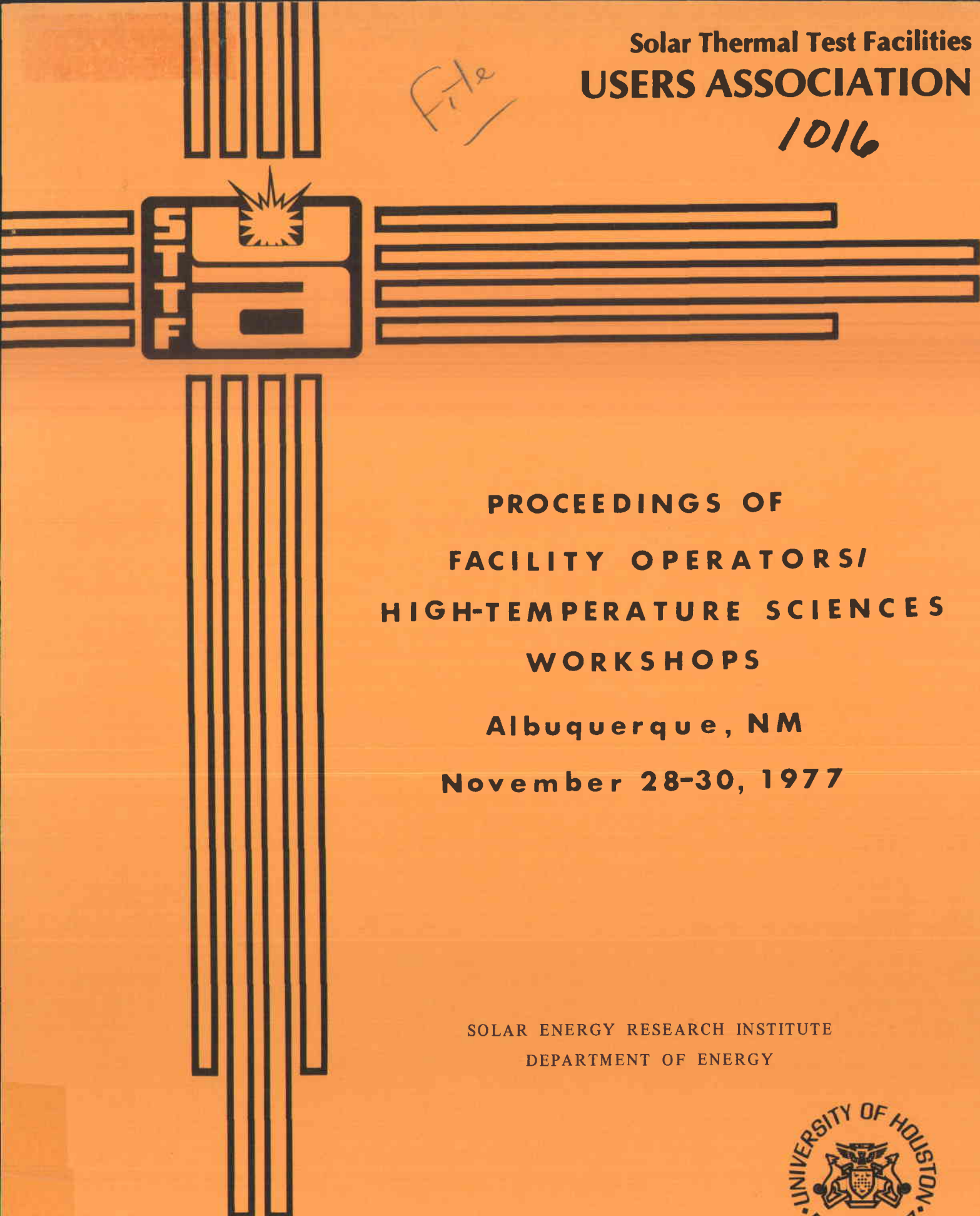


Solar Thermal Test Facilities  
**USERS ASSOCIATION**

1016

File



**PROCEEDINGS OF  
FACILITY OPERATORS/  
HIGH-TEMPERATURE SCIENCES  
WORKSHOPS**

**Albuquerque, NM**

**November 28-30, 1977**

SOLAR ENERGY RESEARCH INSTITUTE  
DEPARTMENT OF ENERGY



## NOTICE

This report was prepared as an account of the meeting sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, nor any of their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its use would not infringe privately owned rights.

Printed in the United States of America

Available from:

National Technical Information Service  
US Department of Commerce  
5285 Port Royal Road  
Springfield, VA 22161  
Price: Printed Copy \$6.00; Microfiche \$3.00

PROCEEDINGS OF  
FACILITY OPERATORS/HIGH-TEMPERATURE SCIENCES WORKSHOPS

Albuquerque, New Mexico

November 28-30, 1977

by

Solar Thermal Test Facilities Users Association

TABLE OF CONTENTS

	<u>Page</u>
I. SUMMARY	3
II. OPENING REMARKS	
- Welcome: M. U. Gutstein, Dr. A. F. Hildebrandt, F. B. Smith	7
- Introduction: F. B. Smith	9
- UA Technical Committee: J. R. Gintz	13
- UA Annual Meeting: Dr. T. Cole	15
III. SERI COMMENTS	
- SERI and Its Objectives for the UA: Dr. C. J. Bishop	16
- SERI Plans and Activities: Dr. J. C. Grosskreutz	24
IV. DR. A. F. HILDEBRANDT - Luncheon Presentation	29
V. FACILITY OPERATORS PRESENTATIONS	
- Sandia 5-MW <sub>t</sub> STTF: J. T. Holmes	33
- Georgia Institute of Technology 400-kW <sub>t</sub> STTF: Dr. C. T. Brown	42
- White Sands 30-kW <sub>t</sub> Solar Furnace: R. Hays	50
- CNRS 1000-kW <sub>t</sub> Solar Furnace: C. Royere	58
VI. DR. P. W. GILLES - Dinner Presentation	59
VII. HIGH-TEMPERATURE SCIENTISTS' PRESENTATIONS	
- Some Proposals for High-Temperature Chemistry Research Using the Various Solar Thermal Test Facilities: Dr. J. L. Margrave	64
- Solar Furnaces Experiments for Thermophysical and Thermochemical Property Studies at Very High Temperatures: Dr. J. P. Coutures	76
- Panel Discussion: Dr. G. Rosenblatt	87
Dr. A. Hertzberg	91
Dr. R. J. Thorn	93
Dr. E. A. Fletcher	97
Dr. S. R. Skaggs	101
Dr. T. Cole	104
Dr. M. Bowman	105
- Metallurgical Processing: Dr. D. C. Cubicciotti	107

VIII. REPORTS OF SMALL WORKING PANELS

- I. Metals and Metallurgy: Dr. D. C. Cubicciotti 112
- II. Materials and Beams: Dr. P. W. Gilles 114
- III. Synthetic Fuels: Dr. J. L. Margrave 115

IX. CLOSING SESSION - Summary: Dr. C. J. Bishop 117

APPENDIX A - Agenda 120

APPENDIX B - Attendee List 122

The workshop was sponsored by the Solar Thermal Test Facility Users Association (STTFUA) to acquaint persons engaged in high-temperature research with the solar thermal facilities and furnaces and to acquaint the STTF operators with research interests and needs of potential STTF users. The workshops were attended by 19 facility operators from Sandia, White Sands, Georgia Tech and Odeillo, 20 high-temperature experimenters from universities, government laboratories and industry, and 13 persons from DOE, DOE/ALO and the Users Association. Dr. John Margrave, Vice President for Research for Rice University and Editor of High-Temperature Science, assisted in organizing and running the workshops.

The STTFUA is supported by the Department of Energy (DOE) and the Solar Energy Research Institute (SERI) to encourage and support the advancement of high-temperature solar technology through the use of high-temperature solar facilities. With respect to the two DOE-funded STTFs in Albuquerque and Atlanta, the role of the Association is:

1. To act as the point of contact for users of the STTFs and as primary access link between users and STTFs.
2. To solicit and review proposals and make recommendations to DOE regarding utilization of the STTFs.
3. To disseminate STTF information on a regular basis.
4. To provide funding for STTF users, subject to DOE program approval.

The Users Association can also make arrangements with the US Army Solar Furnace at White Sands, New Mexico, to make its facilities available through the UA to those seeking UA support, and similar arrangements are being negotiated with the French Solar Furnace in Odeillo, France. The UA has been given responsibility for receipt and evaluation of proposals from all users of the two DOE facilities (except those operating directly under DOE-Washington contracts) and DOE funds have been allocated for support of this work. John Gintz' presentation in Section II provides information on proposal submission and evaluation procedures.

The 5-MW<sub>t</sub> Solar Thermal Test Facility in Albuquerque is operated by Sandia Laboratories; the 400-kW<sub>t</sub> STTF in Atlanta is operated by the Georgia Institute of Technology. Both of these facilities use large fields of sun-tracking mirrors to concentrate the sun's energy on test areas located at the focal points of the mirror fields. The White Sands 30-kW<sub>t</sub> and French 1000-kW<sub>t</sub> furnaces use double reflector

systems consisting of flat mirrors which track the sun and reflect its energy to parabolic reflectors, which in turn focus the energy onto the test area. These facilities are described in Section III of the proceedings and a summary of their specifications is given in the following table:

APPROXIMATE SPECIFICATIONS FOR STTFs AND SOLAR FURNACES

FACILITIES	SANDIA	GEORGIA TECH	WHITE SANDS	ODEILLO
TOTAL THERMAL ENERGY, kW <sub>T</sub>	5000	400	30	1000
NUMBER OF HELIOSTATS	222	550	356	63
HELIOSTAT SIZE, M	66x 6	1.1D	0.6 x 0.6	6 x 7.5
TOTAL HELIOSTAT AREA, m <sup>2</sup>	8257	532	137	2835
TEST AREA DIAMETER*, M	2 3	0.3 1.0	0.08 0.15	0.25 1.0
PEAK FLUX, W/cm <sup>2</sup>	250	375	400	1600
MAX. CALCULATED EQUILIBRIUM TEMPERATURE*, K	2600	2700	2900	4100

\*THE FIRST NUMBER IS AREA RECEIVING APPROXIMATELY ONE-HALF OF TOTAL ENERGY; SECOND NUMBER IS AREA CAPTURING 95% OF TOTAL ENERGY.

\*SMALL AREA AT CENTER OF BEAM.

Possible STTF experiments proposed and discussed by workshop participants included:

- Skaggs: Separation of molybdenum from Mo ores (previous work done by Skaggs and Coutures at Odeillo).
- Margrave, Bowman: Separation of hydrogen from water. Both one-step and two-step processes might be considered.
- Cubicciotti: Carbothermic reduction of iron ore at 1200 K, Fe<sub>2</sub>O<sub>3</sub> to give Fe, is a process which has been done for thousands of years--currently in large quantities--which uses much energy and much carbon. Significant part of fossil fuel used in the process might be saved through the use of solar energy.
- Cubicciotti: Carbothermic reduction of aluminum at 2300 K. Design of experiments is not trivial and one may or may not come up with experiments which are worth doing.

- Chubb: Melting of refractory metals--particularly titanium sponge. It is an energy-intensive process, the price of titanium is very high and is largely energy costs.
- Walton: Silica purification. In heating silica, Mr. Walton finds it becomes purified by a vaporization of the impurities. The purified silica has applications for optical fibers. Bell Labs is considering these seriously for fiber optics.
- Gutstein, Cubicciotti, Hertzberger, Hildebrandt: Production of carbon monoxide from fossil fuels.
- Chubb: Purification of zirconium.
- Cater: Manufacture of lime from limestone (i.e., cement processing).
- Chubb: Thermal disassociation of halides.
- Gutstein: Testing of refractory materials (protective coatings).
- Gilles, et al: Study of properties of beams--flux distributions, temperatures, etc.
- Gilles, et al: Study of phase diagrams and vaporization properties of materials at temperatures greater than 2000 K in controlled atmospheres.
- Gilles, et al: Study of thermal properties of materials at high temperatures: transition temperatures, lattice parameters, segregation phenomena, diffusivity, emissivity, reflectivity, conductivity, heat capacity, enthalpy.
- Gilles, et al: Testing of large pieces of machinery, e.g., from nuclear reactors.
- Margrave: Development of synthetic fuels, such as methanol.

Other observations and conclusions to be drawn from the workshops include:

- High-temperature scientists typically work with small sample sizes and low total heat and are, therefore, unaccustomed to thinking in terms of the kinds of experiments that might be run on the STTFs, which provide hundreds of kilowatts of thermal energy.
- Much basic high-temperature data essential to exploitation of high-temperature solar technological advancements are not now available. The STTFs might be utilized in securing some of these data, but other information might better be obtained from smaller university or industrial laboratory facilities.



- To advance high-temperature solar technology most effectively, a balanced program, supporting both experimental work on the facilities and supporting work in laboratories, is needed.
- Other facilities, such as the Sandia Radiant Heat Facility, might also be useful in preliminary work leading to development of STTF experiments.
- STTFs are sources of very intensive radiant energy for study of photochemical reactions.
- Energy available from a solar facility does not necessarily have to be used alone, but might be used to supplement other heat sources. One might add solar energy to a chemical reaction to give higher temperatures than would be available with either one alone.
- The STTFs provide opportunity for experimental high-temperature studies in an environment free of other electromagnetic radiation.
- There may be a need for windows or containers capable of withstanding STTF temperatures for experiments which require a vacuum or environments other than one atmosphere of air.
- A major impediment to many large high-temperature industrial processes will be the intermittent nature of solar energy, since most processes must be run continuously and shutdowns are very costly. Here again, however, it may be that new processes can be developed where daily, or even more frequent, shutdowns can be tolerated.

It became obvious during the conference that chemical or mechanical engineers intimately familiar with large industrial chemical processes requiring high temperatures and high heat fluxes were not represented at the workshop. Consequently, it was agreed that another workshop should be considered in early 1978, during which these kinds of people might discuss experimental work leading to industrial uses of the STTFs.

Smith - I'm Frank Smith, Executive Director of the Users Association. I'm delighted to see so many of you here. Most of you know that this has been an evolving workshop, and has changed quite a bit since our initial planning. It grew in size from about 10-12 people to the group you see here. We are delighted and grateful that it has attracted so much interest but that has necessitated some changes in the agenda. At this point I want to introduce Dr. Alvin Hildebrandt. Dr. Hildebrandt is the President of the Users Association and Chairman of its Executive Committee. He will be chairing the first session.

Hildebrandt - Thank you, Frank. I'd like to add words of welcome to all of the group; I'm sure it will be a most profitable meeting. We're honored in having several very distinguished international visitors with us: Claude Royere, Claude Etievant and Jean-Pierre Coutures from France and Prof. Giovanni Francia and Dr. Beer from Italy. (All participants introduced themselves; see List of Attendees attached.) I would like to add that we are exploring the possibility of a cooperative program with CNRS, where we might have French scientists using US facilities and US personnel using the French facilities.

Our program is a joint meeting between the operators of the STTF facilities and the high-temperature materials group. I would like to introduce at this time Marty Gutstein from the Solar Thermal Power Office at DOE, who will tell us about DOE objectives for the STTFs and the Users Association.

Gutstein - Good morning. I'm substituting for Gerry Braun, who could not be here today. Mr. Braun is Assistant Director for Solar Thermal Power, in the Department of Energy, and is responsible for development activities in the area of solar thermal. In Solar Thermal Power we have three main subprograms: Central Power Applications, Dispersed Power Applications, and Advanced Technology. In the area of Central Power, we are looking at intermediate load power plants, something on the order of 50 to 300 megawatts. The applications are new plants and possibly retrofitting of existing natural gas and oil-fired plants. The retrofitting might be of smaller capacity, something around the 10-megawatt level. In the area of Dispersed Power, we are looking at total energy, small community systems and irrigating systems. These are generally below the 50-megawatt capacity.

Advanced Technology supports the two applications subprograms. In general, the two I've mentioned, Central Power and Dispersed Power, are aimed at initial demonstrations by the mid-80's. We believe that the solar thermal program will come into commercial implementation shortly thereafter. However, we need to build for the future and we look to the Users Association to help us do this.

We need to explore the far-term applications of solar thermal power to have a balanced program. We need to examine new uses of solar thermal power, possibly materials processing, fuels and chemical production, new storage techniques, and new energy applications. To the extent that the Users Association can bring new ideas in these areas to the fore, and bring them to the test facilities, we think that the Association will play a critical role in far-term applications. That's the role we see for the Users Association. We believe this first workshop will be a first step in that direction.

Smith - The Sandia 5-MW facility and the Georgia Tech 400-kW facility were built primarily to support Central Electric Solar Power Generation work--to test boilers, heliostats and whatever else needed testing to get Central Solar Electric facilities operating. However, DOE realized that these would be valuable test facilities which could be used for a host of other useful things--many related to solar energy and others perhaps not directly related to solar energy but useful to the country's energy programs nevertheless. The Users Association was organized and funded by DOE for the specific purpose of exploring those other kinds of experiments (you will hear them referred to as Track II experiments). That is not to say that the Association has no interest in Central Solar Electric but that those matters (Track I experiments) are being handled directly by DOE Headquarters, Sandia and Georgia Tech.

While we were concerned with the Sandia and Georgia Tech facilities, it seemed that if we wanted to start a vigorous research program the Users Association should also involve other solar thermal facilities. So the White Sands facility is participating, and we will be having discussions at this meeting with representatives from the French Odeillo facility regarding their participation also. We may also be exploring participating with the Italians, Japanese and the Canadians. (The Japanese and Canadians were also invited but this meeting was put together on such short notice that they were unable to attend.)

A word about how we are funded: ERDA gave a contract to the University of Houston to act as an administrative umbrella over organization of the Users Association and its start-up activities. As of today, funds flow from DOE to the University of Houston to the Users Association. That is convenient because both Al Hildebrandt and I are associated with the University and the University handles all of our administration, payroll, accounting, etc. We are reporting administratively and technically to SERI and the next contract will come through SERI.

To identify some of the people involved: Marty Gutstein is our DOE contact in Washington. Gerry Braun, Marty's boss, is the other individual involved in Washington and he reports to Henry Marvin. As for SERI people, you've already met Chuck Bishop and, I expect, many of you also know Charlie Grosskreutz, who will speak to us at lunch tomorrow. They are the two SERI people who will be most involved. Al Hildebrandt is President of the Association and Chairman of the Executive Committee, and I am the Executive Director. We also have with us at least

two other members of the Users Association Executive Committee: Terry Cole and J. D. Walton, and Fred Manasse will be here later.

One other thing I think you will be interested in also: I have heard

Dr. John Deutch, the new DOE Assistant Secretary for Research, speak and I like what I hear. I believe DOE realizes ERDA went too far and too fast with a big expensive hardware demonstration program and tried to bypass R&D. I believe that Deutch would like to rectify that. At the same time Deutch does not control all of DOE's budget and is a realist, so you should not expect to see sudden miracles from Washington. Those of you from universities should not expect that DOE will start funding universities with an additional \$500 million per year. Nevertheless, DOE's attitudes are very encouraging.

You are now witnessing at least one encouraging aspect. We (the Users Association) do have money, \$250,000, to support outside experimenters and we are looking for proposals. It is not a great deal of money but I think it is enough to fund any useful research on the solar facilities that might be proposed within the next several months. The \$250,000 comes through Marty Gutstein's and Gerry Braun's organization, the solar energy side. I have also talked with Jim Kane, who is under Deutch in the DOE research organization. He has assured me that if we come up with proposals that are not entirely related dead center on solar energy but which nevertheless reflect good energy research, he will be receptive to considering additional funding. The Users Association is the funnel through which proposals for that kind of work will flow.

John Gintz of Boeing heads an Experiments Evaluation Subcommittee of about 20 or 25 people who will review proposals. We are now accepting proposals. If you have work you would like to do on the facilities, we would like to get a proposal from you as quickly as you can put it together.

Chuck Bishop mentioned that we want to keep it simple; we are going to try to make the process as simple as possible. We don't want to tie you up with any unnecessary red tape. Just send us a proposal telling us clearly what you want to do, who is going to do it, why you think it is worthwhile, why you think it is justified, what the costs will be, how it will be handled. Make it as brief as you can but give us enough information to evaluate it fairly. Send three copies to the

Users Association here in Albuquerque. If you are not certain which of the facilities you want to use, we will help you sort that out.

The arrangements being worked out with SERI and DOE provide that very small proposals (e.g., a couple of graduate students who want to come down and run some simple experiment) of \$5000 or less can be funded directly by the Users Association. Anything over \$5000 will require approval of SERI, and possibly DOE Washington, and SERI will probably award a subcontract to the experimenter's institution.

Question - Can we get help regarding what is available at the facilities on a nuts-and-bolts level?

Smith - To answer questions like that is the purpose of this workshop; representatives of the four STTFs will be discussing their facilities and you will have a chance to ask them your questions about the facilities.

Question - Can we use Sandia's radiant heater (as part of our experimental work)?

Smith - The Users Association does not have specific authority to set that up, but we will be working closely with Sandia and I think arrangements can be made.

Glen Brandvold, Sandia - I'll be glad to respond to that. All of the Sandia test facilities and test facility operators will be available to do the kind of nuts-and-bolts test experiments that every experimenter needs. We are going to make sure that our engineers are capable of radiant facilities testing. If such an interface is useful, they will suggest it to individual experimenters. I would hope that the Users Association will be aware of that and will suggest it to experimenters who might benefit. We get to another question: a radiant heater test will cost something and the question is how it is paid for.

Question - How do national labs fit into this? Should we go directly to (the Users Association)? We really shouldn't compete with the universities.

Gutstein - If the experiment is a part of a program, I think the proper approach would be to go through the program chain of communications--if it is part of our applications work, it should be coming directly from DOE to the lab. If

it is outside of that, I don't know at this point how to tell you to proceed. There is no policy at this point but possibly the way is to get a review through SERI. Maybe SERI could handle it, or it may go outside of the Users Association.

Smith - If you send it to the Users Association, we won't just lose it because we don't know what to do with it. We will send it to either SERI or DOE and discuss it with them.

I think most of you got the first announcement we put out where we mentioned Track I and Track II experiments. This is the sort of question we are getting into now.

Gintz - I want to tell you about the Users Association Technical Committee and the operational methods. The two objectives of this technical committee are: 1) evaluation of proposals and 2) evaluation of facility capabilities. We currently have one proposal being evaluated.

At least once a year at the annual Association meeting we plan to look at all of the solar facilities available to the potential users to see if there are any experiment requirements for a facility capability that do not exist. We will recommend to the Executive Committee, which will then recommend to SERI or DOE that the capability be added. This includes from the increased capability for higher temperatures or fluxes to facility test support systems. For example, a source of compressed air was mentioned as something that doesn't exist at the facility. The experimenters now have to provide that as we are painfully aware. We'll have a general Experiments Committee meeting just prior to the annual meeting and come up with a list of recommended facility capability improvements.

I'd like to say a little more about the organization and how we plan to handle proposals as they come in. First, we have the general Experiments Committee with about 20 members. Then we've organized into regional subcommittees-- an eastern, midwest and southwest, since that seems to be where a good share of the activity is, and the west coast. Subcommittee chairmen for these areas are: east, Mike Antal; midwest, J. M. Schreyer; southwest, George Mulholland; west coast, Mike Slaminski.

We went with the regional organizations to make them more easily accessible to small experimenters. We wanted to set it up so that someone, for example in the Boston area, who wanted to submit a proposal would have the people evaluating his proposal somewhere near him. They could easily get together with him if needed.

When we get an experiment near a proposal end, we plan to assign it to the appropriate regional subcommittee. Once that committee has finished its evaluation, they will submit it to the Priorities Committee, consisting of myself and the chairmen of each of the four regional subcommittees. We will recommend to the Executive Committee and to SERI a priority for each experiment, not only for funding but also for scheduling.

Small approved experiments costing less than \$5000 can be approved directly by the Users Association; for more than \$5000 will be recommended to SERI, who will issue subcontracts to the proposer's institution.



Comment - Nobody can build experiments for \$5000.

Smith - There is no dollar limit. Right now there's a total of about \$250,000 but if we had really good experiment proposals up to \$1 million I think we'd find DOE and SERI receptive to more funding.

Question - What about proposals from the national labs?

Answer - (We're not sure right now but submit the proposal. If its good research, we'll work out a way of supporting it.)

Cole - I am the Chairman and sole member of the Program Committee for the upcoming Users Association annual meeting. The meeting is to be held at SERI (Solar Energy Research Institute) in Golden, Colorado. The dates are the 11th and 12th of April 1978, and we plan to have a program which will include expository talks by the facility operators similar to what you have heard this morning but perhaps in a somewhat more expanded version, with an update on their experimental plans. At this time we also would like to solicit contributive papers from either Associates of the Users Association or persons who are sponsored by Associates of the Association. The format that we would like is about a 20-minute talk; we would like to have a one-page typed abstract submitted by March 1 and those should be submitted to Frank Smith, Users Association, Suite 1507, First National Bank Building--East, Albuquerque, NM 87108. If there are post deadline emergency problems, I will probably be able to take care of those myself. We would also like to have a complete text by the time of the opening of the meeting. There is a plan to publish proceedings of the meetings to be distributed to members of the Users Association. I think that completes the announcement.

The Solar Energy Research Institute and Its  
Objectives for the Users Association

Dr. Charles J. Bishop, SERI

The Solar Energy Research Institute's overall mission is to provide significant support to the national program of research, development, demonstration, and deployment of solar energy. A central responsibility in this effort is to contribute to the establishment of a solar energy industrial base capable of supporting the widespread commercial use of the technology.

SERI is working toward the creation of a national center of excellence--a resource dedicated to serving the solar energy needs of the public and industry. SERI is initiating continuing programs in (Figure 1):

research,  
analysis and assessment,  
information and education,  
technology commercialization, and  
international solar energy efforts.

In addition, we expect to assume responsibility for the technical monitoring of a number of existing and planned federal solar RD&D programs.

We interpret our charter as rather broad. Our programmatic efforts can be grouped into five general areas:

1. We will be conducting applied research directed toward the timely development of solar energy technologies which have long-term promise.
2. We will participate in an important way in the conception, evaluation, and development of innovative methods for solar energy conversion.
3. We will undertake further analysis of issues which affect the near-term utilization of solar energy.
4. We will carry out efforts designed to reduce remaining uncertainties associated with solar energy--technical uncertainties, institutional uncertainties, economic uncertainties, and social uncertainties.
5. We will develop and implement methods of providing direct assistance to the public and industry--assistance in the form of information dissemination and technology transfer designed to facilitate consumer and business decisions regarding solar energy.

SERI is organized into five operating divisions as shown in Figure 2. The staff currently numbers 150. Our plans call for a total staff of 300 by October 1, 1978, and 480 by October 1, 1979 (Figure 3).

SERI is now housed in interim facilities in Golden, Colorado. We presently have 33,000 square feet of space. An additional 66,000 square feet will be added in the summer of 1978, when the second building is completed. The first experimental laboratories will be designed into the building scheduled for 1978 completion. The Department of Energy (DOE) now holds an option on 300 acres atop South Table Mountain in Golden for the possible site of the permanent facilities.

As our staff comes on board, we are beginning work on 64 tasks which have been identified in discussions with members of the various solar divisions in DOE. Most of these tasks are of two general types:

- planning tasks--on a branch-by-branch basis--to define plans with a time horizon of about two years;

- state-of-the-art assessment tasks designed to establish data bases, examine the efforts that are now under way in different areas, and identify important unattended areas.

This task list is being modified and extended periodically as needs change.

Our programmatic and operational objectives are becoming more clearly defined as we continually assess perceptions of SERI's mission (Figures 4, 5, 6). Clearly, we will be conducting solar energy R&D for all the major functional solar technologies. Support disciplines such as materials, corrosion, surface physics, and so forth, will be undertaken.

Analysis and assessment efforts will include evaluation of national solar energy programs.

We expect to play an important role in the administration of university solar energy research programs--including the evaluation of proposals and the management of contracts. SERI wants to encourage the universities to get back into the creative mode with respect to solar energy.

The technology commercialization effort includes a technology transfer program, a program of assistance to business and industry, and a liaison function--all designed to promote early utilization of solar energy.

SERI has already begun to assume a central responsibility for US involvement in international solar energy programs--including research, information exchange, and technology transfer. A recent agreement has been reached with the Saudi Arabian government to expend \$100 million (\$50 million by each country) over the next five years for joint solar energy research and development. SERI will manage that effort for the first year.

We are establishing an information data bank and library which we expect to become the most extensive solar energy information resource in the nation--indeed, in the world. Utilizing this resource, we should be able to contribute significantly to the Department of Energy's program of providing information on solar energy to the public.

We host and conduct solar energy conferences, seminars, and workshops--those conceived and organized by SERI or DOE and, by request, those which are part of other efforts.

Finally, we have developed a plan for the permanent SERI facilities including research laboratories, a conference center, a library, and administrative facilities.

Several key projects are currently under way although the staff is by no means complete. The staffing plan, initial task definitions, and FY78 financial plan are all complete. The Mission Definition Report, which details the mission, philosophy, and goals of SERI, why it exists, and what it is expected to contribute to the national solar energy program, has been completed and submitted in preliminary draft form to DOE. The Annual Operating Plan, which describes in greater detail the tasks SERI will undertake in FY78, and the Facilities Plan, which will include plans for both the interim facilities and a preliminary version of what the permanent facilities might look like, have been submitted for DOE approval.

In summary, SERI is now an operating organization with a team of highly qualified professionals totally dedicated to the concept of SERI and actively carrying out its intended mission to contribute significantly to the commercial development of solar energy.

Let's discuss this workshop now. SERI's objective for the solar thermal test facilities is that they be used extensively for experimentation. They are unique facilities; we have not had this type of capability readily available to us previously.

Now that they are near-operational, we want them to be used and to be easily accessible to people who have interest in doing research with these systems. The way to implement this is through the Users Association. SERI feels that the objectives for the Users Association are fourfold (Figure 7):

1. They will promote the use of the STTFs;
2. They will be involved in evaluation of proposals that, hopefully, will be coming in for the use of the facilities;
3. They will be coordinating between the individual facility operators and users for such things as times and procedures; and
4. We hope they will be innovative, i.e., through the use of things like these workshops, to come up with new ideas to support the solar energy programs and, in a broader sense, to support national energy research programs.

