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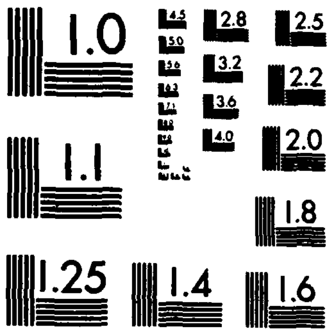

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TECHNICAL REPORT ARBRL-TR-02529

CHARACTERIZATION OF THE THERMAL RADIATION FIELD GENERATED BY A ONE-NOZZLE TORCH

William Rehmann

October 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
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The characteristics of a one-nozzle Thermal Radiation Source were investigated. Liquid oxygen and powdered aluminum were used to produce the radiant torch. Thermal flux and fluence data were mapped at two vertical heights and at horizontal distances that ranged from 25 cm to 90 cm. Thermal pulse shapes associated with three different aluminum injection times were recorded and interpreted in terms of simulated nuclear yields. High-speed photography was used to provide information concerning the flame geometry and dynamics of the source.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Investigations on the response of military equipment to the thermal radiation pulse of a nuclear detonation require, depending on the size of the test object, large area irradiation of the complete object in addition to testing of components and material samples. Such components and samples are often tested by means of nuclear thermal simulators that have rather small, limited test areas. These relatively small test area simulators include xenon or tungsten lamps as well as solar furnaces.

During the last ten years, Science Applications Incorporated (SAI), Albuquerque, NM, has developed a source that can irradiate large complete objects with test areas in excess of 100 m^2. It is a pyrotechnic simulation technique that uses the combustion heat of a mixture of liquid oxygen and aluminum powder to produce the desired high intensity simulation. The radiant pulse has a spectral output comparable to that of a black body radiator with a temperature in the range between 2600K and 3500K. This technique has been successfully demonstrated several times, one prime example being the thermal sources that were utilized in the Mill Race high explosive test at White Sands Missile Range (WSMR) in 1981.

The Ballistic Research Laboratory (BRL) has been involved with this simulation technique since early in its development. This type Thermal Radiation Source (TRS), with a single nozzle torch, was recently installed and made operational at Range 11 of the Ballistic Research Laboratory. The system, when equipped with a modified nozzle configuration, will be installed in a 2.40-meter diameter shock tube facility for the investigation of thermal/blast synergistic phenomena. In addition, several test programs are planned which will use this type of radiation source before a larger facility with 4 nozzles becomes operational at BRL. Programs to be conducted in the near future with the single nozzle source include tests of military equipment as well as basic investigations concerning the effect of fuel composition variations on the radiation characteristics of the TRS.

1.2 Objective

The single nozzle source had previously been used in France, modified (some of the modifications were not properly documented), and stored. It was therefore important that personnel at BRL become familiar with the operation of the torch including the required precise control settings. Detailed thermal output characteristics of the source were also required before the facility could be adequately utilized for test purposes. Radiant flux and fluence mapping was used to reveal the basic thermal pulse shape as well as thermal intensities at a variety of distances from the torch.

2. EXPERIMENT

2.1 Single Nozzle Thermal Radiation Source (TRS)

The radiation produced by the TRS covers the spectral range from the ultraviolet (approximately 0.4μ) to the infrared (approximately 3.6μ) with a maximum around 0.9μ . It is generated by a pyrotechnic torch having a diameter of 0.3 to 1.0 meter, and a height of about 8 meters of which only the lower part can be used for experiments because of turbulence and combustion products in the upper part. The torch is produced by ignition of the fuel mixture which is ejected vertically from the torch unit through a cylindrical nozzle and ignited above the nozzle by contact with three small oxygen/propane ignition flames. Figure 1 shows an operational diagram of the Thermal Radiation Simulator. The fuel components, aluminum and liquid oxygen (LOX), are stored in two tanks in a control unit which is separated from the torch by approximately 7 meters and connected to it by two pipes, one for each of the two fuel components. During the test, the tanks are pressurized with nitrogen gas. The control unit also contains an electrical wiring box, manifolds and valves (for high pressure nitrogen distribution) and several sensor units. When the tanks are pressurized a small flow of nitrogen is maintained through the aluminum line. This is to prevent burn-back of aluminum that could occur by means of the oxygenated residual air in the pipe. After start of the LOX flow, a time lapse of 15 seconds is allowed in order for the flow through the connecting pipe and the nozzle to stabilize. When a stable white column has formed on top of the nozzle unit, aluminum powder is injected from the pressurized aluminum tank into a high velocity nitrogen flow through a connection pipe to the nozzle. At this point the aluminum is injected into the liquid oxygen flow for the duration of the thermal pulse. This mixture forms an extremely brilliant, heat radiating torch that extends to a height of approximately 8m above the nozzle unit, as seen in Figure 2. The duration of the aluminum injection determines the pulse shape. For a more realistic simulation of the nuclear pulse shape cutoff of the aluminum flow is made gradually. The present cutoff valve produces a radiant pulse with a duration of about 3 seconds. An EP-1 sequence timer by PPM, Inc., Cleveland, Ohio, is employed for remote control of the TRS operation.

2.2 Instrumentation

The flux history data were measured by six heat flux transducers (calorimeters), a basic type without cooling, manufactured by Medtherm Corporation. The following ranges of transducers were utilized:

64 500 14 (max. flux 500 Btu $ft^{-2}s^{-1}$ = 135.5 cal $cm^{-2}s^{-1}$),
64 200 14 (max. flux 200 Btu $ft^{-2}s^{-1}$ = 54.2 cal $cm^{-2}s^{-1}$), or
64 100 14 (max. flux 100 Btu $ft^{-2}s^{-1}$ = 27.1 cal $cm^{-2}s^{-1}$).

