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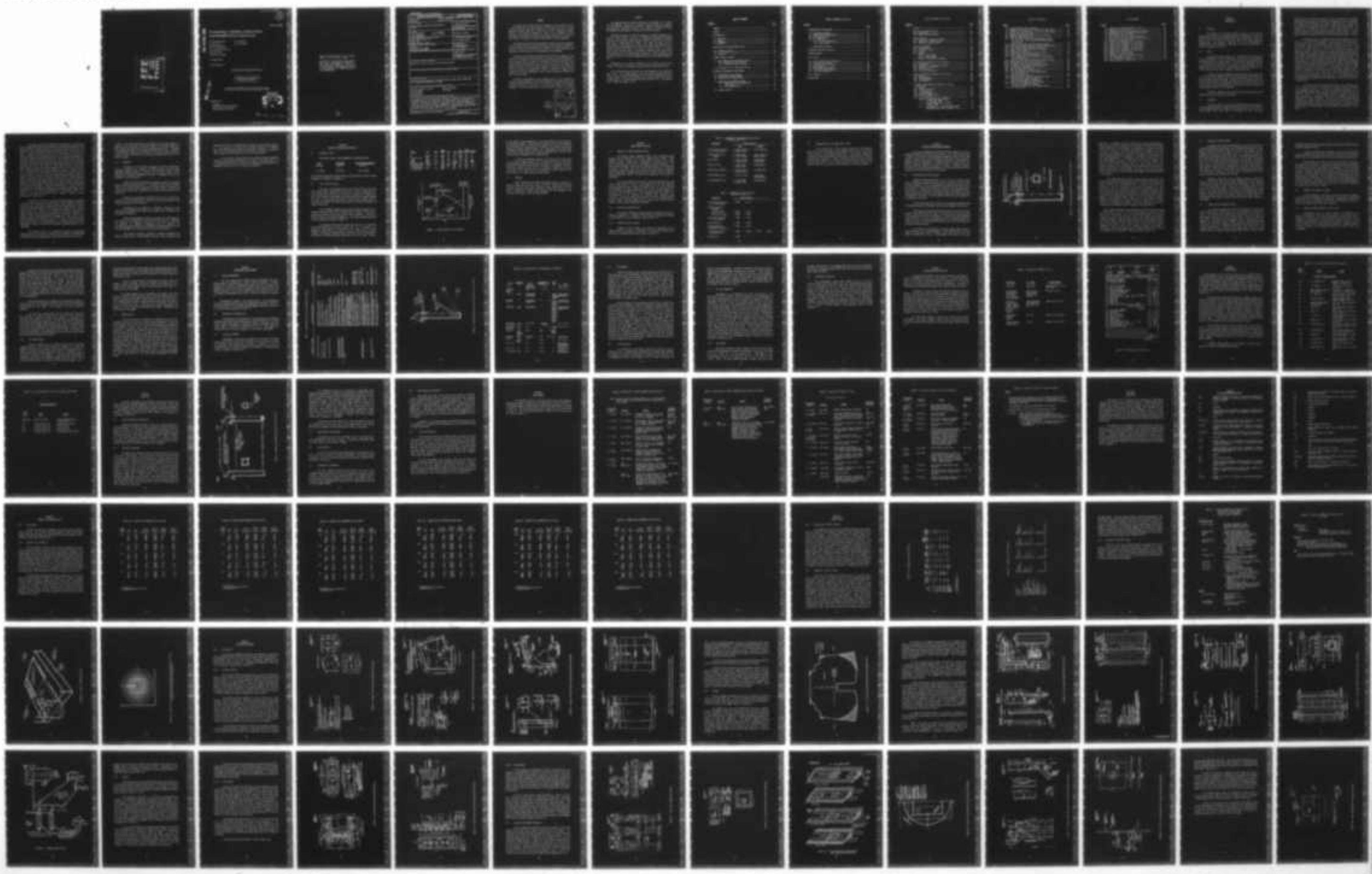

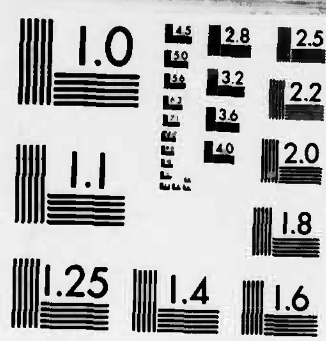

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PLANNING THERMAL RADIATION EXPERIMENTS AT HIGH FLUX

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Technical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers analyses; experimentation; equipment design and fabrication; instrumentation design, selection, fabrication, and tests; and recording equipment selection in preparation for high thermal flux experiments on soil surfaces. The reported effort is preparatory to a continuing program to obtain empirical data and examine parametric relationships on the response of different surfaces and the formation of an overlying thermal and dust layer resulting from the thermal pulse of a nuclear weapon.

SUMMARY

This report covers preparations for experiments to obtain empirical data on the thermal and dust layer created by the thermal pulse of a nuclear detonation through simulation. Specifically, data are required to support analyses of the physical phenomena, as input to the refinement of blast hydrocodes, and to permit the more accurate characterization of surfaces as near ideal or non-ideal with regard to perturbation of blast phenomena.

The reported effort included development of the thermal pulse parameters to be simulated if possible; selection of thermal source; design of apparatus; selection or design of instrumentation; selection of recording equipment; and laboratory and field tests of the performance of the equipment.

The results of the above were selection of the French one megawatt solar furnace as the thermal source capable of simulating the widest spectrum of nuclear thermal pulses of interest, development of apparatus incorporating an ideal light collector-diverter and a four foot long, 6 1/2 inch square test chamber, design of alternative shutter systems for controlling the length and shape of the pulse, instrumentation capable of dynamically measuring the incident flux and the temperature in the air layer, and means of sampling the dust in the air layer.

Calibration and durability tests conducted as part of this preparatory program provided probable flux limits and the bases for equipment redesign for increased probability of survival. The limited preliminary tests included exposure of five soil surfaces to flux and qualitative analysis of response.

PREFACE

The reported work was greatly assisted by the guidance of Dr. George Ullrich, DNA/SPSS, especially in the areas of selecting among the trade-offs and compromises associated with the broad spectrum of desired simulated environments and the physical limitations of available sources.

Planning and conduct of the test program at Advanced Components Test Facility (ACTF), Georgia Institute of Technology Engineering Experiment Station was significantly aided by the participation and advice of Dr. Steven Bomar and Dr. Thomas Brown of GITEES. Drs. Bomar and Brown similarly participated in and supported the testing at the French Centre National de la Recherche Scientifique (CNRS) solar furnace at Odeillo, France. Dr. Claude Royere, CNRS, provided personal involvement and cooperation which permitted early completion of all of the program's objectives. Logistic support of the program in France was assisted by Madame Vassiliyev of the American Embassy, Paris.

Responsible for the overall completion of this report was Mr. Ralph Sievers. The report was prepared by Sonja Ransom and Audra Capas of SAI.

All of the authors were involved with various aspects of the laboratory tests at SAI. Drs. Michael McDonnell and Bruce Gordon conducted the field tests on the ACTF, and Mr. Ralph Sievers and Dr. Gordon conducted the tests on th CNRS furnace. The authors appreciate the assistance of Dr. John Cockayne and Mr. Robert Malinowski of SAI.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1
INTRODUCTION

1.1 Objective

The objective of the effort reported herein was to perform the analyses, design, selection, and tests necessary for readiness for a series of tests on soil surfaces and the overlying air under thermal pulses simulating nuclear bursts. The product of the effort was to be tested apparatus, instrumentation, and procedures, experience, and overall preparedness to perform an extensive test series.

1.2 Scope

The intent of the test program is to gain empirical data leading to fuller understanding of the air layer above a surface which is irradiated by the thermal pulse of a nuclear weapon. The scope of the experimental effort is to provide data for analysis, as input to blast hydrocodes, and for characterization of surfaces for probable extent of their perturbation of the "ideal" blast wave due to their response to the thermal pulse.

The scope included development of apparatus that would permit tests in a vertical, walled chamber which could be instrumented and from which air and dust samples could be withdrawn. The effort was to be based on use of an existing thermal source to simulate peak fluxes and fluences for bursts in the range of one kiloton to ten megatons at scaled ranges of 185 to 1100 feet and scaled heights of burst of 50 to 600 feet.

The effort reported in this report does not include the phase of the project covering the actual soil test series.

1.3 Background

The causes, physical relationships, and prediction of non-ideal air blast phenomena have been of concern since the observation of such effects in nuclear weapon effect tests (NWET) at the Nevada Test Site. The total moratorium on U.S. testing of airburst nuclear detonations has precluded obtaining direct empirical data necessary for modeling, input to hydrocodes, or validating (or modifying) the current categorization of surfaces and predictions of occurrence of "non-ideal" or "heavy dust" blast effects. The thermal pulse is considered to be the cause of these effects. As high explosive detonations do not simulate the nuclear thermal pulse they do not, alone, provide an alternative means for obtaining additional empirical data.

The thermal pulse is an apparent cause of the characteristic "non-ideal" or "heavy dust" blast phenomena. The occurrence or non-occurrence of perturbations of the blast wave have been directly related to the nature of the soil surface, height of burst, and distance from the burst point. With sufficient incident energy and on the "right" surfaces the thermal pulse apparently creates a layer of hotter air than experienced over other surfaces. This "thermal layer" permits formation of a precursor outrunning the Mach stem shock front and permitting increased energy release through that area. The major results are a more gradual pressure rise, lower peak overpressures (although possibly greater overpressure impulses), greatly reduced reflected pressures and reflected pressure impulses, and increased (by possibly 100%) peak dynamic pressures and impulses. An alternative or synergistic effect leading to "heavy dust" blast conditions for the dynamic pressure pulse is scour of the surface by the initial blast pulse and distribution of the scoured material by turbulence in the blast wave. It is probable that both of these mechanisms are enhanced by the thermal pulse on the soil surface prior to shock arrival.

The limited variety of surfaces for which direct, NWET empirical data are available results in uncertainty in offensive targeting and defensive assessment and planning. Current blast prediction guidance, such as contained in the Effects of Nuclear Weapons (ENW), cite types of surfaces for which near-ideal or non-ideal effects would be predicted, and provide predictions for these two extremes. Further, only ideal blast phenomena are predicted for scaled heights of burst greater than 800 feet or ground distances beyond those to which 6 psi overpressure extend. The manuals do not provide bases for predicting other than the extremes of "near-ideal" or "non-ideal."

The physical actions associated with perturbation of the blast wave by the thermal pulse relate to the interaction of the thermal energy with the surface, the air, and the matter from the surface which has been lofted into the air. Actions of concern are those which occur prior to arrival of the blast. Actions which are believed to occur and which may contribute in different extents to perturbing the blast are: the extremely rapid heating of the soil; blowoff of particles from the soil due to the actions of particle fracturing from intense non-uniform heating, the formation of steam from the particles' pore water, the creation of steam under the particles from other water present, and uplift by rapidly expanding void air; emission of particulate or vaporous smoke from organic materials; emission of steam from the soil; re-radiation of heat from the ground surface and lofted particles; heating of the air layer by direct and re-radiated thermal energy, condensing steam, mixing with steam, and surface contact with hot soil particles; and partial shielding of the ground surface from further thermal radiation by absorption or reflection of the energy by the dust or smoke and reflection from the top of the heated air layer (mirage-type action). The complexity of the combination of probable and possible actions generally precludes credible analysis by a first-principles thermodynamic and hydrodynamic model. This results in the need for empirical input to support, verify, or permit modification of such models.

This effort is part of a continuing broad DNA approach to reduction of uncertainties in non-ideal airblast effects. Other elements are development, test, and application of intense chemically-created thermal pulses on surfaces without confinement of the overlying air; combination of a chemical thermal source (e.g., ignition of an aluminum oxide aerosol dispersed in a plastic bag) and a high explosive generated blast to produce a combination of effects, study of other mechanisms or parameters for dust lofting in high explosive testing, and analytical efforts. The latter include the development and application of a blast hydrocode (i.e., the HULL code) with non-ideal perturbations in efforts to duplicate (and explain) phenomena observed in non-ideal NWET.

This specific effort is an outgrowth of analyses and experiments conducted on the U.S. Army's White Sand Solar Furnace (WSSF) which demonstated that blowoff could be generated under laboratory conditions using a solar furnace. The limited total power of the WSSF was insufficient however for tests on soils at the base of a vertical chamber of the height necessary to both transmit the energy and contain the expected thermal layer. The degree of concentration, power, and availability of the solar furnace at Odeillo, France provided an alternative to the WSSF which appeared sufficient for the desired testing.

1.4 Approach

The objective of achieving a readiness to conduct an experimental program of subjecting soil surfaces to simulated thermal pulses has been approached through analysis of desired and achievable thermal pulses; apparatus and instrument development; field test of equipment, facility, and procedures; and test planning.

Thermal flux-time histories were generated based on the desired range of burst conditions (Section 2). Alternative high intensity thermal sources were compared against these desired thermal pulses to select the source on which apparatus, instrumentation, and test planning would be based (Section 3).

Apparatus was designed for compatibility with and to fully use the capabilities of the selected thermal source and to provide containment of the anticipated thermal layer (Section 4).

Instrumentation was selected or, if necessary, developed to integrate with the apparatus and measure and withstand the anticipated test environments (Section 5).

Data recording equipment selection was based on the instrumentation and availability of equipment at the test facility (Section 6). Procedures and equipment for preparing, integrating with the apparatus and instrumentating surface samples to be tested were developed concurrently with the other equipment and in the course of field testing (Section 7).

Field tests of apparatus throughput, equipment performance and durability under high flux and fluences, and test facility operation and support were critical to developing final designs and test planning (Section 8). The results of the field tests included disclosure of equipment durability and performance problems and operational limitations in time for their correction and incorporation in the final test planning.

A plan for soil surface testing was prepared using the equipment, experience, and procedures developed in the course of the above steps. It also incorporated selection of surfaces to be tested and desired thermal pulse parameters to be used in the initial series (Section 9).

SECTION 2

SIMULATING THE NUCLEAR THERMAL PULSE

2.1 Parametric Limits

The desired range of burst parameters are presented below:

Yield (kilotons)	Scaled HOB (ft/KT$^{1/3}$)	Scaled Ground Range(ft) (ft/KT$^{1/3}$)
1 to 10,000	50 to 600	185 to 1100

The principal thermal pulse characteristics associated with a range of these parameters are presented in Appendix 2.

2.2 Flux, Fluence and Time

The shape of the emitted thermal pulse (the relative flux level versus actual time) is determined by the yield of a burst. Modification of this relationship of relative flux with time for the point of reception can occur if the transmissivity between the fireball and point of interest changes with time. It also occurs with change in slant range (slight), angle of incidence and included solid angle due to change in altitude and shape of the fireball with time.

The SAI FIREBALL computer code was used to develop maximum fluxes, fluences, and times of arrival of the shock wave for points on the plane of the ground surface for the desired range of burst parameters. Values for a range of yields are tabulated at Appendix 2. The extreme ranges associated with the conditions are shown in Figure 2.1.

The FIREBALL code does not provide the peak flux or include the fluence associated with the initial thermal pulse. This is regarded as an appropriate approximation for analysis of the thermal pulse on ground surfaces in the study of perturbations of the blast since only approximately one percent of the thermal energy is emitted in the initial pulse. Further,

PARAMETER	LIMIT	YIELD (KT)	GROUND RANGE (ft)	HOB (ft)	TOA (sec)	MAX. FLUX (cal/cm^2sec)	TIME OF MAX. FLUX (sec)	FLUENCE (cal/cm^2)
Flux	Highest	1	185	200	.040	2670	.040	52
Flux	Lowest	10,000	23,699	0	10.4	(7.2)	3.25	35
Flux (not limited by TOA)	Highest	1	185	400	0.11	1270	0.042	75
Fluence	Highest	10,000	3986	12927	4.64	247	2.40	703
Fluence	Lowest	10	399	0	0.020	36	0.020	(0.28)
Time of Arrival (TOA)	Shortest	1	185	0	(0.011)	266	0.011	0.99
Time of Arrival (TOA)	Longest	10,000	23,699	12927	14.5	31	2.40	143
Time of Max.Flux (not limited by TOA)	Shortest	1	185-1100	200-600	0.11-0.67	39-1270	(0.042)	3.6 - 75
Time of Max.Flux (not limited by TOA)	Longest	10,000	12927-23699	0	3.46-10.4	7.2-54	3.25	35 - 83

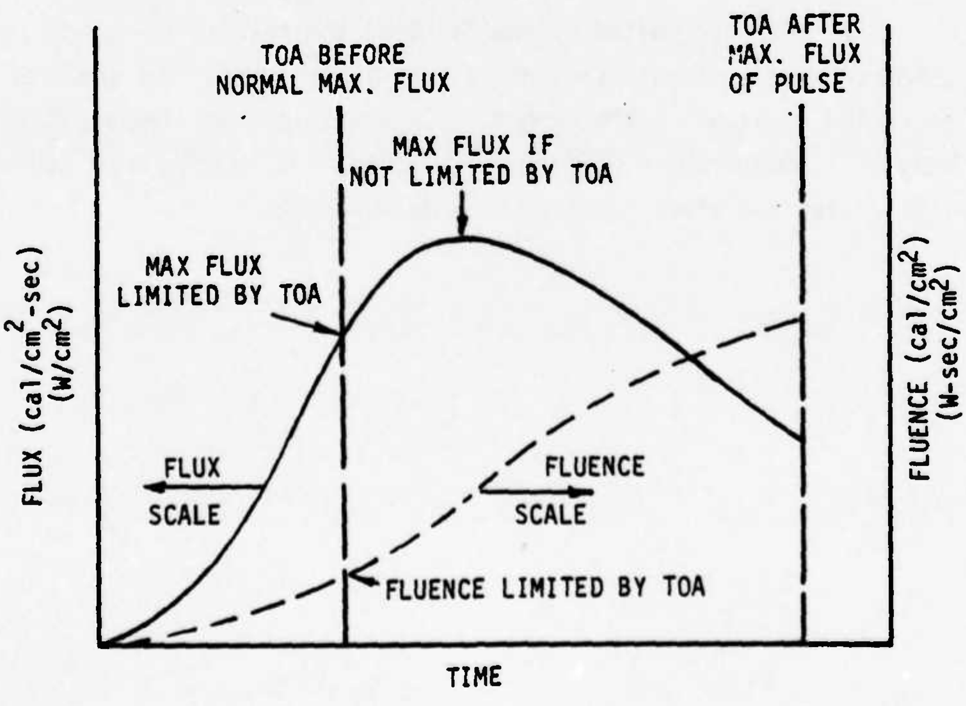


FIGURE 2.1 Extreme Thermal Pulse Parameters.

as the fireball surface temperature is very high during this pulse, much of the radiation emitted is in the ultraviolet region, which is more attenuated by the intervening air than most of the energy in the longer, second pulse ("Effects of Nuclear Weapons" (ENW)). As a consequence, the proportionate contribution of the initial pulse in forming a thermal layer is much less than the one percent represented by the energy release.

It should be recognized, however, that ignoring the initial pulse in this study of thermal action prior to the time of arrival of the shock front may be neglecting much more than one percent of the energy received at the point of concern up until the TOA. The impact is greatest for close-in points where the TOA may occur at a time when only a small fraction of the total energy in the second pulse has been received.

2.3 Spectrum

After formation of the fireball the thermal energy is radiated in a spectral region roughly similar to that of sunlight. The spectrum of thermal radiation received at the ranges of interest is approximately that of a black body at a temperature of 6000 to 7000 degrees Kelvin, but depleted in the ultraviolet and other, shorter wavelengths (ENW).

SECTION 3
THERMAL SOURCE SELECTION

3.1 Requirements Versus Candidate Sources

The desired nuclear detonation thermal pulse simulations were compared against potential high flux and fluence thermal sources. These potential sources include solar, thermochemical reaction, fuel flame, electric heating, and electrical electromagnetic spectrum production. The analyses were performed in advance of this reported contract effort and led to the basis of the effort: use of the French Centre National de la Recherche Scientifique (CNRS) one megawatt solar furnace, located at Odeillo, Pyrennes-Orientale Department, France. The analyses are summarized in this section as background.

The desired features of the source included providing the flux and fluence ranges shown in Section 2 and compatibility with test apparatus configurations that could: contain the thermal layer in a correct radiation and hydrodynamic environment above the soil, test soil surface samples in a horizontal plane and test soils in their undisturbed condition, permit full instrumentation of the response, and provide rapid, repeatable data collection. Simulation of the nuclear thermal pulse would require selecting fluxes, fluences, and pulse shape; use of a source which already had this capability would simplify apparatus development.

3.1.1 Alternative Energy Sources

The primary alternative energy sources considered are shown in Table A3.1 (Appendix 3). A comparison of the principal considerations leading to the selection of a solar furnace is shown in Table 3.1.

3.1.2 Alternative Solar Furnaces

Features of the principal solar furnaces of importance to this effort are shown in Table A3.2. A comparison of considerations leading to the selection of the CNRS solar furnace is shown in Table 3.2.

TABLE 3.1 Comparison of Alternative Thermal Sources
(Reference Table A3.1)

OBJECTIVE	SOURCE RANKING Best	Poorest
Form Thermal/Dust Layer in 4' high chamber	1. Solar Furnaces 2. Radiant Heat	Solar Simulators
Extreme High Flux on Sample	1. Flash Lamps 2. Solar Furnaces	Solar Simulators Radiant Heat
High Fluence	1. Solar Furnaces 2. Radiant Heat	Thermochemical Flash Lamps
Controllability	1. Radiant Heat 2. Flash Lamps	Thermochemical
Development Confidence	1. Solar Furnaces 2. Radiant Heat	Thermochemical
Low Development Cost	1. Solar Furnaces	Flash Lamps Thermochemical
Low Experimental Cost	1. Flash Lamps 2. Radiant Heat	Thermochemical

TABLE 3.2 Comparison of Solar Furnaces.
(Reference Table A3.2)

OBJECTIVE	SOURCE RANKING			
Form Thermal/Dust Layer in 4' high chamber	1. CNRS	2. CRTF		
Extreme High Flux on Sample:				
Through Chamber	1. CNRS	2. CRTF		
Uncontained Sample	1. CNRS	2. WSSF		
High Fluence (through 4' high chamber)	1. CNRS	2. CRTF		
Controllability	1. CNRS	2. WSSF		
Minimum Apparatus Development Constraints	1. CNRS	2. CRTF		
Low Experiment Costs (per test run)	1. WSSF	2. ACTF	3. CRTF	4. CNRS
Availability	1. CNRS			

3.2 Characteristics of the CNRS Solar Furnace

It was evident early in the planning program that the apparatus, data collection and recording, and test operations would have to be tailored to the features of the thermal energy source. The features, capability, resources, and other considerations relating to the CNRS facility at Odeillo are described in Appendix 3. Items of principal concern are cost of furnace time and mobilization on site, large solid angle of source, superior test support capability, high flux, and high speed built-in facility shutters.

SECTION 4
APPARATUS CONFIGURATON DEVELOPMENT

This section summarizes the principal factors leading to the final apparatus design for the initial soil test series. This "final" design, shown in Figure 4.1 was used in the February-March 1980 test series on the CNRS furnace. Results of that series and further modification and development of apparatus are to be presented in subsequent reports of effort under this project. Apparatus nomenclature is shown in Figure 4.1. Appendix 4 presents more details of the apparatus development and includes the apparatus design drawings and specifications used for fabrication.

4.1 Maximizing Flux on the Surface

Obtaining maximum achievable flux on the soil surface through choice of apparatus configuration drove much of the design criteria for the individual components since it was apparent that the peak fluxes desired could not be achieved. A series of trade-offs were required relating concentration, the principle of conservation of optical phase space, and reflection losses. Practical factors of fabrication, maintenance, access, and compatibility with instrumentation were used in choices between alternatives which appeared to be comparable in function.

The basic decisions were selection of the apparatus acceptance area and acceptance angles of incidence, and of the test chamber cross section.

Data were not available on the relative contribution to the flux and pattern of the CNRS furnace focal spot of the energy from various heliostats (or corresponding sectors of the parabola). The focal spot had been mapped (Figure A3.2) and it could be assumed that most of the spread beyond the central area came from the peripheral heliostats, due to their acute angles of incidence on the focal plane.

The principle of conservation of optical phase space provides a quantitative basis for trade-offs between a large acceptance area and a high degree of concentration (ratio of cross-sectional input area to final area

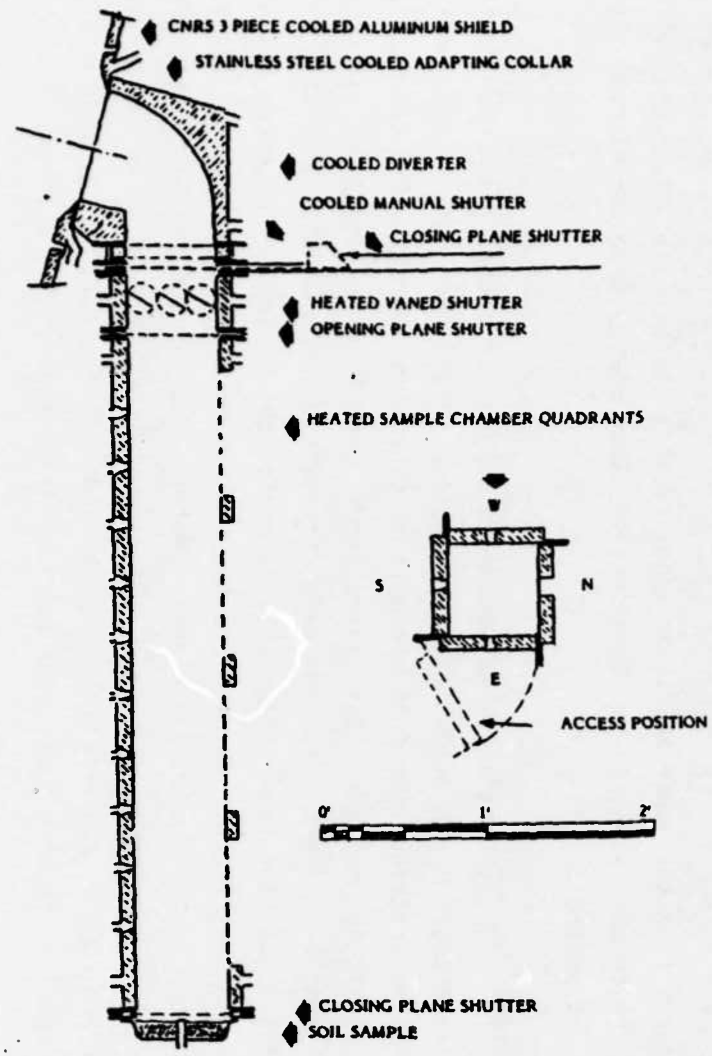


FIGURE 4.1 Apparatus Configuration for Initial Soil Test Series.

minus 1.0). In summary, the principle states that optical energy passing a plane area can only be concentrated at the expense of increasing the average angle of diffusion. Thus, the greater the concentration, the more reflections will occur in transit. Since the average angle of incidence of the CNRS furnace could be assumed to be large, with the energy arriving from a solid angle of approximately 4 to 5 steradians, a low degree of concentration was used (approximately 15%). All concentration was made in the vertical plane due to the diversion of energy in this plane into a vertical chamber. The nature of this diversion indicated that the central sector of the CNRS parabola extending its full height would be the most effective energy source. (Energy from the upper and lower edges of this sector could reach the bottom of the chamber with far fewer reflections than energy from the extreme sides of the parabola.)

No concentration was provided in the horizontal plane due to the extreme angle of the contributing parabola and the (then) lack of data on the relative contributions from parabola sectors. In addition, the fabrication complexities and cost associated with providing concentration in both horizontal and vertical planes were considered to outweigh the uncertain gain which might have been achieved by narrowing the horizontal acceptance angle and widening the acceptance area (achievable by using ideal light collector geometry in the horizontal plane). (Note: data on the parabola's sectors' contributions subsequently available indicates that higher fluxes at the test surface may be achievable by further limiting the acceptance solid angle, increasing the acceptance area and increasing the concentration.)

The collector-diverter as finally configured and fabricated was oriented to receive light from -45^{0} to $+75^{0}$ from the horizontal, had parallel side walls, was of four pieces, each with a water-cooled chamber, and accepted incident light over an area of 6.5x7.5 inches. Inner chamber surfaces were of silverplated copper. Laboratory tests were made to verify acceptance angles. The collector-diverter was also tested on the ACTF and CNRS solar furnaces (Appendices 6 and 7), which led to change in material and manner of construction (from heliarc welded brass to soldered copper) and the addition of a sideport for a calorimeter to provide an index of input flux.

4.2 Transmission Through Chamber

The chamber cross section was determined on the basis of the size of the CNRS furnace focal pattern (Figure A3.2), the estimated diffusivity of the energy exiting the collector-diverter, the height of the chamber, and the estimated reflectivity of the chamber walls. An analysis was made to determine the cross section which would result in the least transmission loss for diffuse optical energy entering the top of a four foot tube. A sectional area of 40 to 50 square inches was determined to be desirable to minimize these losses. A square cross section was used in lieu of a round section to avoid any possible localized flux inhomogenity on the sample surface due to a round section. Fabrication and operational considerations were also favored by a square section, however, this did not govern its selection (the original concept assumed a round chamber would be used).