The objective for this workshop is singlefold: generate potential experiments for the STTFs. We have always felt that workshops are an excellent way of identifying new work and ideas. They bring together experts who can generate new ideas and concrete recommendations. Workshops are a lot of work. But good suggestions often result, and we hope that this will happen here. If we have a representative symbol, or log for this workshop, I'd like to use the letter "S" as the model. The "S" would stand for (Figure 8): Simplicity, Standardization, and Suggestions. From a simplicity standpoint, I'm specifically addressing the facility operators. We want to try to make the facilities easy to use. We want to try to make procedures simple so that the users do not throw up their hands and say, "It's not worth it." So, I would like to encourage you to keep this foremost in your mind as you proceed in establishing rules and procedures. With regard to standardization, we have three or four facilities we are talking about: let's try to standardize operation manuals, the way we report data, and the capabilities of the individual system. Again, we want to make it simple for users to use these facilities.

Lastly, and this one is aimed mainly at the high-temperature scientists present-- we need suggestions in the form of proposals. We would like concrete proposals of work that can be done on these facilities so that we can then move ahead and implement them. There is money available for experiments in the coming year, and Frank Smith will be giving more details on that. We hope to have more money next year and even more the

year after. Our ability to get and disseminate this money for research is going to be highly dependent upon our ability, in this coming year, to show that these facilities are needed and are being used. With that, I wish you a successful workshop. Good luck and thank you.

# SERI PROGRAMS

- Research
- Analysis and Assessment
- Information and Education
- Technology Commercialization
- International Solar Energy Programs

Figure 1

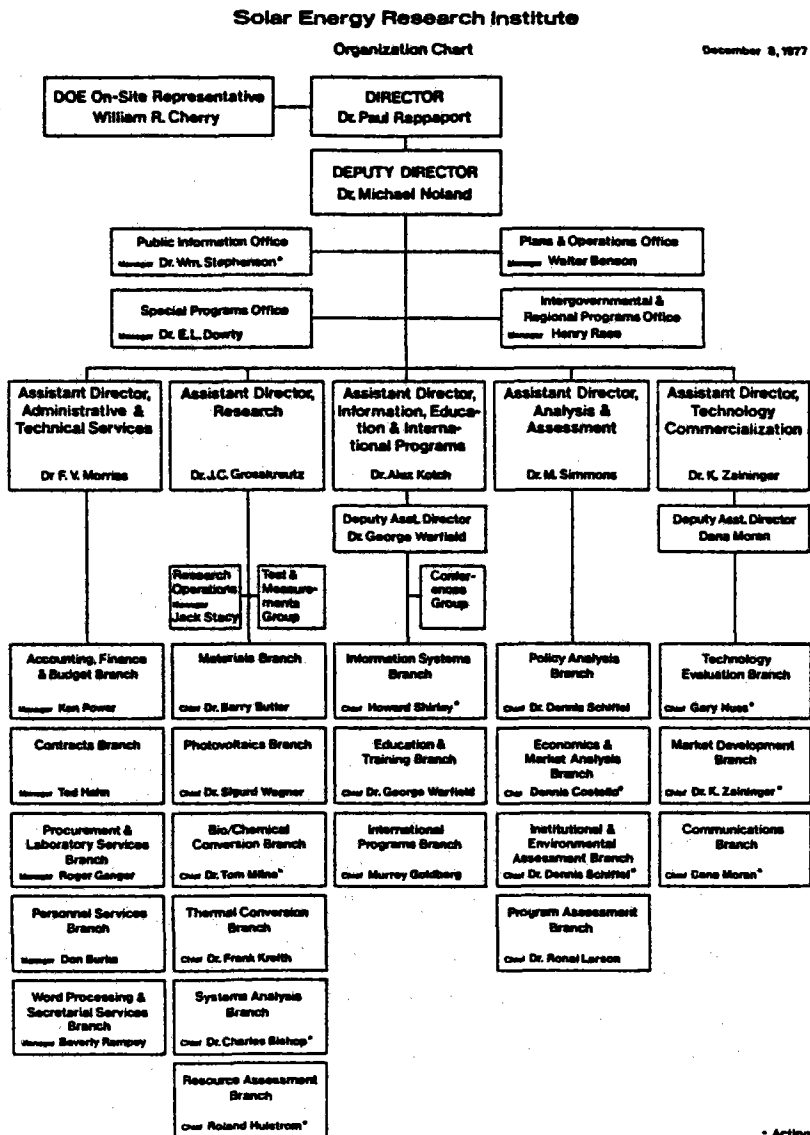
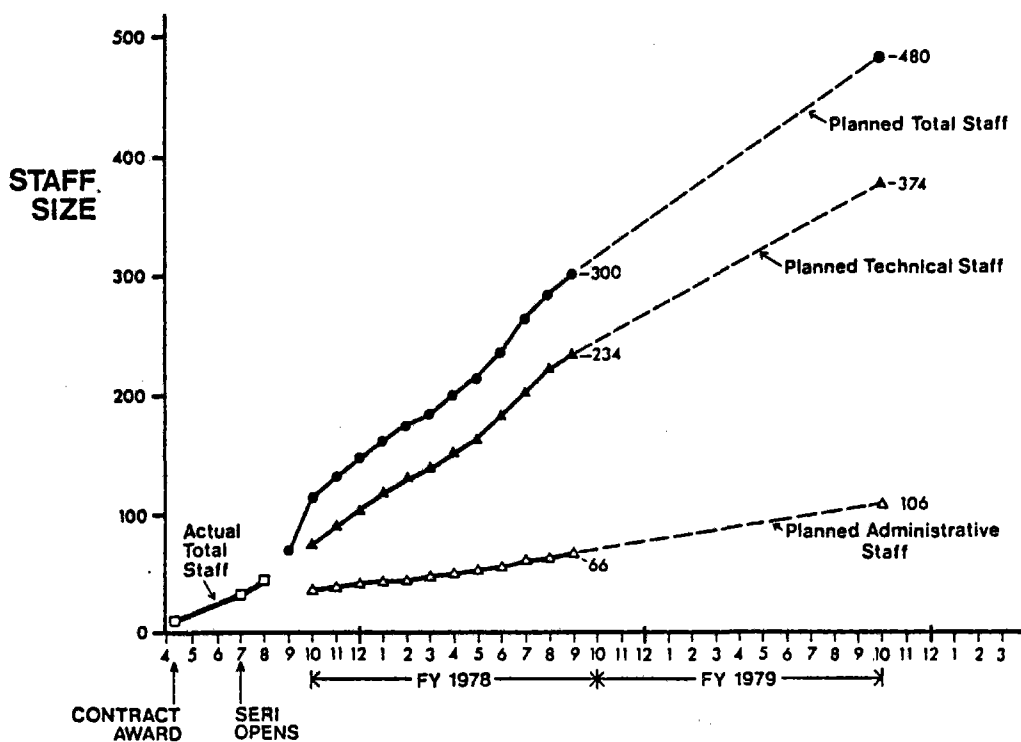


Figure 2

\* Acting





SERI STAFFING PLAN  
(Staff on Board at Beginning of Month)

Figure 3



### SERI OPERATIONAL OBJECTIVES

- Conduct Solar Energy R & D
- Evaluate Solar Energy Programs
- Administer Contract and University Research

Figure 4



### **SERI OPERATIONAL OBJECTIVES (Continued)**

- Promote Early Utilization of Solar Energy
- Coordinate U.S. Involvement in International Solar Energy Programs
- Establish Solar Energy Information Data Bank

Figure 5



### **SERI OPERATIONAL OBJECTIVES (Concluded)**

- Conduct Solar Energy Conferences
- Manage and Coordinate Regional Network
- Develop Plans for Permanent SERI Facilities

Figure 6

#### SERI OBJECTIVES FOR STTF AND UA

- PROMOTE
- EVALUATE
- COORDINATE
- INNOVATE

Figure 7

#### OBJECTIVES FOR WORKSHOP

- SIMPLIFICATION
- STANDARDIZATION
- SUGGESTIONS

Figure 8

## SERI Plans and Activities

Dr. J. C. Grosskreutz, SERI

Hildebrandt - Charlie Grosskreutz has been in the solar tower business since day one, with Black & Veatch. He was with Midwest Research Institute for 15 years, then with Black & Veatch for five years, and for the past four or five months with SERI. He is now the Assistant Director of Research at SERI; he is going to talk about SERI, and will entertain any questions. Without further ado, Charlie Grosskreutz.

Grosskreutz - Thanks, Al. I still feel very much a part of a central receiver power tower development program even though I am not really involved in it any more and the main reason I came down here was just to kibbitz and see what is going on. I really hope that out of this workshop will come something that will launch some high-temperature chemists and maybe some others into research programs on this tower because it is a tremendous resource for them.

We had an orientation program at SERI the other day for new employees that had been there since September 1st. I started my part of the program by saying that for me and for everybody there, the situation was like a guy about my age who was having trouble coping with the situation. He remarked that the trouble was: "the future isn't what it used to be." The future isn't what it used to be for me and for Chuck Bishop and maybe for a lot of you as you're getting into solar energy.

I could talk for a long while on SERI and what we are doing. Chuck Bishop showed you an organizational chart yesterday, so you know what we look like, organizationally, and I won't go through that again. He told you essentially what our mission is in terms of what we are doing: research, analysis and assessment, information, international programs, technology commercialization. The message in the organizational chart and the scope of duties is that we are not just a research institute. We are not doing just research. We are covering the board trying to avoid the mistake that a lot of industries made back in the 50's and 60's when they set up a research lab which they built a campus for, shielded them from the outside world, in hopes that they would come up with great ideas. I can't think of one that still exists; GE's, Westinghouse's, Boeing's, Ford's, General Motors', RCA's (where Paul Rappaport comes from). Each of these laboratories has developed into an integrated laboratory where research is done, but it is tied directly, impedance matched, into the user, or the consumer, or the manufacturing part of that particular industry. That is really the only way that one can realistically bring things out of the laboratory into the field and into commercialization.

We hope to cover the waterfront at SERI in a broad way so that we can fulfill our charter of aiding and abetting the early utilization of solar energy in this country.

We also have an international program. That international program took a rather precipitous rise in its activity when Murrey Goldberg came on board as Branch Chief for International Programs (in another division, not mine). After his first week, he went to Saudi Arabia with a member of the Treasury Department and negotiated an agreement between the Saudis and the US for a \$100,000,000 cooperative solar energy program--\$50,000,000 from the US and \$50,000,000 from the Saudis. Now SERI is involved in planning how that program will go over the next five years.

My particular bag is the Research Division and, as Chuck showed you, we have six branches. We are not trying to cover every base with in-house research, but we are trying to cover all of solar technology with the people we are hiring. I think we are just about to achieve that within the Research Division. We have 30 people committed to come on board by January 1. We intend to grow to 85 professionals within that Division by next October. I think we will make that without any problem. It is fairly evenly distributed among the Materials Branch, Photovoltaics Branch, Biochemical Conversion Branch, Thermal Conversion Branch, Systems Analysis Branch, and a Resource Assessment Branch. Those are fairly self-explanatory as to what they are doing. We wish to avoid categorizing all of the conversion technologies and not talking to one another. One of our traits at SERI is that we talk across branch lines and across division lines; in fact, we have so many seminars going on, I can't find anybody in the office when I go down to look for them! But, getting acquainted and understanding what one another is doing is important.

Our plans are to continue staffing growth through FY 79 to about 400-500 people. Whether we actually do that or not depends a lot on what is going on in DOE right now. As you probably know, SERI initially reported to Dr. Marvin, who was the Director of the Division of Solar Energy, ERDA. We actually reported to a triumvirate of people under him--Bud Annan, as Operations Officer, Lloyd Herwig, and Ray Fields. Now that is being changed and SERI is reporting into a SERI Interim Program Office in DOE. That office is headed by Don Kornreich, who was a member of the Proposal Review Board for SERI. He has a staff which includes Ray Fields, who has followed SERI since its inception. We met with these people for the first time in Golden yesterday and

spent most of the afternoon and night talking with them. It is not clear yet what lines of communication we will have or how they will be set up, but we do know who our bosses are now, and that is comfortable. We will still be working with Marty Gutstein, who is part of the Division of Solar Technology; but I think one of the things that has happened with SERI reporting where we now do is that we will interface not only with the Division of Solar Technology, which is mainly the old Division of Solar Energy, but also with Solar Applications, which has responsibility for all the heating and cooling and industrial process heat. We will also interface with George Deutch, who has the Office of Energy Research, i.e., the old ERDA Basic Sciences Program. This is a broad-brush treatment of what SERI is all about now, though I've rambled a bit.

Perhaps it would be best to stop talking now and answer any questions you may have.

Question - What role does MRI play?

Grosskreutz - Midwest Research Institute is the operator-manager. They hold the contract with DOE to operate and manage SERI. We all work for Midwest Research Institute as a division of MRL. We interface with them in a contractual manner. We have a complete organization at Golden; Paul Rappaport, Director of SERI and Vice President of MRI, down to the accounting departments (we pay ourselves), and so on. We have a contractual office which deals directly with DOE. We do not go through MRI for DOE-related contractual matters. MRI is responsible for the operation of SERI; it's their responsibility to see that we don't goof.

Question - Where will the regional SERI center operations report--to SERI, Golden, or Kornreich?

Grosskreutz - That is not resolved yet. When SERI was formed there were four regional centers formed also: one in the Northeast (Massachusetts), one in the North Central (Minnesota), one in the Southeast (Georgia), and one in the West. Those four regional centers were set up to be satellites of some kind to SERI and, at the time they were announced, it was not at all clear what their mission would be. They were given planning grants of about \$6-700,000 each over a 6-month period to prepare plans, and those are just now beginning to come in. It is clear that their scope will be in the commercialization area. They will work through state and local governments to address the whole issue of implementation and commercialization of solar energy,

trying to remove those barriers that arise when one is trying to get something into the marketplace. I feel, and we all feel at SERI, that such a network is absolutely necessary in order to move solar energy into the marketplace. Where they will report has been a touchy issue. SERI would like to see them report to the Golden office and their work coordinated through us. The people in the states involved obviously would like to report directly to the Department of Energy and not have to come through SERI in Golden. The clamor for how this was to occur got so loud about three weeks ago that Secretary Schlesinger asked for a 90-day study of the situation. He has a staff working now on a recommendation of what to do about this. The decision will not be made until about the First of March.

Question - Is the operation in Golden aimed at immediate problems or problems five or ten years down the road?

Grosskreutz - I regard our basic mission as filling the gap between university research and the programmatic efforts that have been initiated and are now well under way in the Division of Solar Technology. There is a significant gap which we feel we can fill. We don't want to compete with universities in basic research. We also don't want to compete with the Martin Marrietta's of the world or Black & Veatch, where I came from, in the kind of very definite programmatic work they are doing. We would like to do the R&D to support some of that work; for example, high-temperature coatings would be something that would involve SERI.

We certainly are getting involved in the technical management--in some cases, the entire contract management of specific near-term programs for DOE. Those include the Solar Thermal Test Facilities Users Association, the first one we have. The one we are phasing into for Marty Gutstein is the coatings R&D program out of his branch, which we will have full management of by March of next year. Another is the innovative wind systems program that comes under the management of Bob Thresher of DOE. Another is hydrogen from biomass under Roscoe Ward. We are assessing the state of those last two programs now, trying to decide what we are getting into when we assume the responsibility for them.

On the other hand, we feel that we should be doing long-range research that is not being funded anywhere else, or is a high risk, high pay-off area. An example is artificial photosynthesis--fuels or direct generation of electricity from

artificial photosynthesis where one models the photosynthesis process, either biologically or chemically. That probably represents the longest range thing that we have in our plan right now.

Question - Question about bridging the academic and industrial gap and industry's reluctance to talk very much about their immediate problems.

Grosskreutz - We would like to know all of the problems. Many times, not only industry but even universities, won't really tell you their problems, and that is just human. But we would like to know those problems, and Chuck Bishop is putting together a program where we take a hard look at the demonstration programs that have been underway, long enough to generate data and problem data. We can then analyze and focus on some of the problems, or if we can't focus on them, get somebody else to focus on them.

This year we have the STTF Users Association; next year SERI will have programs which it will manage and fund in much the same way that Sandia, Argonne, and the other national labs operate now. I would guess that SERI will follow much the same rationale and methodology that these laboratories have developed--i.e., putting seed money into industry, or doing some internal research, and then letting contracts to industry for further development.

Question - What do you see as university relations with SERI?

Grosskreutz - We have a Division at SERI called Information, Education and International Programs. One of the branches has to do with relationships with educational institutions. The prime objective of that branch, as I understand it (we have just hired Dr. George Warfield as Branch Chief), is to promote relationships with universities and implement, where they don't exist, training programs in solar energy--programs leading to degrees oriented toward solar energy so that we train people to continue the development of solar energy. It is also my understanding that they, together with the Research Division, will be working with the universities to develop research programs in the universities--programs which we will fund. Those mechanisms have not been worked out as yet. I can tell you that Paul Rappaport, the Director, is very anxious to see universities doing the type of work that they do best, innovative research, instead of trying to compete with industrial research.

High-Temperature Sciences and Facility Operators Workshop  
Luncheon Address

A. F. Hildebrandt

Gerry Braun planned to be here as our luncheon speaker but we regret he is unable to do so because of illness. We wish him well.

I would like to announce that John Otts is going to the Los Angeles Operations Office to work on the 10-MW<sub>e</sub> pilot program and that Billy Marshall is now Supervisor of the Sandia Solar Thermal Test Facility Division.

I will review briefly the solar tower history and then the Users Association. In 1969 and '70 the tower concept was developed at the University of Houston, and in '71 we submitted proposals to NSF for solar tower studies. It was most helpful to visit Claude Royere, who is with us today, and Professor Trombe and the Odeillo facility, which did so much to help us get a running start on some of the problems which we faced.

The power tower system is in a way sort of unconventional and develops the big system first instead of doing the 1 watt, the 10 watt, the kilowatt, and the megawatt systems, not leaving out any steps. So there is quite a bit of studying done on why to proceed in a certain way. Basically, the power tower concept is to use a point-focus device to obtain a high radiative equilibrium temperature at the receiver, a large fraction of the solar temperature of 5720<sup>0</sup>K black body equivalent, and then to transfer the energy out very quickly to keep the operating temperature low. We hear again and again that there is really nothing new in solar technology, it's just a matter of economics. Yet there are subtle points that take intensive engineering.

Fossil fuel-fired steam generators have typical cavity power densities of 200-400 kilowatts per square meter. External solar tower receivers, on the other hand, would have power densities in the range of 300-600 kilowatts and higher to avoid re-radiation or convection. Thus, it is a challenge to design steam systems to utilize the high flux densities. If one is to use solar tower energy in chemical disassociation reaction, a power density transformer must be utilized since chemical reactions in heated tubes are typified by power densities of 20-40 kilowatts per square meter. There are a number of advanced systems, including liquid metals and Hitec, on the horizon that are capable of handling receiver power densities of 2 MW/m<sup>2</sup> and matching with steam cycles and chemical reactions. There is also a study of Brayton air



cycles and Brayton helium cycles. Terry Cole told us in Houston that the sodium heat engine using beta-aluminum looks very promising for high-temperature application.

In the chemical storage area there is a new horizon for application of heat pipes. If one stores solar energy by breaking bonds, e.g., ammonium hydrogen sulfate cycle, the chemical reactions require all of the heat at a high temperature. So even if one uses heat exchange fluids like Hitec or sodium, the transfer rate gets rather large because one wants to operate at a high input temperature of say  $900^{\circ}\text{C}$  and the lowest reaction temperature may only be  $800^{\circ}\text{C}$ . Heat pipes, on the other hand, have the unique characteristic of being able to transfer energy with a very low temperature drop.

There is an additional consideration concerning power density. Basically, one can see what happens at the receiver by taking two remote heliostats and having the two divergent beams intersect. (The theoretical minimum divergence is about 10 milliradians due to the solar disc.) The receiver must be placed inside of the beam intersection, either a cavity, a sphere, a bucket, or, for example, the cylindrical external panel receiver of McDonnell-Douglas. The external receiver was chosen for the Barstow site and the decision was largely based on dollars per pound and total dollars, or weight. A cavity receiver is heavy, although it may be a better understood device. There are still a lot of tradeoffs to be studied and I personally believe that there will be 20-30 years of research in fully developing the power tower system.

I would like now to discuss the Users Association. About January '75, we had heard from Washington that there was a consideration of a solar test facility and we at the University of Houston and Texas Tech University submitted a multi-million dollar proposal to ERDA to site a test facility at Lubbock, Texas, with operating funds for a period of five years. Following that it was decided by Bob Seamons of ERDA, and we were informed by Mr. George Kaplan and Dr. Lloyd Herwig, that the 5-MW facility would be sited at Sandia Albuquerque. At the same time they said they would like to have a national users association formed to encourage very wide use of the Sandia facility and possibly to include, we we now have, other solar facilities.

That was in January of '75. In September of '75 we were asked specifically by George Kaplan and Lloyd Herwig to consider forming a users association, which we did. There were a number of legal considerations, charter considerations, and other

problems. We were asked to hold a workshop in Houston, and as a result a report was issued, which many of you have. At that time, many aspects of the solar test facility were investigated: what kinds of problems could be investigated, and uses of the test facility beyond the SRE testing program.

Incidentally, I would like to go back for a moment. The main reason for the 5-MW facility is that the tower program, due to the particular geometry, is rather visible and there is concern that if one simply builds a 10-MW test facility electric power plant without any backup studies, dramatic failures may occur. As a result, the program was moved forward step by step, and the 5-MW, through the SRE program, gives us an opportunity to look at some of these components before we put them on a much larger and more expensive 10-MW electric system.

Also, at Houston in April of 1976 we formed an ad hoc committee to further the organization of the users association. Then in April of 1977 a formal users association organizational meeting was held here in Albuquerque under the auspices of Fred Manasse, the AETA Corporation, and Sandia. The Solar Thermal Test Facilities Users Association is incorporated as a non-profit organization. There is still some legal work going on to clarify the issue concerning tax-exempt status, which takes six to nine months. Present DOE funding for the Users Association is through Oak Ridge and then to the University of Houston. The follow-on contract is anticipated to go from DOE through SERI and to U of H. Two components are expected: the operations office (the employees under the Users Association contract are Frank Smith as Executive Director, Marylee Adams as Project Administrator, Connie Thurman as Secretary, and a part-time secretary in Houston to help the Chairman), and experiments.

There are problems in getting the organization in shape to accept contracts directly from DOE. These involve cost accounting standards and accounting procedures, and are being worked on. The horizon for the Users Association, I think, is very good; the problems we face in the applications area, which I think make for a strong driving force, are work on the collectors, conversion cycles (myriad conversion cycles are possible), and storage (chemical cycles, deep-well storage, for instance).

The outlook for chemical storage is just beginning to develop. I would see it entirely possible in the period of about five to ten years for the same kind of progress on chemical cycles as for power generation cycles to date. The problems are not insurmountable and much can be done. For instance, in one of the systems that we are

Looking at, a liquid-liquid system, we estimate a storage energy density of about one-seventh that of gasoline. The important aspect of storage is first to develop 24-hour storage and then develop one to seven days storage to overcome intermittent inclement weather. I would also like to add that if one looks at the situation further, one can collect solar energy in the southwest, where the solar flux density is best, and transmit the energy out of the region using high-voltage DC. A year and a half ago the transmission cost was about 1/2 cent per kilowatt hour transmitted on a Bonneville-to-California grid, about 1000 miles. With current electric power costs, this is very attractive. A Los Alamos group is looking at superconducting transmission lines on large scale and if one can impact energy over a large distance with high-voltage DC, then the solar energy picture from the southwest changes dramatically. I believe it can have a significant impact.

So often we hear solar reviews which state that solar energy has only a five-hour day in the winter. That is without storage and without meshing into the grid. Interestingly enough, the Barstow site 10-MW system, with seven hours of thermal storage, may have plant capacity factor as high as 0.5. That is quite high.

This concludes a very brief view of the long-term outlook for the solar tower concept and what the problems might be in the applied areas. Beyond the applied areas, we also have many basic problems. I think if we are successful in holding meetings of this type, as John told us earlier, a number of basic high-temperature materials problems can be looked at. If we use the Solar Thermal Test Facilities Users Association as a focal point for drawing these ideas and groups together, there can be a very synergistic effect in the utilization of solar. In the long run, I see where we can help on specific problems, and implement improvements in the test facilities themselves.

Thank you very much.

## Sandia 5-MW Solar Thermal Test Facility

John T. Holmes

As most of you know, the facility is an array of heliostats either on one side, or surrounding, a centrally located tower where experiments can be mounted. I want to tell you a little about the heliostat capabilities and the tower capabilities, as we have it now, and their potential for experimentation. The features shown in Figure 1 are being built into the tower. The facility was designed with flexibility for doing all sizes, shapes and scales of experimentation. There are four major test locations (see Figure 2): the tower top, which is 61 meters or 200 feet above ground level, and test bays located at 48.8, 42.7 and 36.6 meters above ground level on the North face of the tower which can be used for mounting smaller experiments than you would put on top of the tower. In two of the three North face test bays are a scanning laser system that is used to align the heliostats.

This basically describes a steam heat rejection system with a 3-kilogram per second flow rate with 200°C feed water, 5 megawatts steam dissipation through a condenser system, and about a 7-megawatt dry cooling power. In addition (but not listed in Figure 1), we are installing capabilities for air-cooling experiments. One of the first small receivers sponsored by EPRI is an air-cooled Brayton cycle receiver to be tested shortly.

The facility is equipped with data acquisition, transmission and control--features that are pretty standard but very flexible. It will take almost any kind of sensor you have, process it and give you data displays in real time and for recall after your experiment. Standard electrical utilities are available throughout, also lifting devices. Going through the center of the tower is a large elevator that will lift 90,700 kilograms and numerous cranes throughout the facility for lifting, moving and positioning experimental gear. We are able to protect an experiment, or the extremities of an experiment, with modularized thermal protection panels so you can set an experiment in a window that we can tailor for you very easily.

As outlined in Figure 3, currently there are 222 heliostats installed with a total reflective area of over 8000 m<sup>2</sup>. The reflectivity of the heliostats is 70% to 80%, depending on how clean they are. The peak flux in the center of our beam, from calculation, appears to be about 250 watts/cm<sup>2</sup>--about 2500 suns. Total power is 5 megawatts most of the year. During the middle of the day, calculated maximum black body temperature for this kind of flux is 2570°K. Our beam so far has

not been tailored to a nice flat profile. It is a fairly peaked beam with a maximum intensity occurring at the center. The intensity falls off toward the outside. Very roughly, at 1 megawatt the beam size is 1 meter, and at 5 megawatts it is about 3 meters in diameter. We are looking at a couple of other ways of tailoring our beam. The normal STTF beam is obtained with multiple heliostats, 2500 suns peak, intense flux and a test area of some 8000 to 50,000 cm<sup>2</sup>.

Through the Users Association we have a proposal to add a single heliostat reconcentrator for small-scale experiments (see Figure 4). It will have a capability of 1000 to 1400 suns, and a small test area of about 150 cm<sup>2</sup>. The single heliostat reconcentrator probably will be located at ground level rather than on the tower. In addition to that, because we know that some people are interested in higher intensities, we are looking at a design of another concentrator that will be located on the tower. It will use multiple heliostats (possibly all of them, but maybe not). It will provide a test area of about 2000 cm<sup>2</sup> at this higher flux level of about 5-10 thousand suns--4 to 5 fold concentration of the beam. We don't have either of these now. We would really like to know that there are some users for them. We feel sure there will be for the little one, but would like to know if there are some users for a fairly large beam. It will be about one-half meter in diameter. So this is the question we have for you: do you foresee experiments that would utilize this kind of concentrator? The optics design is essentially complete for this. We would like to build a prototype and see if the design is appropriate.

Figure 5 shows some of the diagnostic capabilities that we are designing or already have. A major tool we call a real-time aperture flux system will have a capability of sensing up to a 4000-sun intensity and will provide that information to the experimenter in real time as he is operating his experiment. It is a series of sensors mounted on a moving bar which will scan the aperture of an experiment, on command, and provide input flux information to the experimenter in real time. We can also characterize our heliostats using two systems that have the capability of about 50 suns intensity, one mounted on the tower and one mounted at ground level, for convenience. Then we have a working receiver, a 1-megawatt calorimeter. We can take groups of heliostats up to 1 megawatt power and make calorimetric measurements. It is a water-flow/temperature measuring device, which allows us to characterize specific groups of heliostats you may be interested in for your experiment. There

are also other accessories: photometrics, infrared pyrometry, hot wire anemometers, spectral radiometry, real-time data acquisition, plus a capability to do computer calculation on the beam. All of these things are available to an experimenter coming to the Sandia facility, even in your planning stages. A heliostat analytical beam model is available at any time. If you have an experiment and want to know what you can get, we can very quickly calculate what we can give you.

Figure 6 is a photo showing the tower and part of the heliostat field from the air with the beams aimed at a standby location off the tower. This is one of the tests we have been doing. You'll see this afternoon that all heliostats are in place in the North field.

We do have a fairly sophisticated meteorological station. Data provided, such as wind speed, direction, air temperature, humidity, barometric pressure, atmospheric particulates, can be measured in real time along with your experimentation. Also, we will provide visual range, solar radiation (pyrheliometer), and global radiation (pyronometer). A circumsolar telescope has been put at our site by the Lawrence Berkeley Laboratory which scans the sun and measures the intensity across the disc and beyond the disc of the sun. The Battelle mobile scanning photometer is a total sky photometer which will also provide data to the experimenter. All of this is available to an experimenter as his experiment is running.

Our primary responsibility is to the solar central receiver power plants, however. Our program now consists of testing receivers and heliostats and, maybe at a later time, storage and turbine generator operations. (Figure 8).

Our second reason for being is to provide high-intensity solar testing services to other experimenters--anything you can think of, e.g., materials, coatings, photo processes, photovoltaic, photochemical, chemical and metallurgical processes, high-intensity solar spectrum R&D, anything that would utilize the unique solar spectrum capability of this facility to do research and development.

