TECHNIQUES FOR INVESTIGATING MATERIALS IN A RADIANT HEAT ENVIRONMENT

31 August 1981

Prepared for
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

Under
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GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332
DNA

TECHNIQUES FOR INVESTIGATING MATERIALS
IN A RADIANT HEAT ENVIRONMENT

Georgia Institute of Technology
Engineering Experiment Station
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31 August 1981

Final Report

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The long range objective of this program is to measure quantitatively the behavior of soil specimens while they are subjected to simulated thermal pulses from nuclear weapons. This report describes participation by the Georgia Institute of Technology in a series of test programs for the Defense Nuclear Agency to meet the above objective. Georgia Tech, Science Applications, Incorporated, and the University of Denver Research Institute conducted measurement programs during 1979 and 1980 at the CNRS 1000 kW Solar Furnace in France to acquire data on the behavior of soils under simulated thermal pulses.
SUMMARY

The long range objective of this program is to measure quantitatively the behavior of soil specimens while they are subjected to simulated thermal pulses from nuclear weapons. This report describes participation by the Georgia Institute of Technology in a series of test programs for the Defense Nuclear Agency to meet the above objective. Georgia Tech, Science Applications, Incorporated, and the University of Denver Research Institute conducted measurement programs during 1979 and 1980 at the CNRS 1000 kW Solar Furnace in France to acquire data on the behavior of soils under simulated thermal pulses.
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SECTION I
INTRODUCTION

Prediction of the effects of nuclear weapons is of interest to the Defense Nuclear Agency (DNA) for assessment of the probable damage to targets under various military scenarios. In order to perform these predictions by analytical methods, it is necessary that certain transport properties of the media surrounding the point of detonation be known. In this investigation, the transport properties of the atmosphere near the surface of the ground were of interest.

Under certain combinations of soil type and radiant thermal fluxes from the fireball, it is possible for soil materials, such as particles, water vapor, and smoke from burning vegetation, to be ejected into the atmosphere above the soil surface. If this occurs, the transport properties of the atmosphere are altered and the shock wave, arriving a few seconds after the thermal pulse, behaves differently than if it were traveling through undisturbed air. In order to perform analytical modeling of the shock wave propagation, the transport properties of the atmosphere must be known or estimated. The purpose of this program was to acquire such information by an experimental method.

Solar furnaces provide high radiant heat fluxes with spectral distributions reasonably approximating those emitted by nuclear weapon fireballs. The Centre National de la Recherche Scientifique (CNRS) 1000 kW Solar Furnace at Odeillo, France has the most suitable characteristics of any such facility in the world for simulating the effects of nuclear weapon fireballs on soils: a very high incident flux at the focus (about 1,200 W/cm²) and a high enough power level to illuminate relatively large specimens (about 1 MW of thermal power).

Science Applications, Incorporated (SAI) and the Georgia Institute of Technology (GIT) have worked cooperatively under separate contracts from DNA to carry out a research program for evaluation of soil specimens exposed to simulated nuclear weapon thermal pulses. This report describes work performed by GIT during the period March 1979 through December 1980 under contract DNA001-78-C-0261.

RESPONSIBILITIES OF THE GEORGIA INSTITUTE OF TECHNOLOGY

GIT was responsible for certain clearly defined activities under this cooperative research program for DNA:

(1) To serve as DNA's liaison with CNRS, including coordination with CNRS personnel on test schedules, test plans, and related matters.

(2) To perform coordination between CNRS and the numerous DNA contractors who were active on the program at various times, including SAI, the University of Denver Research Institute (DRI), and others.

(3) To make payments to CNRS, through GIT's Research Services Agreement with CNRS, for solar furnace charges, professional services of CNRS personnel, and reimbursement of freight expenses.

(4) To attend program meetings and participate in the planning of test programs and the review of test results.
To conduct proof testing of the SAI diverter and light pipe assembly during July 1979, prior to the first test program at the CNRS Solar Furnace.

To procure and transport assigned equipment and supplies for test programs at the CNRS Solar Furnace in August 1979, February-March 1980, and September 1980.

To furnish two engineers at the CNRS Solar Furnace during the three test programs, for operation of photographic equipment, work coordination, and assisting in the setup and operation of test equipment.

To make all photographic records of the tests (excluding the light transmission experiment conducted by DRI in March 1980), handle processing of all color films, distribute photographic records to the team members, and forward black and white films to a DNA office in Albuquerque, New Mexico for processing.