Laboratory tests were used to determine specular reflectivity. Tests on the ACTF and CNRS solar furnaces (Appendices 6 and 7) measured transmission and operational characteristics of the chamber. These tests led to a totally new design, shown in Figure 4.1, which retained the 6.5 inch square, 4 foot long configuration. Provisions for instrumenting and viewing action in the chamber were made by use of viewports and prepositioned access adapters through the double wall chamber sides which allowed holes up to approximately .625 inches to be made without breaking the water tightness of the chamber.

4.3 Controlling and Shaping the Pulse

Two different shuttering systems were developed to provide for starting and ending the thermal pulse, and for changing the flux during the pulse. The nuclear burst thermal pulse (ignoring the initial peak) is approximately sinusoidal, but with a different angular rate prior to peak than after peak. This form of pulse suggested use of a rotating vane in the chamber, with adjustable speeds of rotation to permit simulating different yield bursts, and with a different speed before and after the peak. The eventual configuration, of three parallel vanes, each driven by its own stepping motor, was chosen to permit extremely short pulses. The three blades and motors could be driven at faster speeds than one blade, considering blade and motor rotational inertia.

A plane shutter design was developed to shield the vaned shutter blades and chamber from light prior to start of the pulse, and to provide a rapid closure at the simulated time of arrival of the blast wave (Section 2).

These shutters were tested for the resulting pulse at the base of the chamber in the laboratory. In addition, potential materials and platings were tested for survival on the CNRS furnace (Appendix 7). This testing led to use of uncooled silverplated copper blades for both the plane and vaned shutters. The plane shutter used an uncooled galvanized steel frame track system and the vaned shutter used a silverplate on copperplate steel, water cooled housing 4 inches high. The opening area of both shutters was 6.5 inches square (note: subsequent use in tests has led to the abandonment of the vaned shutter system for high flux tests due to recurrent operational problems and short life of the blades).

4.4 Adaptation and Support Equipment

The basic apparatus, consisting of the collector-diverter, chamber, and shutters had to be adapted to the CNRS focal room geometry, shielded from energy which was not accepted by the diverter, and provided with means for testing soil samples in efficient test procedures.

4.4.1 Adapting to CNRS Equipment and Focal Points

The CNRS focal point is fixed in space by the alignment of the facets of the parabola. The focal room (depicted in Figure A3.1) floor is adjustable in elevation and in the east-west direction to permit accurate placement of test apparatus. The furnace's flux pattern, Figure A3.2, is such that the opening of the collector-diverter required a surrounding mask to shield the remainder of the apparatus (especially the hoses, cables, and instruments).

A special collar was made to close the opening between the diverter aperture and a CNRS set of water cooled aluminum shields. This collar was made of stainless steel and was water cooled. It was tested on the CNRS furnace for satisfactory performance. A one-half inch thick, uncooled, aluminum plate collar was also prepared as a backup. This was not tested prior to the February-March 1980 soil test series. (The stainless steel collar failed during the initial testing in that series and the aluminum collar was used without incident for the remainder of the series, over 100 more runs. A cooled, silverplated ½ inch thick copper plate was used as the collar for the September 1980 series, also without incident, and with longer full flux exposures.)

The cooling systems were connected to the French hose systems by inserting the 3/4 inch US pressure hose ends into the French hose ends and holding them with hose clamps. This provided a leak free, convenient connection.

The French water cooled shields and the assembled test apparatus were supported on separate frames made of Unistrut (T.M.) which were configured and assembled at the site. The apparatus was assembled over a floor cutout which provided excellent access to the base of the chamber and which could permit chamber heights greater than 12 feet. The support frames are not shown, as the requirement to rigidly support objects in space could be met by many alternatives and is unrelated to the testing. The Unistrut was also positioned however, to provide added rigidity to the plane shutter frames (which experienced problems with binding).

4.4.2 Soil Sample Holders

Three basic designs of soil or surface sample holders were devised (paragraph A4.5). Each of these provided for placement of a 0.625 inch diameter calorimeter at the center of, and flush with, the tested surface. A one-piece pan with a centered copper pipe insert was developed for use in testing at the bottom of the chamber. A two piece pan was developed in conjunction with the US Army Engineer Waterways Experiment Station for use with undisturbed samples, for testing at the bottom of the chamber. With these undisturbed samples the bottom plate, with a centered copper tube, would be added at the test site to the sample; which had been collected with a square, vertical wall cutting box and which was held for shipment between two plane plastic plates.

A third soil sample holder was developed for testing inside the chamber, to permit placement of the soil surface at the lower sill of a viewport and to achieve higher fluxes by positioning the test surface at a higher position in the chamber.

The sample holders used at the bottom of the chamber were held tightly in place from below with pipe sections inserted through Unistrut "Z" sections attached to the chamber's bottom flanges or the lower plane shutter. The in-chamber sample holders were supported by telescoping pipes from the 4th floor of the CNRS test tower. A Vice Grip (T.M.) -type pliers used at the junction to hold the upper pipe permitted rapid removal, replacement, and repositioning of the sample.

4.5 Chamber Heating

It was desired that the apparatus be temperature stabilized for maximum survivability in the high flux and fluence environments. It was also desired, however, that the air over the tested surface behave and be subjected to environments as nearly like a layer of infinite horizontal extent as practicable. As emission and presence of water vapor was considered to be an important aspect of the response, it was important that the chamber walls not be at such low temperatures that condensation would occur during a test run. A system of heating the chamber walls and vaned shutter housing was developed which would permit wall temperatures greater than 100^{o}C, while providing a sufficient heat sink of circulating fluid to prevent harmful rise of wall temperatures beyond this level. The ethylene glycol heating system described in Appendix 4, was designed to meet these critera. (Note: the system performed poorly during the test series due to failure of the heating elements and, later, leaks occurring in the test chamber compartments from other causes).

SECTION 5
INSTRUMENTATION DEVELOPMENT

5.1 Desired Measurements

The test program goals included extensive measurement of actions taking place at the surface and in the air above the surface. The basic objective was to develop instrumentation which would cover as many of the parameters of interest as feasible and practical within state-of-the-art and budget constraints. This section summarizes the principal results of the instrumentation development effort, which is more fully reported in Appendix 5.

Measurements included in the original goals, and instrumentation techniques investigated to provide those measurements are shown in Table 5.1 and discussed below. The instruments and measurements planned for the initial soil test series are depicted in Figure 5.1

5.2 Approaches and Alternatives

Investigations and considerations of the apparently most promising measurement techniques and instrumentation are shown in Table 5.2. As listed, direct, dynamic measurements of apparently important parameters were not always judged to be within the state-of-the-art or at a cost appropriate relative to that of the overall program or of alternative measurements.

5.3 Surface Environment

Measurement of the thermal environment at the plane of the sample surface was provided by mounting a calorimeter flush with the soil surface. The calorimeter uses running water to maintain a reference (in lieu of a separate physical or electronic "icepoint") and generates a continuous analog voltage in response to applied flux.

TABLE 5.1 Measurement Objectives and Approaches Examined.

PHENOMENON TO BE MEASURED	APPROACH/TECHNIQUES/MEASUREMENT	DISCUSSION/DISPOSITION
Incident radiation to the test set-up	Dynamic insolation and furnace calibration	Adopted - Back-up
	Dynamic flux measurement at entrance	Adopted - Primary
Radiation on soil surface	Dynamic flux measurement in plane of soil	Adopted
Total loss of mass from soil	Pre and post run weighing	Adopted
	Shutter against post-TOA fall back	Adopted
Loss of mass from soil with time	Dynamic record of sample-supporting load cell	Not tested
	Comparison of total mass loss versus dust density in chamber with time	Adopted
	Performance of successive runs with time the only variable and comparison of total mass losses	Available
Air temperature above surface as a function of position and time	Dynamic temperature measurement by air sampling thermocouples inserted in chamber at different heights	Adopted
Concentration of particles above surface as a function of position and time	Dynamic measurement of light reflected from particles drawn by vacuum from chamber into tube shielded from flux reflected from chamber	Tested, not adopted
	Pre and post run weight measurement and particle size and count microscope survey of filters sampling chamber at different heights for selected time interval. (Performance of successive runs with time the only variable for time dependency examination).	Adopted
	Use of commercially available dust particle quantity and size dynamic measurement systems	Under laboratory test (field tested in 1980)
	Close-up cinematography of chamber volume at different heights, subsequent particle counts	(Field tested in 1980)
	Selected light wave interference with cinematography	(Field tested in 1980)
Particle temperature and state (both solid and liquid)	Collection of particles on filter for subsequent microscopic examination for shape change (i.e. degree of increased roundness corresponding to extent of melting) and deduction of temperature and phase.	Adopted (for solid particles only)
	Dynamic infrared sensor measurement of material drawn from chamber and collected on filter	Analyzed, not tested
Sound velocity of mixture above soil surface	Dynamic recording of elapsed time between pulse to emitter and selected sensor signal voltage, across, or along chamber. Pulse repeated at fixed intervals.	Laboratory testing in progress (field tested in 1980)
	Dynamic recording of pulse frequency, emitter triggered by sensor (possibly with time delay)	Still under consideration

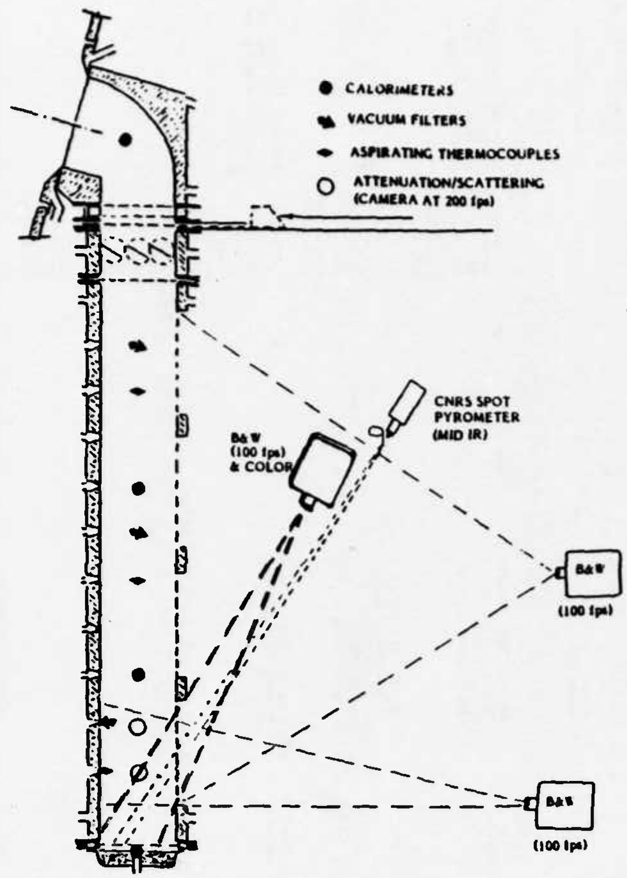


FIGURE 5.1 Dynamic Data Collection for Initial Soil Test Series.

TABLE 5.2 Considerations of Instrumentation Techniques.

MEASUREMENT	RELATIVE COST OF COMMERCIAL INSTR.	STATE-OF-ART	RELATIVE DEVELOPMENT: SUCCESS PROBABILITY	RELATIVE DEVELOPMENT: COST	RELATIVE POTENTIAL ACCURACY	RESOLUTION
Thermal Flux	Low	Accurate measurement by thermocouple - generated analog voltage	Not appropriate		High	Commercial calorimeters, with factory calibration used
Static weight (Filters, test samples, moisture measurement samples)	Low	Accurate by scales and balances	Not appropriate		High	CHRS scale and balance used
Air temperature	Low (thermocouples)	Accurate temp. measurement; prior SAI devel. of aspirated holders. Cooled holder required	High	Low	Moderate (adiabatic temp. changes due to vacuum air flow, and cooled chamber effects)	Commercial thermocouples and SAI fabricated cooled aspirated holder used. SAI laboratory calibration.
Particle Concentration by extent of reflected light	Low	Accurate photocells and light sources. Nothing avail. for high flux environment	Moderate	Moderate	Low (Problems with extraction, shielding from chamber, and calibration)	Limited laboratory testing. Accurate calibration and residual dust big problems.
Particle sampling by vacuum filters	Low (Components)	Adequate (solenoid valves, filters, fittings, etc.)	High	Low	Moderate-collection (Representativeness of sample a question, calibration) Low - Weight change (measuring small difference in relatively large weights, filters subject to handling weight losses and gains	Developed, laboratory tested (limited), and used. Modified and adapted plumbing components.
Microscope particle size, shape and count of particles on filters	Low (microscope)	Inaccurate, Judgmental	Not appropriate Technique definition required		Low	Used in lieu of better means.
Dynamic particle sampling by proprietary commercial equipment	Very High 50-100K	Uncertain	Low	Very High	Possibly high within grain size limits	Adapted for field testing.
Chamber sampling by vacuum bottle	Low - (Components) High - (Determination of contents by commercial lab)	Adequate	High (Sampler)	Low	Possibly moderate (Representativeness of sample)	
Sound velocity by spark emitter and pickup transducer	Low - (Components)	Accurate, in benign environment	Moderate	Moderate	Moderate	Continued testing, problem with chamber environment
Albedo	Low (Photographic photometer)	Accurate	Not Required		High	Commercial photometer used.
Moisture Content of soil	Low	Accurate	Not Required		High	"Speedy" (TM) carbide formation-pressure measurement device used (Feb. '80). Oven drying and balance weighing used (Sep. '80).
Soil grain distribution	Low	Accurate	Not Required		High	Sieve and weighing used for silt and sand. Gravimetric used for clays.
Soil surface temperature	Moderate	Accurate	Not Required		High	CHRS owned Mid-IR and visible range spot pyrometers used.

5.4 Soil Response

A continuous record of soil surface response was provided by use of high speed motion picture photography looking down onto the soil surface and across the soil surface (when the sample surface would be at the level of the viewport sill). In addition, the surface temperature could be continuously measured by a pyrometer looking down onto the surface. (Note: CNRS pyrometers were used in the test series for these. A mid-infrared range pyrometer used in the February-March 1980 test series required removal of the viewport glass or use of a special filter. A KRS-5 filter was used in the September series which avoided having to open the chamber. A CNRS visible range pyrometer, also used in the September series, could view the soil surface through the viewport glass.)

Surface response was also observed statically by pre and post run photographs and measurements of albedo (by photometer), sample strips of the surface collected as microscope slides with adhesive tape pre and post run, and measurement of total weight loss over the course of the run. Although a dynamic measurement of weight loss as a function of time was one of the original measurement objectives it was considered that meaningful measurements could not be provided without extensive development effort. The vibrations of the chamber in response to shutter, valve, and flowing fluid action and the low absolute mass loss would require very precise sensors and insulation from the chamber. Further, fluid flow through the calorimeter mounted on the sample could present a problem. It was considered that dynamic measurement of the amount of dust in the chamber with time could be used with total mass loss to develop an approximation of mass loss with time. Further, a series of tests of the same surface type at different lengths of pulse could provide an indication of loss with time.

5.5 Air Layer Action

It is essential to the program to gain data on actions in the air layer over time. Instrumentation and observation techniques were developed to dynamically record the flux (measured in the plane of the side walls), the air temperature, and any visible growth or rise of clouds or particles (by motion picture photography). Alternative potential dynamic dust particle quantity and size measurement techniques were examined. A dust collection capability acting for pre-set time intervals during the run was developed. (Note: dynamic measurement of dust particle quantity and size distribution with time was attempted by separate techniques in the February-March and September 1980 test series on the CNRS furnace. Results of these tests will be included in the follow-on report.)

5.5.1 Particle Temperature

Measurement of the temperature and state of particles in the thermal/dust layer was desired. No practical means for direct measurement of these were deemed feasible for the test chamber environment for selection, development or testing in the time available, primarily due to the small quantities of particles and the overwhelming influence of the background on any in-chamber measurement. State of the particles and maximum temperatures which may have been reached could be inferred from microscopic observation of particles extracted from the chamber and collected on filters. Through these analyses and with comparison to typical pre-test soil particles of the sample, changes in state and maximum temperatures reached could be roughly inferred from the shape of the particles. For example, if typical particles were angular or sub-angular pre-test and the collected particles were rounded or sub-rounded, some melting would have occured. If the collected particles were round, complete melting would have occured. The possible occurrence of crystals could mean that vaporization had occured. Separate laboratory tests could be used to determine the temperatures at which these states occured, or the fluence required for the corresponding change of shape for the specific tested soil and particle size.

5.5.2 Sound Speed

Measuring the speed of sound through the thermal layer was sought through direct measurement of elapsed time between an emitter on one chamber wall and a sensor set into the opposite wall. Development of this instrumentation was still in progress at the time of the 1980 soil test series. (Note: the sound speed measurement equipment received limited laboratory testing prior to the September 1980 test series and was fielded for that series. No coherent data were obtained in the field test and development efforts were continued.)

5.6 Photographic Recording

Four photographic records were planned as part of the data collection effort for the typical soil test runs. These would be pre and post run still photography of the soil surface, and motion picture photography during runs looking down on the soil surface, looking across the lower viewport sill (which might also be the plane of the soil surface, depending on the type of sample holder being used), and looking at the full height of the test chamber through the vertical line of viewports. The photographic equipment, film, and procedures were developed or selected by the Georgia Institute of Technology Engineering Experiment Station, principally during and as a result of lessons learned in the preliminary testing at CNRS (Appendix 7).

SECTION 6
RECORDING EQUIPMENT SELECTION

The recording equipment for the tests was selected on the bases of type of instrumentation, accuracy, and availability. The preliminary test series on the CNRS furnace demonstrated the suitability of using the facility's strip chart recorders for dynamic measurements. The means of recording for the different measurements to be made are shown in Table 6.1.

Alternatives to the strip chart recorders were considered, but not adopted. An ability to immediately determine whether apparently reasonable data had been collected in a run, as provided by strip chart recording was considered to outweigh potentially more precise measurement which might have been provided by tape recording the analog signals for subsequent playback. A digitizing and recording laboratory computer (used in the SAI laboratory) was not adopted for dynamic recording in the field because of time delay and probable need for an additional member of the test party to operate it if excessive "sun-time" were not to be lost.

Run sheets were prepared to record static data, such as weight measurements of the samples, albedo, moisture content, and observations, and to serve as a checklist of key actions. A typical run sheet is shown in Figure 6.1.

TABLE 6.1 Recording for CNRS Soil Tests

MEASUREMENT	TIME FRAME	RECORDING MEANS
Insolation	Continuous	Dedicated CNRS Circular Disc Chart
Calorimeters, Thermocouples, and Soil Surface Temperature (pyrometer)	Before shutter opening until after shutter closing	CNRS Strip Chart
Mass Loss, Filter Weight Change, Albedo Change, Pre and Post Run Soil Moisture Content	Static measurement made before and after test run	Manually on log sheet
Observations, abnormal events	Post run	Manually on log sheet
Gauge positions, gauge numbers	Pre run	Manually in test book

RUN	DATE	SAMPLE	TIME
50	27/2/80	P10	1630

SCIENCE APPLICATIONS, INC., McLEAN, VA   SOIL TEST LOG CNRS 2/80

SOIL SAMPLE TEST PROCEDURE	TIME	INITIAL
0) PRELIMINARY INFORMATION:		
1) IDENTIFY AND OPEN SAMPLE		
2) INSERT HY-CAL SLEEVE		
3) MOISTURE MEASUREMENT 0.6 %		
4) WEIGH SAMPLE 2190.3		S
5) PHOTOGRAPH SAMPLE 3		B
6) EXPOSURE METER READING 1/125 f 8 EV 13 2/3 160		B
7) COVER SAMPLE		
8) REMOVE COVER		
9) INSERT HY-CAL		
10) INSERT IN TEST EQUIPMENT____ TEST____ REMOVE #_____		
TEST CONDITIONS FLUX _____		
TIME 2		
11) WEIGH SAMPLE 2184.4		
12) COVER SAMPLE		
13) REMOVE FILTERS, BAG		
14) WIPE TUBE, BAG WIPER		
15) REMOVE COVER		
16) PHOTOGRAPH SAMPLE 3		B
17) EXPOSURE METER READING Same _____ E / 13		B
18) MOISTURE MEASUREMENT _________ %		
19) CLOSE SAMPLE FOR SHIPMENT		

NOTES:

FIGURE 6.1 Typical Soil Test Run Sheet.

SECTION 7
SURFACE SAMPLES

Surface samples for the initial soil test series on the CNRS furnace in 1980 were selected by the U.S. Army Engineer Waterways Experiment Station in coordination with DNA and SAI to provide a wide variety of soil types and to include both undisturbed samples and bagged samples (Table 7.1). The undisturbed samples were collected to provide data on dry, desert-type soils of interest. The bagged samples were selected to provide a range of moisture and organic material content and included sands, silts, clays, and highly organic clay.

The undisturbed samples were obtained by pressing a square wall frame into the earth until its flanged top was within about one-half inch of the ground surface. A plastic foam was then sprayed into the frame and a square, plane plastic plate was secured to the top of the frame. The sample was removed from the ground by digging down beside and below it to leave an oversize mass of the material. This was carefully removed by slipping a cutting edge below the sample. On being inverted the material was trimmed to be flush with the cutting edges and a second plane plastic plate was secured onto the frame. A tightly bound "sandwich" was thereby formed, with the original surface protected by the cast-in-place plastic foam.

The undisturbed samples would be opened when it was time for testing. With the sample inverted, the bottom plate would be removed and a sheet copper testing bottom plate with upraised edges and with a central tube to hold a calorimeter would be installed by pressing the tube through the sample. Material displaced by the tube could be used for pre-test moisture content testing.

Disturbed, bagged samples could be prepared by putting the soil into the soil pans or in-chamber sample holders.

TABLE 7.1 Soils Selected For Initial Test Program.

SAMPLE NO.	SOURCE	NATURE
	Disturbed (bagged) Samples:	
P1	Ft. Huachuca, AZ	Reddish & white rocks & pebbles, red sand, dry
P2	Ft. Bragg, NC	Light grey, sandy, very fine, dry
P4	Naval Weapons Station Seal Beach, CA	Grey brown dirt-powder & clumps, soil, slightly damp
P5	Ft. Hood, TX	Black-grey-white, hard clay, rocks, & organic, dry
P6	Barksdale AFB, LA	Reddish brown, baked clay clumps & powder, dry
P7	Jackson Ridge topsoil Vicksburg, MS	Dark clay, humus & organics, very wet
P8	Parker, AZ	Light brown sand, pebbles & small rocks
P9	Luke, AZ	Reddish very fine silt/sand, slightly damp
P10	Ft. Polk, LA	Orange powder (silt) & sand, slightly damp
P11	Parker, AZ	Rock & powder (silt), medium brown, dry
P12	Trading Post, KS	Medium brown clumps 0.1-1.5cm dia. moist, free-field clay, 0-10 ft.
P13	Trading Post, KS	Dark, clumps & powder, dry, free-field clay, 0-½ ft.
P14	Parker, AZ	Light brown powder & clumps, dry, silt 0-5 ft.
P15	Vicksburg, MS	Tan powder granule & clumps moist, loess-silt
P16	Vicksburg, MS	Clay, black clumps, very moist
P17	Camp Shelby, MS	Red-orange-grey clay, clumps, wet

TABLE 7.1 Soils Selected For Initial Test Program (continued).

Undisturbed Samples:

SAMPLE NO.	SOURCE	NATURE
Vegetation	Odeillo, France	To be obtained locally at time of testing
R--I	Ralston Valley, NV	Intermediate alluvium
R--Y	Ralston Valley, NV	Young alluvium
R-4U	Ralston Valley, NV	Playa alluvium
R-U	Ralston Valley, NV	Undifferentiated alluvium

SECTION 8
FIELD TESTS

Apparatus development and survivability testing was addressed by field tests on the Advanced Components Test Facility (ACTF) in July 1979 (report at Appendix 6) and the CNRS furnace in August 1979 (report at Appendix 7). The apparatus and test configurations are shown in Figures A6.1 and A7.1. Changes in apparatus resulting from lessons learned in the testing are illustrated in Figure 8.1.

8.1 Flux Transmission and Magnitude

Determining maximum achievable fluxes was a primary objective of the field testing. The results of this calibration testing are shown in Figures A7.3 and A7.4. The results indicated that the maximum flux at the bottom of the four foot high steel chamber would be approximately 220 watts per square centimeter. Measurements were made with both a GITEES calorimeter array and water reference calorimeters mounted in a special, cooled, silverplate on copperplate steel box which could be placed at the collector-diverter entrance or at different heights within the chamber.

8.2 Apparatus Performance

No problems with apparatus durability were encountered in the test on the ACTF solar furnace. The soft solder holding the one-inch wide silverplated copper strips on the instrument-spacers loosened under high flux on the CNRS tests. No leaks occurred in any of the apparatus during the test program at CNRS as a result of the solar energy, however two serious leaks occurred in joints of the brass collector-diverter in preliminary pressure testing. As the diverter had been fabricated using heliarc butt welds, flexure of the walls under pressure could initiate a crack (and leak) and, especially, renew leaks in repaired joints. The collector-diverter was repaired by a CNRS welder at the facility. This problem led to redesign to use soft soldered copper lap joints which would be less susceptible to failure under flexure and which could be more readily repaired using equipment and skills available at field tests.

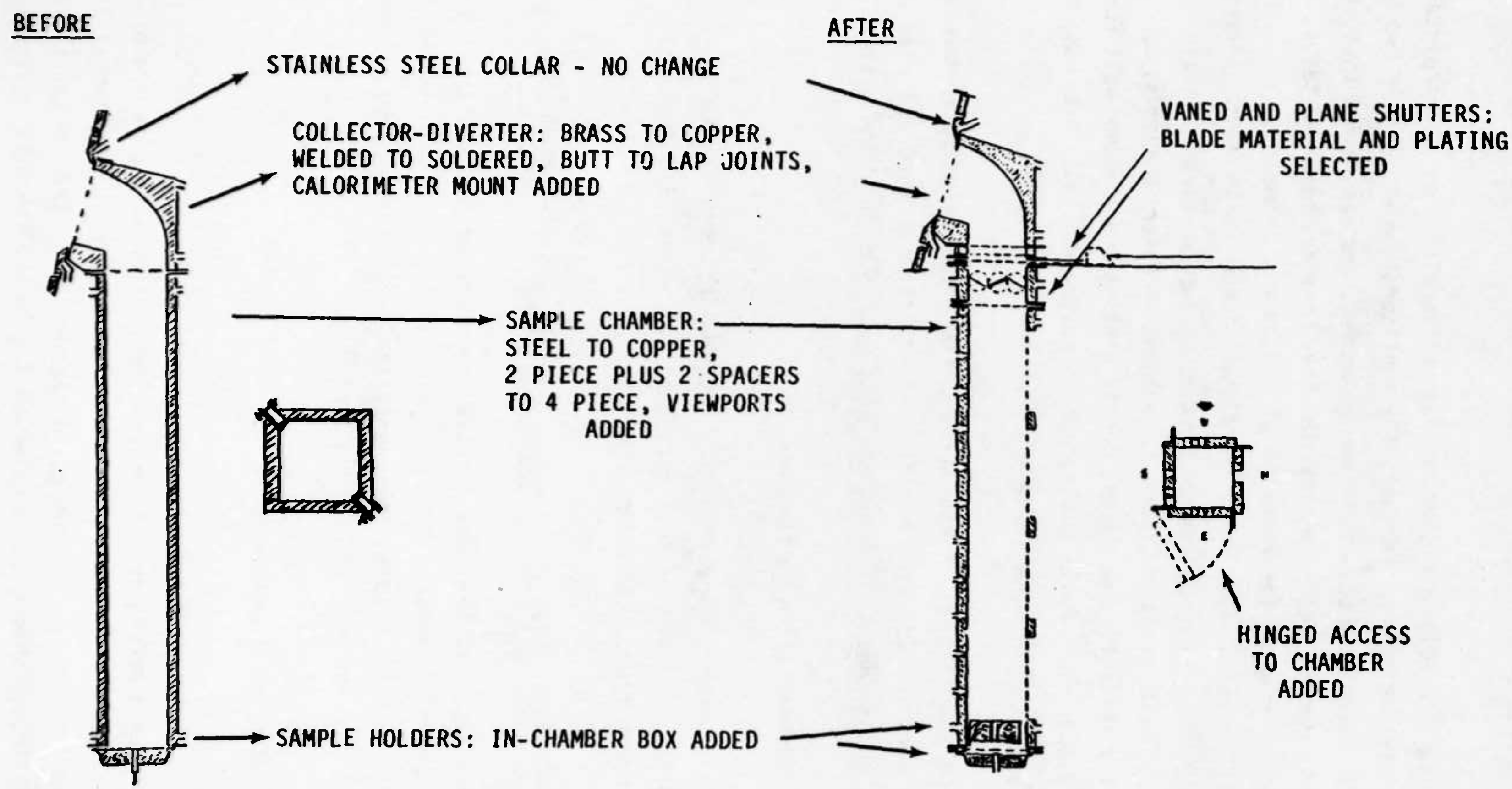


FIGURE 8.1 Apparatus Changes Resulting from Field Testing.

Flux transmission through the silverplate on copperplate steel chamber was disappointing. Further, the configuration using only two halves, each with two walls, and one-inch wide instrument spacers showed that it would not be conducive to ready access to the chamber between tests, or to photographic coverage. The redesign of the sample chamber to one with four separate wall pieces, made of silverplated copper with soft soldered lap joints and a full height line of viewports was a direct result of this experience. These revisions were to achieve greater transmission through higher quality reflective surfaces, permit hinging one chamber wall for ready access, provide for full photographic coverage, and provide greater flexibility in placement of instruments.

