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EVALUATION OF SOLAR COOKERS

VITA REPORT NO. 10

PRELIMINARY DRAFT REPORT

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Dr. Edith B. Fehr

Dr. William Glenn

Dr. William Hillig

Mr. Walter Goodwin

Professor W. C. Aubrey

In addition the following people gave generously of their time to consult with us

Mrs. Mary D. Bliss, Solar Energy Laboratory, University of of Arizona

Dr. R. W. Bliss, Solar Energy Laboratory, University of Arizona

Dr. J. A. Duffie, Director, Solar Energy Laboratory, University of Wisconsin

Dr. G. O. G. Lof, President, Umbroiler Company, Denver, Colorado

Dr. Milton D. Lowenstein, Technical Director, Association for Applied Solar Energy, Tempe, Arizona

Mr. R. Thew, Garrett Thew Studios, Westport, Connecticut

Mr. John I. Yellott, President, Yellott Engineering Associates, Phoenix, Arizona

FOREWORD

This working draft report presents results of tests that were performed on various solar cookers to determine their potential usefulness in countries which are served by the Agency for International Development. Points that were evaluated include cooking performance and efficiency, durability, cost, shipping weight, portability, ease of operation, ease of manufacture in the countries that are involved, and adaptability to local techniques and dietary mores. Of all models that were available to us for testing, a Fresnel-type cooker that was developed by VITA showed the greatest promise, due particularly to its efficiency, low cost and ease of construction with universally available tools and materials.

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1.0 INTRODUCTION

The study reported here, undertaken by Volunteers for International Technical Assistance (VITA) for the United States Department of Commerce, Office of Technical Services, was to test various solar cookers for their potential usefulness in countries served by the International Cooperation Administration. Specific points to be evaluated were performance and efficiency in cooking, durability, cost, shipping weight, portability, ease of operation, ease of manufacture in the countries involved and adaptability to local cooking techniques and dietary mores. Information was collected on satisfactory designs to adapt manufacturing methods and materials to the technology of the countries involved. VITA also contracted to submit suggestions for the improvement of existing models if no fully satisfactory design could be found.

An evaluation of cooking performance requires actual food preparation and is necessarily a subjective criterion. The efficiency of the cooker and the heat output to the cooking pot were measured in ways chosen to eliminate the effect of the cooking pot itself on performance. The experimental technique used was to measure the heat output when the pot was at ambient temperature. In winter, this was accomplished by observing the time to melt a known quantity of snow. In warm weather, a flow calorimeter was used; i. e., the temperature rise of water flowing through the cooking vessel at a known rate was measured. Durability was estimated from a knowledge of the materials and designs used although, in some cases, field test data were available. Costs were based either on published analyses by the various manufacturers, or on purchase prices, or on estimates. The shipping weight was defined as the weight of a single, finished item plus whatever packaging material was required for safe

shipment to VITA. In the case of multiple shipments, the unit weight might be substantially reduced. Portability and ease of use again required somewhat subjective evaluations. Although a reasonable estimate can be made regarding adaptability to local manufacture and adaptability to local cooking techniques and mores, a final appraisal depends on actual field experience.

In the study to date, models of six commercially available cookers were purchased and three othere were built from descriptions in the literature. Two original VITA designs were also built and tested. In addition, such information is included as is available for those designs which have come to VITA's attention, but which were not included in the present test program because of lack of availability or other difficulties in obtaining test models.

2.0 DESCRIPTION OF COOKERS

The solar cookers described in this report are either the direct or indirect type, corresponding roughly to surface burners and ovens in modern kitchen stoves. The direct type permits frying, broiling and boiling to be done. The relatively large heat requirement is provided by intercepting a large amount of sunlight by a reflecting solar concentrator and focusing this onto the cooking vessel as illustrated in Fig. 1. These concentrators may be either rigid or collapsible. The direct cookers utilize direct sunshine only, and hence are relatively sensitive to short term variations in solar intensity due to cloud movement and haze. Refocusing is required at 15 to 30 minute intervals.

In the indirect type, shown in Fig. 2, a smaller amount of heat is directed into a thermally insulated box containing the cooking vessel. The indirect type is adaptable to slower cooking techniques and it is sufficient to use simple, flat reflectors to provide the necessary heat. Because these cookers utilize scattered as well as direct sunlight, and by virtue of their insulation as well as their solar capacity, they are less sensitive to variations in solar intensity and to shifts in the sun's position.

The performance of both types is influenced by ambient conditions. In addition, cooking performance depends on such design factors as the total heat available for cooking, distribution of the heat over the cooking surface, the ability of the cooker to compensate for the apparent motion of the sun, and the nature of the cooking vessels used.

For purposes of this report, the cookers are divided into three groups: (1) direct cooking types with rigid reflectors, (2) direct cooking types with

collapsible reflectors, and (3) indirect cooking types with either rigid or collapsible reflectors. Comparative data on the cookers described will be found in Section 3.0, Table 1. Most of the descriptions that follow are based on tests carried out by VITA. The descriptions marked with an asterisk (*) are of those models which, for various reasons, VITA did not test independently.

2.1 RIGID REFLECTOR TYPES

Most rigid focusing reflectors devised for solar cookers are more or less saucer-shaped. Such spheroidal or paraboloidal reflectors are commonly used in automobile headlamps. In addition, other designs of rigid reflectors are possible. Rigid reflectors can be made to close tolerances and, with ingenuity, can be constructed cheaply. However, the rigidity and frequently the weight work against convenient portability of the finished product.

2.1.1 Wisconsin Cooker*

Probably the best known direct cooker, and the one which is the standard against which all other cookers must be compared, is the molded plastic reflector developed at the Solar Laboratory of the University of Wisconsin (1, 2). The most recent model uses a drape-formed, high-impact polystyrene shell of 48 inches diameter and 0.060 inch thickness, stiffened at the rim with a ring of 0.5 inch diameter, thin-wall aluminum tubing. The cooker, which has an effective area of about 11.5 square feet, delivers about 40 to 55 percent of incident beam radiation to a cooking vessel seven inches in diameter; e. g., maximum delivery rates of 400-500 watts at an incident beam total energy of 1.0 kilowatt on the unshaded reflector. A reflective lining of aluminized Mylar polyester film is applied to the shell. This polyester film is supplied with an adhesive coating applied to the aluminized side. The clear film forms a protective covering over the specular surface. The new-condition specular reflectivity of this material is in the range of 75-80 percent. However, the

reflective material cannot be expected to last more than two years with regular use. The metal parts of the cooker should have a lifetime of five to ten years with reasonable care. Although the lifetime of the reflective material is dependent upon the ambient conditions and the severity of usage, the chemical stability of the adhesive under field conditions is probably a significant factor. This is a troublesome aspect of plastic-coated reflectors, and may necessitate replacement of the aluminized plastic from time to time.

The units are light; the reflector weighs 5.2 pounds and the frame 15.6 pounds. The frame permits horizontal and vertical angular adjustment. Horizontal adjustment is provided by a rotating disc at the base. Solar altitude adjustment is provided by a locking device on a sector attached to the reflector. The grill is supported from each side for additional stability. The frame members are thin-wall steel tubing and 19-gauge sheet metal formed by stamping or spinning. The published (3) estimated individual cost for these cookers in lots of 10,000 and/1,000,000 is:

	10,000	1,000,000
Materials (including packaging)	$ 7.70	$6.33
Labor ($2.00 per hour) and overhead	7.00	.48
Freight, selling expenses, etc.		1.26
Return on investment	1.47	.59
Total	$16.17	$8.66

The latter total probably represents a lower limit on the cost of the unit.

These costs are based upon manufacture in a developed economy with subsequent transport to the country or area of ultimate usage.

A cooker used intermittently in the laboratory for several years gave the following performance. At an average beam radiation of 1.35 cal/ cm^2 / min (vertical sun corresponds to about 2.00 cal/ cm^2 / min), this cooker brought two pounds of water from 90° F to boiling in 13 minutes; four pounds took 28

minutes and eight pounds, 62 minutes. In independent tests (4) performed by the FAO in Rome, Italy, roughly 50 percent longer heating times were required under average local conditions.

Altogether, some 200 models of this cooker have been built as the designs evolved. Some 20 cookers of an earlier configuration were field-tested over a period of four years in northern Mexico. Anthropologists living in the village where the studies were made observed reactions to the cookers and also studied a variety of economic and cultural aspects of village life which affected the reactions of the people to the innovation. Frequent (usually daily) visits were made to families using the cookers, and the anthropologists helped them by providing techniques of use and making any necessary repairs.

In the winter of 1961, five cookers of the advanced type shown in Fig. 1 were given to families in villages of this region. All five were used constantly for cooking meals and heating water and irons. Four of them were used on almost all possible days and the fifth on about 75 percent of the possible days. The inherent limitations of the design were appreciated by the villages and it was accepted as a supplemental rather than a substitute cooking method.

The earlier types had essentially the same reflector, but the cooker stand was insufficiently rugged for long-term use. The cooker also had a tendency to blow over in a stiff wind. These defects were eliminated at a substantial increase in cost, but with a substantial increase in local acceptance.

2.1.2 Spun Aluminum Parabolic Reflector

The best commercially available cooker that VITA studied is produced by Garrett Thew Studios of Westport, Connecticut, and is shown in Fig. 3. The reflector is 89 centimeters in diameter and is made of spinning a sheet of

aluminum 1/32 inch thick against a paraboloidal form built up out of several layers of thick plywood. This requires the use of relatively heavy machinery, such as a heavy duty lathe. The edges are then rolled back to improve stiffness. A simple, inexpensive support of bent iron rods is used. This requires some blocking by stones or stakes driven into the ground, particularly when the sun is high. The wing nut which controls the reflector tilt is also difficult to use at high solar altitudes. The pot must be removed from its support for adjustment for either altitude or azimuth. The weight is moderate—about 3.5 kilograms for the complete assembly. However, the reflector area is only 0.64 square meters. A one square meter reflector would weigh about 5 kilograms. The retail price of the unit is $29.50; estimated small-lot manufacturing cost is approximately $20.

Heating performance measurements were made after six months of intermittent use. It delivered a measured 250 watts on a clear day, as determined by the flow calorimeter technique (Appendix B). This corresponds to 400 watts per square meter of reflector surface. A photograph of the focal spot, made at the same time, is shown in Fig. 4. It is not possible to make a comparison with the Wisconsin cooker since we were unable to procure a model of the latter cooker. New reflectors which have recently been received are noticeably more reflective and have a better defined focal spot. The inhomogeneity of the focal spot leads to local overheating and occasional cracking of ceramic pots and makes frying inconvenient. However, the cooker performs well in preparing small quantities (about 1 pint) of rice or stew. It heats one liter of water at a rate of 2° to 3° C. per minute and is quite suitable for pan-broiling individual portions of meat. For family-size cooking it would have to be scaled up to a surface area of at least a square meter. Such a construction would require even heavier machinery for construction.

2.1.3 Other Simple Metal or Plastic Reflectors

In a somewhat different approach, Stam (5) suggests using reflectors similar to the Wisconsin or the Thew reflectors. However, he proposes simplifying the design to its most primitive aspects. By placing the reflector shell over a depression in the ground, the stand for the cooker can be eliminated. The sun's rays are focused onto the pot by rocking the reflector-pot holder assembly. This scheme requires an assymetrically shaped reflector. It has not been tested experimentally.

A number of cookers described in the literature use strips of polished metal, riveted together, to form a more or less adequate approximation of a spherical parabola. One of these, developed in Burma (6), has been reproduced by us from blue prints obtained through the designer, Dr. Freddy Ba Hli. Reflectivity and mechanical rigidity of this reflector (Fig. 5) is poor and the focal spot is very large and diffused. It is impossible to center a pot properly and the heat is inadequate to bring 1 quart of water to boiling in spite of the large reflector size. This may be due in part to the lack of availability of truly specular sheet aluminum. Furthermore, the equipment is hard to stabilize on a windy day, although it is very heavy (13 kg.). Tests on this model have been abandoned in favor of more promising designs.

Other metal reflector designs are supposedly in commercial production in Japan (7-9) and India (10-12). These sources have been contacted, but in spite of considerable effort, VITA has been unable to obtain models or accurate design details of these cookers.

2.1.4 Fresnel-Type Reflector

Of the models actually tested by VITA to date, this cooker (Fig. 6) has given the best results. Because the design of this cooker is not yet available

in the literature, detailed directions for its construction are given later in Appendix E. The reflector uses only simple, curved surfaces and is constructed out of 1/8-inch Masonite to which aluminized Mylar has been cemented. By cutting a series of rings out of such a flat sheet of material, removing sectors, and rejoining, a series of nesting collars that focus light are formed. These collars are supported on a simple wooden frame. The design is simple enough to permit construction with the tools, skills, and materials (except for the aluminized Mylar) that are locally available throughout most of the world.

The reflector is 46 inches in diameter and has a focal length of 30 inches. On a clear day, it delivers in excess of 500 watts to a focal spot of about 6 inches in diameter. The focal spot is quite uniformly illuminated, as shown in Fig. 7. A square, black, aluminum pan (7x7x2 inches) with a fitted, sliding lid (Fig. 8), is obtained from the Piolyte Plastics Company, Salem, Mass., as part of their "Solar Chef" equipment, makes a very convenient cooking pot. Two tripod-type support stand designs have been used. In one, the reflector is supported on the ground at one point, and two legs, in the form of a U-shaped, bent iron rod bracket completed the support. This design, which is similar to that used in the Thew cooker, is relatively easy to orient, but is not as stable in the wind as the second design. In this, the reflector is supported at two places on the ground, and a single pivoting wooden leg supports the cooker at the desired angle. Although even this mounting of the reflector may not be adequate to hold it securely in very heavy wind, the wind resistance appears to be intrinsically less than in reflector cookers having one-piece construction. The pot holder consists of a rod to which a grill is attached which holds the pot at the proper focal distance, and which permits the pot to be held horizontally, independent of the reflector position.

In the empirical cooking tests, six portions (4 cups) of rice were prepared in 30 minutes and a small chicken was browned in an open pan and completed in a closed pan in 30 minutes total cooking time. No adjustment of the cooker was necessary during the cooking, although it was slightly defocused at the end of the cooking period. Large (6-inch) pancakes were prepared with very uniform browning in a small enamel frying pan with a black bottom. A simple type of bread (English muffin) was also quite successfully prepared using the black aluminum pan. Four muffins were baked at once, requiring about 20 minutes (10 minutes on each side). In general, cooking time and performance were comparable to that of a small surface burner on an electric range or a small electric frying pan or casserole.

In addition to the features already discussed, this cooker is sufficiently simple that if the necessary materials are available, anyone skilled in the use of simple hand tools, such as a hammer, a saw, and a screw-driver, cannot only construct it, but also repair it if and when necessary. Furthermore, it is believed that local construction of this cooker would facilitate its introduction into a developing area from a psychological and sociological point of view. Finally, the performance of the cooker is the equal of almost any cooker of comparable size, and there is reason to believe that its performance can be improved upon still more.

The most serious drawback of this cooker is that which plagues other designs as well—the deterioration of the aluminum reflecting surface of the cooker due to weathering. Even bulk aluminum loses its high reflectivity on exposure to the elements. On the other hand, this design allows convenient replacement of the reflective material whenever dictated by a loss in performance.

2.1.5 Fixed soil-Cement Spheroidal Reflectors

In one such reflector (13), a spheroidal depression in the ground is lined first with a mixture of soil and cement to stabilize the shape and then with aluminized plastic. The symmetrical depression is formed by swinging a pendulum, or blade, fastened to a wire which is secured at a fixed point above the ground on a tripod. After the rough shape is hollowed out, a shallow layer of a soil and cement mixture is placed in the depression, smoothed with the blade and wetted. When this has set, and after some further work on the surface. a reflective lining of aluminized Mylar pressure-sensitive tape is applied. The cooking pot support is built so that the pot follows the shift in the focal spot due to the daily motion of the sun.

The advantages of this cooker are its simplicity and ease of construction in the field and the large sizes possible. No reflector mounting is necessary, and the cooking pot support is simple to fabricate. The orientation can be fixed during construction so as to make the reflector usable during the desired time of day. The cost of material for the laboratory models, exclusive of the reflective lining, was less than a dollar.

The disadvantages of this cooker are its lack of mobility, which might result in physical damage due to weather conditions, and the limited period of time during which it can be used (estimated at 4 hours a day).

Stam (5) Fig. 8a suggests a variation of this design in which he proposes integrating a large reflector, capable of delivering 2000 watts or more, into the design of a desert home. Such a device constitutes the nucleus of a solar kitchen. Stam has worked out a whole system of cooking and utilizing the solar energy in such a design. The reflectors would be made out of adobe, or some

such material, and lined with a reflective material such as aluminum foil. Only a scale model has been constructed to date.

2.1.6 Lightweight molded aggregate reflectors

Reflector shells have been made of lightweight, concrete aggregates of sawdust and vermiculite, which are formed over molds and lined with aluminized plastic and plastic tape.

The most successful of this type of cooker (13) is a reflector 42 inches in diameter with a focal length of 18 inches, made of a vermiculite aggregate and reinforced with wire and a rim of thin-wall tubing. The total weight is about 50 pounds. The reflector mount is a wooden post in the ground, arranged to pivot about its axis. Holes are drilled through it to hold a rod from which hangs a pan-support basket. The top edge of the reflector leans against the post and its lower edge is supported at variable distances from the post on an arm secured to the post.

The advantages of this type of cooker are the simplicity of the mounting device and its component parts and the possibility of using locally available materials and labor for its construction. Major disadvantages are the weight of the reflector, which makes it cumbersome to handle, and the fact that the reflective lining is difficult to apply.

Another inexpensive method of fabricating this type of reflector has been suggested by J. R. Jenness (14). A convex, wire-reinforced, plaster, paraboloid die is first cast from a centrifugally formed, concave, paraboloid mold. The cost of this is stated to be $10. This figure presumably represents only the cost of materials in the United States. The surface of the die is coated with wax, then a layer of wood pulp, papier mache or laminated newspaper is spread over it. After a few layers are built up, they are pressed to

squeeze out excess liquid. The process is repeated until the compressed laminate is 1/8 to 1/4 inch thick. Then the rim of a wooden "wagon wheel", reinforcing framework is glued in place. Woven basketry is suggested as an alternative method of reinforcement. After removal from the die, strips of aluminum foil are pasted on the surface. Finally, a stiff hoop is clamped to the front surface. Jenness states that the process would require 6 to 8 hours of labor and a material cost of 25¢. He gives no test results and does not state whether any such reflectors were actually produced.

2.1.7 Lightweight Plastic Reflectors

A different fabrication technique has been developed by the Boeing Aircraft Company (12) primarily for space applications. The high cost of this reflector and the thinness of its coating make it unsuitable for our purposes. It was included in our study, however, because of its light weight and high rigidity and also because it provided an opportunity to test the cooking performance of a nearly perfect parabolic reflector.

We are indebted to K. G. Wood, manager of manufacturing engineering of Boeing's Seattle office, for making two reflectors available to VITA on a loan basis. The first of these had a diameter of 53.5 centimeters with a focal length of approximately 30 centimeters and a weight of 450 grams. A rough test of its efficiency made by the snow melting technique (Appendix 1), gave a value of 437 watts per square meter. The spun aluminum cooker (see Section 2.1.6), which served as the standard at the time of these tests, gave a value of 300 watts per square meter under identical conditions.

Navy searchlight mirrors serve as the blank for the reflector. A convex tool is first made from the original concave mirror using Simonize auto wax as the parting agent. The convex tool is then Simonized and rubbed to a high

gloss. A film of epoxy resin is spread on and the wet resin-coated tool is enclosed in a transparent vacuum bag and smoothed until it is uniformly covered with resin. After the resin has cured, a 2-mil fiberglass cloth is impregnated with epoxy and placed on the cured film. Aluminum honeycomb of .0005 inch web thickness is laid on this wet fiberglass cloth. Three-dimensional flexibility is achieved by slitting the honeycomb cell walls. The slitting operation is performed with the cell walls in a collapsed conditions. A second layer of impregnated fiberglass cloth is placed on top of the honeycomb to form a sandwich. A bag is placed over the assembly and a 3-psi effective pressure applied by partially evacuating the bag. The entire mirror assembly is then cured at 250° F The paraboloid is given a reflective first surface by applying a coat of aluminum in a vacuum chamber. A silicon-oxide coating is deposited on the aluminum to protect the reflective surface. Reflectivity of the coated surface is about 90 percent. The weight of the completed paraboloid is 0.2 to 0.4 pounds per square foot. Maximum efficiency of energy collection as measured with a flow colorimeter is 72 percent.

The main disadvantage of these reflectors is their high cost and the very advanced technology required for their manufacture. Unit costs have been estimated at $18 for a collector of 36 inch diameter in lots of 1000. This includes 1-1/2 hours of labor and overhead at $8.25 per hour.

In addition to the above, the Goodyear Tire & Rubber Company (16) has introduced the technique of making rigid reflectors out of a rigidized, foamed plastic. Although this technique is primarily intended for fabricating reflectors for space technological purposes, this technique may be used to produce reflectors for cooking devices as well. The mold-shape is produced by simply inflating an aluminized plastic balloon. This then becomes the reflecting wall

of the finished reflector after being backed up by a rigid foamed plastic. The cost of materials for such a reflector is probably less than $2 for a 48-inch reflector.

2.1.8 Spun Liquid Plastic Reflector

An interesting method for producing parabolic mirrors is described by P. B. Archibald (17). A liquid in a revolving horizontal pan takes the shape of a paraboloid, and a liquid resin suitably catalyzed to harden after this form is taken will retain this shape. With the development of the epoxy resins, satisfactory material has become available. Apon 828, catalyzed with 5-percent piperidine and cured at 80° to 90° C has been found to give satisfactory results.

The focal length of the finished reflector is controlled by the speed of rotation of the pan. The formula for the focal length may be simplified to $\sqrt{f} = 38.4/\text{rpm}$, where f is the focal length in feet. A 36-inch focal length requires a speed of only 22/7 rpm. Additional resin may be poured on to the first surface after it has set. In general, superior surfaces are obtained on the second or third pour. Reinforcing material such as fiberglass can be placed on the surface before the second surface is poured.

The quality of the reflectors produced to date is better than anything that can presently be made without the use of grinding and polishing techniques. This is, however, not a significant factor in cooker considerations. However, the estimated weight of such a 36-inch diameter reflector is about 30 pounds for a 1/2-inch thickness. The cost of this much epoxyresin is estimated at $25-$35. Hence, although this technique could perhaps be used for making a master mold, it does not appear that this offers a practical solution for low cost solar cookers.

2.2 DIRECT COOKING TYPES WITH COLLAPSIBLE REFLECTORS

There are at least four designs of collapsible reflectors commercially available. Most are designed for occasional use by campers or sportsmen. Since the emphasis is on easy portability, the weight is kept low and the structure simple. Thus, all models tested were inadequate from the point of view of stability on windy days. Several reflectors might possibly be modified by designing a heavier and more durable support structure, preferably one that can be built from local materials. Collapsible designs are cheap and easy to ship and also easy to move indoors for protection against weather. In certain nomadic societies, the easy portability might be especially desirable.

2.2.1 Solar Chef

This design (Figs. 9a and 9b) is an intermediate between the rigid and collapsible types. The reflector consists of two thin plastic sections, about 60x40 centimeters, which form a sort of cylindrical parabola. The plastic is vapor coated with aluminum and the two sections can be stacked. The support structure consists of a pointed rod to be stuck into the ground and four other support pieces. Altitude and azimuth adjustments require removal of the pot. The evaporated aluminum coating on our purchased cooker was very thin and transparent. The focal spot was diffuse and matched the pot poorly. We did not succeed in bringing water to a boil with our model and therefore abandoned further tests. This weak performance must be attributed in part to the inadequate collector area.