These flux transducers were placed inside heat sink collars and mounted on pipe frames in such a way that two instruments were located at each measurement station, both at the same distance from the torch axis, but one at 61 cm above the nozzle orifice and the other at 109 cm above the orifice (Figure 3). According to information from SAI, placing tranducers at these heights would center them around the hottest part of the flame. The distance of the measurement stations from the torch axis varied between 25 cm and 90 cm. The data were recorded on a Honeywell 7600 tape recorder and

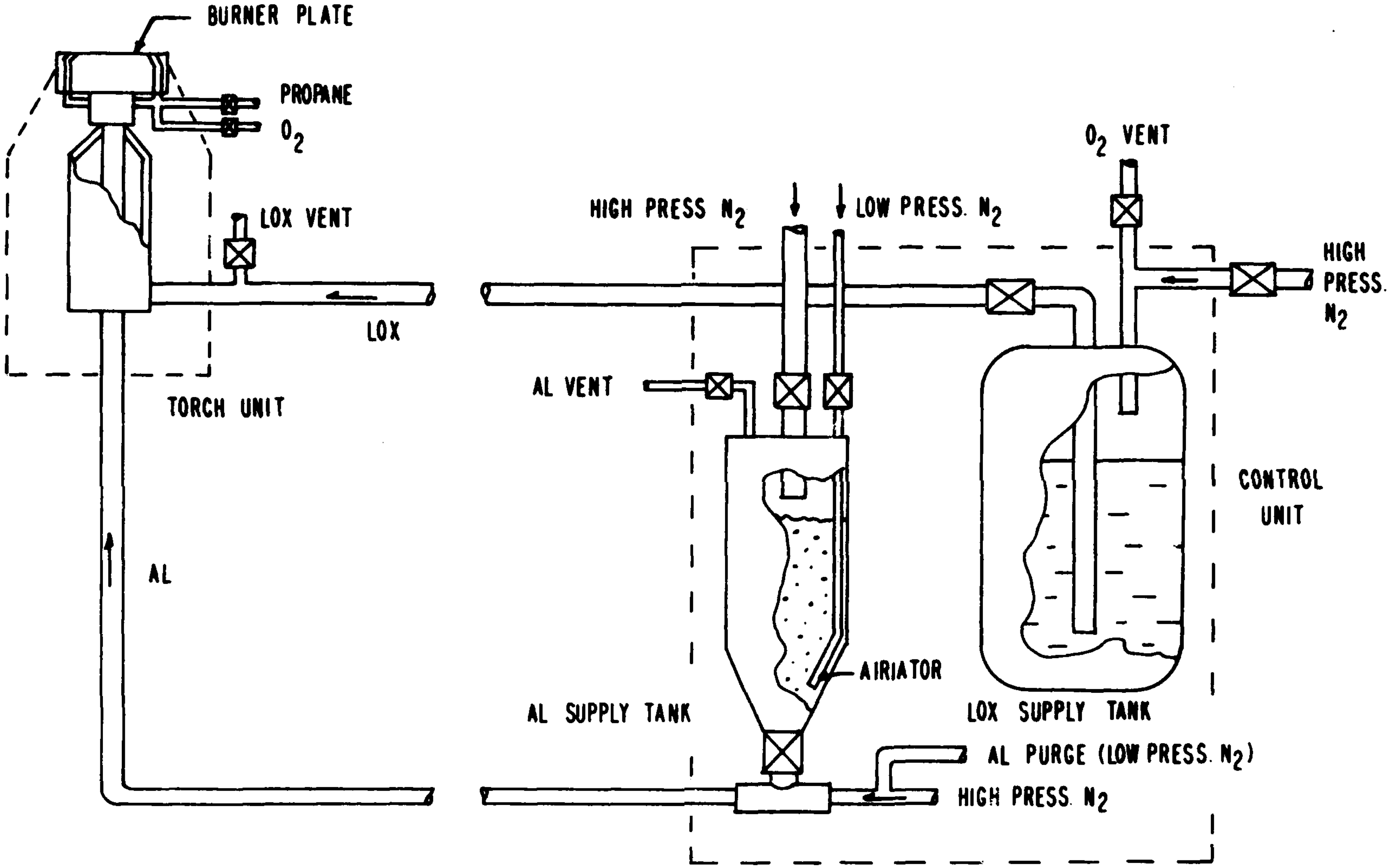

Fig. 1 TRS Operational Diagram

Fig. 2 TRS Torch

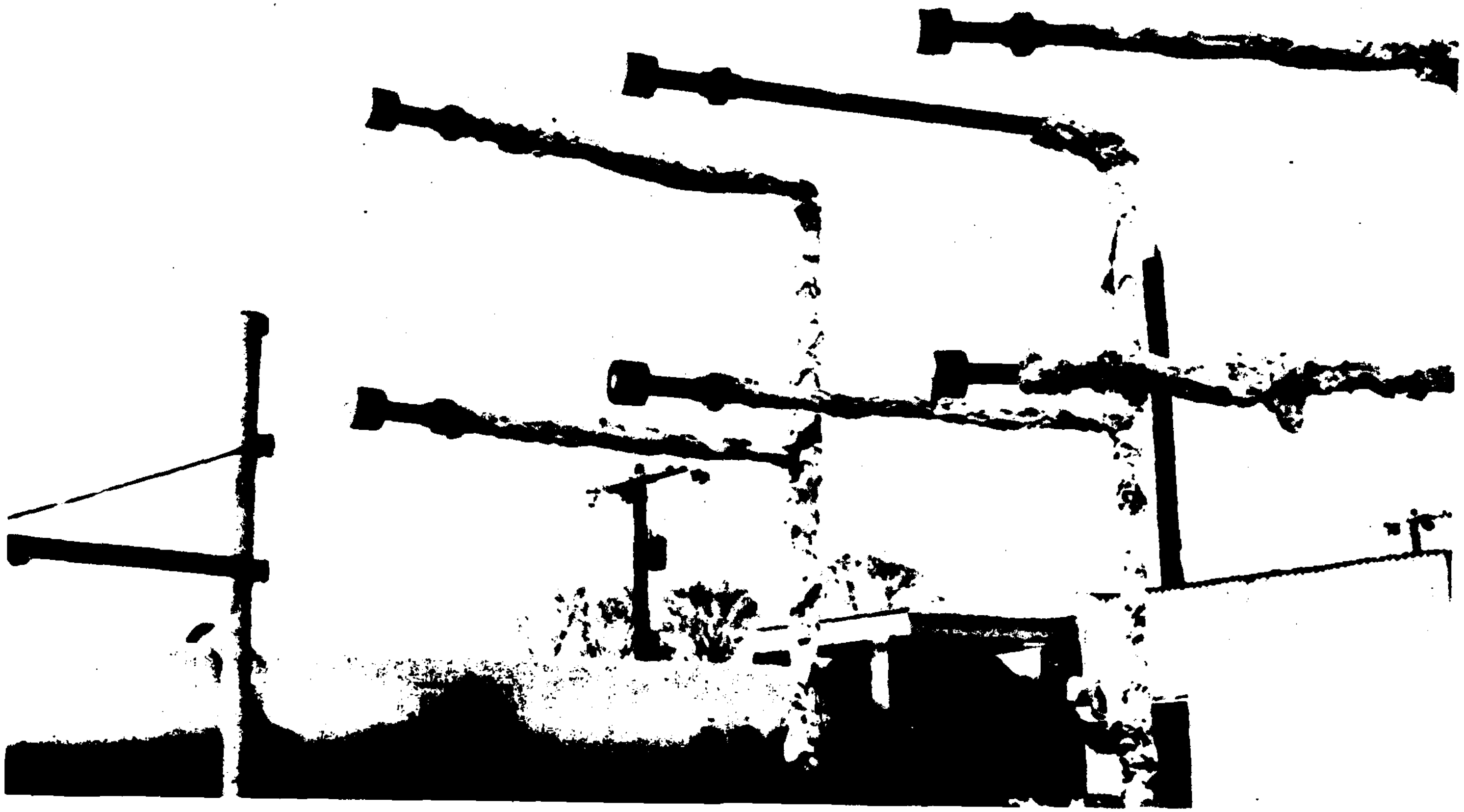

Fig. 3 Array of Heat Flux Transducers

processed for integration and plotting on a Tektronix 4051 computer. Additionally, a 64 200 14 reference calorimeter was placed at a constant distance of 80 cm from the torch axis in order to monitor variations in flux and pulse shape of the source. This signal was recorded on a Tektronix 5223 digitizing storage oscilloscope and was consequently photographed.

After each experiment, the heat flux transducers were removed from their fixtures and their response sensitivities checked against three selected reference transducers, one of each type. This was done to detect any variations in transducer sensitivity and was accomplished by using a Cintra 506 thermal/light source made by Physics International Corporation. Minor deviations from the reference transducers were compensated for by correction factors.