To prepare and distribute written inputs for test program reports, including descriptive materials and logs of the photographic films.

TEST REQUIREMENTS

The incident beam at the CNRS 1000 kW Solar Furnace arrives at the focus from an approximately horizontal direction. DNA and its contractors defined the following test requirements for the soil evaluation tests at that facility:

1. The soil sample should lie in a horizontal plane with the incident radiation arriving downward from a direction approximately normal to the sample plane.

2. The atmosphere above the soil should be surrounded by a column with reflecting walls so that the atmosphere appears to be an infinite medium; the height of the column should be two to four meters.

3. The linear dimension(s) of the sample should be 15 to 30 cm (6 to 12 inches); a round or square sample configuration is preferred.

4. The transport properties of the atmosphere must be determined as functions of time and height above the sample plane, beginning at the time of initiation of the thermal pulse and ending at the time of shock wave arrival for the weapon parameters under consideration.

5. The soil behavior must be documented photographically and particle samples should be collected at various heights above the specimen plane.

6. The optical system used to turn or otherwise process the beam of concentrated solar radiation arriving at the focal zone of the solar furnace must cause a minimum attenuation of the incident flux.

In order to conform to the test requirements, SAI designed and constructed a water-cooled light pipe with a curved section at the top to turn the incident focused solar radiation along the axis of the pipe. The light pipe was mounted
vertically, with the inlet aperture of the curved section (the "diverter") positioned at the focus of the solar furnace. The soil specimen was usually placed in a pan at the bottom of the pipe, lying in a horizontal plane (some runs were conducted with the sample pan supported inside the light pipe rather than at the bottom). Various sampling ports and transparent windows were placed along the length of the light pipe (the "sample chamber") in order to permit samples of the atmosphere to be withdrawn, temperature probes to be inserted, and photographs to be made during the runs.

A preliminary evaluation of candidate materials for the light pipe wall was conducted by GIT at the CNRS Solar Furnace in April 1979, during a test program for another sponsor; these tests provided a basis upon which SAI could select wall materials and reflective coatings. A light pipe assembly was proof tested at the Advanced Components Test Facility (a solar thermal test facility operated by GIT for the Department of Energy and located on the GIT campus) in July 1979; this test gave some assurance that the light pipe would survive exposures in a solar furnace before resources were committed for a trip to France. Three test programs were conducted at the CNRS 1000 kW Solar Furnace in August 1979, February-March 1980, and September 1980; these programs conducted soil exposure experiments and collected data for subsequent analysis. SAI was responsible for the light pipe and experiment design, with input from other members of DNA's project team; GIT's responsibilities have been listed earlier.
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TESTS OF CANDIDATE WALL MATERIALS

GIT conducted tests of candidate light pipe wall materials at the CNRS 1000 kW Solar Furnace during the period April 18 through May 2, 1979. At that time, a test program was underway on another research contract and the addition of a small number of samples for this DNA program could be accomplished without significant costs, except the costs of the specimen materials. SAI furnished approximately 30 specimens and Georgia Tech furnished 12 specimens. These tests provided a basis for selecting light pipe construction materials.

Weather conditions at the solar furnace during the test period were very poor and only nine specimens were run. The specimens were exposed to the full flux available at the focal point of the facility at the time the tests were conducted. Front surface temperatures were measured by an infrared optical pyrometer, back surface temperatures were measured on some samples by thermocouples, and 16 mm color movies were made on all samples. Essential data, as determined from the movie records, are shown in Table 1. The aluminum reflecting films on three substrates were applied by vacuum evaporation. The silver films on the remaining substrates were electroplated and polished to give the best smoothness and specular reflectance possible; the steel substrates retained some evidence of tool marks.

The movies and the data shown in Table 1 show that silver is superior to aluminum as a reflective material for the light pipe walls. Copper seems to be the preferred substrate because its high thermal conductivity causes heat to move away from the surface rapidly; it and brass can also be polished more easily than steel. These tests, on uncooled samples, indicated that the light pipe should be expected to survive irradiation near the focus of the solar furnace.

