent with experience on MIKE, with the possibilities being: atmospheric refraction effects, reinforcement of the shock wave by thermal radiation, and an experimental tendency to read long because of hysteresis effect on the gauge, or the flat pressure-time curve on long duration waves.

Sandia Corporation measured a peak pressure of 0.36 psi on Parry, in comparison with 0.7 psi for an ideal surface and homogeneous medium; 0.45 psi as predicted from a rough estimate of the refraction effect, based on MIKE; or finally about 0.1 psi, which would be indicated by straight scaling from MIKE. Curiously enough, this is exactly the same pressure observed on Parry from MIKE, and practically the same as the 0.35 psi observed on Parry from

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Greenhouse-Dog Shot. The rise time on KING was, however, much faster than for MIKE. As in the case of MIKE, this reduction in peak pressure appears to be a refraction effect; the measurement is of little or no value for determining a yield quickly.

Surface Effects

Of the several laboratories participating in blast measurements on KING, only preliminary data from Sandia Corporation are available at the present time. Nonetheless, their results seem clear enough to justify some conclusions.

In order to compare the blast wave over relatively ideal and a relatively poor surface, two blast lines were instrumented by Sandia, one line over water on the submerged reef, the other line through the center of Runit. It was expected that the rise times would be fast over water, and pressures close to ideal; the rise times would be slow over land, and the "thermal" curves of LA-1406 be applicable. Preliminary readings of Sandia's pressure-time records amply confirmed this prediction. On water stations approximately 5500 feet and 6500 feet from zero, the pressures are nearly ideal, with fast rise times; on the other hand, an even more distant land station, about 7450 feet, had a very long rise time, and peak pressure considerably below ideal values*. The Ivy test is then the logical completion of the Buster-Tumbler-Ivy series, all of which amply confirm the theory of surface effects proposed in LA-1406 and other papers during the past year.

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* Meanwhile, these records have been more carefully examined by Sandia. Cox reports the same general conclusion, "the rise times are faster, and the pressures higher over water than over land".

The predicted time of arrival curve was amply verified in a novel manner on KING shot. Due to a failure of several cameras used to establish the actual burst coordinates, there was considerable interest in confirming the coordinates subsequently established by other cameras. The time of arrival measurements by Sandia over two blast lines furnished such a confirmation, and accordingly, a "predicted" time of arrival vs. horizontal distance curve was deduced by numerical integration, using the height of burst curves from LA-1406, its time of arrival for free air, the fireball yield, and the intended height of burst. With this curve, and the observed time of arrival, the burst position could be plotted as lying on a circle about each station. From the intersection of these circles, from various stations, the actual position could be plotted. The method is of course poor, because the arcs of the circles are nearly parallel, and an extremely high degree of accuracy is required in the time of arrival curve. Nonetheless, the burst position, as plotted from time of arrival, is in excellent agreement with the burst position from surveying cameras. Conversely, it also means that the predicted time of arrival curve will be confirmed as closely as one can read the graphs. This agreement is further gratifying because the prediction involved the height of burst curves, and because of the fundamental nature of the time of arrival curve to hydrodynamic theory.

A camera station had been improvised on Runit to observe the thermal effect photographically over various types of surfaces, and in particular, to photograph a thermal blow-up or the precursor action resulting from it. Fussel of EG&G reports that two out of three of the records were probably lost because the photographic filters were burned by thermal radiation. A preliminary view of the third camera indicates a thermal blow-up, but the precursor shock, if any, was probably obscured by pre-shock dust and smoke. In view of Sandia's pressure records, there seems little doubt that a thermal effect occurred on Runit, perhaps to horizontal distances like 10,000 feet.

Damage Survey

The blast damage on Parry from KING shot was very much greater than from MIKE; this was still of a minor nature; a large number of aluminum panel sidings were slighting buckled in, some buildings shifted a fraction of an inch from their foundations. The results are particularly interesting because the peak pressures were nearly identical.on the two shots. The difference in damage is due of course to the sharp rise on the shock in KING and the slow rise on MIKE. As pointed out in J-14033 , this slow rise is partly the argument for exploitation of the thermal effect as a defensive measure against atomic weapons.

The large aircraft hangar on Eniwetok was by far the most vulnerable structure to blast damage in the personnel area. For KING Shot, the roof arch had been braced using telephone poles, and a photographic record was obtained of the blast wave passing over the hangar. No appreciable damage occurred, except for several pieces of corrugated siding blowing loose on the back side, from pressure reflections on the interior of the building.