High-speed motion picture photography was used to obtain more detailed information concerning the dynamics of the torch. This included flame geometry, in particular the size of the lower, more useful, part of the torch. A remotely controlled Redlake Hycam Model 41-0004 camera, set to run at 500 fps, was used for the motion pictures. The camera was placed approximately 20 m from the torch.

3. RESULTS

3.1 Pulse Shape

Figure 4 shows three typical waveforms of the flux history corresponding to aluminum flow times of 1/2, 1, and 2 seconds (i.e., time lapse between "Al on" and "Al off" on the sequence timer). These curves show distinct intensity fluctuations, especially during the first part of the pulse. These fluctuations are more pronounced at close distances to the torch. For an estimate of the simulated yield, by use of the peak flux/fluence ratio, we can use the following equations (Reference 1):

$$P = 0.35W$$

$$\dot{P}_{max} = 3.18\ W^{0.56}$$

$$P/\dot{P}_{max} = Q/\dot{Q}_{max}$$

P: total thermal energy radiated from detonation in KT

W: yield of weapon in KT

$\dot{P}_{max}$: peak thermal flux from detonation in KT s^{-1}

$\dot{Q}_{max}$: peak flux in cal cm^{-2} s^{-1}

Q: fluence in cal cm^{-2}

result in

$$W = (9.09\ Q/\dot{Q}_{max})^{2.273}$$

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[1] *S. Glasstone, PH. J. Dolan, "The Effects of Nuclear Weapons," Third Edition, 1977.*