The adapting stainless steel collar, the calorimeter box and the soil sample pans for use at the bottom of the chamber were all used without problem and no changes to design were made as a result of the tests.

8.3 Instrumentation Performance

Calorimeters were the only instruments used in the field tests. These performed well and without incident. An aspirating thermocouple tube was tested under flux, also without incident.

8.4 Data Recording

The tests at the CNRS furnace demonstrated the suitability of the CNRS strip chart recorders for dynamic measurement, and provided testing experience to assist in planning operations and personnel responsibilities for the soil test series.

8.5 Photographic Improvements

The small viewport provided near the lower end of one of the instrument spacers proved unsatisfactory for photographic coverage of surface response. It was useless for any coverage of action in the thermal layer of air above the surface (not intended in the design). The potential value of much more extensive photographic coverage led to the viewport design included in the new copper chamber.

8.6 Soils Handling and Analysis

Five tests were made of soils during the testing on the CNRS furnace. These were made to provide a subjective indication of soil response and of material or moisture collection on the chamber walls. The surfaces included soils, sand, and vegetation. The occurrence of condensation on the chamber walls in these tests led to development of a system for heating the chamber walls. Experience in photographing the pre and post run surfaces in these tests led to planning for a floodlit, fixed camera arrangement for the full test series, with a standard color reference to be photographed with each soil surface.

Experience in soil sample preparation, handling, and testing led to a requirement for a minimum of eight sample holders, to avoid testing delays for sample preparation.

8.7 Field Data Reduction

The preliminary testing on the CNRS furnace indicated that there could only be a minimum of data reduction during the testing, if testing were not to be delayed. Use of the strip chart recorders permitted spot checks that data were being obtained and occasional calculation of flux levels being measured. The latter would be especially important where a specific maximum flux were sought, to be achieved by not operating some of the heliostats. Other field data reduction would be desirable to confirm that reasonable results were being obtained.

For most measurements, data reduction could take place after the field test program or possibly during an extended overcast period. Periods of overcast of a day were generally most usefully applied to equipment rehabilitation and balance weighing needed to be done at the site (pre and post run weighing of filters and, if used, soil moisture content specimens) or other on-site action, such as sieve analysis of silty and sandy soils.

SECTION 9
TEST PLANNING

The experience gained in the field testing led to the apparatus configuration shown in Figure 4.1 and instrumentation as shown in Figure 5.1. The planned sequences of mobilization, testing, and demobilization are shown in Table 9.1. The actions associated with a typical soil test run are shown in Table 9.2. The soils that were selected for testing in the initial series are listed in Table 7.1.

TABLE 9.1 Mobilization, Testing, Demobilization Planning.

Basis: Testing starts on a Monday (T-day) and is continuous while there is good sun for an equivalent net of approximately 5-7 sun days.

APPROXIMATE DATE	LOCATION	ACTION	PERSONNEL INVOLVED
T - 4+ mos.	U.S., France	Test dates arranged, soil sample collection, shipment to SAI, return to U.S. arranged	SAI, DNA, GITEES, CNRS, USDA
T - 1-2 mos.	U.S., France	Reservations, rental truck, rental car arranged. American Embassy-Paris log.off. alerted	SAI, Amer. Embassy - Paris
T - 10 days	U.S. airport	Crated soil samples, test equip. delivered to air freight line for shipment to Charles de Gaulle airport (CDG)	SAI
T - 7 days	CDG, France	SAI test personnel arrive CDG, obtain truck, get crates through customs, drive to CNRS Odeillo.	SAI, Amer. Embassy - Paris
T - 6 days	CNRS, Odeillo	Offload, turn in truck (Perpignan) draw car, uncrate, start assembly and bench tests	SAI
T - 5 to T - 3 days	CNRS, Odeillo	Apparatus and instrumentation assembly and test, Design and assembly of support frames. Weigh filters on CNRS balance	SAI
T - 4 to T - 1 days	CNRS, Odeillo	Arrival, uncrating, assembly and test of photographic equipment	GITEES
T - 3 to T - 1 days	CNRS Focal Room	Movement of apparatus, instruments and equipment into position. Layout test support supplies, hose and power connections. Assembly and test of chamber heating system	SAI, GITEES
T	CNRS Focal Room	Connection to CNRS recorders. Calibration and thruput testing of new apparatus. Instrument checkout. Shutter operation under flux testing. Photographic calibration, test film exposure, and development for aperture settings. Trial soil test run.	SAI, GITEES CNRS

TABLE 9.1 Mobilization, Testing, Demobilization Planning (continued).

APPROXIMATE DATE	LOCATION	ACTION	PERSONNEL INVOLVED
T + 1 thru. testing	CNRS Focal Room	Run soil tests (see Table 9.2). Weigh filters on CNRS balance. Check thermocouple calibrations. Repair and maintain apparatus as necessary. Reorient test program based on results, dictates of weather, and/or apparatus/ instrument problems	SAI, GITEES, CNRS
Post Testing	CNRS Focal Room	Clear focal room of all equipment, supplies, etc. as soon as possible (to avoid unused "sun-time"), crate equipment for return to SAI or GITEES. Rewrap and crate soil samples for return via USDA Quarantine Station. Exchange data records with CNRS. Depart (via TWA flight from Barcelona--most convenient and least expensive)	SAI, GITEES

TABLE 9.2 Actions for Typical Soil Test.

Test starts at time "S"

APPROXIMATE TIME	LOCATION	ACTION	INDIVIDUAL INVOLVED
S - 2 hours	Focal Room	Chamber heating system energized.	SAI
S -5 minutes to 2 hours	4th Floor	Soil sample prepared, sample collected for moisture test, adhesive strip sample taken of soil surface.	SAI, CNRS Tech.
		"Speedy" moisture test conducted (if used).	CNRS Tech.
S -10 minutes	5th Floor	Cooling water turned on to correct pressures.	SAI, CNRS Tech.
S - 6-8 minutes	Focal Room	Chamber surfaces wiped and polished (if necessary); shutters cocked, if used.	SAI
S - 5 minutes or earlier, as necessary	Focal Room	Motion Picture Film loaded (magazines suitable for multiple runs).	GITEES
S - 5 minutes	Focal Room	Instruments, pumps energized. Filters installed.	SAI
S - 4 minutes	Focal Room	CNRS pyrometer positioned.	CNRS
		Soil sample surface photographed.	GITEES
		Soil sample surface albedo measured.	GITEES
S - 3 minutes	4th Floor	Soil sample weighed. Calorimeter installed in sample holder, sample positioned at bottom of, or in, chamber.	SAI
S - 1 minute	5th Floor	Outer clamshell door opening initiated.	CNRS Tech.
S - 5 seconds	Focal Room	CNRS shutter countdown initiated, recorder(s) started.	CNRS
S - 1 second	Focal Room	Cameras started.	GITEES
S	Focal Room	CNRS shutters open, SAI controller triggered. Plane and vaned shutter operation triggered (if used), vacuum filter sequence triggered.	SAI

TABLE 9.2 Actions for Typical Soil Test (continued).

APPROXIMATE TIME	LOCATION	ACTION	INDIVIDUAL INVOLVED
S + ¼ to 6 seconds (Simulated TOA)	Focal Room	SAI plane shutter closes CNRS rolling shutters close. CNRS clamshell door closing initiated. Filter valves close.	SAI CNRS
S + TOA + 1-2 seconds	Focal Room	Recorders stopped. Cameras stopped.	CNRS GITEES
S + TOA + 2-4 seconds	4th Floor	Soil sample removed, calorimeter removed, soil sample weighed.	SAI
S + 10 seconds	5th Floor	CNRS shutter air pressure released.	CNRS Tech.
S + 20 seconds	4th Floor	Rolling shutters opened partially, ladder placed against one shutter, concentrator-diverter surfaces examined and wiped (polished if necessary), shutter blades wiped (polished) and repositioned, lower filter removed, placed in bag and bag marked. New filter installed. Ladder removed and rolling shutters closed.	SAI
S + 15 seconds	Focal Room	CNRS Pyrometer moved aside	CNRS Tech.
S + 20 seconds	Focal Room	Filters removed, put in bags, and bags marked. Chamber opened. Walls wiped, wiping cloth bagged, and bag marked. Walls polished if necessary. Shutter blades repositioned. Chamber closed. Shutters cocked.	SAI
S + 1 minute	4th Floor	Soil sample photographed, albedo measured.	GITEES
S + 5 minutes	5th Floor	Recorded traces examined for apparent test validity. Observations recorded.	SAI, CNRS
S + 5 minutes	4th Floor	Adhesive strip sample taken of soil surface. Observations recorded.	SAI

TABLE 9.2 Actions for Typical Soil Test (continued).

NOTES

1. Run Data Sheet book maintained at 4th Floor Sample Handling Station. (Log of observations, gauge positions, etc. maintained by SAI on 5th Floor. Log of motion picture film-run correspondence maintained by GITEES on 5th Floor).

2. Time between soil test runs approximately 6-10 minutes.

3. Maximum number of test runs per day approximately 35-40.

4. Staffing: 1 SAI, 1 GITEES at Focal Room (5th Floor)
   1 CNRS Scientist/supervisor on recorder (5th Floor)
   1 CNRS Technician on Shutters/and door controls (5th Floor)
   1 CNRS Technician operating heliostat field (5th Floor heliostat control room)
   1 SAI, 1 GITEES at 4th Floor (1 CNRS technician if used for sample preparation and concurrent moisture measurements).

SECTION 10
CONCLUSIONS

The product of the apparatus and instrumentation development, laboratory and field testing, and test planning is a viable capability and readiness for extensive soil surface and thermal and dust layer testing. Fluxes as great as those sought are not available, with the practical limit being approximately 50 calories per square centimeter on the soil surface. Pulse shaping is possible with the apparatus, however problems with the developed shutters makes use of the facility shutters much more practical when maximum flux and a given fluence are the principal thermal pulse features to be simulated.

The apparatus and instrumentation developed provide a means for making most of the desired measurements, with the major exceptions being particle temperature and sound velocity of the air-dust mixture above the soil surface. Planned measurements beyond those originally required should enhance the parametric characterization and comparison of surface types and provide additional bases for determining the existence of, and quantifying, potential relationships between burst and surface characteristics and surface and air responses.

APPENDIX 1
GLOSSARY AND CONVERSION FACTORS

ACTF - Advanced Components Test Facility (solar furnace operated by GITEES on campus of Georgia Institute of Technology, Atlanta, Georgia).

Ag - Silver

Al - Aluminum

Bar - Approximately one atmosphere, a measure of pressure (10^6 dyne per square centimeter = 0.987 atmosphere = 29.53 inches of mercury).

Br - Brass

BTU/ft^2-sec - British Thermal Unit per square foot per second, a measure of thermal flux (1BTU/ft^2-sec = 1.135 W/cm^2).

Cal/cm^2 - Gram Calories per square centimeter (equal to 4.184 Watt-seconds per square centimeter). A measure of thermal fluence.

Cal/cm^{2}sec - Gram Calories per square centimeter per second (equal to 4.184 Watts/square centimeter). A measure of thermal flux.

cm - centimeter

CNRS - Centre National de la Recherche Scientifique (French National Research Institute) (specifically the CNRS facility at Odeillo, France).

CRTF - Central Receiver Test Facility (U.S. Department of Energy, 5MW solar furnace operated by Sandia Corporation on Kirtland AFB, Albuquerque, N.M.).

Cu - Copper

DNA - Defense Nuclear Agency

ENW - "Effects of Nuclear Weapons", Manual edited by S. Glasstone and P. Dolan, published by U.S. Departments of Energy and Defense, 1977.

G - Gauge: U.S. Standard Gauge for sheet steel, American Wire Gauge for copper, brass, or aluminum sheet.

g - grams

GITEES - Georgia Institute of Technology Engineering Experiment Station.

GZ	-	Ground zero, the point on the ground under or at which a nuclear burst occurs.
HOB	-	Height of burst above ground level of a nuclear detonation.
Hz	-	Hertz, cycles per second.
KT	-	Kiloton (TNT equivalent).
kW	-	Kilowatt
M	-	Meters
mm	-	millimeter
MW	-	Megawatt
Ni	-	Nickel
NWET	-	Nuclear Weapon Effect Tests
oz	-	Ounce, ounces per square foot, a gauge of sheet copper thickness.
psi	-	Pounds per square inch (gauge).
T.M.	-	Trademark
TOA	-	Time of arrival, time from instant of nuclear detonation until the shock front arrives at the point of concern.
v	-	Volts
W	-	Yield of a nuclear burst in Kilotons.
W/cm^2	-	Watts per square centimeter (equal to 0.239 cal/cm^2-sec) a measure of flux.
$W/cm^2/Sec$	-	Watt-seconds per square centimeter (equal 0.239 cal/cm^2). A measure of thermal fluence.
W/M^2	-	Watts per square meter. A measure of insolation.
WSSF	-	White Sands Solar Furnace, operated by U.S. Army on White Sands Missile Range, N.M.

APPENDIX 2

THERMAL PULSE CHARACTERISITCS

A2.1 Requirements

Original and modified requirements for nuclear burst simulation stated yields of 1, 10, 40, 200, 1,000, and 10,000 KT, with scaled ground ranges of 185, 400, 600, 800, and 1,100 ft/KT$^{1/3}$, and scaled heights of burst (HOB) of 50, 200, 400, and 600 ft/KT$^{1/3}$.

A2.2 Thermal Pulse Parameters

The SAI FIREBALL program was used to obtain parameters associated with the thermal pulse and its time of arrival at the point of interest. This program ignores the initial pulse, which may contain about one percent of the total fluence, and which has a spectrum which reduces its relative impact in causing thermal responses at the ranges of concern. The parameters calculated using the FIREBALL program were flux in calories per square centimeter per second over the time of the pulse until arrival of the blast wave, and fluence received with time. Time of arrival of a non-ideal blast wave was calculated for the yield, range, and HOB to identify the peak flux and fluence experienced until that time as being of the most concern for this study.

Extracted data showing maximum fluxes and fluences until blast wave time of arrival are shown in Tables A2.1 through A2.6. Generally, maximum fluxes are shown to occur at a common time for a single yield. In cases where the flux is still increasing at the time of arrival of the blast wave the flux at that time is shown. For some relatively close in points the time of maximum flux occurs later than for the maximum flux received at further points, due to the effect of fireball growth and the amount of solid angle occuped by the fireball.

TABLE A2.1 THERMAL PULSE PARAMETERS FOR 1KT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX (cal/cm^2/sec)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
185	0*	0.011	266	0.011	0.99	90
	50	.018	838**	0.018	4.9	272
	200	.040	2670	0.040	52	1300
	400	.11	1270	0.042	75	682
	600	.22	659	0.042	51	232
400	0	.070	267	0.057	10	143
	50	.091	334	0.049	18	198
	200	.11	608	0.042	37	336
	400	.18	601	0.042	44	244
	600	.28	435	0.042	36	129
600	0	.16	71	0.057	5.7	36
	50	.20	97	0.049	8.0	40
	200	.22	215	0.042	17	77
	400	.28	290	0.042	24	86
	600	.36	267	0.042	23	64
800	0	.28	29	0.057	2.9	10
	50	.33	40	0.049	3.8	12
	200	.35	97	0.042	8.3	24
	400	.40	152	0.042	13	33
	600	.48	163	0.042	15	31
1100	0	.48	11	0.057	1.2	2.5
	50	.44	15	0.049	1.6	2.9
	200	.57	39	0.042	3.6	6.3
	400	.61	68	0.042	6.3	10
	600	.67	83	0.042	7.8	12

* Fireball Radius exceeds Ground Range
** Determined by TOA

TABLE A2.2 THERMAL PULSE PARAMETERS FOR 10KT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX ($cal/cm^2/sec$)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
399	0*	0.020	36	0.020	0.28	140
	108	.038	416**	0.038	5.3	139
	431	.086	1830**	0.086	65	756
	862	.24	993	0.115	141	588
	1293	.46	515	0.115	102	222
862	0	.15	252**	0.151	16	107
	108	.20	296	0.138	34	170
	431	.24	475	0.115	68	283
	862	.38	470	0.115	86	226
	1293	.59	340	0.115	72	122
293	0	.35	65	0.156	12	34
	108	.43	83	0.138	17	40
	431	.47	168	0.115	33	70
	862	.59	227	0.115	48	81
	1293	.78	209	0.115	47	60
1724	0	.60	26	0.156	6.6	11
	108	.71	35	0.138	8.6	12
	431	.75	76	0.115	17	23
	862	.86	119	0.115	27	31
	1293	1.02	128	0.115	30	29
2370	0	1.04	9.8	0.156	2.9	2.8
	108	1.19	13	0.138	3.7	3.1
	431	1.22	30	0.115	7.5	6.1
	862	1.31	53	0.115	13	9.9
	1293	1.45	65	0.115	16	11

* Fireball Radius exceeds Ground Range
** Determined by TOA

TABLE A2.3 THERMAL PULSE PARAMETERS FOR 40KT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX (cal/cm^2/sec)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
633	0*	0.029	34	0.029	0.5	18
	171	0.061	297	0.061	6.2	102
	684	0.14	1310	0.136	69	493
	1368	0.37	857	0.211	202	546
	1710	.54	605	.211		329
	2052	0.74	445	0.211	152	205
1368	0**	0.24	219	0.239	20	83
	171	0.31	279	0.256	47	152
	684	0.39	413	0.212	98	251
	1368	0.61	405	0.211	128	210
	2052	0.94	294	0.211	110	117
2052	0	0.55	61	0.287	20	36
	171	0.68	77	0.256	27	40
	684	0.75	146	0.212	50	67
	1368	0.94	196	0.211	73	78
	2052	1.24	180	0.211	73	59
2736	0	0.95	25	0.287	11	12
	171	1.13	32	0.256	14	12
	684	1.19	66	0.212	26	22
	1368	1.36	103	0.211	42	31
	2052	1.62	110	0.211	47	29
3762	0	1.64	9.2	0.287	4.8	2.9
	171	1.89	12	0.256	6.0	3.2
	684	1.93	26	0.212	12	6.2
	1368	2.07	46	0.211	20	9.7
	2052	2.30	56	0.211	25	11

* Fireball Radius exceeds Ground Range
** Determined by TOA

TABLE A2.4 THERMAL PULSE PARAMETERS FOR 200KT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX (cal/cm^2/sec)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
1062	0*	0.058	37	0.058	1.08	19
	292	0.10	151	0.100	5.4	54
	1170	0.23	826	0.228	70	304
	2339	0.64	729	0.429	295	461
	3509	1.26	376	0.429	244	191
2339	0	0.41	171**	0.048	23	56
	292	0.53	266	0.524	62	117
	1170	0.66	352	0.433	144	218
	2339	1.04	342	0.429	198	190
	3509	1.61	247	0.429	177	110
3509	0	0.94	58	0.592	32	34
	292	1.17	70	0.524	45	38
	1170	1.28	124	0.433	80	63
	2339	1.61	165	0.429	118	73
	3509	2.13	152	0.429	119	56
4678	0	1.62	23	0.582	19	12
	292	1.93	29	0.524	24	12
	1170	2.03	56	0.433	43	21
	2339	2.32	86	0.429	69	30
	3509	2.78	93	0.429	78	28
6432	0	2.81	8.5	0.582	8.7	3.1
	292	3.23	11	0.524	11	3.4
	1170	3.31	23	0.433	19	5.7
	2339	3.55	39	0.429	34	9.6
	3509	3.93	47	0.429	42	11

* Fireball Radius exceeds Ground Range
** Determined by TOA

TABLE A2.5 THERMAL PULSE PARAMETERS FOR 1MT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX (cal/cm^2/sec)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
1850	0*	0.12	35	0.118	2.0	17
	500	0.18	112	0.178	7.8	43
	2000	0.40	502	0.397	73	183
	4000	1.10	608	0.871	402	365
	6000	2.15	316	0.871	375	174
4000	0	0.70	123**	0.699	27	39
	500	0.91	225**	0.195	77	85
	2000	1.13	301	0.887	197	174
	4000	1.78	288	0.871	308	173
	6000	2.75	208	0.871	284	103
6000	0	1.61	56	1.18	50	31
	500	1.99	65	1.07	75	38
	2000	2.18	106	0.887	125	57
	4000	2.75	139	0.871	189	69
	6000	3.64	128	0.871	193	53
8000	0	2.77	22	1.18	32	12
	500	3.30	26	1.073	42	13
	2000	3.47	48	0.887	71	20
	4000	3.97	73	0.871	113	28
	6000	4.75	78	0.871	128	27
11,000	0	4.80	7.9	1.18	15	3.1
	500	5.52	9.9	1.07	19	3.4
	2000	5.65	19	0.887	33	5.8
	4000	6.06	32	0.871	56	9.2
	6000	6.72	40	0.871	70	10

* Fireball Radius exceeds Ground Range
** Determined by TOA

TABLE A2.6 THERMAL PULSE PARAMETERS FOR 10MT BURST

GROUND RANGE (ft.)	HOB (ft.)	TOA (sec.)	MAX FLUX (cal/cm^2/sec)	TIME OF MAX FLUX (sec.)	FLUENCE TO TOA (cal/cm^2)	AVERAGE FLUX (fluence/TOA)
3986	0*	---	---	---	---	---
	1077	0.30	21	0.299	3.1	10
	4308	0.86	234**	0.856	73	85
	8617	2.36	474**	2.36	565	239
	12,927	4.64	247	2.40	703	152
8618	0	1.51	70**	1.51	32	21
	1077	1.97	148**	1.97	94	48
	4308	2.43	242**	2.43	269	111
	8617	3.82	225	2.40	548	143
	12,927	5.93	163	2.40	534	90
12,927	0	3.46	54	3.25	83	24
	1077	4.29	59	2.99	145	34
	4308	4.70	85	2.49	231	51
	8617	5.93	109	2.40	356	60
	12,927	7.80	100	2.40	380	49
17,235	0	5.96	20	3.25	68	11
	1077	7.12	23	2.99	88	12
	4308	7.47	38	2.49	142	19
	8617	8.55	57	2.40	223	26
	12,927	10.2	61	2.40	256	25
23,699	0	10.4	7.2	3.25	35	3.4
	1077	11.9	8.7	2.99	42	3.5
	4308	12.2	15.4	2.49	68	5.6
	8617	13.1	25.0	2.40	114	8.7
	12,927	14.5	31.0	2.40	143	9.9

* Fireball Radius exceeds Ground Range
** Determined by TOA

APPENDIX 3
THERMAL SOURCES

A3.1 Comparison of Potential Sources

This project was based on use of the CNRS one megawatt solar furnace from its initiation, this discussion summarizes those considerations which led to that direction. The simulation of high flux thermal pulses could conceivably be made using many different sources, or even combinations of sources. The principal alternative sources are described in Table A3.1. The selection of a solar furnace over other means was based on availability, peak flux, and unlimited fluence (governed only by the time of exposure and flux). Solar furnaces are inconvenient in that equipment and personnel must be mobilized at a remote location for a test program of limited length subject to weather vagaries. A dedicated, laboratory, high flux and fluence capability would permit greater flexibility, allow for the repair of equipment or analysis and redirection without costing expensive sun time or personnel travel expenses, and permit more orderly test programming. With the exception of the weather vagaries, and with a reduced cost for usage, the above factors also apply to use of existing solar simulators or radiant heat facilities.

A3.2 Comparison of Solar Furnaces

Table A3.2 lists features of concern of the four principal solar furnace test facilities. The basic choice for this test program was between the Central Receiver Test Facility (CRTF) and the Centre National de la Recherche Scientifique (CNRS) solar furnace at Font Romeu - Odeillo, France (Odeillo is a division of Font Romeu). The large solid angle of the CNRS parabola as seen from the focal point indicates that little concentration can be attempted. The principle of conservation of optical phase space must be considered in determining the extent of concentration. The principle states that if the area through which the energy passes is reduced the angular diversion will increase, and, conversely, that greater collimation of the energy can only be achieved at the expense of passing through a greater area. The relatively small solid angle of the CRTF source field indicates that concentration almost 5 times could be used and not exceed the diffusivity of

TABLE A3.1 Comparison of Thermal Sources.

SOURCE	MAXIMUM FLUX ($cal/cm^2/sec$)	INCIDENT AREA (M^2)	FLUX SPECTRUM (Black Body)	FLUX CONTROL	RELATIVE FLUENCE CAPABILITY	SOURCE AVAILABILITY	RELATIVE DEVELOPMENTAL AND ADAPTATION EXPENSE	RELATIVE EXPERIMENTAL EXPENSE
Solar Furnaces	30-360	*0.03-0.10 **up to 1.0	5600°K	Mech.	Unlimited	4 (2 Principal)	Low	High
Solar Simulators	0.024-24	up to 42	5600°K	Elec.	Unlimited	9 or more	Low	Moderate
Radiant Heat Facilities	20-100	up to 5	2000°K	Elec.	Unlimited	6	Low	Moderate
Thermochemical Reactions	20-200	depends on cost	2600°K	Ignitions	v. Low	Unlimited	Moderate	High
High Intensity Flashlamps	up to 4000	depends on cost	9000°K	Elec.	v. Low	Concept only	High	Low
Hybrid, combination of some of above for high flux and fluence	up to 4000	up to 1.0	2000°K to 9000°K	Mech.-Elec.	Unlimited	Concept only	Very High	High

* Flux above $100 cal/cm^2/sec$.
** Flux approximately $30 cal/cm^2/sec$.

Table A3.2 Comparison of Solar Furnaces

Abbreviation:	CRTF	ACTF	WSSF	CNRS
Operator:	Sandia Corp.	Ga. Inst. of Tech.	U.S. Army	CNRS-Odeillo
Location:	Kirtland AFB,N.M.	Atlanta, GA.	White Sands Msl. Rg.	Font Romeu,France
Collecting Area, m^2	8257	532	132	2835
Total Energy, kW	5000	325	30	1000
Focal Plane Orientation:	Vertical	Horizontal	Vertical	Vertical
Energy Incidence (Approx.)				
Horizontal:	90^o	348^o	46^o	160^o
Vertical:	-14^o to 65^o	-45^o to -83^o	$+23^o$ to -23^o	$+75^o$ to -45^o
Approximate Included Solid Angle, Steradians	1	1.8	0.6	4 3/4
Concentration				
50% Energy, diam. m	2	.5	.08	.25
95% Energy, diam. m	3	1.0	.15	1.0
Peak Flux W/cm^2	240	125	400	1600
Shutters	No	Yes	Yes	Yes
Access During Test	No	Yes	Yes	Yes
Working Area	1 level, spacious	1 level, limited	1 level, limited	2 levels, spacious

the CNRS furnace. This would assume, however, that the usable energy of the CNRS furnace was received uniformly from over the contributing solid angle. This was not probable, although at the time of the choice of furnaces the actual distribution of flux contribution from the CNRS parabola had not been mapped. The selection of the CNRS one megawatt solar furnace for the test program was made on the basis of maximum achievable flux on the test sample surface. Test operation and test working area convenience were not considered in the choice of furnace (these favor the CNRS facility).

A3.3 Features of the CNRS Furnace

Table A3.3 lists the principal additional characteristics of the CNRS facility of concern to the soil test program. Figure A3.1 is a sketch showing key features of the testing area of importance to the soil test program. Figure A3.2 is the flux distribution of the CNRS furnace on the vertical focal plane, with the 6½ by 7½ inch aperture of the collector-diverter (paragraph A4.2) superimposed.

TABLE A3.3 Features of CNRS Solar Furnace Facility (In addition to those shown in Table A3.2 and Coordination/ Logistics data at Appendix 8)

EXPERIMENTAL AREA

Electric Power:	240v 50Hz (Commercial Power) 120v 60Hz, 208v 60Hz 3 phase "Y" (GITEES 10kw Motor Generator).
Compressed Air:	12 Bars (Approximately 170 psi)
Vacuum :	Portable Vacuum Pumps Available
Water :	8 high volume separately valved outlets with individual pressure gauges (to approximately 50 psig)
Water Drainage:	Hose to below test platform level.
Shutters :	Slow (1 minute) Swinging Exterior Doors Fast (compressed air operated) Rolling, Water Cooled Shutters, located five inches in front of vertical focal plane.
Access :	Freight elevator, as wide and deep as test area. Small personnel elevator.
Closed Circuit TV :	Monitors, Camera, Recording. Observation platform in parabola face opposite focal room.
Recording :	Multiple, multi-trace strip chart recorders. Continuous insolation record.
Measurement :	Precision Balance Scales (5 Kg range).
Dimensions :	CNRS Water Cooled Aluminum Shields. Side Pieces - 59.5 x 119 x 3cm Center Piece - 50 x 119 x 3cm, with centered 37cm diam. hole. Cutout in deck below focal point - 165cm deep, 140cm wide, 142cm width between outside of vertical flanges 2½cm high. Cutout is open to front. Sectional cutout covering grid available. Focus is approximately 170cm above level of adjustable (elevation and east-west direction) steel deck.

SUPPORT

Test Area Shop:	Electric hand tools Drill press. Oxyacetylene Torch Set Hand tools.
Professional Shop Support :	Welding (include heliarc) Full machine shop.

TABLE A3.3 Features of CNRS Solar Furnace Facility (continued)

SUPPORT (cont.)

Instrument Availability:	Microscopes (Spectrometer, chemical analysis, etc. laboratory capability at the facility).