The pot, however, which is furnished as part of the assembly, is very suitable for use on other cookers. We obtained four additional ones at a price of $1 each.

2.2.2 Umbroiler

This reflector (Figs. 10a and 10b) is constructed like an umbrella (18). It is made with a light aluminum frame, has 16 ribs, and is covered with aluminized Mylar-rayon laminated cloth. It is 46 inches in diameter and has a focal length of about 24 inches. The reflecting material between adjacent ribs forms a wedge-like segment which has a base length of 9 inches between rib tips. Hence, any pot that is less than 9 inches across will not receive all the light that is reflected back. For a 6-inch pot, about 1/3 of the light gathered near the periphery is lost. Increased efficiency would result from introducing more ribs. Our studies show that the focal point is quite diffuse (Fig. 11), due partly to the folds in the cloth, and partly to fluttering of the cloth in a stiff wind.

The reflector is supported by a tripod frame which incorporates an adjustable swivel joint for proper alignment of the cooker with respect to the sun. Adjustment of the altitude angle requires removing the cooking vessel. Considerable difficulty was encountered on windy days because this cooker tended to blow over.

The designer and manufacturer of this cooker, G. O. G. Lof, has suggested a number of modifications to make this design more rugged and suitable for continuous use. These include heavier fabric, larger tube diameter for the umbrella shaft, heavier grill and more rugged support joint for the entire unit.

The present wholesale price in small lots is $18 and the manufacturer estimates a possible wholesale price of $10 in large lots. The retail price is about $30. However, Lof suggests that a cost reduction of 50-68% is possible based on manufacture in areas in which they are to be used.

Cooking performance was adequate, but the 400 watts reported could not be obtained. It is interesting to note that one unit has tested at 60° N Latitude in Sweden and cooked satisfactorily.

2.2.3 Solnar

This elegant cooker (Figs. 12a and 12b) is manufactured in France from designs by A. Tarcici. The design is covered by a number of French and U. S. patents (19, 20, 21).

The reflector consists of two sets of 18 reflecting blades forming a fan-like array. The curvatures are such that the assembly approximates a paraboloid of revolution. The tripod frame and metal carrying case are ingeniously combined to form a one-piece assembly, including a grill. Adjustment of cooker orientation without removing the pot, although possible, is difficult. The focal spot is very diffuse (Fig 13), consisting of somewhat overlapping areas. In our model, the grill was poorly centered on the spot. Thus, the pot had to be put near the edge of the grill, causing instability and occasional spilling. Maximum output was only about 200 watts per square meter. The retail price of the cooker in New York City was $37.50. We have been unsuccessful in obtaining additional cost and manufacturing information from the designer or the importer. The fan-like reflector is inherently cheap and easy to manufacture with simple tools. A reflector made on this principle but with a different support may merit consideration.

2.2.4 Inflatable Plastic Reflectors

Reflectors of this type were first reported by the workers at the University of Wisconsin Solar Energy Laboratory. The reflector they described (B) is a parabola of revolution constructed of aluminized plastic, supported on a stiff outer ring of thin-wall tubing and having an air-tight cover of clear plastic.

The aperture is 42 inches and the focal length 18 inches. Mylar has been used as the plastic. The reflector weighs about 5 pounds. It is believed that this type of reflector could also be used with the mounting for the plastic shell cookers described in section 2.1.1..

VITA has also considered such a design (Fig. 14) with the view that the reflector element, independent of the supporting frame, potholder, etc., can be produced at a low cost and can be folded into a small lightweight package for easy shipment into remote areas. The cost of such a reflector unit is estimated to be 75¢ and the weight less than a pound. The supporting frame orientation, and the like could be constructed locally.

In the 48-inch diameter prototypes that VITA constructed, there was no difficulty in concentrating sunlight sufficiently to ignite paper. However, several difficulties arose. One was the problem of maintaining air within the reflector. An appreciable rate of reflector deflation occurred, either because of pin-hole leaks or because of permeation itself. Furthermore, the reflector surface fluttered in the wind, causing defocusing. Another mild disadvantage of this design is that there are two extra interfaces between the vessel and the reflector, with the radiation passing twice through each. The direct radiation from the sun to the reflector is normal to the interfaces; the reflected radiation from the parabola passes through the interfaces at angles of incidence which become progressively less favorable from the center to the rim. Each passage of the radiation through an interface results in reflection loss. However, this is simple to remedy by increasing the reflector size. Another problem is that these reflectors can be damaged if handled very roughly. Finally, the lightweight and high surface area tended to make this cooker unstable in a strong wind.

Another large, inflatable solar collector made of Mylar, developed by G. T. Schjeldahl Company of Northfield, Minnesota, has been briefly described in a magazine article (22). We were unable to obtain further details of this structure.

2.3 OVEN-TYPE COOKERS

Two oven-type cookers were manufactured for VITA from descriptions in the literature by Yellott Engineering Associates, Phoenix, Arizona. One of these designs, described by Gosh (23), did not perform well in our latitudes; however, it may be quite suitable for use in the tropics. The other one was based on a design by M. Telkes (24, 25, 26), except that no heat storage chemicals were included. It performed very well.

The ovens are essentially plywood boxes with sheet metal lining. Both are sturdy and adaptable to simple manufacturing methods. The box could be made of any of a wide variety of woods. The sheet metal liner could be made with hand tools. Material costs for the ovens would range from $4 to $7 and labor costs would vary widely according to the methods used and number produced. Dr. Telkes (27) has suggested even simpler construction, making use of locally available basket crafts. The reflectors for these ovens, on the other hand, are relatively fragile, but are also simple to manufacture. They require only tin snips and a punch or drill, provided polished aluminum is available. It should be possible to make the reflectors more rugged by adding wooden or metal frames. Dr. Telkes has designed various modifications of the design that VITA tested. In addition, a somewhat similar design has been tested (4) by F.A.O.

Two designs, intermediate between the direct and indirect, have come to VITA's attention. One of these, employing simple, folding, aluminized, cardboard reflector, was included in our tests. The information on the other was taken from the literature.

2.

The oven (Fig. 15) is a box of plywood approximately 48x48 centimeters at the base and 41 centimeters high. One side is cut off at a 45° angle and the opening is covered with a double glass window. Surrounding the window are four polished, flat, aluminum sheets hinged to the side of the box. Each sheet is 34x34 centimeters. Triangular pieces of polished aluminum are fitted between the larger sheets to complete the reflector. One side of the box has a hinged door. The interior is lined with sheet metal, painted black. A 3-quart casserole fits easily in the oven. Assembly is simple, requiring the equivalent of a screwdriver to assemble the reflector and about 15 minutes. The oven, which weighs about 13.6 kilograms, can be lifted by two handles. The reflector, while flimsy, is sufficiently rigid to stand up in a strong wind. It maintained its setting and required little adjustment during cooking tests.

Although the temperatures reached were low (315° F on a day when outdoor temperature was 46° F), the oven could be used to cook simple dishes with such foods as meat, rice and potatoes by increasing the ordinary cooking time. The Food and Agriculture Organization of the United Nations carried out a series of tests in Rome during the summer of 1959 on a solar oven of almost identical design. They report (4) that this cooker required an average of 112 minutes to heat 2 liters of water from tap temperature (15° -20° C) to boiling. Although the latter cooker did possess a container of heat storage chemical, the heating time was increased by the time of any cloud cover during the test.

Telkes and Andrassy (27) have carried out extensive cooking tests on a modification of the same basic cooker. They report being able to achieve temperatures as high as 460° F near New York City on a clear day. They were able to prepare the following foods successfully in the oven: Rice (1 lb. + 1 lb.

of water) in 45 minutes; lentils (1 lb. + 4 lbs. of water) in 2 hours; dry peas and black beans (1 lb. + 4 lbs. of water) in 3-4 hours; meat roasts (8 lbs. beef) in 3 hours: stew (meat and vegetables) in 2 hours; bread, rolls and cake (2 lbs. of bread) required 45 minutes: fruit preserves (2 lbs. fruit + 1 lb. sugar + 0.5 lbs. water) in about 3 hours. The foods cooked as they would in a standard oven.

2.3.2 Reflector Oven (Gosh)

The oven (Fig. 16) was a plywood box, 56x56 centimeters on the base and 32 centimeters high. The top, hinged, double glass window, served as the oven door. The reflector was one flat sheet of polished aluminum supported by a system of light bars and flat sheet metal strips which would not hold the reflector in any breeze. The interior was a sheet metal, painted black. No assembling was required. The weight was about 18.2 kilograms. The maximum temperature reached with this model was 238° F at an ambient temperature of 45° F. The reflector would stay in position only in calm weather and frequent adjustments were needed. This design should perform much better at high solar altitudes, as in the tropics. The tests made in Schenectady at solar altitudes between 30° and 40° are probably not indicative of its performance under optimun conditions.

2.3.3 Folding Paper Conical Reflector

This design (Figs. 17a and 17b), marketed by Honor House Products, Lynnbrook, N. Y., is midway between the folding reflectors and the oven types. At a retail price of $3.98 it has the distinction of being the only cooker of this type with a cost well within the $5 limit generally accepted as maximum price for wide distribution in fuel-poor countries. The price includes a cardboard packing box, which also serves as a support for both cooker and reflector, and

a cooking pot with a blackened lid. The reflector is made of thin, aluminized cardboard. All of the other parts except the pot are also cardboard. The reflector folds and rolls in an ingenious fashion to fit inside the pot. At our geographical latitude, it is not possible to cook liquids, since the pot must be tilted to intercept solar radiation. However, in the tropics, wet cooking may be possible. The cooker performed quite well with some foods, heating frankfurters or cooking thin steaks or hamburgers in about 20 minutes. Durability is necessarily poor. We estimate that this cooker would last for about 20 or 30 cooking sessions, or less if the cooker were subjected to moisture. If it were necessary to fold the reflector after each use, durability would be inpaired, as it is difficult to avoid damaging the reflector when opening and closing it.

2.3.4 Cylindro-Parabolic Solar Cooker

This cooker was designed by A. S. Prata (28) in Portugal, to combine the best features of the previously discussed direct cookers and the oven types. It is shown in (Fig. 18). In this design, the oven consists of a 10-inch ID x 24-inch insulated metal drum with doors in the ends for inserting the cooking vessels. A strip of metal is removed along the length of the drum, and is replaced with a plate of glass which permits light to be concentrated by a cylindrical reflector made by bending a sheet of highly reflective metal. Instead of a focal spot, this produces a line of concentrated sunlight. The oven is supported by a wooden frame, which holds it in the right position with respect to the reflector, so that the focused light enters the oven through the glass window. In this way, considerably more heat can be directed into the oven than was possible with the cookers described in 2.3.1 and 2.3.2. Accordingly, some improvement in cooking time was found in the cooking tests.

The cooker cannot be considered simple. The designer estimates that the cost of the materials is $18, plus 8 hours of labor. Although the apparatus weighs only 18 kilograms, it is a relatively bulky design. It may be advantageous in an area where it must compete with conventional electric, gas, or wood-burning ovens.

3.0 SUMMARY

TABLE 1 gives comparative data on the properties of the cookers and reflectors which were tested.

No commercially available unit tested thus far has met the criteria of low cost, efficient operation, and ready transportability. Furthermore, the majority of the effort has not gone into developing designs suitable for local manufacture. In particular, none of the commercially available cookers appear to be well adapted to such manufacture. It is felt, however, that a Fresnel-type solar cooker would meet these criteria. The Fresnel-type cooker performed acceptably in cooking tests and standard tests. It can be produced using about $5 worth of materials plus about one day of locally available labor and simple tools.

We have been unable to make direct comparison between the Fresnel cooker and the more widely known Wisconsin cooker. Although the material cost in the United States are comparable, the Fresnel cooker involves simpler construction techniques and is more adaptable to the use of indigenous materials and skills.

Comparative merits of the oven-type and the direct-cooking type have not been quantatively established. Some tests were noted in the literature (4), but their results were inconclusive. VITA studies indicate that the direct-cooking devices have the advantage of greater speed. On the other hand, the oven-type cooker will retain heat for a much longer period of time after the sun has set or cloud cover has formed, and the food is also protected from contamination and damage by animals and insects. There appears to be no inherent reason why a low-cost oven-type cooker cannot be made locally.

It is felt that a choice between the two depends on local dietary mores and local meteorological conditions. Indeed, it may be desirable to utilize both types, just as we utilize both surface units and ovens in a modern electric or gas stove.

There appears to be important gains in heat utilization possible with simple pot shielding.

RECOMMENDATIONS FOR FURTHER STUDY

I. 1. Better cementing techniques

2. Test merits of different pot supports

3. Improve reflector material

a. Evaporate protection layer over aluminum

b. Other evaporated materials such as chromium

c. Try burnished aluminum

d. Some sort of satisfactory spray paint

II. Construction of very cheap oven type

III. Try marrying an oven to a Fresnel cooker

IV. Develop cooking pots with lower convection losses

TABLE 1

COMPARATIVE DATA ON 12 SOLAR COOKERS

Cooker	Type ++	Reflector Area (m^2)	Focal Length (cm)	Weight (kg) Net	Weight (kg) Packaged	Approx. Size (packaged) (inches)	Performance	Retail Cost (Dollars)	Estimated Manufacturing Cost (Dollars)
Wisconsin Design (2.1.1) +	D-R	1.2		9-10			***		8.66-16.17
Boeing Reflector[1] (2.1.7)	D-R	.21	36	0.45		22x22x4	***		18.00
Thew Cooker (2.1.2)	D-R	.64	45	3.5	6.2	42x42x8	**	29.50	20.00
Burmese Design (2.1.3)	D-R	2.5	~ 60	13.2	20.	52x52x10	—	12.00	
Fresnel Type[2] (2.1.4)	D-R	1.	~ 60	5.3 10.	7.	50x50x10	***		< 5.00
Solar Chef[3] (2.2.1)	D-F	0.5		1.3	2.5	25x16x6-1/2	—	19.95	12.00
Umbroiler (2.2.2)[4]	D-F	1.2	45	1.4	2.4	29x10x4	*	29.50	15.00
Solnar (2.2.3)	D-F	Ellipsoid ~1.	45	3.7	4.2	22x10x3	*	37.50	10.00-12.00
Inflatable Type[5] (2.2.4)	D-F	1.3	~ 50	0.2	.25	5x5x1	**		< 5.00
Oven, Telkes Design (2.3.1)	I-F	0.46		13.6			***		
Oven, Gosh Design (2.3.2)	I-R	~0.2		18.2			*		
Conical Paper Ref. (2.3.3)	I-R	0.59		0.72	1.07	11x11x5	*	3.98	2.00

+ Numbers in this column refer to corresponding sections in text.
++ D = Direct; R = Rigid; I = Indirect; F = Folding or Collapsible.

*** = Very Good
** = Good

* = Fair
— = Unacceptable

[1] Reflector only. Manufacturing cost is based on a 36-inch reflector

[2] Not optimized for weight.

[3] Our model may not have been optimum.

[4] Performance tests hindered by wind; better support possible.

[5] Data refer to reflector without frame.

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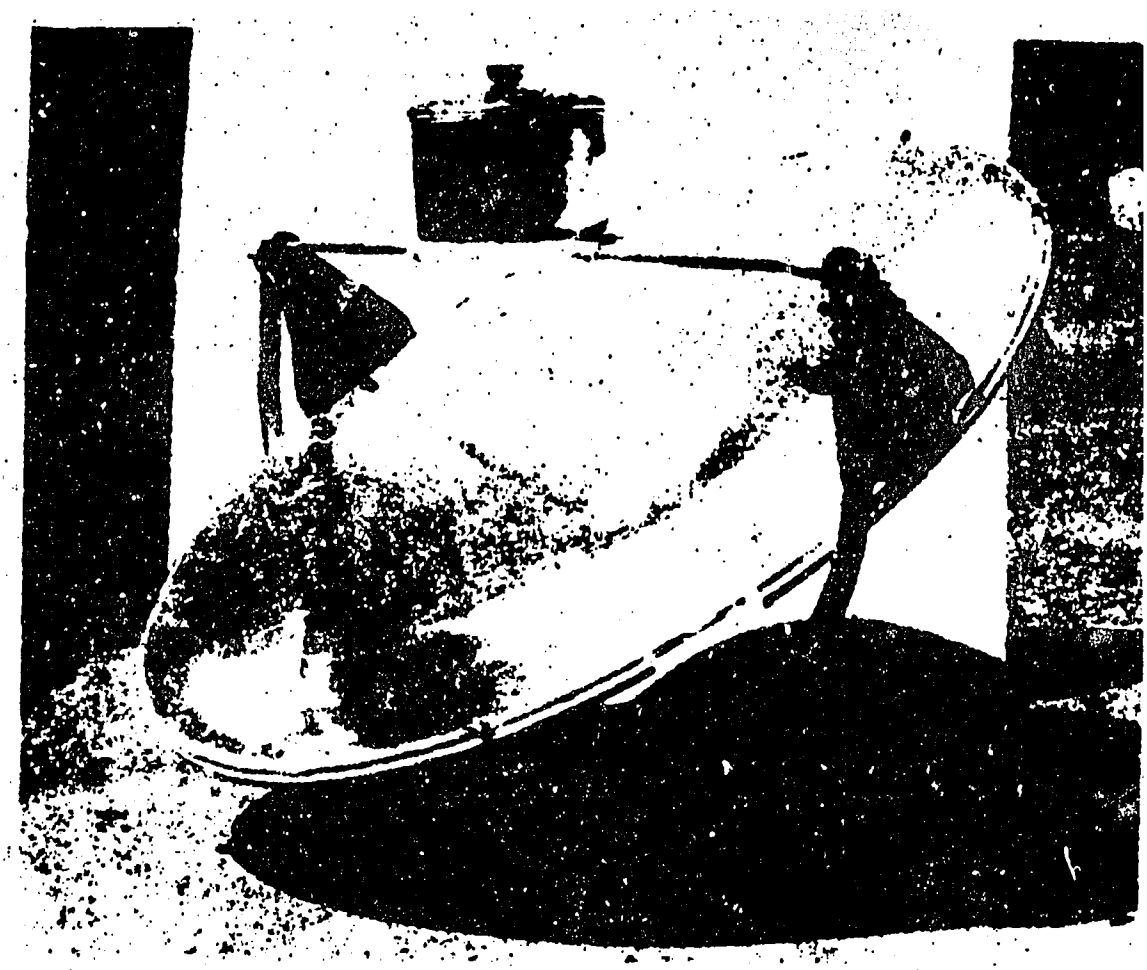

FIG. 1

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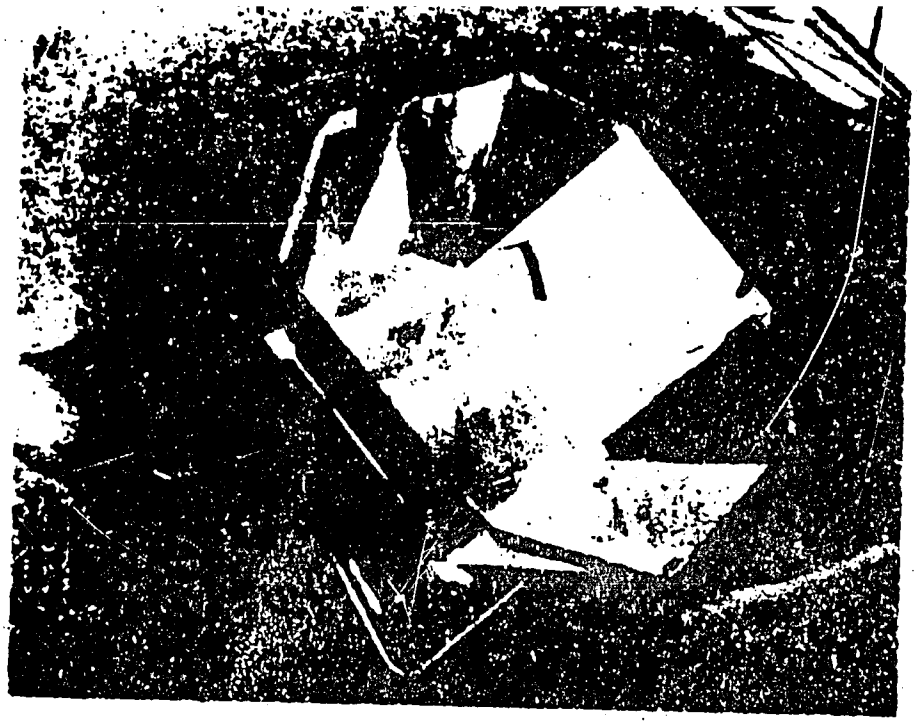
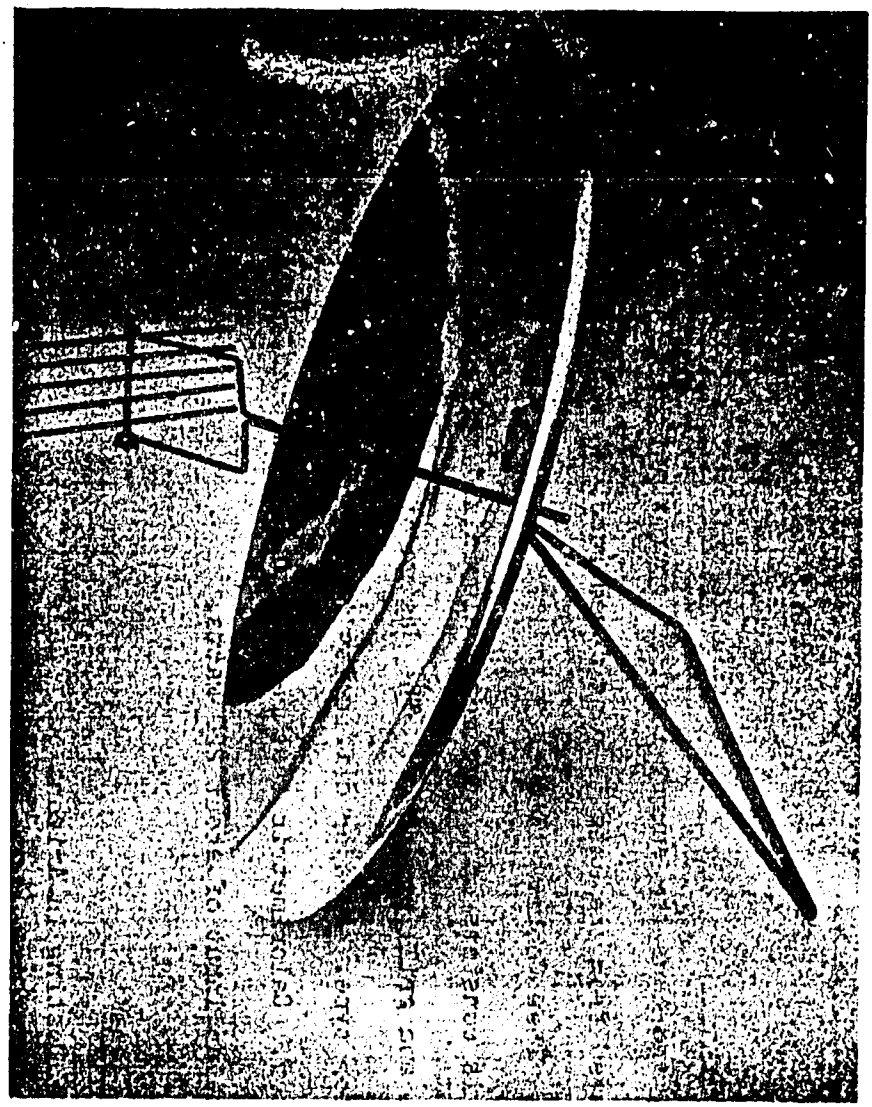