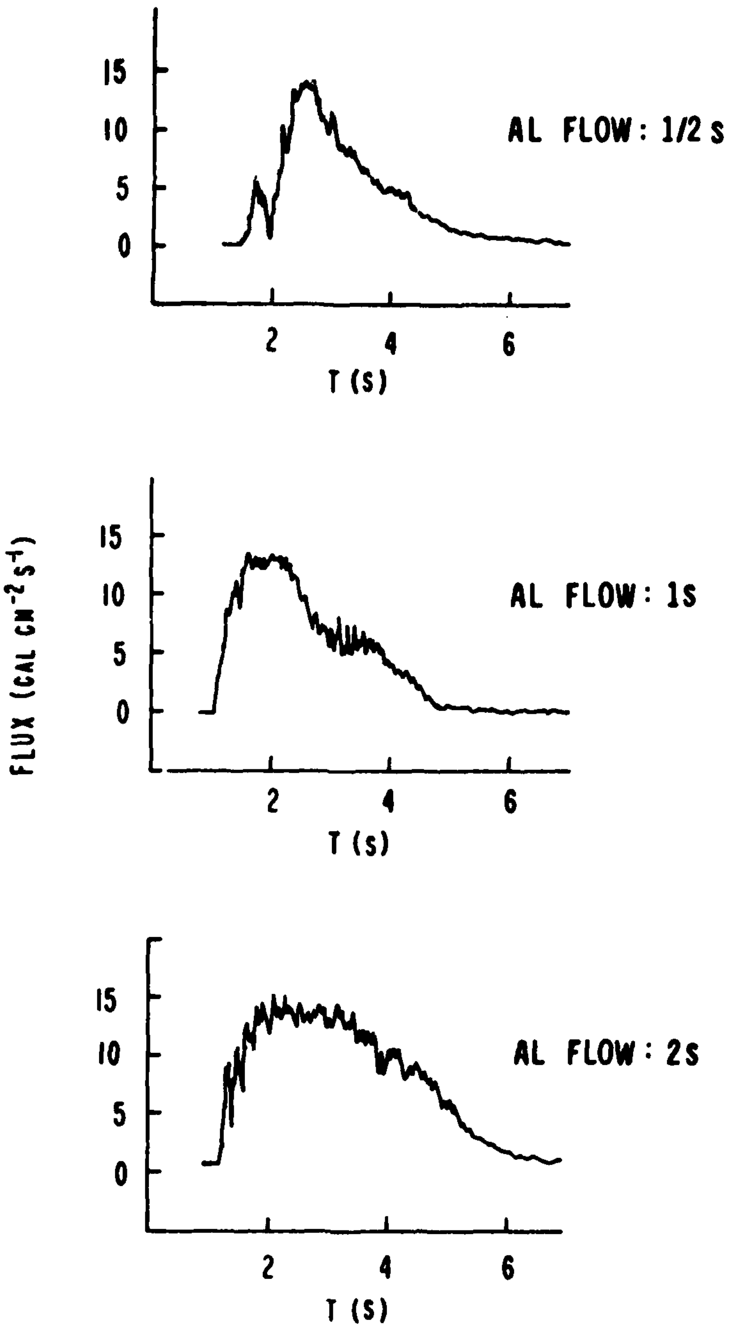

Fig. 4 Pulse Shape at 80 cm Distance for Al Flow Times 1/2 s, 1 s, 2 s

After averaging the ratio $\dot{Q}/\dot{Q}_{max}$ of the data taken at different locations for each burn, and calculating the average values for W of the different burns for each aluminum flow time setting, one arrives at the following simulated weapons yields:

Al flow (s)	W (KT)
1/2	460
1	810
2	1600

This proves that the slow decay of the thermal pulse generated by the TRS, due to the operational design of the aluminum flow valve, prevents the production of short pulses that simulate small yield tactical nuclear weapons.

3.2 Flux and Fluence vs. Distance

Ten test runs were made for field mapping in the distance range from 25 cm to 90 cm from the flame axis. Due to disturbance of the aluminum flow and system malfunctions, only the data of eight tests were useful for the mapping. These and the test conditions are listed in Tables 1 and 2. Test numbers are listed according to the actual test records.

Flux and fluence vs. distance data were obtained from the flux time history curves measured at two different heights above the nozzle, 61 and 109 cm, and for three different pulse shapes. Figures 5-8 show these curves. The flux data demonstrate that, within the limits of reproducibility, essentially the same peak flux was reached for the three different pulse shapes at corresponding locations in the radiation field. The fluence data show distinct differences in the various pulse shapes which are not proportional to the aluminum flow time adjustment because of the slow aluminum flow cutoff.

3.3 Flame Dynamics and Geometry

High-speed motion picture photography was employed to provide information on combustion dynamics and flame geometry. During the initial part of the pulse, strong pulsations of the flame are visible and indicate an unstable aluminum flow. These fluctuations continue to a lesser degree during the entire pulse. The increased initial pulsations are most probably created by perturbations of the aluminum flow caused by the injection of aluminum into the high-speed nitrogen flow and by the length of the connection pipe between the control unit and the torch. This effect may be inherent in the current design of the single nozzle TRS.

In Figures 9 and 10, the flame geometry during maximum aluminum flow is shown. It has a conical shape with some asymmetry in the edge inclination between the forward (left) area and the turbulent rear edge. In the forward portion, in an area about 1.5-2 meters high, we find a reasonably well-defined radiating surface that is well suited for testing. During the cutoff process of the thermal pulse the front edge of the flame changes its inclination to a more vertical position.

TABLE 1. TEST DATA, TEST NOS. 1-6

Test #	Date	Al Flow Time	Sensor Position		Flux	Fluence
		[s]	Distance	Height	[cal $cm^{-2}s^{-1}$]	[cal cm^{-2}]
1	16.11.82	2	25 cm	109 cm	80	236
			25 cm	61 cm	65	209
			50 cm	109 cm	40	116
			50 cm	61 cm	31	99
			90 cm	109 cm	22	62
			90 cm	61 cm	16	47
3	18.11.82	1	25 cm	109 cm	88	175
			25 cm	61 cm	65	160
			50 cm	109 cm	33	67
			50 cm	61 cm	31	61
			90 cm	109 cm	18	36
			90 cm	61 cm	14	27
5a	23.11.82	2	25 cm	109 cm	84	210
			25 cm	61 cm	59	210
			50 cm	109 cm	36	95
			50 cm	61 cm	33	99
			90 cm	109 cm	19	54
			90 cm	61 cm	15	45
6	23.11.82	0.5	25 cm	109 cm	80	120
			25 cm	61 cm	71	120
			50 cm	109 cm	36	52
			50 cm	61 cm	34	56
			90 cm	109 cm	19	27
			90 cm	61 cm	15	24

TABLE 2: TEST DATA, TEST NOS. 7-10

Test #	Date	Al Flow Time	Sensor Position		Flux	Fluence
		s	Distance	Height	cal $cm^{-2}s^{-1}$	cal cm^{-2}
7	29.11.82	0.5	30 cm	109 cm	60	94
			30 cm	61 cm	57	98
			40 cm	109 cm	44	71
			60 cm	61 cm	45	79
			70 cm	109 cm	28	45
			70 cm	61 cm	22	38
8	30.11.82	0.5	30 cm	109 cm	66	114
			30 cm	61 cm	62	106
			40 cm	109 cm	50	80
			60 cm	61 cm	47	81
			70 cm	109 cm	27	43
			70 cm	61 cm	21	37
9	7.12.82	1.0	30 cm	109 cm	71	141
			30 cm	61 cm	63	137
			40 cm	109 cm	46	100
			40 cm	61 cm	49	105
			70 cm	109 cm	27	58
			70 cm	61 cm	23	49
10	7.12.82	2.0	30 cm	109 cm	67	155
			30 cm	61 cm	59	155
			40 cm	109 cm	44	113
			60 cm	61 cm	43	116
			70 cm	109 cm	27	71
			70 cm	61 cm	21	56

