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CHARACTERIZATION OF POINT FOCUSING TEST BED CONCENTRATORS AT JPL*

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ABSTRACT

This paper briefly describes the Solar Test Bed Concentrators that E-Systems installed at Edwards Air Force Base near Lancaster, California, for JPL. It describes the characterization work that has been accomplished on the test units thus far and provides the test results. The characterization data has been measured using both a flux mapper and a cold water calorimeter. The flux mapper uses a Kendall Radiometer as the sensing device. It is mounted on an x, y, z motor-driven positioning mechanism that allows the sensor to take an x-y flux raster at several Z planes in the vicinity of the concentrators nominal focal plane. Various concepts were tried to protect the concentrator structure from being damaged by the sun's energy during sun acquisition and deacquisition. A description of both the passive and active protective systems is presented.

INTRODUCTION

Point Focusing Concentrator evaluation is evolving as part of the Solar Thermal Power Systems (TPS) Project assigned to the Jet Propulsion Laboratory (JPL). The objective of the Concentrator Development Task is to develop, via contracts with industry, technology and designs that will result in concentrators which are characterized by high kWth per dollar of cost for solar energy into a cavity receiver.

PURPOSE

The Test Bed Concentrators (TBCs) were developed as an early tool for use in the solar energy development program to provide a precise, consistent, and highly reliable source of thermal solar energy for testing a variety of receiver and/or power conversion subsystems. The TBC test data to date has substantiated that the TBCs have fullfilled their design purpose by providing flux densities well in excess of those required for nominal testing sequences. In fact, the peak fluxes measured with the initial mirror alignment have been purposely reduced by defocusing a part of the central mirror facets. This was done in order to minimize thermal damage to the TBC receiver mounting structure and the receiver components. The defocusing did not significantly reduce the overall available energy even though the peak flux is down almost threefold.

CONFIGURATION

Two papers describing the TBCs were presented at the first Annual Review meeting. In way of a brief review, E-Systems has installed two TBCs at the

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Parabolic Dish Test Site (PDTS) located at Edwards Air Force Base near Lancaster, California. These TBC dishes have a plan form diameter of nominally 11 meters, are parabolic in shape with a reflector having 224 JPL-developed, rectangular shaped, second surface, back silvered, long radius, spherical contoured mirrors. Each mirror facet is individually aligned. The concentrators are of the Elevation over Azimuth tracking type with an azimuth wheel and track design and a jack screw elevation design. The sun sensor/control loop keeps the concentrators pointed to within 0.05° of the sun's true position.

CHARACTERIZATION

The characterization process for the TBCs was conducted in discrete steps to minimize any thermal damage from the sun's image and to provide the test team with low level solar operational experience. These steps consisted of uncovering the concentrator mirrors in five discrete groups. The process was additive in that the previously tested group of mirrors was not re-covered when the next group was uncovered. A complete set of flux mapping data was recorded using a Kendall Radiometer for each step in the mirror uncovering process. A set of data included a minimum of three rasters. Each raster consisted of 1056 discrete data points. For several of the mirror configurations, rasters were taken one inch in front of and behind the nominal focal plane and then every two inches along the Z direction thereafter (concentrator axis). Each raster took approximately 45 minutes to complete if everything performed smoothly and when this time is added to the TBCs' sun acquisition and normal operational sequence time, one complete raster consumed at least one and a half hours. An overall view of the TBCs with the flux mapper installed on the right hand unit is shown in Picture 1. A close-up of the flux mapper from the outer end is shown in Picture 2 and from the inner end is shown in Picture 3.