OPERATION

Facility can be scheduled for use year round.
Staff reduced in August.
Local hotels limited from mid-October to mid-December.
Test Day - generally while insolation greater than 800 W/M^2 less approximately 90 minutes French lunch period.

COST

For Sun Time on Facility, covering CNRS Facility and Support (1980).
Approximately $10 per available test minute.

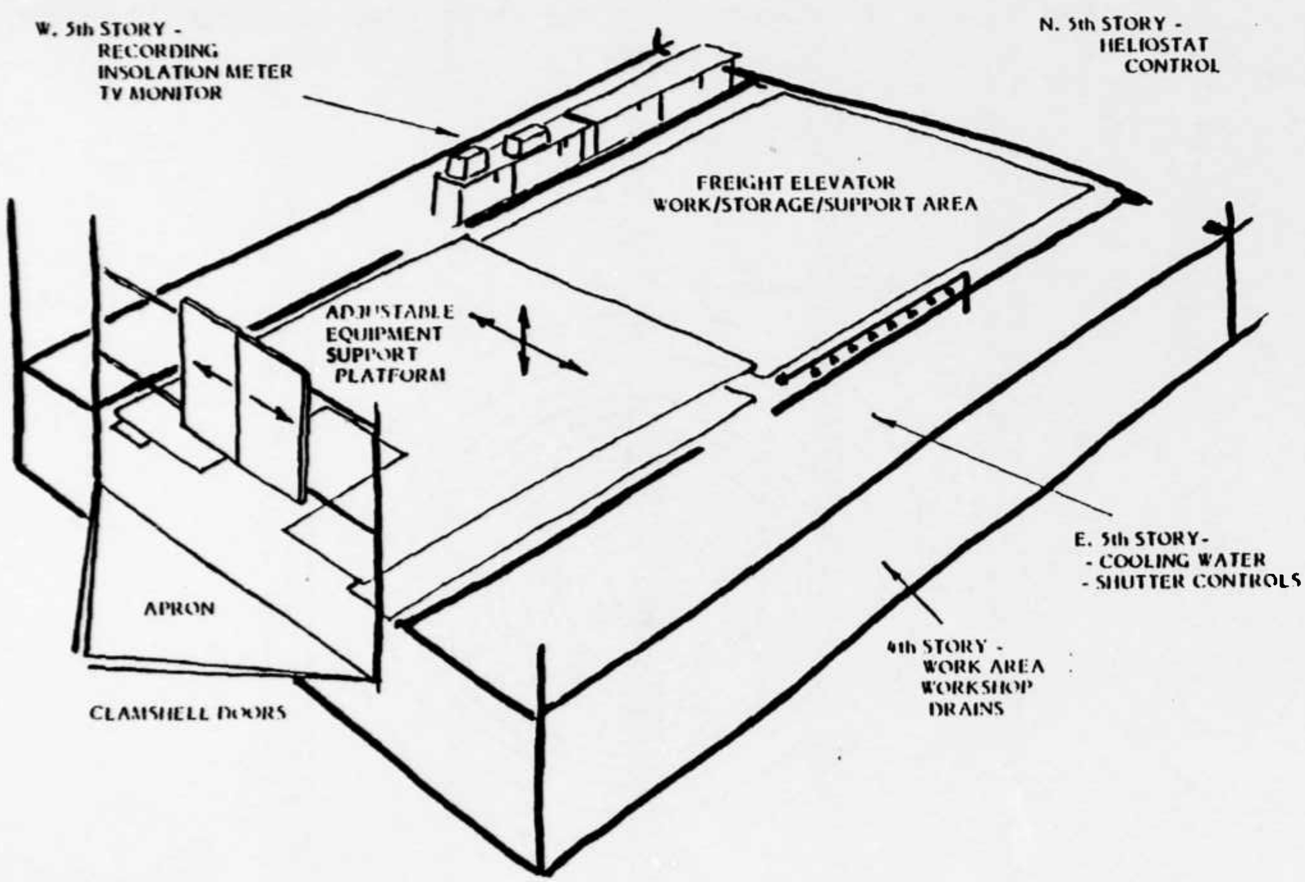


FIGURE A3.1 Sketch of CNRS Testing Area.

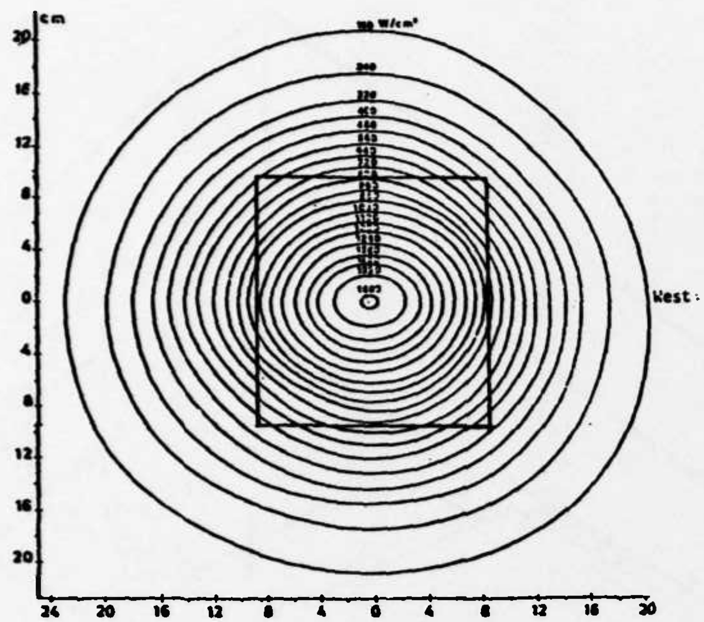


FIGURE A3.2 CNRS 1 MW Solar Furnace Flux Distribution In the Vertical Focal Plane (Collector-Diverter Aperture Superimposed).

APPENDIX 4
APPARATUS DEVELOPMENT

A4.1 Introduction

The apparatus development described in this appendix was associated with preparation for the initial soil test program, which was conducted in February-March 1980 on the CNRS furnace. Apparatus nomenclature and positions are as shown in Figure 4.1. The apparatus components are described in the same general sequence used in Section 4.

A4.2 Collector-Diverter

The collector-diverter configuration was driven by the desire to optimize light collected in the focal plane of the CNRS furnace, and by the need to transmit it in a vertically downward orientation into the top of the 6½ inch square test chamber section. Design and assembly techniques were guided by a perceived need for full water cooling of exposed, inner surfaces. Details of the shield configuration or necessary adapting collars were not available at the time of design, with the result that a mating collar had to be designed separately to match the CNRS water cooled shields.

The collector-diverter prepared for use on the first soil test program is shown in Figure A4.1. The copper collector-diverter shown ("beam diverter") was the third generation, all of which had identical geometry for the inner reflecting surfaces. The first collector-diverter was built as one unit, of steel with 4 mils copper plating and 2 mils of silver plating. The reflecting surfaces of this diverter were generally poor and very hard to polish. Specular reflectances of 0.78 to 0.92 were measured from selected, polished surface areas. Additional plating was performed to correct the poor areas, consisting of a copper flash and four mils of silver. Reflectances of 0.84 to 0.92 were then measured, but areas of poor polish remained.

A four piece brass collector-diverter was fabricated, essentially in the configuration shown in Figure A4.1, except that plates were joined by heliarc welded butt joints and there was no instrument access port in the West

SAI COPPER BEAM DIVERTER
26 September 1979
Page 1 of 9

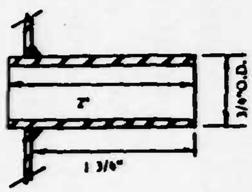
NOTES:

1. ALL SHEET MATERIAL 16oz COPPER, COLD ROLLED OR SOFT.
2. ALL JOINTS SOLDERED. ALL SHEET METAL JOINTS LAPPED, EITHER OVERLAP OF BY 1/2" WIDE 3/4 PIECE LAMPING 2 PIECES TO BE JOINED.
3. PIPE SECTIONS 3/4" O.D. COPPER
4. SURFACES UNFINISHED BUT WITH BURRS REMOVED.
5. PRESSURE TEST: WATER AT 10PSIG OR 25' HEAD
6. 4 PIECES REQUIRED

   1 - LOWER THROAT (SOUTH) PAGES 2,3
   1 - UPPER THROAT (NORTH) PAGES 6,7,8,9(CURVE)
   1 - WEST SIDE PAGES 2,4,5
   1 - EAST SIDE PAGES 2,4,5

   (EAST SIDE IS MIRROR IMAGE OF WEST SIDE)

7. PAGE 9 (ORIGINAL DRAWING) IS FULL SCALE REPRESENTATION OF CURVE FOR UPPER THROAT SURFACE
8. TYPICAL PIPE DETAIL: EAST SIDE OF LOWER THROAT LOWER PIPE OF UPPER THROAT AND LOWER PIPES OF EAST AND WEST SIDES



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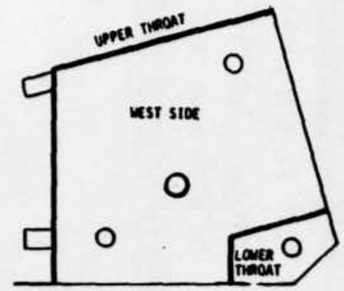
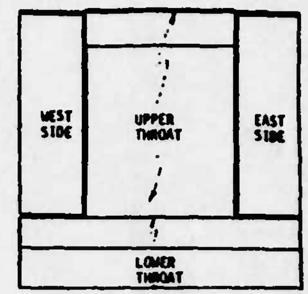
SAI COPPER BEAM DIVERTER
12 SEPTEMBER 79
PAGE 2 OF 9

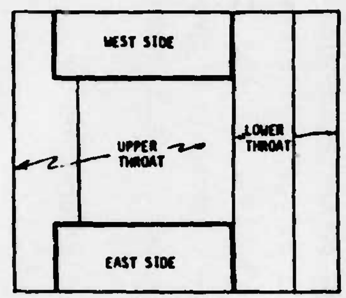
EXTERNAL VIEWS - ASSEMBLED



WEST VIEW



FRONT (S) VIEW



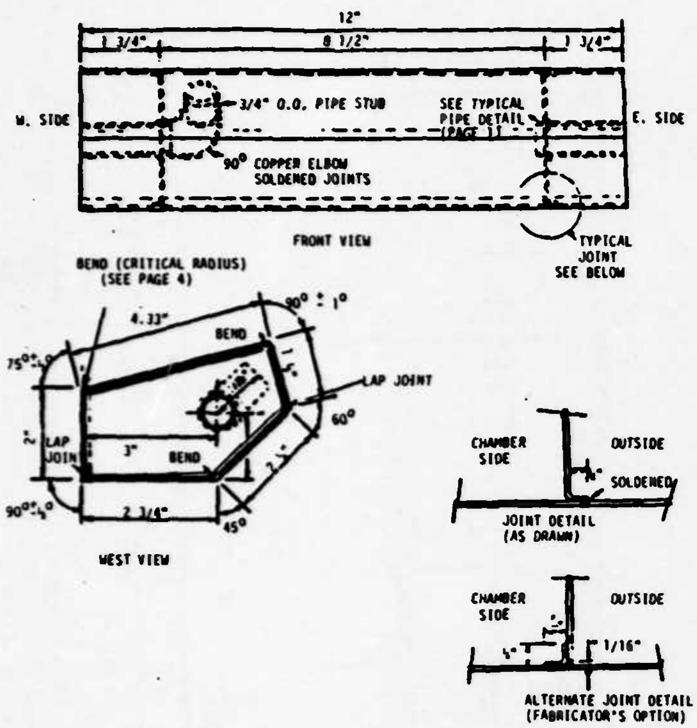
VIEW FROM BELOW

FIGURE A4.1 Copper Collector-Diverter Fabrication Drawings.

SAI COPPER BEAM DIVERTER
12 SEP 1979 RHS
PAGE 3 of 9

LOWER THROAT

(SEE PAGE 2 FOR POSITION IN OVERALL ASSEMBLY)



SAI COPPER BEAM DIVERTER
12 September 79
Page 4 of 9

SIDES

(EAST SIDE A MIRROR IMAGE OF WEST SIDE)
(SEE PAGE 2 FOR POSITIONS IN OVERALL ASSEMBLY)

NOTE: CRITICAL BEND RADII SHOWN - FOR SNUG FIT WITH UPPER AND LOWER THROATS. RADIUS OF OUTER SURGACE OF INNER PIECE MUST NOT EXCEED RADIUS OF INNER SURFACE OF OUTER PIECE.

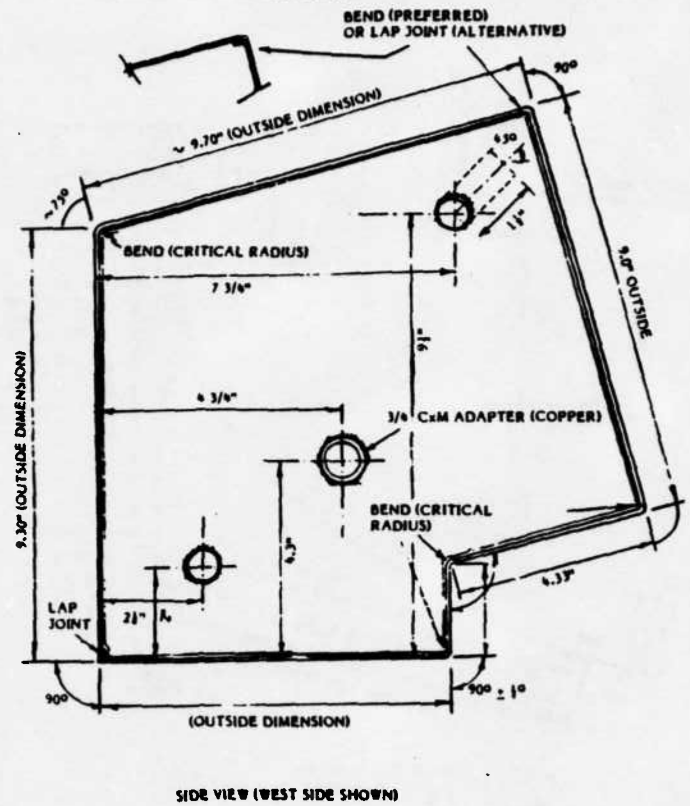


FIGURE A4.1 Copper Collector-Diverter Fabrication Drawings (continued).

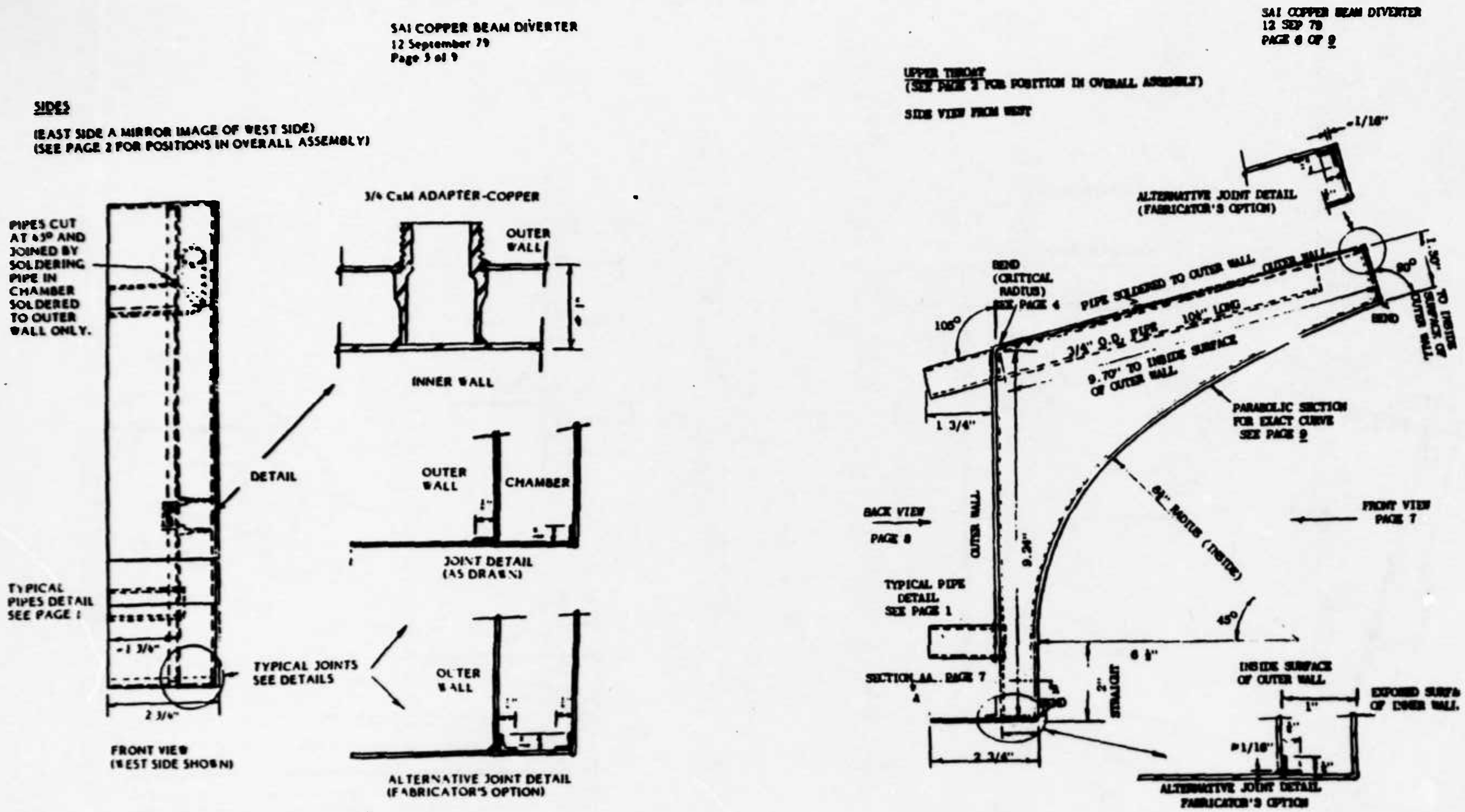
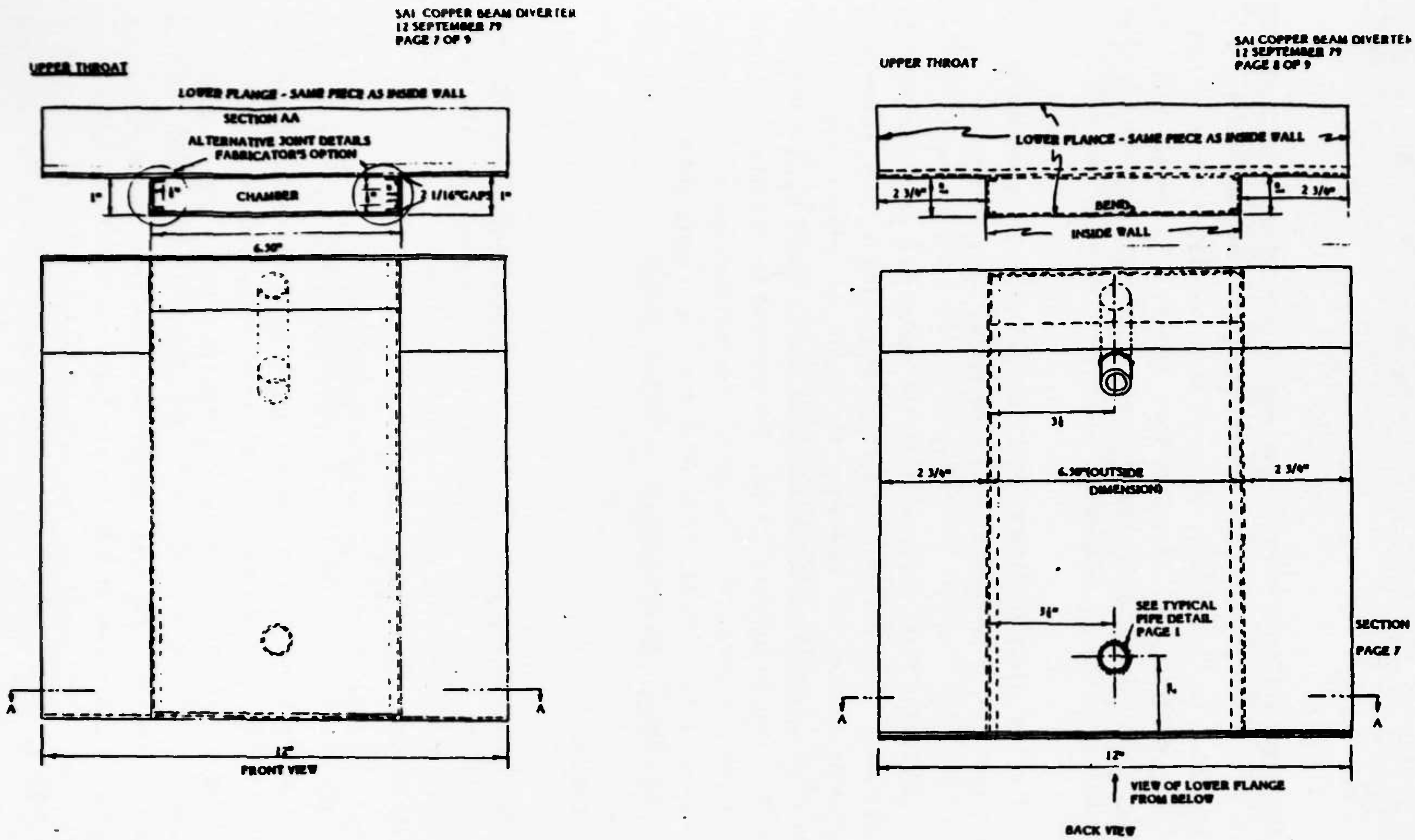


FIGURE A4.1 Copper Collector-Diverter Fabrication Drawings (continued).



(NOTE: Page 9 of 9, Full Scale Upper Throat Curve, not included)

FIGURE A4.1 Copper Collector-Diverter Fabrication Drawings (continued).

side. The brass collector-diverter was used in transmission tests at ACTF (Appendix 6) and CNRS (Appendix 7). Experience gained on those tests led to the design shown in Figure A4.1, which is of silverplated copper and uses soldered lap joints in lieu of welded butt joints. The brass collector-diverter was repaired and refinished after the August 1979 CNRS testing to be used as a backup to the copper model.

The four piece configuration of the collector-diverter avoids any interior corners and allows achieving a high specular reflectance.

Laboratory tests verified that the acceptance angle was -45° to +75° as designed. This testing was accomplished using a laser at measured angles of incidence over the aperture. The results of this testing are shown in Figure A4.2, which compares the acceptance solid angle against the CNRS solar furnace input to the focal plane. The accepted solid angle is approximately 92 percent of the total solid angle. The portions not accepted are at the extreme horizontal angles, from which the energy must undergo a large number of reflections before reaching the tested surface.

A4.3 Chamber

The test chamber was designed on the basis of containing a thermal layer at least one meter high. A four foot high section was selected to provide some cushion over this height and in recognition that instrumentation to the full height of the chamber would not be practical.

The chamber cross section was determined on the basis of computer analysis of propagation losses in a square versus round tube and by comparison of flux intensities on the sample for different entry areas using the CNRS flux distribution pattern (Figure A3.2). Separate programs were prepared for square and round tube propagation. The programs determined average transmission losses for different length over width or diameter ratios and used assumed reflectivities of 0.8, 0.9 and 0.95. Up to 2500 different rays, with random intercept points in the entrance plane and with a range of incident and azimuth angles were used for each condition of L/R and reflectivity.

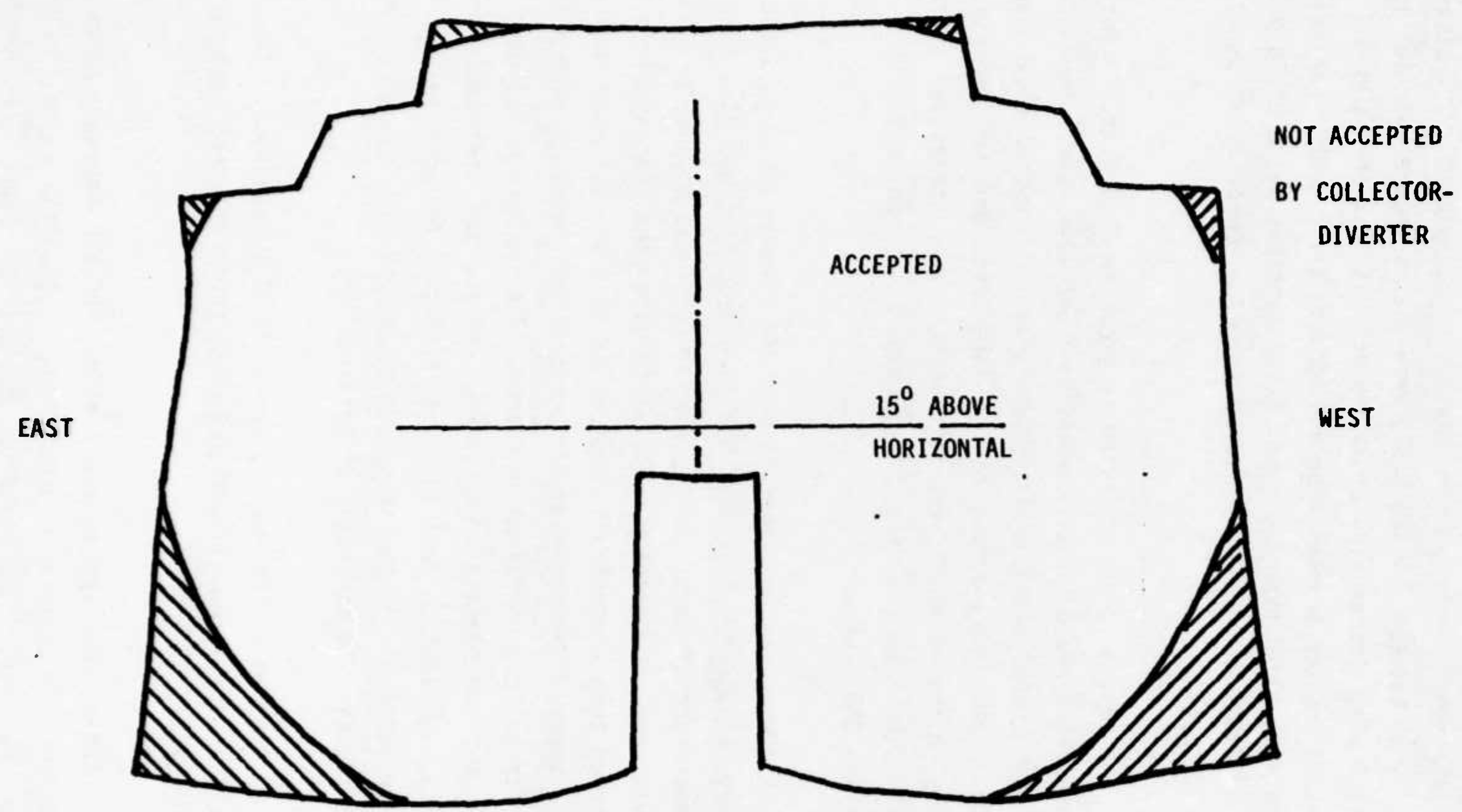


FIGURE A4.2. COLLECTOR-DIVERTER ACCEPTANCE OF CNRS PARABOLA INPUT

The results of the computer code analyses, for an assumed silver reflectivity of between 0.9 and 0.95, were that a square tube 48" long should be between 6 and 7 inches wide to obtain maximum flux at its exit. The square tube provided greater transmission and reduced the probable variation in flux across the exit plane over the round cross section, which could provide some focusing approximately half a radius from its center. A 6½ inch square section was chosen.

The initial chamber design is shown in Figure A4.3. This was used in laboratory and field tests (Appendices 6 and 7). Poor specular reflectivity from the plated steel walls, lower than anticipated flux transmission, difficulty in obtaining access to the interiors, and lack of viewports for photography in the one-inch wide instrument spacer strips led to the chamber design shown in Figure A4.4. This chamber was fielded for the 1980 test series on the CNRS furnace.

A system was developed to heat the chamber walls to avoid condensation of water vapor driven from a sample during testing. An initial goal of fluid temperature of approximately 215° to 220°F was sought, to ensure that no vapor would form. Laboratory tests using pure ethylene glycol as the heated medium showed this temperature range to be feasible but near the temperature limit for steady-state operation of the motors of the 12v direct current pumps obtained for battery operation in France. The system was designed for use of two pumps and two heaters with hoses, valves, and thermometers to permit flexibility, redundance, and flow adjustment. An open to the atmosphere accumulator was included in the system to ensure that the system remained at low pressure, even in the event of boiling.

A diagram of the heating system is at Figure A4.5. The chamber and vaned shutter housing were heated as having surfaces where condensation might affect the tests.