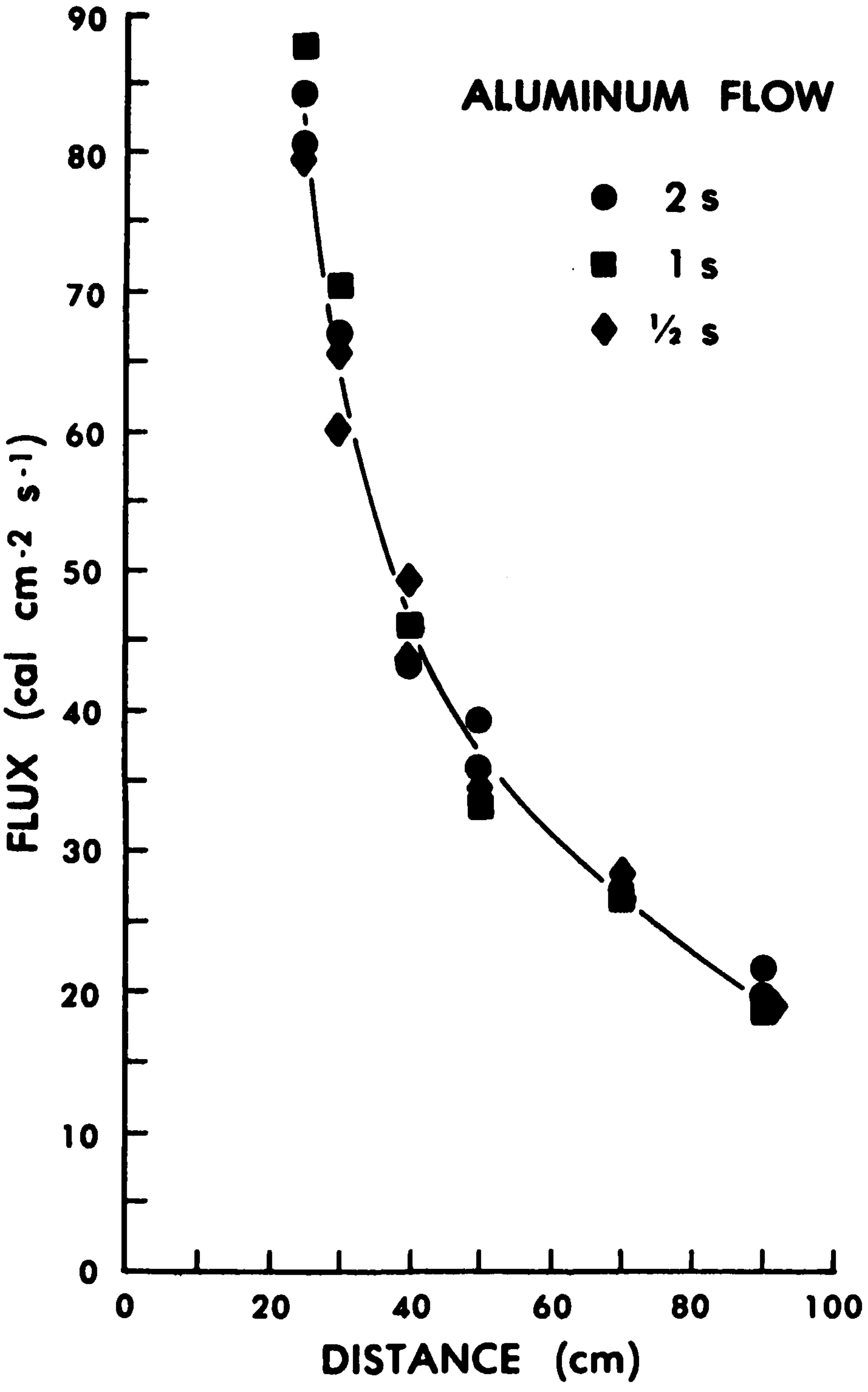

Fig. 5 Flux vs Distance from Flame Axis at 109 cm above nozzle

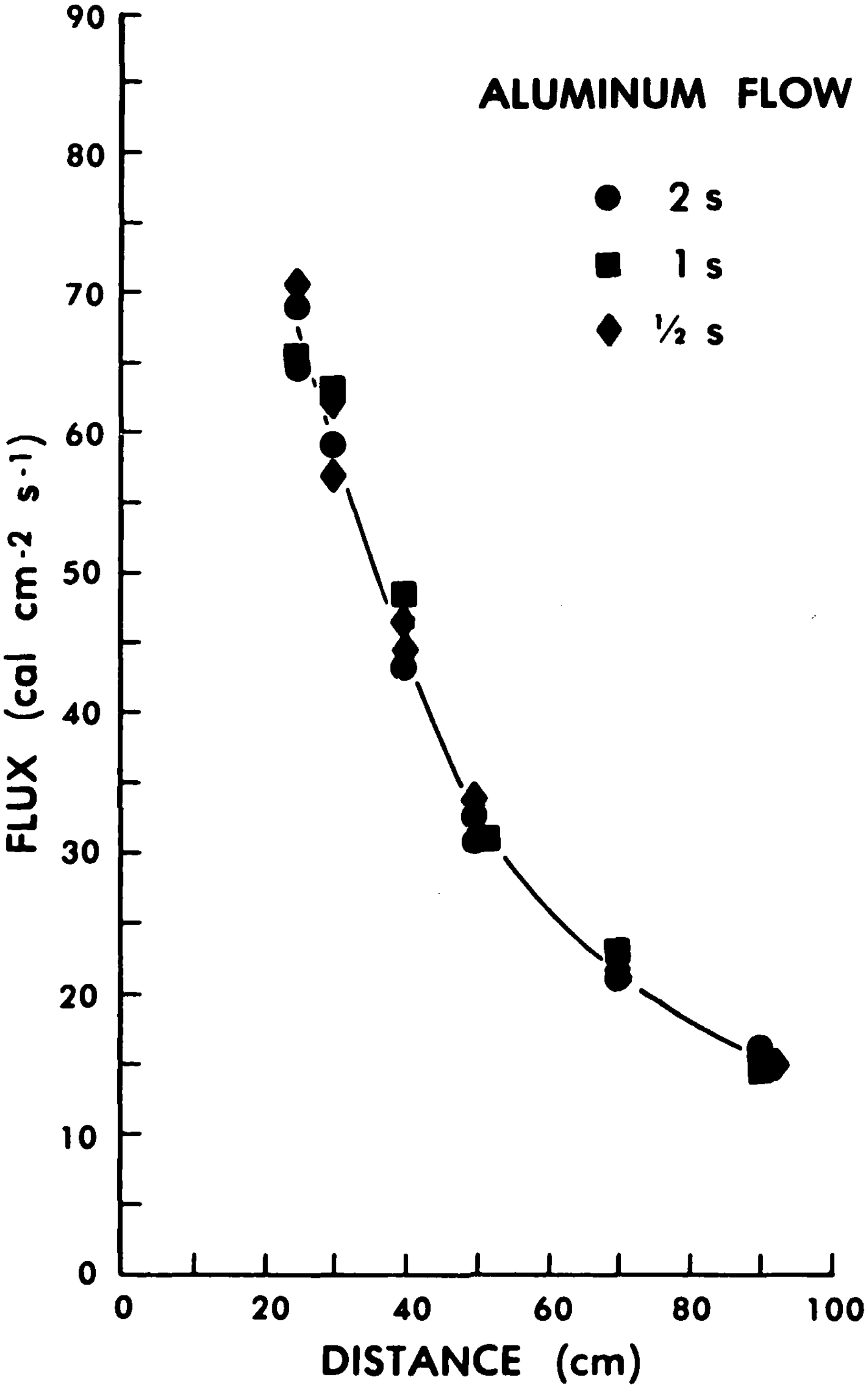

Fig. 6 Flux vs Distance from Flame Axis at 61 cm above nozzle

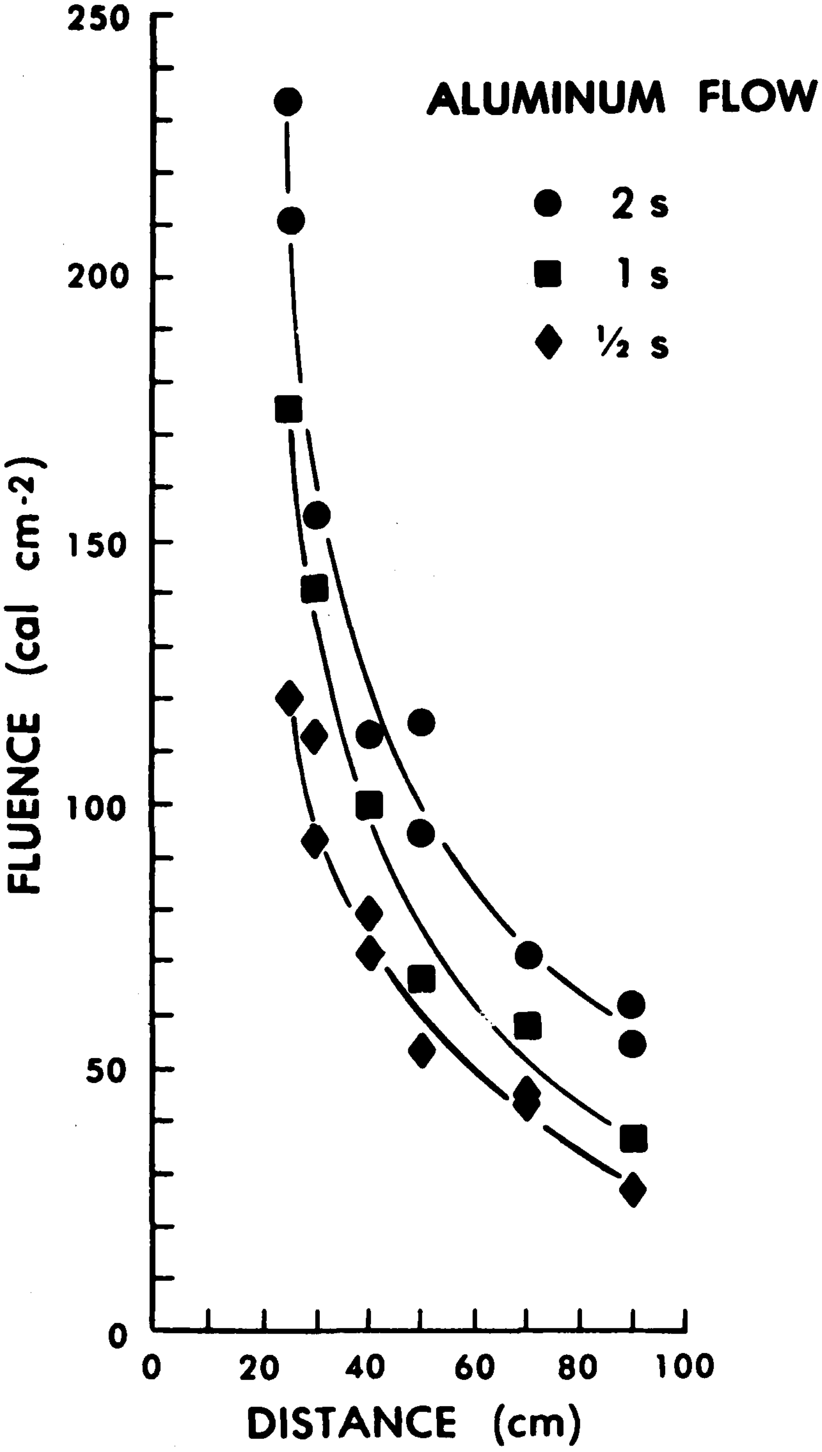

Fig. 7 Fluence vs Distance from Flame Axis at 109 cm above nozzle

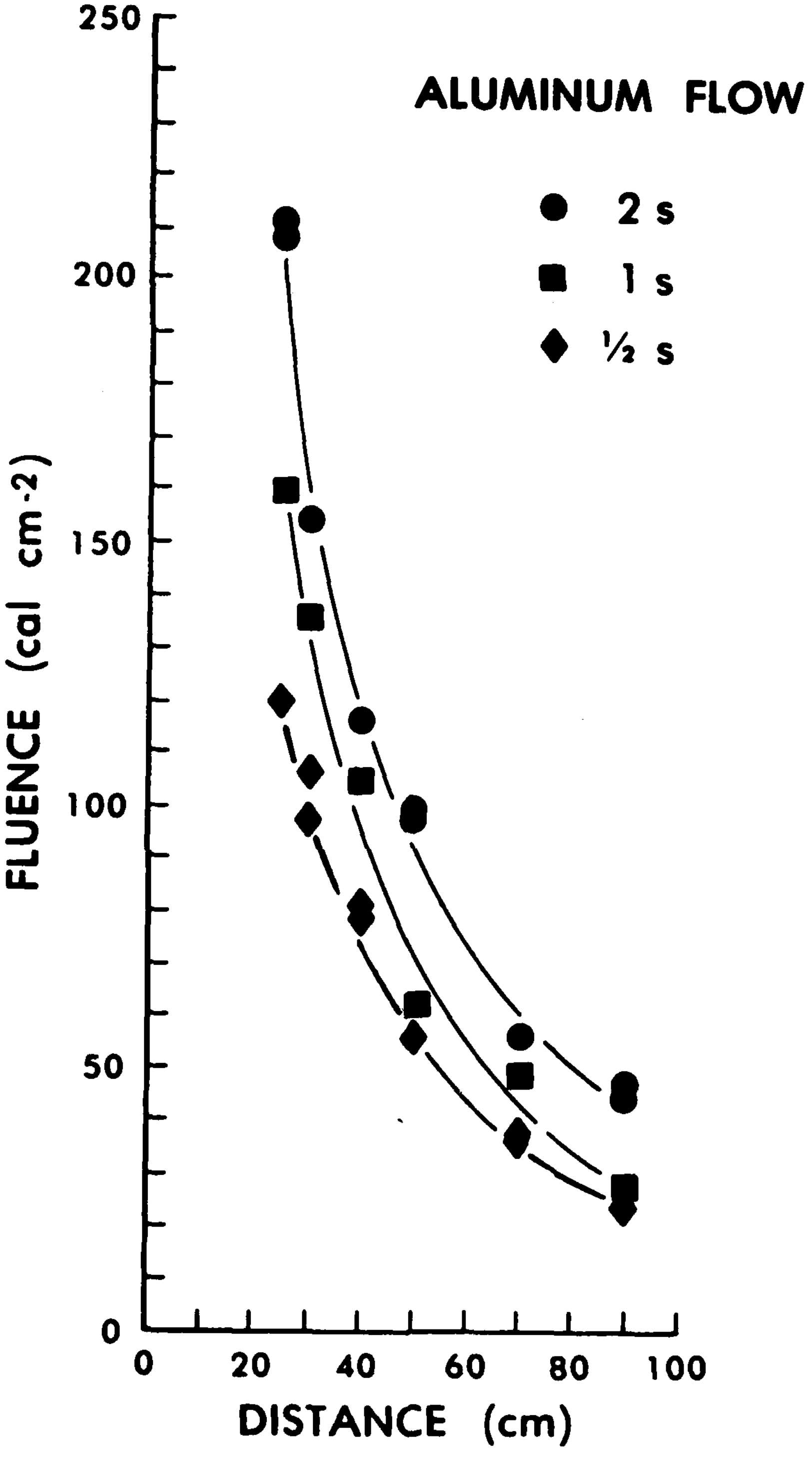

Fig. 8 Fluence vs Distance from Flame Axis at 61 cm above nozzle

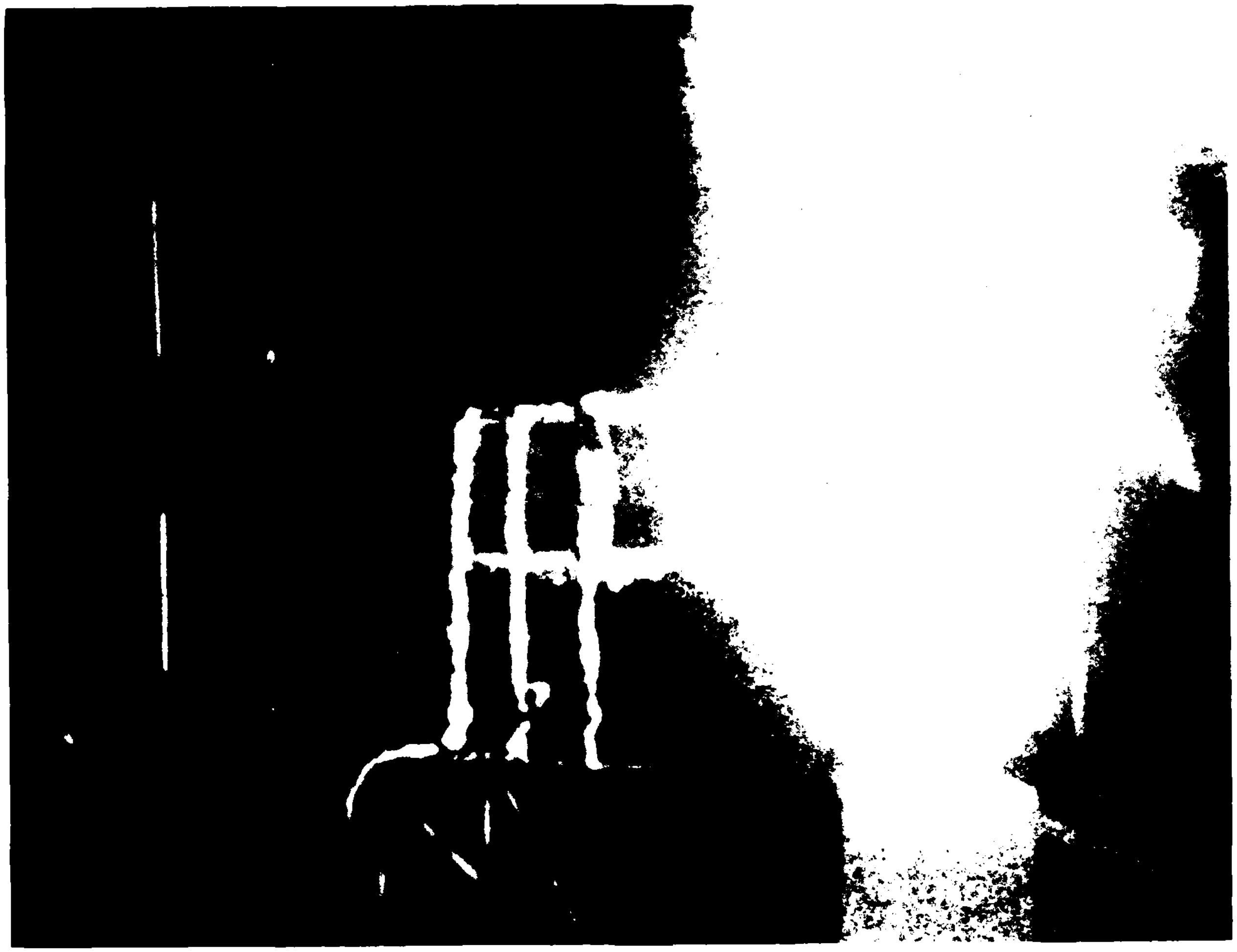

Fig. 9 TRS Torch, Lower Part

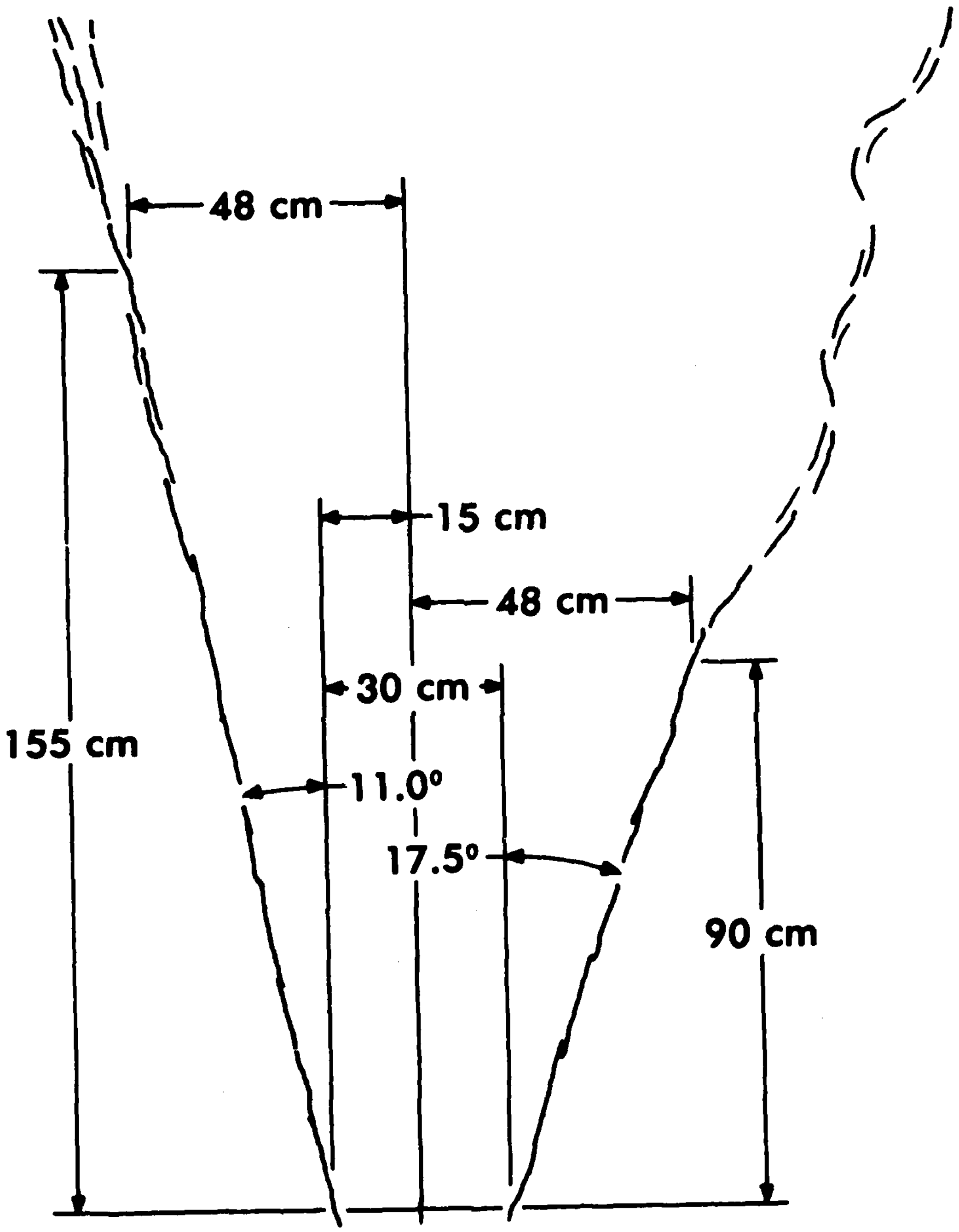

Fig. 10 Flame Geometry of TRS, Lower Part

4. CONCLUSIONS