PROOF TESTING OF THE LIGHT PIPE ASSEMBLY

SAI constructed its proposed light pipe assembly, consisting of a curved, beam-turning section (the diverter) and a four-foot long straight section (the sample chamber) in early 1979. The diverter was built from brass with all surfaces exposed to the solar flux being silver plated and the sample chamber was made from steel with exposed surfaces silver plated. It was generally agreed that a proof test at a solar facility in the U. S. was needed before time and resources were expended to conduct testing at the CNRS Solar Furnace in France. SAI proposed to conduct proof testing at the Central Receiver Test Facility (CRTF), a solar thermal test facility operated by Sandia Laboratories for the Department of Energy in Albuquerque, New Mexico. The CRTF's schedule could not accommodate a test of the SAI device before a test program scheduled at CNRS in August 1979.

It was determined that the proof testing should be conducted at the Advanced Components Test Facility (ACTF), a solar thermal test facility operated by GIT for the Department of Energy. These tests were conducted during the period July 23-28, 1979. Photographs of the ACTF and the light-pipe assembly are shown in Figures 1 and 2.

The objectives of the proof testing were:
Table 1. Solar Furnace measurements of wall materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Incident flux (cal/cm²-s)</th>
<th>Maximum fluence (cal/cm²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum plated on brass</td>
<td>273</td>
<td>2785</td>
<td>Melting began at 2129 cal/cm²; pouring began at 2348 cal/cm²; Run II/35</td>
</tr>
<tr>
<td>Aluminum plated on copper</td>
<td>173</td>
<td>2543</td>
<td>No damage at end of test; 2 in. diameter by 1/4 in. thick; Run I/12</td>
</tr>
<tr>
<td>Aluminum plated on steel</td>
<td>274</td>
<td>2795</td>
<td>Melting began at 1644 cal/cm² Run II/37</td>
</tr>
<tr>
<td>Silver plated on brass</td>
<td>186</td>
<td>2734</td>
<td>No damage at end of test; 2 in. diameter by 1/4 in. thick; Run I/11</td>
</tr>
<tr>
<td>Silver plated on copper</td>
<td>192</td>
<td>2803</td>
<td>No damage at end of test; 2 in. diameter by 1/4 in. thick; Run I/10</td>
</tr>
<tr>
<td>Silver plated on copper</td>
<td>229</td>
<td>4946</td>
<td>Slight decrease in reflectance after test; 2 in. diameter by 1/4 in. thick; Run I/16</td>
</tr>
<tr>
<td>Silver plated on copper</td>
<td>273</td>
<td>4778</td>
<td>Sample melted at end of test; Run II/33</td>
</tr>
<tr>
<td>Silver plated on steel</td>
<td>274</td>
<td>4740</td>
<td>Particles ejected at 4274 cal/cm²; melting began at 4357 cal/cm²; Run II/34</td>
</tr>
<tr>
<td>Silver plated on steel</td>
<td>273</td>
<td>5324</td>
<td>Particles ejected at 4750 cal/cm²; Melting began at 4859 cal/cm²; Run II/36</td>
</tr>
</tbody>
</table>

(1) To determine whether the cooling water system was adequate to protect the assembly from damage during run times of to ten seconds.

(2) To measure the flux at the diverter exit and at the sample chamber exit, so that the flux at these planes during tests at the CNRS Solar Furnace could be estimated.

Although the characteristics of the ACTF and the CNRS Solar Furnace do not match very well (the rim angle is 45 degrees at the ACTF versus 74 degrees at CNRS and the power level into a six-inch aperture is about 25 kW at the ACTF versus about
Figure 1. General view of the Advanced Components Test Facility.
Figure 2. SAI light pipe assembly installed at ACTF for proof testing.
250 kW at CNRS) the high cost of an unproductive trip to France seemed to warrant testing under the conditions available at the ACTF.

A total of 19 runs were made, 24 with the diverter and sample chamber and six with the diverter only. Fluxes at the three measurement planes were measured using eight Hycal calorimeters mounted on an aluminum heat sink plate. Throughput fluxes for a typical run are shown in Table 2; the overall flux throughput of 25 percent was about half the expected value, but if that fraction of the inlet flux were obtained at CNRS, useful measurements could be made. The uniformity of flux at the light pipe exit was within 10 percent of the average, which was considered acceptable. The water cooling system worked satisfactorily at the low power input levels available at the ACTF. It was concluded that the CNRS test program in August 1979 should be carried out.