INSULATION

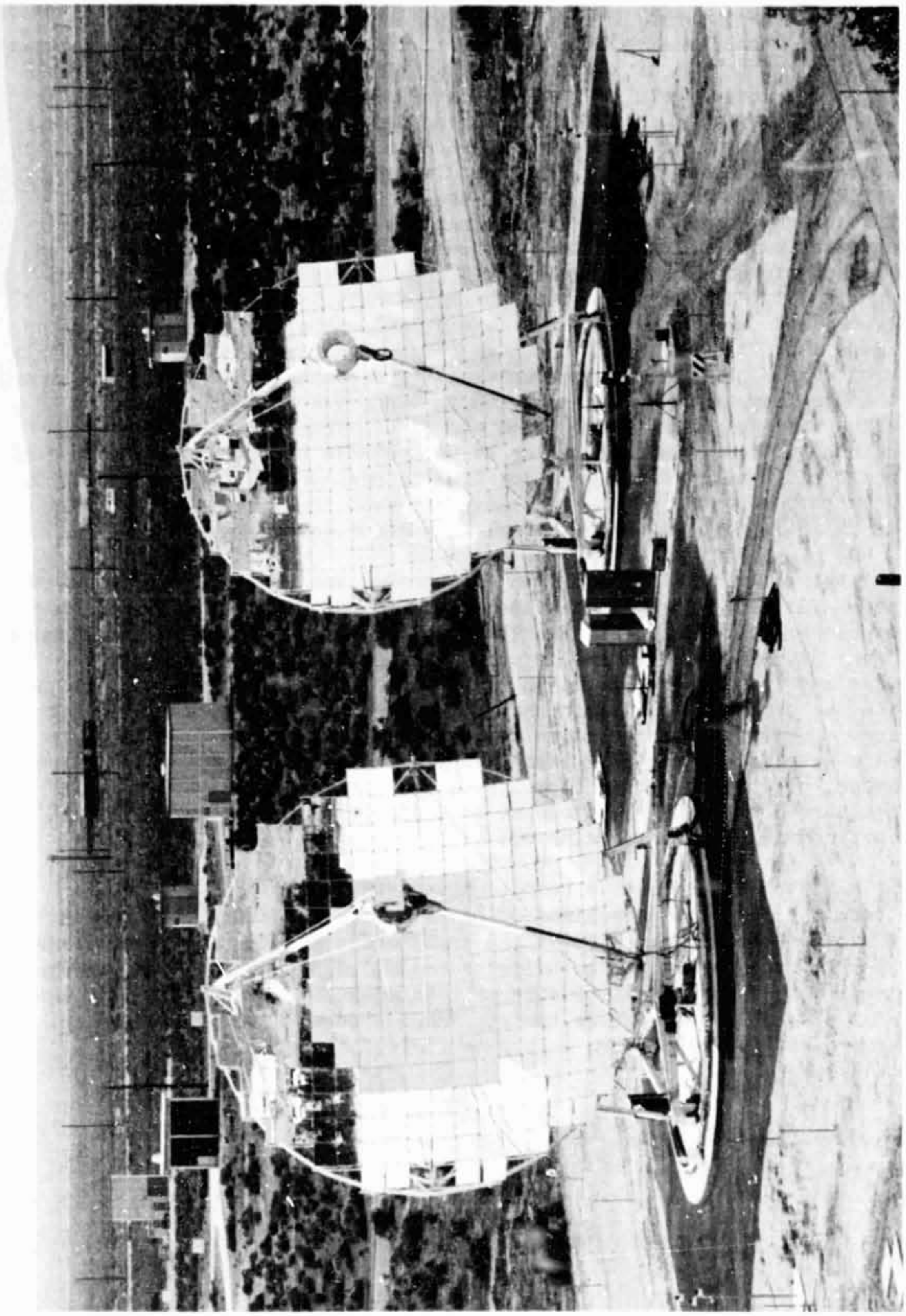
To preclude damaging the receiver mounting structure of the TBCs, during sun acquisition and deacquisition, this area was covered with an insulating material. An aluminum oxide material, Fiberfrax^{R} Hot Board, was chosen initially. This material has a melting point of 1260°C (2300°F). This material worked well on the inside of the receiver ring but deteriorated very rapidly on the front face of the ring where it was normal to the sun's image. As more and more mirrors were uncovered, the ablation rate of the Fiberfrax^{R} went up rapidly. The Fiberfrax^{R} was supplemented in the high heat area with a pure Zirconia held together with a Yttria binder. This material was far more expensive (by an order of magnitude) but has a greater melting temperature of 2593°C (4700°F). The ablation rate of this material was much less, however, with the full 224 mirrors the rate was still a problem because the molten material was dropping on the concentrator mirrors and causing damage. An active water-cooled plate was installed in the area where the sun spot traverses the receiver ring structure. The plate was made of 1/4 inch aluminum with a single pass water flow at a flow rate of 11 to 15 gals/minute. This plate, in conjunction with the Fiberfrax^{R} used in the less critical heat areas, solved the thermal protection problems in the TBCs.

RESULTS

The initial flux mapping results indicated that the TBCs, with the initial mirror alignment, where all the mirror facets were focused on the center of the target at the nominal focal plane, produced a peak flux of 1500 watts per square centimeter when the insolation was normalized to 1000 watts per square meter (see Figure 1). Flux densities of this magnitude produce almost instantaneous temperatures in excess of 2760°C (5000°F) which would severely damage most passive receiver aperture materials. It should be noted from the figure that 98% of the energy is within a 20.3 cm (8 inch) diameter aperture. Flux mapper results also indicated that the majority of the peak flux was being produced by the center mirror section which totaled 68 facets. In addition to being nearly on axis, these 68 mirror facets had focal lengths very close to their geometric nominal requirement. It was concluded that by readjusting these center mirror facets, the peak flux could be reduced, thereby reducing the possible thermal damage to the TBC structure and the receiver cavities. During the second mirror alignment, all the images from the center 68 mirrors were centered on a fifty-one (51) millimeter (2 in.) diameter circle on the target at the nominal focal plane. This produced a slightly reduced peak flux of approximately 1250 watts per square centimeter (see Figure 1). This was still too high for our initial testing requirements so a third mirror alignment was undertaken. The center mirrors were realigned so that their image was geometrically on the opposite side of the target as compared to their physical location on the dish. Their images were centered on a one hundred two (102) millimeter (4 in.) circle but across the center of the target. This alignment change drastically reduced the peak flux down to the 550 watts per square centimeter range but kept the total energy through the 20.3 cm (8 inch) aperture essentially constant (see Figure 1).