Figure 2

SOLAR COOKING OVEN WITH TUBULAR STAND



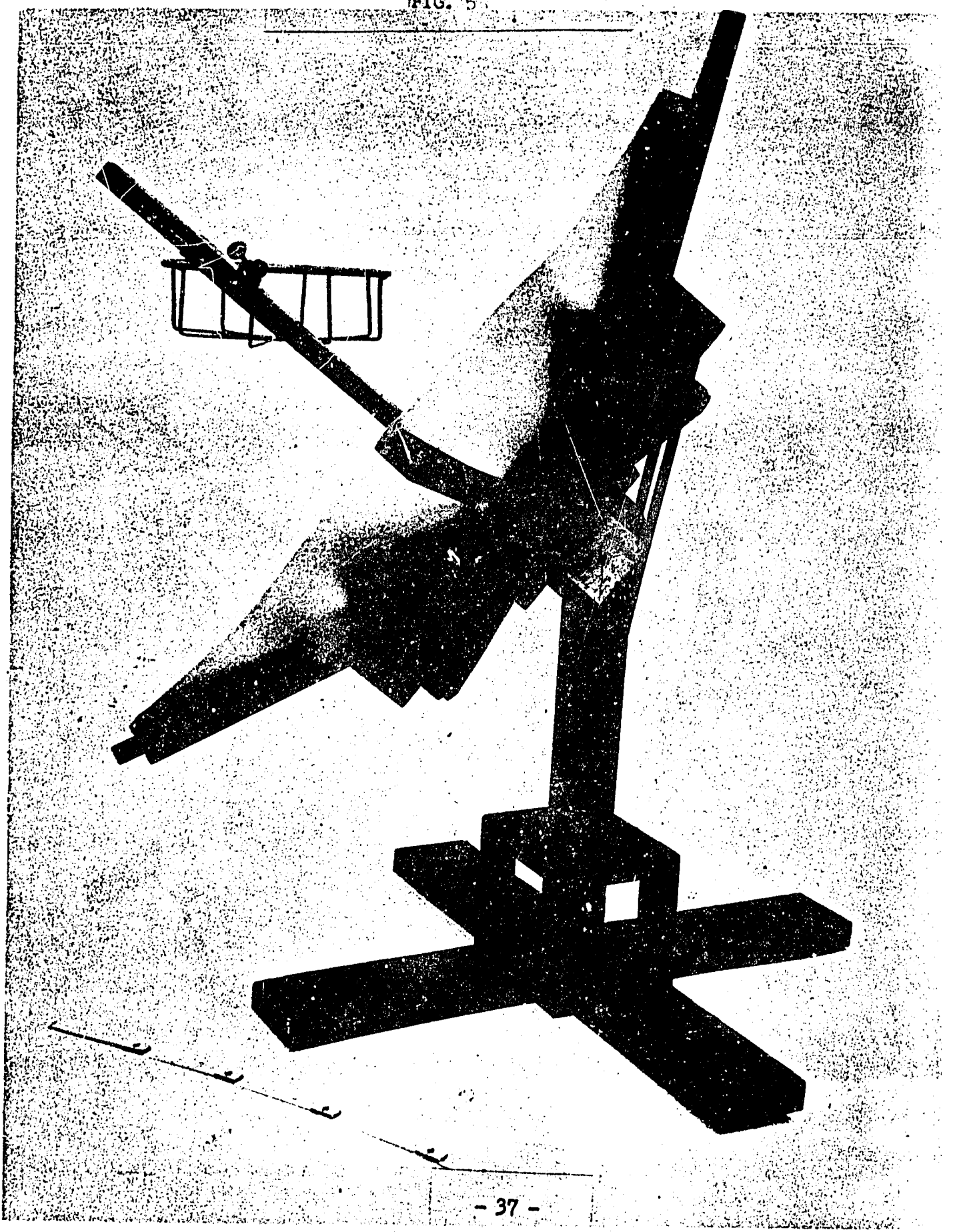
"Thew" Cooker

FIG. 3

FOCAL SPOT SHAPE OF THE COOKER

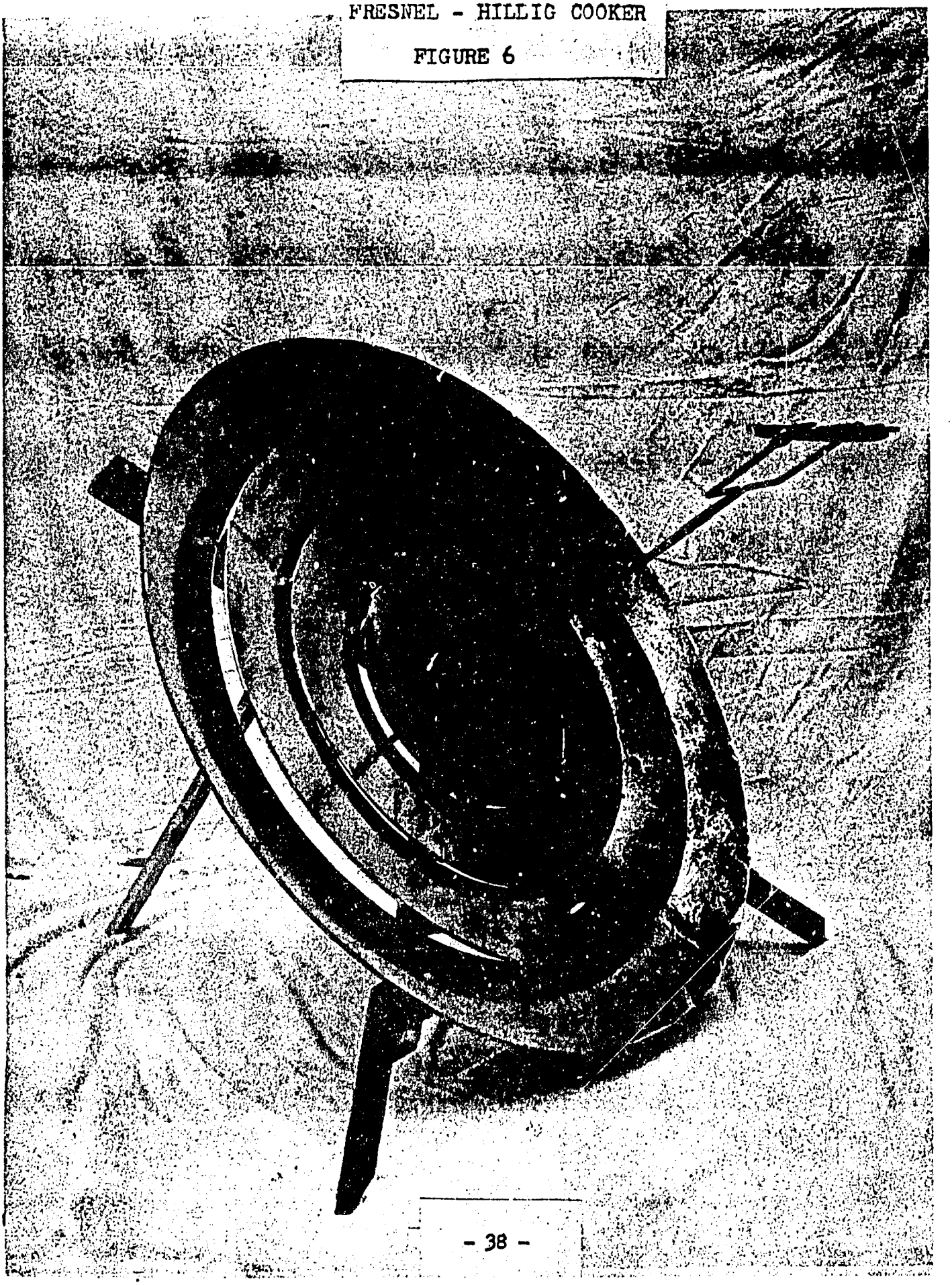
FIG. 4.

FIG. 5



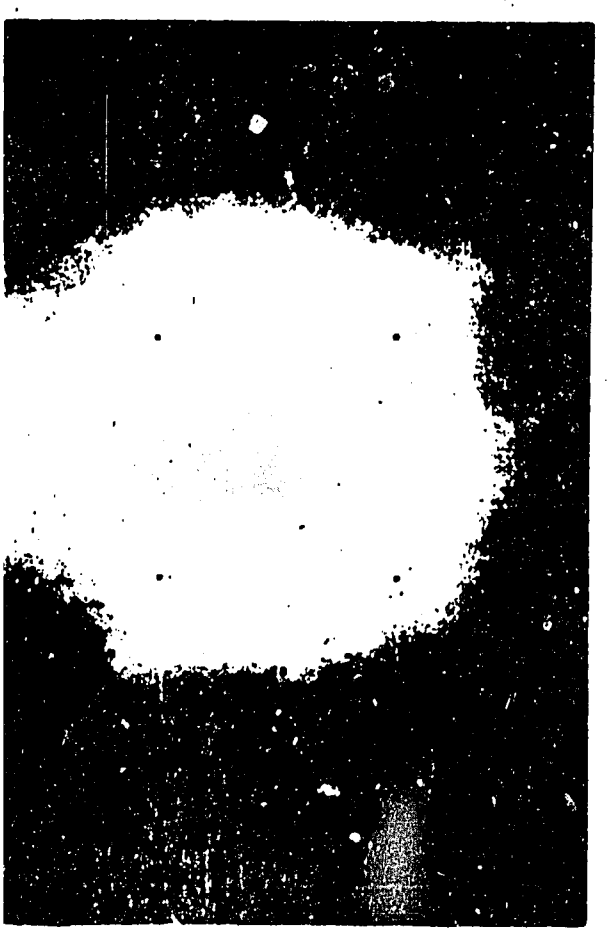
FRESNEL - HILLIG COOKER

FIGURE 6



FOCAL SPOT SHAPE OF FRESNEL - HILLIG COOKER

FIGURE 7



SPHEROIDAL SOLAR KITCHEN IN USE

FIGURE 8

SOLAR CHEF

FIGURE 9a

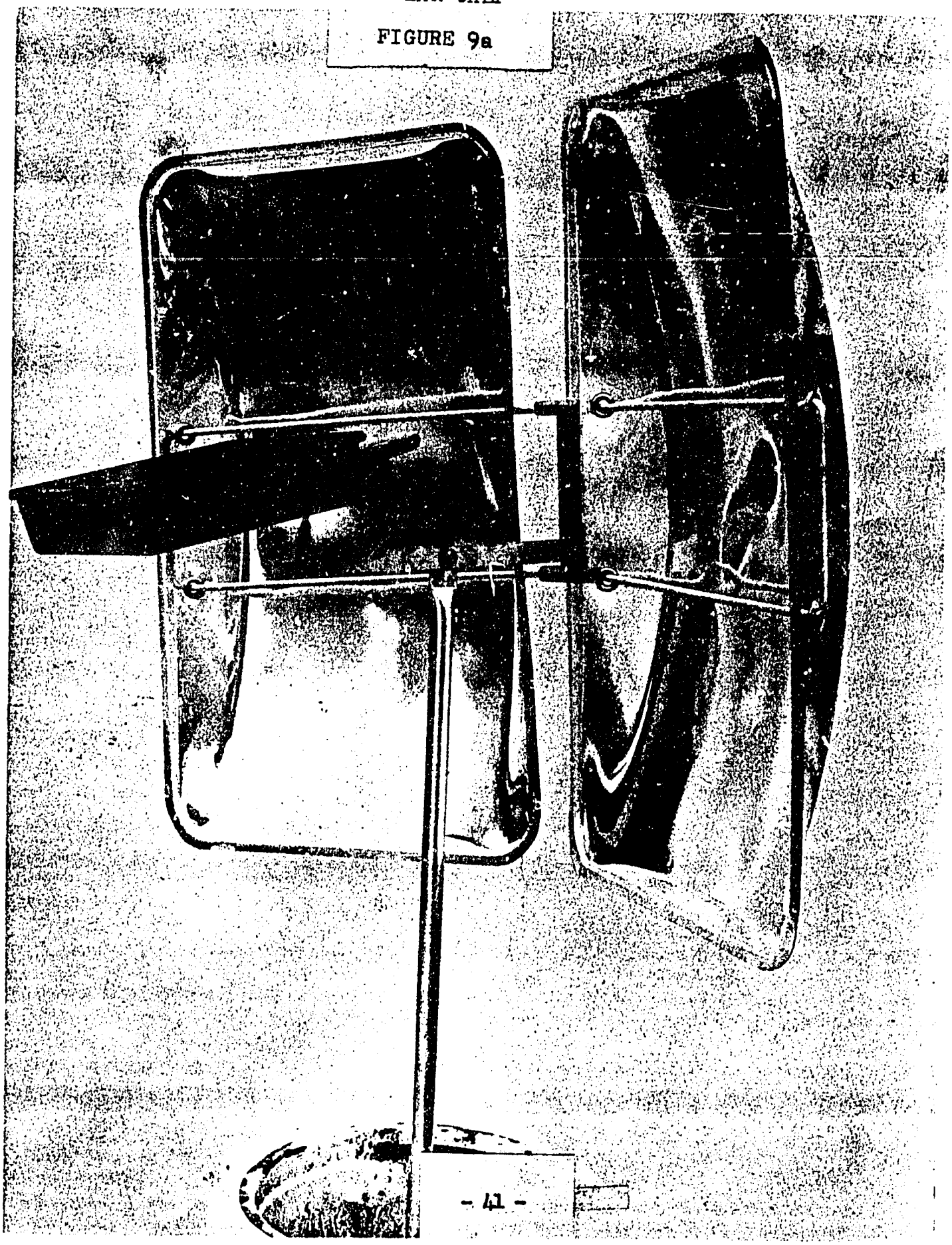
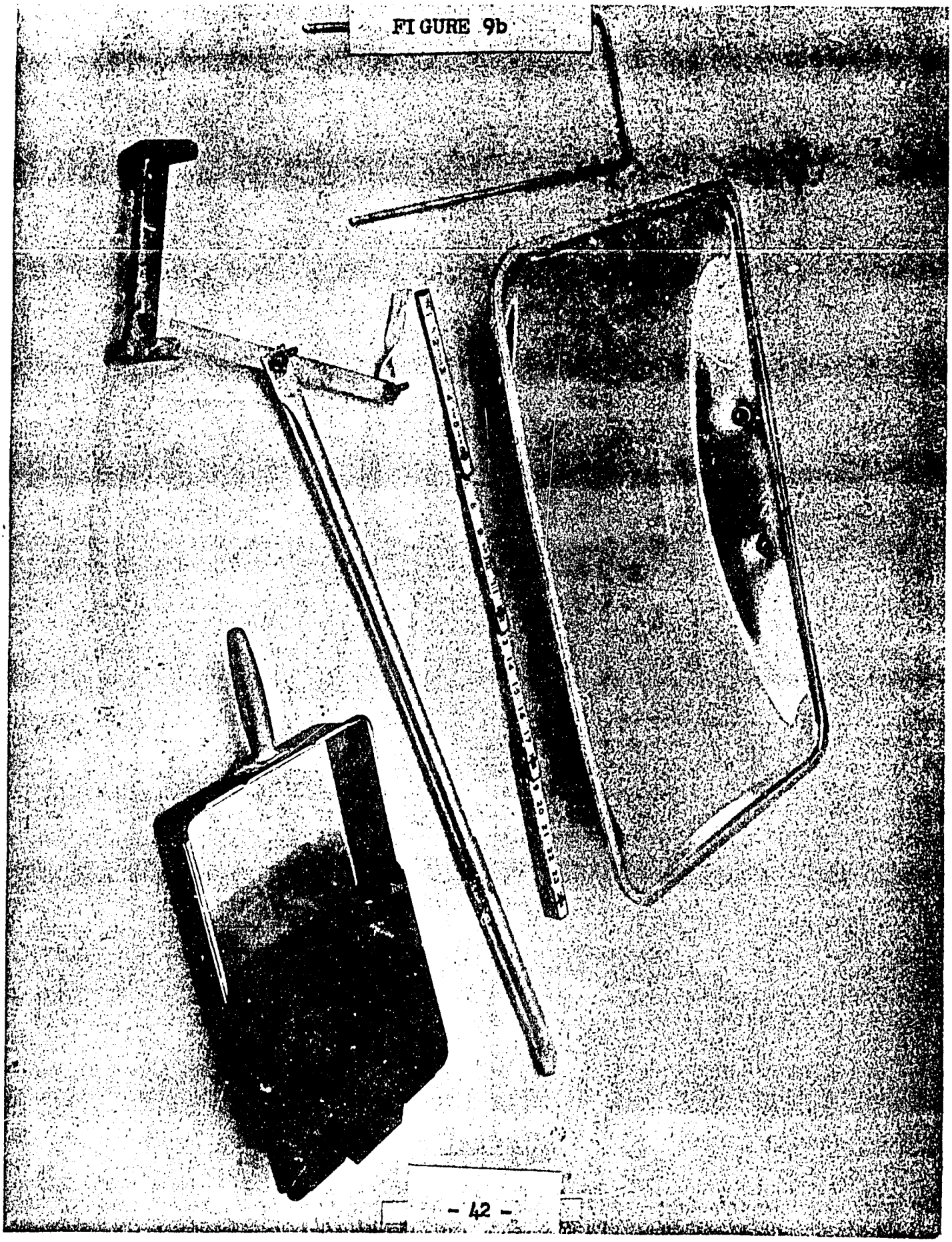
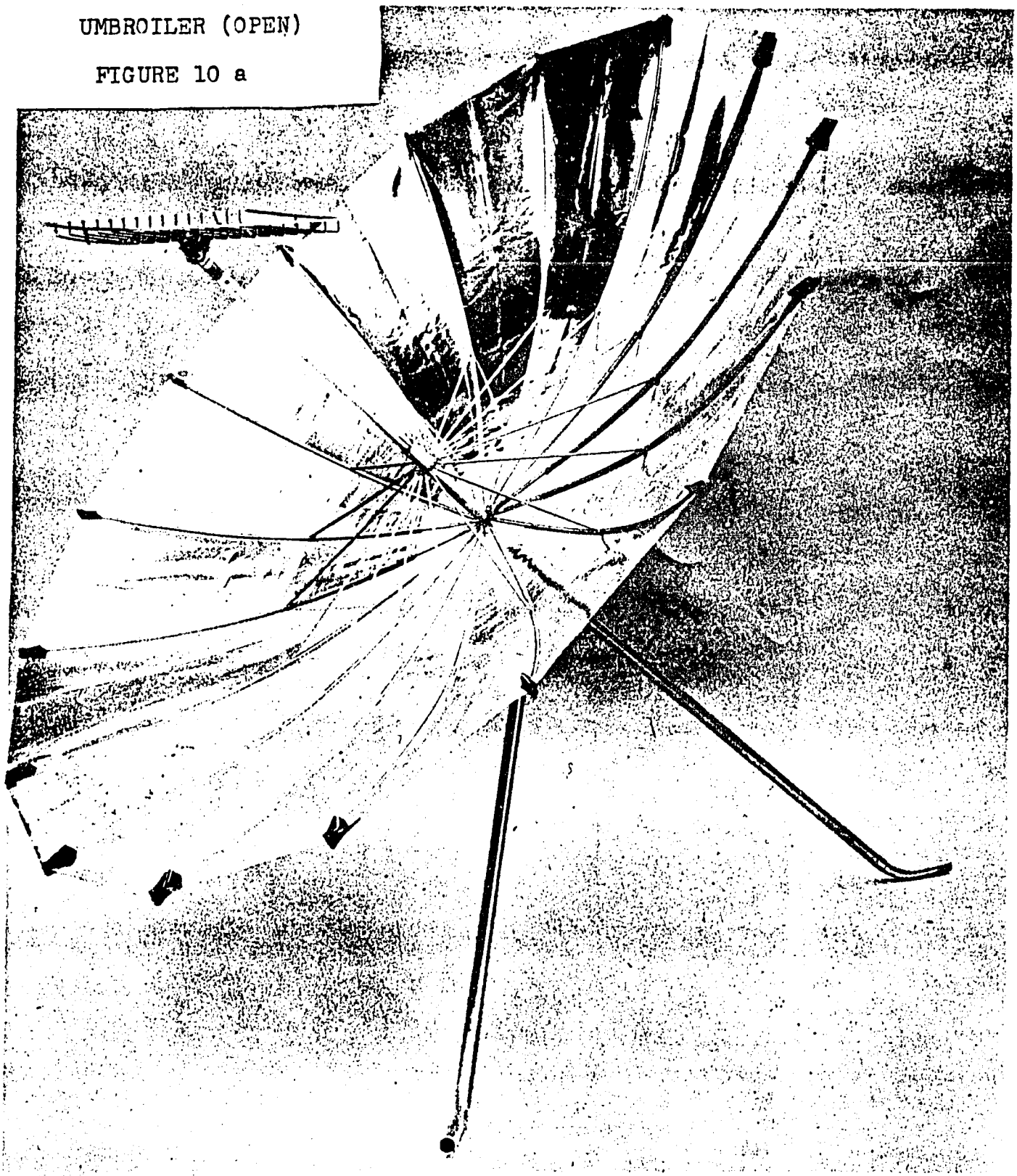


FIGURE 9b



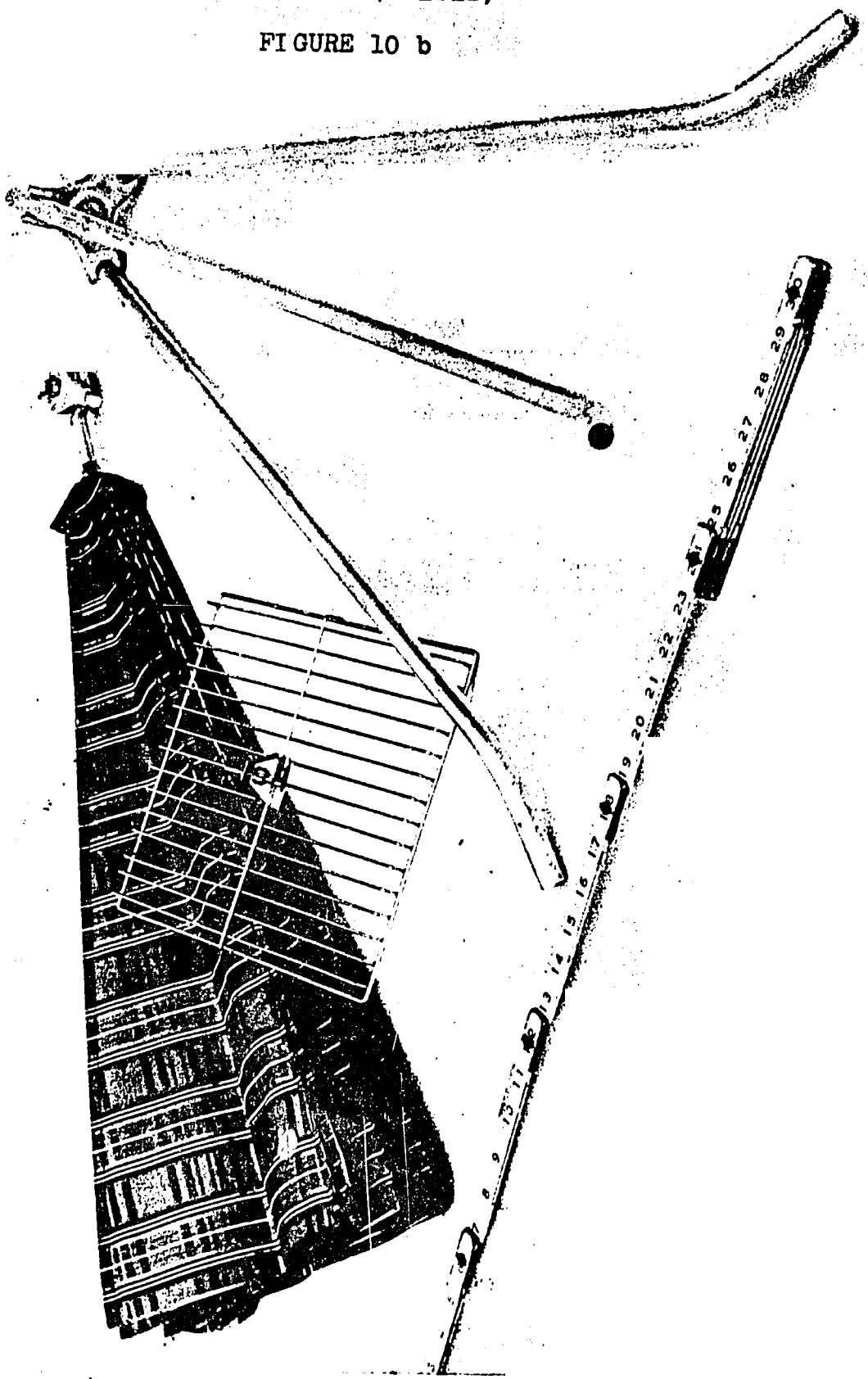
UMBROILER (OPEN)