(Note: The system was fielded for the February-March 1980 test series on the CNRS furnace as described. Experience gained in that series indicated that wall temperatures as low as approximately 140°F were sufficient to avoid condensation. In addition, it was found that use of

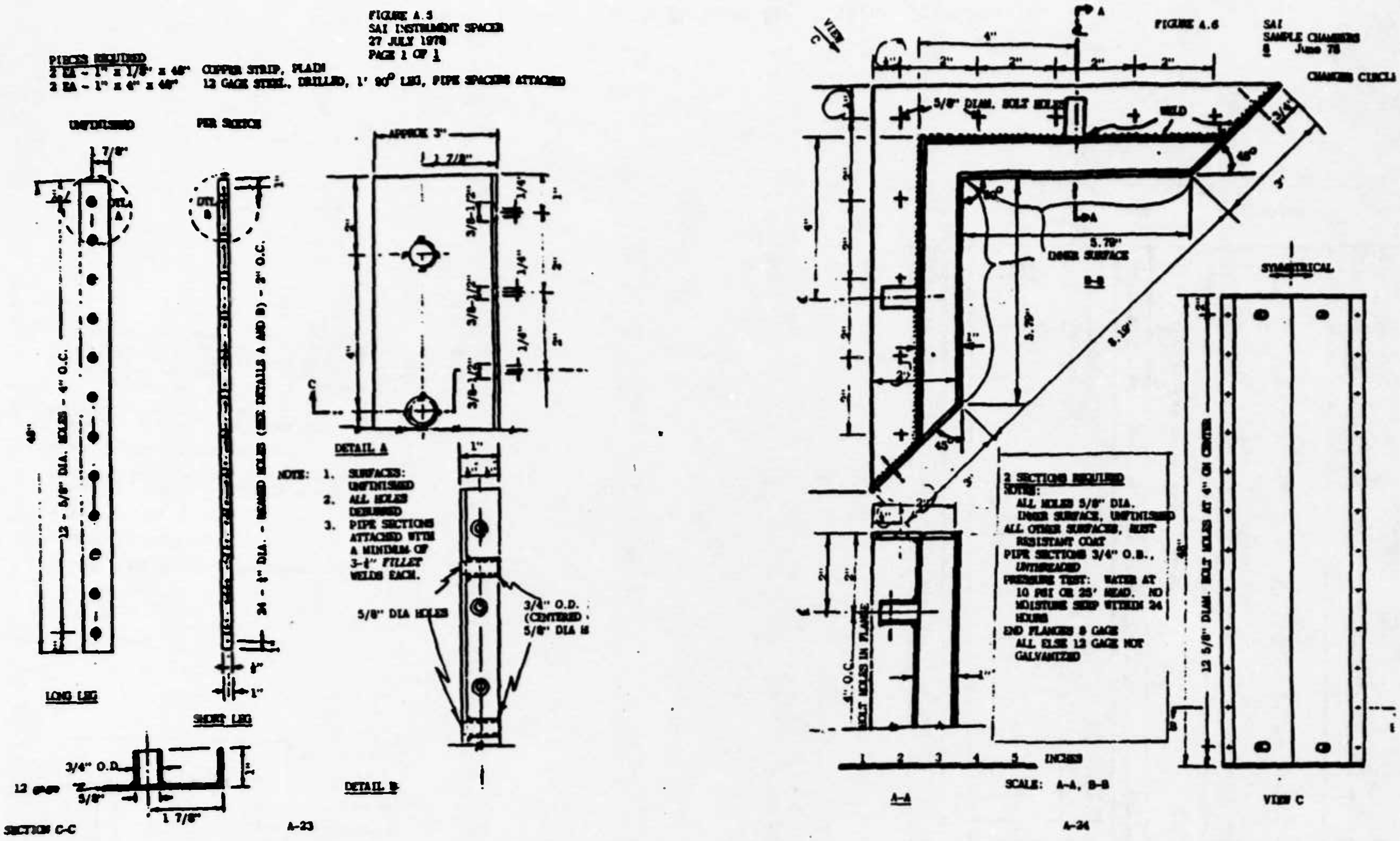
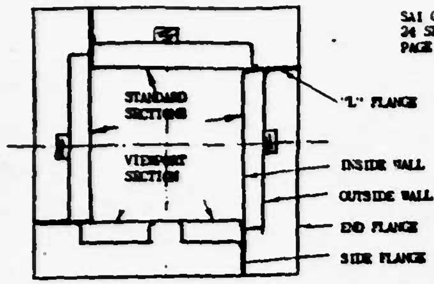


FIGURE A4.3 Steel Sample Chamber Fabrication Drawings.



SA1 COPPER SAMPLE CHAMBER
24 SEP 1979
PAGE 1 OF 6

ASSEMBLY CONFIGURATION

1. REQUIREMENT
   4 - STANDARD QUARTERS
   1 - VIEWPORT QUARTER
2. 48 oz (PER SQ FT) COLD ROLLED COPPER SHEET
3. ALL SHEET METAL JOINTS LAPPED. NO BUTT JOINTS.
4. ALL JOINTS SOLDERED.
5. PRESSURE TEST: WATER AT 10 SPIG OR 25 FT HEAD. REQUIREMENT: NO MOISTURE SEEN IN 24 HOURS.
6. SURFACE UNFINISHED BUT WITH BURRS REMOVED.
7. ALL PIPE SECTIONS COPPER. PIPE THREADS CLEAN. FREE TURNING TO A 3/4" COPPER COUPLING.
8. ASSEMBLY SEQUENCE: 1. INSIDE WALL. 2. ELBOWS TO TEE AND WASHERS TO 3/4" CxM ADAPTERS PRE-ASSEMBLY. 3. FLUID CONNECTIONS AND ADAPTERS ATTACHED TO INSIDE WALL. 4. ONE EXTREME FLANGE LAYER TO INSIDE WALL. 5. OUTSIDE WALL TO INSIDE WALL FLANGE LAYER, FLUID CONNECTIONS, AND ADAPTERS. 6. 2d EXTREME FLANGE LAYER. 7. BACK FLANGE LAYERS.

ENCL 3

SA1 COPPER SAMPLE CHAMBER
28 AUG 1979
PAGE 3 OF 6

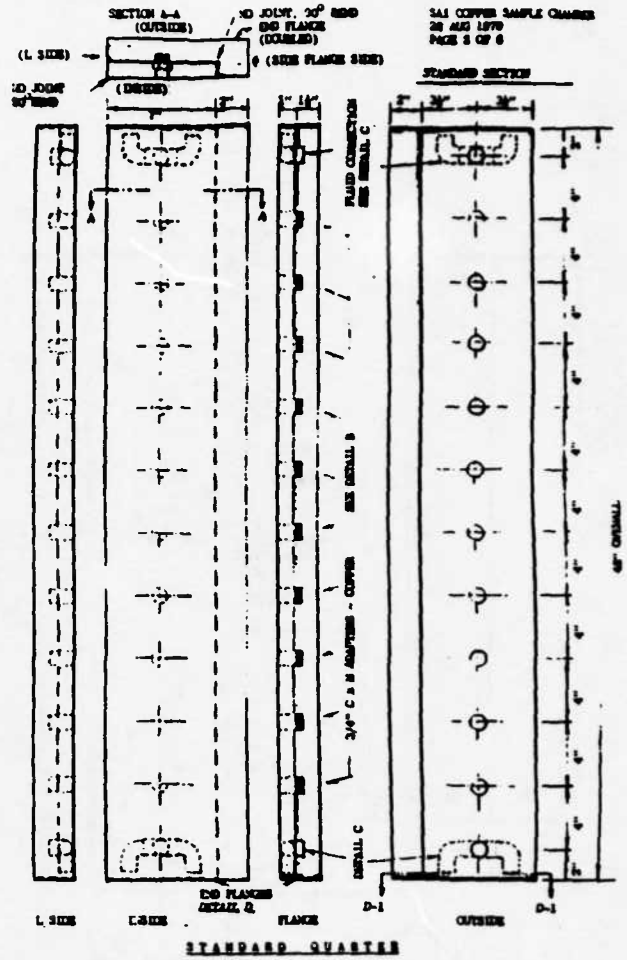
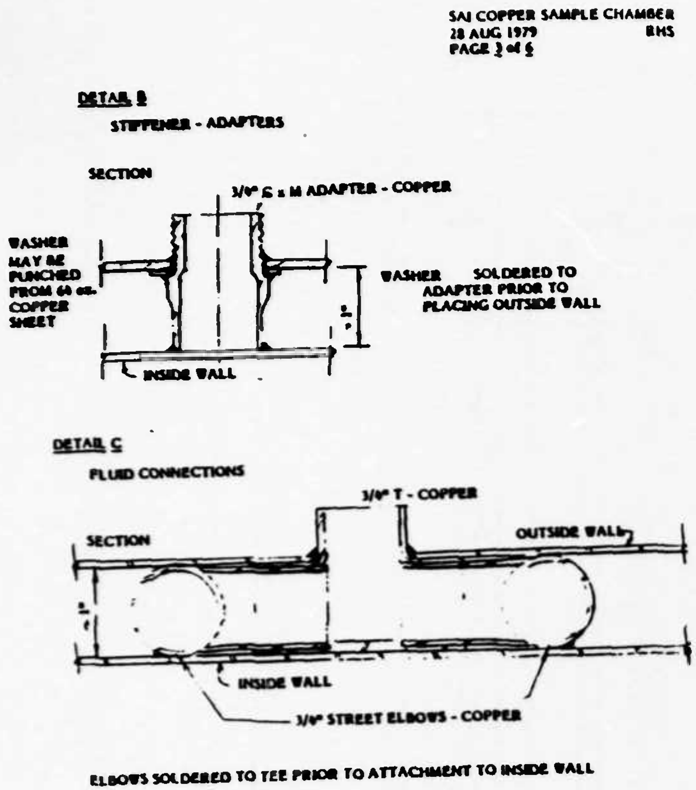


FIGURE A4.4 Copper Sample Chamber Fabrication Drawings.



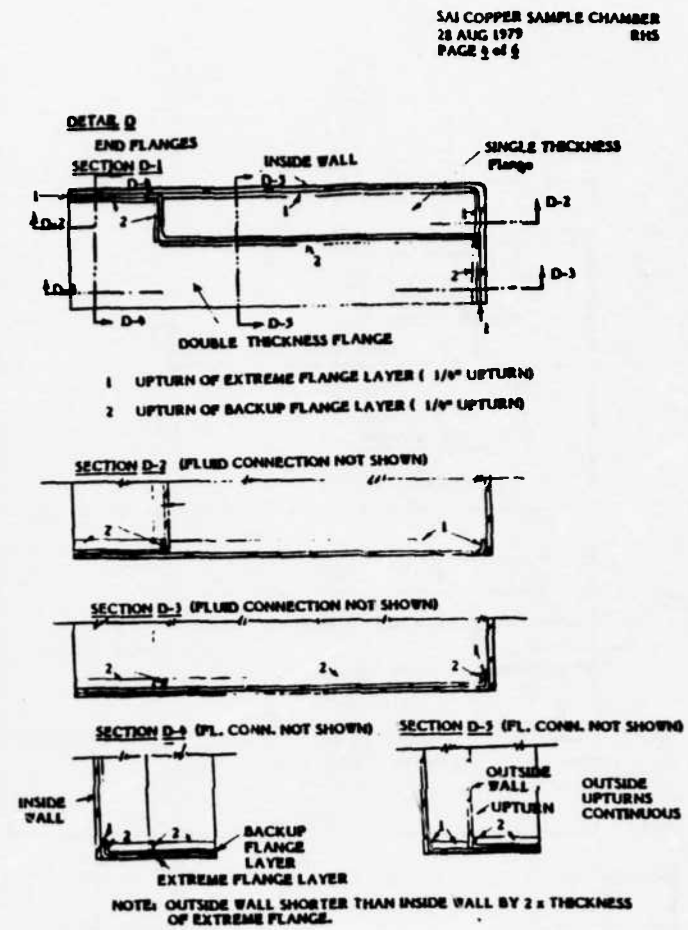


FIGURE A4.4 Copper Sample Chamber Fabrication Drawings (continued).

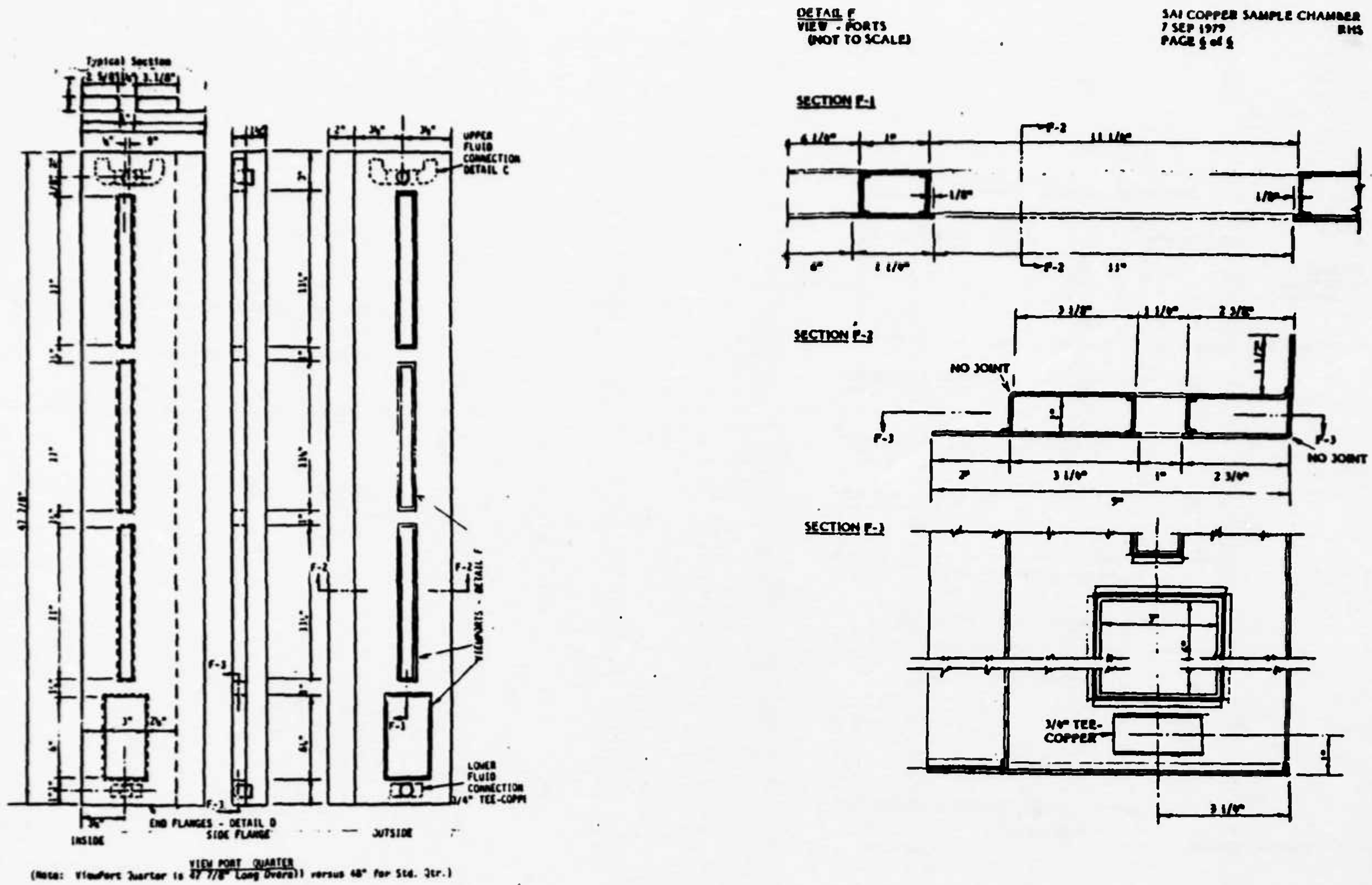


FIGURE A4.4 Copper Sample Chamber Fabrication Drawings (continued).

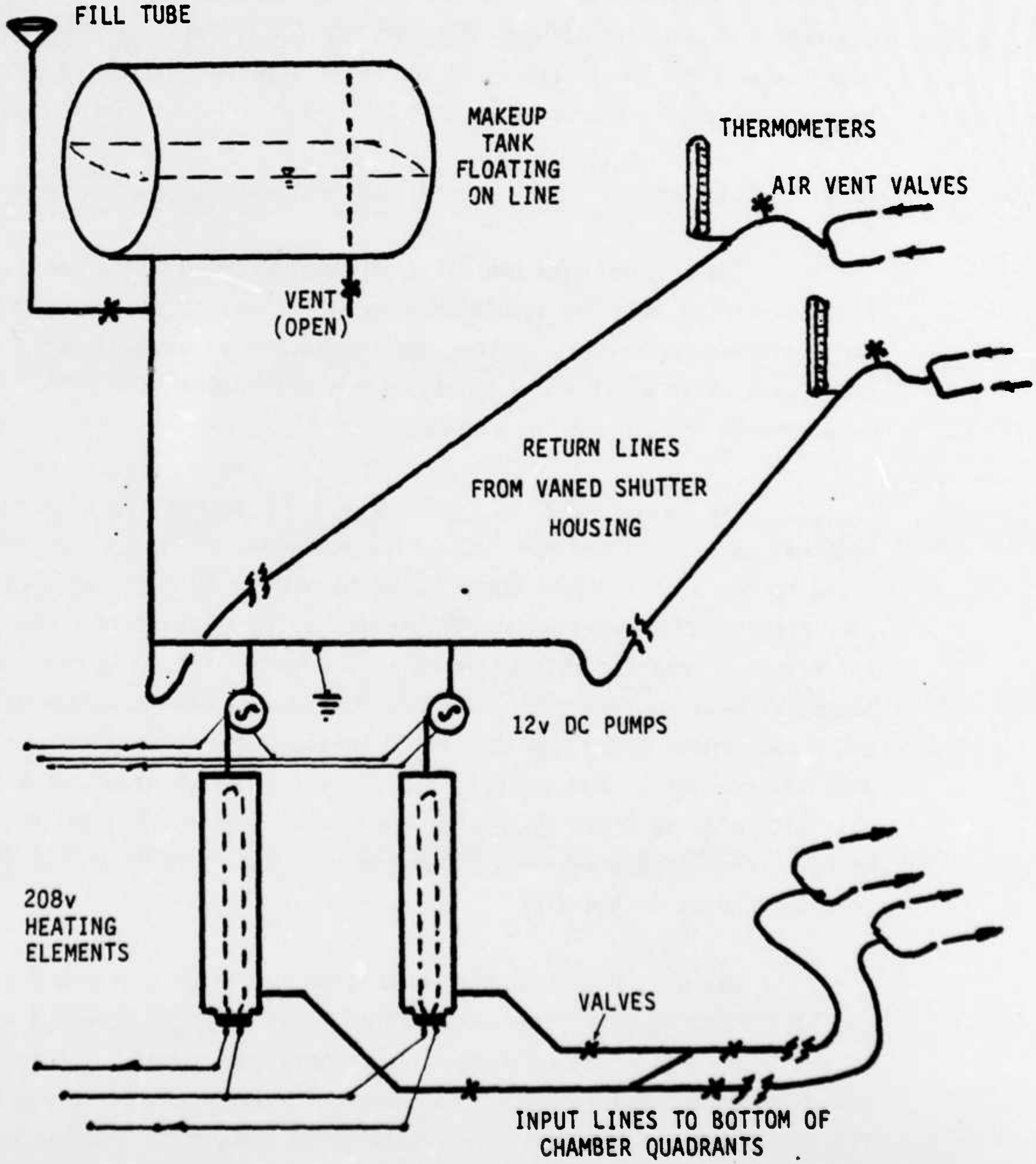


FIGURE A4.5. CHAMBER HEATING SYSTEM

ethylene glycol aggravated problems from otherwise minor leaks in the chamber, due to its burning and smoking the walls. Problems were also experienced with low lifetimes of the heaters in use; they were operated at a lowered voltage to improve that life.)

A4.4 Shutters

The requirements for pulse shaping and providing a rapid shutoff of flux coinciding with the simulated time of arrival of the shock front caused many different potential shutter configurations to be analyzed. The basic types were those which would rotate within the chamber and those which would move through the chamber in a plane.

The requirement to simulate a 1 KT thermal pulse dominated the problem, as it required the chamber to be opened in 11 milliseconds. This could be met by a straight edged blade travelling 50 feet per second on a 26 inch diameter disc rotating at 900 rpm and having an aperture occupying 60° of the disc. A separate shutter, such as in-chamber butterfly could open while the flux was shuttered by the 300° solid portion of the disc and reclose after the pulse formed by passage of the 60° opening, prior to return of the opening over the chamber. This would involve achieving high speed in an asymetric disc with complex integration with the chamber system. The pulse shape could be tailored by treatment of the opening and closing edges of the disc, or by graduated holes in the disc.

Use of a linear shutter also presented major problems for achieving the 11 ms opening time. Acceleration of 9000 feet per second is required to move a blade 6½" in 11 ms from stop to open the chamber. A force of 5250 pounds would be required if a 0.050 inch thick steel shutter blade were used. The force can be reduced by increasing the length of the blade, allowing acceleration before the edge of the blade reaches the opening, but the added mass to be accelerated and practical dimensional constraints limit this reduction. In any event the forces and vibrations would be extreme.

The results of the preliminary analyses indicated that the goal of simulating the pulse shape or even matching opening and closing times regardless of pulse shape for 1 KT bursts could not practically be achieved with mechanical shuttering suitable for field experiments. The shuttering development effort then sought to achieve the shortest practical opening and closing times and pulse shapes.

A4.4.1 Vaned Shutter

A shutter with three contra-rotating vanes was designed to provide the sinusoidal shape desired for close approximation of the nuclear burst thermal pulse. Three blades, each powered by its own stepping motor, were used to achieve the maximum speed for 90° of rotation. Use of three blades reduced the rotational moment of inertia of the blades to 1/27th that of a single blade of the same thickness and permitted use of thinner sections. A controller was developed to control the motors. The cycle of operation is to step the motors through 90° from the closed, horizontal position at one angular rate of rotation and then to step them through another 90° to the horizontal, closed position at a different, slower rate. A common ratio of angular velocities was used, with the actual values determined by the time to peak flux for the yield burst to be simulated.

Blade samples were tested under full flux at the collector-diverter exit in the preliminary testing on the CNRS furnace (Appendix 7). The relative durability of the different materials, plating combinations, and thicknesses tested led to use of 32 ounce (per square foot) copper, with 1 mil thick silverplating for the blades. The testing also showed the importance of a flawless surface, and silverplating accomplished after final trimming of the blades.

The vaned shutter housing design is shown in Figure A4.6.

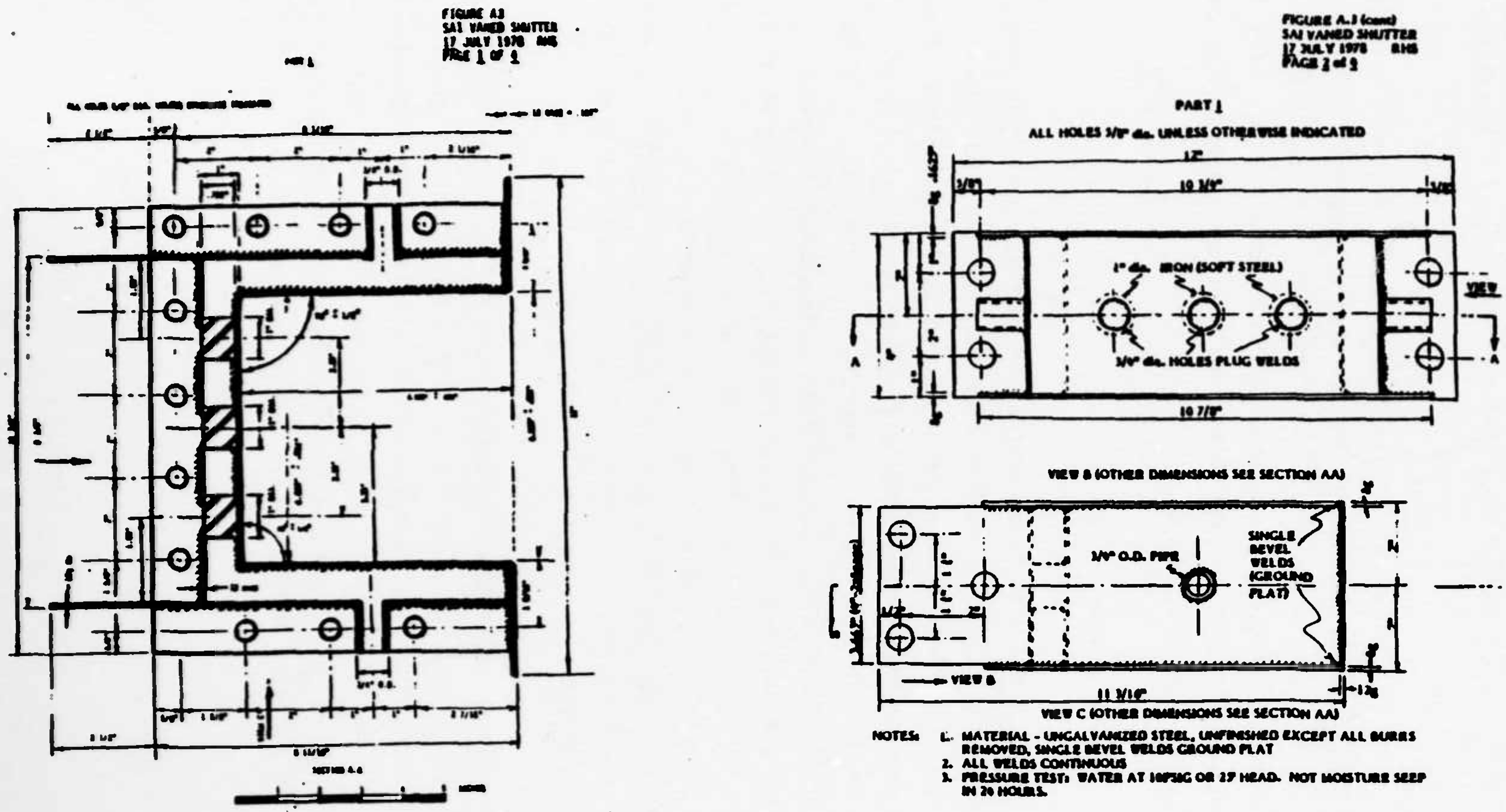


FIGURE A4.6 Vaned Shutter Housing Fabrication Drawings.

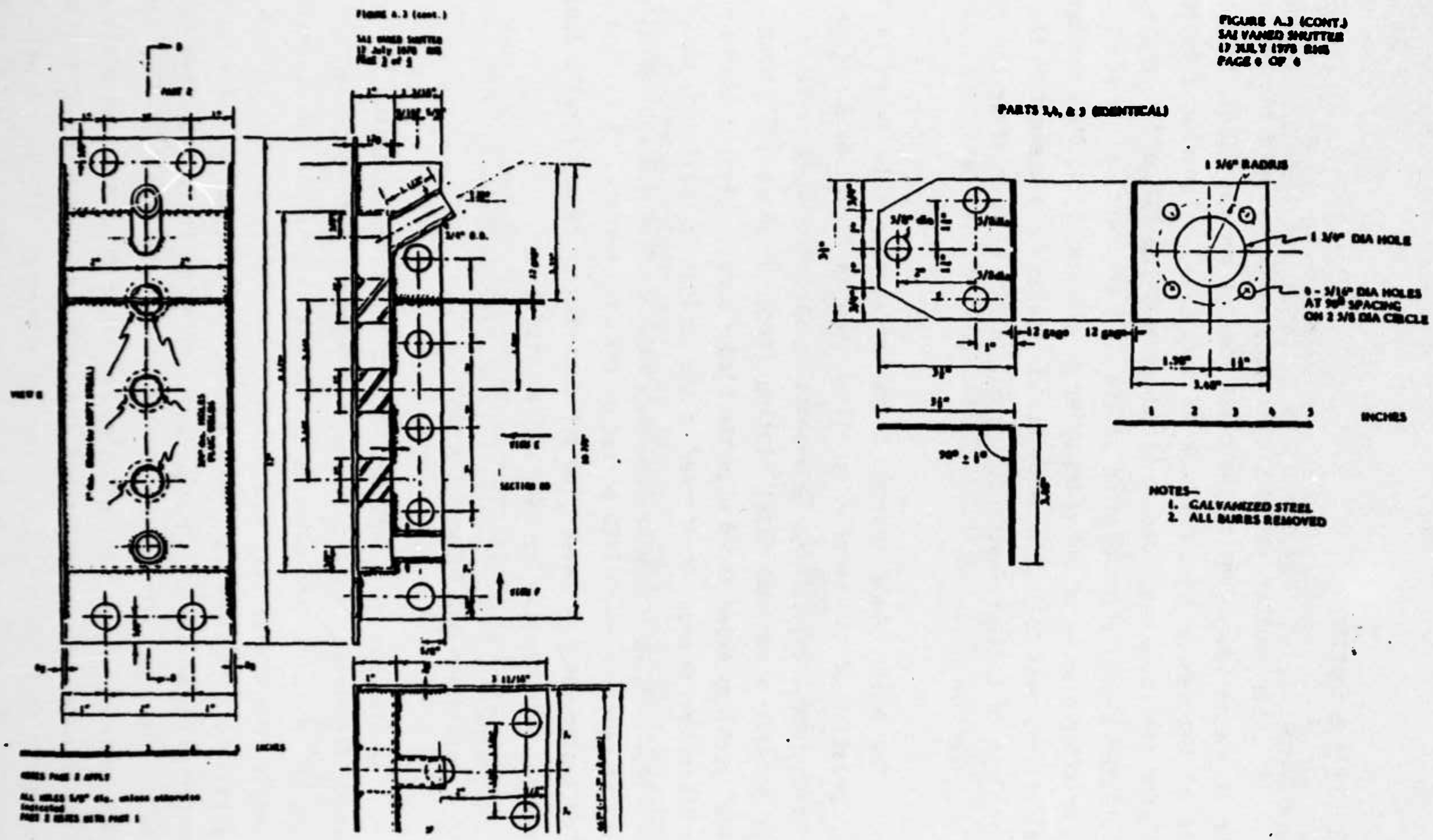


FIGURE A4.6 Vaned Shutter Housing Fabrication Drawings (continued).