Our tentative schedule is shown in Figure 9. At the top of the tower we will soon have a series of tests starting with the McDonnell Douglas 5-MW boiler, followed by a Martin Marrietta 5-MW boiler, followed by a McDonnell Douglas commercial version of the original boiler. The goal is to provide data for the Barstow 10-MW pilot plant. At two of the lower test levels we have heliostat alignment going on now but that should end shortly after the first of the year.

We will also be evaluating and testing heliostats for the 10-MW and future plants, and then a program involving testing prototypes of the 10-MW pilot plant heliostats. Although this looks to be a very full schedule, I think that when we get into the testing of boilers and gas-cooled receivers, we will have much time when the facility will be available for running other experiments in other test bays. I envision many experiments which need about one hour. I think we will have a lot of time to do experiments that will take an hour or two, or maybe a day. Most of our maintenance on this equipment will be done at night. We will keep the daylight hours open.

We have published an experimenters manual which describes the capability of the facility, the implementation process, and the requirements of an experimenter at the STTF. Do not be intimidated by the manual. Come talk to us because we are much less intimidating than the document might suggest. It was written with large-scale experiments in mind but we will work with you on a less formal basis. There is some useful information in the manual about the capabilities and how we expect to work with you. Figure 10 lists some considerations for experimenters.

These are some questions I'd like you as experimenters to consider about how this facility should develop its capabilities. Is there anything unique about high-temperature testing or materials testing that would warrant a universal test station--a high-temperature test facility that would meet a lot of the common needs? Do you have requirements for flux uniformity that we don't have right now and possibly won't have even with the concentrators that we are thinking of adding? How important is it to have a flat flux profile over a very large area? Is gravitational orientation important; do you want to be radiated from the top, bottom, side or how? (The beam now comes up from the ground at an angle if your experiment is located on the tower.) Are you going to have things that are going to melt and drip, and do you want to contain them in a crucible that must be radiated from the bottom or top? Coolant: we are talking about high temperatures and a lot of things that may be adjacent to your experiment that may need to be cooled. Our capabilities now are steam and air. Our low-temperature capabilities are water and chilled water. Do you need molten salts or liquid metals? Do you need cryogenic capabilities? We don't have them but we can provide them if you need them. Experiment diagnostics: we plan to develop diagnostic capabilities and if you give us some input we will know better what to supply. Do you have data processing, real-time or otherwise, or experiment control requirements that we don't have right now? (What we have is

described fairly well in this experimenters manual.) I am sure we don't have all of the tools you will need right now but if you let us know what they are, we will try to provide them. The resources at Sandia are large but we are not listing all of them until we know what your requirements are.

Question - What about fluctuations in the beam?

Holmes - I don't think we have a good answer for that right now because we have not taken any real measurements. We do use our analytical models to characterize the beam and I don't think we have done any short-time, minute-to-minute calculations.

Question - What about perturbations in a certain wave length region due to dust kicking up or something like that?

Holmes - I would say that if you have a concern like that and if there is a better time to operate, we would fit it into our schedule for your specific purpose. You could operate your experiment in the morning if wind is a problem.

Question - What is the extent of your software development?

Holmes - The software is being developed now. The heliostat control software is well in hand. Software for heat rejection systems is being developed. Software for data display and the experiment will depend on the experiment. People on our staff will work with you on that. We would expect to give you the kind of information and control you require.

Question - What kind of computer operating systems are you using?

Holmes - The heliostat control system was supplied by Martin Marietta Corporation. Those are Modcomp minicomputers. The facility master control system is a series of Hewlett Packard minicomputers.





Sandia Laboratories  
Solar Thermal  
Test Facility

### STTF TOWER FEATURES

#### TEST LOCATIONS

- TOWER TOP 61.0m
- NORTH TEST BAYS 48.8m, 42.7m, 36.6m

#### HEAT REJECTION

- FEEDWATER 3.0kg/s, 200°C
- 6MW STEAM DISSIPATION 2.5kg/s, 520°C
- 7MW DRY COOLING TOWERS 25kg/s

#### DATA ACQUISITION, TRANSMISSION & CONTROL

- A/D, D/A CONVERSION

- THERMOCOUPLES (K or T)
- STRAIN GAUGE CONDITIONERS
- LINEAR POSITION SIGNAL

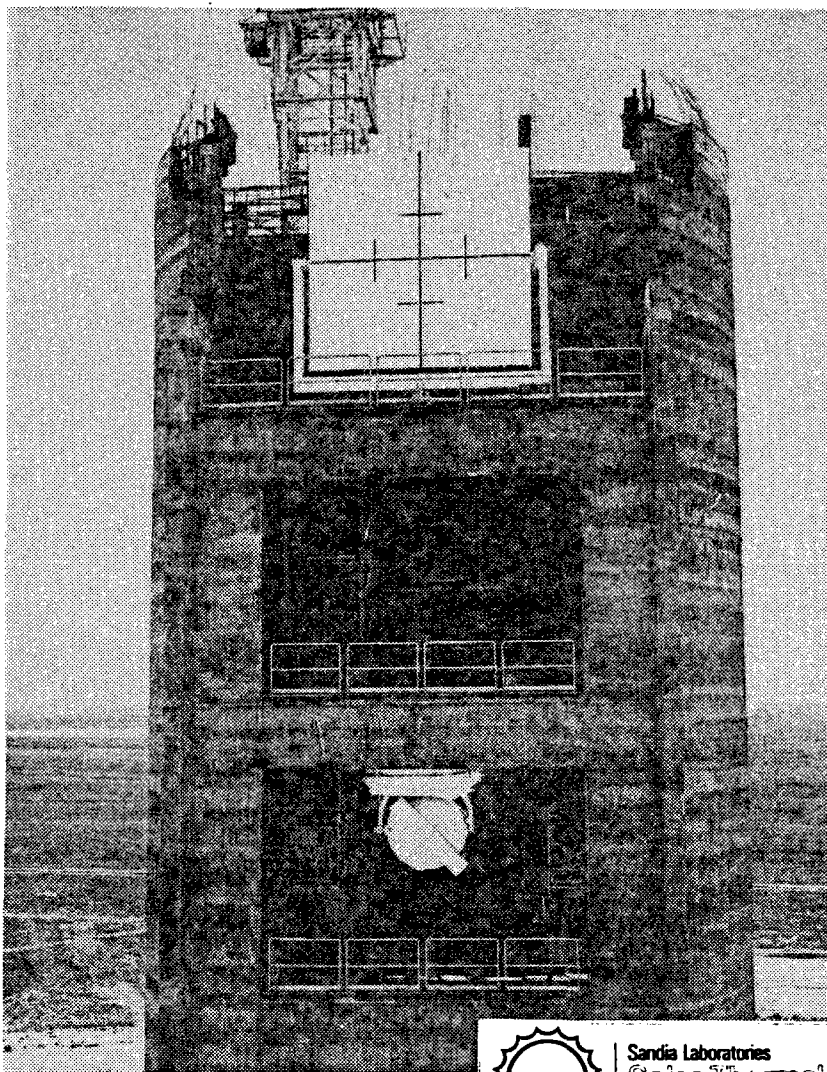
#### ELECTRICAL 115, 208, 440VAC

#### LIFTING DEVICES

- ELEVATING MODULE 90,700kg
- BRIDGE CRANES (2) 4,500kg
- JIB CRANES (3) 4,500kg

#### MODULAR THERMAL PROTECTION

Figure 1



Sandia Laboratories  
Solar Thermal  
Test Facility

Figure 2



Sandia Laboratories  
Solar Thermal  
Test Facility

**STTF BEAM CAPABILITIES**

- 222 HELIOSTATS – 8250m<sup>2</sup> TOTAL REFLECTIVE AREA
- REFLECTIVITY – 70 to 80%
- MAXIMUM FLUX – 250 w/cm<sup>2</sup>
- TOTAL POWER – 5000kw
- MAXIMUM BLACK BODY TEMPERATURE – 2570°k
- BEAM SIZE – 1m DIAMETER AT 1000kw – 3m DIAMETER AT 5000kw

Figure 3



Sandia Laboratories  
Solar Thermal  
Test Facility

PROPOSED SOLAR FLUX CONCENTRATORS

	<u>NORMAL STTF BEAM</u>	<u>STTF CONCENTRATOR</u>	<u>U OF A CONCENTRATOR</u>
NUMBER OF HELIOSTATS	MULTIPLE	MULTIPLE	ONE
FLUX	2500 SUNS PEAK	5000-10,000 SUNS	1000-1400 SUNS
TEST AREA	8000 TO 50,000 CM <sup>2</sup>	2000 CM <sup>2</sup>	150 CM <sup>2</sup>

Figure 4



Sandia Laboratories  
Solar Thermal  
Test Facility

**STTF HELIOSTAT BEAM & EXPERIMENT DIAGNOSTIC TOOLS**

- |   |   |
|---|---|
| REAL TIME APERTURE FLUX SYSTEM _____ (4000 SUNS)  | ACCESSORIES   |
| DIAGNOSTIC BAR _____ (50 SUNS, GROUND LEVEL)      | • PHOTOMETRICS                                      |
| CALIBRATION SYSTEM _____ (50 SUNS, TOWER MOUNTED) | • IR PYROMETRY                                      |
| WORKING RECEIVER _____ (1MW <sub>e</sub> )        | • HOT WIRE ANEMOMETERS                              |
|   | • SPECTRAL RADIOMETRY                               |
|   | • DATA ACQUISITION SYSTEM (REAL TIME DATA DISPLAYS) |
|   | • HELIOS (ANALYTICAL BEAM MODEL)                    |

Figure 5

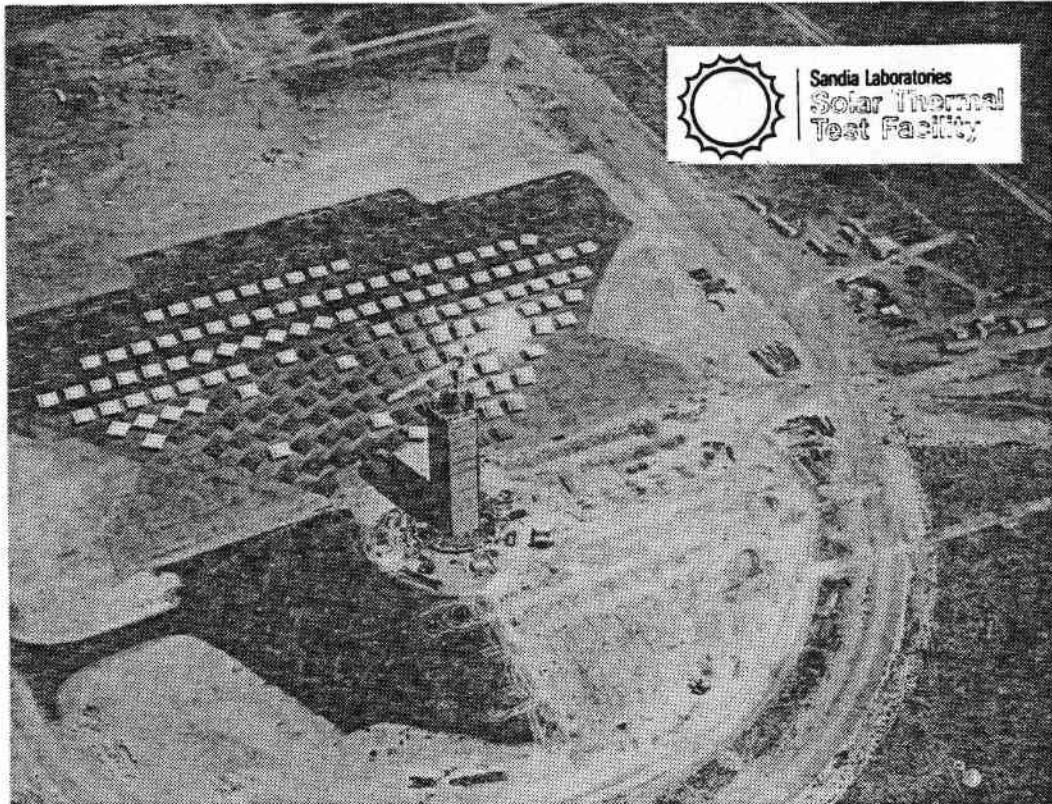
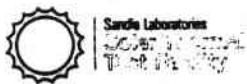


Figure 6



**STTF METRO DATA**

**WIND SPEED AND DIRECTION**

**AIR TEMPERATURE**

**HUMIDITY**

**BAROMETRIC PRESSURE**

**ATMOSPHERIC PARTICULATES  
(NEPHELOMETER)**

**VISUAL RANGE**

**SOLAR RADIATION (PYROHELIO METER)**

**GLOBAL RADIATION (PYRANOMETER)**

**CIRCUMSOLAR TELESCOPE (LBL)**

**MOBILE AUTO-SCANNING PHOTOMETER  
(BNW)**

Figure 7



**SPM SOLAR THERMAL TEST FACILITY PROGRAMS**

**TEST COMPONENTS FOR SOLAR CENTRAL RECEIVER POWER PLANTS**

1. RECEIVERS
2. HELIOSTATS
3. (STORAGE)
4. (TURBINE GENERATOR)

**PROVIDE HIGH INTENSITY SOLAR TESTING SERVICES FOR EXPERIMENTERS**

1. MATERIALS/COATINGS
2. PHOTO-PROCESSES
3. CHEMICAL/METALLURGICAL PROCESSES
4. HIGH INTENSITY SOLAR SPECTRUM RAD

Figure 8



Sandia Laboratories  
Solar Thermal  
Test Facility

TENTATIVE STTF TESTING SCHEDULE (9/77)

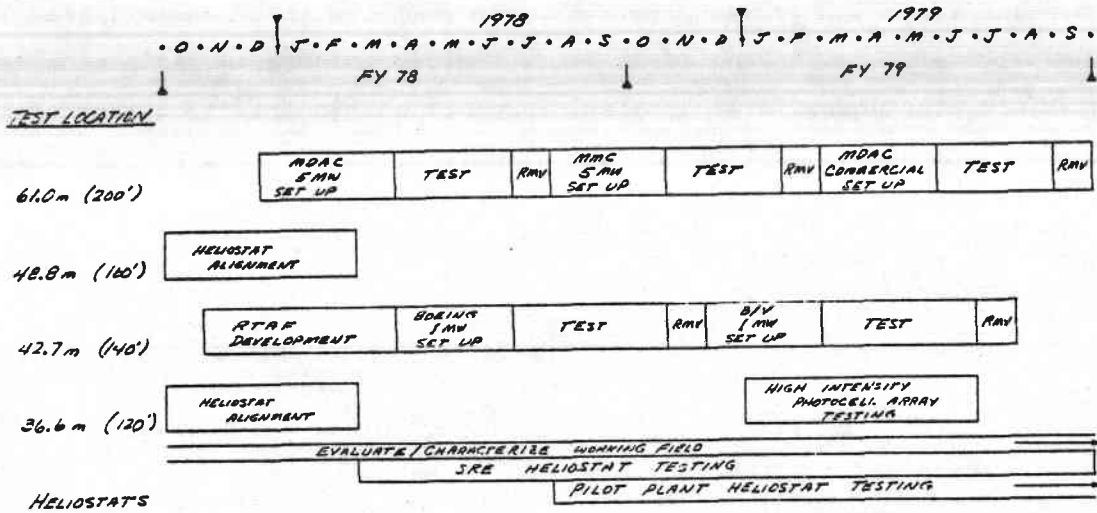


Figure 9



Sandia Laboratories  
Solar Thermal  
Test Facility

CONSIDERATIONS FOR EXPERIMENTERS

- "UNIVERSAL" MATERIALS OR HIGH TEMPERATURE TEST STATION
- FLUX UNIFORMITY, EXPERIMENT SIZE: TOTAL POWER
- GRAVITATIONAL ORIENTATION: BEAM DIRECTION
- COOLING: HIGH TEMPERATURE (STEAM, AIR, ...)  
LOW TEMPERATURE (WATER, CHILLED WATER, ...)
- EXPERIMENT DIAGNOSTIC REQUIREMENTS
- DATA PROCESSING AND EXPERIMENT CONTROL REQUIREMENTS

Figure 10

Georgia Tech 400-kW Solar Thermal Test Facility  
by  
C. Thomas Brown

The Georgia Tech 400-kW Solar Thermal Test Facility is presently nearing completion. The facility, located on the Georgia Tech campus in the heart of Atlanta, is shown in Figure 1. It is patterned after a 135-kW solar thermal steam plant built near Genoa, Italy, by Giovanni Francia, but differs in three basic aspects: At Georgia Tech, the power level is about three times higher, the number of mirrors is nearly doubled, and each mirror is approximately one-third larger in diameter. This larger facility was designed by Francia, engineered and built by Ansaldo, SpA\* a major Italian engineering firm, and is presently being installed and characterized by Georgia Tech.

Our program has two primary objectives at this point: The first to transfer to the United States the Italian solar thermal technology that has been developed under Giovanni Francia's direction for the past 15 years or so. Of particular interest in this technology transfer are the mechanically-driven heliostat mechanisms and the rather efficient, cavity-type Francia receiver. The learning period associated with this technology transfer should be completed near the end of January 1978.

The second objective of the program is to operate a very general-purpose solar thermal test facility to support a wide variety of high-temperature experiments. We envision testing receivers of various types, facilitating studies of high-temperature materials, chemical reactions, synthetic fuel production, and, in general, providing a flexible test facility. Operation as a test facility should commence in February 1978.

Figure 2 illustrates the major components of the Georgia Tech solar thermal Facility and their relative location. The basic field consists of 550 mechanically-driven mirrors arranged in an octagonal pattern. These mirrors concentrate and focus direct sunlight to a point in the vicinity of the central test tower. A thermal cycle pad exists near the west side of the field to support the feed pump, heat rejection equipment, and experiment controls for the Francia receiver experiment. The control building on the western edge of the field, houses the computerized data acquisition system.

---

\* Ansaldo, SpA, Genoa, Italy

As previously mentioned, installation of the facility is nearing completion. All heliostats are installed, mounted and aligned. The drive system has been operated. The tower and its supporting utilities have been installed and checked out.

Figure 3 illustrates our present operating schedule. We are currently in the advanced stages of characterization of the basic facility. At the moment, the heliostats are being adjusted and the resulting beam is being described. Characterization of the Francia receiver, which was first operated at design conditions on October 6, 1977, is continuing and should be completed by the end of January. At that time the existing central tower will be removed and replaced with a much more substantial structure capable of supporting a 20,000-lb test load. The first experiment beyond the characterization activities involves the testing of an air-cooled Brayton cycle receiver that is presently being designed by Sanders Associates.\* The testing of the Sanders receiver is scheduled for the June-July 1978 time frame.

A schematic representation of the Francia solar steam facility is shown in Figure 4. On the left is one of the 550 kinematic motion devices. Each one supports a mirror that is 111 cm in diameter. These mirrors track the sun throughout the day, redirecting the solar energy to the focal plane of the facility. Each of these mirrors may be operated flat, yielding a concentration of about 550 suns at the focal plane, or focused, giving a concentration of approximately 2000 to 2200 suns. The mirrors are driven by an open loop control system. No sun sensors are required in the reflected beam. A close-up of one of the kinematic motion devices is shown in Figure 5. In many ways, these devices are like telescope mounts, in that each has a polar axis. A line shaft drives the polar axis of each device in a direction counter to the earth's rotation.

The Francia-type receiver now installed atop the central tower is a 350-kW<sub>th</sub>, high-temperature, high-pressure steam generator. It is a once-through unit, generating superheated steam at 1024<sup>0</sup>F and 1700 psi. The steam loop was illustrated in Figure 4 as part of the Francia solar steam plant. Its main components are the feed pump, receiver, pressure control valve, spray desuperheater and condenser. The receiver, constructed completely of 316 stainless steel, incorporates a glass antiradiation structure to minimize thermal losses at the aperture. The unit generates about 700 pounds of steam per hour.

---

\* Sanders Associates, Nashua, NH 03060



Question - Do you have any idea what the glass is made of?

Answer - It is a Pyrex glass.

A scanning flux calorimeter will be mounted on the aperture of the receiver in the near future. This instrument is shown in Figure 6, in a view looking at the device from below. It is a water-cooled structure and looks much like a picture frame. To give an idea of the scale, each side is 6 feet. Thirty-seven Gardon gage calorimeters\* are mounted on the scanning bar on 2-inch centers. The bar can scan the 6' x 6' area with a 2" x 2" resolution in about three minutes. The interior structure of the calorimeter is designed to interface with the Francia receiver and may be altered to mate with other equipment.

The facility is equipped with a computerized data acquisition system, shown in the schematic in Figure 7. Built around a 16-K word PDP-8 computer,\*\* the system presently accommodates 108 analog channels and can be expanded to the order of 1000 channels if required. The system can accommodate essentially any type or kind of transducer which operates an electrical signal. The system is currently designed to accommodate up to 50 thermocouple channels (any type or types of thermocouple) and 40 strain gage or Wheatstone channels for use with very low level signals. Raw data collected during an experiment are, in general, stored on magnetic disks and displayed in real time in engineering units on a video terminal. The system can also generate real-time hard-copy data from a line printer.

A sample display of the video output is shown in Figure 8. In this illustration, four thermocouple channels are being displayed. The horizontal axis represents time, with each major division corresponding to three minutes. Thus, the graph gives a history of data for the past 15 minutes. The vertical axis for each of the four channels can have its own engineering units and scale. The current values from the last reading are shown up in the corner. In this particular mode, approximately 120 channels can be treated. Important channels can be shown continuously, while other channels can be retrieved at specified intervals of time. Initialization of the program includes the setting of alarm points for each channel. The computerized data acquisition system has been used very successfully to support the Francia receiver characterization activities.

---

\* Hy-Cal Engineering, Santa Fe Springs, CA 90670

\*\* Digital Equipment Corporation, Maynard, MA

Design of the more substantial and permanent central tower is nearing completion. Figure 9 is a conceptual design for that tower. The focal point for the new tower will be identical to that of the present tower, and thus, approximately 72 feet from the mirror plane to the focal point. The support columns for the new central tower will be spaced 14 feet apart in order to give a large working area and minimize blocking by the structure. It will be able to support a 20,000-lb test load at the working level.

The next view, Figure 10, is of the working level and shows the focal point at this region. The tower allows an 8' x 8' clear area in which to pass the beam if nothing is installed, or if the experiment is smaller than the allowed area. The attachment points for an experiment are located on approximately 9-foot centers. The center of gravity of an experiment can be located anywhere within the attachment points.

A scissors-type lift working from 25 feet below the focal point up to the focal point will provide a platform to facilitate servicing of the experimental area. During solar operation, this lift will be lowered out of the region where it might block the radiation. The small building shown in the figure will house the remote data acquisition instrumentation. The close proximity of the data system allows for very short cable runs from the experiment to the analog-to-digital converter data part.

Question - Is the facility available to outside experimenters?

Answer - By all means. As a Department of Energy facility, we are very interested in working with and servicing the outside user. The scheduling of experiments into the 400-kW facility will be based on recommendations from the STTF Users Association and the Department of Energy. A Georgia Tech 400-kW STTF Users Manual describing the facility can be obtained from the STTF Users Association or from the Solar Energy and Materials Technology Division of Georgia Tech.



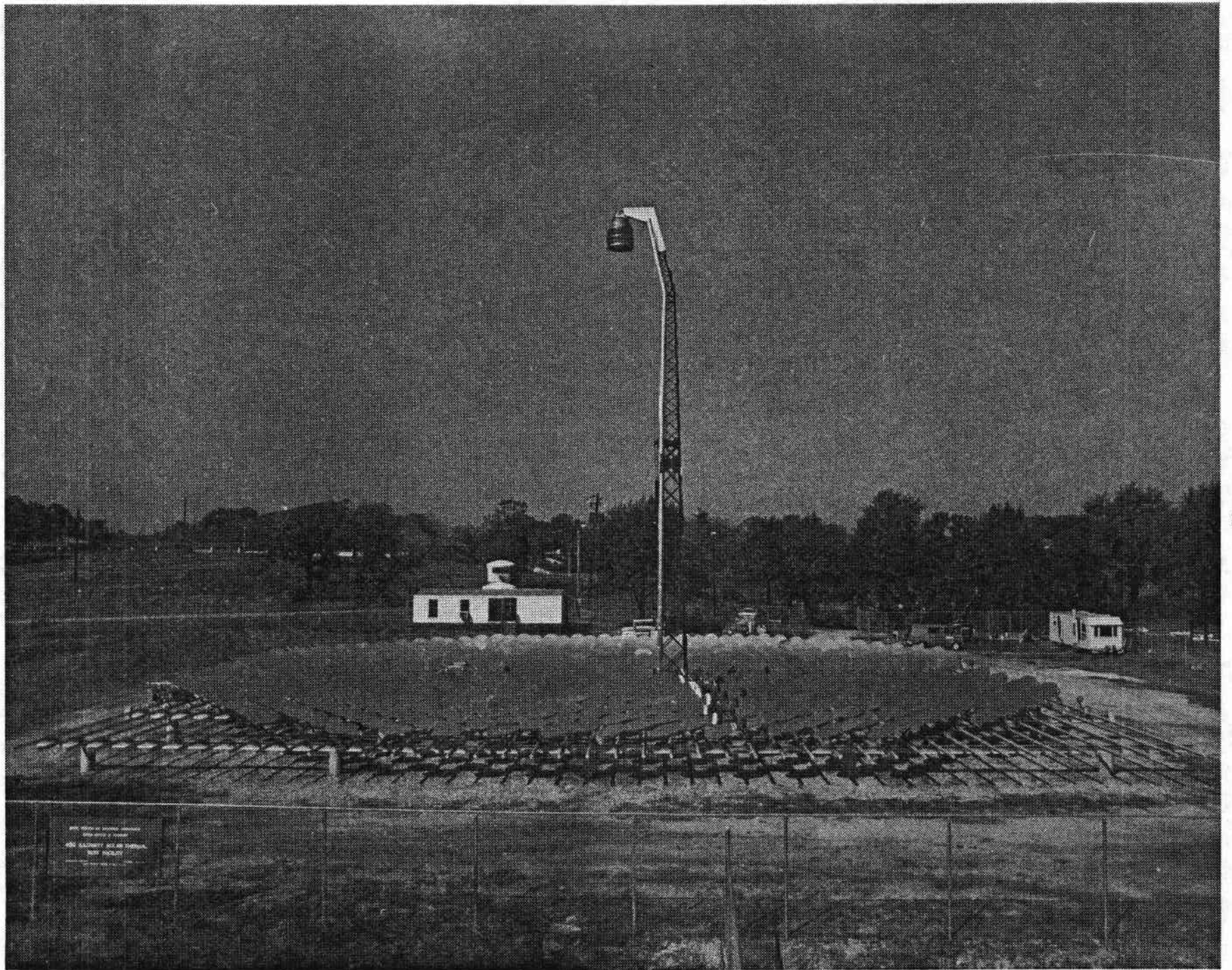


Figure 1. Overall View of the Georgia Tech Solar Thermal Test Facility

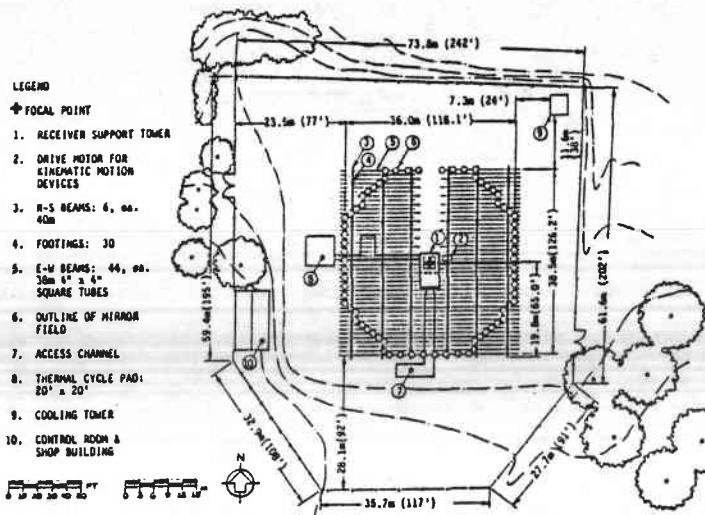


Figure 2. Ground Layout of the Georgia Tech Solar Thermal Test Facility.

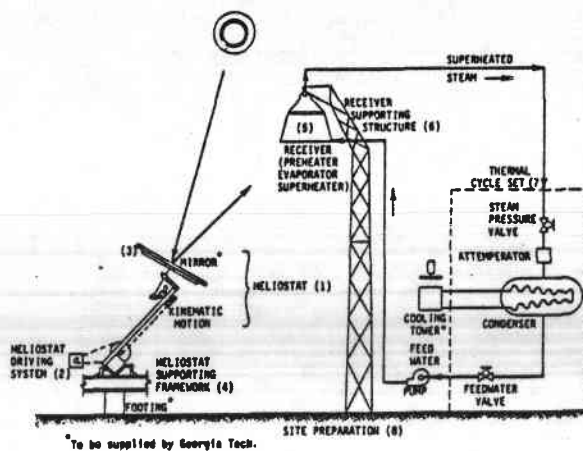


Figure 4. Major Components of the Georgia Tech Solar Thermal Test Facility.

GEORGIA TECH 400 KW SOLAR THERMAL TEST FACILITY SCHEDULE 11/8/77	1977				1978									
	8	9	10	11	12	1	2	3	4	5	6	7	8	9
1. 400 KW STPV INSTALLATION														
2. FLUX SCANNER														
(a) DESIGN (ACCOMPLISHED PRIOR TO 8/12/77)														
(b) CONSTRUCTION														
(c) LAB CHECKOUT														
(d) INSTALL ON RECEIVER														
(e) SOLAR FLUX CHECKOUT														
3. FACILITY CHARACTERIZATION														
(a) INSTALLATION & CHECKOUT OF INSTRUMENTATION														
(b) FIRST GENERATION OF STEAM														
(c) ANSALDO CHECKOUT - BLEEDING														
(d) FULL TEMP. PRESSURE CHECKOUT														
(e) HELIOSTAT ALIGNMENT AND FLUX CHARACTERIZATION														
(f) RECEIVER CHARACTERIZATION														
4. CENTRAL TOWER DESIGN, CONSTRUCTION														
(a) CONCEPTUAL DESIGN														
(b) DETAILED DESIGN DRAWINGS														
(c) BID PROCESS, AWARD CONTRACT														
(d) CONSTRUCTION														
5. SANDERS RECEIVER TEST														
(a) INTERFACE PLANNING														
(b) INTERFACE FIRM														
(c) TEST PLAN, PROCEDURES														
(d) IMPLEMENT TEST SUPPORT REQUIREMENTS														
(e) BEAM ALIGNMENT														
(f) INSTALLATION & CHECKOUT OF RECEIVER														
(g) SANDERS RECEIVER TEST														
(h) REMOVE SANDERS EQUIPMENT														

Figure 3a. Operating Schedule for the Georgia Tech Solar Thermal Test Facility.