There is considerable visual evidence that Runit was partially inundated by wave action from water on the reef near ground zero. It is entirely possible that the reef was exposed on Sandia's close-in "water" stations. A battery of rocket launches, used by NOL, were completely swept away, and scattered about one-half mile down blast across Runit; this too is suggestive of wave action.

DISCUSSION

In the long run Operation Ivy may well mark a turning point in blast measurements on nuclear weapons, although it is only fair to say this statement may be no more than a personal conviction or pious hope on the part of the author. However, a completely theoretical and self-consistent hydrodynamic theory now exists which was used to make predictions for Ivy and, which are principally reported in J-12372, concerned specifically with Ivy and, LA-1406 concerned with the theory of surface affects.

Starting with the analytic solution for fireball growth, which has been used to determine the yield of these weapons, a major calculation for the blast wave was correlated with this solution and used to extend the range of hydrodynamic theory down to very low pressures. To this extent, and including the nature of the reflection process over an ideal surface, hydrodynamical theory now seems to be on firm ground; both theoretically and empirically. In addition to this, two major perturbations exist in blast from atomic bombs: the theory of surface affects, whose general quantitative features have been given in LA-1406, appear to be justified; the other perturbation characterised as due to large scale inhomogeneities, are better understood. While an immense amount of work remains to be done within the broad framework of this theory, there is good reason to hope, as was demonstrated on Ivy several times, that the basic field variables of blast have passed from the status of experimental measurement into the status of a diagnostic tool.

The analytic solution for fireball growth was used to establish the fireball yields from Ivy on a considerably firmer basis than would have been obtained by methods of fireball analysis used prior to Ivy. A complete discussion of its merits and limitations are not appropriate in this summary, but one further evidence of confirmation may be appropriate here. In the analytic solution the density distribution of air behind the shock wave plays a fundamental role. It also happens that this same density distribution markedly effects the intensity of gamma rays as a function of time as observed on very large scale weapons, such as MIKE, where a large number of mean free paths are present for gamma ray absorption. For example, this hydrodynamic effect increases the intensity of gamma ray radiation at 4000 metersfrom MIKE by a factor of 150. The same density distribution used in the analytic solution was furnished J. Malik, who then used these data to correct the intensity vs. time curves in Project 5.3. He reports that this theoretical hydrodynamic correction then modifies the gamma ray intensities to the extent that good fission yields are obtained from the gamma ray measurements at fairly long distances. This is a rather crucial test of the density distribution used in the analytic solution, partly because it is at long distances where the theory is considered least reliable. More important, the air absorption here amounts to factors e^{-13}; the hydrodynamic correction amounts to e^{+5}; it follows from the mathematics that only a small error in the density distribution would result in very large errors in the corrections for gamma ray intensity. While these calculations are only of a very preliminary nature, it is felt that the success to date is significant.

In the discussion throughout this report one may be struck by the consistent recurrence of the term "approach ideal pressures". This has a real meaning in the general theory for blast, which has been set up in the theory for surface effects. By theory the basic framework of the blast pattern is established. It is the nature of this phenomena that in the perturbations from the simple theory one always loses and never gains on peak pressure.

This is another statement of general "principle of least pressures" which has been apparent for some time in blast hydrodynamics. More fully, this statement is that, in a hydrodynamic process which might involve a number of possible paths by which a blast wave could change from one configuration to another, a general property of these hydrodynamics exists by which the blast wave will follow that pattern, which results in the smallest possible peak pressures. Based on this principle, it may not seem so surprising that the ideal pressures always seem to be approached and seldom realized in actual measurement.

CONCLUSIONS

Barring a major reversal of the preliminary data, some tentative conclusions to be drawn from Ivy are:

(1) The basic blast pattern from nuclear explosions now appears to be established on quite firm theoretical and empirical grounds, in a self-consistent theory beginning with the growth of the fireball, and extending to pressures less than 1 psi.

(2) Large scale atmospheric inhomogenieties markedly affect the blast variables at the long distances in the region of interest for large scale weapons in the megaton range. In particular, under the conditions of normal lapse rate of temperature with altitude, as in MIKE shot, the peak pressure at long distances are markedly reduced.

(3) The general theory of surface loss, as explained in LA-1406, are again confirmed, here, with regard to the behavior expected over ideal surfaces.

(4) A great deal of work remains to be done on the detailed mechanisms of the two major perturbations of the blast wave: atmospheric inhomogeneity and surface effects. Blast effort can now be diverted from measurement of the basic pattern of blast hydrodynamics to these studies.

(5) Blast hydrodynamics offers considerable immediate promise as a diagnostic tool on tests of atomic weapons.