Flux and fluence of the thermal radiation field of the TRS were mapped for use in the definition of test parameters and to assist in the preparation of experiments. The data have also demonstrated that the single nozzle TRS unit, being one of the earlier designed devices, has certain limitations in performance. Some of these deficiencies are correctable.

The radiation output fluctuations, especially on the leading edge of the pulse, can be attributed to instabilities in the aluminum transport and injection mechanism. It should be noted that fluctuations during the later part of the pulse become less pronounced when seen by a flux probe located at a large distance. This is because the probe has an opportunity to average over a larger flame area at the greater distance. It appears that the device is therefore more suited for tests requiring lower flux levels at larger distances.

It would be desirable to have an additional, shorter cutoff time, injection valve for aluminum powder in order to permit the simulation of small size nuclear weapons. As can be seen from Figure 10, the left (target side) flame surface has a deviation from vertical of 11° which causes some vertical increase in flux. Therefore, an improvement in the vertical uniformity of the radiation field could be achieved by operating the torch unit at an inclination angle of 11°. This should produce a vertical flame surface.

ACKNOWLEDGEMENTS

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LIST OF REFERENCES

1. S. Glasstone, PH. J. Dolan, "The Effects of Nuclear Weapons," Third Edition, 1977.

LIST OF SYMBOLS

P	total thermal energy radiated from detonation, KT
W	yield of weapon, KT
$\dot{P}_{max}$	peak thermal flux from detonation, KTs^{-1}
Q	fluence, cal cm^{-2}
$\dot{Q}_{max}$	peak flux, cal $cm^{-2}s^{-1}$

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