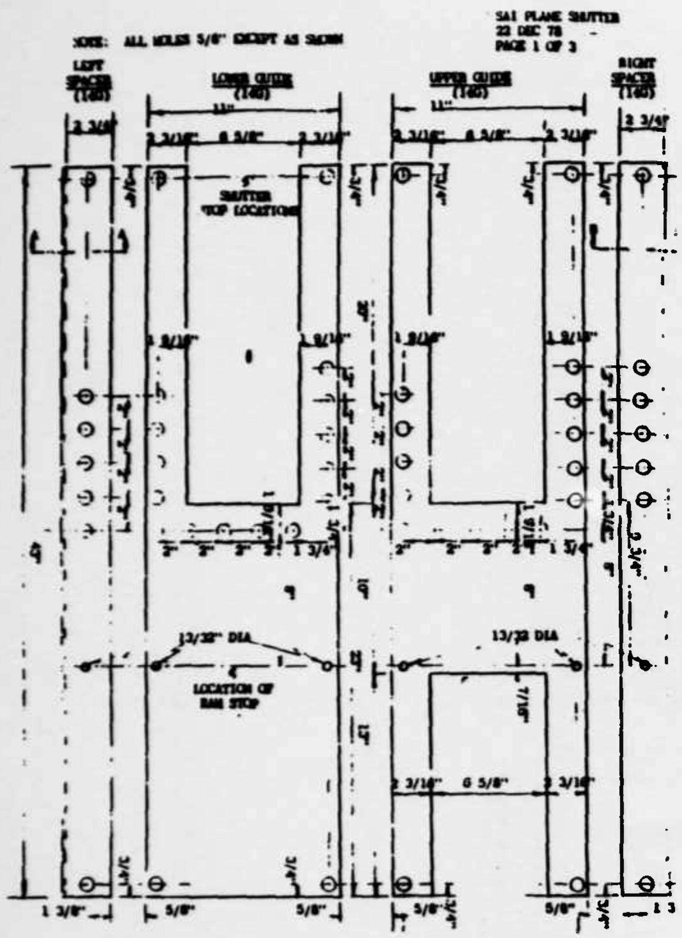
A4.4.2 Plane Shutter

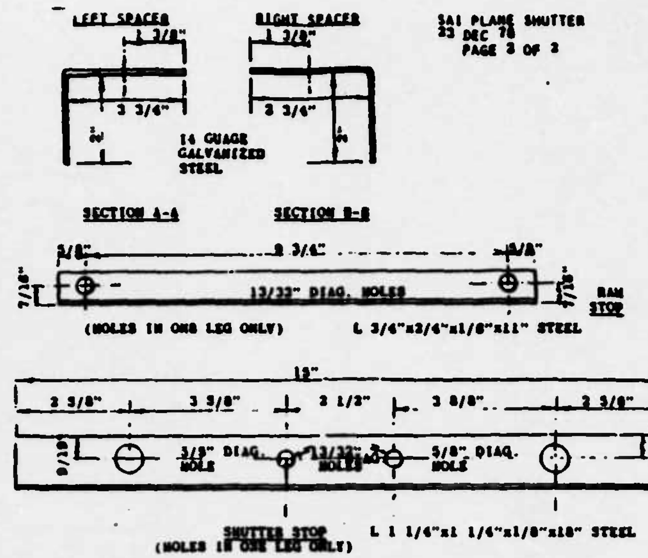
A plane shutter was designed to provide a rapid closure of the chamber at a time equivalent to the blast time of arrival (TOA), to seal the surface of the sample from fallback of particles, to provide a collection surface for particles suspended in the chamber at the TOA, and to protect the vaned shutter blades after opening of the CNRS shutters before start of the pulse, or after closure of the vanes prior to closure of the CNRS shutters. A special sticky, dust collecting material was tested for placement on the lower shutter blade to collect dust settling out of the chamber after the thermal pulse was over.

The basic plane shutter frame configuration is shown in Figure A4.7. Operation of the shutter is illustrated in Figure A4.8. Laboratory tests using four heavy springs gave shutting speed as short as 17 ms. These springs provide a maximum total closing force of about 130 pounds. The principal problems experienced with the blades were in binding due to warping of the blades or ram under the forces of the springs or collisions between the ram and blades and their stops. (Note: The spring operated configuration was used in the February-March 1980 series on the CNRS furnace. A falling-weight operated system was developed using the same shutter frames for the September 1980 series, with greatly improved reliability.)

A4.5 Adaptation and Support Equipment

Special equipment was designed to adapt the apparatus to the CNRS geometry and shields, and to support calibration and soil testing. Two adapting collars were fabricated to shield the exterior of the apparatus and instruments from energy not intercepted by the collector-diverter. A water cooled stainless steel collar, Figure A4.9, was designed to fit within a 36 centimeter diameter opening in a CNRS set of water cooled aluminum shields. This collar was used without incident in the preliminary full flux tests on the CNRS furnace. A separate, uncooled half-inch thick aluminum plate collar was also prepared. This collar was 16" square with an 8" by 9" rectangular cutout to fit over the collector-diverter entrance. (Note: A wall of the stainless steel collar's water cooled chamber burned through early in the





NOTES:
1. ALL EDGES AND HOLES DEBURRED.
2. GUIDES (2), SPACERS (2), RAMS (3) GALVANIZED STEEL.
3. SHUTTERS (2) - STAINLESS STEEL.
4. CORRESPONDING HOLES IN SPACERS, GUIDES, AND STOPS MUST ALIGN. HOLES CORRESPONDING TO BASIC HOLE PATTERN (PAGE 2) MUST ALIGN WITH THAT PATTERN.
5. 13 PIECES:
   - 1 - UPPER GUIDE
   - 1 - LOWER GUIDE
   - 1 - RIGHT SPACER
   - 1 - LEFT SPACER
   - 1 - RAM STOP
   - 1 - SHUTTER STOP
   - 2 - SHUTTERS
   - 3 - RAMS
   - 2 - 15"x1/2" DIAMETER SOLID STEEL RODS
6. ALL HOLES 5/8" DIAMETER UNLESS OTHERWISE INDICATED.

FIGURE A4.7 Plane Shutter Fabrication Drawings.

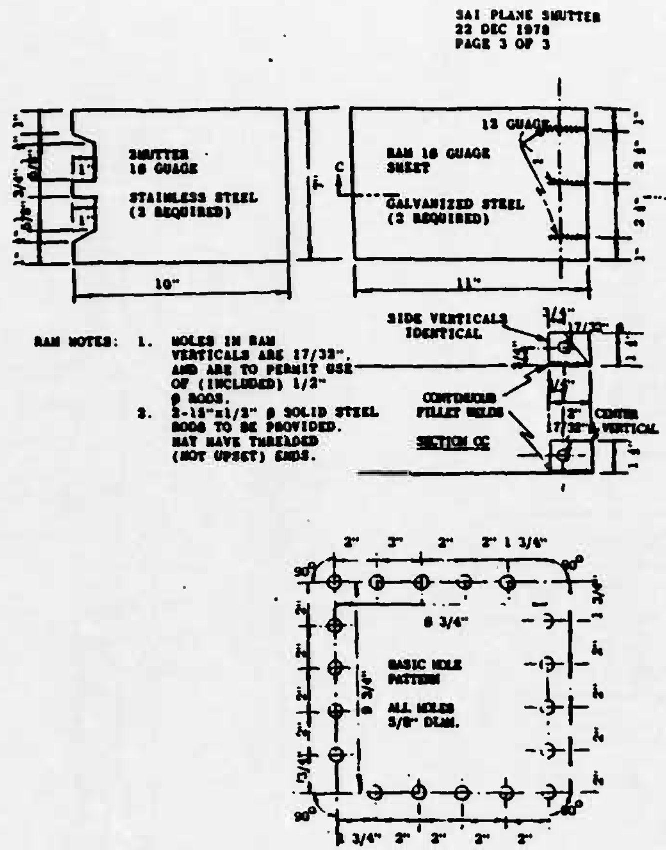


FIGURE A4.7 Plane Shutter Fabrication Drawings (continued).

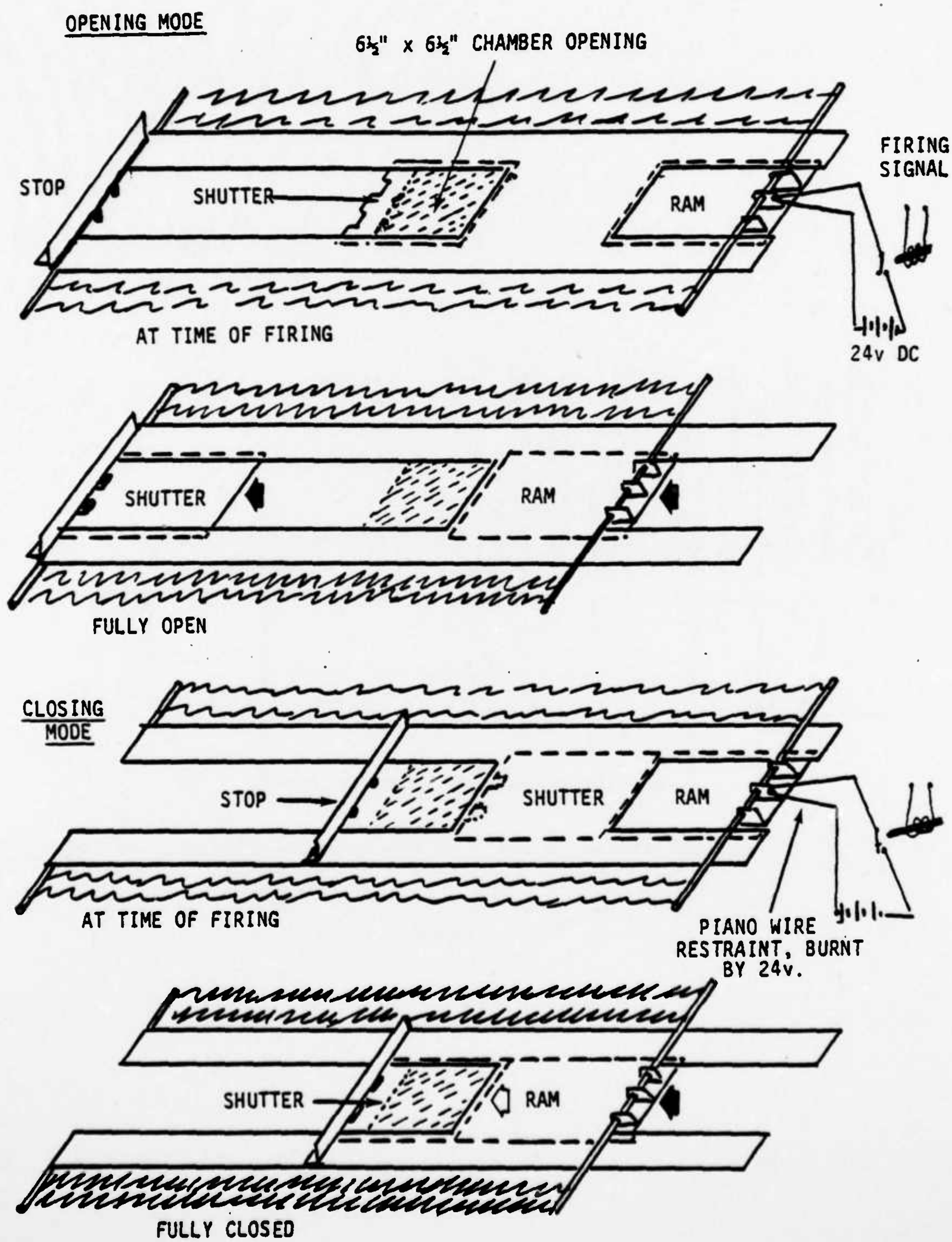


FIGURE A4.8. TYPICAL OPERATION OF PLANE SHUTTERS USING SPRINGS AND EXPLODING WIRE

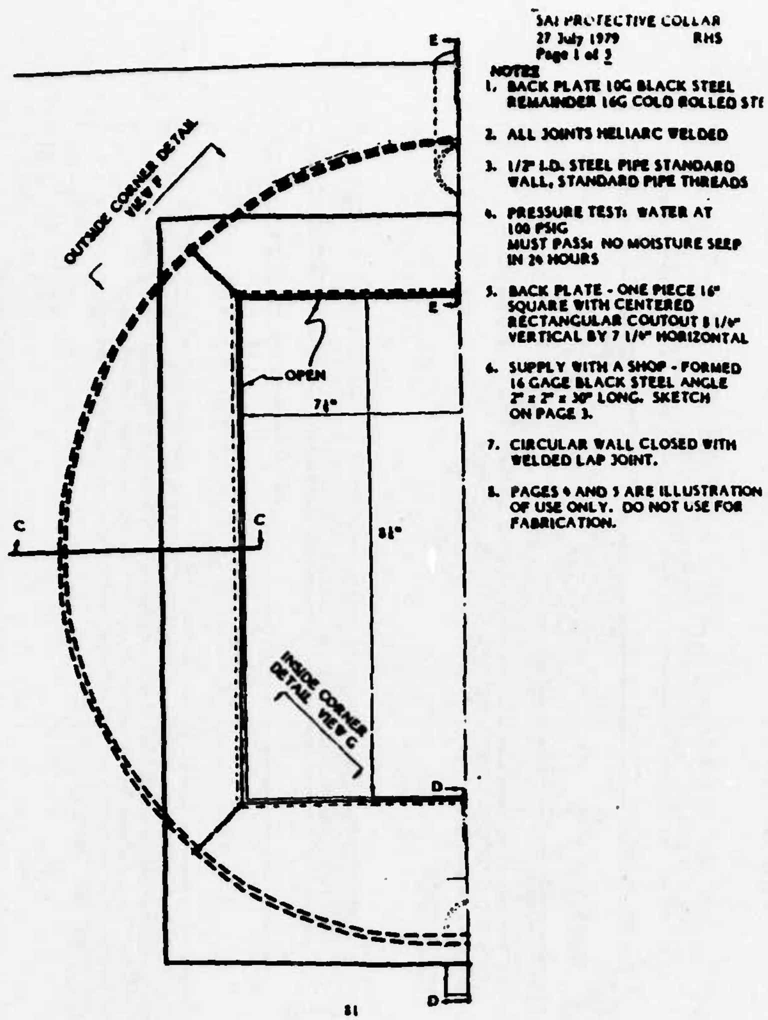


FIGURE A4.9 Stainless Steel Adapting Collar Fabrication Drawings.

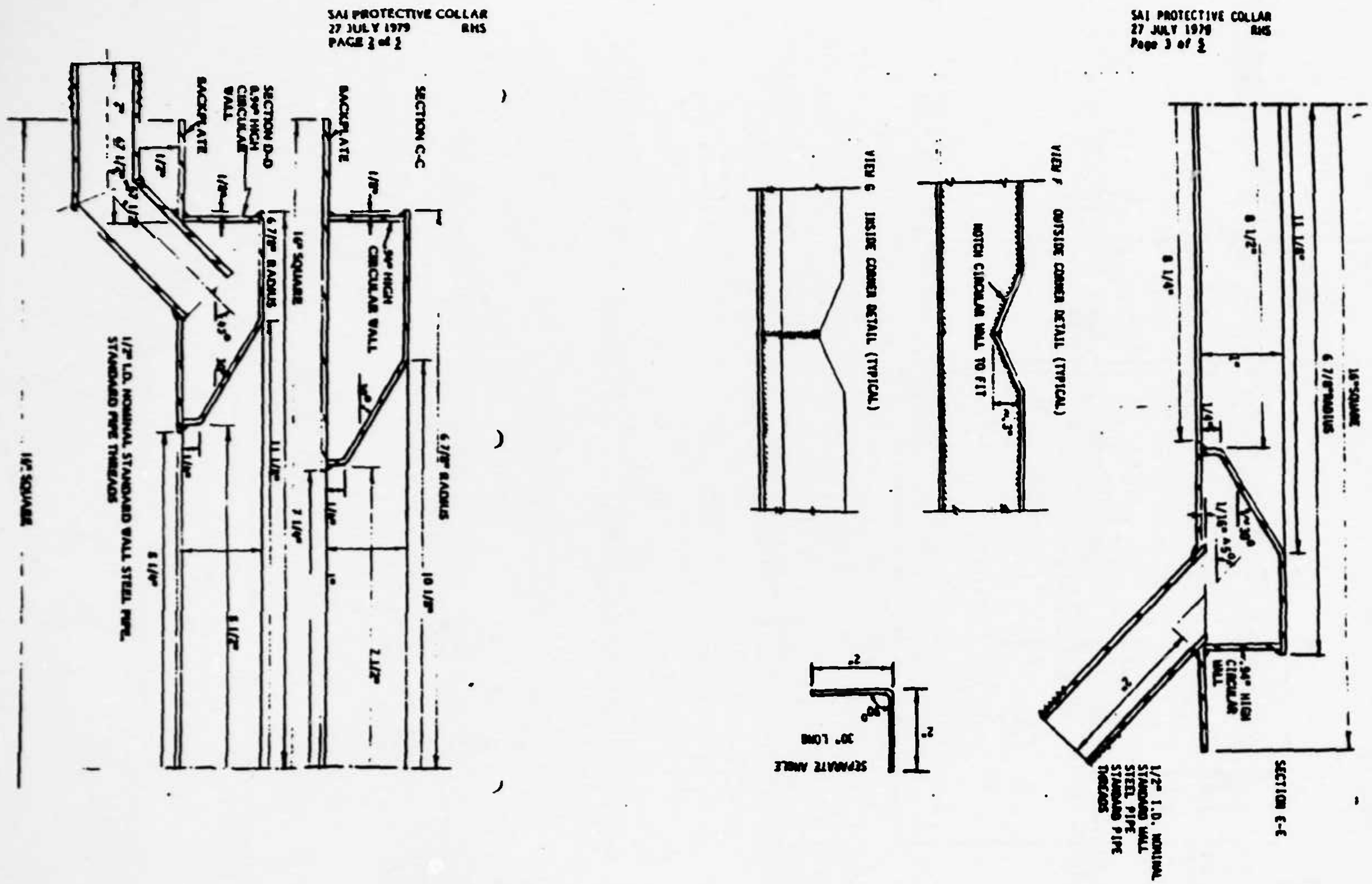
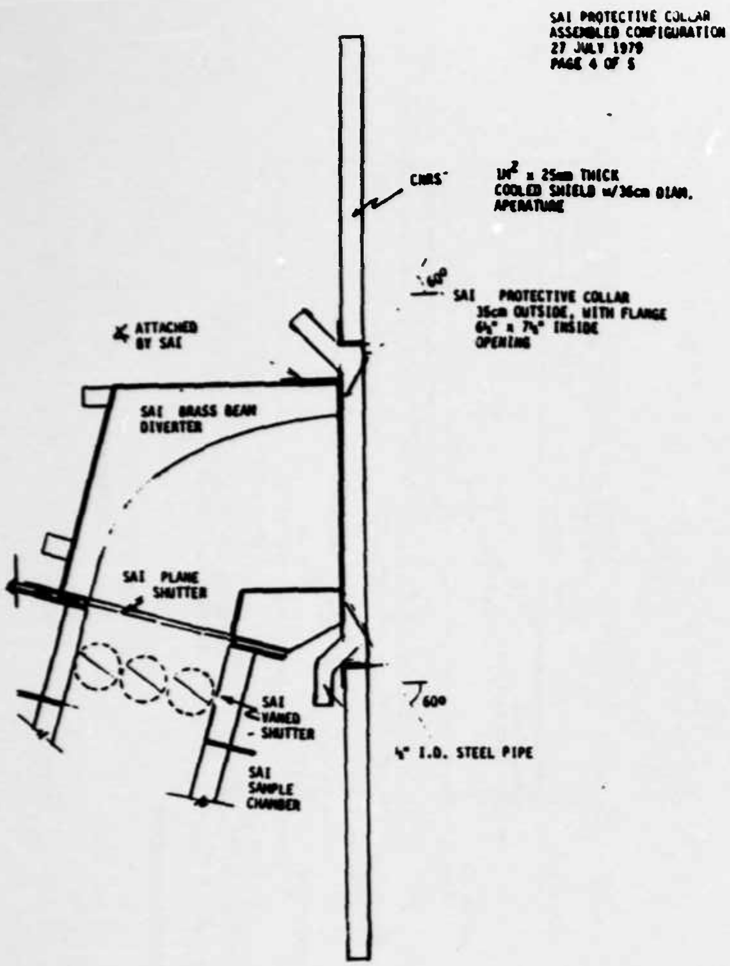


FIGURE A4.9 Stainless Steel Adapting Collar Fabrication Drawings (continued).



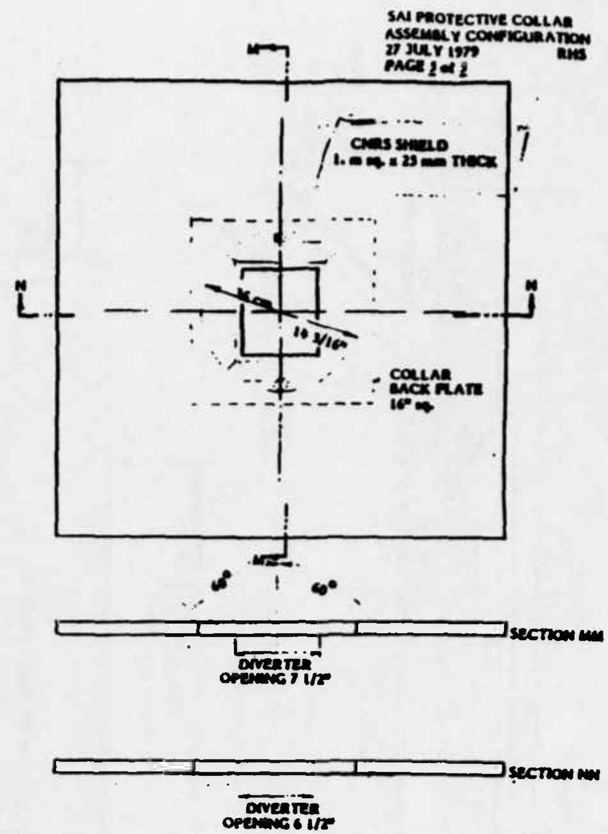


FIGURE A4.9 Stainless Steel Adapting Collar Fabrication Drawings (continued).

February-March 1980 CNRS test series. The backup aluminum plate collar was used for the remainder of the tests without incident. A cooled half-inch thick silverplated copper plate collar was prepared for the September 1980 test series, Figure A4.10.)

A special silverplate on copperplate water cooled steel box was designed to hold calorimeters for calibration testing within the chamber. This box is shown in Figure A4.11. It was shaped to permit it to fit within the steel chamber halves with their one-inch diagonal instrument spacers in opposite corners, however, it was also fully functional in the copper chamber. The box can be used at the collector-diverter entrance with a filler, such as asbestos wool, used to block the additional inch of cross section height.

An in-chamber sample holder was developed to permit tests on surfaces placed at the viewport sill level or at higher levels in the chamber to achieve higher fluxes. The holder design is shown in Figure A4.12.

A holder for soil samples used at the bottom of the chamber or below a lower plane shutter was devised from 8 inch square, 2 inch deep cake pans. The pans were adapted by drilling a 5/8" diameter hole in the bottom and soldering on a 2" long 3/4" diameter copper pipe section to provide for a centered calorimeter with top flush with the soil surface.

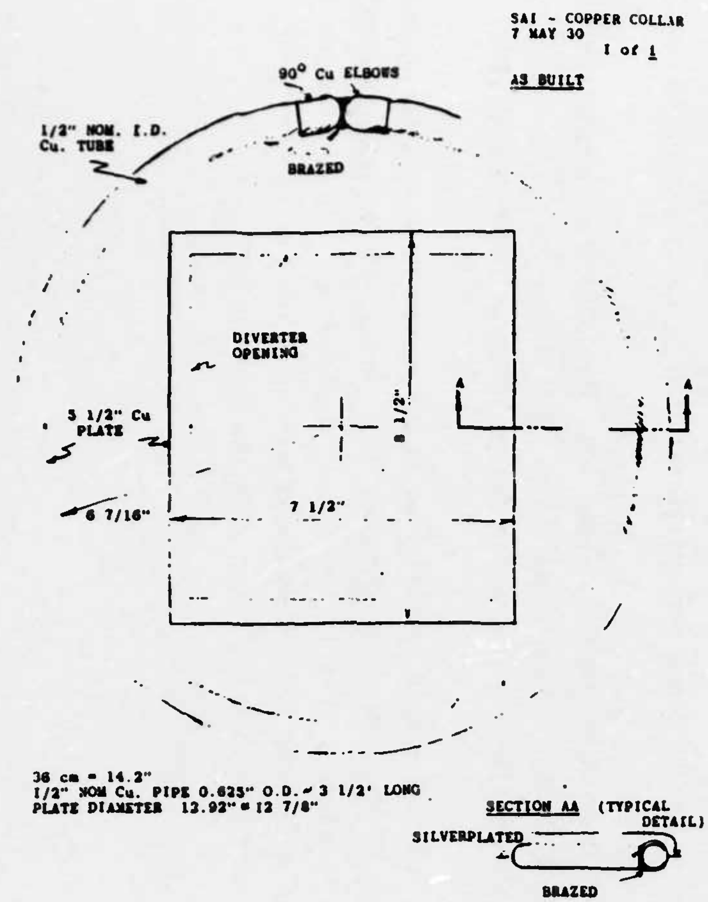
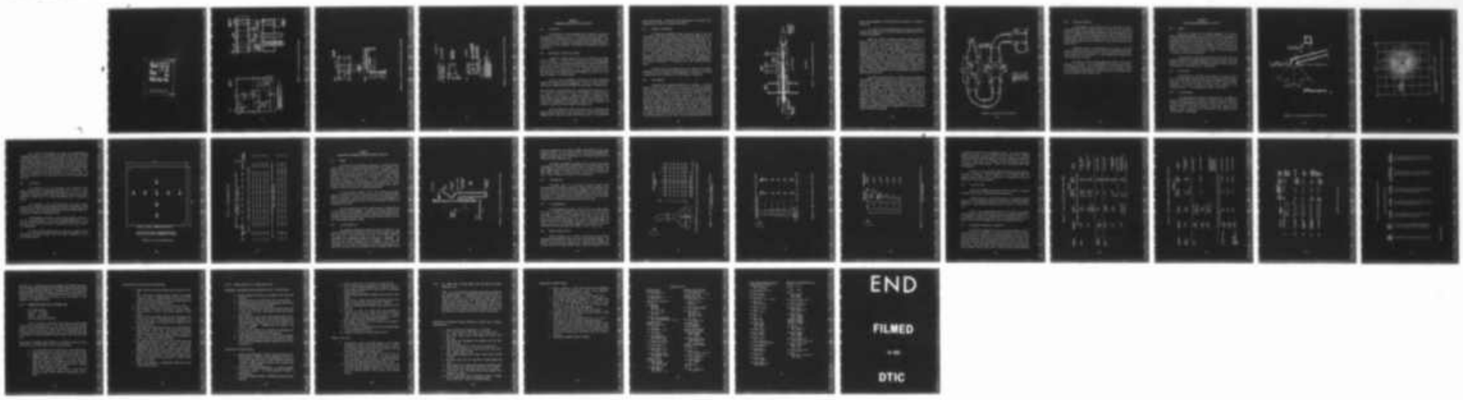
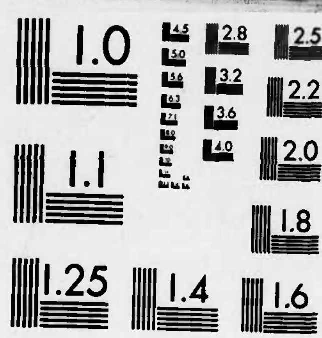


FIGURE A4.10 Copper Adapting Collar Fabrication Drawing.

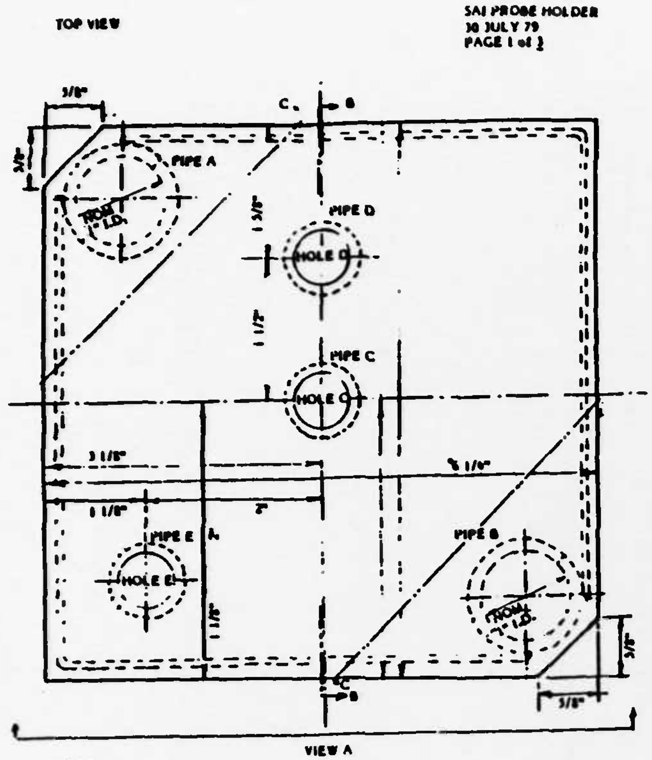
AD-A152 998 PLANNING THERMAL RADIATION EXPERIMENTS AT HIGH FLUX(U) 2/2
SCIENCE APPLICATIONS INC MCLEAN VA M KNASEL ET AL.
27 OCT 81 SAI-79-867-WA DNA-4790F DNA001-78-C-0203

UNCLASSIFIED F/G 13/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



NOTES:

1. 16 GAGE HOT ROLLED BLACK STEEL, UNFINISHED
2. PIPES STANDARD WALL, STANDARD PIPE THREADS (A,B 1" NOM. I.D.; C,D,E 1/2" NOM. I.D.)
3. WELDS BEVELED AND FILLET, AS SHOWN
4. PRESSURE TEST: 100PSIG WATER. NO SEEP IN 24 HOURS.