FIGURE 10 a



UMBROILER (FOLDED)

FIGURE 10 b



FOCAL SPOT SHAPE OF UMBROILER

FIGURE 11

SOLNAR COOKER (OPEN)

FIGURE 12a

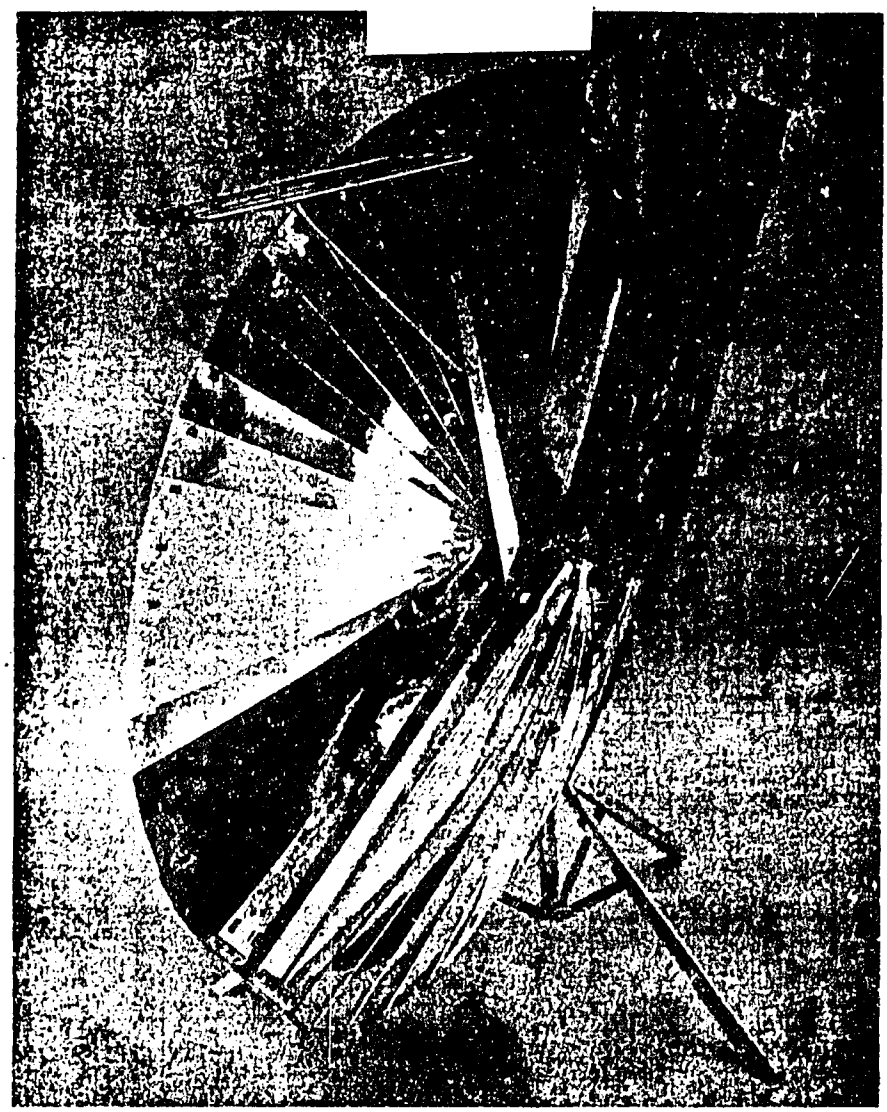
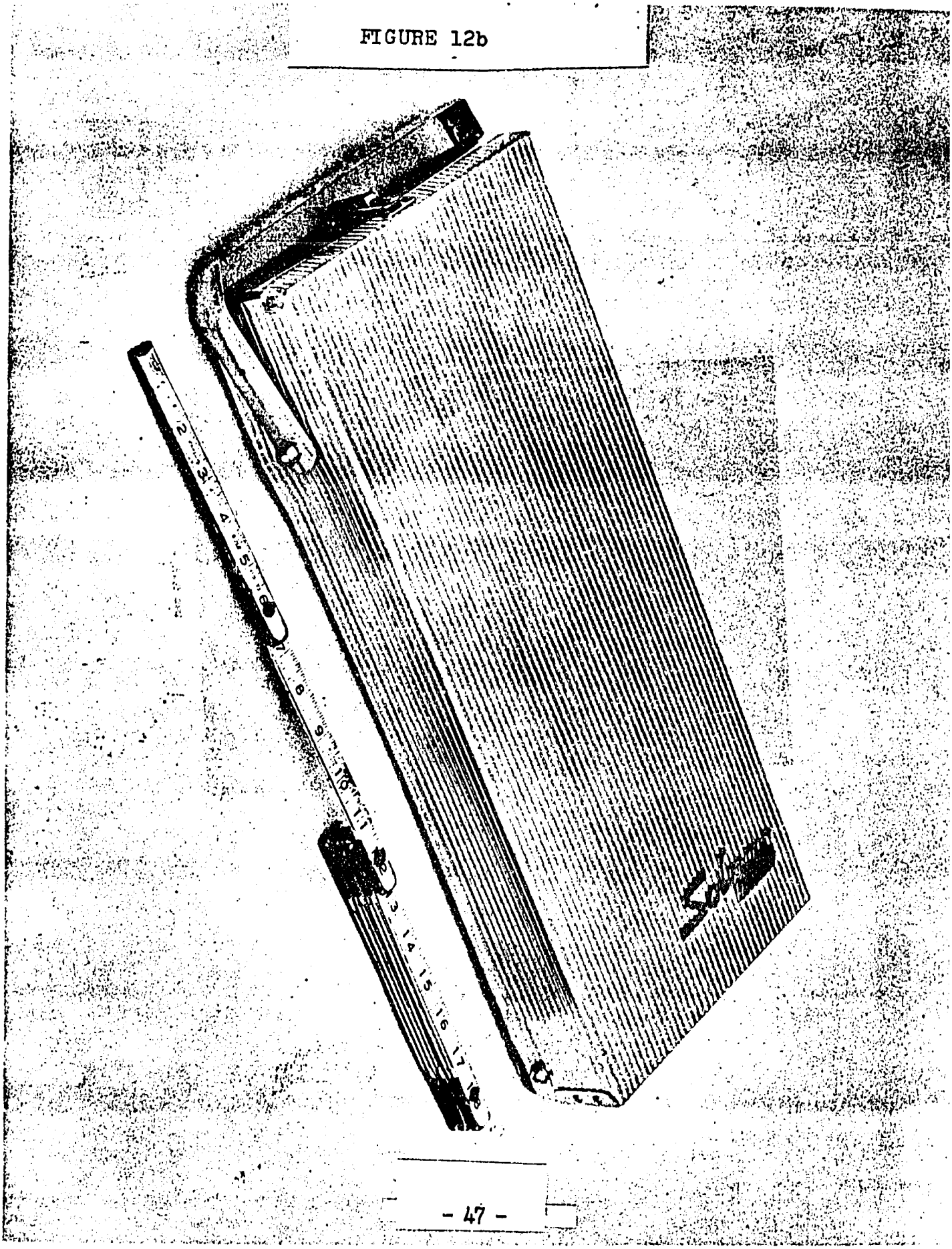
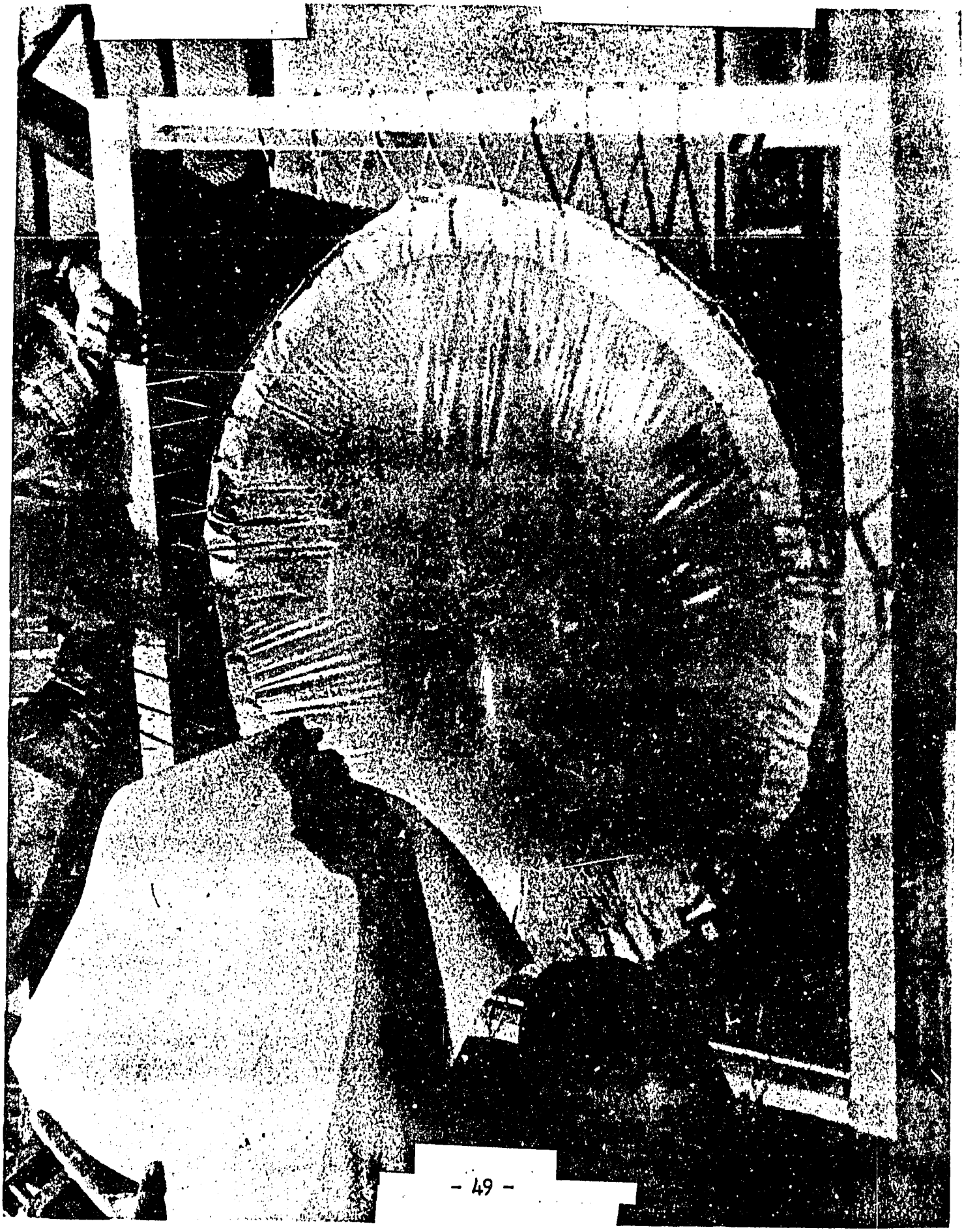