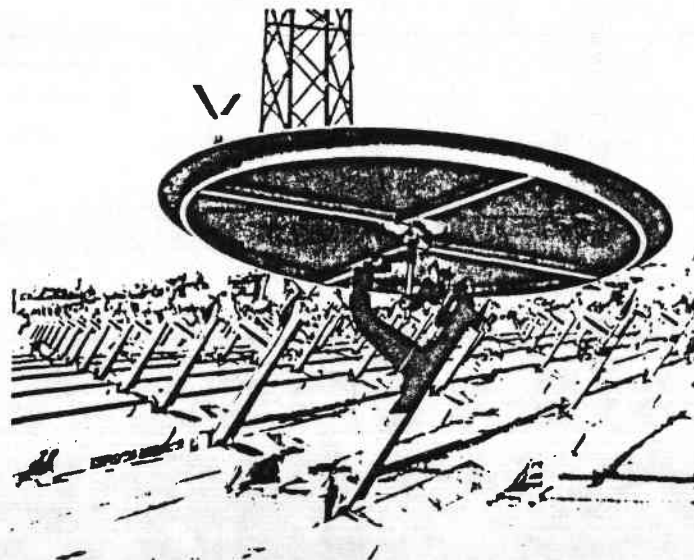


Figure 5. Close-up View of Kinematic Motion Device.

GEORGIA TECH 400 KW SOLAR THERMAL TEST FACILITY SCHEDULE 11/2/77	1977				1978									
	8	9	10	11	12	1	2	3	4	5	6	7	8	9
6. VISITOR VIEWING STAND														
(a) SITE SELECTION														
(b) CONCEPTUAL DESIGN														
(c) DETAILED DESIGN (PPD)														
(d) BID PROCESS, AWARD CONTRACT														
(e) CONSTRUCTION														
(f) COMBINE INVENTOR WITH AUDIO VISUAL EQUIPMENT, ETC.														
7. OPERATIONS & MAINTENANCE														
(a) ADMINISTRATION														
(b) INFORMATION DISSEMINATION														
(c) FACILITY MAINTENANCE														
(d) OPERATIONS														

Figure 3b. Operating Schedule for the Georgia Tech Solar Thermal Test Facility (continued).

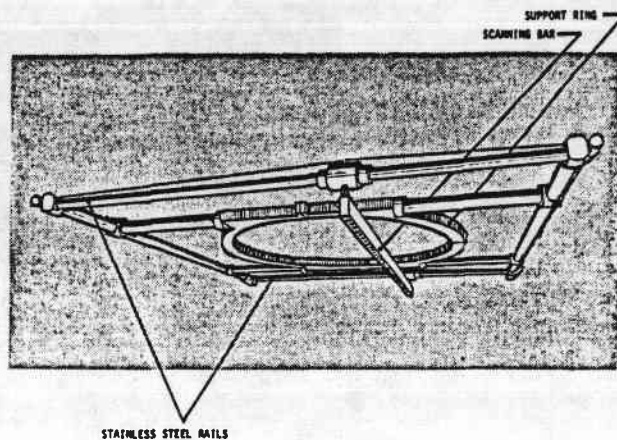


Figure 6. Perspective of the Scanning Flux Calorimeter.



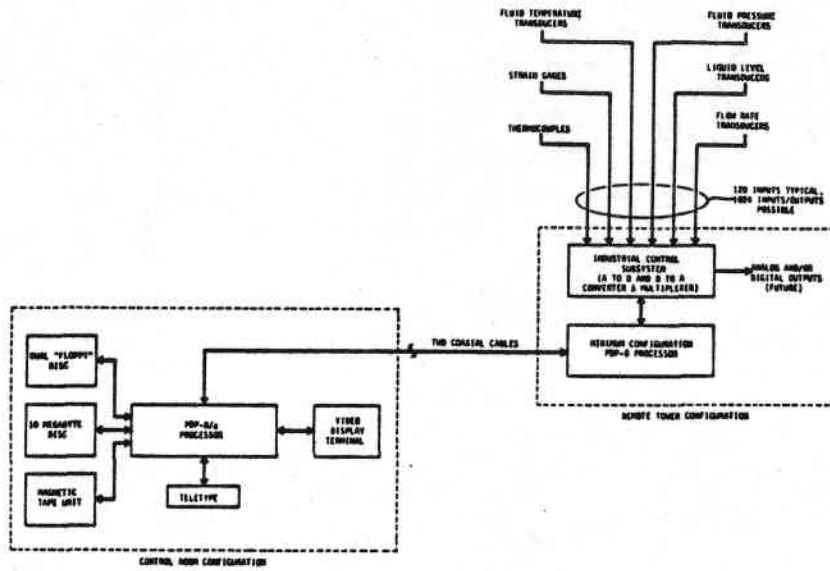


Figure 7. Block Diagram of the GT/STTF Data Acquisition System.

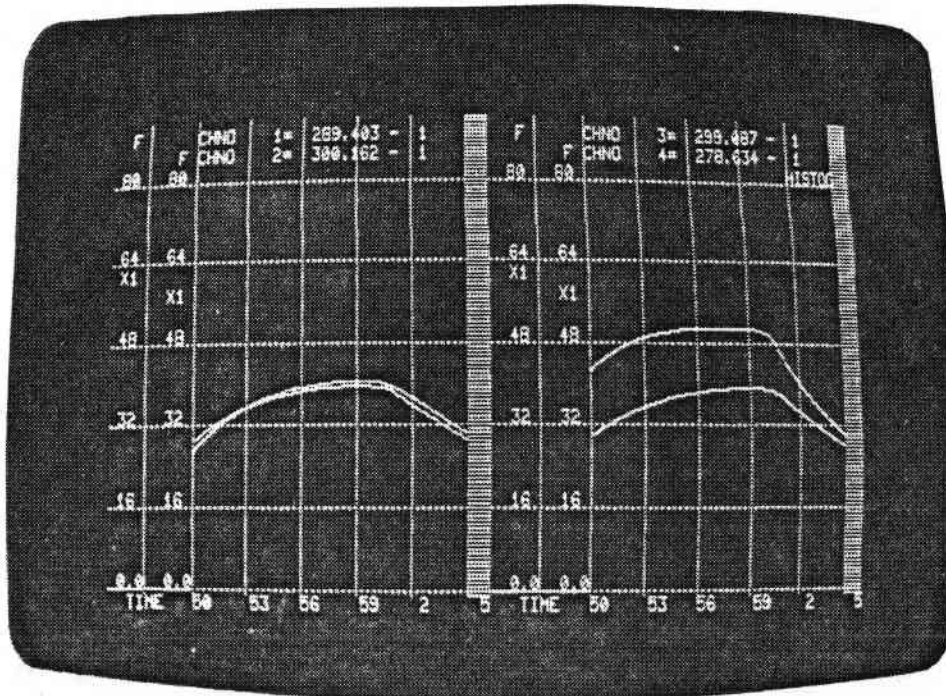


Figure 8. Sample Display of Video Output from Data Acquisition System.

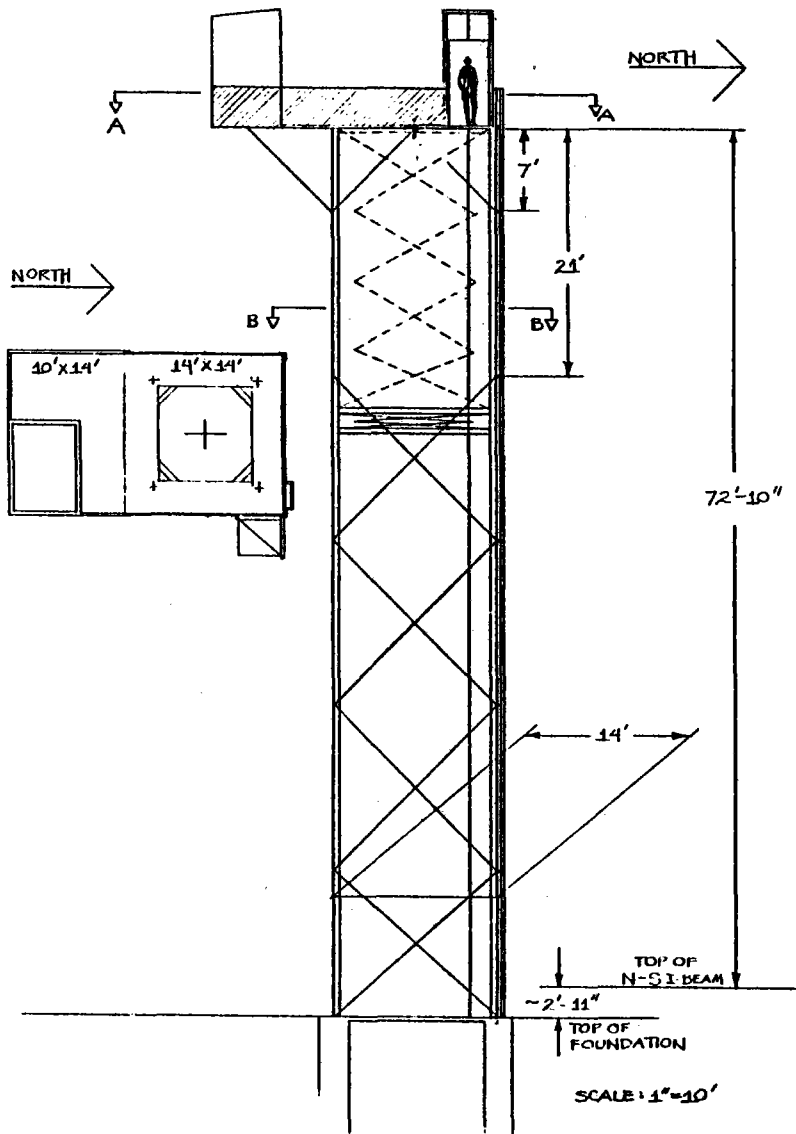


Figure 9. Concept of Central Tower.

AEC 11/10/77

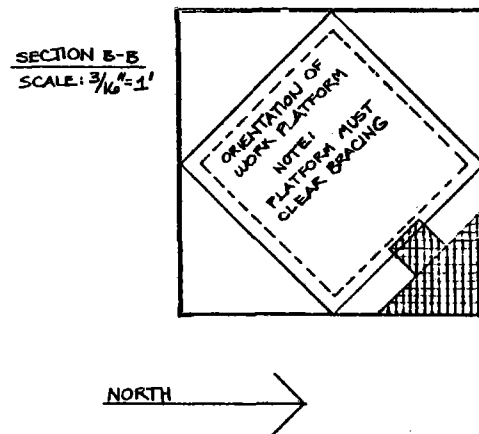
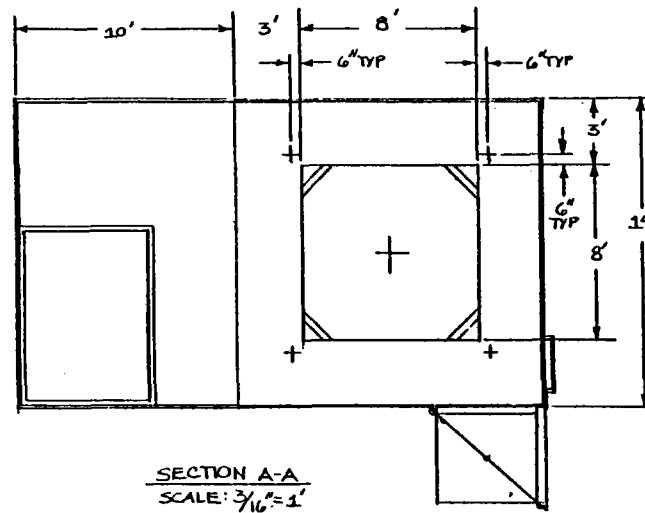


Figure 10. Dimensions of Working Platforms.

AEC 11/11/77

## White Sands 30-kW Solar Furnace

Richard Hays

The White Sands facility is directly under the control of the Department of the Army. Our primary mission is in nuclear weapons effects testing. A secondary role is interfacing with the solar energy community, providing a test bed for high-temperature experimenters or anybody in the solar community to come and test, if our facility meets their particular test requirements. We just officially sent a letter to the Users Association stating that we can work with them in furthering developments of solar energy studies and experimentation. Figure 1 shows the existing White Sands solar facility. It is composed of four major components. The heliostat which you see and the other mirror surface is a concentrator. In between, the large louvered structure is an attenuator and a test control chamber is in the center. This facility has been around for about 20 years. It was originally built in Natick, Massachusetts, in 1958. It was disassembled and shipped to White Sands and reassembled as you see here in late 1973, and became operational in early 1974.

The heliostat is 36' x 40' square; has 356 mirrors, each 2 feet square, which track the sun and reflect solar energy into the concentrator which, in turn, concentrates the energy down to a 4-inch diameter exposure area. The total energy is contained within 5-1/2 inches at a focal plane, located inside the test control chamber. Inside this test chamber is a large water-cooled shutter which has roughly two gallons per minute of water flowing through with a heat exchanger located downstairs at the base of the test control chamber. It has air blowing through which removes the heat from the water when the experiment is not being exposed.

Behind the water shutter we have a guillotine-type fast-shutter arrangement, two stainless steel blades roughly 6 x 5 inches. One of the blades drops down exposing the test item and then the top shutter comes down shutting it off, producing a rectangular pulse. For weapons testing work (which I don't think is very applicable to solar energy testing), we can simulate the thermal pulse from detonation of a nuclear weapon with yields from about 50 megatons down to about the subkiloton level.

This new pulse shaper was installed about six months ago. It could possibly have some use in the solar energy experiments. One can program this shaper to provide any type pulse shape that might be required. Also, the attenuator can be set at power levels from zero to 30,000 watts.

We can also cycle the attenuators to simulate sunrise and sunset within about two minutes cycle time, which might be useful for some of your experimentation.

Over a four-inch diameter exposure area, we have a maximum flux level right in the center of about 90 calories per square centimeter per second. In the four-inch diameter area, it is reduced by 50 percent, and at about six inches, by 90 percent. That basically describes our flux profile at the focal point of the facility.

Energy test programs have been performed on this facility since it became operational in 1974. The Sanders Associates hot air receiver program will start in June 1978. They tested a 10-kW hot air receiver on this facility two summers ago. Sandia has several times tested insulation materials that will be going into their power tower here. McDonnell Douglas, through a subcontract to Rocketdyne, has been running some coating material tests at the facility for quite some time now. There are interests now from Autonetics, Rockwell and also from Motorola, in Arizona, to use the UV concentration of the facility to look at photocells and photovoltaic work. We are now in the process of trying to characterize what the spectrum is in the UV region, i.e., how much UV energy we actually have.

The facility provides a monitoring of the flux area for you. Also, in the test control chamber, we have a three-axis programmable table on which one can mount several specimens across two inches in diameter, say if you have a dozen or two dozen. One can sequence this table across and get all the test items exposed in a very short length of time. As you know, you can't work when the sun doesn't shine or when there are bad weather conditions so one must optimize test time and set-up time so that you have everything ready to go to make maximum use of the sun when it is available. We have found that this three-axis table works out quite well. We previously had a small machinist's mill which was manually positioned so it could take a week to do what can be done in a day with the new three-axis table.

The facility is available to anybody and everybody through the Users Association, or directly through White Sands. The only catch may be that at Sandia and Georgia Tech one does not have to pay for facility operation as long as it is sponsored by the Department of Energy, whereas on our facility you do have to pay for operational time. It costs about \$500 per day for use of the facility. That provides for operators and whatever instrumentation we have available. Anything peculiar that we can't acquire for you will be an additional cost. We can measure surface temperatures using optical pyrometers. We have calorimeters to measure the flux levels at the focal

point. We can acquire thermocouple recorders and thermocouples for use in some of your experimentation, but to get the thermocouple instrumentation we have to go outside our organization and there is an additional nominal fee for that.

This basically describes our facility and some of the capabilities we have now.

We are in the process of developing a new test facility (Figure 2). At the missile range, we have a very large radar dish with an aperture at 84 feet in diameter which is ideally suited for some of our requirements. In weapons testing, we require flux levels greater than the existing facility can achieve so we looked around and came up with modifying a large radar dish into a solar test facility. The dish you see will be lined with aluminized mylar. Cryogenic grade aluminized mylar which has a reflectance of 92 percent will be used. We put mylar on the dish surface and also, at the focal point of the radar, we have a Cassegrain reflector which will collimate the beam and redirect it down to the flat planar mirror to direct the energy to the base of the tower to provide a vertical beam. The radar was ideally suited in that the tracking system is already there. All we need do is modify the front end to a solar tracker. We will use a computer for a control mechanism. To vary the power level we will have an attenuator structure spanned across the aperture of the dish.

We have just started the design under a contract let to New Mexico State University. (There was a comment here about universities being innovative.) NMSU came up with the basic idea of this through a proposal to White Sands; so far as I'm concerned, they are pretty much on the ball. They came in with a proposal to solve our problem this way.

We are looking at power levels at the test area of around 300 kW thermal. We could possibly go up to about 325 kW. We are looking for a variable exposure area from 6 to 18 inches in diameter, which will, in turn, change the flux power level from about  $417 \text{ cal/cm}^2/\text{sec}$  down to a minimum of about 75 calories, which is in the operational range of the existing solar furnace. This facility, hopefully, will be operational in about two years. We are in the design phase now. Some of the problem areas being looked into are the Cassegrain reflectors and the relay mirrors. The support facilities for the new solar furnace are quite good. In the support facility there is a very large air compressor to provide large volumes of high-pressure air. We have a very large water pump for cooling reflectors and for cooling some of the experiments. The area in the building is about 8000 square feet.

(Possibly more than we really need; we are now using a very small room.) The new lab will have experimental labs set up for long-term experiments where no one else will be bothered by the setting up or tearing down of experiments. If there is a rush for experimenters to get on this facility, there are different levels inside the facility so it could accommodate more than one experimenter at a time. While one experimenter was setting up, say at the bottom level, another experiment in the mid-level could be under construction or in operation. The facility will be operational in about 2 years.

Question - What are some of the dimensions?

Answer - The dish aperture is 84 feet in diameter, the focal point is 25 feet, the tower is approximately 102 feet high.

Hays - One drawback of the solar furnace at White Sands is wind. If winds are more than 20 mph, there is a very large wind loading on the heliostat, which causes the beam at the focal point to wander up to 1/2 to 1 inch. The new radar facility is very rigid; we should be able to operate in winds up to 30 knots, whereas the present one cannot be operated in winds greater than 14 knots. We got about 1600 hours of operational time on the existing facility this last year, based on a 2080-hour work year, 8-hour day, 5 days a week. So, sometimes in the morning and sometimes in the afternoon we could utilize the facility if required. The new facility is expected to have operational time in excess of about 1800 hours for two reasons: first, because of wind, and, second, because of cloud coverage. In the existing facility, when we had clouds, the analog tracking system would drop out and we had to reacquire track. The new system will be computer-controlled--as soon as the sun comes out from behind the cloud testing can resume. Of course that may perturbate your test but it doesn't perturbate nearly as much as on the old facility.

We are operating in a somewhat different mode than the other solar test facilities of the Users Association. The Association can schedule time in for us, they can sponsor experiments but since we are a Department of Defense facility, Defense test programs will have priority. Fortunately, most Defense test programs last no more than two or three days, and we are now running only about a dozen a year. So, the facility is pretty well open for experimentation. Any questions?

Question - Where is this facility located?

Answer - It is located on White Sands Missile Range. It is about 5 miles north of the Oro Grande gate and about 30 miles northeast of the Main Post area. It



is located in the boondocks, so to speak, but that may be an advantage. Several people from astronomical observatories are looking at using this facility. We have already had one experiment along that line on the existing solar furnace but there was too much background light. Out where this is located, I guarantee it is darker than hell--at night, that is.

Question - You fly into El Paso, don't you?

Answer - Yes.

Question - And the old facility is a back-surface?

Answer - In the old facility, the concentrator mirrors are all front-surface and the heliostat mirrors were back-surface, but we are going to all front-surface mirrors, primarily to enhance the UV component of the spectrum for weapons work and also for some photovoltaic work.

Question - Does that enhance the infrared too?

Answer - Somewhat, yes. You don't lose any energy at the glass-surface interfaces.

Question - Do you have information available now on the spectral distribution of the light that you have?

Answer - No, we are in the process of doing that. There is a radio spectrometer that is supposed to have arrived at our organization a month ago but we are still waiting. As soon as it gets there, or within about two weeks time, we should have this information.

Question - What is the reflection coefficient that you expect to have in the mirror?

Answer - The mylar coating will have a 92 percent reflectance; there are three surfaces so it would be  $0.92^3$ , that is the optimum. We had an overall coefficient of 63 percent. I took an 86 percent reflectance for each surface, which is standard for aluminum.

Question - The last mirror, is it flat?

Answer - Yes. It would be rectangular and flat.

Question - Did you say that all three reflectors in the proposed facility are mylar?

Answer - No, the first one is. The second one will probably be an aluminum coating with a ceramic, or pyrex, backing, and the 45-degree mirror will be similar.

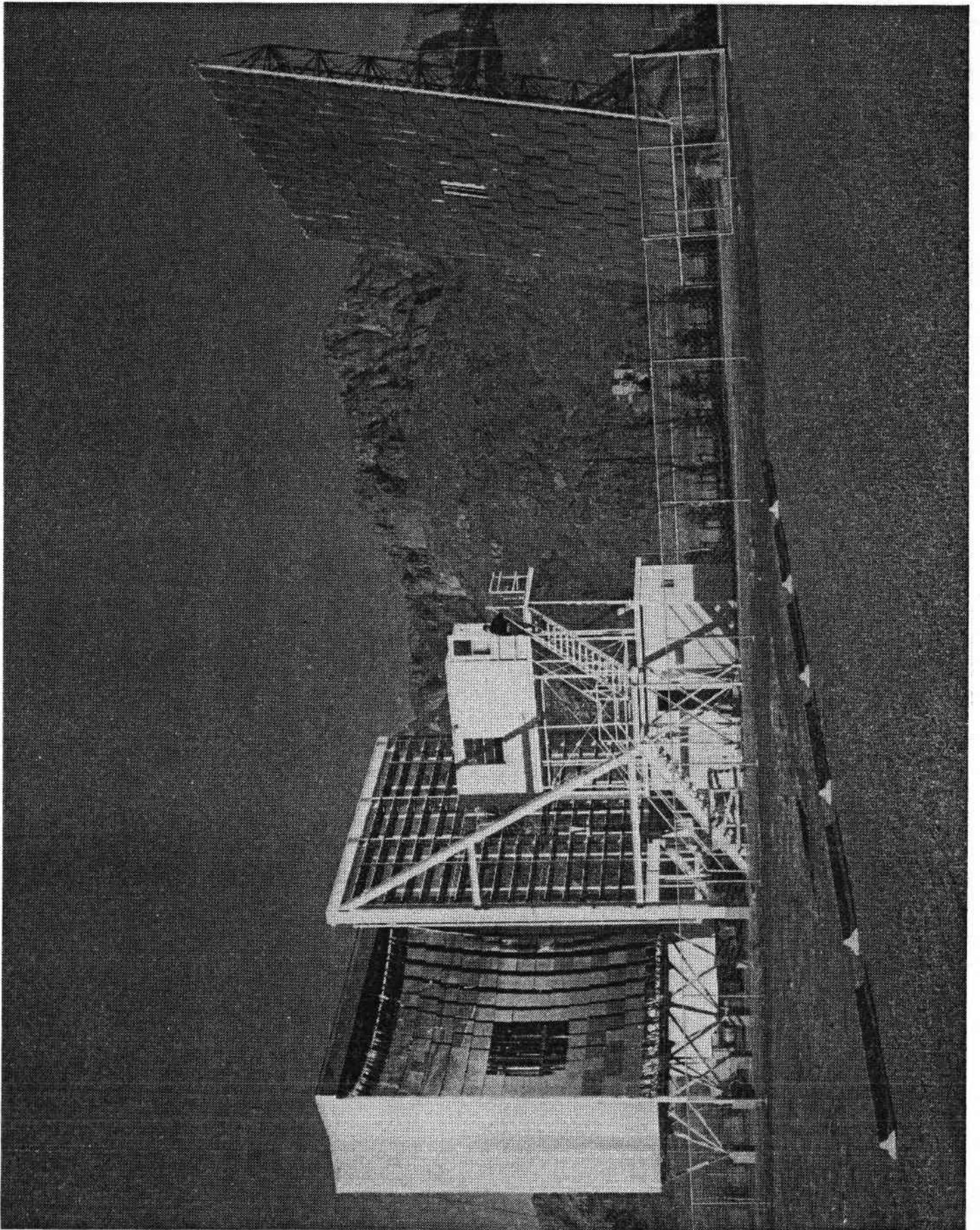


Figure 1

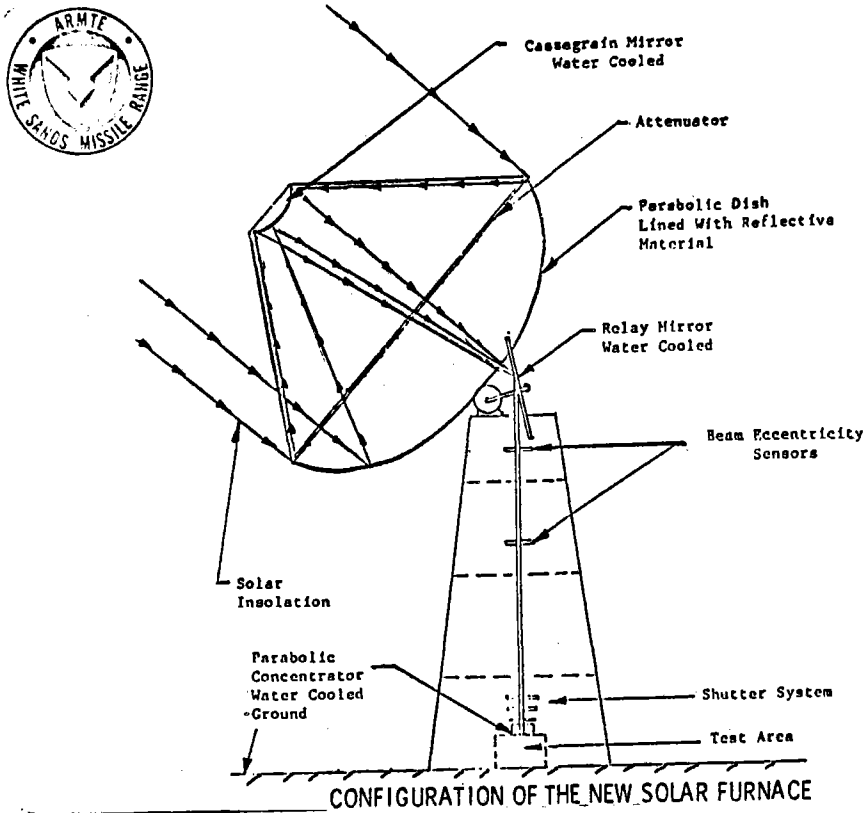


Figure 2



COMPARISON WSSF AND HISTF TEST CAPABILITY

<u>CHARACTERISTIC</u>	<u>WSSF</u>	<u>HISTF</u>
THERMAL POWER	40,000 WATTS	310,000 WATTS
TEST AREA	81 - 113cm <sup>2</sup>	177 - 1600cm <sup>2</sup>
WEAPON SIMULATION	20KT - 50MT	SUB-KT-50MT
FLUX	1 - 70 CAL/cm <sup>2</sup> SEC	1 - 417 CAL/cm <sup>2</sup> SEC
<u>OPERATIONAL CAPABILITY</u>		
WIND	< 15 KNOTS	<30 KNOTS
CLOUD COVER	< 50%	<75%
<u>AVAILABLE OPERATION</u>	<u>1200</u>	<u>1800*</u>
TIME PER YEAR	2080	2080

Figure 3

French CNRS 1000-kW Thermal Solar Furnace

Claude Royere

Mr. Royere's talk is not available for inclusion in these proceedings due to recording problems. Anyone wishing a copy of his talk may contact the Albuquerque office of the Users Association and a copy will be provided as soon as available. Following is a brief description of the facility.

The CNRS 1000-kW<sub>t</sub> Solar Furnace is operated by Claude Royere. It is located in the Pyrenees at Odeillo, Font-Romeu (altitude, 5900 ft), about 40 miles east of Andorra, and consists of 63 heliostats (each 6 x 7-1/2 m) which follow the sun and reflect the sun's rays onto a parabolic reflector. The parabolic concentrator (20,000 ft<sup>2</sup>) concentrates 1 MW of thermal energy into an area of about 40 cm in diameter at the focal point of the parabola. At the center of the focal point, in an area 4 cm in diameter, the heat flux is 1600 W/cm<sup>2</sup> and the temperature reaches 4100 K.

## Solar Energy Research

By

Dr. Paul W. Gilles

One thing that this meeting has brought out very clearly, I think, is international cooperation in the solar energy field. Claude Royere mentioned this morning that in this field, international cooperation has been superb. There is another field in which it has been superb as well, and that is MHD. The best MHD generator that currently exists is in the Soviet Union; the interaction between the Soviet scientists and the American scientists has been excellent. Being installed now is a superconducting magnet that was designed and built at Argonne National Laboratory. So here are two instances of major programs that represent good international cooperation.

I'd like now to respond to the six questions that were raised this morning by John Holmes.

(1) What would high-temperature scientists like in the way of "universal materials for high-temperature test stations?" You already have received some of the answers. First, we want to be there; we want to be able to get our hands on the equipment; we want to be able to look at it with our pyrometer. As far as special facilities are concerned, we would like to have one of each of the three types of the mass spectrometers: a magnetic instrument, a time-of-flight instrument, and a quadruple instrument. We need a centrifugal apparatus to hold the sample as they do in France. We would like a photoelectric pyrometer and we clearly need spectrophotometers to do the chemistry that we would like to do.