Table 2. Flux measurements at ACTF

<table>
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<tr>
<th>Measurement plane</th>
<th>Average flux (W/cm²)</th>
<th>Transmission factor (percent)</th>
</tr>
</thead>
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<tr>
<td>Diverter inlet</td>
<td>54.1</td>
<td>100</td>
</tr>
<tr>
<td>Diverter outlet</td>
<td>42.2</td>
<td>78</td>
</tr>
<tr>
<td>Sample chamber outlet</td>
<td>13.5</td>
<td>25</td>
</tr>
</tbody>
</table>

Data are normalized to a direct insolation of 875 W/m².

TEST PROGRAM AT THE CNRS SOLAR FURNACE, AUGUST 1979

The light pipe assembly was tested at the CNRS 1000 kW Solar Furnace during the period August 20-24, 1979. Photographs of the solar furnace and the light pipe assembly installed in the focal room of the facility are shown in Figures 3 through 5. The diverter inlet was positioned at the nominal focus of the solar furnace and the sample chamber was oriented vertically with provisions for installation of a soil pan at the bottom of the sample chamber.

The objectives of this test program were:

(1) To perform an overall checkout of the light pipe cooling system, verify the durability of the reflecting surfaces under exposure to the full solar flux available at the facility, and identify design deficiencies.

(2) To measure the flux throughput at the diverter exit, the sample chamber exit, and at several intermediate positions within the sample chamber.
Figure 3. General view of CNRS 1000 kW Solar Furnace.
Figure 4. SAI light pipe assembly in focal room of CNRS 1000 kW Solar Furnace.
Figure 5. Interior of focal room of CNRS 1000 kW Solar Furnace during August 1979 test program.
(3) To check the survivability of thin shutter materials which were to be used without cooling for pulse-shaping shutters.

(4) To run several soil samples for qualitative inspection of their responses to high-intensity radiant energy, their tendency to deposit dust on the chamber walls, and any unexpected behavior.

(5) To make trial exposures of movie films.

Approximately 70 runs were made during this test period, about 42 for calorimetry at various locations, 11 for evaluating shutter materials, five for soil tests, and 12 by CNRS for calorimetry.

The calorimetry measurements were in rather good agreement with similar measurements made at the ACTF, considering the difference in characteristics of the two facilities; flux throughput was found to be about 33 percent (versus 25 at the ACTF) and flux uniformity was found to be within about 10 percent of the average (the same value measured at the ACTF).

The cooling system worked satisfactorily except for failure of a water cooled shield which matched the square inlet aperture of the diverter to a circular aperture in the CNRS shields. Boiling was heard in some areas of the equipment, but this was controlled by increasing cooling water flow rates and rearranging hose connections to minimize the formation of air pockets.

Of the shutter materials, specular silver plating on copper and brass substrates and polished silver alone withstood five to ten seconds of exposure at the diverter outlet plane. Aluminum, nickel, diffuse silver plated on brass, stainless steel, and combinations of silver and nickel plateings failed in two to six seconds. The shutter material tests indicated that none of the thin, uncooled materials could be expected to withstand the flux at the diverter exit for more than about ten seconds; synchronizing of the water-cooled shutters and the pulse-shaping shutters would thus be a critical requirement.

The five soil tests were made on separate samples obtained from the lawn near the CNRS focal building. Fusing of particles, darkening, and ejection of material was observed on vegetation-free soils. The vegetation on one soil burned immediately upon exposure and filled the sample chamber with smoke, thereby protecting the soil surface from fusing and charring. Color movies were made on four of the soils; the first run was used for exposure measurement. There was a pronounced tendency for dirt particles to collect on the sample chamber walls during the soil runs, necessitating cleaning after each run to prevent deterioration of the flux level at the soil plane.

The following system modifications were identified for future tests:

(1) Larger window areas were required in the sample chamber to allow most of the soil surface to be observed by cameras; this was a high-priority item because of the importance of the movie data.

(2) A hinged panel was needed on the sample chamber to permit cleaning of the walls after each run.

(3) A system for heating the circulating water was needed to prevent condensation of atmospheric moisture on the sample chamber walls and the cooling system piping should be arranged to avoid air pockets.
(4) Several movie cameras were needed to obtain adequate documentation from different perspectives.

(5) A stiffer frame was needed to support the apparatus rigidly.