FIGURE 12b



FOCAL SPOT SHAPE OF SOLNAR COOKER

FIGURE 13



TELKES TYPE COOKER TESTED

FIGURE 15

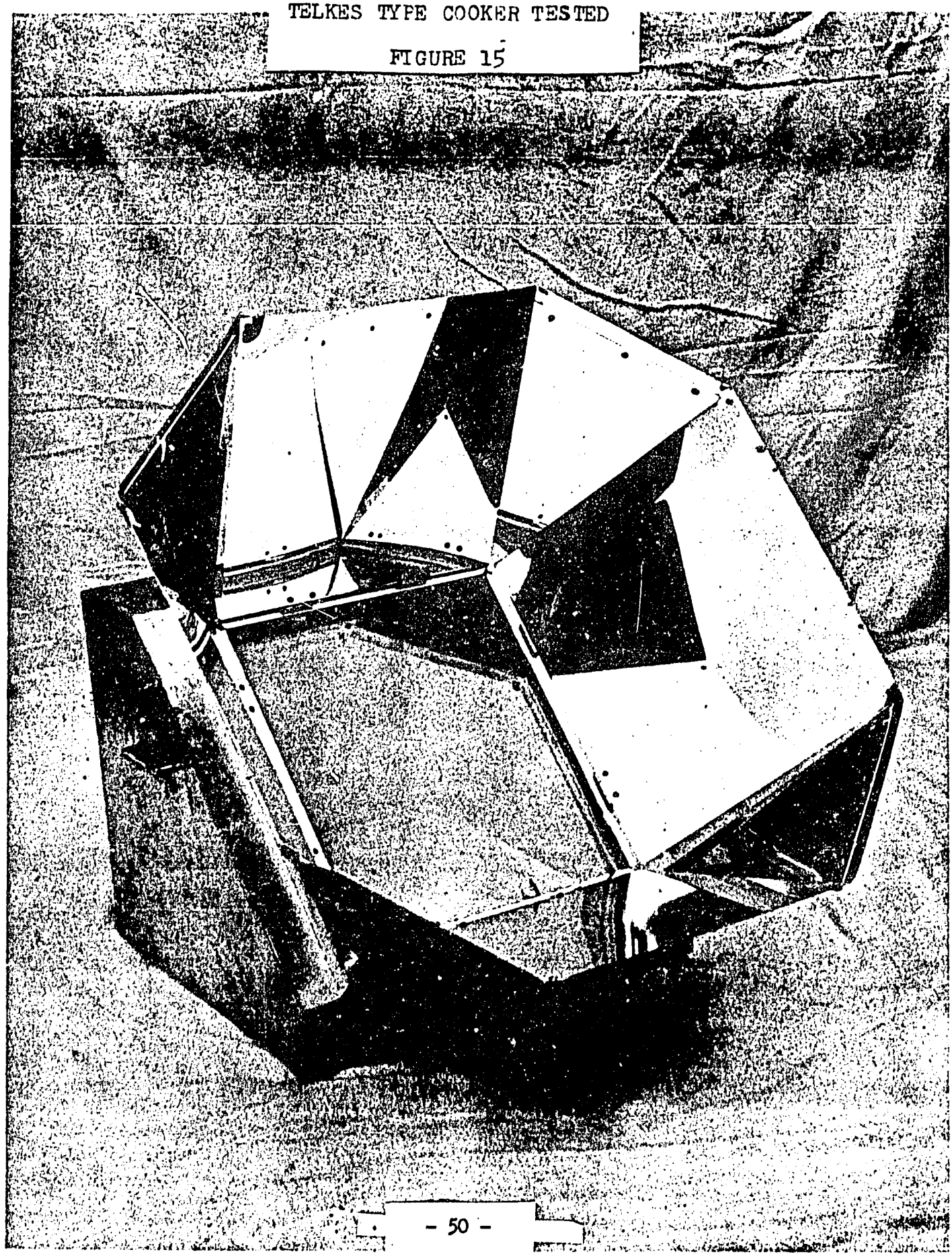


FIGURE 16

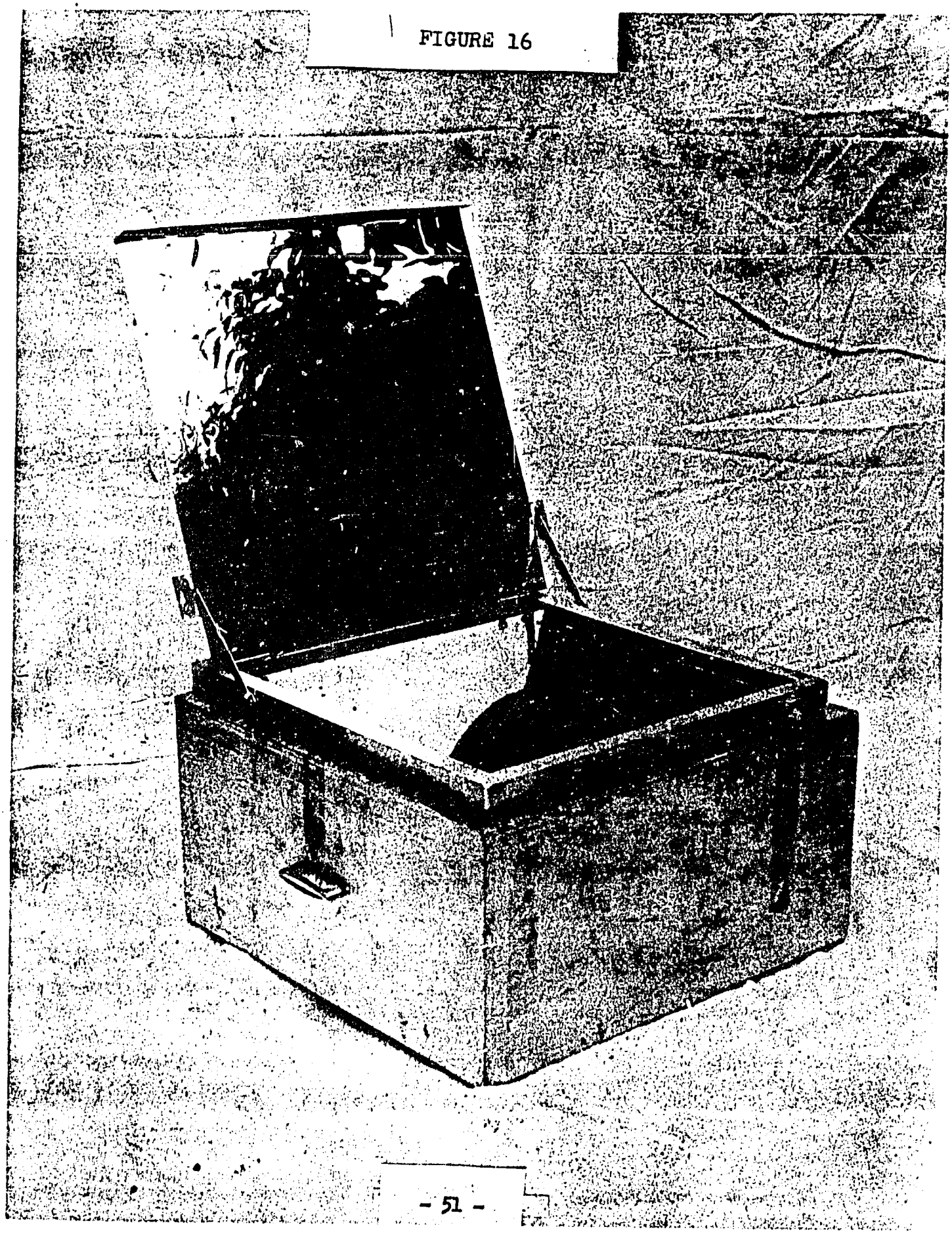


FIGURE 17a

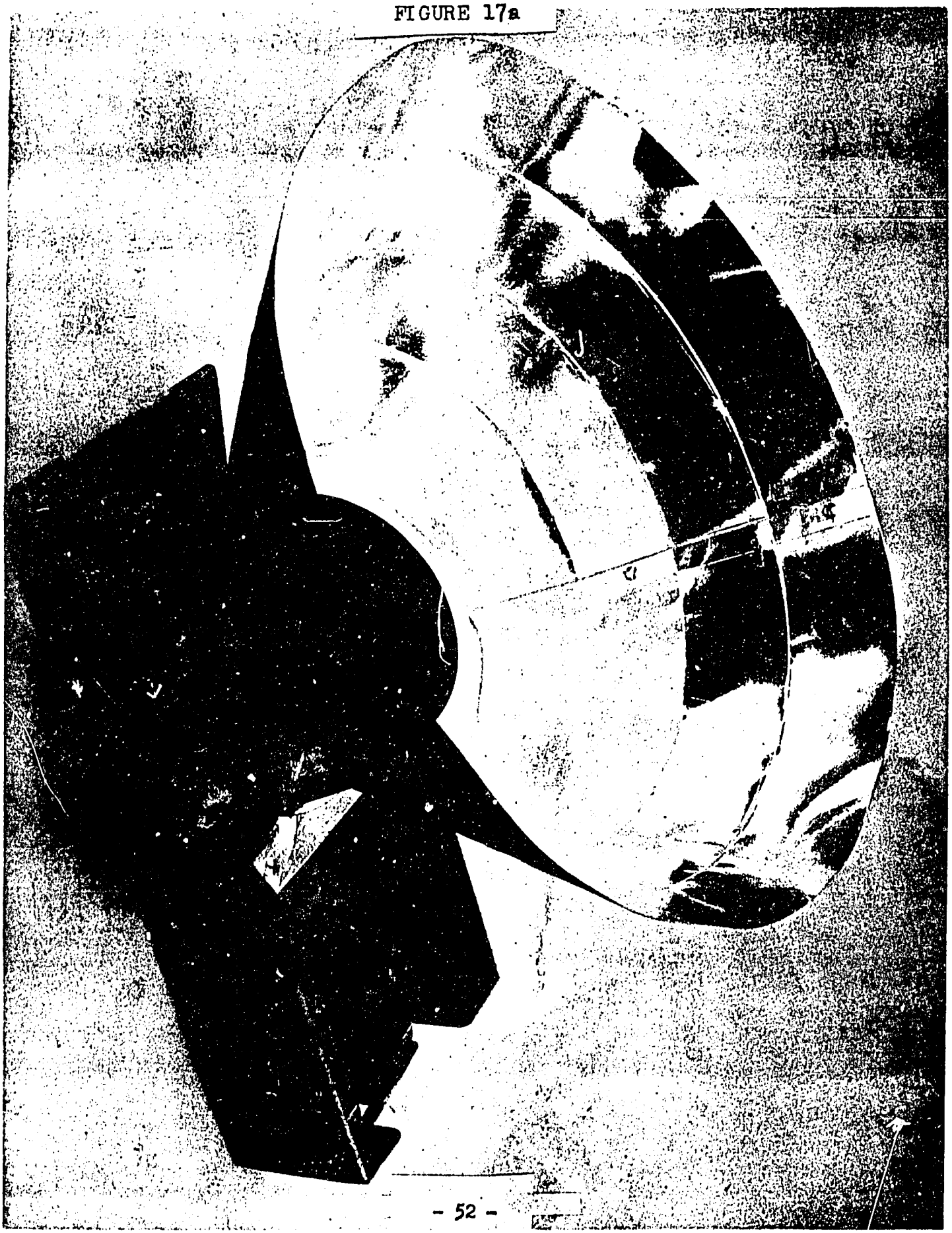
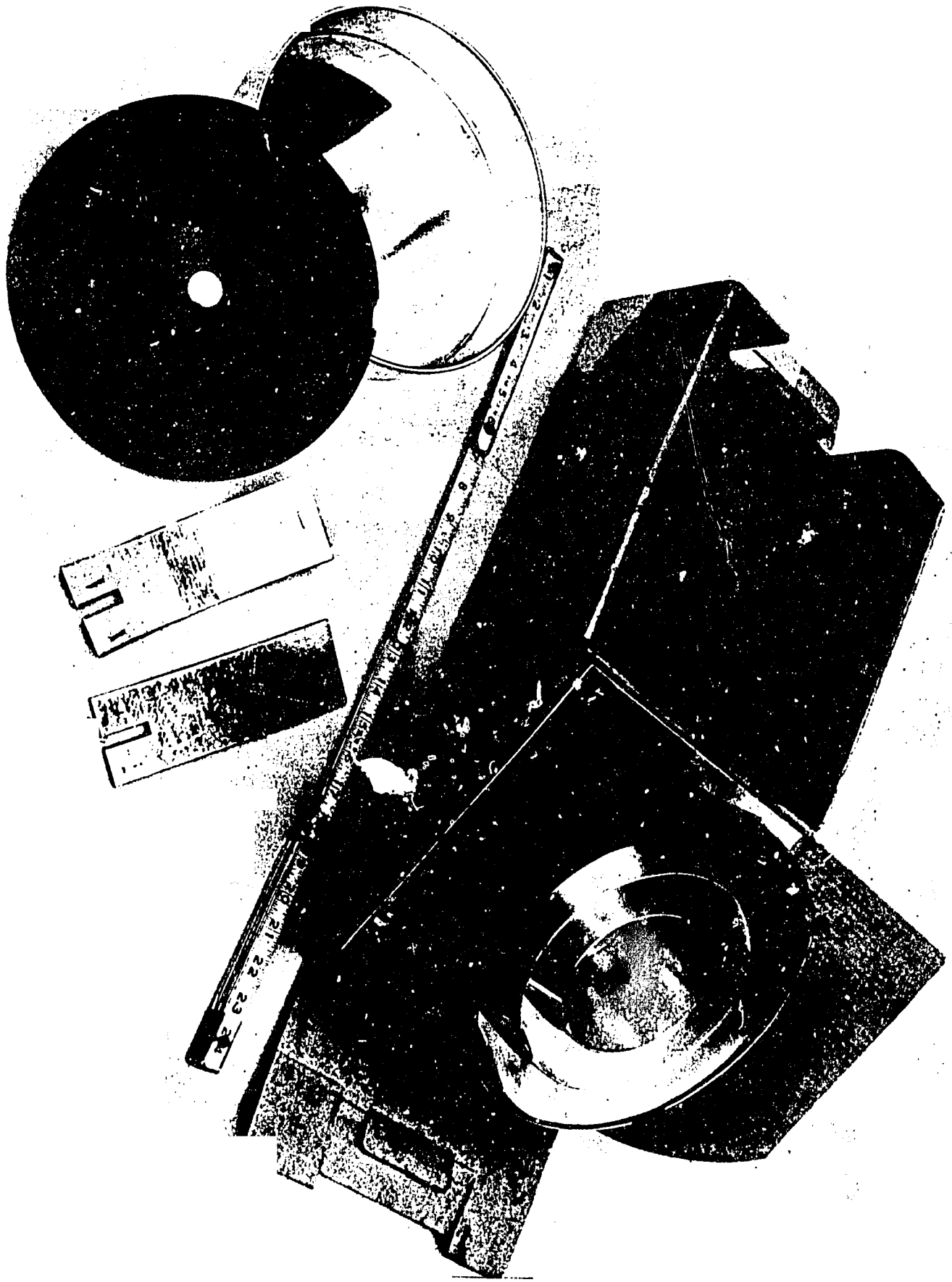
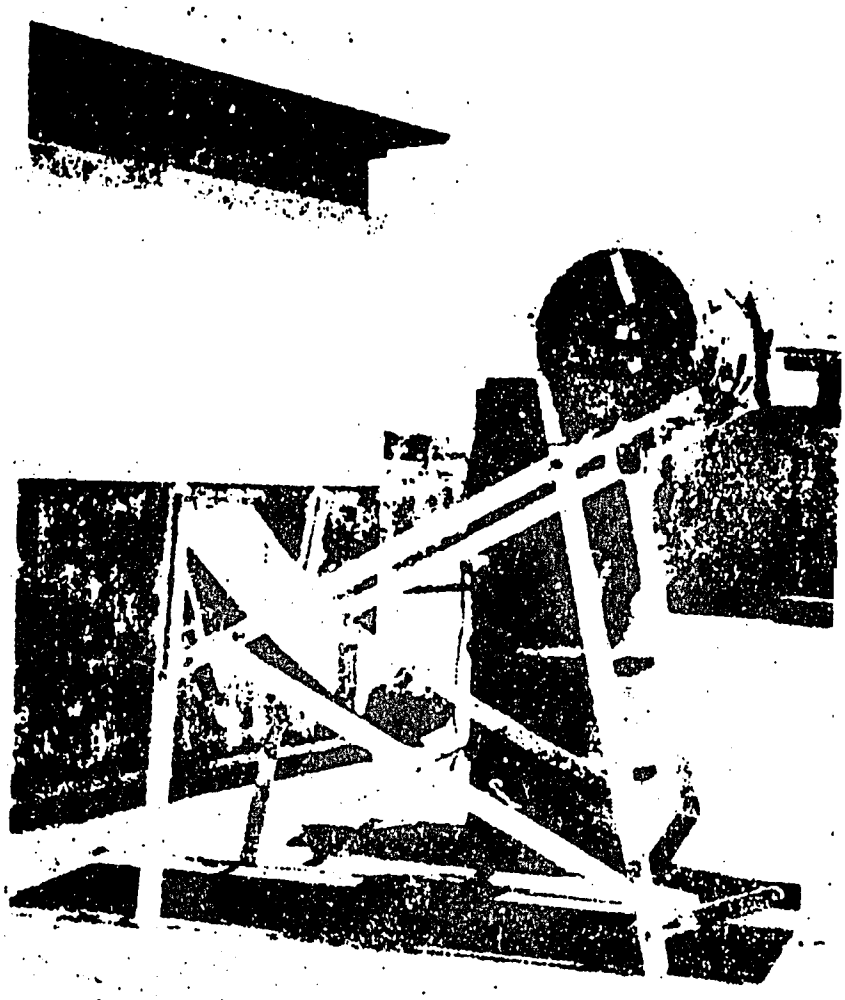


FIGURE 17b



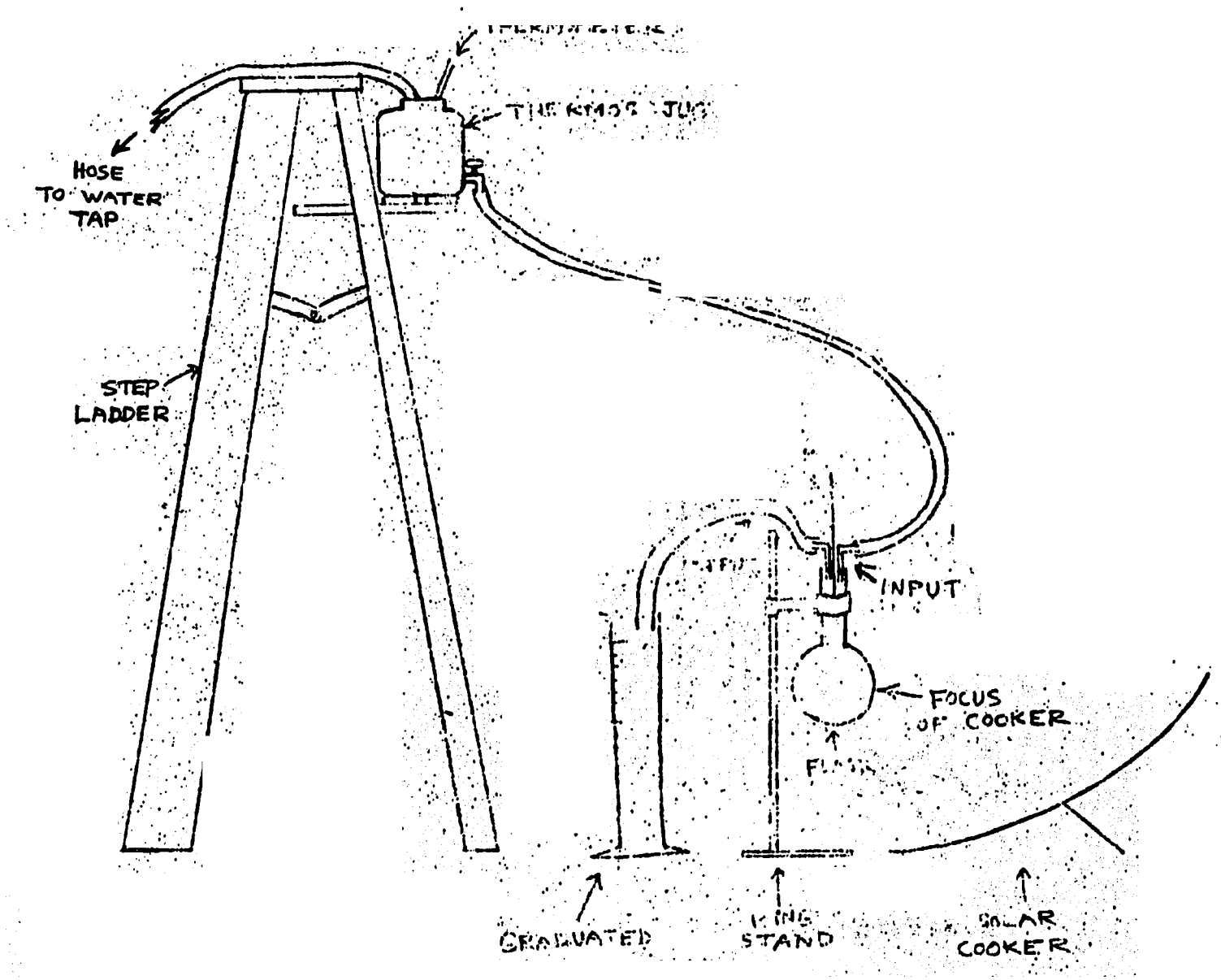
CYLINDRO-PARABOLIC SOLAR COOKER VIEWED FROM THE SIDE OF THE SLIP RINGS.

FIGURE 18.



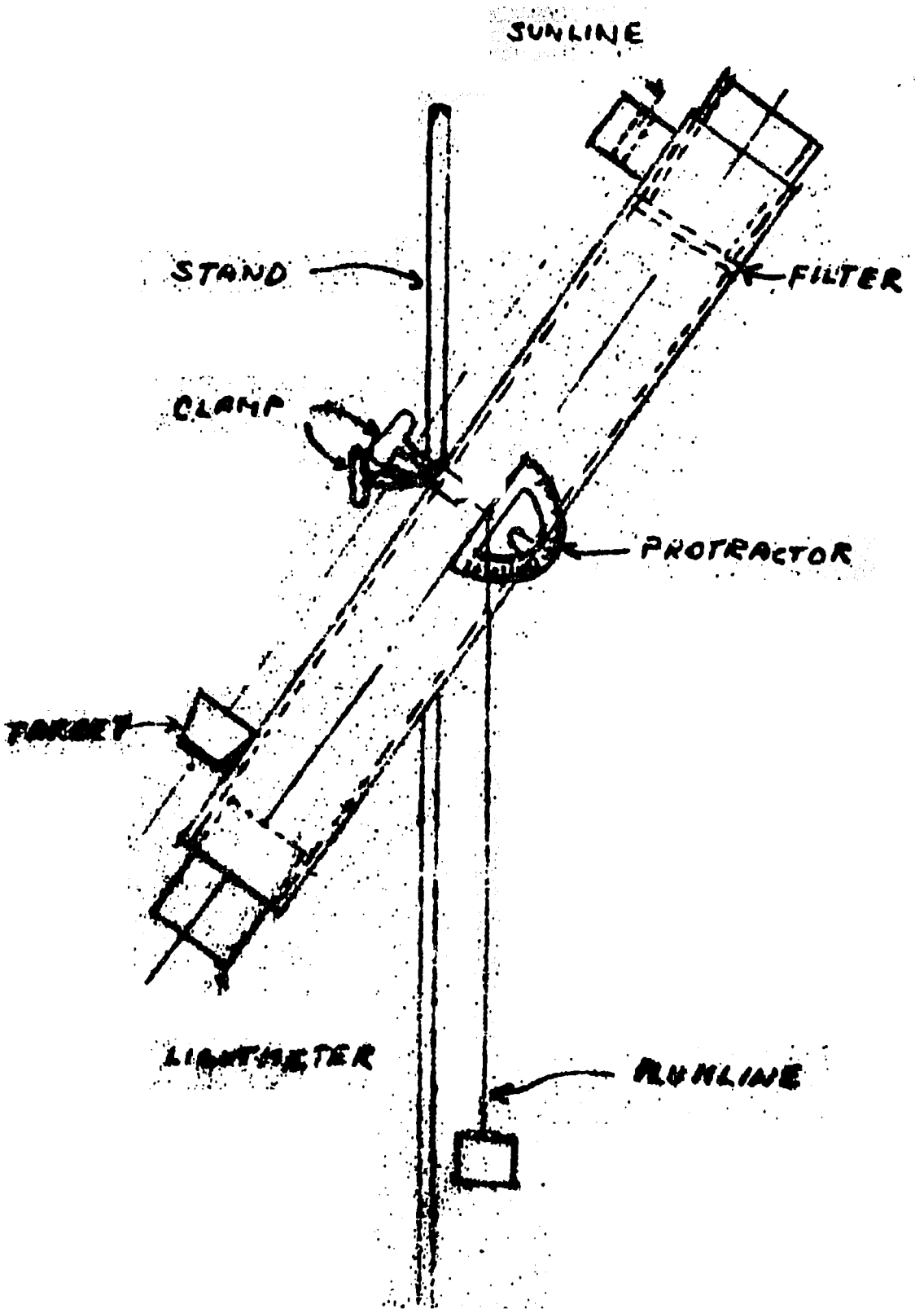
COLORIMETER TEST ARRANGEMENTS

FIGURE 19



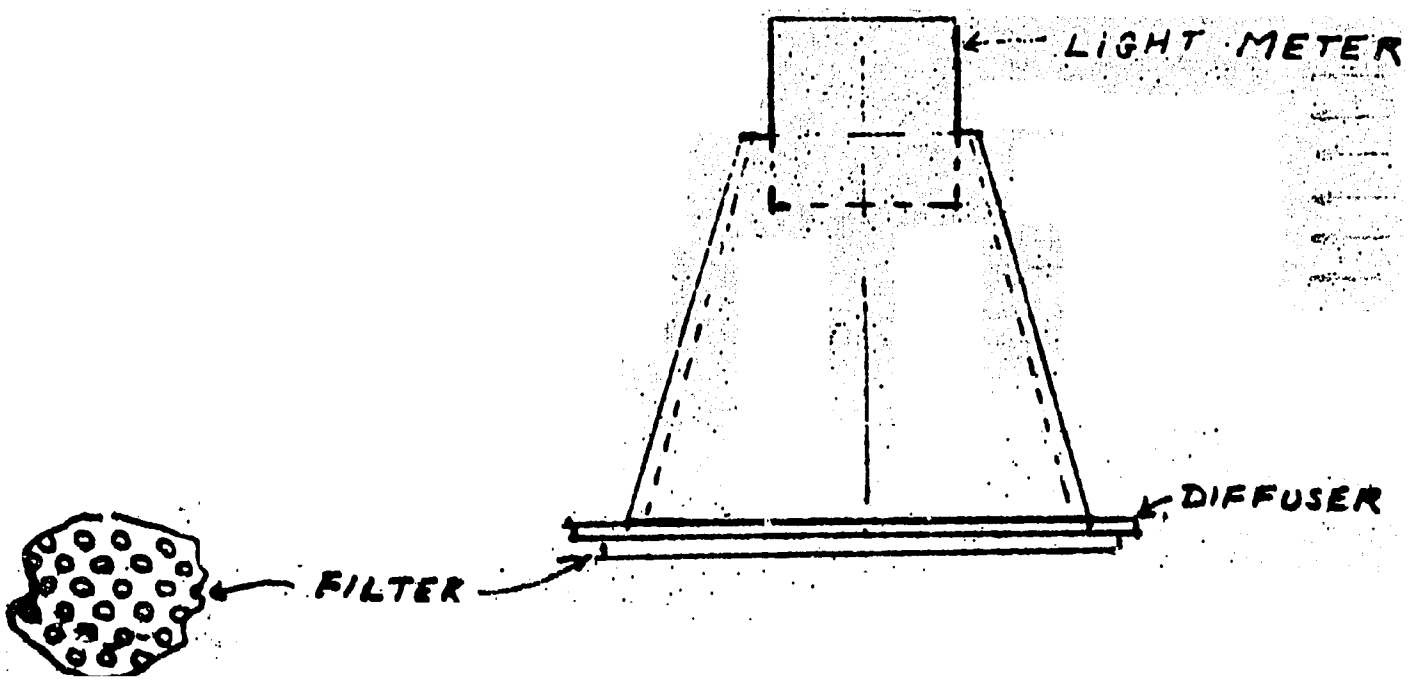
CRUDE PYRRHELIOMETER

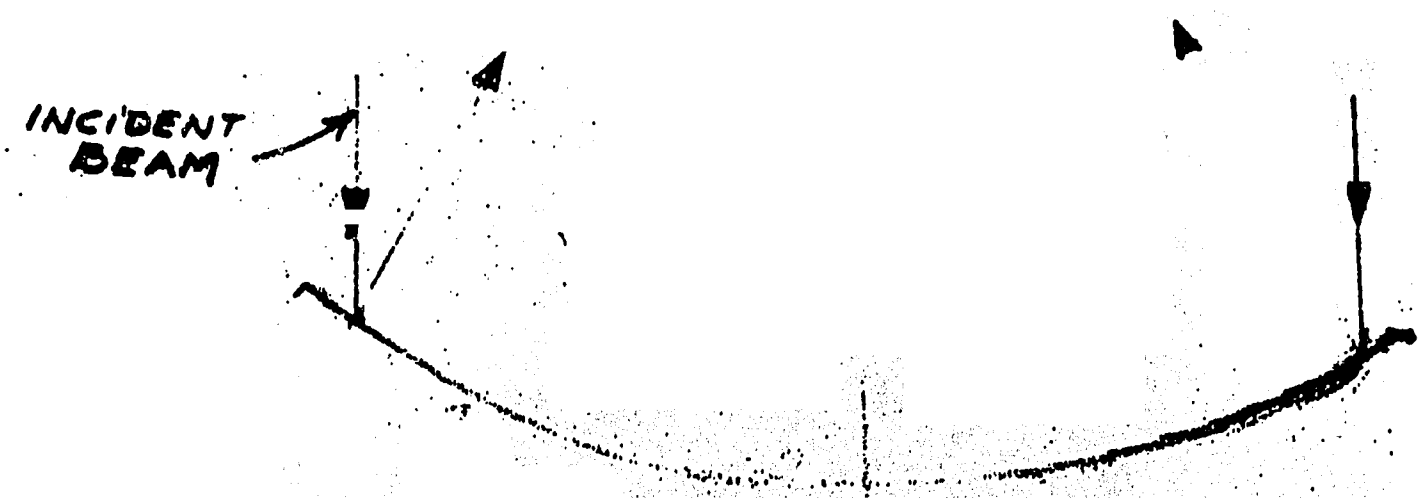
FIGURE 20



ARRANGEMENT FOR INCIDENT LIGHT MEASUREMENT

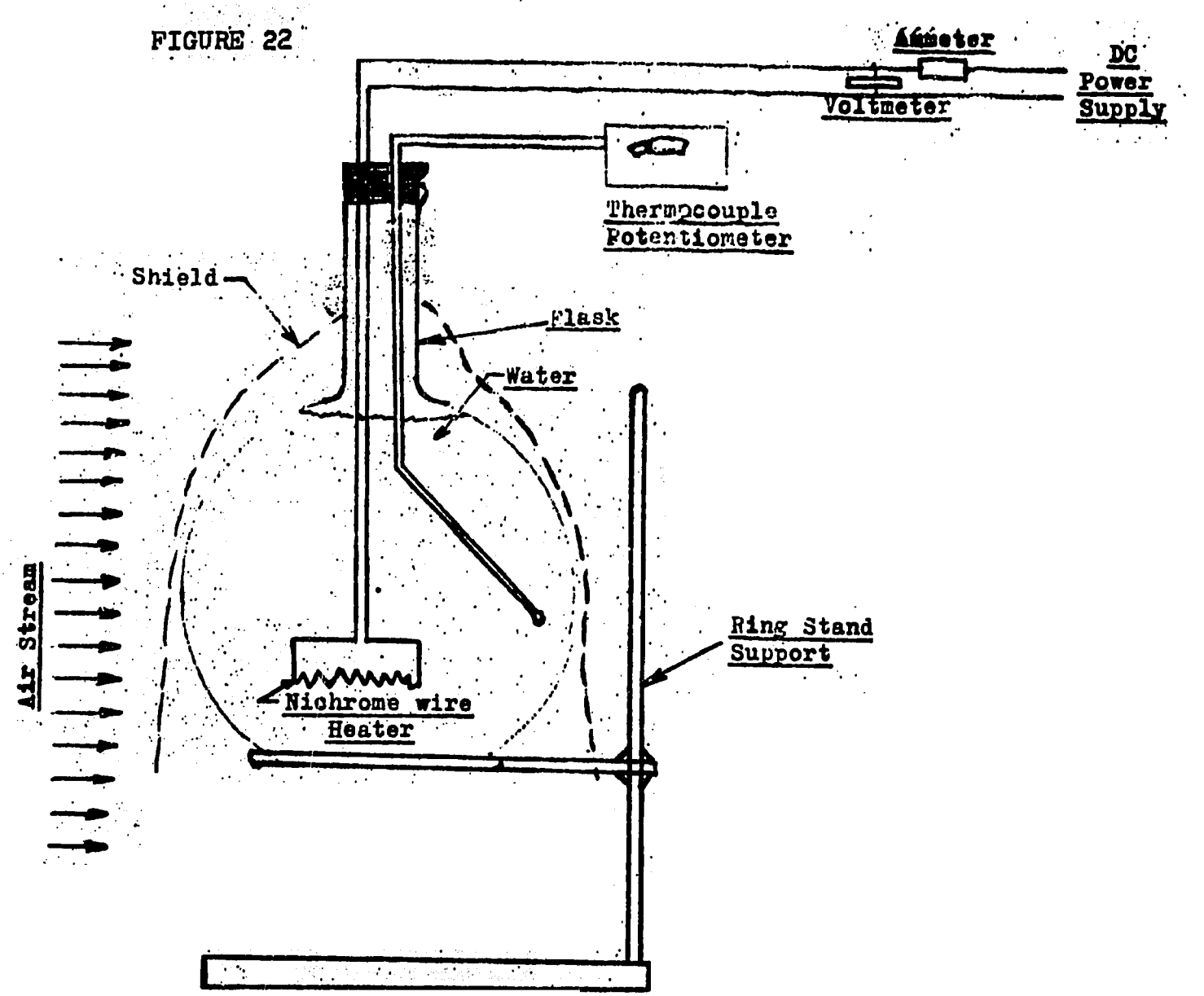
FIGURE 21





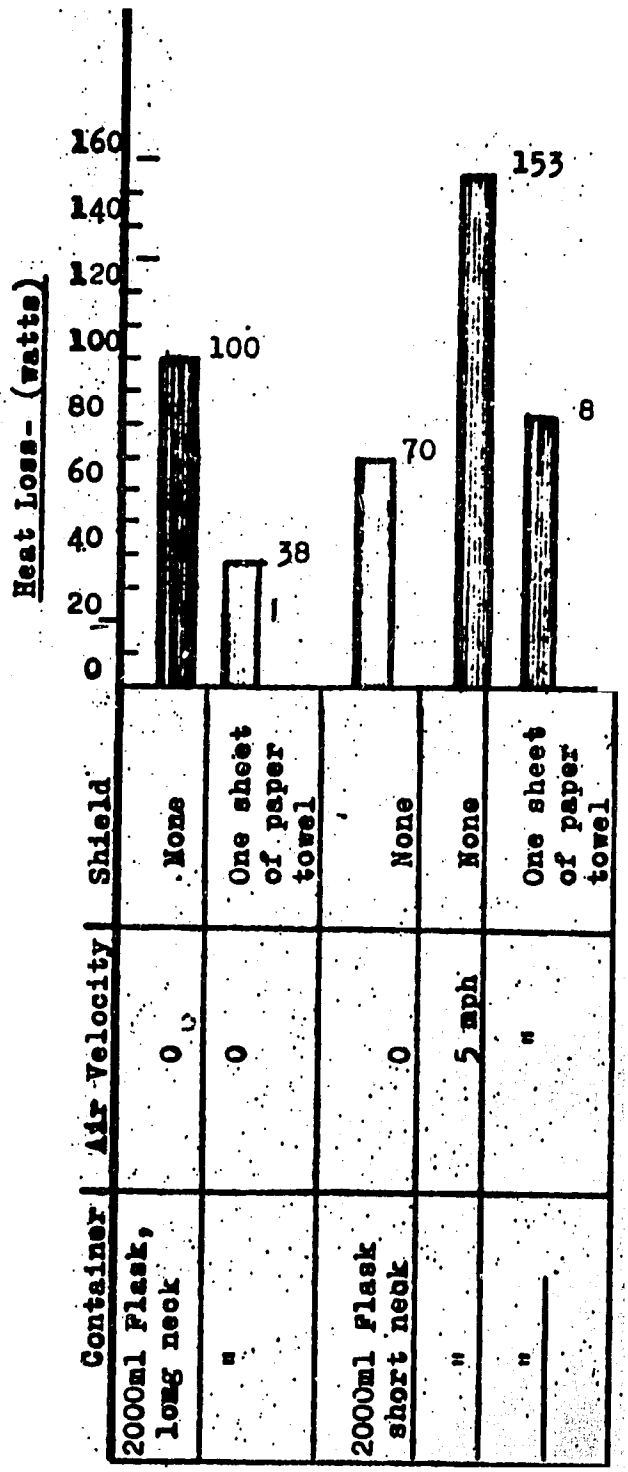
RRANGEMENT FOR HEAT LOSS EXPERIMENT

FIGURE 22



RESULTS OF PRELIMINARY HEAT LOSS TESTS

FIGURE 23



APPENDIX A

Construction Methods for Inflatable Cooker

A particular advantage of the inflatable type is that the small reflector weight of only a few ounces, which makes shipment cheap. This is important because the reflector would have to be produced in a relatively developed country since its manufacture must be carefully controlled in order to attain the proper shape. The frame of the cooker could be constructed in the country where it is to be used from local materials of wood or metal.