(2) What about flux uniformity, size and total power? Let's get to about a one-centimeter size, which is the customary size for the chemists.

(3) Gravitational orientation: we'd like to be able to heat from the side, with the beam aimed upward from the bottom; and, in some circumstances, we'd like to be able to heat from the top.

Regarding (4) cooling, and (5) diagnostic experiments: I have no suggestions.

(6) Data processing and equipment control raises an issue that is a source of conflict among high-temperature chemists. There are some who claim that the computer puts the scientist farther away from the experiment; others claim that the computer puts him in a much better position to do the kind of chemistry he wants to do. I fall in the latter category; I'm not afraid of computers; I think they are a wonderful asset. Still, however, we do need to be able to get close to the apparatus; we will need appreciable software. Buying a computer and plugging it in does not make it useful; programs must be written, and that is no small job. As we looked around the Sandia STTF computer setup today, I think I saw no digital voltmeter. A digital voltmeter has the advantage that you get more bits than you get out of ordinary A to D converters. Of course it is slower, but in many instances we can put up with slower devices.

There are the answers to your six questions, and speaking on behalf of all of us high-temperature chemists, we very much appreciate the interest that you facility operators have shown today.

Still speaking to the facility operators, may I review the history of high-temperature chemistry and give some sort of indication about the current status? The funding situation currently is not very good, so I won't have very much to say about that.

First, let me describe for you meetings. The Gordon Research Conferences have been running for many years. In 1960, the first Gordon Research Conference on high-temperature chemistry was held; it has met in alternate years since then. Chairmen of several of these high-temperature chemistry conferences are with us. LeRoy Eyring was chairman once, Dan Cubicciotti was chairman once, Gerd Rosenblatt was chairman once, Bob Thorn was chairman once, Dave Cater is chairman for next year, John Hastie is chairman for three years from now, and I was chairman once.

Some 13 years ago three people in the Midwest region independently recognized that much high-temperature chemistry occurs in the middle part of the US. As a result, the three people got together and arranged a conference called the Midwest High-Temperature Chemistry Conference. It has met in alternate years, alternating with the Gordon Research Conferences. Among those present here, Dave Cater has been chairman, and I have been chairman.

These conferences, starting in 1965, have been held at university campuses in the general Midwest region. They are low-budget meetings. It is the only meeting I know where professional high-temperature chemists in industry, national laboratories, research institutes, and universities can mingle with post-doctoral associates and graduate students, and where graduate students can have good, easy, and informal contact with the professional people in their areas. I think it is a splendid meeting.

Various symposia in the general field of high-temperature chemistry have run under the auspices of the International Atomic Energy Agency. Several sets of symposia have been held on thermodynamics. The American Chemical Society, the Electrochemical Society, and even the American Physical Society have held symposia that relate to high-temperature chemistry. The International Union of Pure and Applied Chemistry held a meeting at Odeillo last summer.

There are no organizations of high-temperature chemists--not even a Users Group. The NRC has a committee on High-Temperature Science and Technology which various persons present here have served on and chaired. The current chairman is Wayne Worrell and Gerd Rosenblatt is on the committee now. This group is currently very active. Gerd Rosenblatt reports that there will be an NSF workshop in October to look at where high-temperature chemistry basic research is going and at Federal funding. It may also try to assess where the applied needs are and implications for research.

Another National Research Committee was appointed recently to inquire into the funding of small research projects in materials sciences. It has met twice and will meet two more times before it produces a final report. When John Margrave was chairman of the committee about which Gerd Rosenblatt spoke, he arranged a symposium in Houston that led to a small publication entitled Current and Future Problems in High-Temperature Chemistry.

The International Union of Pure and Applied Chemistry has a number of divisions which have commissions; the Division of Inorganic Chemistry has a Commission on High-Temperature and Refractory Materials which sponsored the meeting at Odeillo



I mentioned earlier. It also encourages the publication of a high-temperature bibliography and carries out other studies designed to lead to international standards. A tentative suggestion from the workers at Odeillo is a melting point standard and the material under consideration is  $Y_2O_3$ .

Education in high-temperature chemistry arose spontaneously in four places in the United States: Berkeley, Urbana, Ames and Cambridge. They began work in high-temperature chemistry in the late 1930's and the early 1940's. The founders were Leo Brewer of Berkeley, Thomas Phipps of Urbana, Frank Spedding of Ames, and the Norton at MIT. As a result of the educational activity, education has now gone through at least six generations of students, and here tonight we have one three-member chain.

To give a little more review about the people in high-temperature chemistry, I have a dozen names here of people I would like to mention. Leo Brewer started in the field in Berkeley and set the course for high-temperature chemistry as it exists today. Inghram at the University of Chicago was the first to use mass spectrometry. Mel Bowman has not been in a university for some time, but to him must go considerable credit for education. I recently spoke the following about Mel: "Mel Bowman is a person in Los Alamos who deserves a high mark in my evaluation. Mel had a group of 30 or 40 people who were radiochemists. Almost single-handedly, he converted this group into a high-temperature group. I tell you that is no small achievement."

Aristed Von Grosse, a person with origins in the Soviet Union and China, was an early leader in high-temperature chemistry in the United States. He did not turn out many students, but certainly had a good long-range view of fundamental high-temperature chemistry and he kept prodding many of us to go to higher and higher temperatures. Harold Schafer in Germany is the world's authority on chemical transport reactions. Richardson and Alcock in Britain applied high-temperature principles to metallurgical techniques. Gurvich in the Soviet Union, Trombe and Foex in France, Goldfinger in Belgium, Demaria in Italy, Haraldsen in Norway, Magneti in Sweden, and J. S. Anderson in Britain are all people who originated creative work in high-temperature chemistry.

Science in the past in high-temperature chemistry has consisted, as I see it, of efforts in six fields: vaporization studies, phase behavior investigations, x-ray diffraction studies designed to give structural information, thermodynamic investigations, spectroscopic investigations, and mass spectrometric investigations. You see through the high-temperature field these kinds of studies going on, and they will continue to go on.

John Margrave mentioned earlier today the importance of chemical synthesis, and much creative work has occurred involving the use of high temperatures, high-temperature techniques, and high-temperature species in chemical synthesis.

My first experience with solar energy occurred at the University of Wisconsin when I was visiting John one day. He showed me the solar furnace that was not operating because it was cloudy that day. My next experience came when Farrington Daniels visited the University of Kansas to give a lecture. He was talking in those days about nuclear reactors, about getting power from the nucleus, and he made some comments about the hazards involved. He said it would be good if we had a big nuclear reactor we could put off some place and not worry about all the hazards and just let it go forever and ever. Everybody agreed, of course, and he said, "We already have it--it is up there in the sky."

Now, the high-temperature chemists look forward to exciting new opportunities in solar energy.

Some Proposals for High Temperature Chemistry Research Using  
The Various Solar Thermal Test Facilities

by

John L. Margrave

It is a pleasure to meet with you today and discuss some of the viewpoints of a high-temperature chemist as he looks at the Solar Thermal Test Facilities which have been described in such exciting detail by scientists and engineers from the Albuquerque facility, the US Army facility at White Sands, the Georgia Tech facility in Atlanta and the French Solar Energy facility in Odeillo. I have had the pleasure of seeing several of these facilities first hand and certainly one has to agree that not only is the sun a diffuse pleasant source of warmth for us as individuals when we bask on the seashore but also the sun can be an intense, fiery, concentrated source of energy for chemical research and hopefully for chemical processing on a viable economic basis under conditions of high temperatures.

Let me first make some general comments about solar energy with emphasis on the advantages and disadvantages. These may seem obvious and many have already been discussed repeatedly in the literature and at this meeting. Nevertheless, it is important to emphasize in any serious discussion of solar systems the basic advantages and disadvantages.

To the public and sometimes to politicians one of the big advantages seems to be the fact that solar energy is free and available to everyone everywhere. This kind of an energy resource involves no geographic problems, requires no decisions about distribution, and therefore represents an optimum kind of situation. Although it is free and although solar energy is "everywhere", it is also everywhere at a very low intensity. The area irradiated is large but the energy intensity per square centimeter per second is sufficiently low that one has difficulty in evolving useful systems even for small-scale experimentation based solely on the energy that a mirror reflector of moderate size can collect and focus on a laboratory-style experimental region. In addition, when one thinks about a source of energy, he usually hopes for a source which is constant in intensity, even if small, and reliable in time and response. Solar energy unfortunately suffers from the short-term fluctuations which may be induced simply as clouds in the sky make the sun "come and go" or at least

fluctuate in the brightness with which it irradiates a given point on earth. Furthermore, the solar energy source is subject to long-term fluctuations, of the order of days in many parts of the country where direct sunlight may not be regularly available. Thus, one is limited in utilizing solar energy to applications where the constancy and minute-by-minute reliability of the source may not be critical.

When one plans to use a source of radiant energy, he needs to know exactly the range of wavelengths which will be available in the radiation source--a definitive measure of the extent of infrared radiation available as well as visible ultraviolet and vacuum ultraviolet if possible. The optimum situation would involve a black body source but a source providing radiation in a given wavelength region could be useful as long as the wavelengths are well known. The solar radiation is generally characteristic of a black body radiating at the surface temperature of the sun--5600 K--but there are absorptions due to the various constituents of the atmosphere:  $O_2$ ,  $N_2$ ,  $O_3$ ,  $H_2O$ ,  $CO_2$ , and the various organic and inorganic contaminants introduced by man. These atmospheric contaminants limit the intensities at various wavelengths and, thus, there is a limit as to the maximum temperatures which can be generated by a solar device. If all the radiation at all wavelengths coming from the sun could be collected and reflected in perfect mirrors and concentrated at a very small point then, theoretically, one might approach the surface temperature of 5600 K. The absorptions by real atmospheric gases, the fractional reflection coefficients of real mirrors and the problem of focusing the intensity in small regions all combine to establish a situation in which it is safe to say that one can fairly easily obtain temperatures in the range of 2000-2500 K using front-surface solar mirror systems. Under certain conditions with extensive collectors and expensive mirrors one can attain 3000-3500 K and melt tungsten or tantalum or the highly refractory oxides. I am unaware of an experiment in which a solar device has been able to generate temperatures anywhere near 4000 K.

In adapting solar collector systems to high-temperature chemical experiments, it is necessary to think of the sorts of reactors and pressure-temperature-time requirements that chemists and ultimately engineers would need. One can think of several sets of conditions which are desirable--large volumes at high temperatures for short periods of time, large volumes at high temperatures for long periods of time, small volumes at high temperatures for long periods of time, etc. The traditional laboratory experiments in high-temperature chemistry make use of one or more

of the appropriate heating devices for a given type of chemical process. In the solar mirror one is considerably more limited by the practical conditions of construction, the availability of sunlight at the moment desired, the short time fluctuation due to clouds, etc. Therefore, when one thinks of a solar reactor, especially one which might accomplish chemistry on a macroscale for industrial applications, there is a problem of reactor design and adaptation to the realities of chemical processing and engineering requirements. Among the various systems one finds available in the current state of the art are the "tower of power" concept as demonstrated at the Albuquerque facility which we will have the pleasure of visiting today; the "street-light" concept as demonstrated by the Italian solar energy design currently being developed at Georgia Tech; the multiple heliostat with large, fixed parabolic receiver as demonstrated by the Odeillo arrangement, etc. Each of these represents one of the ways in which a relatively large volume can be raised to high temperatures on a scale sufficient for processing chemicals on a kilogram or pound basis, at least, and yet meeting the various optical and mechanical requirements.

Let me now discuss one of the truly unique advantages which I, as a high-temperature chemist, see in a solar energy device. Almost uniquely, the solar mirror offers the opportunity of generating rather high temperatures in the absence of applied electric and magnetic fields. An essentially unanswered question in many kinds of high-temperature experiments has to do with the possible synergistic effect of electric or magnetic fields on processes like vaporization or surface corrosion. Whether or not negative ions are formed; whether electrons are emitted by surface activation; whether ionic surface species are significant; etc., represents an essentially unanswered set of questions. Quantitative science done in the presence of solar radiation field, in the absence of these field effects, could determine whether or not these problems are important. Since one gets only surface heating by solar radiation, this is a different kind of heating as contrasted with electric resistivity heating or induction heating. Parameters like thermal diffusivity, thermal conductivity, etc., will be especially significant in applications of solar energy devices.

In yet another area, there is a special problem about solar energy and its utilization by science and industry. The sun is only "on" in the daytime, yet a considerable amount of scientific and industrial effort occurs at other periods of the day. There is an important and unsolved problem in terms of thermal energy

storage. One needs to find methods for collecting and converting solar energy into storable form--either as active chemicals with intrinsic chemical potential energy; as electric current or charged species like ions or electrons which are produced by the solar radiation; or as stored electrical energy in batteries or fuel cells. This intrinsic problem, how to convert, store and ultimately utilize solar energy, perhaps represents the largest void into which research efforts and engineering developments should be directed. One needs to investigate electronic conversion devices, photovoltaic devices which can directly convert light into electricity; the various types of batteries; and chemical storage systems. Because there are so many options in this regime, it will require a mammoth effort on the part of chemists and chemical engineers to evaluate critically and select strategically the ultimate systems which will be applied in solar energy collection and the ultimate conversion applications.

One of the obvious chemical conversion approaches is, of course, the conversion to some sort of fuel. For instance, one can use solar energy to dissociate water into the elements hydrogen and oxygen, separate them, and then at some later time recombine the hydrogen with the oxygen to produce energy. Carbon when heated in hydrogen can produce acetylene or other hydrocarbons and these can be burned later to provide heat or to do work, or one can just store this energy. Or, if you don't convert it to electricity but collect heat in a heat exchange unit, there is the problem of chemical storage in a chemical system, through fusion or other transitions or plain heating up a solid or liquid material. These problems are not as trivial as sometimes thought.

Finally, chemists need to reexamine some of the classical approaches of the chemical process industries, in terms of this newly developed, newly available source of power, and see if some of the old things can be done better, or at least equally well, without using up our fossil fuels or other resources. Solar energy would certainly be attractive for that.

Let me reiterate the features of the solar thermal test facilities because in a way this is what the chemist looking at it has to consider. First, you give us a high flux of radiant energy over long or short times; I was a little disappointed in the time scales which sounded like tenths or hundredths of seconds. Chemists today are beginning to worry about microseconds and picoseconds. The time scale for studying modern chemical phenomena must be refined if solar systems are

going to be useful here. One not only has a high flux, but a variable flux, through the venetian blind-type control or deflection devices.

Secondly, one can get large total power, in the megawatt range. To a high-temperature chemist, other than wanting to make a lot of something that takes a lot of energy to make. I'm not sure this is an advantage. To have one, five or ten megawatts may be an advantage to a chemical engineer, i.e., to the person trying to make a ton of something, but there is a distinction. Initially we don't look at gross size as an experimental parameter. One of the big advantages that I see is that you have the tower constructed and newly ready for action. It reminds one somewhat of the Fermi Lab in Illinois, or the Argonne National Laboratory, or of the cyclotrons and synchrotrons and other gadgetry available to the high-energy physicists. Here are large devices that do all sorts of special things and the physicists have to think of things to do with them. We have another large experimental facility for solar research and the chemists are asking, "What can we do with it?"

Initially, I don't think we need 5 megawatts of solar power but ultimately it might be nice to have the 5 megawatts if one needs to make a large amount of something by solar methods. There are some real advantages, speaking as a chemist, and although two have already been mentioned, I will reemphasize them because I think they are very important. One is the option of working at high temperatures and/or high pressures in the presence of an oxidizing atmosphere. It is really hard to do an experiment in an atmosphere of pure oxygen at 2000 degrees and 5000 psi, just to mention some conditions. There are not very many materials and there are not very many ways one can set up an experiment with a high-pressure oxidizing atmosphere, simultaneously at high temperatures, and this represents a unique advantage of solar heating devices. The same obviously is true of reducing atmospheres and high temperatures. One has here a very versatile kind of system that could work at both extremes, and lead to truly innovative chemistry. For example, the possibility of growing very large crystals in controlled atmospheres could be of interest and yield unique products. Thus, if one can heat a large volume, there are some possibilities for large-scale crystal growth.

I have now come to a section of my notes labeled, "How High-Temperature Chemists Can Use Solar Thermal Test Facilities," and this is clearly a crucial part of the

discussion. It seems to me that there are some dividing lines which we may draw and, at the risk of using cliches, I will indicate the basic and applied areas. As I look at the potential problems and current understanding of what is going on in some of the systems that have been discussed already, and some of the systems I can imagine studying, there are a lot of missing data of a very fundamental type. In many cases, the high-temperature chemist probably can acquire the information in his own lab with smaller laboratory facilities. For example, one needs reliable values for emissivities and reflectivities. There is much information on these and much more is being collected, but still the information is not complete. There are further complications: one can study pure systems in a vacuum and have nice clean surfaces; one can also have real systems out in the air, which are very different, and when one undertakes practical problems, he will need to know the emissivity as a function of temperature, wavelength, stoichiometry, and perhaps other variables.

Then there is the area of thermal properties. Although one often thinks of these thermal properties as routine and predictable, they turn out to be vital in developing a realistic process for storing thermal energy, in choosing the optimum fluid or solid which can absorb the rays' fluxes provided by the concentrated solar energy, etc.

There are an incredible number of materials for which simple things like  $C_p$  are poorly known,  $\Delta H_{\text{transition}}$ ,  $\Delta H_{\text{fusion}}$ , etc., are not known. There are still, surprisingly, many systems for which the phase diagrams are not known. What I am saying is that there is basic background of high-temperature chemistry that one must have before he can accomplish these applications. It is not all in the handbook. One can dream up an exotic hydride-fluoride system and no one may know whether or not there are compounds in that system, and whether or not one could use it for a practical storage system. Thermal conductivity and thermal diffusivity are similar properties for which data are incomplete.

Then, there are photo conversion processes. We need to know more about silicon crystals and their uses; about copper sulfide and other systems of this kind that might offer cheaper alternatives to silicon single crystals; and alert all of the crystal growth technology. These areas will be important in ultimate uses, on a large scale, of these solar devices.



There are also chemical synthesis which should be considered. I think we too often forget that a primary function of the chemist is to make new compounds. Other scientists may measure the properties and develop uses, but chemists should have a prime interest in making new materials. There are some intriguing new possibilities in syntheses. Some of these are "old hat" ideas, but they still are not very well understood. There are various suboxides of silicon, aluminum, gallium, and other elements, that are not very well characterized. There are subhalides, which can have important implications in metallurgy. We need more information in these areas.

Finally, there are some new applications with which high-temperature chemists are only beginning to get involved where solar energy might play a role. For example, one of these is to couple solar energy with other methods for generating high temperatures. Without intending to deprecate solar energy, 3000° is really not a super high temperature. There are a lot of ways to generate temperatures higher than 3000° in the laboratory, especially over volumes of the order of a few cubic inches. Electrical discharges, plasmas, chemical flames, etc., will easily work. Low-temperature plasmas or chemical flames could be supplemented with solar energy to get high temperatures more economically. You may hear from some of the other speakers that one can use such systems to generate charged particles, and, ultimately, power from the magnetohydrodynamic approach.

These are just some of the ideas that one would want to keep in mind in discussing solar thermal facilities because many kinds of data you will need won't be available. Speaking to the people who make funding decisions, it seems clear to me that this backup basic information must be acquired in order to get the most out of the solar thermal test facilities.

Question - Will the Users Association fund any of that kind of work?

Smith - Our response, I think, is that the Users Association would be receptive to this. It is basic information of the type the country needs to advance solar power technology.

Margrave - In the storage area, it seems to me, that one might easily justify it. If we have good solar systems for generating a certain amount of power, we

have to do something with it. Systems which will adequately handle (store) it need to be found. It seems to me that there might be a close relation.

Question - Isn't there a thermal properties area at Purdue?

Margrave - They essentially collect the literature results. They have a very modest experimental program. They primarily collect data, analyze and evaluate it and present a "best"-value set of data. They make some measurements, but are limited in experimental programs. For instance, the high-temperature properties of many metals, and of alumina, and many oxides are really not known very reliably above 1500° or 1800° and there would be justification for some higher temperature studies. Maybe they can be done in a solar system, but it is easier to conceive of studying a 10-gram or a 2-gram sample back home in the lab than to come out to a 180-foot tower with a focus of a square meter and do such a study.

In the applied areas, we need to seek new fuel materials and chemical ways to transmit the energy. Obviously, if we can't transmit electrical power effectively enough, or we cannot find batteries that are adequate, or if we can't store energy in heat capacity or enthalpy in a volume of material, then another way to store energy is in chemical potential energy as a fuel. The fuel usually mentioned is hydrogen. Also, one should consider acetylene, which is a high-temperature molecule. One that is usually ignored, but I don't understand why, would be the general ROH--methyl alcohol, ethyl alcohol, etc.--not thinking of 3000° processes but a few hundred-degree processes. This might be an economically significant fuel system.

In getting these kinds of fuels, we talk about flash vaporization, or pyrolysis of materials, or maybe high-temperature equilibria followed by a rapid quench to get acetylene in the carbon-hydrogen system. For example, one should also seek expensive high-temperature chemicals--things one can't make by other methods. Obviously, economics will play a role here, because if one can do it back home by burning wood in a wood stove, it will not be practical to build a plant around one of these solar thermal test facilities.

There are many high-temperature processes. One classical example is carbo-thermic reduction: iron oxide plus carbon, or silicon dioxide plus carbon, or

magnesium oxide plus carbon, or titanium dioxide plus carbon, to make either metals or metal carbides. These represent one of the kinds of high-temperature reactions that might be considered.

Another kind of chemical problem would be making special crystals, which I discussed earlier. If one could really make large crystals of alumina or titania or some sulfide or some other desirable substances, this could be uniquely useful. In this area, I will talk about higher oxides--like  $\text{CrO}_2$  or  $\text{BO}_2$  or other of the higher oxides--that form under high pressures of oxygen. Very little is known about many of these systems, although  $\text{CrO}_2$ , of course, is widely synthesized and widely used commercially in recorder tape systems. One anticipates that there are other transition metal higher oxides that should be important.

There are also vapor deposition possibilities. One can have vapor deposition of carbon, boron, silicon, or other metals from either the hydrides or the mixed hydrohalides. When these molecules contact heated objects, one gets dehydrohalogenation or just thermal decomposition of the relatively unstable hydride. A number of these processes have been tried already by the French solar energy group.

Of course, Professors Trombe and Foex, and others, have tried to produce iron on a large scale by carbon reduction. Now, this has been done in the same way for many hundred years. It would appear that chemists, given their modern facilities and intellectual abilities, should be able to improve the process, but we still seem to be making iron the same old way. Here is a situation where consumed power is important because huge amounts of iron are required. Can one utilize solar power to carry out the carbothermic reduction of iron oxide? Maybe some other chemical process--chlorination, for example--followed by reduction would be more feasible.

Along this line, another prospective application that occurs to me is mineralogical processing. As my plane flew in this morning, I had a good view of the solar tower as we zoomed in for a landing. I could also see the barren ground (if New Mexico residents will excuse me) around there, but I know that barren ground is filled with minerals and resources which could be processed. One can conceive of locating a solar tower in a region where mineralogical resources are available. There have been interesting, significant developments in the chlorination of mixed iron-

aluminum-titanium-silicon-oxide systems--literally digging dirt from your yard and passing chlorine over it, allows one to separate the iron from the aluminum, from the titanium, etc. Economically profitable, chlorination of oxides, even very low-grade oxide ores, might be quite conceivable.

There are hydrothermal processes which look interesting. For instance, if one passes water vapor over hot borates, he can volatilize  $H_3BO_3$  and  $HBO_2$ , and quite effectively extract the boron from native borate ores. By passing water, at a pressure of an atmosphere or so, and a few hundred degrees centigrade, one can remove the beryllium from beryllates as the  $Be(OH)_2$  gaseous species, or remove the volatile tungstic acid from tungsten ores. Wherever there is a volatile hydrated oxide species--borates, molybdates, tungstates, beryllates, silicates--all are susceptible to these hydrothermal types of processes.

Finally, one comes to the general question of the surface itself. Richard Hays, from White Sands, said it most emphatically in talking about the flux corresponding to a 50-megawatt explosion. I am not sure, at the current stage of chemical kinetics, that anyone really understands what happens when a surface is exposed to an energy flux equal to a 50-megawatt explosion. This sounds like an area we need to know more about, but, initially, I have a feeling it is more a pragmatic question--how much of the surface survives, and for how long. Clearly, this does offer a kind of ultimate approach, much more controllable than a nuclear explosion, to study the behavior of surfaces in the presence of oxygen or in other atmospheres, and other pressure ranges up to several tens of thousands of atmospheres.

An interesting idea, which was discussed by one of the previous speakers, involves the generation of high-temperature species in one volume, and then letting those high-temperature species react with either room-temperature or even lower-temperature species, on a cool surface. I would vote for adding liquid nitrogen and liquid helium to the facility as a cooling technique. One of the reasons I would most like to study a high-temperature reaction, would be the possibility of condensing out some of the molecules on a cryogenic surface, to have them there long enough to study and carry out reactions. The future of chemistry in reactive matrices, I think, represents one of the important extrapolations for the next 25 or 30 years.

Finally, let me add some thoughts for the future; especially for high-temperature chemists. First, high-temperature chemists need to think about new and practical problems. As a high-temperature chemist of some 25 years experience, and as editor of High Temperature Science, I can say that there is an unfortunate lack of originality in the kinds of things many high-temperature chemists do. Some have been measuring vapor pressures for the last 25 years. I know there are more compounds and the results are always interesting, but there are other things to do. Perhaps with the current combination of a very nice facility, the availability of funding, and the need for high-temperature input, we will be able to extend our fields of vision.

We also need to remember economics and try to do things that have some practical relationships with the world and its current needs. We need to utilize more engineering approaches, although, we still have basic needs, as I have intimated here.

We need to be open to innovative suggestions. Too often, really creative ideas have been ignored. We need really to be on the alert for new ideas from our colleagues and from our students. We are obviously training the students who will provide the future staff for these solar test facilities. From the pragmatic view of a professor, I am glad these new facilities exist, because maybe some of them will want to employ some of my students. To make them more employable, I need to "think solar" and our work needs to be directed in ways that will help make these intentions most likely to occur.

Finally, I would like to argue that chemists haven't thought long enough, or perhaps recently enough, about the possibility of improving the classical approaches to some of the important chemical problems of our society. For instance, the refining of iron, as I said earlier, has been done in essentially the same way for at least two or three hundred years, with very modest improvements. A recent modification, of which I am aware, has been the preparation of new refractory materials, which allows the use of more extreme oxidizing conditions. The aluminum refining process was developed by Hall while he was a graduate student at Oberlin. He started ALCOA and obviously was very successful. Researchers are still investigating the details of that electro-chemical process, and one wonders if the combination of cryolite, aluminum oxide and electrolysis is truly the best way to prepare aluminum metal.

As a former professor at the University of Wisconsin, I watched Farrington Daniels utilize solar energy and almost every other technique of high-temperature science for much of his lifetime in trying to find a better way to make nitric oxide. He got beyond a pilot plant into an actual full-scale plant which did make NO and nitric acid eventually, but his process was ultimately phased out because it just couldn't beat the Haber-Ostwald process. It is amazing that that process survives in spite of our tremendous advances in chemistry in general, so here is another possibility. In the preparation of acetylene, the same situation exists. Dupont developed an electric arc process which was put into full-scale operation, but after a couple of years that also was phased out because they couldn't beat throwing calcium carbide in water to make acetylene. I feel that there are possibilities here for utilizing the combination of high-temperature chemistry and some of these new exotic research facilities using solar power.

## Solar Furnaces Experiments for Thermophysical and Thermochemical Property Studies at Very High Temperatures

J. P. Coutures  
Laboratoire des Ultra-Refractaires, CNRS  
BP n° 5 - 66120 - Odeillo, Font-Romeu, France

Radiation concentration devices such as solar or thermal imaging furnaces or CO<sub>2</sub> lasers are very appropriate for high-temperature studies. In fact, it is then easy to avoid contamination of the sample, by using self-contained or cooled earth devices, and to work under controlled atmosphere (oxidizing, neutral or reducing) and without electromagnetic fields. With solar furnaces we could achieve a very good stability of the image, and the variation of the radiation, unlike with CO<sub>2</sub> lasers and thermal imaging furnaces, is not sharp but gradual, varying slowly during the day.

It is the subject of this paper to present a review of work, done by the "Interactions gas-condensed phases" group of the Laboratoire des Ultra-Refractaires, using laboratory scale solar furnaces.

### 1. Temperature Measurements

Each chemical process or thermochemical or thermophysical study required good control and knowledge of the working conditions plus accurate temperature measurement, which is the major problem with solar furnaces. Three points are important:

- homogeneity of the temperature of the product wall inside a water-cooled rotating furnace (self-contained device),
- practical emissivity of the sample and its variation during the temperature measurement, and
- parasitic reflection of the sun's radiation by the sample and the sample holder due to the characteristics of the sun's radiation spectra.

Most of the commercial pyrometers worked at 0.65 microns and didn't operate satisfactorily because of point 3. If point 2 is known, the best method is to stop the sun's radiation, but that gives a very high cooling speed producing a cooling process very removed from the thermodynamic equilibrium conditions.

Pyrometric measurements with sun radiation are possible but only in two wavelength ranges:

- in the ultraviolet region by stopping the sun's radiation below 0.4  $\mu$  and using a pyrometer working at 0.36  $\mu$  [1], and
- in the infrared region by using a pyrometer with a filter working at

-- in the infrared region by using a pyrometer with a filter working at  $2.91 \mu$  (atmospheric-window  $2.5-3.0 \mu$ ). But in this case, one must take care concerning the nature of gas which could be given off by the sample [2].

Generally the emissivity of the sample is unknown and it is necessary to perform temperature measurements in good blackbody conditions (that is possible, as we see later) or to measure directly the sample emissivity which is generally very difficult.

But it is interesting to note that the error in the temperature measurement due to an error of the emissivity value is one half if we used UV pyrometer ( $0.36 \mu$ ) rather than  $0.65 \mu$  pyrometers. At high temperature also, the sensitivity of UV pyrometer is greater than the other pyrometers working at  $0.65$  or  $2.91 \mu$ .