TEST PROGRAM AT THE CNRS SOLAR FURNACE, FEBRUARY 1980

The first test program whose objective was to acquire soil response data in a systematic manner was conducted at the CNRS 1000 kW Solar Furnace during the period February 18 through March 7, 1980. This program included the acquisition of extensive photographic data, the use of a large number of diagnostic techniques by SAI, and a light transmission experiment conducted by the University of Denver Research Institute (DRI).

It was determined at a meeting of DNA and its contractors in January 1980 that the primary documentary movies should be made on Eastman Kodak Linagraph Shellburst 2476 film at 200 frames per second. This is a black and white film with very wide exposure latitude, developed for photographing events which have wide variations in brightness. It was planned that densitometry scales would be spliced onto each roll prior to processing, so that quantitative measurements of brightness could be made. It was also decided that a red filter would be used in order to minimize the recording of scattered light. DRI was in possession of suitable movie cameras owned by DNA, and furnished four D. B. Milliken 4CD cameras for the test program. These are electrically-driven, pin-registered, 16 mm cameras, capable of framing rates up to 500 images per second.

Tests of the camera, film, filter and processing combinations began at GIT on February 1, 1980. Three Kodak Wratten filters were tested, #25 with a short wavelength cutoff at 5900 Angstroms, #70 with a short wavelength cutoff at 6500 Angstroms, and #92 with a short wavelength cutoff at 6200 Angstroms. Using a Kodak Versamat film processor, speeds of 2, 3, 4, and 6 feet per minute were used to process the film. Light meter readings were taken on a Kodak 18 percent neutral gray test card prior to exposing each test film using an assumed ASA setting of 250, and two different graded gray scales and a color control card were photographed. The resulting test negatives were used to evaluate the processing, determine if an equivalent ASA speed of 250 was appropriate, and select an exposure factor to compensate for the red filter. At a processing speed of 4 feet per minute, satisfactory agreement between the light meter readings at ASA 250 and the negative densities was found. It was then determined that a filter correction of four stops was needed for the #70 Wratten filter.

Two GIT engineers arrived at the CNRS Solar Furnace in February and participated with SAI personnel in setting up apparatus in the focal room, including equipment assembly, documentation of equipment positions (for future geometric analyses), and hookup to the 60-Hertz power system provided by GIT. A description of the movie camera arrangement is shown in Table 3 and a photograph of the interior of the focal room is shown in Figure 6.

Testing began on February 18 with characterization of the light pipe, radiation flux calibrations, and trial light meter readings on samples of sand. There followed seven days without sun, during which camera exposure discrepancies were recognized and plans made for resolution. When testing resumed on February 26, trial exposures were made using a fourth DBM camera and the films were processed on-site. Beginning with Test No. 35 on February 27, the camera settings shown in Table 3 were adopted.
Figure 6. Interior of focal room of CNRS 1000 kW Solar Furnace during February-March 1980 test program.
Table 3. Movie camera arrangement, February-March 1980

<table>
<thead>
<tr>
<th>Camera</th>
<th>Settings</th>
<th>View and rationale</th>
</tr>
</thead>
</table>
| DBM No. 1    | f:22
1/3000 s #70  | Downward view of sample surface, because cameras pointed horizontally could not see soil surface |
| DBM No. 2    | f:16
1/3000 s #70  | Horizontal view of bottom window in sample chamber, to permit particle velocity measurements immediately above sample surface |
| DBM No. 3    | f:16
1/3000 s #70  | Horizontal view of all four windows in sample chamber, to permit particle velocity measurements along entire chamber length |
| Bolex H16    | f:5.6
1/125 s 3.00 ND | Kodachrome 25 film, 24 frames per second, held on tripod with view similar to DBM No. 1 to document appearance of sample in color |

During this test program a total of 152 runs were performed. Sixty runs were made on "parametrically chosen" soils, 56 runs were made on natural (undisturbed) soils, and five runs were made on man-made surfaces such as concrete and floor tiles; the remaining runs were for apparatus checkout and calibrations. The DBM movie cameras using Linagraph Shellburst film were operated by GIT for every test and the Bolex camera using Kodachrome 25 film was operated on most tests. Before- and after-test photographs of each test specimen were made on 35 mm color slides with a reference color chart in the picture. Brightness measurements using a Minolta 1-degree spot meter were recorded before and after exposure of each specimen.