The intrinsic cost of both these cookers is well below $5. Materials for the reflective element of the inflatable cooker cost about 50 cents and although manufacturing techniques have not yet been worked out, it is believed that the manufacturing costs could be quite minimal, perhaps $1 per reflector. The frame cost would be largely dependent on local material cost but in general should be low (about $1.50 in U.S.). The pot cost would be similar to that for other cookers.

The inflatable cooker consists, in essence, of a circular air pillow constructed of two sheets of thin Mylar plastic having a diameter of about 4'. One sheet is 1/2-mil aluminized Mylar; the second is 1-1/2-mil clear Mylar. The two are cemented together around the edges and holes, reinforced with 20-mil vinyl plastic tabs at the rim so that the plastic can be lashed or fastened by bands to a suitable frame. The fastenings are used to hold the reflector taut so that when the space between the two sheets of plastic is filled with air, the reflector will form a pillow-like shape. The frame may be made of wood, bamboo, pipe or some other locally available material. The frame of the

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prototype was made of eight pieces of 1" x 3" lumber fastened together at the ends to form an octagon. The reflector is inflated through an air tube formed at the edge of the plastic.

Light from the sun passes through the clear plastic, is reflected off the aluminized inside surface of the reflector, again passes through the clear plastic and is focused upon a spot which can be used for cooking. The amount of air that is blown into the reflector determines the focal length. Focal lengths of about 30" have been obtained in practice.

Mylar was selected as the plastic because of its strength and light weight. The Mylar is quite resistant to abuse and can be repaired, in case of punctures, with a plastic tape. However, Mylar is not very elastic and this causes wrinkles to form around the edge of the reflector when it is inflated, resulting in some astigmatism of the focal spot and waste of energy.

It is believed that this problem can be eliminated either by shaping the plastic through the addition of seams or, most probably, by softening it with heat so the wrinkles can be annealed out. A technique must be developed in the latter case that will avoid introducing other irregularities and which will produce a final shape approaching the ideal spherical section.

It is believed that these reflectors could be mass produced once the proper technique for shaping them is developed. The finished reflector can be easily shipped to any place where it may be needed. There a new frame can be provided and the reflector fastened to it and inflated. Hence, this type would be particularly suitable for areas where transporation is a problem.

The rest of this cooking device consists of a pot holder, which would probably be independent of the reflector frame, and of supports for the frame.

Such an arrangement could consist simply of some legs fastened to the frame and a pole or tripod which might support the cooking pot.

The cooker cannot be inflated by simply blowing into it because moisture in the breath forms a condensation which will probably quickly damage the aluminized surface. A pump, bellows or air bag, can be used to inflate the cooker. However, since the air capacity is quite large, a very large amount of energy would have to be expended in inflating the cooker with a tire pump. Therefore, some cheap pump or bellows design would be required to make the cooker attractive for remote use. It appears reasonable that a design could be made with the use of a small amount of sheet plastic which would be included with the reflector.

APPENDIX B

Test Methods

Performance of any solar device can be described by a heat balance for the solar energy absorbing surface expressed by the following formula:

$$H_{\hat{b}} A_{\hat{r}} r \, Yoc = q_{\hat{u}} + q_{\hat{th}}$$

Here $H_{\hat{b}}$ is the intensity of beam radiation, fixed by weather and time of day; $A_{\hat{r}}$ is the unshaded area of the reflector; and r is the specular reflectivity of the reflector. Y is an intercept factor which denotes the fraction of the specularly reflected radiation which is intercepted by the cooking vessel. It is a function of the accuracy of the reflector shape, the precision of orientation of the system and the size of the vessel, and in a good system properly used is near unity. The absorptivity of the vessel for solar radiation is oc. Useful heat delivered to the contents of the vessel is $q_{\hat{u}}$, and thermal losses from the vessel by convection, radiation and evaporation are denoted by $q_{\hat{th}}$.

A complete performance analysis of a solar cooker would require measurements of all these quantities. However, for a comparison of cookers from a practical point of view a complete analysis is not necessary. Our measurements were therefore limited to the determination of $q_{\hat{u}}$ (the useful heat developed in the cooking pot) as a function of $H_{\hat{b}}$ (the solar radiation). Heat losses ($q_{\hat{th}}$) are discussed in Appendix C.

Measurement of Useful Heat

Three methods were used: empirical cooking tests, measurements of rate of temperature increase, and calorimeter tests.

1. Empirical Cooking Tests. Typical methods of food preparation--such as moist cooking (rice, vegetables, stew), frying (meat, pancakes) and baking (bread, cake)--were tried for each cooker and required cooking times for various quantities were observed. This method is, of course, of prime interest in a practical evaluation, but it is not very accurate for comparison of different cooker designs, since it does not permit quantitative correction for differences in solar radiation, ambient temperature and wind conditions from day to day.

2. Measurement of Rate of Temperature Increase. A better method for comparison of heat production for the cookers is determination of the heating rate of a given quantity of water. This simple method was used during the earlier tests (see graphs in reference 29) and permitted a rough comparison of the various designs. A variation of this method (used during the winter when dry snow was available and when the heat losses at the low ambient temperatures were too large to bring water to a boil) consists in melting a known quantity of snow. The heat needed for melting (79.2 cal./g.) is roughly equivalent to the heat required to bring an equivalent amount of water from ambient temperature to boiling. This method has the advantage of being nearly independent of heat losses due to convection and of the heat capacity of the container, since the container temperature is nearly constant at about 0° C and not much higher than the ambient temperature.

3. Calorimeter Tests. In our later tests a more accurate and convenient method was used. A simple flow calorimeter was constructed as shown in Figure 19. A 1-gallon insulated thermos jug with a bottom spout was used as a reservoir of cold water. A 3-quart Pyrex flask, painted dull black, served as heat absorber. This was sufficiently large to absorb all heat that could be focused

onto a 2- or 3-quart cooking pot. By measuring the flow rate (e.g., the time required to collect one liter of water in the discharge vessel) and the difference in temperature between the inlet water and the outlet water, the heat absorption rate in K Cal/hour could easily be computed. This, in turn, was converted into watts by the conversion:

1 kw. hr. = 860 kcal; or 1 kcal./hr = 1.163 watts.

Measurement of Incident Solar Energy

A conventional method of measurement of incident solar energy is by means of a Pyrrheliometer calibrated in Langley:

1 Langley = 1 cal./sq. cm. = 69.7 milliwatts.

The so-called solar constant equals about 2 Langley/min. This represents the amount of energy received outside the earth's atmosphere and corresponds to a probable radiation of less than 1400 watts per square meter on a surface normal to the incident rays. On the surface of the earth this is reduced to between 800 and 1000 watts per square meter on a clear day. We did not have a Pyrrheliometer available, but constructed a simple instrument for comparative measurements, using a photographic light meter (General Electric type 58). Figure 20 illustrates this device. The light meter is mounted with its slotted cover (filter factor = 10) at the end of a cardboard tube 62 cm. long and blackened on the inside. An additional filter with a factor of 19.3 is mounted at the other end. An aperture with a 1/4" hole (made of a slice of cork) is mounted on the outside near the top of the tube. When the image of this aperture is focused on a target plate at the bottom of the tube the device is pointing at the sun and maximum brightness readings are obtained. A transport is mounted parallel to the axis of the tube and a string and weight permit an approximate reading of the solar angle. We plan to calibrate this device

against the Pyrrheliometer at the U.S. Weather Bureau Station in Ithaca, New York. As our tests are primarily comparative this absolute calibration is not imperative.

Two types of measurement were used to determine the effectiveness of the reflectors: (a) the concentration ratio (the ratio of energy in the spot to the incident solar energy) and (b) the uniformity and size of the focal spot. For cooking purposes the concentration ratio need not be very high. It is more important to have a uniformly heated area matching the size of the cooking pot--approximately 6 inches in diameter. A focal area or spot which is much smaller than the bottom of the pot is acceptable for wet cooking, but not suitable for frying or baking. An area larger than the pot leads, of course, to a waste of energy.

A photographic method was used to record the size and uniformity of the focal spot. A dull finish (sand blasted) plate with a 5x5 cm. grid inscribed was placed at right angles to the incident light. The camera was placed behind the reflector with the lens parallel to the interceptor place to avoid parallel distortion. Figures 7 and 11 show some typical photographs of focal spots.

A relative measurement of the incident amount of light to a 5" area was obtained again using the General Electric photographic light meter. Figure 21 shows the simple arrangement used. The light is reduced to suitable values by a 5" mechanical filter plus a glass filter (1.93% transmission) placed in front of the photo cell. The mechanical filter consists of a perforated brass plate backed up by a plate of opaque diffusing glass. Transmission of this combination is about 15 percent. Readings were taken both in a plane normal to the incident light and in a horizontal plane. The latter values are important when

flat-bottomed cooking utensils are used and vary, of course, as a function of the solar angle. At low solar angles it is desirable to use a globular pot. Where heat can be absorbed on the side as well as the bottom, or at least utilize light falling on the sidewall of the pot facing the reflector. One is thus limited to wet cooking methods at the higher geographic latitudes, particularly during the early and late hours of the day.

The test methods used at present give relative values only, since the combination of photographic light meters and filters does not furnish values directly convertible into heat energy units; however, we believe that the relative values are accurate within 10 percent. We are considering the possibility of making more accurate measurements using a silicon photocell.

APPENDIX C

Heat Loss from Cooking Pots

Since experiments with solar cookers have shown that a slight wind greatly affects the heat loss from pots, tests were carried out (a) to obtain data so that heat loss and incident solar energy magnitude could be compared and (b) to determine simple methods for minimizing the effect of the wind.

Methods

The data were obtained by heating water in 2,000 ml. flasks, 6" in diameter by an electric resistance heater made of nichrome wire. Figure 22 is a schematic sketch of the test arrangement. The electric power was obtained from a DC supply with measurement of volts and amps. The water temperature was measured by a thermocouple immersed in the water. The air temperature, which varied between 82 and 88° F, was measured by a mercury thermometer. The air velocity was measured by probing with a velometer at various points in a plane upstream of the flask

The heat losses were determined at equilibrium conditions, equilibrium being determined by comparison of successive water temperature readings taken at approximately 5-minute intervals. At equilibrium, the electrical power input was equal to the heat loss from the flask. The water temperature was held at approximately 205° F, rather than at boiling (212° F), to simplify detection of equilibrium conditions.

Results

The test conditions and test results are summarized in Figure 23. Results are preliminary.

The paper towel shield was wrapped around the flask to form a crude cone extending below the bottom of the flask. Care was taken to use one thickness of paper only. A test using flannel cloth as a shield yielded results similar to the results with one sheet of paper towel.

Conclusions

1. The preliminary tests indicate that simple shielding can considerably reduce the heat loss in a 5-m.p.h. wind for a 2,000-mil. spherical flask. Similar trends would be expected for pots having other shapes but no tests have yet been performed to check this.

2. The greater heat loss for the long neck flask compared to the short neck flask loss is attributed to the condensation of vapor on the "cool" neck which acts as a condenser. Additional surface also accounts for some of the additional loss.

APPENDIX D

Sun Availability and Radiation Angle

The problem of the usefulness of the solar cooker depends on many variables beside the question of need. These include such factors as the availability of sunlight, angle of solar radiation, atmospheric dust and moisture and actual number of days of sunshine.

Atmospheric dust and moisture are too variable to be considered on more than a local level. In extremely arid regions or near cities dust can be a serious factor. Moisture in valleys or near a coastal area may reduce energy received at the cooker. Yet these factors may become negligible in areas nearby which have some elevation. For example the quantity of received solar energy would be higher in elevated areas of Mexico than along coastal zones where moisture is of importance. Furthermore, valleys will be poor areas whereas the adjacent hills may be excellent for the use of the cookers. The amount of sunshine may also be affected by obstructions. A valley often will have less sun than surrounding areas and in some cases may be in direct sunlight only for very short periods each day. Obviously these factors are better left to the consideration of the inhabitants of the local areas themselves.

Determination of the number of days of sunshine for a given area involves a detailed study of weather conditions over a period of at least 10 years. Such data are available for the United States and for much of the world but it is too voluminous to digest in this report and is better handled locally.

A world map of the annual total hours of sunshine is attached at the end of this report. The reverse side of the map provides a series of references

for weather data in various parts of the world. Simply stated, the map is similar to a topographic map using contour lines. In this case, however, the lines connect points of equal number of sunshine hours per year. All the lines are of equal value whether solid, heavy solid or dashed. The number of hours of sunshine (in hundreds of hours) per year are indicated by a number on that line, e.g., a line numbered 18 indicates that 1800 hours of sunshine can be expected each year in that area. Where several lines converge to become a heavy solid line an abrupt change in the available sunshine hours per year can be expected across that line. For example, in central Mexico about 2400 hours of sunshine may be expected each year. However, along the east coast and south west along the Yucatan Peninsula the changes are abrupt from the coastal areas toward the interior.

The angle of solar radiation for a given area may be determined by reference to Table 170 (Solar Altitude and Azimuth) of the Smithsonian Meteorological Tables, Sixth Revised Edition, 1951, published by the Smithsonian Institution, Washington, D. C. The azimuth portion of the tables will provide data on the daylight hours at various latitudes during the various months of the year. It is merely necessary to determine the latitude of the area under consideration, locate that position on the diagrams for that latitude and by reference to the various dates determine the extremes of that angle of solar radiation based on solar time. Where these tables are unavailable, a general rule may be followed: North of latitude 40° north and south of latitude 40° south the angle of solar radiation (altitude) is less than 25° during half the year. This general rule is useful since it is based on a 50 percent cut-off as a basis of evaluating the minimum utility of the solar cooker. Also the efficiency of the cooker is apparently low when the angle of solar radiation

is below 25° from the horizon. If the angle of radiation is less than 25° for half the year the solar cooker appears to be of marginal usefulness. The 40° north and south latitude figures are, of course, not precise but are reasonable approximations. Virtually all developing countries where the cooker might be useful fall between these parallels.

APPENDIX E

The Fresnel Reflector Cooker

The use of the principle of the Fresnel reflector in the VITA solar cooker is thought to be unique among the various known solar cooker designs. Such a reflector is able to concentrate light and heat by means of several simple curved reflecting surfaces. This is in contrast to the doubly-curved reflecting surface typically found in the more conventional designs of reflective cookers. Not only does the Fresnel design facilitate easy construction by skills and tools available in small work shops, but it also provides a number of advantages in operational performance. The complex parabolic dish-shaped reflectors typically require relatively sophisticated fabrication techniques of metal spinning, plastic molding, or die-pressing. Furthermore, this type of concentrating reflector must purposely be defocused because the extremely high degree of heat concentration of which they are capable is undesirable from the points of view of safety and cooking performance. Ideally, the heat rays which the concentrator collects should be reflected to impinge uniformly over the entire cooking surface. The Fresnel reflector provides such a broad uniform focal spot. Within very wide limits, any desired diameter of the focal spot, or focal length, can be produced by the designer. In addition, the total area of the reflector can be selected in accordance with the desired power output or "effective wattage" of the cooker.

The Fresnel cooker described in this report was designed to provide:

1. Adequate heat output to provide for the cooking needs of a small family unit. This requires that a reflector area somewhat in excess of 1 square meter be used.

2. Use of the cheapest, readily available materials, consistent with satisfactory service and performance.

3. The simplest design possible consistent with convenience and simplicity of construction and use. In the United States these material requirements are met by the use of Masonite sheet, aluminized Mylar, wood, and iron strip as the main construction materials.

It should be observed that because this cooker was designed and its construction outlined in such a way as to use the cheapest materials, it requires a rather large amount of labor as compared, say, to a single aluminum spinning. Thus, in the United States, the construction cost per cooker may not look relatively so attractive. However, as the objective was cheap construction in rapidly developing countries, this should not be used as a criterion.

INTRODUCTION

The unique feature of this solar cooker as compared to others lies in the use of a so-called Fresnel reflector. The important characteristic of this reflector is that it has no compound curvature; rather, it possesses simple reflecting surfaces bent in one direction only. This significantly facilitates construction since a flexible reflecting surface can be readily deformed by bending into the required shape. In contrast, the complex surface of the other types of rigid reflectors require a cumbersome metal spinning or plastic molding operation.

At the time of this writing about 10 Fresnel reflector cookers have been constructed; those tested have been found to perform satisfactorily in cooking tests. No attempt was made to optimize systematically all of the material and design variables. Furthermore, the best choice of materials for local construction may vary from place to place. Instead, the efforts were directed to

evolving a more or less general design which is capable of being modified to accommodate local needs and materials. For example, very little effort has gone into selecting the best woods, or in constructing reflecting surfaces out of alternate materials which might be more readily available in other countries. Any sheet material such as plywood or certain sheet metals should be a satisfactory substitute for the Masonite. It is possible that even certain types of thin unlaminated wood could also be used, although this would require a modified construction procedure.

Even though every attempt was made to simplify the construction, a certain amount of experience and skill must be developed in order to attain the necessary proficiency. It is strongly recommended that anyone using this report to construct this type of cooker should work out construction techniques on several preliminary prototypes. From the experience in the development of this cooker, learning how to apply the aluminized Mylar onto the Masonite or other backing will probably require a few trials.

DESIGN PRINCIPLES

The principal component or a solar cooker is the reflector. However, the design of the cooking pot support and the reflector legs must provide for simple, convenient cooking and for the necessary adjustments in following the sun's position. A reflector possessing a desired focal length, focal spot diameter, and total reflector area can be most easily designed by geometrical construction, making use of the fact that the angle of incidence equals the angle of reflection. A five-inch diameter focal spot and a thirty-inch focal length were adopted to match the dimensions of typical cooking pots and to place the "burner surface" at a convenient height. The geometrical construction as given in Fig. A at half scale represents the cross-section of the cooker shown in

Fig. B. Reflectors possessing any desired set of characteristics can be designed as follows:

From the base line (passing through points p and T) construct the center line at point P perpendicular to the base line. The length of the center line p O determines the focal length. At point O, construct the line AB parallel to p T. The points A and B are marked off symmetrically around O, and determine the diameter of the focal spot. The points a and b are similarly marked off on the base line at the same distance from the center line. Now mark off the point p', the distance p p' being equal to the focal spot diameter AB, and construct the line Op' and the line p'R' perpendicular to the base line. The line p'R' represents a direct ray of sunlight, which is reflected at point p' in the new direction p' O until it impinges on the center of the cooking vessel placed at point O. The angle Op'R' is equal to twice the angle of incidence. Hence the reflecting surface must be constructed perpendicular to the bisector of the angle Op'R' at the point p'. The length of the reflecting surface a'b' is such that the projection of a'b' on the base line is equal to the focal spot diameter.

The placement of the more remote annular rings follows a slightly different procedure, because the outer edge of the immediately preceding inner ring may interfere with the reflection from the inner edge of the outer ring. This is avoided as follows: construct the ray Ab' intersecting the base line at d and extending somewhat beyond. Mark off point e such that segments cd and de are equal. From point e mark off the point p'' at a distance equal to the focal spot radius. Construct the reflected ray p''O, and the direct ray R''p'' and proceed as previously described for the innermost ring. This procedure is repeated until as many rings as desired are constructed.

The angle that the reflecting surface a''b'' for example forms with respect to the base line is given by $\theta = 1/2 \arctan \frac{p\,p''}{Op}$. It is now necessary to consider how to produce a reflecting cone possessing such an angle out of originally flat material. If a sector of angle φ is removed from a flat circle of original radius R, a cone is produced. This is shown in Figs. C and D. Such a cone has a base radius of r and a cone angle θ which are related to the circle from which the cone was constructed by:

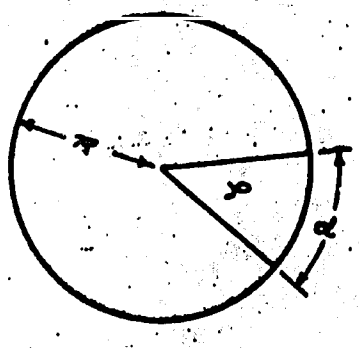


Fig. C

$$\varphi = 2\pi (1 - \cos \theta) \text{ radius}$$

$$\varphi = 360 (1 - \cos \theta) \text{ degrees}$$

and $r = R \cos \theta$, $d = 1/2\ 2\pi R (1 - \cos \theta)$.

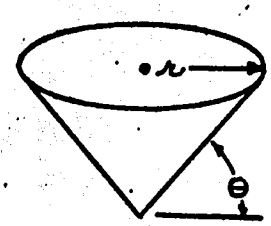


Fig. D

Of course, for our purposes we are only concerned with producing segments of cones. Thus, the various concentric reflecting rings can be produced by cutting a single flat sheet of material into rings of appropriate dimensions. Then the rings are formed either by removing angular sections and rejoining, or by splitting the various rings and overlapping the ends the corresponding amounts.