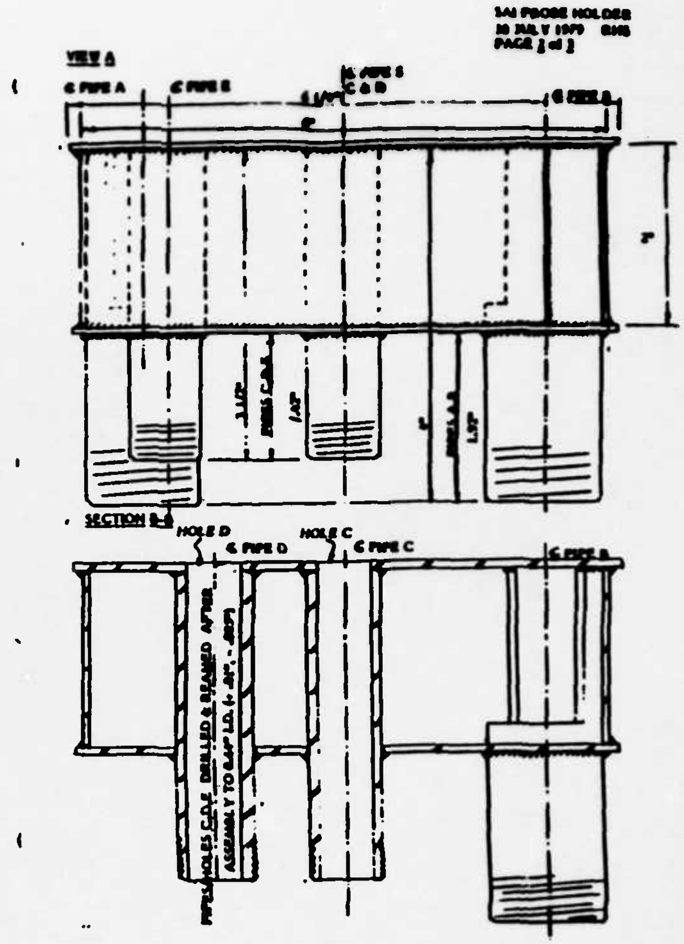


FIGURE A4.11 Calorimeter Box Fabrication Drawings.

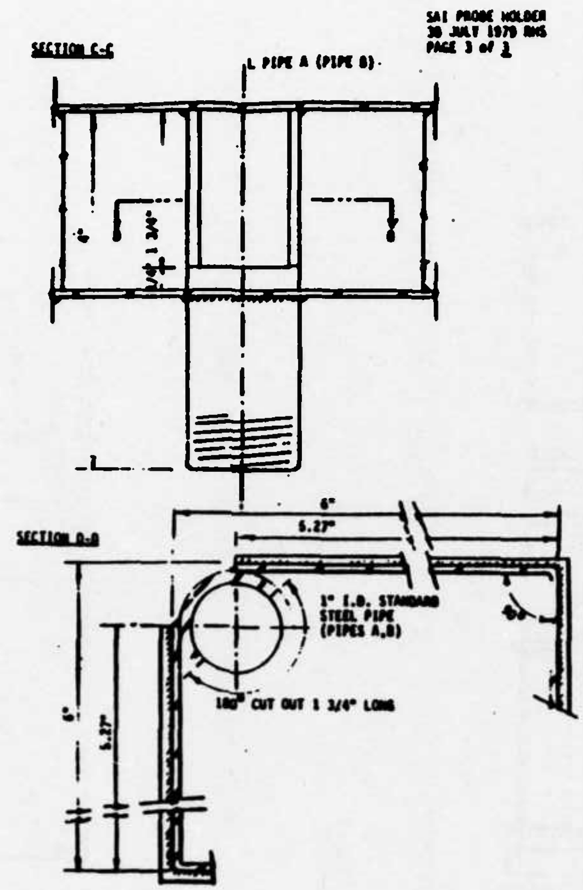


FIGURE A4.11 Calorimeter Box Fabrication Drawings (continued)

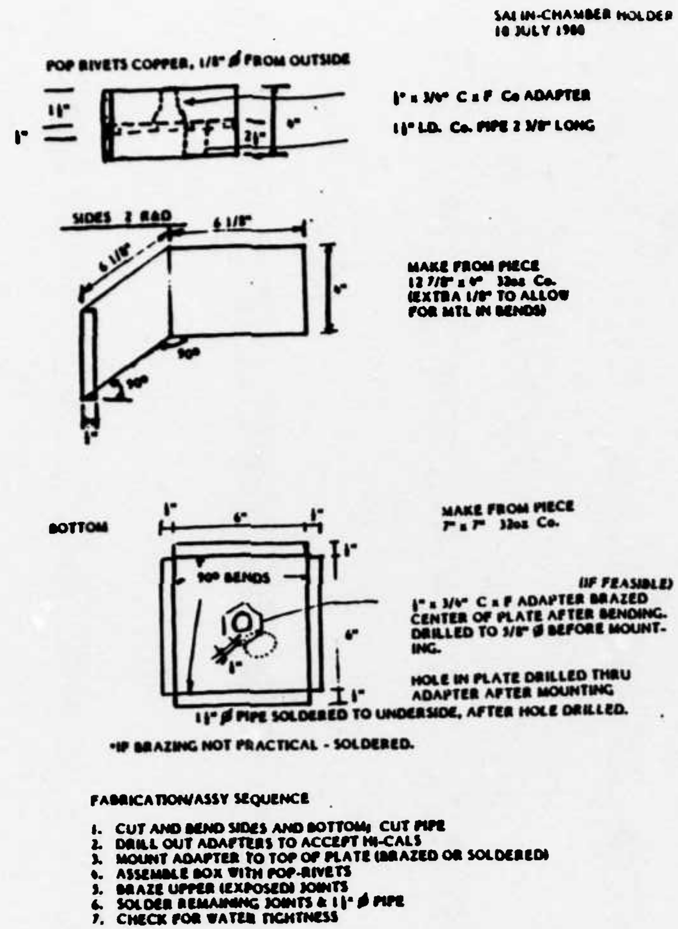


FIGURE A4.12 In-Chamber Sample Holder Fabrication Drawing.

APPENDIX 5

INSTRUMENTATION CHARACTERISTICS AND DESIGN

A5.1 Introduction

The objectives of the instrumentation and techniques investigated are summarized in Tables 5.1 and 5.2. This appendix provides specifics of instruments which were selected for use in making dynamic measurements in the soil test series, and of analyses and laboratory tests which were performed in conjunction with their selection. The sequence of presentation follows that of Section 5.

A5.2 Measurement of Thermal Environment

A means of directly measuring the flux incident on the sample surface is essential. In addition, it is desirable that an index measurement of flux at the top of the chamber be made concurrently to permit determination of the extent of alteration of the flux on the surface is due to dust or other material blown off the sample during a test. Additional information on the dust layer might also be obtainable from measurements of thermal flux on the chamber sidewalls at different heights.

High flux range calorimeters manufactured by HyCal Engineering Company were selected for these measurements. The specific models used were: C1300 Series, 300BTU/ft^2-Sec and 1000BTU/ft^2-Sec maximum flux capabilities.

These calorimeters use flowing water as a steady temperature reference in lieu of a physical or electronic "ice point" and generate voltage essentially proportional to the variation in temperature between an absorbing carbon black, exposed surface, approximately 5/8" in diameter and the reference. The calibrations accompanying the calorimeters permit direct conversion from voltage to calories per square centimeter per second flux.

The calorimeters were factory calibrated, their calibrations were checked against each other in the laboratory in the lower range with flux generated from a carbon rod source, and they were used in the preliminary solar furnace testing. Calibrations were checked after this testing in the laboratory and by return for factory recalibration.

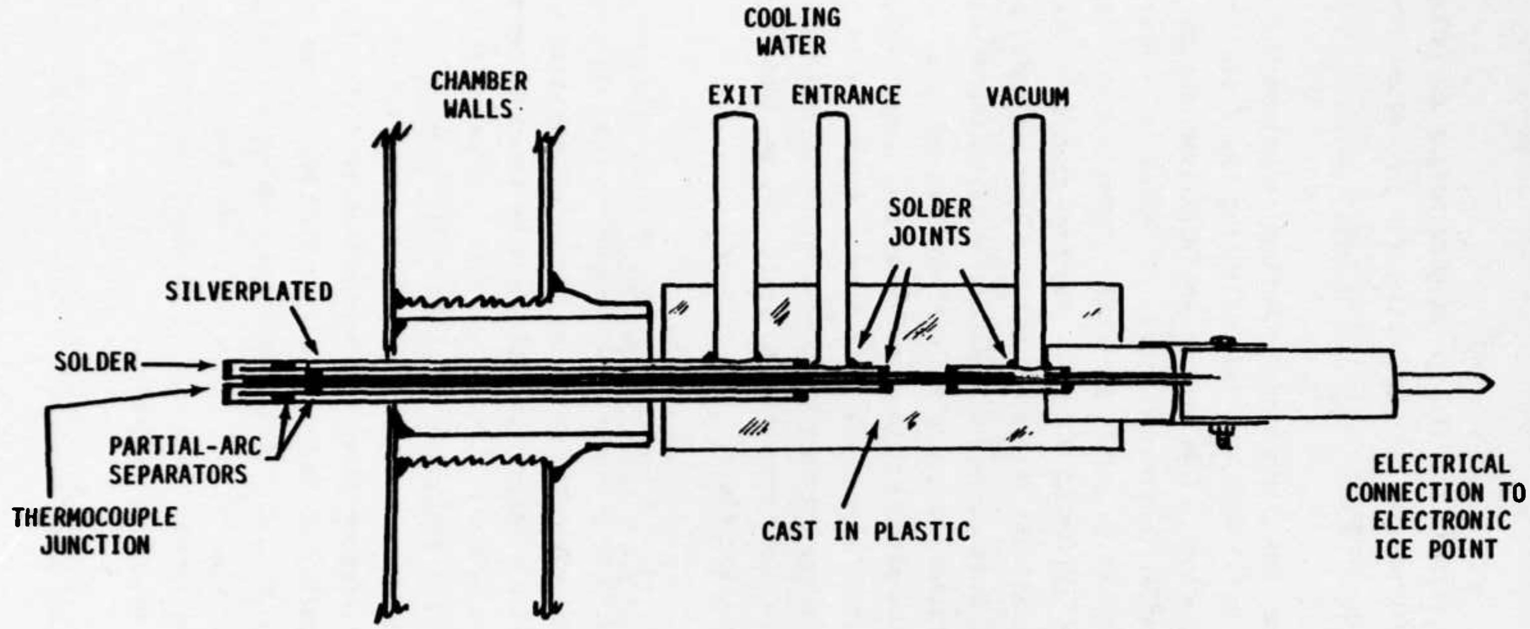
A5.3 Chamber Air Temperature

An aspirated thermocouple design previously used by SAI and illustrated in Figure A5.1 was selected for measuring the temperature of air within the chamber. This design was selected as permitting the sensor to be closest to the point of sampling, while shielding the sensor from direct flux and protecting the holder with a silverplated, circulating water jacket. The sensors used in the thermocouples are unsheathed chromel-constantan one mil and three mil diameter wire thermocouples manufactured by Omega Engineering, Inc. Electronic thermocouple reference junctions made for these thermocouples by Omega were used with each thermocouple. Each thermocouple is connected to its own vacuum gauge and control. A vacuum of approximately 4 psi pressure differential is maintained across the thermocouple-tubing system.

Laboratory tests were conducted using oven heated air and mercury thermometers for an air source of known temperature. A test oven at the CNRS furnace permits field verification and recalibration if necessary.

A5.4 Dust Sampling

Alternative dust sampling techniques were analyzed. The system adopted for use in the initial soil test program uses solenoid operated valves, suction, and replacable filters; with additional samples obtained by wiping the chamber walls and plane shutter surfaces after each test run. The filters are retained for microscopic examination of particle size distribution, relative quantity, and shape compared to a pre-exposure sample. Increase in degree of roundness due to partial or full melting is detectable. This, with the size of particles undergoing some melting can indicate the temperatures reached and states of particles in the chamber. The solenoid valves and the timer-sequencer control permits obtaining of particle samples at a specific time interval during or after a run and, with successive runs with the same material and flux levels, allows a progressive sampling over



Full Scale

FIGURE A5.1 SAI Aspirated Thermocouple Cross Section.

time of layer development. The valved vacuum filter system is illustrated in Figure A5.2.

The filters may also be weighed before and after use to obtain a quantitative estimate of dust collection for comparison among different soils or other test parameters.

Other dust sampling techniques examined included washing the chamber walls after each run and collecting the fluid for analysis of the particles collected. This system was dismissed due to its complexity of operation, special constraints it would impose on chamber design and other instrumentation (e.g., the aspirated thermocouples), and difficulty in examining the collected fluid. Another procedure would be to use a commercially available sticky mat cut to fit on a closing plane shutter blade at the bottom of the chamber. The mat would be protected from the flux by timing the shutter to close no earlier than an upper shutter. Material collected on the mat could be examined by microscope or by removal from the mat for separate analysis. A sonic cleaner was tested in the laboratory as a means of separating the particles from the collecting mat. Removal by this means in a fluid was incomplete and still left the problem of analysis in, or separation from, the fluid.

Collection of particles by use of a solenoid valve and vacuum bottle was considered. This means would provide a sampling both of the gas and particles in the chamber. By timing the valve operation and use of multiple bottles at multiple heights samples could be taken to represent any stage of the layer development. The electrical and mechanical aspects of this collection system presented no significant problems. Bottles could be evacuated in advance or on site. Analysis could include identification and relative quantities of gases and examination of dust which could be readily removed by gravity or wiping from the bottle. Finer particles could be removed by washing, with the associated problem of analyzing particles in suspension or reseparating the particles for examination. This collection system was considered to provide little added benefit over the valved vacuum filter system which was adopted.

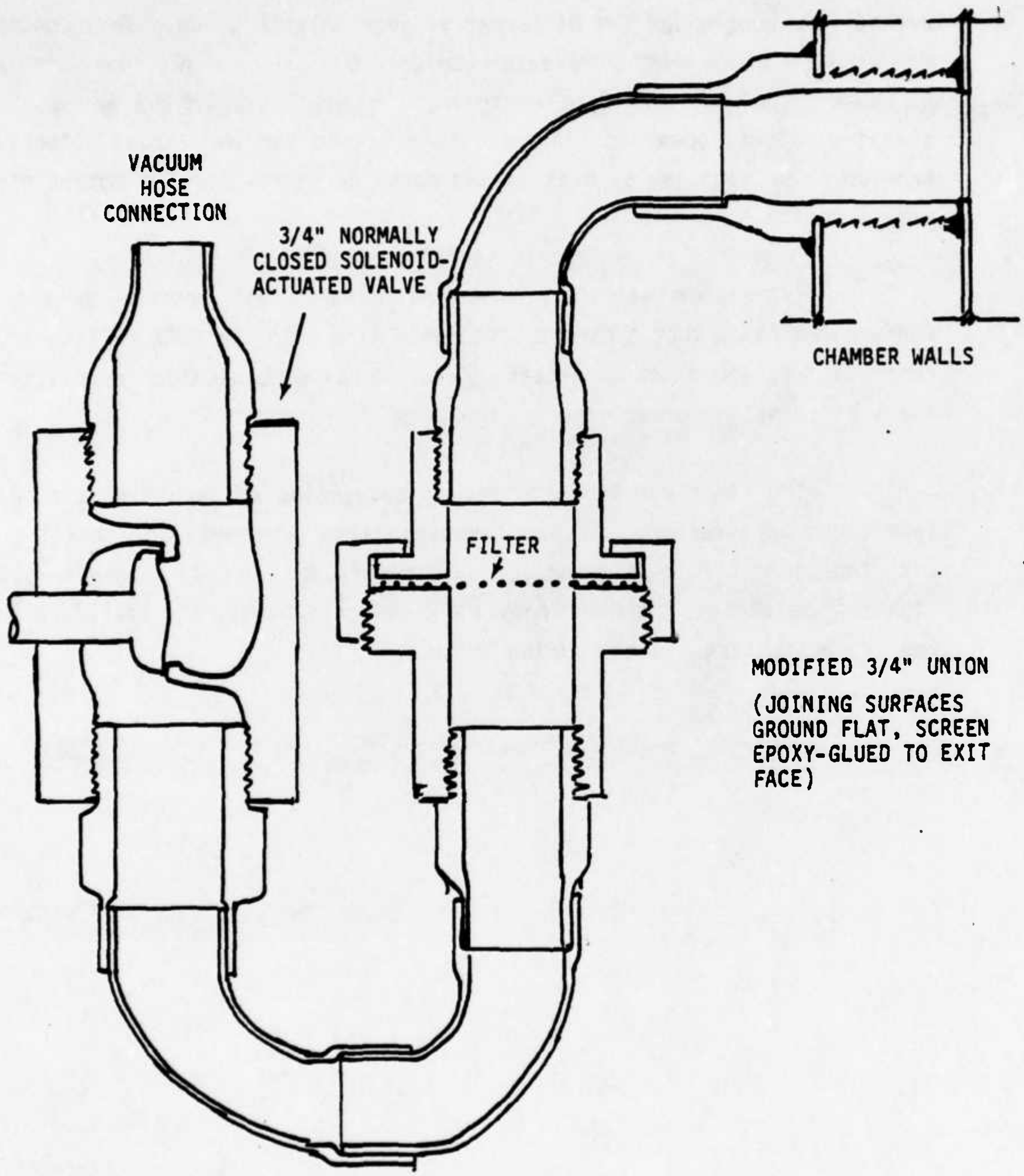


FIGURE A5.2 Vacuum Filter Cross Section.

A5.5 Timing and Sequencing

A timer-sequencer was fabricated by the SAI laboratory to provide preset time control of the different actions in a test run. This controller can fire the plane shutter releases (trigger the solenoid switches which allow current to explode the fine restraining wire), control the vaned shutter stepping motors, open and close solenoid valves for the vacuum filters, and provide other signals, such as timing marks or start-stop for motion picture camera controls.

Experience gained in the preliminary test program on the CNRS furnace indicated that a direct electronic link with the CNRS rolling shutter control-timer would not be necessary, as verbal communication permitted very close coordination of actions.

The timer was built to permit sequencing of events to the nearest thousandth of a second. It has the capability of providing control pulses with independently preset start or stop timers for up to 9 channels. (Note: flux and thermocouple measurements are made continuously and therefore do not require activating signals during a run.)

APPENDIX 6

TESTING ON ADVANCED COMPONENTS TEST FACILITY

A6.1 Summary

Tests were conducted on the Advanced Components Test Facility (ACTF) to determine throughput of the collector-diverter and test chamber and to provide limited durability testing of the items on a solar furnace prior to preliminary testing on the French CNRS furnace. The collector-diverter was determined to have a flux transmission of between 75 and 80 percent and the chamber's transmittance was approximately 32 percent, based on average flux levels at the entrance and exit planes of the items. No durability problems in leakage or surfaces were experienced.

The testing took place during the period 23 to 28 July 1979. SAI personnel involved were Dr. Michael McDonnell and Dr. Bruce Gordon. Principal Georgia Institute of Technology Engineering Experiment Station personnel involved were Dr. Steven Bomar and Dr. Thomas Brown.

A6.2 Configuration

Characteristics of the ACTF solar furnace are included in Table A3.2. Tests were made with the collector-diverter entrance plane horizontal, resulting in the exit plane being 75° above horizontal and the chamber longitudinal axis being 15° above horizontal (when assembled to the collector-diverter). This configuration is shown in Figure A6.1.

A6.3 Flux Measurement

Flux measurements were made with thermocouple-type calorimeters by the ACTF personnel using ACTF recorders, calibration and data reduction. Entrance plane measurements were made by calorimeters mounted on a bar which moved horizontally to map the flux pattern in that plane. Results of this mapping is shown in Figure A6.2 with the position of the collector-diverter entrance aperture superimposed.

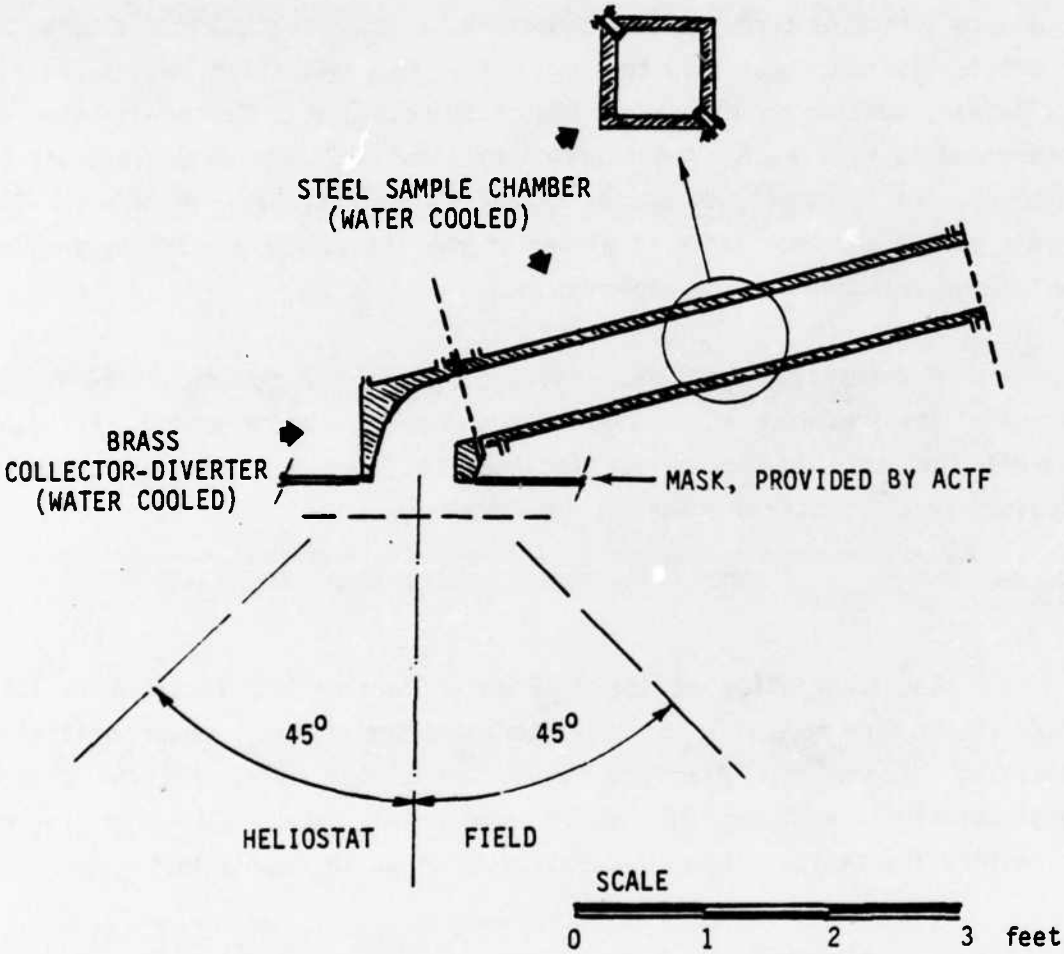
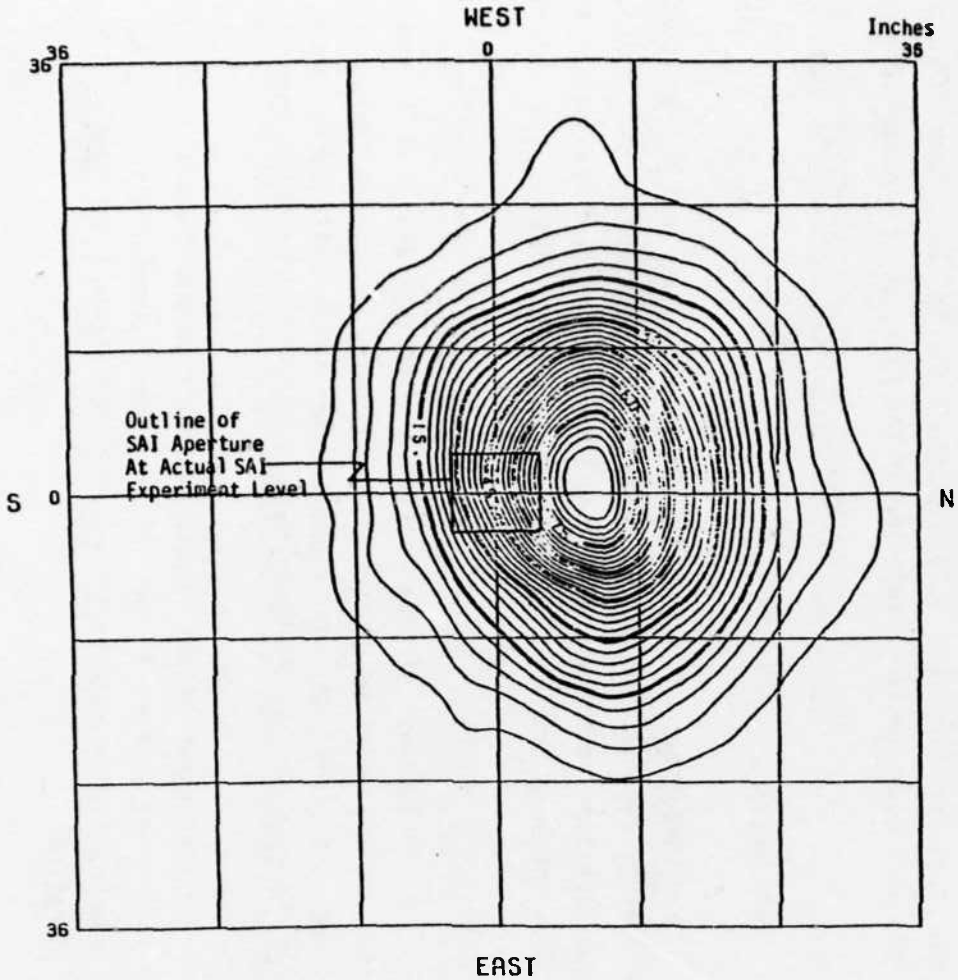


FIGURE A6.1 Test Configurations on ACTF Furnace.



Flux normalized to insolation of 900 W/M^2
Flux in W/cm^2

FIGURE A6.2 ACTF Flux Pattern and Concentrator-Diverter Entrance Position.

Exit plane flux measurements were made with thermocouple-type calorimeters mounted to an aluminum plate as shown in Figure A6.3. The data collected with the plate at the collector-diverter exit and at the exit of the sample chamber (assembled to the collector-diverter) are shown in Table A6.1. Fluxes are normalized to 900 Watts per square meter insolation. Data were not corrected for the effect of the separation of the actual collector-diverter aperture above the true focal zone (and plane of flux measurement). This effect was considered by the ACTF personnel to be less than 10%. No corrections were made for time variation of the flux, which was approximately ½% to 1%.