## 2. Measurement of Thermal Properties

The thermal analysis apparatus previously described [3-4] was used in conjunction with a 2-kW horizontal axis solar furnace (parabolic mirror 2 m diameter, focal length 0.85 m, focal spot 10 mm, power  $\sim 2$  kW).

The use of a centrifugal furnace allowed us to produce, by rotation and centrifugation, cavitation of the melted compound, homogenization of the liquid composition, good temperature homogeneity and a cavity with a suitable shape for simulating blackbody conditions.

Usually a  $25\text{-cm}^3$  furnace is used and the mean parameters of the crucible after solidification are: diameter of the aperture, 8 mm; length, 25 mm; weight, 40 g. The average speed of rotation was between 800 and 1000 rpm.

The emissivity at  $0.65 \mu$  in the liquid state of most of the refractory oxides studied at the laboratory is between 0.80 and 0.85 and the calculation of the practical emissivity in the case of the cylindrical approximation, taking into account the multiple reflections, give respectively 0.97 and 0.98. At 2500 K, for example, the temperature correction is between 5.6 and 9.5 K.

These values are valid only in the liquid state or at the liquid  $\rightarrow$  solid transition. After solidification  $\epsilon_{\ll \gg}$  is lower than  $\epsilon_{(( )})$  and the blackbody approximation is not so very good. Usually the temperature was measured with two optical pyrometers, one working at  $0.65$  or  $0.81 \mu$  (with a cesium detector) and the other at  $2.91 \mu$  (with a lead sulfide detector) [4].



In all cases, the pyrometer calibration is made against the alumina and yttria melting point ( $\text{Al}_2\text{O}_3$  mp =  $2054^\circ\text{C}$  [5] -  $\text{Y}_2\text{O}_3$  mp  $2440^\circ\text{C}$  [6]). Taking into account the calibration precision, the blackbody conditions, we estimate the temperature error at  $\pm 10$  K up to 2700 K and at  $\pm 20$  K in the range 2700-3000 K.

By using a quartz tube between the furnace holder and the pyrometer head it is possible to perform thermal analysis experiments under controlled atmosphere with oxygen pressure between  $10^{-4}$  and 1 atmosphere.

As an example of the use of this device, Figure 1 shows liquidus curves of the  $\text{La}_2\text{O}_3$ - $\text{Cr}_2\text{O}_3$  system when the sample is melted under pure argon ( $\text{PO}_2 \sim 10^{-5}$  atm.) Curve A, under air Curve B, and under oxygen Curve C.

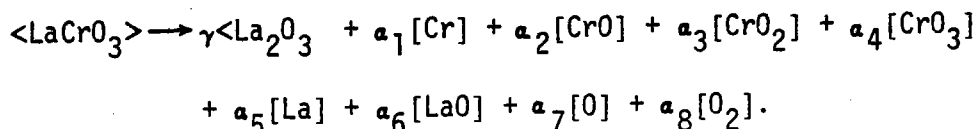
For a given sample the depression of the freezing point when the amount of oxygen rises is related to the oxygen dissolution in the melt. The biggest cryoscopic effect is for the definite compound and the eutectic point between  $\text{LaCrO}_3$  and  $\text{La}_2\text{O}_3$ , and we see later that at this point the oxygen dissolution is maximum (exothermic character of the dissolution). As another example, Figure 2 shows the cooling curves of the definite compound melted under argon (A), air (B) and oxygen (C). The perturbations after the solidification on Curves B and C are related to a spitting phenomena when the dissolved oxygen is evolved.

## 2.2 Transpiration Analysis

The transpiration apparatus is also associated with a 2-kilowatt horizontal axis solar furnace [8]; Figure 3 shows a schema of this device. The sample was melted or sintered in the water-cooled centrifugal furnace to produce a crucible-shaped ingot; a small hole was made at the bottom and in the axis of the crucible to provide a connection with a platinum tube inserted in the hollow axis of the furnace. The hot gases saturated by the vapor were condensed on the platinum tube which was indirectly cooled by the cooling water of the furnace. The hot gases saturated by the vapor were found by weighting the tube before and after a run. The temperature was measured and recorded continuously with an infrared pyrometer (PbS cell) operating at  $2.91 \mu\text{m}$  in the presence of sun radiation. The flow of the carrier gas was controlled with a micropump in the range 1 to  $10 \text{ l h}^{-1}$ . Preliminary tests were carried out to establish the appropriate flow rate, essentially the plateau region of the curve  $\text{Ln}G/v : f$  (flow rate), ( $G$  is the weight of the condensed vapor,  $v$  the total volume of the carrier gas) in which the vapor pressure is independent of the

flow rate. In this region the carrier gas is saturated by the sample vapor and diffusion does not influence the results. In most cases the flow rate was near  $4.5 \text{ l h}^{-1}$ .

Because of the practical importance of lanthanum chromite as MHD electrodes, its vaporization was examined by this method. The vaporization process is not congruent (in the vapor the  $\frac{\text{Cr}}{\text{La}}$  ratio is greater than 1) and the vaporization equation could be written as:



The stoichiometry of the lanthanum chromite depends on the oxygen partial pressure of the atmosphere; nevertheless, this effect was very low and could be ignored in a first approximation.

Because of the noncongruent vaporization, it is necessary to know the  $\gamma$  value of the above reaction in order to calculate the different species partial pressure. Activation analysis could be used to attain this value; for example, at  $2000^\circ\text{C}$  the  $\frac{\text{La}}{\text{Cr}}$  ratio of the condensed vapor is  $\frac{1}{6}$  under argon and  $\frac{1}{90}$  under oxygen.

For experiments under oxidizing conditions, care must be taken because the weight gain of the platinum tube included extra weight due to the oxidation of the condensed vapor by the oxygen carrier gas. In these cases, weight gain must be measured after annealing the platinum tube under argon at  $1000^\circ\text{C}$ .

In all cases, weight gain measurements and activation analysis permit calculation of the vapor species partial pressures.

### 2.3 Free Vaporization Studies

A schematic diagram of the apparatus using a 2-kW vertical axis solar furnace is shown in Figure 4. The sample (0.5 g) is fused on a water-cooled copper plate surrounded by a 5-liter Pyrex bell jar. The vessel could be evacuated and a statically or dynamically controlled atmosphere could be maintained up to a pressure of 630 mbar. The vapor condensed on the Pyrex bell jar or collected by targets put on the cold finger was analyzed by X ray or thermogravimetry; the sample weight loss was measured by gravimetry.

The free vaporization studies of some melted rare-earth sesquioxides under hydrogen showed that the vaporization decreases in the yttrium series [9]. The

chemical analysis of globules indicates that the nonstoichiometry is also decreasing from  $Gd_2O_3$  to  $Lu_2O_3$ .

X-ray examination at room temperature of the vapor collected on the cooled target or on the Pyrex vessel shows that  $B Ln_2O_3$  is obtained, and pointed out the dependency on the sample crystallization of: nature and pressure of the gas and distance sample-target. Better crystallization is obtained for oxides of the end of the yttric sery melted under pure argon at atmospheric pressure. Operation under low pressure or short sample target distances yield poor crystallized materials. The average dimension of the microcrystallites measured by high-resolution electronic microscopy is about 30 Å, that meant some atomic plans, which give a very high chemical reactivity, and explained the obtention of metastable phases ( $B Ln_2O_3$ ,  $Q ZrO_2$ ,  $\delta Al_2O_3$ ..). In each case moderate annealing produces the stable phase.

### 3. Thermochemical Studies

With the above apparatus some chemical reactions like: reduction, carburation by  $CH_4$ , oxidation, nitridation, could be performed. Also, ore treatment, like molybdenite, could be studied. But "in situ" measurements are impossible.

#### 3.1 Thermomanometric Studies

In many cases at the solid-liquid transition a gas dissolution occurs; this dissolution depends essentially on the liquid temperature, gas pressure, time and, in some cases, melt composition. When the solidification occurs, most of the dissolved gas is evolved very shortly producing a spitting phenomena [10].

This behavior is currently seen with oxygen and most oxides (simple or complex mixtures) and with water vapor and slags (especially  $CaO$ ,  $SiO_2$ ,  $Al_2O_3$  mixtures). Special apparatus have been built at the laboratory to study this spitting phenomena. A schematic diagram of the thermomanometric apparatus, associated also with a 2-kW vertical axis solar furnace, is shown in Figure 5.

The product is melted on a small water-cooled copper plate which is surrounded by two quartz vessels containing cooling water. The change of the pressure inside the laboratory vessel, during the spitting phenomena, is measured by a differential pressure transducer and recorded by a high-speed recorder. The response time of the complete data acquisition system is 2 milliseconds. Solidification of the sample is obtained through a variable-speed DC motor by a vertical translation of the measurement chamber in the solar heating cone resulting in a liquid cooling speed between 1 and  $250^{\circ}C s^{-1}$ .

Knowing the pressure variation during the solidification and calculating the average gas temperature, it is possible to know the amount of evolved gas; then by the chemical analysis of the solid sample, the liquid composition could be obtained.

This apparatus is used for the examination of the oxygen dissolution in liquid. For the studies of water vapor dissolution, we used the same kind of apparatus but, in this case, we have a water vapor generator (up to 3 bars), only one quartz vessel. To prevent water vapor condensation the copper plate is cooled at 120°C by an organic liquid, and all the gas circuits and the pressure transducer are also heated at 120°C.

In the case of oxygen, the dissolution occurs at the solid-liquid transition for oxides like  $\text{CoO}$  or  $\text{FeO}_x$  ( $x \sim 1.33$ ) and even for  $\text{Ln}_2\text{O}_3\text{-A}_2\text{O}_3$  mixtures ( $A = \text{Al}, \text{Cr}$ ). This dissolution yield in the case of  $\text{CoO}$ ,  $\text{FeO}$  and  $\text{Ln}_2\text{O}_3$  melts an oxidation of the cations in the melt ( $\text{Co}^{2+} \rightarrow \text{Co}^{3+}$ ,  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ ,  $\text{Cr}^{3+} \rightarrow \text{Cr}^{6+}$ ). The dissolution of oxygen is maximum at the eutectic compositions (exothermic dissolution), but higher for the  $\text{LnAO}_3\text{-Ln}_2\text{O}_3$  eutectic giving an important cryoscopic effect. In the case of  $\text{Ln}_2\text{O}_3\text{-Cr}_2\text{O}_3$  for a given composition (ratio  $\frac{\text{Ln}_2\text{O}_3}{\text{Cr}_2\text{O}_3}$ ) the dissolution increases with the basic nature of the rare-earth oxide and the oxygen partial pressure square-root. This fact is related with the dissolution of oxygen at the atomic state [11-12].

As an example, Figure 6 shows the pressure change at the solidification of cobaltous oxide melted under pure oxygen (sample weight 230 mg, time of fusion: 1 minute, atmosphere: pure oxygen at 0.83 atm, cooling speed of the liquid phase 250°C s<sup>-1</sup>). One can note the beginning of the solidification and the plateau due to the evolved oxygen. The final peak is caused by the many thermal effects linked to the spitting.

The same kind of studies are made with water vapor giving the same result (dissolution on  $[\text{P}_{\text{H}_2\text{O}}]^{1/2}$ , not greatly affecting the dissolution by the melt temperature ( $\Delta H \sim 0$ )).

This apparatus allowed us to measure melt composition over a wide range of "temperature," pressure and time. A thermodynamic approach could not be made essentially for three reasons:

-- temperature is not well known ( $\pm 50^\circ\text{C}$ ),

- thermodynamic data like heat of fusion or phase transition or mixing enthalpy are unknown, and
- no knowledge of species present in the liquid state.

To obtain some information on species present in the liquid state, indirect studies could be made on splat-cooled samples.

### 3.2 Indirect Structural Studies on Melts

Splat-cooling experiments of liquid  $\text{Ln}_2\text{O}_3\text{-A}_2\text{O}_3$  mixtures (A = Al, Ga) allowed us to obtain amorphous materials. For this purpose a hammer-anvil device (Figure 7) associated with a 2-kW vertical axis solar furnace is used. By this way cooling speed between  $10^{40}\text{C s}^{-1}$  and  $10^{50}\text{C s}^{-1}$  could be obtained, and the glassy-like compounds obtained could be seen as a picture of the liquid.

The structural properties are studied by X-ray diffractometry and electronic microdiffraction. Also, by using  $\text{Nd}^{3+}$  or  $\text{Eu}^{3+}$  as local structural probe, the average coordination number of the rare earth cation could be obtained. Thermal properties (recrystallization temperature, recrystallization heat) are examined either by differential thermal analysis or by differential scanning calorimetry.

By using  $\text{Nd}^{3+}$  as local probe, it appears that the average coordination of the  $\text{Ln}^{3+}$  cation is independent of the rare earth oxide concentration and its ionic radius (CN = 9). Also, the average Ln-O distance decreases when the concentration of rare earth increases or when  $r_{\text{Ln}^{3+}}$  decreases. The structural disorder seems also to be independent of the two parameters above [13-14].

The use of  $\text{Eu}_2\text{O}_3$  is also interesting as a chemical probe because of oxydo-reduction reaction in these melts, the knowledge of the  $\frac{\text{Eu}^{2+}}{\text{Eu}^{3+}}$  ratio being related to the  $\text{O}^{2-}$  activity in the melt [15].

### 4. Conclusion

This paper presents a brief survey on the use of laboratory scale solar furnaces in the field of high temperatures.

The basic advantages for chemical studies are:

- noninteraction of molten product with the sample holder,
- very high temperature under reactive atmospheres: oxygen, water vapor in a wide range of pressures  $10^{-6}$  to 1 atmosphere,

- absence of electromagnetic radiations, and
- no dead time during the heating or cooling process (melting obtained quite instantaneously).

Actually the major problem is to achieve good temperature measurements because of the emissivity and the sun's reflection by the sample is unknown. More efforts are necessary in this sense to propose "in situ" emissivity measurement methods resulting in good temperature measurements. But one must notice that these experiments are more difficult with liquids than with solids because of the reflectivity properties of the liquids.

Also, a very important thing is that such laboratory solar furnaces must be located very near the different megawatt facilities. I think that the success of Odeillo is due to the one-megawatt facility and about ten laboratory-scale solar furnaces. In my opinion it is necessary to check each chemical process project for a megawatt-scale solar facility with a laboratory-scale furnace. Exchanges between people involved in basic research with laboratory solar furnaces and chemical engineers working with the big facilities are better, if all of them are located in the same area, and also save time and money.

- 1) M. FOEX and J.P. COUTURES, J.Physique Appliquée 1969, 4, p. 381.
- 2) M. FOEX, J.P. COUTURES and G. BENEZECH, Bull.Cooperation Me-  
diterranéenne pour l'Energie Solaire 1970, 18, p. 67.
- 3) M. FOEX, Rev. Int. Htes Temp. et Refract. 1966, 3, p. 309.
- 4) G. BENEZECH, R. BERJOAN, J.P. COUTURES, B. GRANIER, M. MIZUNO  
and M. FOEX, Colloque International du C.N.R.S. n° 205 (Odeil-  
lo, Sept. 1971) p. 67.
- 5) S.J. SCHNEIDER, Cooperative determination of the melting point  
of  $Al_2O_3$ , 1969 Report on the Task Force on secondary tempera-  
ture standards. Commission for High Temperatures and Refrac-  
tory Materials I.U.P.A.C.
- 6) M. FOEX, Cooperative determination of the melting point of  
 $Y_2O_3$ , 1977 Report on the Task Force on secondary temperature  
standards. Commission for High Temperatures and Refractory  
Materials I.U.P.A.C.
- 7) R. BERJOAN, J.P. COUTURES and M. FOEX, C.R.Acad.Sc. 1970,  
270 C, p. 1654.
- 8) G. BENEZECH, J.P. COUTURES et M. FOEX, Colloque International  
Thermodynamics of nuclear materials, Vienne, Oct. 1974, Vol.  
II, p. 337.
- 9) J.P. COUTURES, R. RENARD, Tenth. Rare Earth Research Confe-  
rence Carefree Arizona, Mai 1973, Vol II, p. 1977.
- 10) J.P. COUTURES, Colloque International "Refractory oxides  
for High Temperatures energy sources". Odeillo, Juin 1977.
- 11) J.P. COUTURES and M. FOEX, N.B.S. Special Publication 364,  
p. 471.
- 12) R. BERJOAN, Rev. Int. Htes Temp. et Refract. 1976, 13, p. 119.
- 13) J.P. COUTURES, G. BENEZECH and E. ANTIC, Mat.Res.Bull. 1975,  
10, p. 539.
- 14) J.P. COUTURES, G. BENEZECH, E. ANTIC-FIDANCEV, M. LEMAITRE-  
BLAISE, Rev.Phys.Appl. 1977, 12, p. 667.
- 15) J.P. COUTURES, G. BENEZECH and E. ANTIC, J.Chim.Phys. 1977,  
9, p. 984.

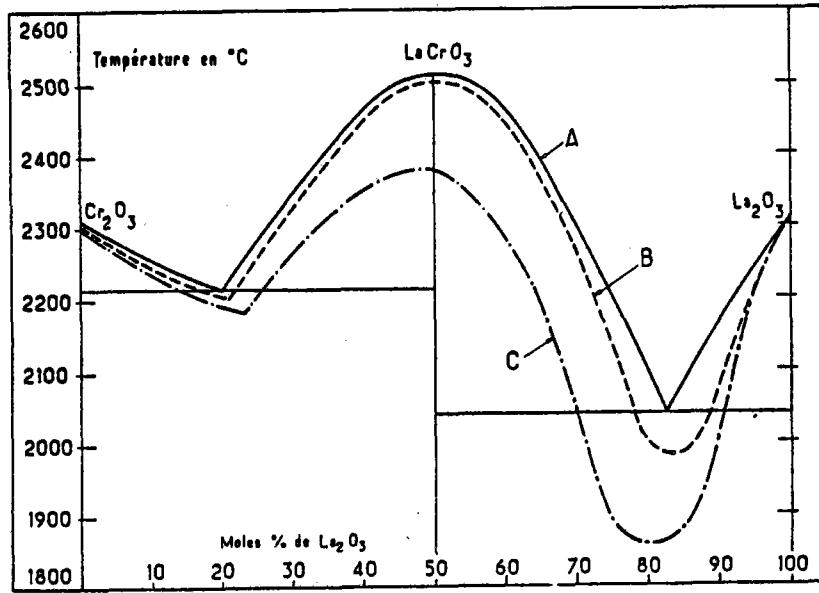


Figure 1 - Liquidus Curves of the  $\text{La}_2\text{O}_3\text{-Cr}_2\text{O}_3$  System [7]  
 A: Pure Argon    B: Air    C: Oxygen

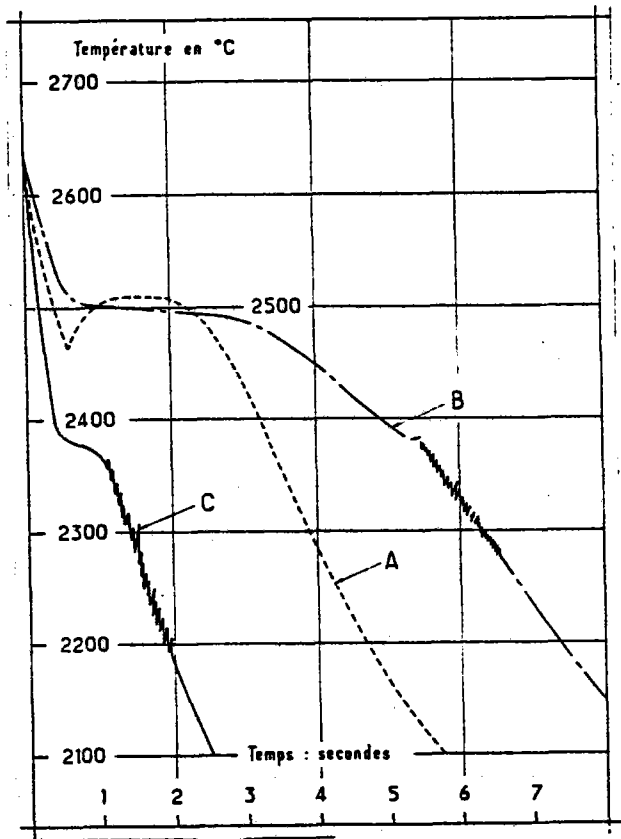


Figure 2 - Cooling Curves of  $\text{LaCrO}_3$   
 A: Pure Argon    B: Air    C: Oxygen

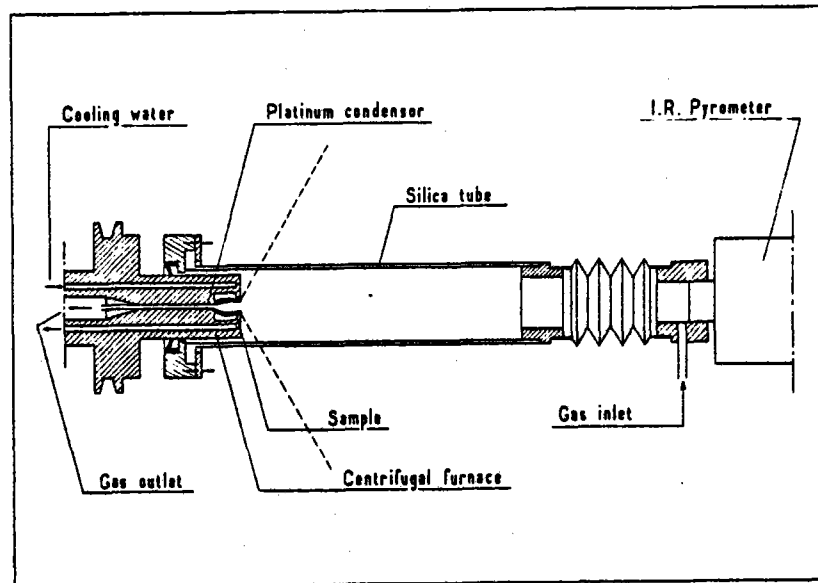


Figure 3 - Transpiration Analysis Device



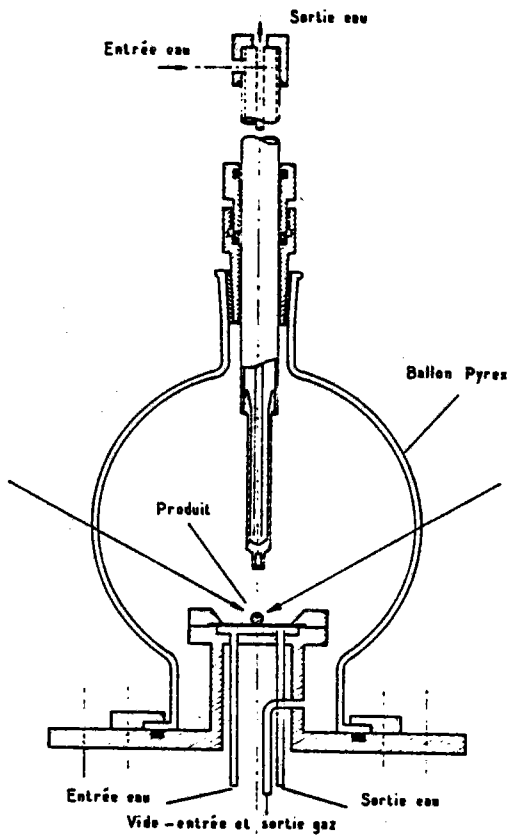


Figure 4 - Free Vaporization Studies Apparatus

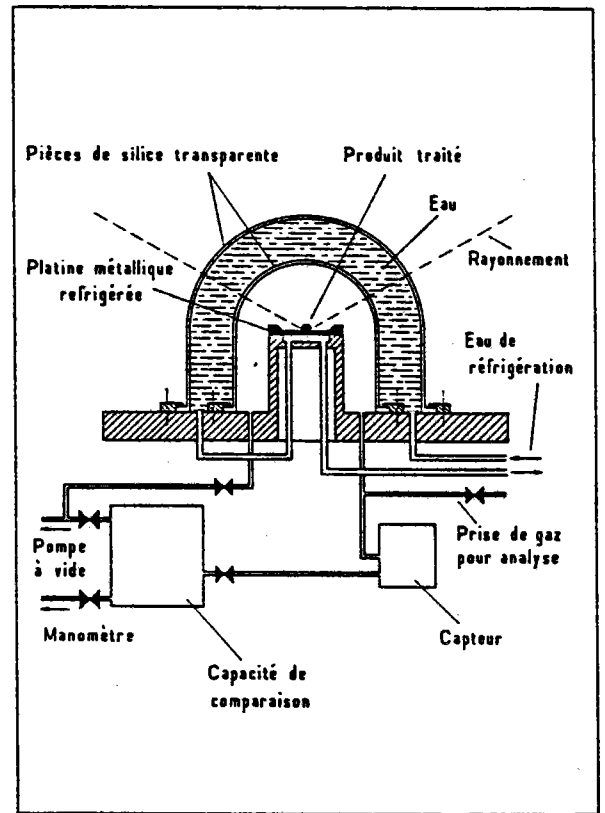


Figure 5 - Thermomanometric Apparatus

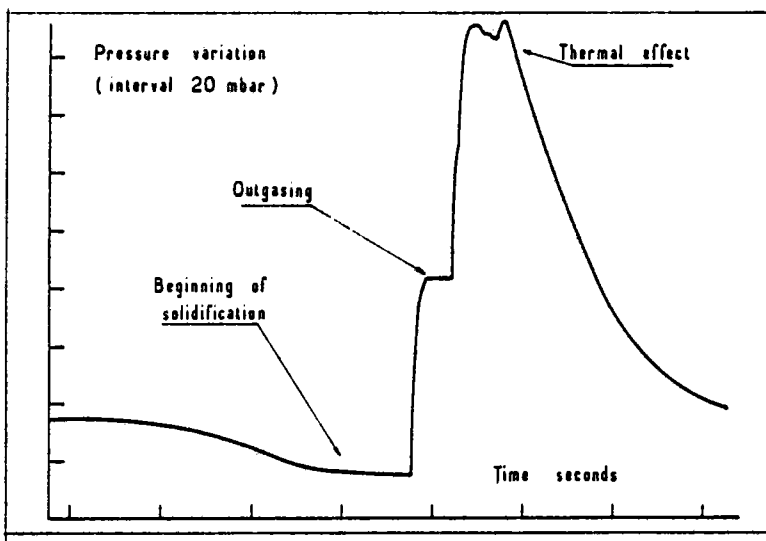


Figure 6 - Pressure Variation with Time at the Solidification of CoO after Melting Under Pure Oxygen

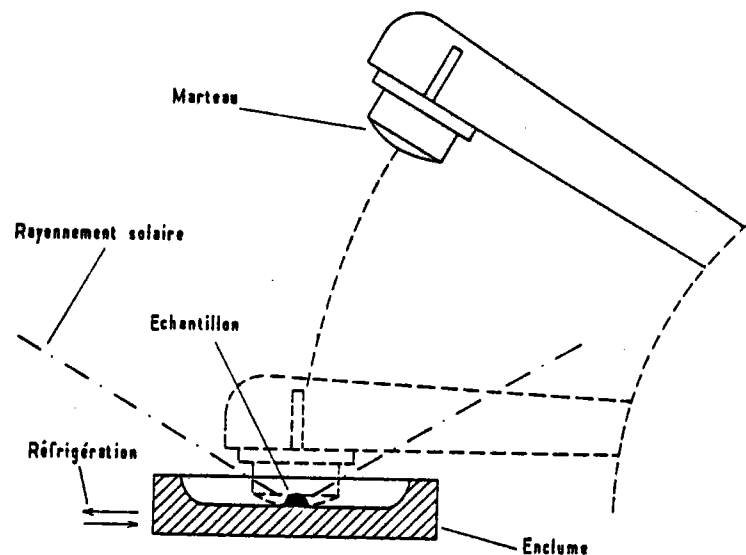


Figure 7 - Splat-Cooling Apparatus

Rosenblatt - The comments I have are more in the form of questions to remind you how someone who primarily does basic research looks at a new area or a new tool. Professor Margrave focused on certain things that could be done related to solar thermal test facilities, both basic experiments that could be done in the laboratory related to these facilities, and then on the whole applied research that use these facilities. Going on to the third potential kind of use to see whether these can be used as basic research tools per se, whether this would be in energy-related research or not, we then start asking the kinds of questions that are asked whenever we are introduced to a new apparatus or a new tool. One of the first things is what is unique about these facilities compared to other research tools. The ability to reach the temperatures obtained per se are not so unique. The ability to work without containers and oxidizing atmospheres is perhaps so. The large size as noted earlier is not usually an advantage in most of the experiments that we envision. In fact, we shudder at the thought of square meters of heat flux coming at us.

In addition to this question as to what is unique about this tool as a heat source, it seems to me that there is one other potentially interesting area from the point of view of a physical or high-temperature chemist. That is, in addition to being a heat source, the solar facilities are also light sources. I don't have a good feel for what the light characteristics are but am trying to take some of the numbers we heard this morning and think about them: it seems that perhaps they are quite unique light sources. It seems that available flux densities are integrated over the whole visible structure and probably are higher by orders of magnitude than we can get continuously with any visible lasers at the moment. It seems possible that with further focusing of the beams the flux densities in a given relatively small wave length increment of a few angstroms are of the same order as the typically more powerful visible lasers that we have--argon ion lasers and argon ion pumped-dye lasers. One wonders if there is a possibility of using these as spectroscopic tools by combine their heating capability and focusing some of this energy to use as a selective light source in this environment.

It would probably be helpful to us not in the field to have a lot more quantitative feel for the spectral and power characteristics of the solar facilities as light sources and what can be done with the image: Can it be focused, how finely can it be focused, etc.? Remember, the things we are usually interested in in light sources are photons/cm<sup>2</sup>-sec.

Eyring - I would like to extend Dr. Rosenblatt's comments a bit. I was considering whether or not, with a high flux of energy in this range, one could not study reactions a long way from equilibrium--in fact, where one has inverted populations to some extent, and where one is bound to have lack of equilibrium between the degrees of freedom, likely to get all sorts of new molecules. As a research tool I would like to see what sort of pulses could be had and what kind of atmospheres. These are important things that I don't have a feel for. This would seem to me to open up a whole new possibility of chemistry far from the equilibrium: or if not that much, at least getting far out on equilibrium distributions.