CONSTRUCTION DETAILS

The annular rings, which are formed into conical sections, are supported at 90° intervals, on a wooden frame formed from two crossed pieces of 3/4"x4" wood. These pieces have notches of angles and dimensions determined from the geometrical construction given in Fig. A and described in the preceding section. The template given in Figs. E and F is designed to match a reflector having a 5" focal spot and a 30" focal length. Alternatively, the dimensions and specifications are given as follows:

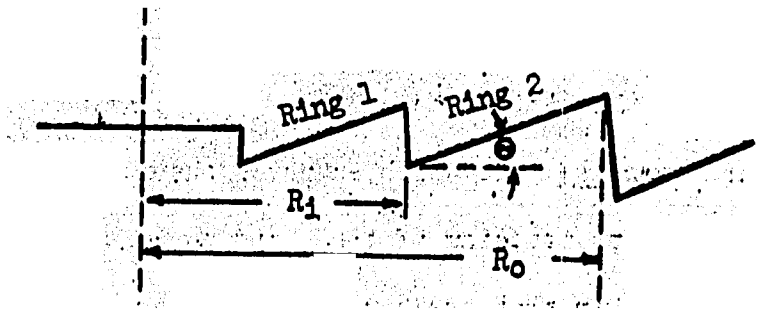
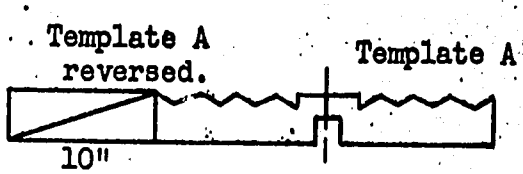


TABLE I

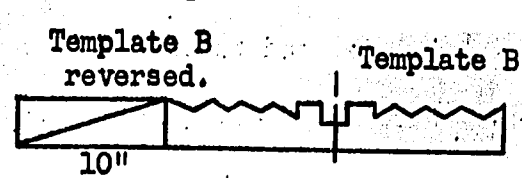
Ring number	1	2	3	4
Inner radius R_i	2-1/2"			
Outer Radius R_o	7-19/32"	12-27/32"	18-13/32"	24-15/32"
Wedge angle θ	4.8°	9.5°	14.0°	18.1°
Tan θ	0.084	0.168	0.249	0.327

The mid-point of each wedge must lie on the base line of the construction. This is <u>not</u> the top edge of the board. It is very important that the angles of the wedges be cut to exact specifications in order that various rings all focus at the same place, and to avoid introducing unnecessary astigmatism. For convenience in laying out the angles precisely, the tangents of the angles are given in the above table, i. e., the ratio of the depth of the wedge measured from the base line to the length of the wedge measured along the base line.

For the prototypes prepared to date, normally 1" x 4" lumber (3/4" x 3-5/8" actual dressed dimensions) has proven satisfactory for these cross-supports. Both hard (oak) and soft (pine) woods have been used. The oak offers substantial strength advantages over the pine, and has less tendency to split. Templates such as shown in Figs. E and F are used to lay out pattern.



added leg on
Template A reversed.



added leg on
Template B reversed.

The lower portion of each cross-member is extended and cut at an angle to serv as legs for the reflector. The angle at which the legs are cut is not critica although an angle somewhat sharper than 45° is recommended. By placing the le points on the edge of the board opposite that which supports the reflector, certain complications regarding the positioning of the third support for the cooker are avoided. Care must be taken that the notches which permit the cross members to overlap are cut on the proper sides and are cut to make a tight fit. It is very important that the wedges which support the rings are cut out as accurately as possible for proper alignment of the rings. Having cut out the supporting members, these two pieces are set aside and attention is given next to the reflecting rings.

The rings are cut out of a sheet of 4'x4'x1/8" Masonite in such a way as to make use of as much of this area as possible. Preparing the rings consists of two operations--mounting the reflective material to the Masonite and cutting and mounting of the rings.

A variety of techniques and materials have been investigated for applying a reflective layer on the Masonite. Although even the best procedure has certain shortcomings, several satisfactory alternatives exist.

Masonite comes in tempered, i.e. designed to out-door use, and untempered or interior grades. The interior grade is appreciably cheaper. Since the Masonite is covered with an impermeable reflective coating on the top surface, and can be sealed on the under surface, this material should be satisfactory. However, for initial field studies, it is probably advisable to use the weatherable grade, and to determine subsequently whether the interior grade can substitute satisfactorily.

The reflective material investigated has included paper-backed aluminum foil, aluminized vinyl and aluminized Mylar R. The vinyl and Mylar sheeting come in various thicknesses, and the Mylar comes in a standard and a "weatherable" grade. The plastic can be applied with the aluminized side out or the plastic side out. In addition, and in part depending on the choice of the above, consideration must be given to the adhesive used.

Ideally, a highly reflecting painted surface would be most convenient. As a result of a suggestion offered at an AID meeting, an investigation was undertaken of the feasibility of using aluminum paint, applied over a well-prepared and sealed Masonite surface. This spray painted aluminum surface was further sealed with a clear plastic spray. Although the total reflectivity of such a surface is high, the specular reflectivity was only about 1/4 as efficient as the aluminized plastic. Hence, this approach was abandoned.

Among the various adhesives investigated are: (1) contact cement; (2) asphalt sealing compound; (3) rubber cement; (4) shellac; (5) du Pont thermoplastic cement No. 46971, recommended for joining Mylar to Mylar; (6) alkyd resin varnish; (7) a polyester resin used for sealing fiberglass boats; (8) asphaltum paint. All of these were successful to some extent and may provide suggestions for alternative materials which may be locally available. We have found that asphalt sealer, the thermoplastic cement, and the polyester resin to be the most satisfactory, with the asphalt sealer somewhat better than the other two. The major difficulty is that when the rings are bent to form the conic sections, the plastic sheet is placed under compression, and the sheet tends to lift off and to form bubbles. This can largely be eliminated by use of the proper construction techniques, as will be discussed later.

TOOLS USED

The rings can be cut out of the Masonite sheet using a suitable hand saw Most of our prototypes were constructed with the aid of a power sabre saw. This saw was also very convenient for cutting out the support wedges. A ligh 1/4" electric drill was also useful for drilling holes in the wood and iron parts of the cooker. No other power tools were used. A 4" bench vise, plus common hand tools, e.t. hack saw, file, hammer screw driver, cross-cut saw, coping saw, etc. were used.

PROCEDURE AND MATERIALS FOR CEMENTING AND CUTTING REFLECTING RINGS

Because the flat sheet material must be subjected to elastic strain in order to form the conical segments, there is a tendency for the reflective sheet material to lift off of its supporting surface. Several avenues are open for solving this problem: (1) use of very strong adhesives; (2) use of thinner gauge plastic reflective sheet; (3) relieving the stresses in the plastic sheet. Actually combinations of all of these have been used in improving the quality of the prototypes.

Although some possible gains in durability, and in optical smoothness may accrue from the use of heavy gauge Mylar, our experience suggests that .0005" Mylar offers substantial advantages in having a significantly lower tendency to form blisters and air pockets than did .001" or .002" Mylar sheet. Furthermore, since the cost of this sheet is roughly proportional to thickness, there is also a cost advantage in the use of the .0005" Mylar.

The various types of adhesive require differing techniques to produce satisfactory surfaces. Some types of adhesives are of the thermo-plastic type; i.e. upon the application of warmth and/or pressure, a bond can be made and

remade a number of times. If the placement of the plastic is not perfect, then the plastic sheet can be pulled off and re-bonded in an adjusted position. Typical of such adhesives are asphalt, and the du Pont adhesive. In some other types, the plastic must be positioned perfectly without any adjustment possible. Rubber cement and contact cement are of this type. The bond is very strong, but air bubbles and wrinkles are difficult to remove if once formed. In a third class the adhesive is fluid and allows adjustments of the plastic to be made. However, the adhesive "sets up" due to solvent evaporation or a chemical reaction. The polyester fiberglass-type resin, and shellac are typical of this class. In all cases some experience is needed to learn just how much "tackiness" the optimum for each type of adhesive.

In all types it is most important that the Masonite surface be sanded smooth, and in some cases sealed to prevent the adhesive from soaking into the sheet. All dust must be carefully removed, a clean brush or applicator must be used, and every effort must be made to have as smooth a coating of the adhesive as possible. The aluminized Mylar reproduces the texture of the adhesive coated surface, and much specularity is lost if the surface is rough.

Whatever method of application is used, it should provide a very uniform, even, smooth surface. The consistency of the adhesive, the preparation of the surface to which it is applied, the temperature of the adhesive and the surface and the cleanliness of the tools and area are all significant factors. We have found that brushing, and rolling on the adhesive are both effective. We did not have equipment for spraying. However, this might offer substantial advantages.

Each type of adhesive used had its own idiosyncrasies. We encountered great difficulty with contact cement in trying to apply it smoothly. Invariably when the Mylar film was applied, a multitude of small bumps, brush marks, etc. became apparent. The polyester resin was especially convenient to use. The backing surface must first be sealed with thinned shellac, for example. However, the Mylar should form a blister or should pull away from the backing surface once the resin has set, it cannot be rebonded without applying additional adhesive. The polyester resin on the whole seemed to offer considerable promise.

The du Pont adhesive #46971 is a thermoplastic resin that must be applied to both the Myler and the backing surface. Heat and pressure are required to make the bond. A home electric clothes iron proved convenient for this purpose. With the heavier gauges of Mylar considerable difficulty was encountered in avoiding bubbles and wrinkles. If the iron is too hot, the Mylar shrinks. If the iron is too cool a satisfactory bond does not result. Although a satisfactory bond can be made, especially with .0005" Mylar, this technique is relatively slow, and requires considerably more skill than required of some of the other adhesives.

The most successful, and cheapest adhesive was the use of an asphalt foundation sealing compound which is normally used to render the outside walls of cellars waterproof. If this material is rolled onto the backing surface and also lightly on the Mylar surface to which the bond is to be made, a good seal can be made that can be remade any time in the future by applying pressure. Such a bond tends to produce air blister if the Mylar is under stress, but it also allows the stresses to be relieved most conveniently as is described subsequently. It is necessary to seal the backing surface with a previous coating

of asphalt or with thinned shellac, before applying the final coat of asphalt. Care must be taken not to build up too heavy a layer of asphalt or the asphalt will flow under the Mylar as stresses are relieved or as the solvent evaporates, with a resultant puckered surface. As much solvent as possible should be allowed to evaporate off before the bond is made, although the asphalt should feel tacky to the touch. There is advantage to working in a high room temperature (80-90°F) as more solvent can be evaporated off and still retain a tacky surface. The more glass-like is the appearance of the asphalted surface, the higher quality reflector is produced.

Handling the very thin Mylar sheet also presents some awkwardness, especially if the Mylar should make unintentional contact with the adhesive surface. It was found convenient to use a wooden form, somewhat larger than the Masonite sheet. The Mylar sheet is tacked to this support frame. By placing the support frame over the adhesive coated sheet and pressing down on the taut Mylar, contact is made only where desired. Especially important is the convenience this offers in applying the Mylar while avoiding the formation of trapped air pockets. By applying pressure always from the already bonded areas in the direction of the unbonded areas, using a clean cloth or the hands, a very satisfactory bonded specular surface can be produced. After bonding, the rings are cut out of the coated Masonite. This sequence is not absolutely necessary. However, if the rings are cut out before the cementing operation, they must be nested to form a flat surface. It is somewhat more difficult to apply an even coating of adhesive, and some fiber fragments usually pull off of the sawed edges, resulting in a less perfect reflecting coating.

If contact cement or rubber cement is used, the cementing operation must be done with particular care if undesirable wrinkles and air pockets are not to result. If asphalt or the polyester resin is used as the adhesive,

considerable more latitude is available to the fabricator. In the latter case, it is desirable to form the rings into the conic segments as soon as possible because the stress on the Mylar will lift off the sheet, even though the bond is very tight when the Masonite sheet is flat.

When the rings have been formed into conic sections, the initial cementing must be considered to be a "basting" operation which aligns the plastic sheet properly with respect to the Masonite. The Mylar is then slit across the width of a ring, and is carefully stripped off of a sector of the ring, (taking care that no dirt falls on the adhesive surface), and is then carefully rebonded using pressure. The pressure is always applied from the already bonded areas to the new areas to avoid wrinkles and air pockets. This procedure removes the stress on the Mylar and avoids the formation of wrinkles and blisters upon standing. When the stress has been relieved in one sector, the procedure is repeated on another sector until each ring has been completely treated.

The rings can be formed into conic sections by securing them by nails to the wooden cross supports. If the templates given in Figs. E and F and the dimensions given in Table I are used, it will be necessary to notch out the rings in order that they fit on the supports. This is preferable to notching out the support pieces as this would weaken the support frame. Furthermore, notching the rings tends to make a more rigid structure, as the notches lock the wooden members in place. Care must be taken that the outer rings in particular are mounted symmetrically, otherwise the rings will not reflect at a common focus and will introduce astigmatism. Although this was not done in preparing our prototypes, it might be desirable to have a mounting fixture to insure proper alignment of the reflecting elements. Such a fixture could be constructed as is shown in figure G.

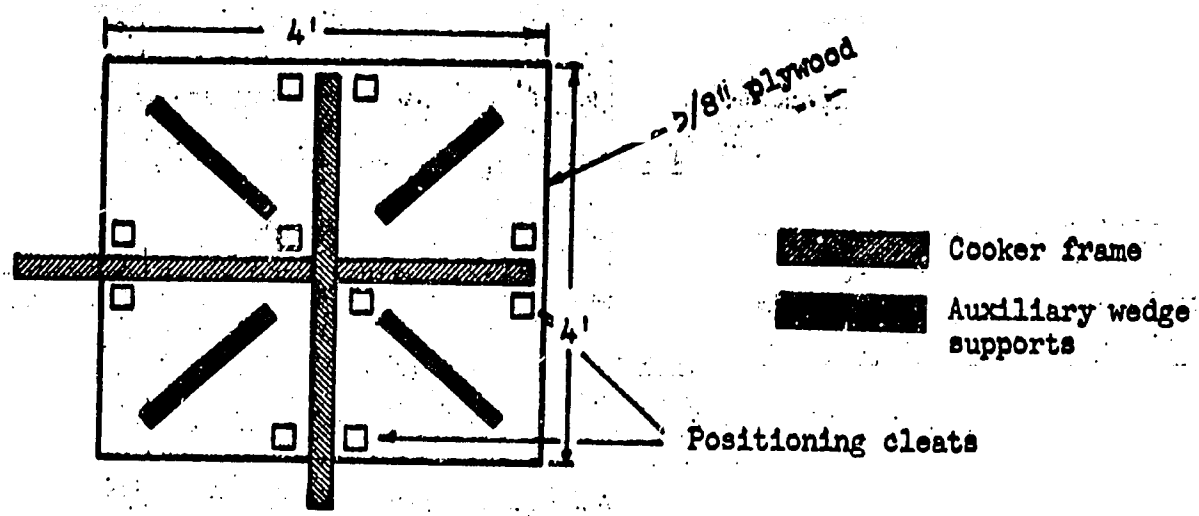


Fig.

COOKER SUPPORT

Having mounted and properly oriented the rings and stress-relieved the plastic, we now focus our attention on the leg supports and on the cooking pc supports.

Whatever scheme is used for supporting the cooker, it must (a) hold the reflector securely in the desired orientation so as to make best use of the sun; (b) provide for convenient adjustment; (c) be as simple and sturdy as possible. We have tried two tripod arrangements. In the one the end of one of the wooden cross-supports serves as a leg, around which the cooker can pivot; the other two legs are combined to form a large metal ⊔ -shaped bracket. The ends of the upright members are attached to the other wooden cross-support, near to the outer edge, with the base of the "U" lying on the ground. By placing a stone on the base, the cooker can be anchored against wind gusts, etc. However, using this arrangement the reflector is not as stable toward a flexing motion. This might weaken the cooker with usage and was a

possible source of accident if the cooking pot support is an integral part of the cooker.

In the second arrangement, the ends of the two of the cross-supports form two of the legs of the tripod, and a third leg was hinged to a piece of wood which bridged across the other two arms of the cross-support frame. Actually two legs were attached here--a long one to be used when the sun was low in the sky, and a short one to be used with the sun nearer the zenith. The most convenient lengths of the legs in the Schenectady area were 30" and 15". However, at lower latitudes, shorter legs would be more convenient. This design holds the reflector more securely with respect to flexing. It is only slightly less convenient to adjust the cooker position to follow the sun. In regions where heavy gusts are common, it may be desirable to anchor the legs with stakes or pins driven into the soil. It must be recalled that the wind stability problem was much less severe with the Fresnel design compared with the other designs that we were able to test. However, because of the large surface area of any effective reflector cooker, they will all tend to behave somewhat like kites in a heavy wind.

In our cooking tests we have found that both of these designs offer no marked disadvantage from the point of view of convenience. However, the arrangement employed in the Wisconsin cooker shown in Fig. 1, is undoubtedly even more convenient. It may be that in certain areas, the additional expense of such a scheme will be offset by the increase of ease of orienting the reflector, and less handling of the pot while adjustments are being made (once every 20-30 minutes).

A variety of arrangements can be used to provide a suitable "grill" upon which to place the cooking pot. For optimum performance, the pot should be placed so that all of the reflected light falls on it. By arranging the grill so that it is automatically in the focal spot, the cook need merely be concerned with seeing that the reflector is aimed at the sun. The pot support that we have evolved accomplishes this in a low-cost easy to construct manner. If this arrangement is not the most useful for a particular area, it is strongly suggested that alternatives be investigated. Among the alternatives are the very convenient combined reflector and pot support shown in Fig. 1. (Part I) This is a more costly and difficult to make design. On the other hand, even simpler--but probably significantly less convenient--arrangements are shown in Fig. K.

The pot support arrangement that we have incorporated into the present design corresponds to that which has been tested by Dr. E. Fehr and was found convenient in cooking tests. The support consists of a 1"x1"x30" wooden rod, which is clamped to the corner formed by the intersection of the two cross-supports. The clamp is formed in the shape of a W. One leg of the clamp is permanently secured, and the other end is fitted with a bolt and wing-nut so as to be able to apply pressure on the pot-support rod. This is shown in Fig. H. An even simpler method of clamping, shown in Fig. I, is in some respects even more satisfactory and is just as convenient to use. There is the danger of losing the wing-nut, etc. when the pot support rod being placed into or removed from the position of use.

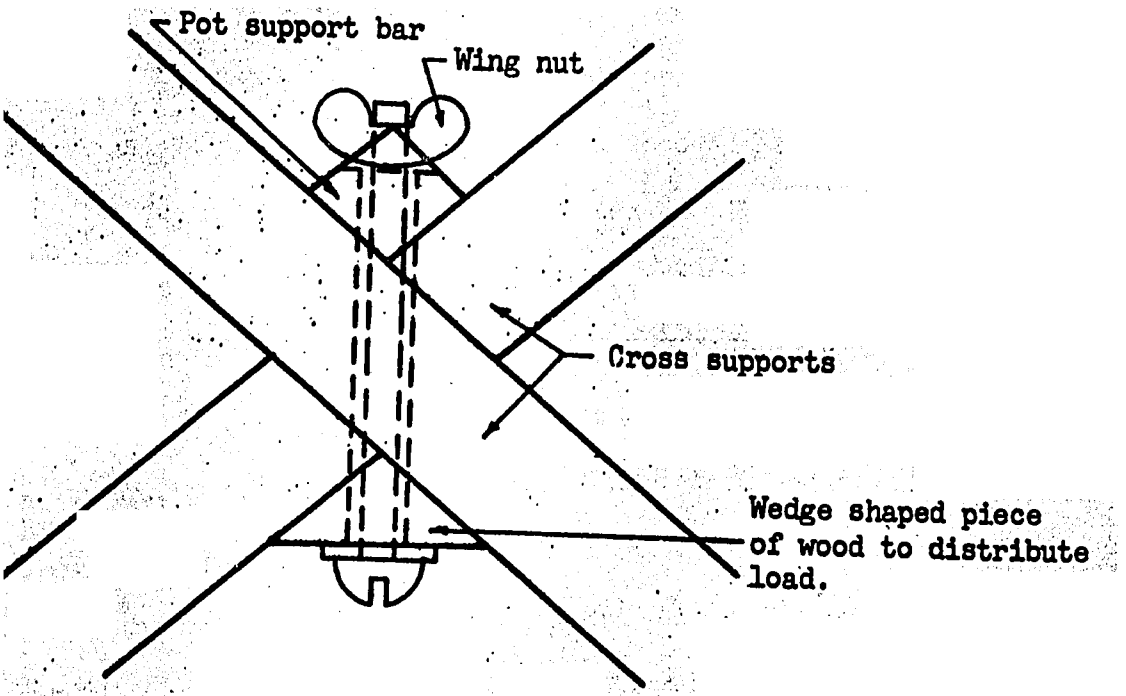
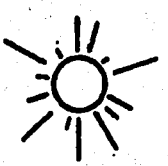


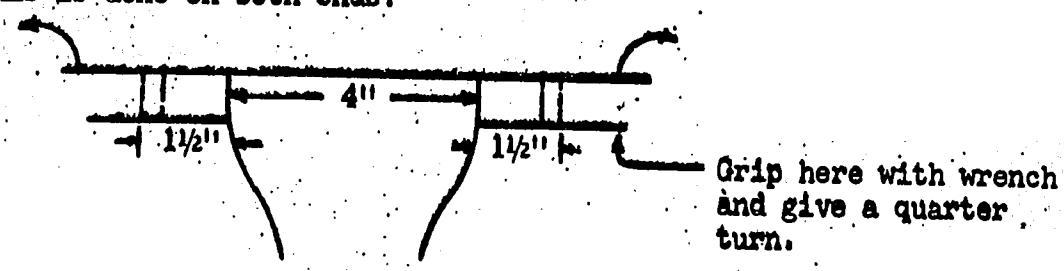
Fig. I Simplified method of clamping.

The pot itself is supported on a 6" diameter ring Figs. (H, J), which is formed out of a 21" strip of 1/2"x1/8" hot-rolled iron. a 1/4" hole is drilled about 1" from one end of the strip. Using a cold chisel it is desirable to make radial indentations around the hole on the side of the strip that will be on the outside of the ring after it is formed.



The strip is conveniently formed into a circle by bending it around a D-shaped wooden form in which the radius of the semi-circle determines the ring diameter. The original 1/4" diameter hole is now extended through the two ends of the strip at the place where they overlap to form the closed ring. Another hole is drilled at the spot on the ring directly opposite the first hole. The strip is scored on the outside around this hole as before. These holes are the pivot points which allow the cooking surface to be adjusted horizontally. A yoke is next made out

of a 16" length of 3/4"x3/16" hot-rolled iron strip. Two 1/4" diameter holes are drilled 3/8" from each end of the strip. The strip around these holes is scored with a chisel as before. Then the strip is placed in a vise so that the middle 4" or 5" are securely held. Using a wrench with adjustable jaws, the strip is gripped about 1-1/2" out from the vise jaw and the piece is given a quarter turn. This is done on both ends.



If the center portion of the strip is gripped in a vertical position, the ends of the strip should now lie in a horizontal plane, but the rod should be straight otherwise. The horizontal portions are now bent upward to form a U, taking care to match the distance between the upright legs reasonably close to the diameter of the ring and that the scored surfaces face inward. The U is now adjusted to make a good fit with the ring.