A minimum-run contingency test plan was developed in association with SAI early in the test program. This was necessary in case the number of good test days was not sufficient to allow all samples to be tested. The weekend preceding the last week of testing was devoted to adapting the light pipes and experimental setup to accommodate the DRI transmission experiment. This required modification of the light pipe. By this time all of the undisturbed soils had been tested. Approximately 80 sample exposures had been made.

All Milliken cameras and the Bolex camera were able to continue to record the remaining 42 tests conducted during the third week. The test series consisting of the exposure of approximately 112 different soil samples was completed on Friday, March 7, 1980 at 3:11 p.m. when solar insolation decreased due to cloudy conditions.

A total of 99 rolls of Kodak Linagraph Shellburst film 2476 were hand carried back to the United States and subsequently returned to LASL for processing. This lot included 79 rolls of film from cameras 1, 2 and 3, two control rolls and 18
rolls of film exposed by DRI. Six rolls of Kodachrome movie film from the Bolex camera were also returned for processing along with 21 rolls of 35 mm film. Copies of these slides and color movie films were supplied to SAI along with a titled set of all runs including before and after slides and the movies of the tests. This color test movie is approximately 1200 feet in length. A film log indicating the approximate content of each roll of linagraph film was also generated. This was to facilitate processing by LASL and allow the results to be cataloged.

At a program review meeting in May 1980, personnel from LASL expressed the judgment that all films from DBM Camera No. 1 were overexposed except at the initial opening of the shutters. This film was exposed with a #70 Wratten filter in the optical path, which transmits less than 0.1 percent of radiation of a wavelength less than 6415 Angstroms. The high-density image recorded by DBM Camera No. 1 may be due to black body radiation emitted by the soil as its temperature increases. This radiation is above the lower wavelength limit of the filter and below the upper wavelength sensitivity of the film (7000 Angstroms). As the soil sample heats up, the amount of black body radiation between 6415 and 7000 Angstroms will increase in proportion to the fourth power of the absolute temperature. Although the Linagraph Shellburst films were judged to be overexposed, this was preferable to underexposure because all data can be retrieved due to the four decade dynamic range of the film.

**TEST PROGRAM AT THE CNRS SOLAR FURNACE, SEPTEMBER 1980**

The second test program whose objective was to acquire soil response data in a systematic manner was conducted at the CNRS 1000 kW Solar Furnace during the period September 8 through 26, 1980. At a meeting of the several DNA contractors participating in this program on May 29, 1980, the following modifications of procedures used in the February-March program were defined:

1. The film used in the No. 1 movie camera should be changed from Linagraph Shellburst to Kodachrome 25 in order to acquire color information on all runs; the value of black and white densitometry measurements on films viewing the soils at oblique angles was deemed marginal.

2. The No. 2 and 3 movie cameras should be changed from 16 mm to 35 mm and the positioning of these cameras should be rearranged in order to increase the image sizes used for densitometry traces.

3. Other changes, within SAI's sphere of responsibility, should be made in order to insure that data collected in the field were compatible with program needs; specifically, direct measurement of dust and air temperature, collection of dust particles, pulse shaping, and the use of a Knollenburg probe to sample dust particle sizes were identified as being important.

LASL was able to supply three 35 mm Mitchell movie cameras with film magazines, motor drives, and suitable lenses and DRI supplied one 16 mm DBM camera which had been used in the February-March test program. The required mounting apparatus was assembled at Georgia Tech and trial films were exposed and processed. GIT purchased the necessary film supply, based on the filming time experienced in the February-March test program, and shipped the equipment and film to the CNRS facility.
GIT personnel arrived at the CNRS Solar Furnace on September 5 and participated with SAI personnel in setting up the experiment. The arrangement of the cameras is described in Table 4 and a photograph of the interior of the focal room is shown in Figure 7.

Table 4. Movie camera arrangement, September 1980

<table>
<thead>
<tr>
<th>Camera</th>
<th>Settings</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBM No. 1</td>
<td>fill</td>
<td>Downward view of sample surface through lowest window, Kodachrome 25 film, 100 frames/s</td>
</tr>
<tr>
<td></td>
<td>1/2880 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00 ND</td>
<td></td>
</tr>
<tr>
<td>Mitchell</td>
<td>f:16</td>
<td>Horizontal view of two lower sample chamber windows, Linagraph Shellburst film, 100 frames/s</td>
</tr>
<tr>
<td>No. 2</td>
<td>1/2400 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#70</td>
<td></td>
</tr>
<tr>
<td>Mitchell</td>
<td>f:16</td>
<td>Horizontal view of two upper sample chamber windows, Linagraph Shellburst film, 100 frames/s</td>
</tr>
<tr>
<td>No. 3</td>
<td>1/2400 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#70</td>
<td></td>
</tr>
</tbody>
</table>