Hastie - We might consider (STTFs) or IR sources. Much of the chemistry that Eyring mentioned can be done in the IR.

Eyring - In connection with the instrumentation for these solar facilities, since we have introduced the prospect of spectroscopy and wavelength selection, can we have optical spectrometers on these facilities? Actually, I think, if we have a gaseous environment and are interested in some chemical process between a ceramic and a gas at high temperature, it would be very useful to know the gas temperature. One way of doing that would be to have an optical spectroscopic method in the facility. A laser Ramen spectroscopic method would seem feasible to add to these facilities.

John Margrave mentioned this morning the possibility of using solar light to augment other energy systems, such as conventional combustion, or a plasma. I think there is quite a bit of merit in that idea. It could be possible to improve the efficiency of combustion, for example, by augmenting a normal combustion process with solar radiation. By providing extra energy and heat to the combustion process, one would increase the number of free radicals and have a possibility of producing chemicals such as NO and acetylene by subsequent quenching of the hot gases. There is a problem in using laser Ramen spectroscopy as a diagnostic tool in combustion systems where there are particles present. An interesting experiment might use solar radiation as a means of vaporizing these particles at the same time as you are doing a laser Ramen experiment.

Margrave - I think the supplementation of either flames or plasmas might be quite interesting. There is a basic chemical limitation: if one burns a normal hydrocarbon with oxygen, he is stuck with  $3000^{\circ}$  or less even in most cases. But if he could now supplement this and carry it on out, especially in seeded systems where one

might get unusual concentrations of ions and electrons, some of the potential for extracting electrical energy from the high-temperature mixture looks much better. In using the sun, one then escapes the limitation of the chemical flame to go up to a range of  $4000^{\circ}$  or  $5000^{\circ}$ . Between the two, one might come much closer to the sun-surface temperature. Solar energy alone is limited to about  $3000^{\circ}$  and chemical energy is limited to about  $3000^{\circ}$ , but together it may increase to the  $4000-5000^{\circ}$  range. There are very few chemical systems capable of getting to that range, and the ones that are have difficulty. They are expensive, unstable and hard to handle. By combining solar with hydrocarbon oxygen flames, one could move into the next level of gas temperatures.

Question - Can we use the current facility for temperatures above  $3000^{\circ}$ ?

Margrave - No. The solar facility by itself won't go above about  $3000^{\circ}$ .

Hertzberg - You would have to seed it. We can make potassium plasmas with solar radiation. We were surprised at the ease with which we could absorb solar energy. We started with calculations on the use of potassium vapor but, in fact, any of the alkaline vapors can be used as seeds, or in the pure form, to create high-temperature plasmas. They seem uniquely suited for that. The absorption length depends on the degree of pressure broadening. What surprised us was the degree of pressure broadening which created all those black body absorbers. We are looking for ways of generating high-temperature plasmas with the sun. We couldn't find an absorber. We tried to disassociate enough steam to get the Hertzberg bands (a different Hertzberg). That did improve things significantly--that's in the visible spectrum. We then went to mercury. It turned out that all the alkaline vapors have a few good lines that are easily pressure-broadened, and one can, within the limits of the focusability of any light source (i.e., white light source like the sun), reach plasma temperatures like one would calculate with black bodies. In your facility, it would be on the order of  $3000^{\circ}\text{K}$ . One can further use that through temperature amplification devices to transfer that plasma energy to other gases and use it as a temperature amplifier. But that is a different plasma machinery of which an engineer is familiar. I'll talk about that tomorrow.

Question - What is the possibility for secondary focusing of the light? What is the ultimate capability? How sharply can you focus this beam? What is the smallest area you can concentrate this beam into?

Holmes - We think we can produce a beam size of 1/2 meter diameter and have a concentration of about 10,000 suns using a reconcentrator. And with the tertiary reflector we think we can go beyond that. I think, as Dr. Hildebrandt says, one could approach the sun-surface temperature. It becomes a matter of economics, and hardware losses in the optical systems, etc.

Hildebrandt - Yes. With each step you lose power density. Solar flux at the sun is 64 megawatts per square meter at a temperature of  $5720^{\circ}$ . If we calculate for any one of these systems that half of the energy is lost at each reflection, one can estimate the temperature. Do you get  $4100^{\circ}$ K at Odeillo?

Royere -  $3800^{\circ}$ C. In fact, we know that we achieve effectively  $3200^{\circ}$ C.

Smith - Dr. A. Hertzberg, Aerodynamic Research Department of Cornell Aeronautical Laboratories, Inc., Buffalo, NY, spoke on "The Energy Exchanger, a New Concept for High-Efficiency Gas Turbine Cycles." An abstract of Dr. Hertzberg's paper follows:

A method of circumventing the turbine inlet temperature limitation of present-day gas turbines is presented. This method is based on a direct fluid-to-fluid energy exchanger whereby the available energy of expansion of the hot combustion gas in a gas turbine cycle is transferred directly to a colder gas.

The aerodynamic wave processes in several possible modes of operation are examined to determine the inherent limitations in efficiency of direct fluid-to-fluid energy exchange processes. In particular, it is demonstrated that, by using a system of isentropic compression waves to avoid shock losses and by carefully choosing the molecular weights of the fluids utilized in the energy exchanger, perfect energy exchange is possible in principle. When allowances are made for losses due to mixing, leakage, and viscous effects, an energy exchanger utilizing heated combustion air at 3240 deg F to drive steam at 1500 deg F with a potential energy exchange efficiency of 85 percent is feasible.

Applications of the air-stream energy exchanger operating in gas turbine cycles utilizing a conservative choice of component efficiencies indicate that thermal efficiencies of gas turbine power cycles of 50-60 percent may be possible.

Dr. Hertzberg also mentioned "Nitrogen Fixation For Fertilizers By Gasdynamic Techniques." An abstract of this paper follows:

A method of fixing nitrogen suitable for fertilizer production is presented. This method employs gasdynamics technology based on advanced shock tube concepts to process air at high temperatures so that fixed nitrogen in the form of NO is generated. An examination is made of the efficiency and productivity of this system, and it is shown that this system has the potential of significantly reducing the present cost of fertilizer. The system is energy efficient

using any convenient source of energy and is independent of petroleum-based feedstocks. As such, it offers a solution to a near-term national need as well as a long-term world problem in that it promises an increase in agricultural productivity and a decrease in the price of food.

We will reference these and other papers by Dr. Hertzberg which may be of interest to workshop participants. They may be requested from the Users Association Albuquerque office.

R. C. Weatherston, A. Hertzberg, "The Energy Exchanger, A New Concept for High-Efficiency Gas Turbine Cycles," Journal of Engineering for Power, April 1967, p. 217.

A. Hertzberg, "Nitrogen Fixation For Fertilizers By Gasdynamic Techniques," Reprinted from: Modern Developments in Shock Tube Research, Proceedings of the Tenth International Shock Tube Symposium, Kyoto International Conference Hall, 1975.

A. T. Mattick, Absorption of Solar Energy By Alkali Vapors, University of Washington, November 1977.

A. Hertzberg, High Power Gas Lasers; Applications and Future Developments, AIAA 15th Aerospace Sciences Meeting, January 24-26, 1977.

A. Hertzberg, E. Lau, High Temperature Rankine Binary Cycle With Wave Energy Exchange, University of Washington, November 1977.

O. Yesil, Solar Pumped Gas Lasers, University of Washington, November 1977.

Thorn - I think most of the comments that I have to make have been discussed either by John Margrave or Jean-Pierre Coutures, but I will make them anyway. First, concerning the list that John Margrave gave regarding the basic measurements of emissivities and thermal properties. It seems that these items will continue to be neglected unless there is a directed effort to obtain these data. It seems that they are valuable enough that some thought should be given to that kind of measurement. The trouble is that nobody is prepared to fund them. Unless someone says that we need those data as part of our operations and is willing to spend the money to get them, I don't think it's going to be done. We will wait until we really need them and then we shall thumb through the thermal physical compilation that Purdue is trying to make and we shall find that they are missing.

Smith - Do I understand that there are data derivable from basic investigations that do not necessarily use the solar tower but are necessary prerequisites to making use of the facility?

Thorn - Right. Emissivities,  $C_p$ , heats of fusion--basic thermodynamic data.

Smith - I understand. But the Users Association thus far has not been given authority to fund anything much beyond work on the towers.

Holmes - There are all sorts of things that we would like to calculate right now and are unable to because the data are not there for the ranges we need.

Thorn - The other remarks which I wish to make, I put into the context of a practicing high-temperature chemist. They are reinforcements of the comments made by Jean-Pierre Coutures or John Margrave. They are the kinds of items that I shall think about with respect to our program and to the use that we might make of solar furnaces. I hope that they are of some use.

I have listed six items that I wish to cite, and I shall make a few comments concerning each. John Margrave has already cited the first item and Jean-Pierre Coutures has illustrated it. This is the area of gas solid reactions at pressures near one atmosphere and under conditions where one controls the atmosphere. This area is unexplored in high-temperature chemistry. It has two facets: one involves the vapor transport that ceramic materials experience and the kind of solid-state chemistry which exists because of the controlled atmosphere and which concerned



associated phenomena such as the conductivity in solid materials. The other facet is the area of metallic systems in which one might be interested in corrosion processes. I haven't thought through the details concerning what advantages solar energy might have, but I'm sure it might have at least enough so that one could use it for studying problems in these areas.

Another item on my list is in the other area that has already been cited by Coutures, namely, phase diagram. Perhaps solar heating might be used in conjunction with high-temperature X-ray diffraction. For years we have tried to carry out studies of systems and the determination of their phase diagrams using high-temperature X-ray diffraction. One of the problems encountered is to heat the sample in such a way that one can get both the heating energy and the X rays in and out. Conventional laboratory techniques don't work very well. For techniques such as induction and resistive heating, some of the elements always get in the way. If I remember correctly, years ago we did consider such techniques as arc imaging and decided that such was probably the way to go. I think that the technique should be studied further to see whether the solar furnaces can be used with these studies.

Another area which I cite is related to the nonequilibrium processes such as transport in temperature gradients. We are becoming more and more interested in what happens during transport in solid phases, or through the gas phases, in temperature gradients. Definitive experiments in this area have not yet been performed, but certainly they are needed in the area of nonequilibrium transport in solid phases.

Another item, which does not necessarily entail use of solar furnaces, but does relate to the kind of materials that might be used in solar energy systems, is materials that have fast oxygen or hydrogen transport. This area still has not been investigated very systematically. We know that some materials have relatively high oxygen and hydrogen transport but we still do not understand the phenomena well enough to design such materials. Perhaps the desire to produce energy from these solar furnaces will give emphasis to these kinds of studies.

Being experimentalists, we would like to do exploratory experiments, but when we see all that computer hookup to this facility we don't see much possibility for the exploratory kind of experiment. I think such is needed if one is an experimental chemist.

The final item that I cite is, again, one which reinforces a point that Margrave made. It is that this source of energy is free of electromagnetic radiation. There must be a number of properties that can be advantageously studied in such a field. I might cite a few of them. I don't know whether these require such a field, but they are the kinds of properties that come to mind when one thinks of the kind of studies that are needed in conjunction with MHD or perhaps other energy systems. They are the properties such as thermionic emission from ceramic-like materials and the optical properties, of course. Perhaps such properties as Hall coefficients could be better measured if one heats independently with some means that doesn't require an electrical current. Perhaps one could more adequately study insulators in a field-free region, especially their breakdown. And finally, one might more adequately study ceramic conducting electrode materials which are needed in MHD kinds of operations.

Finally, for emphasis, I return to phase diagrams. A great deal of study is needed on the alumino-silicate systems and on glasses. The phase diagrams of these systems are highly inadequate, e.g., in MHD areas. Extensions of the kind of phase diagram work that Jean-Pierre illustrated could be a very viable kind of research to be done.

Question - What about safety rules with respect to experimenters not being in the tower?

Holmes - As far as the Sandia facility goes, right now our attitude is that experimenters will not be in the vicinity of the experiment--unless we do something to provide that ability, shielding and so forth. We do not have that design right now but I hear clearly that that is probably needed. I think we should look into that. It is different to shield a person than to shield a piece of equipment.

Walton - I would like to comment about small-scale experiments. I don't know that we should feel any pressure to do small experiments on a 5-megawatt facility, or necessarily to modify the 5-megawatt facility to do small experiments. We put two searchlight reflectors with heliostats on campus at Georgia Tech with very nominal capital outlay. One has a vertical axis, and the other one has a horizontal axis. I don't know what the future situation may be, but I feel that the more people to become involved in small-scale experiments, the more likely we are to develop the larger experiments that we want to do in the future using the 5-megawatt facility. So the more we can scatter the small facilities around the country, the more you do small

experiments in your own lab, you begin to encourage graduate students to get involved. If they have to travel to Albuquerque to do a small experiment, we may find very few people doing them. I don't know whether we may think in the future of assisting people to set up small facilities at their own universities, this question has not come up in the Users Association. But I feel that may encourage experiments on the big facilities faster than anything else we could do. And then we could use the big facility for the bigger experiments.

Comment - One thing to consider however with respect to doing small-scale experiments in Chicago is that we don't have the sun that you have in the Southwest.

Walton - Well, you might be surprised. It doesn't take long to run some of these experiments. Most of our time is really spent in getting ready for an experiment. And there is a possibility of using the searchlight reflectors or building an arc image furnace. And you could do this indoors without using the solar at first. I feel we should consider this as an evolutionary process.

Hertzberg - I agree. Anytime one takes something up the tower he must be deadly serious about it. Without a lot of scale model experiments, he will find out he is doing scale-model experiments on a scale he can't afford. Aerospace engineers make good use of wind tunnel facilities. They spend thousands of hours before they get anything to fly. Your situation is similar. You don't have these subfacilities to start out the experiments properly. You can list a hundred experiments but only one or two of them are going to work and you will find that out in the lab before you commit yourself to a big production experiment.

Manasse - One of the things that brings to my mind is that there is some pretty obnoxious stuff you've got to play with. There are no provisions there for vacuums, and having windows and things of that sort. You are going to have a lot of trouble trying to get the sun into a vacuum chamber, I think. Also, I'm not going to play with cyanide.

Hertzberg - I'm sort of a newcomer to the field and inexperienced but I look at these facilities as something far more than hardware. I view them as sources of people who either have or soon will have a lot of talent in high-temperature technology. I may be able to develop, over the years, a small capability at my university, but in the meantime there are many questions that I think I can get answered faster if I get help from the facility here, aside from the fact that it has a big solar tower.

Fletcher - I would like to make effusion membranes out of materials that will withstand very high temperatures. Iridium has a melting temperature of about 2700 K, but it is said to not be a suitable material for use in oxidizing atmospheres; however, the oxides may become unstable at very high temperatures. How does iridium behave when it is quickly taken through temperatures where the oxides are stable? Can it be used at very high temperatures?

Margrave - That has been done; it goes through an island of instability.

Fletcher - That's good news. It is said that iridium can absorb large amounts of hydrogen at higher temperatures. Is iridium permeable to hydrogen in the temperature range of 2200-2600 K? If it is, that opens up very interesting possibilities for making hydrogen and oxygen from water in solar high-temperature facilities.

Margrave - I don't think that has been done.

Fletcher - We have also been able to make thoria membranes surprisingly easily. You use gas-mantle manufacturing techniques. To make a gas mantle, one impregnates a thorium compound, like thorium nitrate or peroxide, into a cloth of artificial silk or rayon. When the cloth is burned away, you get a pure thoria reproduction of the cloth. I would like to know how these things hold up in contact with water substance at 2200-2800 K. The melting point of thoria is of the order 3500 K, and I would like to consider using thoria for effusion on membranes.

I would also like to know if one can weld thoria membranes onto stronger thoria support structures. Can one use the image of the sun for welding a fairly large area of thoria membrane onto some physical structure such as a thoria support?

I would also like to know about ceramic sealing materials, and I'd like to know how these sealing materials may interact with other materials at high temperatures.

I would like to know how platinum group metals react with halogens, especially bromine, at high temperatures.

Tungsten and molybdenum have very high melting points, but they do not hold up in water atmospheres at those high temperatures. Can they be coated with thoria or zirconia or other ceramic materials? Will the films be self-healing?

Comment - That has been done by spraying materials with titanium, a single-phase material, at 2800°C. There is very little thermal expansion, and so far it is working fairly well.

Fletcher - I would like to know how they hold up at 2500 K. Could we use heat from the solar furnace for doing the plating process? Could we plate 1/2 m<sup>2</sup> of electro-etched tungsten or molybdenum screen, for example, with these materials? Would the film be self-healing if it were held at high temperatures?

Margrave - That's the first big experiment we've heard about that needs on the order of a square meter.

Fletcher - Finally, I am to some extent intimidated by the size of these facilities. I want the answers to a number of questions for the purpose of making decisions about the directions in which my work ought to go. I would like to explore the possibility that we can run parasite experiments alongside other larger experiments when these facilities are being used. When I was at NASA, we frequently did small parasitic experiments in the very large wind tunnels as other very large-scale work was being done.

Gutstein - How many hours will the refractory metal coatings survive?

Margrave - We have not tested it very long. I think that we have not spent large amounts of money testing refractory metals.

Gutstein - My understanding is that it has all been very unsuccessful. One must be very careful about protecting the refractory metals.

Comment - The trouble is they do not fail gracefully; all you need is one pin hole.

(Gutstein mentioned a National Academy of Sciences survey paper on the subject; also, discussions of the high-temperature characteristics of aircraft engine turbine blades, with a comment that they are now very good but there is still need for great additional improvement.

Moss - The next generation of Tokamaks will require limiters with a pulse power of 2 kW/cm<sup>2</sup>, pulse times of 1 second, with 300 seconds between pulses. Maximum surface temperatures will be about 2000°C, with a gradient of about 5000° per inch in the thickness direction, and with temperature rises of about 1500°C per second.

How do we simulate these conditions or test the materials? Possibly one could use the solar facility by rotating samples in the beam to simulate pulsing conditions.

Royere - It is very difficult to do research with those large facilities. They are good for large material studies, but for basic research with large samples and high temperatures, we should develop new concepts in the field of fuels and in the broad field of energy. Most people now think that the future of solar energy is in chemistry. Finally, you should think about how to prepare your reactions; and then from your basic small-scale experiments, you could develop them for large facilities. I think those are the questions to ask instead of trying to go back through the field of what we did for 30 years in France. Mr. Coutures gave you an interesting example. He has noticed that the devices he developed in the basic research laboratories for quenching materials are not as efficient as ones we have developed with the large facilities. We developed these procedures for processing materials and we can use them now for preparing materials for basic research. It is not a problem of the effectiveness of quenching. Except for the quantities, there are few cases where one sees those advantages. Normally a large facility is to develop a process; these facilities were built for testing scale boilers. They should be used for developing processes that came from basic research.

Question - It seems to me that these facilities might be used for titanium processing or melting; has anything been done on that?

Royere - We have melted some titanium-aluminum alloys. This requires very pure controlled atmospheres. We could do it with small (samples) but we never tried with large facilities. I think it is possible those processes are done very well with electron bombardment furnaces.

Comment - The best efficiency with beams is 50-60%. This is something that the Users Association should be interested in. It could be a competitive process.

Royere - The advantage of electron bombardment for processing titanium is the vacuum.

Comment - But there are transparent windows so one could have a vacuum; it doesn't have to be an on-line process.

Margrave - This requires the construction of a really good vacuum system, and by the time you do that you come close to duplicating the expense of electron bombardment--even if it is only 50% efficient.

Royere - It's not the same for metallurgy. In the case of high-temperature alloys which are processed in quantities around 1000 pounds, I think the solar furnace may be competitive. It is very easy to build a crucible out of refractory materials and one can use two hours of sun and during the rest of the day you mix other compounds, etc.

Chubb - What about iodide purification of titanium where the heat might come from the sun rather than a filament that will get heavy and alloy with the material?

Coutures - Professor Trombe's team in the Sixties worked on purification of metals.

Chubb - Were any of these adaptable for tonnage production?

Coutures - There is another case where solar furnace may be used for the purification of mercurious oxide materials. (Tape recorder temporarily stopped at this point.)

Skaggs - I want to talk briefly about an ore treatment experiment that Dr. Jean-Pierre Coutures and I performed at Odeillo last July. The idea was first proposed by Goldfarb and Beserra from Brazil while they were on a six-month visit to Odeillo. The objective is to separate the Mo metal as ore oxide from the silicate feldspars present as gangue minerals, see Figure 1. The apparatus is shown schematically in Figure 2. A water-cooled aluminum platen holds the sample in the focus of the 2-kW vertical-axis solar furnace. This is surrounded by a Pyrex globe which can be evacuated. An atmosphere of oxygen is introduced into the globe at the rate of 5 liters/min after evacuation is complete. The entire apparatus is on a trolley that rolls into and out of the focal zone of the furnace.

As soon as the focused energy strikes the powder on the platen, smoke evolves and coats the inside of the globe. Apparently it is mostly silica because the radiation intensity at the platen is not appreciably decreased. The ore contains a few percent molybdenum sulfide with the balance being feldspars. In the oxygen atmosphere, molybdenum trioxide vapor is formed from the sulfide and is transported out of the molten area of the sample. It condenses quite rapidly near the circumference of the sample in long, acicular, light yellow, platey, crystals. A gray smoke is transported by the flowing  $O_2$  through the exhaust tube into a cyclone separator. The residue that remains on the platen after melting appears to be a blob of glass.

We collected samples from several different locations as shown in Figure 3, and subjected them to analysis by x-ray diffraction, x-ray fluorescence, semiquantitative omission spectroscopy, and wet chemistry. A summary of the results is shown in Figure 4. From an ore that was 1% Mo (as  $MoS_2$ ), we were able to obtain  $MoO_3$  crystals which were almost pure  $MoO_3$  (66% Mo). The smoke collected from the inside of the globe is apparently very pure  $SiO_2$  and very fine crystallites, also. Smoke collected in the transfer pipe was enriched by a factor of 5 in Cr, Mu, Cu, and Pb. For some unexplained reason, we got an enrichment of 30 in the element boron. Residue from the circumference of the powder pile was enriched by a factor 5 in Mg and Ca. Some of the powder collected in the cup of the cyclone separator was very rich in molybdenum, indicating that  $MoO_3$  crystals were probably entrained in the gas stream and precipitated out by the centrifugal action of the separator. And finally, a few of the fairly volatile oxides were caught on the fine mesh stainless steel screen in the exhaust port of the cyclone separator.



We achieved excellent separation of Mo from Si in a single heating of the ore in a 10-g batch. We think that a second or several more passes of the material fractions may produce reagent-quality material. We want to try to separate ore on a larger scale and are planning a kilogram-size experiment for the near future in which we will try to do a mass balance. If that experiment is successful, then we would be ready to engineer an experiment for the STTF. For this we would need the help of metallurgical, mining, or chemical engineers.

A question was asked about the use of cover gases since Cl is indicated as one of the gases in Figure 2. As of now, we have only used argon, air, and oxygen, but we have discussed the use of hydrogen or halogen gases.

Another question asked was what the temperature of the melt was. We think initially that the temperature of the powder was greater than  $2000^{\circ}\text{C}$ , and after heating for a few minutes, it cooled to about  $1600^{\circ}\text{C}$ .

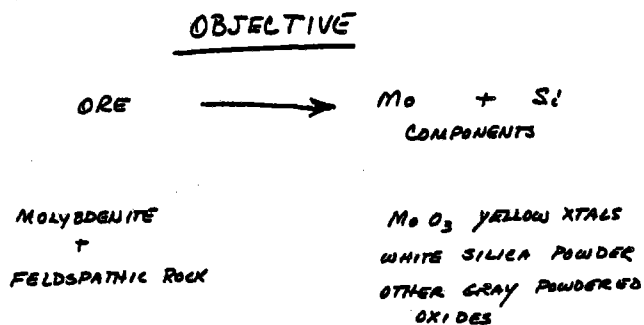


Figure 1

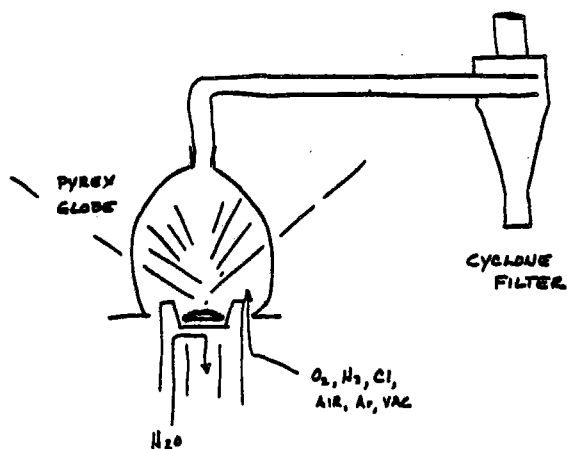


Figure 2

<u>SAMPLE</u>	<u>LOCATION</u>	<u>COMPOSITION</u>
YELLOW CRYSTALS	EDGE OF PILE OF POWDER	RELATIVELY PURE MoO <sub>3</sub>
WHITE POWDER	INSIDE OF GLOBE	AMORPHOUS SiO <sub>2</sub>
GRAY POWDER	TRANSFER TUBE	Si, Al, K, Na, Mg,
GRAY POWDER	FILTER	Ni, Cu, Sn, Pb
CYCLONE RECEIVER RESIDUE	CYCLONE CUP	Fe, Cr, Mn, Ni

Figure 3

<u>ENRICHMENT</u>
Mo: FROM ~ 1% IN ORE TO "PURE" MoO <sub>3</sub> (66%)
Mn, Cr, Cu, Pb, Mg, Ca: ENRICHMENT RATIO ≈ 5
BORON: ≈ 30
Al, Fe, Ni: ≈ 2
Nb, Zr: APPARENTLY FOLLOW THE Mo
EXCELLENT SEPARATION OF Mo AND Si.

Figure 4

Smith - Dr. Terry Cole, Ford Motor Company, Dearborn, Michigan, spoke on Thermo-electric Energy Conversion With The Sodium Heat Engine. An abstract of Dr. Cole's paper follows:

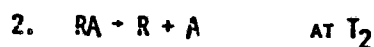
The Sodium Heat Engine (SHE) is a new device for direct thermoelectric energy conversion. It uses the ionically conducting ceramic  $\beta$ "-alumina, to form a high-temperature concentration cell for elemental sodium. The vapor pressure (activity) gradient across the cell is maintained by a high-temperature heat source on one side of a  $\beta$ "-alumina membrane and a low-temperature condenser on the other side. The high-temperature ( $T_2$ ) region operates in the range of 600-1000° with the low-temperature ( $T_1$ ) region at 100-200°C.

Theoretical analysis of the SHE shows that under quasi-reversible conditions the efficiency should be more than 90 percent of Carnot efficiency. For typical operating conditions of  $T_2 = 800^\circ\text{C}$ ,  $T_1 = 110^\circ\text{C}$ , a specific power output of 0.7 watt/cm<sup>2</sup> has been achieved in laboratory models of the device. If certain design criteria involving parasitic heat losses can be met, the SHE should achieve overall thermal efficiencies of 20-40 percent at a power output of 0.5-1.0 watt/cm<sup>3</sup>. These efficiencies are virtually independent of the size of the SHE. The SHE will accept heat from any source, including solar, has no moving parts, and is made from readily available materials.

Dr. Bowman discussed production of hydrogen:

1. Most hydrogen production studies consider a nuclear reactor as the heat source; solar heat has different characteristics and may be better.
2. One normally uses a two-step process (equations 1 and 2 on Figure 1): a reactant plus water to give an oxide plus  $H_2$ , and then thermal decomposition of the oxide at a higher temperature to give  $O_2$ .
3. To get good efficiency, one must approximate an ideal  $\Delta S$  which matches an ideal  $\Delta H$ .
4.  $FeO$  seems to match most closely: first a reaction of  $FeO$  with water to give iron oxide plus hydrogen, followed by a decomposition of  $Fe_3O_4$  to give iron and oxygen. This has been done at Odeillo.
5. Bowman suggests more study of these processes as related to the use of solar energy--not only the thermal chemistry, but the reaction rates. In some instances, the rates may be heat-transfer-limited; in others, there may be mechanistic limitations.
6. Equations 1 and 2, Figure 2, illustrate a two-step decomposition of sulfur and molybdenum oxides with water to give hydrogen and oxygen. Equations 3, 4 and 5, Figure 2, show conceptually another possible way of decomposing water into hydrogen and oxygen, using sulfur dioxide and barium sulfates.
7. If other alkali or earth metals are used in place of barium sulfate, there are many possibilities where a solar furnace might be uniquely useful. A great deal of data is needed before one could know whether these processes might be practical. Bowman suggests a demonstration of methods of getting solar energy into the chemical reactions.

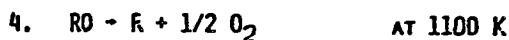
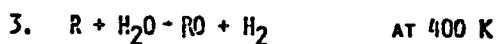
"IDEAL"  $\Delta S^0$  AND  $\Delta H^0$  VALUES



$$\text{"IDEAL" } \Delta S^0 = \frac{-\Delta G_F^0(AB)}{(T_2 - T_1)}$$

$$\text{"IDEAL" } \Delta H^0 = \Delta S^0 \times T_2$$

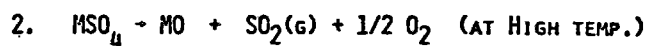
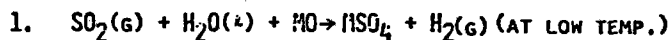
TWO-STEP DECOMPOSITION OF  $H_2O$



$$\Delta S^0 (B-4) = 320 \text{ J/K, } \Delta H^0 (B-4) = 350 \text{ kJ.}$$

Figure 1

OXIDE-SULFATE CYCLES



COMPLEX OXIDE-SULFATE CYCLES

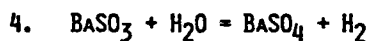
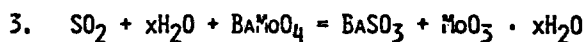


Figure 2

### Metallurgical Processing

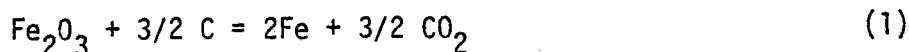
Cubiciotti - Our committee on metallurgical/mineralogical processing had several suggestions for experiments that should be considered, namely:

1. Carbothermic reduction of iron ore
2. Carbothermic reduction of alumina
3. Molybdenite ore processing
4. Remelting of refractory metals
5. Silica purification
6. Calcination of limestone
7. Thermal decomposition of metal halides

These are all energy-intensive processes that might be considered for high-temperature solar energy utilization. Brief descriptions of experiments to investigate the first and third of these have been promised by D. Cubicciotti R. Skaggs, respectively. The other suggestions were made more tentatively and their authors plan to consider them more carefully before pursuing them further. Bob Skaggs will talk about the work he has done on molybdenite ores and I will discuss the potential iron ore reduction experiment further.