A slot is next cut into the end of the pot support rod to accommodate the yoke snugly. The slot is cut so that the yoke pivot holes are horizontal. A snug fit can be made by cutting a somewhat narrower slot than the thickness of the yoke. The slot should be about 1" deep. By using the iron strip as a chisel, the slot can be opened to just the proper width to fit the yoke. After the slot is fitted, a 1/4" diameter hole is cut through the wood perpendicular to the slot, and through the yoke which was inserted and centered in the slot. Flats are filed onto both ends of the hole through the support rod. A 1"x1/4"/2 stove bolt and nut are used to secure the yoke to the support rod as can be seen in Fig. J. The pot-support ring is now mounted in the yoke, aligning a star-type lock washer between the holes in the yoke and the ring. The scored

surfaces on both the yoke and the ring should be facing one another. They serve to provide a high friction joint which will not swivel accidentally and upset a cooking pot which might be set on the ring. Two 1"x1/4"/20 stove bolts passing through the two sets of holes, serve as pivots permitting the ring to be given any desired orientation. Wing nuts are used to clamp the ring at this position. If a grill is required to accommodate pots smaller than 6" diameter, or for other reasons, this can be improvised out of locally available materials. The ring allows pots with round bottoms to be positioned easily.

In order to avoid scorching the wooden pot support rod, and minimize the amount of the heat absorbed and re-radiated by the yoke and the pot-support ring, it is desirable to paint these components with aluminum paint.

COST

An estimate of the cost of building a Fresnel-reflector cooker is indicated below. All prices are retail costs of items purchased for the construction.

Material Cost Analysis:

2 @, 1" x 4" x 5' Oak Cross supports	0.53	
1 @, 1" x 2" x 2' Cross Piece)		
1 @, 1" x 2" x 2-1/2' Leg)	0.16	0.74 @ 16¢ Bd. ft.
1 @, 1" x 2" x 15" Leg)		
1 @, 1" x 1" x 2-1/2' Leg)	0.05	
Nails		
54" x 54" x .0005" aluminized Mylar*	0.50	
3/4 x 3/16 x 18 iron; pot support yoke	0.12	
5/8" x 1/8" x 21" iron; pot support hoop	0.13	
5/8" x 1/8" x 6" iron; pot support rod clamp	0.04	
1/8" x 4' x 4' Masonite, untempered	1.00	($1.10 F.O.B. Montgomery-Wards)
Assorted 1/4"/20 stove bolts, washers, nuts, etc.	0.15	
Adhesive	0.05	
	2.78	

* Obtained from Plaster Coatings in Ridgewood, New Jersey.

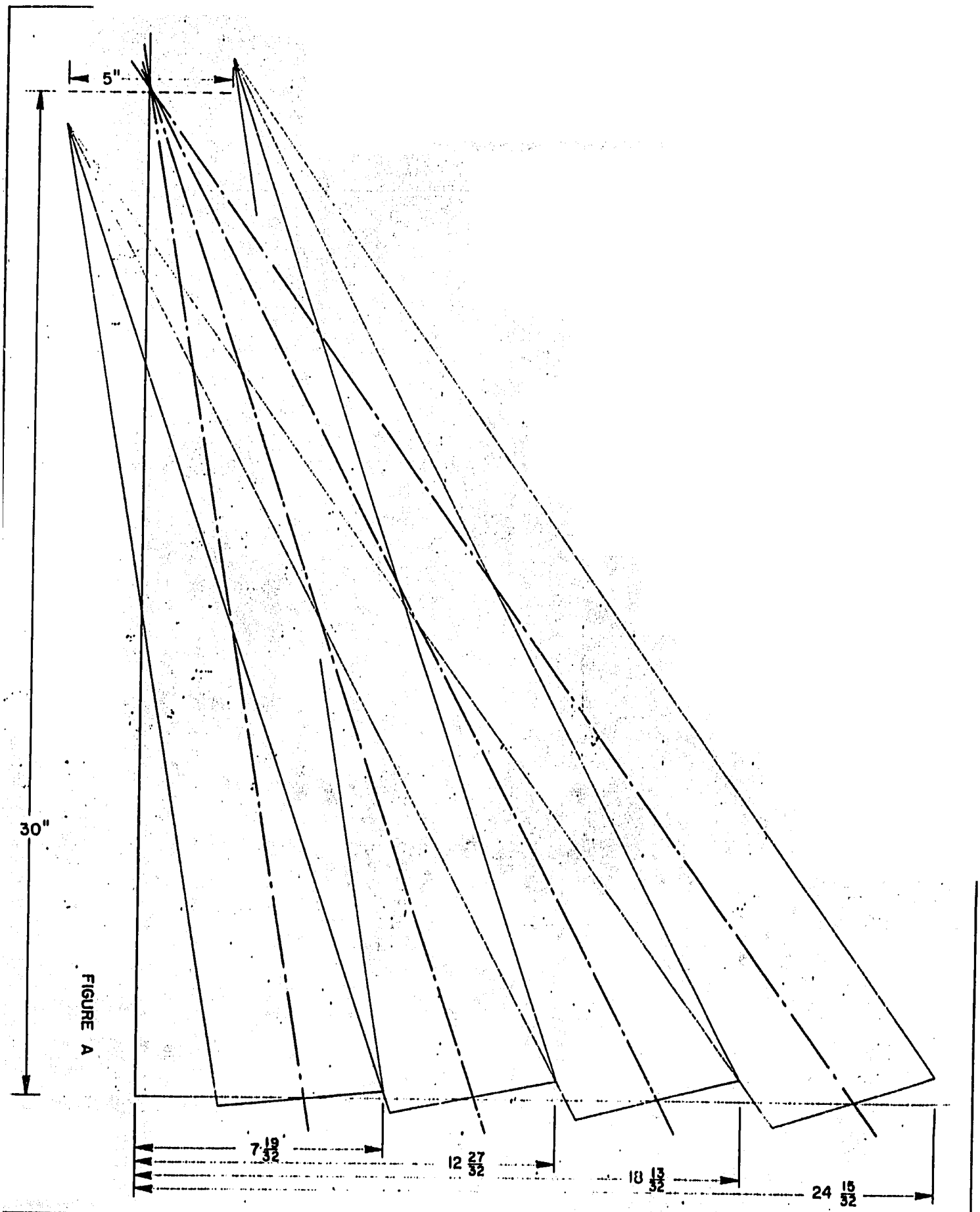
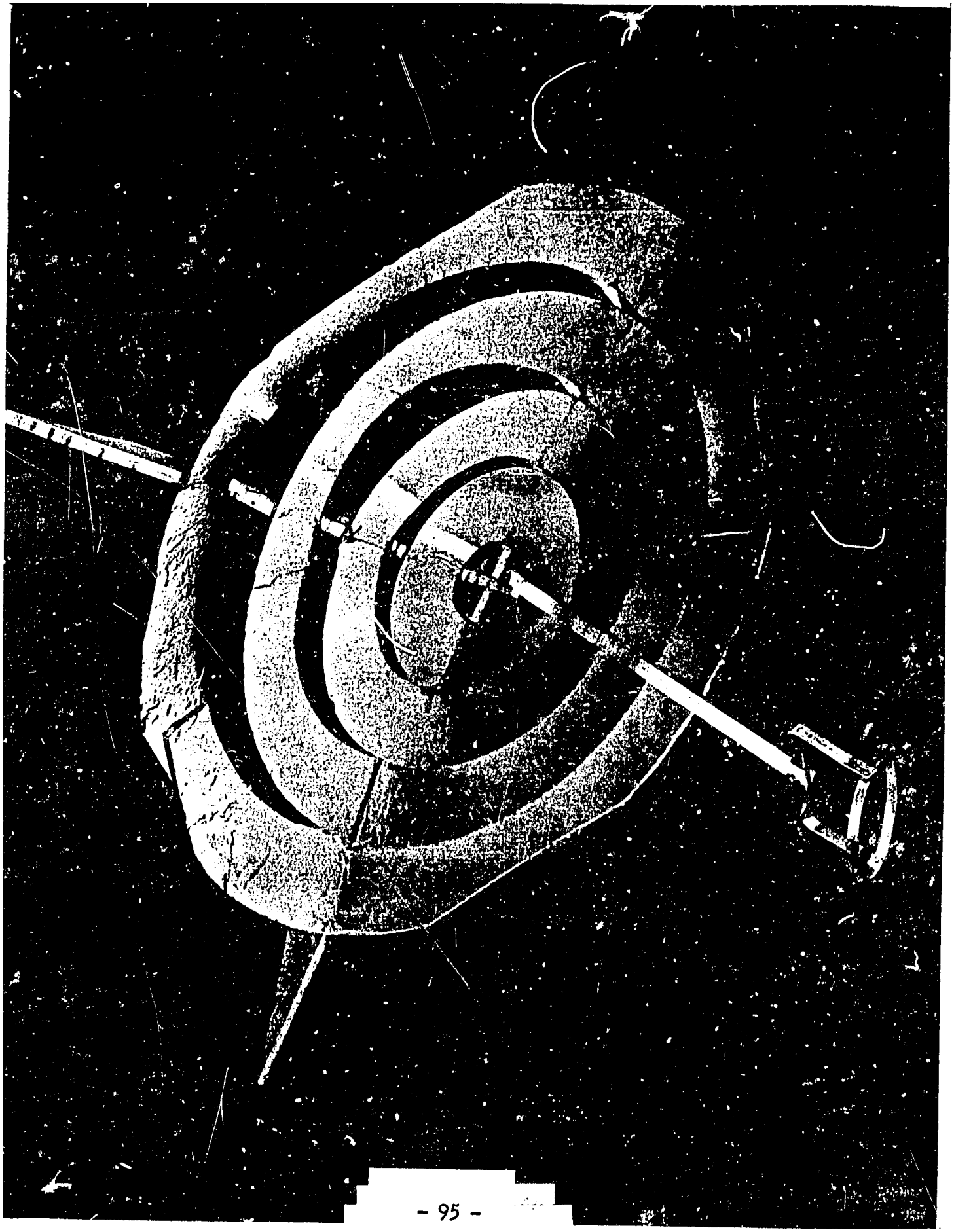


FIGURE A



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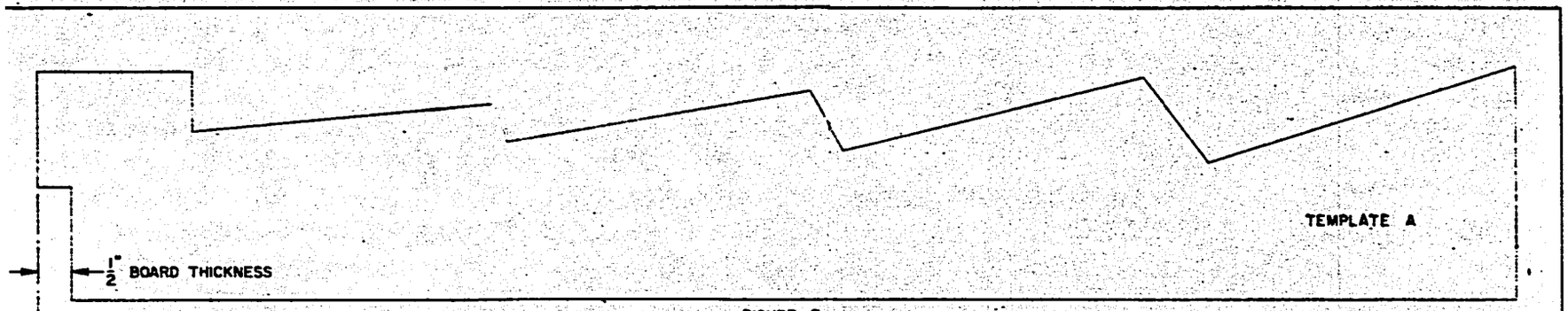


FIGURE E

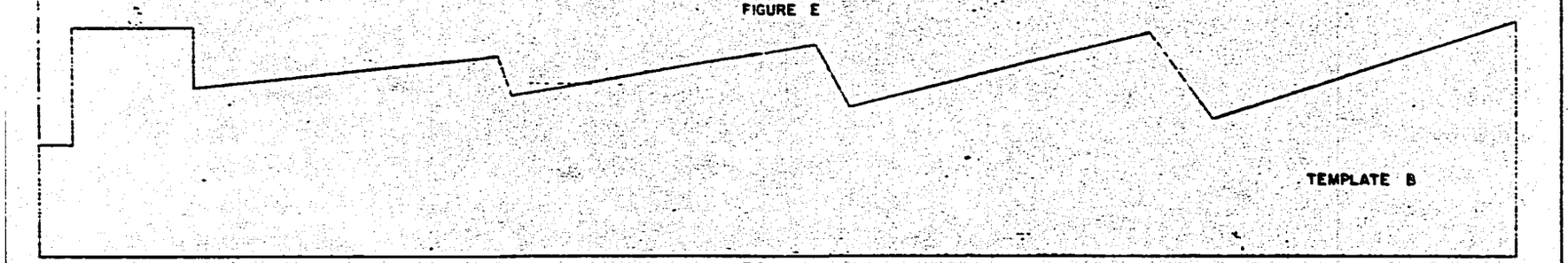
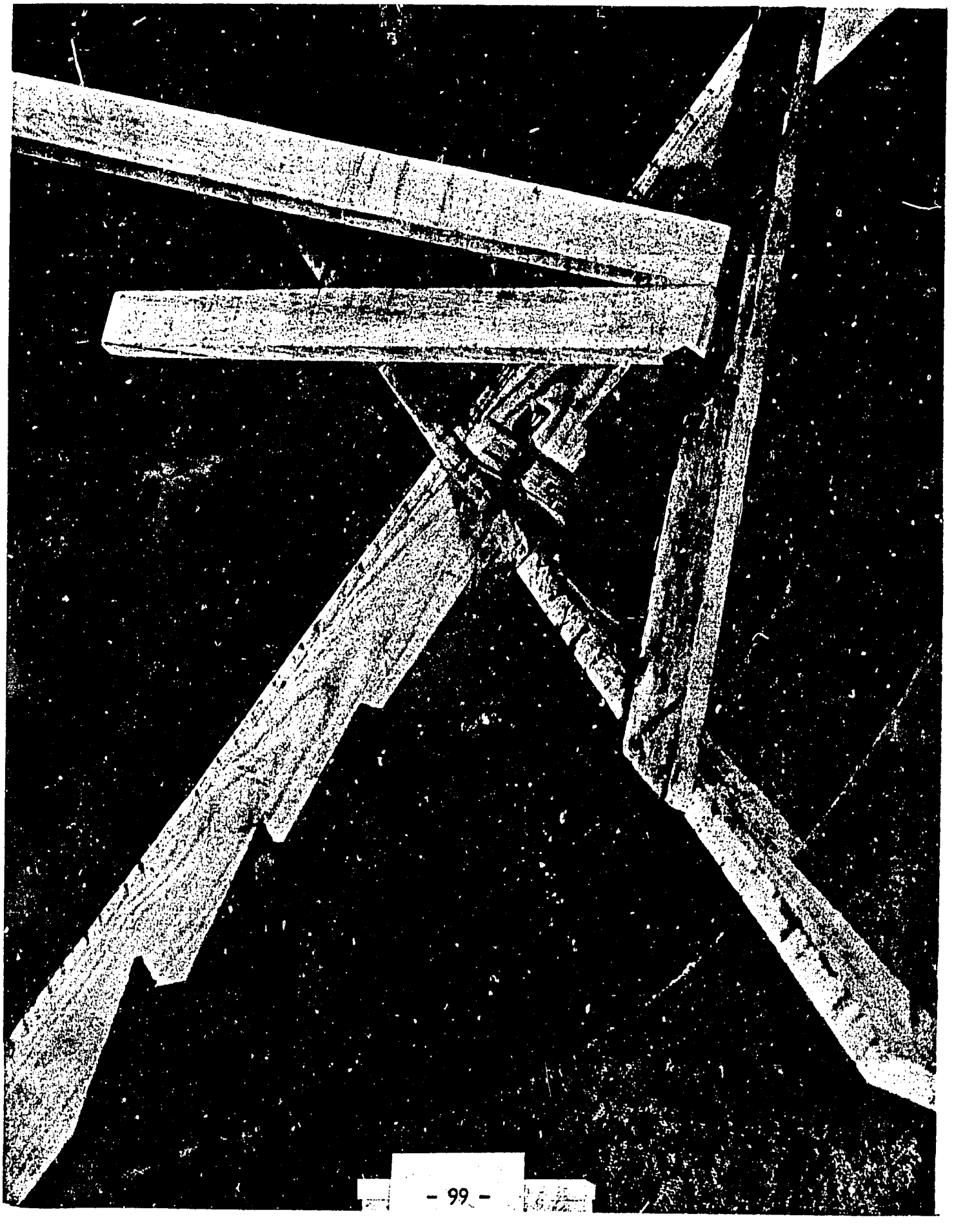
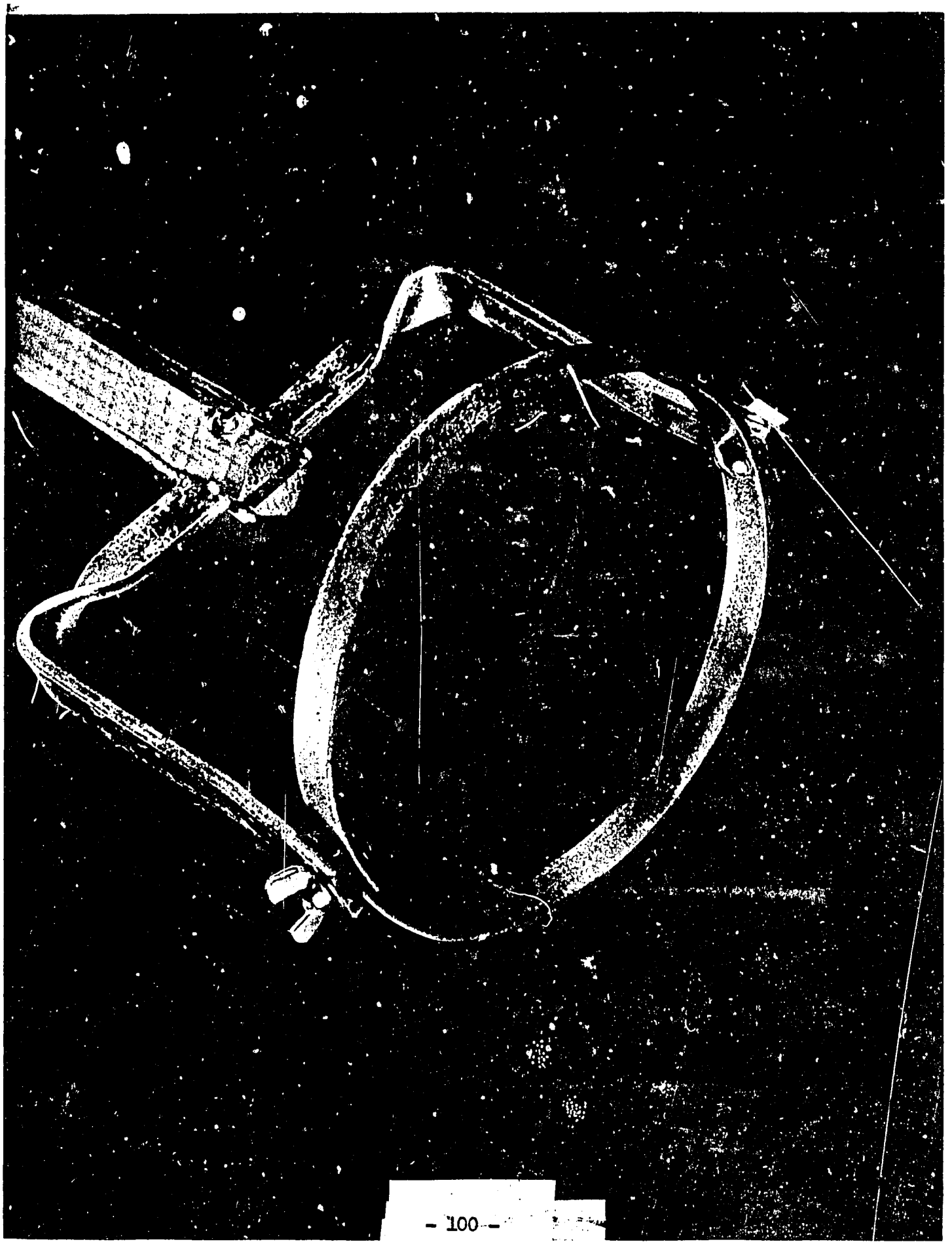
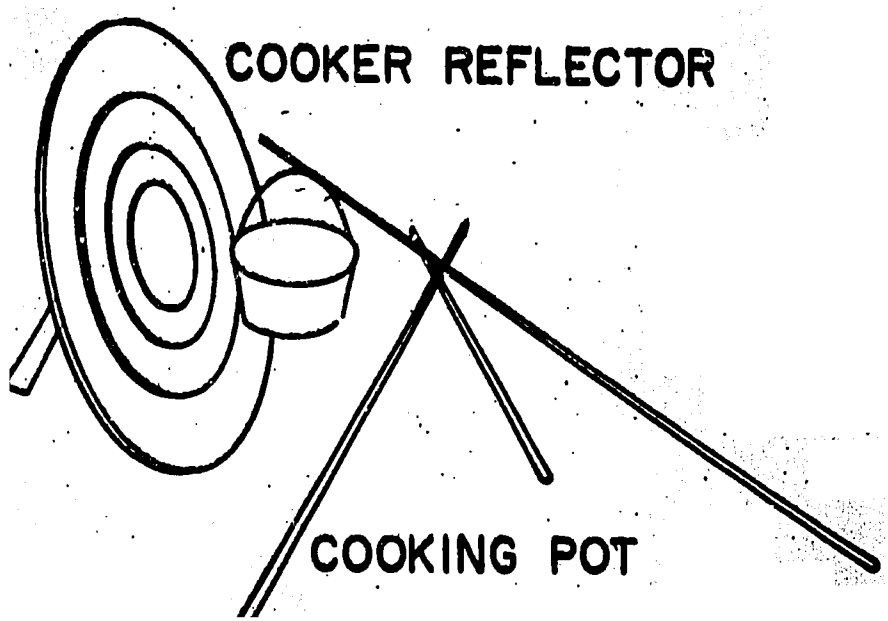


FIGURE F







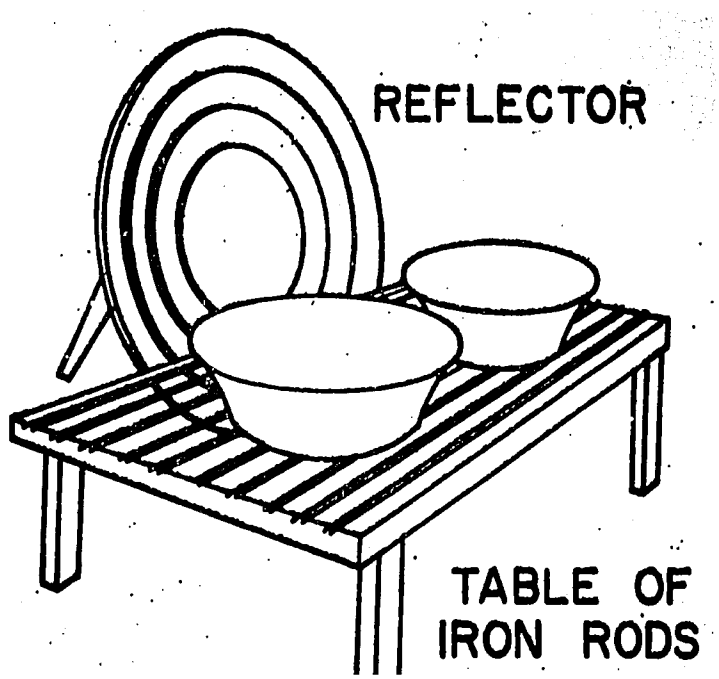


FIGURE F