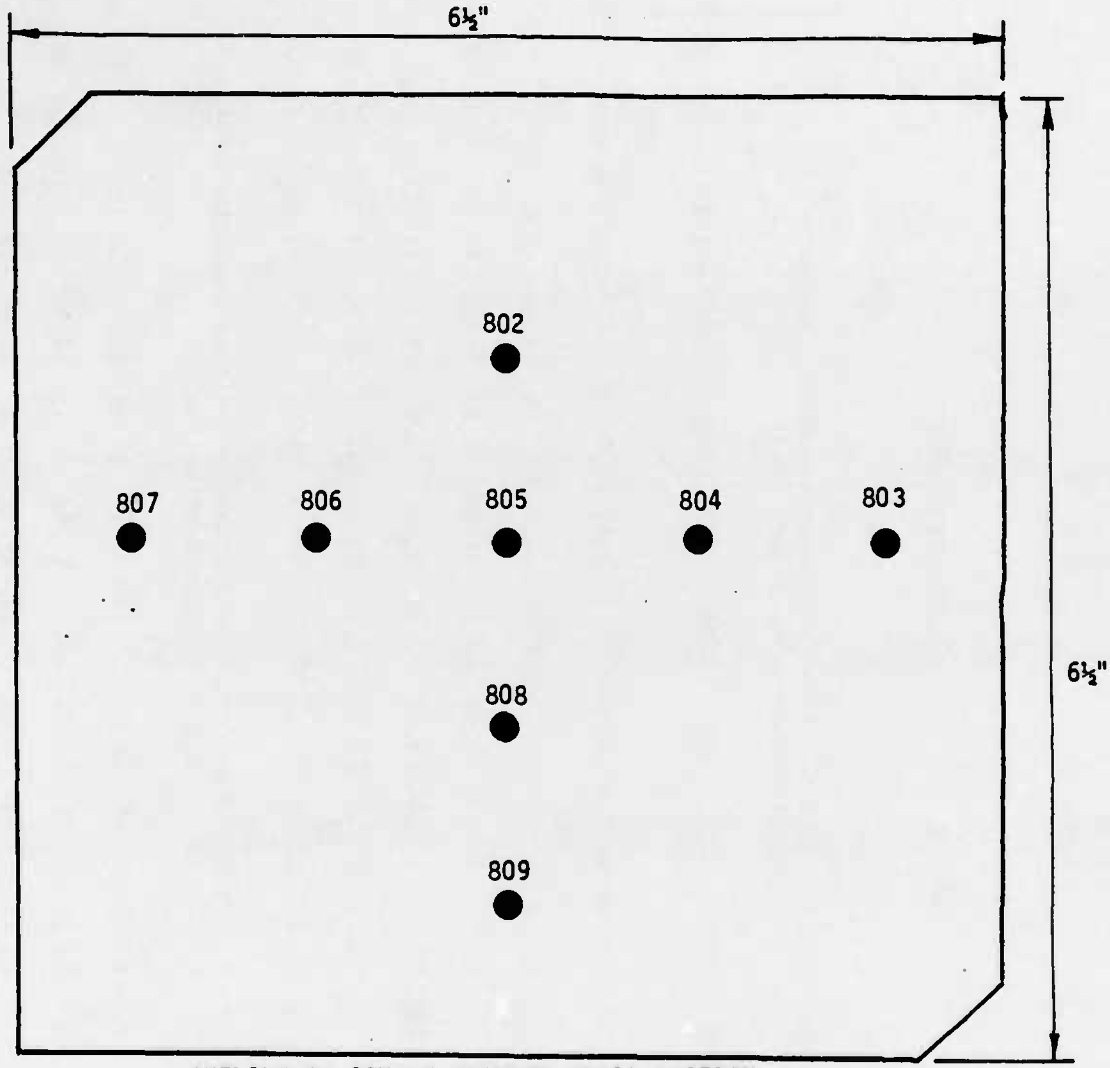
A6.4 Test Results

The throughput of the collector-diverter was estimated as 78%, based on average flux at its entrance and average flux at its exit. Actual throughput, considering the approximately 15% reduction in cross section area between the entrance and exit is then approximately 68% of the entering energy.

The throughput of the collector-diverter and sample chamber combination was estimated as approximately 25% based on average fluxes in the entrance and exit plans. When the concentration of the collector-diverter is considered, throughput was approximately 22%.

The throughput of the steel, two piece sample chamber alone (with one inch instrument spacers in two corners) was approximately 32%. As the tube had a uniform cross-section there is no decrease in this value to account for concentration.

The brass collector-diverter and two piece steel chamber survived the testing and handling without leaks and without degradation of the silverplated surfaces.



OUTLINE OF SAMPLE CHAMBER CROSS SECTION

Calorimeters mounted to aluminum plate which
serves as heat sink and temperature reference.

FIGURE A6.3 ACTF Calorimeter Plate.

TABLE A6.1. FLUX MEASUREMENTS AT ACTF

RUN	INSOLATION W/M^2	Normalized (to $900 W/M^2$) Flux Measurements - Watts/centimeter^2 (Gauge Number - See Figure A6.3) 802	803	804	805	806	807	808	809	AVG	AVG/FLUX	TRANS-MITTANCE
Runs 2.1 - 2.6 made with measurements at exit of Brass Collector-Diverter												
2.1	816	44.75	55.14	51.96	52.73	51.26	49.97	42.69	24.57	46.63	41.52	.82
2.2	867	41.98	51.54	48.50	47.90	47.10	44.20	41.90	25.10	43.53	39.52	.74
2.4	843	41.39	50.57	49.36	49.48	47.94	46.88	41.60	25.37	44.07	39.47	.76
2.5	875	44.89	53.76	53.83	53.47	51.12	49.58	43.79	26.31	47.09	42.25	.78
2.6	878	47.22	55.97	55.55	57.02	55.70	53.19	45.43	26.57	49.58	44.10	.81
Runs 1.9 - 1.11 made with measurements at Sample Chamber exit of Collector-Diverter-Sample Chamber Combination												
1.9	703	12.68	12.33	11.66	12.26	12.19	11.72	11.36	11.48	11.96+6%	12.05	.25
1.10	688	13.70	13.16	12.95	13.29	13.30	12.49	12.45	12.45	12.97±5%	13.06	.25
1.11	695	13.70	13.44	12.81	13.59	13.44	12.36	12.45	12.55	13.04±5%	13.10	.25

APPENDIX 7

PRELIMINARY TEST PROGRAM ON CNRS SOLAR FURNACE, AUGUST 1979

A7.1 Summary

A preliminary test program was conducted on the French national Centre National de la Recherche Scientifique (CNRS) one megawatt solar furnace during the period 20-24 August 1979 to determine apparatus performance and suitability and provide a first hand basis for detailed test planning. SAI participants were Mr. R. Sievers and Dr. B. Gordon. GITEES participants were Dr. S. Bomar and Dr. T. Brown. The principal CNRS participant, and manager of the 1MW furnace, was M. Claude Royere. The test program involved 3½ days of on-site preparation, 16-19 August, and 5 days of testing, in which sun availability was approximately 60%.

The test program included 70 test runs involving calorimeter operation, transmission losses, flux patterns, and various candidate shutter materials and plating. Five tests were run on local soils and vegetation to obtain a subjective estimate of action, and dust and moisture collection or degradation of the walls.

The test program provided the required data on transmission and flux levels which could be expected. In addition, the lessons learned led to extensive redesign of apparatus and change in materials and assembly design. The experience provided permitted the necessary detailed planning for the soil test programs conducted in 1980.

A7.2 Test Configuration

The apparatus configuration used was as shown in Figure A7.1. The brass collector-diverter (paragraph A4.2) and steel sample chamber (paragraph A4.3) were used. Both were cooled with water at an input pressure of approximately 0.6 atmospheres (gauge) with drainage to atmosphere. The stainless steel collar (paragraph A4.5) was adapted to the larger than anticipated (37 cm versus 36 cm) opening in the French aluminum shields by adding two continuous loops of approximately 3/8 inch diameter copper tubing

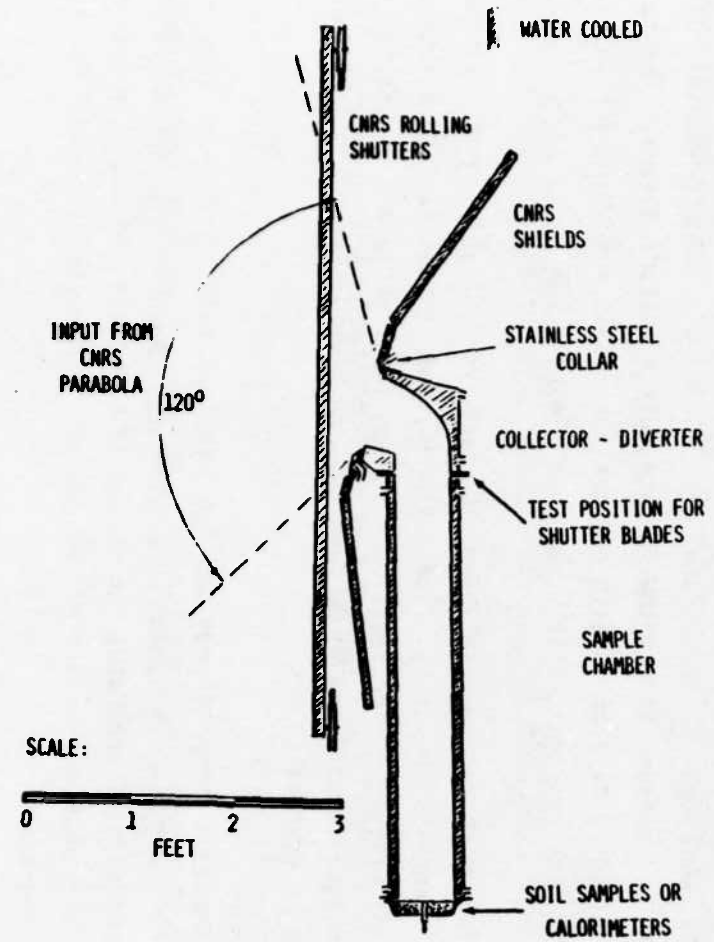


FIGURE A7.1 Configuration for Preliminary Testing at CNRS.

around the periphery of the collar's chamber and separately running water through the loops. This was effective and no trouble was experienced with leakage of flux past the collar and tubes (i.e., no sintering of the stainless steel collar back flange occurred).

The "HyCal" calorimeters (paragraph A5.2) were used in the cooled calorimeter box (paragraph A4.5) and held against the bottom flanges of the sample chamber by pipe run through Unistrut (T.M.) "Z" sections bolted to the lower chamber flanges. This was also used for holding the soil test pans in place. It was arranged on site and was fully satisfactory.

A7.3 Instrumentation

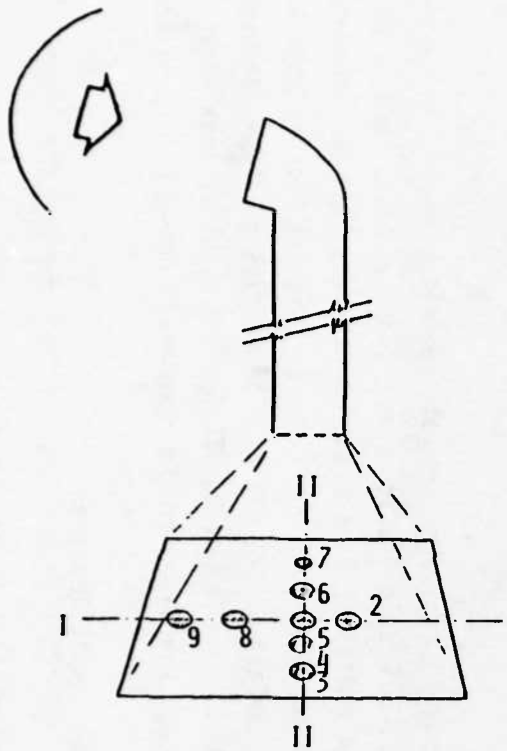
Instruments used in the preliminary program included GITEES thermocouple-type calorimeters mounted on a plate which had been used in the July 1979 tests at the ACTF solar furnace (Appendix 6) and "HyCal" water-reference calorimeters obtained by SAI (paragraph A5.2) and used in the cooled calorimeter box. Calorimeter records were made on CNRS strip chart recorders. A CNRS facility pyrometer provided concurrent insolation data.

A7.4 Flux Measurements

Flux measurements were made at the exit plane of the sample chamber with both the GITEES calorimeter plate (Figure A7.2) and with the SAI calorimeters. In addition, flux measurements were made at the entrance and exit of the collector-diverter and at the 1, 2, and 3 foot heights within the chamber with the "HyCal" calorimeters. The results of these measurements are shown in Figure A7.3. The resulting estimated loss of average flux level with transmission through the diverter and chamber is shown in Figure A7.4.

A7.5 Material Sample Testing

Material samples to aid in design of the vaned and plane shutters (paragraph A4.4) were tested at the exit plane of the collector-diverter. The material was positioned by loosening the connecting bolts between the collector-diverter and sample chamber flanges, inserting the material so that



GITEES CALORIMETER PLATE
(W/cm^2)*

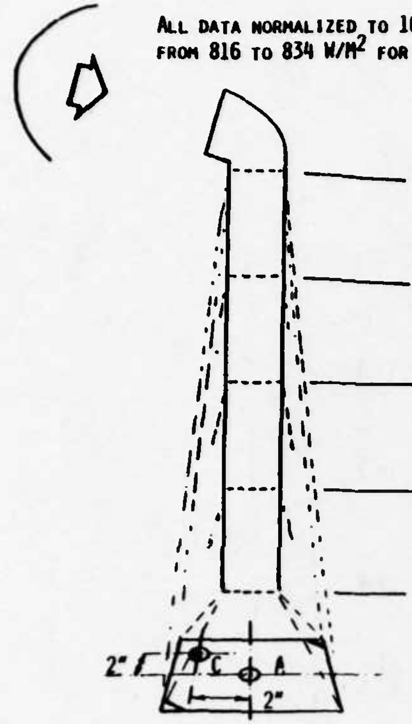
RUN	I				II				
	2	5	8	9	3	4	5	6	7
8	222	232	191	213	239	231	232	208	191
9	226	230	198	214	238	230	230	210	197
10	223	232	198	213	235	230	232	208	195
11	222	229	193	212	235	228	229	207	194
12	221	227	192	210	234	227	227	207	195
AVG	223	230	194	212	236	229	230	208	194

DEVIATION FROM AVERAGE FLUX - %
+3.4 +6.6 -10.1 -1.7 +9.4 +6.1 +6.6 -3.6 -10.1

*ALL DATA NORMALIZED TO 1000 W/M^2 INSOLATION. ACTUAL INSOLATION RANGED FROM 870-880 W/M^2

FIGURE A7.2 CNRS Flux Distribution at Chamber Exit Measured With GITEES Calorimeters.

ALL DATA NORMALIZED TO 1000 W/M^2 INSOLATION. ACTUAL INSOLATION VARIED FROM 816 TO 834 W/M^2 FOR RUNS 20-29.



	A CENTER W/CM^2	C CORNER W/CM^2
4'	729	559
	714	543
3'	473	427
	455	416
2'	367	344
	362	331
1'	297	297
	293	270
0'	264*	264*
	234	234
	222	222

*PREVIOUS DAY'S DATA: INSOLATION OF 773 W/M^2

FIGURE A7.3 CNRS Flux Distribution in Steel Chamber.

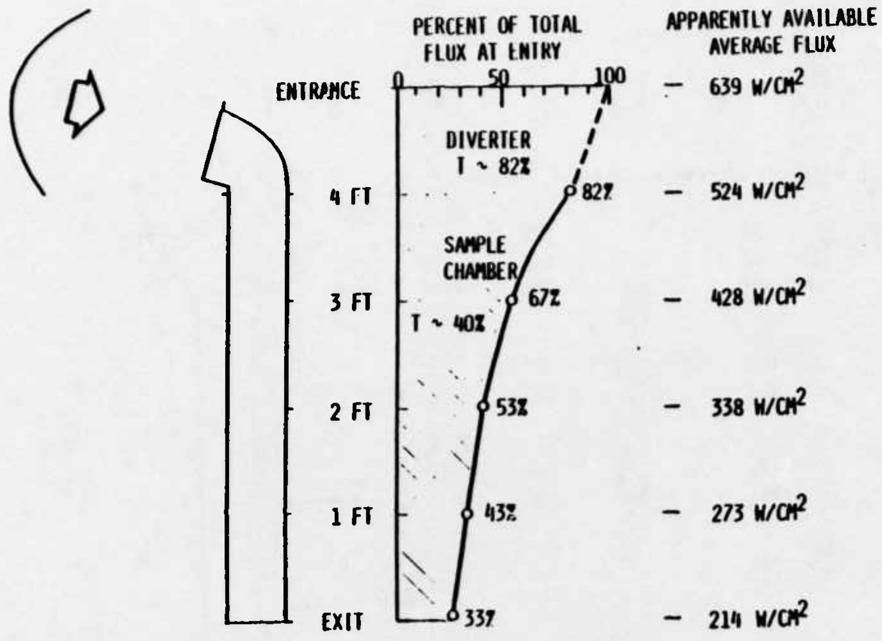


FIGURE A7.4 Flux Loss in Transmission Through Collector-Diverter and Steel Sample Chamber.

it spanned the chamber, and retightening the bolts. Two sizes of material samples were used: one which spanned the full 6½ by 6½ inch opening (simulating the plane shutter blades), and one which spanned the opening but was only 2 inches wide, and therefore was only restrained at the ends (simulating vaned shutter blades). Three of this type sample were tested simultaneously.

Table A7.1 lists the material samples tested and the test results. The results indicated a decided superiority of silverplated copper for uncooled shutter blades, and a sensitivity to discoloration and rapid deterioration with surface blemishes.

A7.6 Trial Soil Tests

Figure A7.5 summarizes the results of the soil tests. The thermal pulse was as provided by using the CNRS rolling shutters.

The great reduction in flux on the surface of the vegetation sample apparently due to the smoke immediately produced was considered especially significant. Data obtained by sieve analysis of the soil is listed in Table A7.2.

The soil tests demonstrated a need for full access to the sample chamber between soil test runs, the desirability of heating the chamber walls, the inadequacy of viewports positioned along the instrument spacers, and the need for a four foot high chamber for study of the thermal/dust layer.

A7.7 Microscopic Examination of Tested Soil

Two of the soil samples (no. 5 and no. 3) were examined by use of a low power binocular microscope for a better understanding of activity taking place at the surface. Samples of the surfaces were taken by pressing a strip of masking tape onto the surface and then placing the strip on a glass slide. What was visible then were the undersides of the top layer of grains, one grain thick. Strips were taken from the exposed surface and from below the surface (exposed surface scraped aside). Strips were also taken and examined

TABLE A7.1. TESTS OF MATERIALS ON CNRS SOLAR FURNACE

MATERIAL	THICKNESS	PLATING	EXPOSURE TIME @ FULL FLUX	EXPOSURE FLUX (W/cm^2)	RESULTS
The following samples were the size of vaned shutter blades.					
COPPER	0.032"	1 mil silver	2.1 sec 5.9 sec 11.7 sec	380 to 500	no major effects observed
	0.032"	1 mil silver over 1 mil nickel	2.1 sec 5.9 sec 11.7 sec	380 to 500	dulling of silver plating
ALUMINUM	18g (0.040")	None	2 sec	380 to 500	melted through
BRASS	0.060"	Diffuse Silver	6 sec	380 to 500	melted through
	0.032"	1 mil silver	1.3 sec 2.1 5.5	380 to 500	no deterioration observed
			11.7		melted through
	0.032"	1 mil silver over 1 mil nickel	1.3 2.1 5.5	380 to 500	blistering and dulling of plating
			11.7		deformation

TABLE A7.1. TESTS OF MATERIALS ON CNRS SOLAR FURNACE (continued)

MATERIAL	THICKNESS	PLATING	EXPOSURE: TIME @ FULL FLUX	EXPOSURE: FLUX (W/cm^2)	RESULTS
BRASS (con't)	0.060"	1 mil silver	1.3 2.1 5.5 11.7 (2x)	380 to 500	no deterioration observed
STEEL	20g (0.037")	1 mil silver over 1 mil nickel			melted through
	22g (0.031")	1 mil silver	12 sec	380-500	surface spotting
	22g (0.031")	1 mil silver over 1 mil nickel			surface spotting, clouding, and discoloration; some blisters
The following samples were the size of plane shutter blades:					
STAINLESS STEEL	18g (0.049")	None	2 sec	450-600	melted through
	18g (0.049")	None	(1 sec)	about ?	severely warped
REFRACTORY GRADE STAINLESS STEEL	2mm (0.079")	None	2 sec	400-430	severely warped

	SOIL TYPE	CALORIMETER (W/CM^2)	OBSERVATIONS DIVERTER ENTRANCE	CONDENSATION ON WALLS	PARTICLES ON WALLS	SURFACE POST-RUN
1	CLAY/SILT/SAND	160, 70 – 103	VAPOR	TO 3/4 FT	SOOT TO 8"	CENTER BLACKENED & FRINGE WHITENED
2	CLAY/SILT/SAND	66 – 70	NEGL.	TO 2 FT	SOME FELT IN CONDENSATION	SOME FUSING
3	CLAY/SILT/SAND (WETTED)	47 – 67	NEGL.	TO 2 FT	SLIGHT	BAKED, NO FUSING
4	VEGETATION ON CLAY/SILT/SAND	26 – 33	LIGHT SMOKE	TO 2 FT	SOOT TO 8"	CARBONIZED VEGETATION IN PLACE. SOIL UNCHANGED
5	SILT/SAND/GRAVEL	64 – 70	LIGHT SMOKE	TO 2/3 FT	SOME FELT IN CONDENSATION	LIGHT FUSING

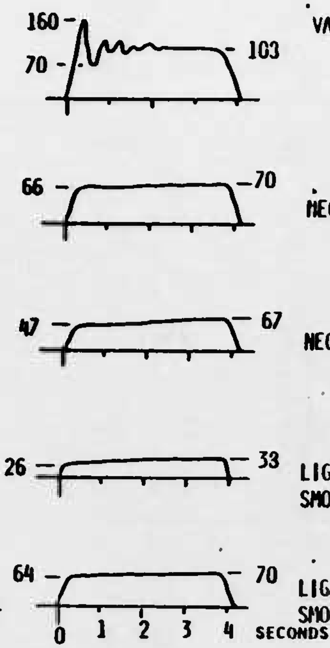


FIGURE A7.5 Soil Test Results.

TABLE A7.2. SIEVE ANALYSES OF TESTED SOILS

Soil Sample Sieve Analysis (g)

SIEVE NUMBER (AFNOR*)	SIEVE OPENING (mm)	#1 CLAY/ SILT/SAND	#2 CLAY/ SILT/SAND	#3 CLAY/ SILT/SAND	#4 VEGETATION ON CLAY/SILT/SAND	#5 SILT/ SAND/GRAVEL
38	5.00	123.3	203.2	359.2	280.2	397.7
36	3.15	147.9	200.1	83.2	192.9	219.3
34	2.00	263.6	267.8	150.6	267.5	266.5
32	1.25	362.6	322.3	235.8	325.5	317.0
30	0.80	368.8	263.7	220.2	257.0	244.0
28	0.50	321.3	196.1	225.4	223.3	192.8
26	0.315	310.9	125.8	169.6	317.1	107.8
24	0.200	278.5	102.2	149.1	119.1	87.3
22	0.125	181.9	101.8	133.0	116.7	84.3
20	0.080	54.2	52.2	37.8	60.2	37.3
19	0.060	18.3	41.0	22.0	41.8	32.7
18	0.050	1.5	5.7	3.5	111.8	10.4
17	0.040	0.7	2.3	0.9	4.8	4.3
Pan	0	0.1	27.6	13.7	41.9	22.4

*French Standard

concurrently of a crushed sand which had undergone four seconds exposure at full flux (these tests were made during the February 1980 test series at CNRS during an extended period of overcast). The observations of these samples are described below. The extent of information available from the strips led to taking such surface sample strips from soils as a routine matter of test procedure in the 1980 test series.

A7.7.1 STANDARD SAND SAMPLE TESTED 18 FEBRUARY 1980

Four second exposure
Peak flux 13 cal/cm^2
Fluence 51 cal/cm^2
Moisture content when tested 0%

This is a review of a strip taken from standard sand sample tested 18 February 80 and comparison with a strip taken from the below affected surface. Both of the strips were taken with masking tape pressed down into surface and then mounted against a glass slide. Size comparisons were made with standard sand sieved using AFNOR (French Standard) sieve sizes (see Table A7.2).

Observations of unexposed sample (generally at 7½ power) ("grains" used for larger grains, "particles" used for "pan" sized particles):

1. Full distribution of grain sizes down to and including "pan."
2. Larger grains have "pan" sized particles coating much of them.
3. Composition appears to be principally clear, light or white quartzite, angular and subangular at all grain sizes; some darker grains present which appear to be surface discolored quartizite. Some mica or other flaky particles, or separate flakes, generally dark in color present.
4. Overall color impression of the surface is light tan with occasional darker grains comprising approximately 15% of total.

Observations of Strip taken from exposed sample

1. General absence of discrete particles smaller than sieve size 26.
2. "Pan" size particle coating generally absent from exposed surfaces of grains. Evidence on many grains that the "pan" sized particles have fuzed with the grain and may be source of black or dark coating on exposed grains.
3. Grains of mica appear to have had mica leaves split apart.
4. Much cementing of various sized grains by darker material (black surface on clear or light quartz apparent in many cases).
5. Many more dark colored appearing grains and generally more red or brown color than in unexposed surface. Essentially all dark particles appear to be a coating on the quartzite or the naturally dark mica.
6. Many rounded and subrounded particles, which have apparently passed through a molten state. Some show pitting as though outgassing had occurred. Some fresh fractures in grains of quartz. Freshness of fractures apparent due to the absence of particles or coating on fracture surfaces.
7. Most quartzite particles of sieve size 30 and below have undergone some rounding of exposed surfaces, or have been agglomerated with other grains. Changes in larger grains appear mostly due to actions on fine grains on their surfaces.
8. Evidence of significantly greater physical effect on overall grains that have the black or dark coating (caused by the melting of fine particles on the surface?). Similar relative effect at all sizes.
9. Overall color impression - approximately 50-50 black and red or brown colored grains.

A7.7.2 Granular Sample (No. 5) Tested August 1979

Observation of unexposed surface (uncovered post test), unsieved material

1. General absence of discrete grains between sieve size 24-26 and "pan".
2. Extensive coating of all grains with "pan" size particles.
3. Agglomeration of many smaller grains apparently with the "pan" size coating material serving as binder.
4. Overall color impression of light tan to gray principally due to light color of "pan" sized material over often darker colored grains.
5. Grains generally clear, white, and discolored quartzite(?), some with black surfaces over clear or white interior; with some darker material (generally in a flake or with some flat or flint-like cleavage). Agglomerations may comprise wide variety of material.
6. Bulk of material appears to be subangular to subrounded, with further softening of angularity by the coating.
7. Coating appears to be generally 80 to 100% of grain surfaces.
8. Loose fines apparently coating particles are generally angular (not flat) and are apparently quartz (quartzite ?) with little discoloration.

Observations of exposed surface

1. General overall impression - black or very dark surface of all exposed surfaces. Extensive lateral agglomeration in plane of soil surface, some over 1-½" in width, essentially one grain thickness in depth, darker and shiny on front surface, dark and dull on reverse surface.
2. Essentially all material agglomerated. Top surfaces smoothed with molten material. All sized particles included in agglomerations.
3. All exposed surfaces rounded or softened, by coating or grain melting.

4. Source of black color is principally in molten coating.
5. Pits in molten material possibly due to escape of gas(?) or surface tension spanning voids for which there was inadequate molten material to fill.
6. Material below molten material appears to be principally white quartz.
7. Overall color is black or dark gray, with light relief on the bottom of larger grains (sieve size 34-36 or larger).
8. "Cement" of agglomerations apparently due to melting of finer particles.
9. Transition of fines on a larger grain from unexposed to exposed surface goes from light color coating, to darker (gray) coating of otherwise similar appearance to softened gray to glassy black (or sometimes glassy white).
10. Mica present invariably has split leaves but no evidence of heat softening or melting.
11. Grains of sieve size 30 and below which are more exposed appear to have undergone some melting.
12. Evidence of fracturing in some large-size grains.

Comments on the above,

1. The coating of fines on the surface appear to stay in place, changing color, melting and joining the host grain, or melting and coalescing to form a molten coating which tends to coat the host grain and agglomerate adjacent grains.
2. The principal change in color appears to occur in the fine particles coating the larger grains - this change generally being a blackening. Some fines however, probably with minimum impurities, may become molten and remain white in color.
3. No evidence that the fines are being lost in observation of the transition from the unaffected underside of a larger grain to the fully affected (molten fines coating), fully exposed surface.

A7.7.3 Soil Sample (No. 3) Tested August 1979 (moistened just before exposure to flux)

(NOTE: The act of extensively wetting the sample may have either of two, opposite effects: it may wash the fines into the surface of the overall sample; or, if sufficient water is used it may cause fines to rise to the surface. The latter would be expected in a flooded sample, which #3 was not. Some washing of upper grains would have been anticipated with the test procedure used, in which the material was not stirred or otherwise disturbed after water had been poured on it, generally over the full area of the surface.

Observations of Unexposed Surface (obtained by scraping away the upper, exposed material):

1. General observation of appearance: tan to brown.
2. Full range of particle sizes down to and including "pan".
3. Most grains appear almost 100% coated with "pan" sized particles.
4. Many grains are conglomerates held together with the "pan" sized particles.
5. Most grains quartzlike of various colors and much white.
6. Some free and attached mica, some of which has leaves split apart. Mica(?) dark in color.
7. Grains appear subangular with further rounding due to coating of fines.
8. Occasional grains with less than 50% of surface coated with fines.
9. Basic composition of larger grains appears to be white quartz and dark mica and/or other dark mineral with flat cleavage.
10. Loose fines of the size coating most particles appear to be subangular to angular.
11. Bits of coated organic matter (vegetation) present -- filament type and some dark, larger, and crumpled-looking.

Observations of Exposed Sample:

1. General appearance - black smaller grains and tanish-gray larger grains (the undersides of grains - due to method of collecting sample specimen of the surface).
2. Full range of particle sizes down to and including "pan".
3. No noticeable additional agglomeration. It appears that grains that were agglomerated (note 4, above) may have remained so but that the fines did not become molten, coalesce and form additional conglomerates.
4. All leaves of mica grains appear to have split apart.
5. Unexposed sides of grains continue to have extensive to 100% coating of "pan" size particles.
6 Black and gray colors apparently due to mica and to discoloration of "pan" sized particles coating grains.
7. No evidence of melting of grains, rounding of edges, or even melting of the "pan" sized particles coating grains (except slight rounding of fine particles on a fully exposed surface, a grain which presumably was reoriented during the collection process).
8. Some charred vegetable material present.

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