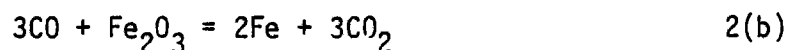
Iron ore reduction is a large industry that is very energy intensive.

About 20 percent of US coal consumption occurs in that industry and only high grade coking coal or petroleum coke can be used. More than 60 percent of the coke is consumed to provide heat for the process either for heat for the reduction reaction or for sensible heat and heat losses. If solar heat could provide that heat, a substantial savings in fossil fuel could be effected. In current practice, each ton of steel requires 800 pounds of coke, of which 330 pounds combine chemically with the oxygen of the ore in the reaction



That amount of coke cannot be supplanted by solar heat (unless direct decomposition is invoked--at temperatures like 3500K). The remainder of the coke (470 pounds per ton) is used to provide the heat of reaction (~28 kcal/mol of Fe) and maintain the temperature of the blast furnace, and could be replaced by solar heat.

The overall process of iron ore reduction can be separated into two parts in which CO acts as an intermediate, namely:



Step 2a is endothermic (about 31 kcal per mole of Fe) and absorbs all the heat needed for the overall reaction. Therefore if reaction 2a were carried out in a solar furnace, the hot CO produced would be capable of reducing iron ore with substantial savings in the coke needed.

Step 2b has been tested, at least on pilot plant scale, and the product is a metallized oxide containing about 90 percent metal which is suitable for charging into a steel-making furnace. Step 2b itself consists of a series of reactions in which the oxide is reduced stepwise from  $Fe_2O_3$  to  $Fe_3O_4$  to FeO and finally to Fe. Those reactions all proceed at about 1200 K so the overall reduction can be carried out at that temperature. Step 2a has also been well-studied and the rate can be evaluated from the literature.

The purpose of an experiment in a solar test facility would be to learn techniques for interfacing the solar heat source to such a process, to invent designs that might be adaptable to commercial use, to find out what problems might arise and perhaps lay a basis for estimating process costs for economic evaluation of the feasibility on commercial scales. The experiment will probably be fairly expensive. However, the experiments being designed and constructed for the main tower receiver are quite costly and technologically much simpler--namely, boiling water and heating air.

The reaction vessel would consist of two parts. In one part  $CO_2$  would be passed over C in reaction vessel which acts as a solar heat absorber. The hot CO produced would be conducted over iron oxide in a second reactor where it would be reduced in stages to Fe. If the solar absorber section could be made of a transparent window-like quartz, the solar energy could be absorbed by the C particles directly; however, keeping the window clean and cool would be a problem. Other container materials, such as metals or ceramics, may be better. An important consideration in the design of this kind of experiment is control of temperatures of components to prevent overheating in the large solar fluxes. Although we anticipate difficulties, it should be possible to design an experiment to test the application of solar heat to iron ore reduction.

Gutstein - It seems that the CO itself is a valuable product. Whether you want to go to iron oxide reduction or some other use might be a subsidiary consideration. The CO could be used with water or steam to get H<sub>2</sub>. Maybe the issue is not iron ore reduction, but what do you do with carbon and carbon dioxide. I am suggesting that you work on a problem of making CO.

Comment - We have been looking at some possibilities of CO<sub>2</sub> and I'm surprised that we haven't thought of using the very high temperature to shift it to CO. Burning the coal char in the CO is really neat. A simple aerodynamic nitrogen window (could be used). It doesn't have to be high pressure.

Comment - Many coal gasification schemes use the same idea. They mostly react coal with water to get CO and H<sub>2</sub>; how expensive it is I don't know.

Comment - The container could be steel, it doesn't have to be quartz. In quartz, the light comes through and heats the carbon itself, but steel may be more practical.

Gutstein - I am suggesting that the CO itself may be a valuable product. You may want to explore that for itself.

Cubicciotti - That is an excellent point; it simplifies this experiment and the CO may have many uses.

Question - To what temperature do you have to heat the carbon?

Answer - Any temperature above 1200 K for the iron ore reduction.

Cubicciotti - The aluminum concept is a little different, more complicated also. The direct reduction of aluminum with carbon is being tested by ALCOA under DOE funding. This is another endothermic reaction in which perhaps solar energy could be used to save fossil fuel which is otherwise used simply to heat things up. I thought perhaps one could brickette a mixture (of carbon and aluminum oxides) and drop it as particles through the solar flux. As they dropped through, if this heating is as rapid as it seems to be, one might collect at the bottom a significant amount of material. The problem here is that these will probably explode because of the sudden generation of CO gas. It might otherwise be possible to use a crucible in which the C and Al<sub>2</sub>O<sub>3</sub> were contained.



One must have 2300 K for this reaction. There may be a deposition of the aluminum metal on the window. But one might be able to do some sort of gas sweeping if that happens. It may get hot and vaporize off.

Comment - The aluminum deposits on the window and it becomes a mirror. That is a problem. We may have to consider seriously a gas shielding of these windows but that requires a very little power.

Cubicciotti - The gas could be CO in this case, a comparatively cheap gas.

Gutstein - Does this reaction develop CO?

Cubicciotti - It generates CO. In this reaction you are working at such high temperatures that you have CO rather than CO<sub>2</sub>.

Hastie - I thought that there were chemical problems associated with this process that were tried long ago. One was high-temperature production of volatile aluminum suboxides.

Answer - Yes. The possibility of formation of volatile gasses, Al<sub>2</sub>O, does exist. Perhaps one can invent geometries to avoid that. I am just suggesting some concepts which are commercially interesting, but how to interface them and what the problems are is another matter.

Question - Do you have to start with pure aluminum or with ores containing other impurities?

Cubicciotti - The important ores, of course, contain silicon. Silicon impurity in aluminum is not good; it degrades many metallurgical properties.

Smith - Do you envision any possibly not-too-complicated experiments that might actually be run on the solar facilities in the near term?

Cubicciotti - This is why I brought this up. Simple heating of coal, or coal char, to form CO looks feasible, but the problem of how one handles this megawatt heat must be considered--whether one can put in enough CO<sub>2</sub> to cool it and other problems that may arise.

Hildebrandt - What typical halide reaction (did you mention)?

Cubicciotti - Thermal decomposition of halides is conceptually a way to make metals.

There is an iodide process for metals. I wasn't planning to discuss all of these but I'll tell you about this one. When one tries to purify zirconium he takes impure zirconium and heats it to about 300°C and runs a filament down the middle at about 1000°C. This is a closed system. You put in a few torr of iodine vapor. This forms zirconium tetraiodide gas. When the zirconium tetraiodide hits the 1000°C surface, it decomposes directly to zirconium and iodine and zirconium metal plates out. Chubb suggested we consider this sort of thing for a solar experiment. We could shine a light on the filament and get the surface hot enough to effect the reaction with even more recalcitrant halides than the iodides. Dr. Chubb said he would like to take that idea home and explore it on paper and see if there is an experiment that he might prepare.

Comment - That is identical to a process whereby they form boron filaments to produce the boron out of the tetrachloride to make very strong wires.

Cubicciotti - Limestone calcination is a high-energy, large-industry process. There might be ways of utilizing solar energy in local facilities for calcining limestone.

The possibility of titanium remelting is one of Chubb's suggestions.

The remelting of refractory metals to form ingots is an energy-intensive processes. Normally, sponge titanium is electron-beam or arc-melted into ingots. One takes a sponge ingot and a copper, water-cooled ladle or crucible, strikes an arc between the two, and it gets hot enough to melt and forms an ingot of molten material. There is a lot of energy that goes into that process. So, Chubb suggested, shine sunlight on the sponge in an inert atmosphere, and melt it into ingots.

Comment - I think you really want a vacuum.

Cubicciotti - OK. Normally, the electron beam requires a vacuum.

Gutstein - I think you have a problem with the window. In that case, it will act as a condenser.

I. Metals and Metallurgy - D. C. Cubicciotti, Chairman

1.  $\text{Fe}_2\text{O}_3$  Carbothermic ( $1200^\circ\text{K}$ ) - Cubicciotti
2.  $\text{Al}_2\text{O}_3 + \text{C}$  ( $2300^\circ\text{K}$ ) - Cubicciotti
3. Molybdenite Ore Processing - Skaggs
4. Melting Refractory Metals, Titanium Sponge - Chubb
5. Silica Purification - Walton
6. Lime from Limestone, i.e., Cement Processing - Cater
7. Thermal Disassociation of Halides - Chubb

Following is brief discussion of previous items:

1. Carbothermic reduction of iron ore,  $\text{Fe}_2\text{O}_3$  at  $1200^\circ\text{K}$ , is a process which has been done for thousands of years--currently in large quantities--which uses much energy and much carbon. It would be interesting to learn whether solar energy could be used. Dr. Cubicciotti will be willing to consider a proposal for this kind of experiment.
2. Carbothermic reduction of aluminum requires considerably higher temperature ( $2300^\circ\text{K}$ ). Design of experiments is not trivial and one may or may not come up with experiments which are worth doing. Dr. Cubicciotti will agree to put in a proposal along those lines also.
3. Molybdenite ore processing--Bob Skaggs has done work in Odeillo on this.

The following experiments are less well-in-hand, but might be considered:

4. Melting of refractory metals--particularly titanium sponge (Dr. Chubb). It is an energy-intensive process, the price of titanium is very high and is largely energy costs.
5. Silica purification--J. D. Walton. In heating silica, Mr. Walton finds it becomes purified by a vaporization of the impurities. The purified silica has applications for optical fibers. Bell Labs is considering these seriously for

information transmission devices. It may have other uses; for example, manufacture of semiconductor-grade silicon.

6. Manufacture of lime from limestone (e.g., as in cement processing) is a very energy-intensive process. Would also include the processing of other kinds of minerals. Might make sense to build a solar tower where the minerals are.
7. Thermal disassociation of halides--Chubb

The first three above will probably result in proposal of experiments for the STTFs. It was not clear whether J. D. Walton would prepare a proposal on No. 5 at this time, and the other three (4, 6, 7) are possibilities.

## II. Materials and Beams - P. W. Gilles, Chairman

This group considered property measurements of (a) beams and (b) materials. Also considered the solar furnace as a source of light as well as heat, with an absence of electromagnetic fields, and with homogeneous temperatures over large areas.

### Beams

Properties of the beam of interest to scientists include characteristics of the flux as a function of a) distance from the target, b) radiation wavelength, and c) angle of incidence. Also, interest in the position and flux level at center of the beam as a function of time both over a period of several minutes and over a much shorter time scale, i.e., how rapidly can we change flux levels? How fast can radiation be turned off? Also interested in temperature and minimum size of the high-temperature area. Large size of the beam may provide a good homogeneous temperature over a reasonably good-sized area.

### Materials

Many measurements are uniquely possible with the solar furnace. The ones that can best be done with the solar furnaces include:

1. Study of phase diagrams of materials at temperatures greater than  $2000^{\circ}\text{K}$  in controlled atmospheres.
2. Vaporization properties at temperatures greater than  $2000^{\circ}\text{K}$  in controlled atmospheres--especially oxidizing atmospheres.

Other measurements that might be made (but which might perhaps be better made with other facilities such as CO lasers or electrical resistive heaters), include x-ray diffraction to get structures, transition temperatures, lattice parameters, segregation phenomena, diffusivity and emissivity measurements, thermodiffusivity measurements, heat capacity and enthalpy.

Materials that might be uniquely studied by solar furnaces include oxides, perhaps refractory metals, sulfides, and perhaps surfaces. Solar furnaces may also be useful for heating large parts of high-temperature machinery or apparatus, e.g., from parts of nuclear reactors or parts of fission reactors. Effective emissivity depends upon character of the surface. To get meaningful temperature one must measure emissivities and reflectivities of the sample in situ. Gilles urged that efforts be made to make such measurements. As temperatures become higher and higher, above  $2500\text{-}3000^{\circ}\text{K}$ , solar furnaces look better and better.

### III. Synthetic Fuels - J. Margrave, Chairman

- A.  $H_2$ 
  - 1. Thermal disassociation equilibrium  $H_2/O_2$
  - 2. Thermal chemistry
  - 3. High-temperature electrolysis
  - 4. Photo-assisted high-temperature elec
- B. Other Fuels, Methanol  $CH_3OH$
- C. NO (not a fuel) - Hertzberger's idea
- D. Materials
  - 1. Refractory metals and oxides
  - 2. Membranes
- E. High-Temperature Support Data for Systems of Interest (e.g., storage system)

#### Hydrogen

Most discussions were about hydrogen.

- 1. Thermal disassociation equilibrium of water
- 2. Thermal chemistry--including hydrogen bromide and iron oxide--ones that have been widely studied
- 3. High-temperature electrolysis was also considered--at  $1500^{\circ}K$  or higher, the free energy relationships are very attractive for high-temperature electrolysis of water, and even better, photo-assisted high-temperature electrolysis of water.

Outside the solar field, many investigators are active in these investigations; it might be profitable if their efforts could be associated with solar energy.

#### Methanol

Production of methanol also discussed pyrolysis of biomass to produce methanol

Production of NO (Hertzberg)--preheating of a membrane latticework of zirconium dioxide through which nitrogen-oxygen mixtures are passed at  $2000^{\circ}K$ , followed by compression to produce temperatures of the order of  $3000^{\circ}K$ , from which one can recover nitric oxide. The general view was that this experiment could be done on the tower relatively quickly. The zirconium dioxide preheat and compressed air experiments could show whether production and recovery of NO is feasible.

Properties of Materials--1) refractory metals and oxides, and 2) membrane materials for use in high-temperature fuel cells or other devices. For example, Professor Fletcher is interested in thorium dioxide and membrane-type systems or catalytic surfaces.

High-Temperature Support Data for related systems of interest, e.g., storage systems. The thermal dynamics of basic materials may not be well enough established to allow the necessary calculations.

Alternative Way to Make H<sub>2</sub> is a water gas reaction, e.g., alternative method of producing acetylene. But acetylene is no better than hydrogen, so we discussed hydrogen mostly.

Royere - When I return to France I will compile all our papers for about 30 years on these topics and will send them to the UA if they will make them available to members who are interested.

Question - May I ask if a lot of this we are talking about has already been done?

Answer - That is not exactly what I want to say. The only thing I would like to say is that I know it is very difficult to look at papers but I would like some of you to know the subjects which have been studied to prevent (work from being repeated).

Question - So, would you circulate a list of titles?

Smith - Yes, we will probably circulate a list of titles and if you want specific ones I think we can reproduce them, unless it gets out of hand. We will find some way of handling it.

Hertzberg - Why don't I send you a list of my papers and you can send that out. I would like to extend the suggestion to the whole meeting that we use your services as a clearing house if you would make up a list of titles of papers in the area and send them out.

Smith - I think that is a good suggestion and we will do it.

## Summary

Charles J. Bishop, SERI

The intent of the summary session was to 1) identify additional facility needs which would make experimentation feasible or easier to perform, and 2) document potential experiments which might be proposed for the STTFs in the near term.

Facility Additions

With regard to desirable additions/modifications, the following items were identified by the group:

1. Direct Visual Observation - It was felt that an ability to approach within 2-3 meters of the experimental area was necessary to observe the reactions occurring in the test facility. The use of a television system was not considered adequate for the monitoring which would be required.
2. Controlled Environment - There is a need to maintain a controlled environment within the experimental area. Typical environments include vacuums on the order of  $10^{-6}$  torr to pressures of 10-15 atmospheres using such gases as hydrogen, argon, oxygen, nitrogen and halides.
3. Windows - The requirement for controlled environments generated a discussion of the need for a practical window for solar receivers to enclose the reactor chamber and maintain the required environmental conditions. The design and fabrication of a cooled window, capable of withstanding the solar insolation, is required.
4. Cooling - The ability to utilize low temperatures (i.e., liquid nitrogen) was also identified as a required capability.
5. Small Facilities - Considerable discussion was directed at the availability and desirability of small test facilities, which are capable of generating beam spots on the order of a few square centimeters, rather than the meter-sized beams of the Sandia facility. It was requested that someone generate and publicize a list of available small facilities of this type. Their usefulness as precursors to using the larger STTFs was identified by several group members.

It was also suggested that several of the small test facilities be made available to experimenters, either as supplemental facilities to the STTFs or as facilities which could reside at the institution performing the experiments. Although the pros



and cons of each alternative were discussed, no concensus was reached as to which is most desirable. This matter should be considered for future resolution.

### Potential Experiments

Three major experimental areas emerged as a result of group discussions: metallurgy, properties of materials, and fuels.

A total of seven experiments were identified in these areas as being of interest to various group members and of relevance to the goals and objectives of the STTFUA.

Two specific metallurgical experiments were identified in metallurgy. Dr. S. R. Skaggs, Los Alamos Scientific Labs, is interested in a continuation of the studies of molybdenum ore reduction, first initiated in the summer of 1977 at the Odeillo facility. Larger sample sizes are envisioned for the proposed experiment. A January 1978 proposal submittal date was suggested.

The second metallurgical-type experiment involves the reduction of  $\text{Fe}_2\text{O}_3$  to  $\text{Al}_2\text{O}_3$  to the metallic state. Dr. D. C. Cubicciotti, SRI International, proposed submitting a request to pursue such studies, again in the January 1978 time frame.

The second category of experiments involve the studies of material properties. In this category experiments involving studies of the mechanical properties of surfaces were identified as being of interest to Dr. D. Avery, Brown University. No specific date was identified for proposal submittal. It was also suggested that Dr. M. Moss, Sandia Laboratories, would be interested in studying materials for fusion systems.

The third category of interest is fuels production. Within this area, three proposals were identified. Dr. A. Hertzberg, University of Washington, suggested studies of NO fixation. Dr. E. A. Fletcher, University of Minnesota, indicated an interest in pursuing studies on membranes which would relate to high-temperature production of hydrogen. Dr. Hildebrandt, University of Houston, suggested a study of the reaction:  $\text{C} + \text{CO}_2 \rightarrow 2\text{CO}$ , with a proposal submitted in the January 1978 time frame.

Smith - I think we have had a very good workshop and would like to thank, on behalf of DOE, SERI and the Users Association, all of you who have contributed so capably and enthusiastically.

I am greatly impressed with the many possibilities for practical and economical use of solar energy which I have heard discussed in this meeting. At the same time, I realize that there is a tremendous amount of work that must be done between now and that time in the future when some of these processes become economically feasible. I hope that, starting now, we can begin to define in workable detail the kinds of experiments we need to undertake to provide the needed data and answer the questions that must be answered. Perhaps two or three years from now you will be able to say that you helped start something really productive and worthwhile at this meeting.

Agenda for  
High-Temperature Sciences/Facility Operators Workshops  
Albuquerque, NM, Airport Marina Hotel  
November 28-29, 1977

Monday, November 28

7:30	Registration - First Floor, Outside Main Ballroom
8:30	Session I Chairman - A. F. Hildebrandt, University of Houston
8:45	DOE Objectives for STTFs and UA - M. U. Gutstein, DOE
9:00	SERI Objectives for STTFs and UA - C. J. Bishop, SERI
9:15	STTF Funding and Procedures for Proposal Submission and Review - F. B. Smith, UA
9:30	STTF Descriptions - 5-MW Sandia STTF - J. T. Holmes
9:45	- 400-kW Georgia Tech - C. T. Brown
10:00	Coffee Break
10:15	STTF Descriptions - 30-kW White Sands - Richard Hays
10:30	- 1000-kW Odeillo - Claude Royere
10:45	High-Temperature Research and Possible Uses of STTFs - J. J. Margrave, Rice University
11:30	Discussion
12:00	Lunch - Speaker: A. F. Hildebrandt - History of Central Solar Electric Power Generation & Role of UA
1:30	Tour of Sandia Laboratories STTF
	Session II Chairman - J. J. Margrave, Rice University
3:30	Panel Discussion on Use of STTFs in High-Temperature Research - Chairman, J. J. Margrave; Panel Members: J. P. Coutures, L. Eyring, J. W. Hastie, G. Rosenblatt and R. J. Thorn
5:30	Adjourn
6:00	No Host Happy Hour - Main Ballroom
7:00	Dinner - Speaker: P. W. Gilles, University of Kansas - Solar High-Temperature Research
8:30	Subgroup Discussions as Needed
10:00	Adjourn

Tuesday, November 29

---

7:30 Breakfast - Continuation of Subgroup Discussions

---

Continuation of Session II  
Chairman - J. J. Margrave

---

9:00 Results of Subgroup Discussions

---

9:45 Coffee Break

---

10:00 Abraham Hertzberg, University of Washington - High-Temperature  
Solar Machines

---

11:00 Other Speakers to be Announced

---

12:00 Lunch - Speaker: J. C. Grosskreutz, SERI - Q&A on SERI Plans and  
Activities

---

Session III  
Chairman - C. J. Bishop, SERI

1:30 Finalization of Results:

List of Possible Experiments and Experimenters

When Experiments Could Be Ready

Development of Proposals

Scheduling

Funding

Suggested Modifications to Facilities

---

3:00 Summary - Where Do We Go From Here - F. B. Smith

---

4:00 Adjourn

---

Facility Operators Meeting has been rescheduled for Wednesday,  
November 30

4:15 Brief meeting for Facility Operators to plan agenda for their meeting  
of Wednesday

---

Attendees  
 Facility Operators/High-Temperature Sciences Workshops  
 Solar Thermal Test Facilities Users Association  
 Albuquerque, New Mexico  
 November 28-30, 1977

Department of Energy

Mr. M. U. Gutstein  
 Division of Solar Energy  
 DOE  
 600 E Street, NW  
 Washington, DC 20545  
 Phone: (202) 376-1937  
 FTS: 376-1937

Solar Energy Research Institute

Dr. C. J. Bishop  
 SERI  
 1536 Cole Blvd.  
 Denver West Office Park, Bldg. No. 4  
 Golden, CO 80401  
 Phone: (303) 234-7121

Dr. J. C. Grosskreutz  
 SERI  
 1536 Cole Blvd.  
 Denver West Office Park, Bldg. No. 4  
 Golden, CO 80401  
 Phone: (303) 234-7314

Dr. B. F. Butler  
 SERI  
 Same as above  
 Phone: (303) 234-

Dr. T. Milne  
 SERI  
 Same as above  
 Phone: (303) 234-7325

STTF Users Association

Dr. A. F. Hildebrandt  
 Solar Energy Laboratory  
 University of Houston  
 Houston, TX 77004  
 Phone: (713) 749-4861

Dr. Fred K. Manasse  
 Professor of Engineering  
 University of New Hampshire  
 Kingsbury Hall--247  
 Durham, NH 03824  
 Phone: (603) 862-1779

Mr. F. B. Smith  
 STTF Users Association  
 Users Association  
 Suite 1507  
 First National Bank Bldg. East  
 Albuquerque, NM 87108  
 Phone: (505) 268-3994

Mr. J. D. Walton  
 Engineering Experiment Station  
 Georgia Institute of Technology  
 Atlanta, GA 30332  
 Phone: (404) 894-3661

Dr. Terry Cole  
 Manager, Chemical Engineering  
 Scientific Research Staff  
 Ford Motor Company  
 PO Box 2053  
 Dearborn, MI 48121  
 Phone: (313) 323-2968

Ms. Marylee Adams  
 Project Administrator  
 STTF Users Association  
 Suite 1507  
 First National Bank Bldg. East  
 Albuquerque, NM 87108  
 Phone: (505) 268-3994

Mr. John Gintz  
 Boeing Engineering & Construction  
 Mail Stop 8K-20  
 PO Box 3707  
 Seattle, WA 98124  
 Phone: (206) 773-8211  
 FTS: 438-8211

Facility Operators

Mr. Glen Brandvold, Manager  
Solar Energy Projects Department  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-6866  
FTS: 475-6866

Mr. J. R. Doyle  
Division 3442  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-8128  
FTS: 475-6866

Mr. J. T. Holmes  
Division 5713  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-6061  
FTS: 475-6061

Mr. N. R. Keltner  
Division 9337  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-9180  
FTS: 475-9180

Dr. B. W. Marshall  
Division 5713  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-2280  
FTS: 264-2280

Mr. L. K. Matthews  
Division 5713  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-6061  
FTS: 475-6061

Mr. J. V. Otts  
Division 5713  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-2280  
FTS: 475-2280

Mr. J. H. Scott, Director  
Energy Projects & Systems Analysis  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-8031  
FTS: 475-8031

Mr. L. O. Seamons  
Division 5713  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-4141  
FTS: 475-4141

Mr. L. L. Young  
Division 3442  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-3876  
FTS: 475-3876

Dr. C. Thomas Brown  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, GA 30332  
Phone: (404) 894-3654

Mr. Armando De La Paz  
White Sands Solar Facility  
Attn: ARMTE-AN  
White Sands, NM 88002  
Phone: (915) 678-  
FTS: 898-

Mr. Darin Farwell  
White Sands Solar Facility  
Attn: ARMTE-AN  
White Sands, NM 88002  
Phone: (915) 678-  
FTS: 898-

Mr. Marcel Fritz  
White Sands Solar Facility  
Attn: ARMTE-AN  
White Sands, NM 88002  
Phone: (915) 678-  
FTS: 898-

Mr. Richard Hays  
White Sands Solar Facility  
Attn: ARMTE-AN  
White Sands, NM 88002  
Phone: (915) 678-1161  
FTS: 898-1161

Dr. Claude Etievant  
E.D.F.-C.N.R.S., Projet THEM  
6 Quai Watier  
78400, Chatou, France  
Phone: 988-02-44, Ext. 7510

Professor Giovanni Francia  
Centro Studi di Matematica e  
Meccanica Applicata  
Genova, Italy  
Phone:

Mr. Claude Royere  
CNRS, Solar Energy Laboratory  
BP No. 5, Odeillo, 66120  
Font-Romeu, France  
Phone: 33-68-10-24

Dott. Ing. Gino Beer, Vice Direttore  
Ansaldo  
Societa Generale Elettromeccanica SPA  
Via N. Lorenzi, 8  
16152 GE-Cornigliano, Italy  
Phone:

High-Temperature Scientists

Dr. Robert Behrens  
MS-348  
Los Alamos Scientific Laboratory  
PO Box 1663  
Los Alamos, NM 87545  
Phone: (505) 667-7437  
FTS: 843-7437

Dr. Talbot A. Chubb  
Code 7120  
Naval Research Laboratory  
Washington, DC 20375  
Phone: (202) 767-3580

Dr. Melvin Bowman  
MS-756  
Los Alamos Scientific Laboratory  
PO Box 1663  
Los Alamos, NM 87545  
Phone: (505) 667-6014  
FTS: 843-6014

Dr. Jean-Pierre Coutures  
CNRS, Laboratoire des Ultra-  
Refractaires  
BP No. 5, Odeillo, 66120  
Font-Romeu, France  
Phone: 33-68-10-24

Mr. Arthur Bridgeforth  
Mail Stop 198-220  
Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 91103  
Phone: (213) 354-  
FTS: 792-

Dr. Daniel C. Cubicciotti  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025  
Phone: (415) 326-6200, Ext. 3940

Dr. E. David Cater  
Department of Chemistry  
University of Iowa  
Iowa City, IA 52242  
Phone: (319) 353-4580

Dr. Leroy Eyring  
Department of Chemistry  
Arizona State University  
Tempe, AZ 85281  
Phone: (602) 965-7087

Dr. Kenneth E. Cox  
Los Alamos Scientific Laboratory  
PO Box 1663  
Los Alamos, NM 87545  
Phone: (505) 667-7059  
FTS: 843-7059

Dr. Edward A. Fletcher  
Department of Mechanical Engineering  
Room 465  
University of Minnesota  
111 Church Street, SE  
Minneapolis, MN 55455  
Phone: (612) 373-4525

Dr. Paul W. Gilles  
Department of Chemistry  
University of Kansas  
Lawrence, KS 66044  
Phone: (913) 864-3829

Dr. John W. Hastie  
National Bureau of Standards  
US Department of Commerce  
Washington, DC 20234  
Phone: (301) 921-2859  
FTS: 921-2859

Dr. Abraham Hertzberg  
Director of Aerospace & Energetics  
Research Laboratory  
FL-10  
University of Washington  
Seattle, WA 98195  
Phone: (206) 543-6321

Dr. Jack Kay, Head  
Department of Chemistry  
Drexel University  
Philadelphia, PA 19104  
Phone: (215) 895-2638 or 2639

Dr. John Margrave  
Advanced Studies and Research  
Rice University  
Houston, TX 77001  
Phone: (713) 527-8101, Ext. 4820

Dr. Marvin Moss  
Division 5842  
Sandia Laboratories  
Albuquerque, NM 87115  
Phone: (505) 264-7934  
FTS: 475-7934

Dr. Gerd Rosenblatt  
Department of Chemistry  
Pennsylvania State University  
University Park, PA 16802  
Phone: (814) 865-7242

Mr. Darrell Ross  
MS 198-220  
Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 91103  
Phone: (213) 354-4049  
FTS: 792-4049

Dr. Robert Skaggs  
MS 3418  
Los Alamos Scientific Laboratory  
PO Box 1663  
Los Alamos, NM 87545  
Phone: (505) 667-6074  
FTS: 843-6074

Dr. Robert J. Thorn  
Chemistry Division  
Argonne National Laboratory  
9700 South Cass Avenue  
Argonne, IL 60439  
Phone: (312) 739-2657 or 2649  
FTS: 388-2657 or 2649

Department of Energy/Albuquerque Operations Office

Mr. George W. Rhodes  
Senior Program Coordinator  
Special Programs Division  
DOE/ALO  
Albuquerque, NM 87115  
Phone: (505) 264-8257  
FTS: 475-8257