During this test period a total of 276 runs were performed, of which 238 were with soil or other test surfaces and 38 were for equipment checks or calibration. Because the test runs were being made more rapidly than expected, one of the Mitchell movie cameras was abandoned about September 18 to conserve film. The supply of Linagraph Shellburst film was finally exhausted on September 24, although runs were continued until midafternoon on September 25. All runs were photographed using the DBM movie camera with Kodachrome 25 film and before- and after-test slides were made on each specimen as had been done in February-March. Brightness measurements were recorded before and after exposure of each specimen.

The following collection of photographic film was returned to the U. S. for processing and analysis:

- 53 rolls, Kodachrome 25, 35 mm, 36 exposures
- 2 rolls, Ektachrome 160, 35 mm, 36 exposures
- 5 rolls, Ektachrome 400, 35 mm, 36 exposures
- 25 rolls, Kodachrome 25, 16 mm movie, 100 feet
- 2 rolls, Ektachrome 160, 16 mm movie, 100 feet
- 16 rolls, Linagraph Shellburst, 35 mm movie, 500 feet

GIT had all color film processed, the color movies copied, and distributed appropriate films to SAI and DNA. The exposed black and white movie films were turned over to a DNA office in Albuquerque, New Mexico for handling. The DBM movie camera was returned to DRI and the Mitchell cameras were held at GIT pending instructions for disposition.
Figure 7. Interior of focal room of CNRS 1000 kW Solar Furnace during September 1980 test program.
A program review meeting was conducted on October 24 to critique the test program. At this time, there appeared to be a consensus among DNA's program contractors that data reduction should be carried out on at least one soil before additional test programs are attempted at the CNRS Solar Furnace.
SECTION III
CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been reached on this research program:

(1) The basic concept of the SAI designed and constructed light pipe was adequate to permit tests of soils exposed to simulated thermal pulses from nuclear weapons. The construction and the diagnostic instrumentation were not well executed, however, and serious equipment failures were experienced on each test program. For example, no soil tests with shaped pulses were ever completed during a total of 498 runs conducted at the CNRS 1000 kW Solar Furnace.

(2) Photographic techniques appear to have been refined to the stage that adequate documentary movies can be made. Color movies are correctly exposed but further adjustment of exposure on black and white films may be required to facilitate processing by scanning densitometers. Compromises with respect to filtering may be required to overcome the tendency of emitted radiation to increase film exposure levels.

(3) A large body of experimental data on many soils and other surfaces has been acquired. Most of this information has not yet received adequate analysis. The analysis appears to be a very formidable task, but should be completed for at least a few soils before further measurement programs are undertaken.

The following recommendations with respect to future work are offered:

(1) Since analysis of the experimental data has not been completed, it is not yet clear whether the soil measurements are suitable to meet DNA's program needs. It is recommended that the entire matrix of experimental data for one soil be assembled and inspected for usefulness. The data considered should include movies, information of temperatures, particulate material collected, weight losses, soil composition, changes in brightness and visual appearance, and anything else available. The collection should then be reviewed by manual techniques to identify those conclusions which might be obtained, such as temperatures and dust loadings as functions of time, particle velocities, redundant determinations from separate runs, etc. If it appears that detailed analysis is warranted, the collection should be processed to extract correlations meeting the DNA's needs, for the single soil selected. The feasibility of processing data from other soils can then be established from the patterns identified under this limited study.

(2) If additional soil measurement programs are undertaken in the future, these should emphasize the acquisition of high quality physical data rather than the survey of large numbers of soils. The rule should be that all diagnostic instrumentation and measurement apparatus will be functioning correctly and calibrated before a run is made. If a piece of diagnostic data, such as a thermocouple output, has so little value that calibration is not worthwhile, then the instrument should be removed in order to simplify the experiment; conversely, if data are worth...
measuring, they are worth measuring correctly. The practice of abandoning instruments when they fail, but continuing to expend solar furnace time and personnel effort to run more specimens, can no longer be justified with the contention that many soils need to be surveyed.