After the third mirror alignment, the flux mapper was operated at several "Z" locations. The data from this test sequence indicated that the actual focal plane is closer to the dish surface than the nominal or geometric focal plane (see Figure 2). This difference is primarily attributable to using a finite-distant light source to align the mirror facets. It is also obvious that with the cross defocused mirrors, the sun's beam is highly converging diverging. Currently the technique for determining the flux on a receiver wall is to extrapolate the x-y plane data from several "Z" positions of the flux mapper, plotting constant flux lines, and estimating where they will intersect a receiver. The development of a direct flux receiver wall measurement device is being evaluated.

The initial calorimeter results to date have established that each concentrator will produce a maximum of 82 kWth with 1000 watts per square meter of insolation through a 56 cm (22 inch) and a 25.4 cm (10 inch) diameter aperture, Picture 4 shows the calorimeter installed on the TBC. The energy measurement data from the calorimeter will be measured as a function of the various aperture sizes in future tests. The apertures will range from the totally open sunlit end down to a 15.2 cm (6 in.) diameter hole.



Picture 1: TBCs WITH FLUX MAPPER INSTALLED ON RIGHT-HAND UNIT

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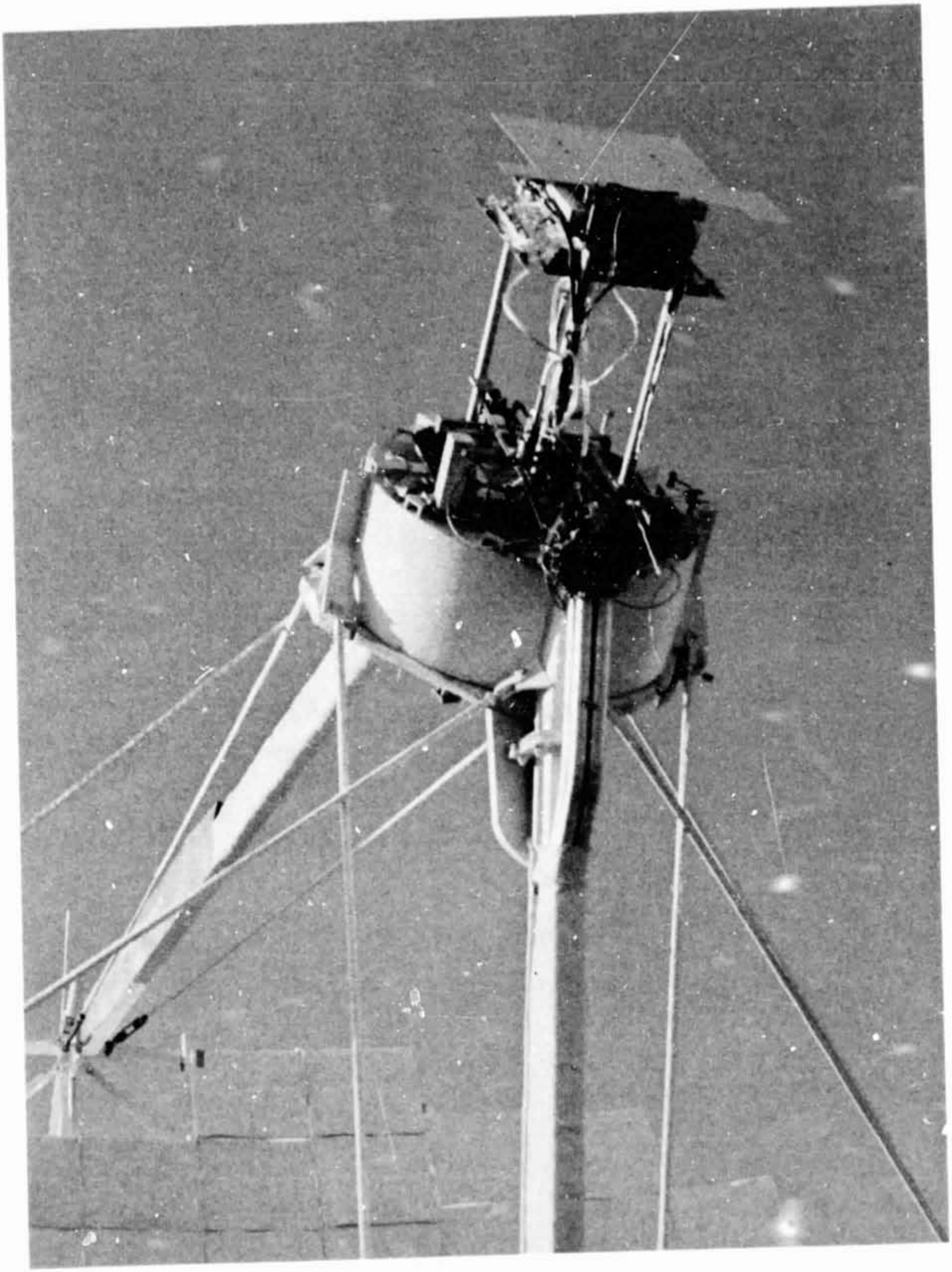
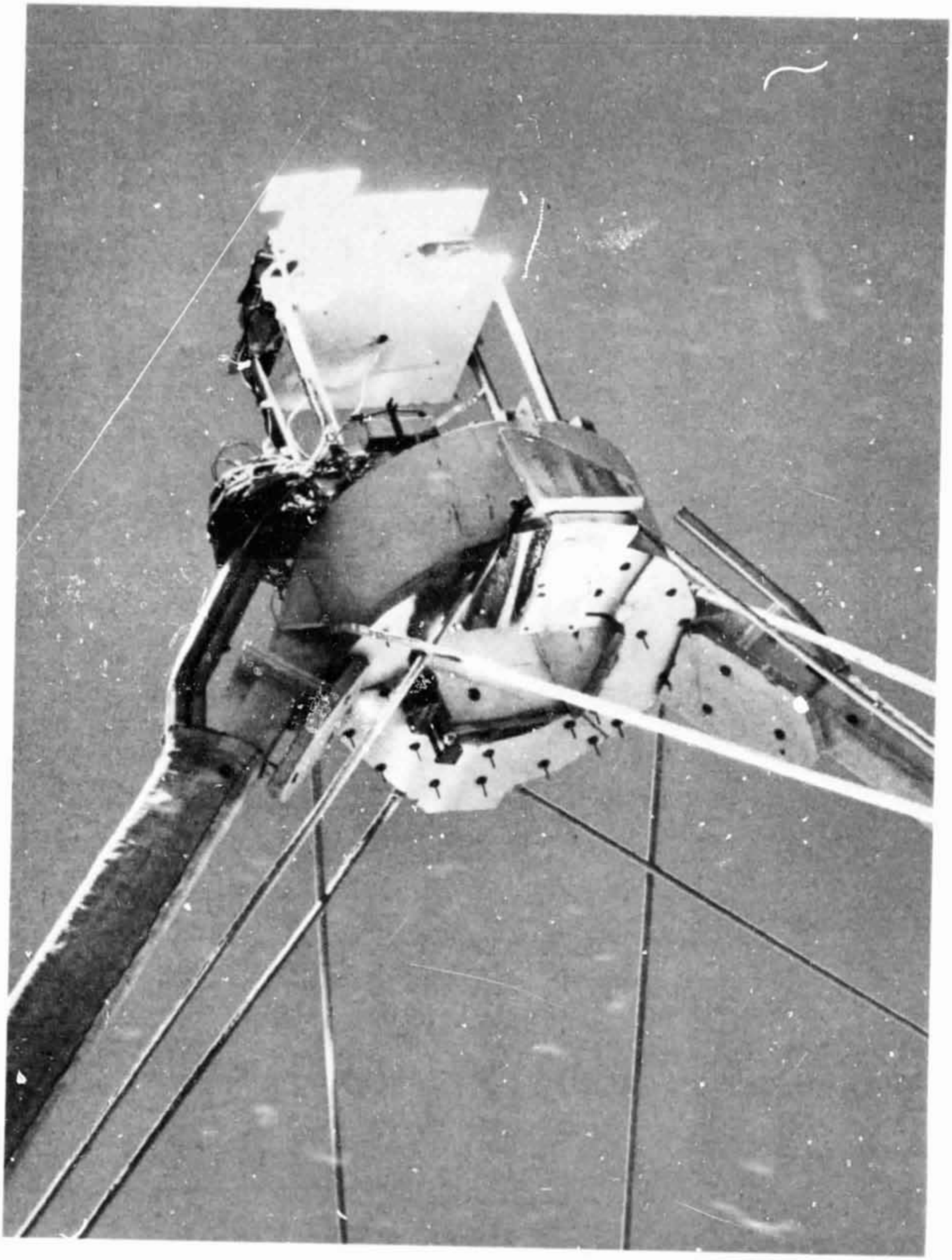
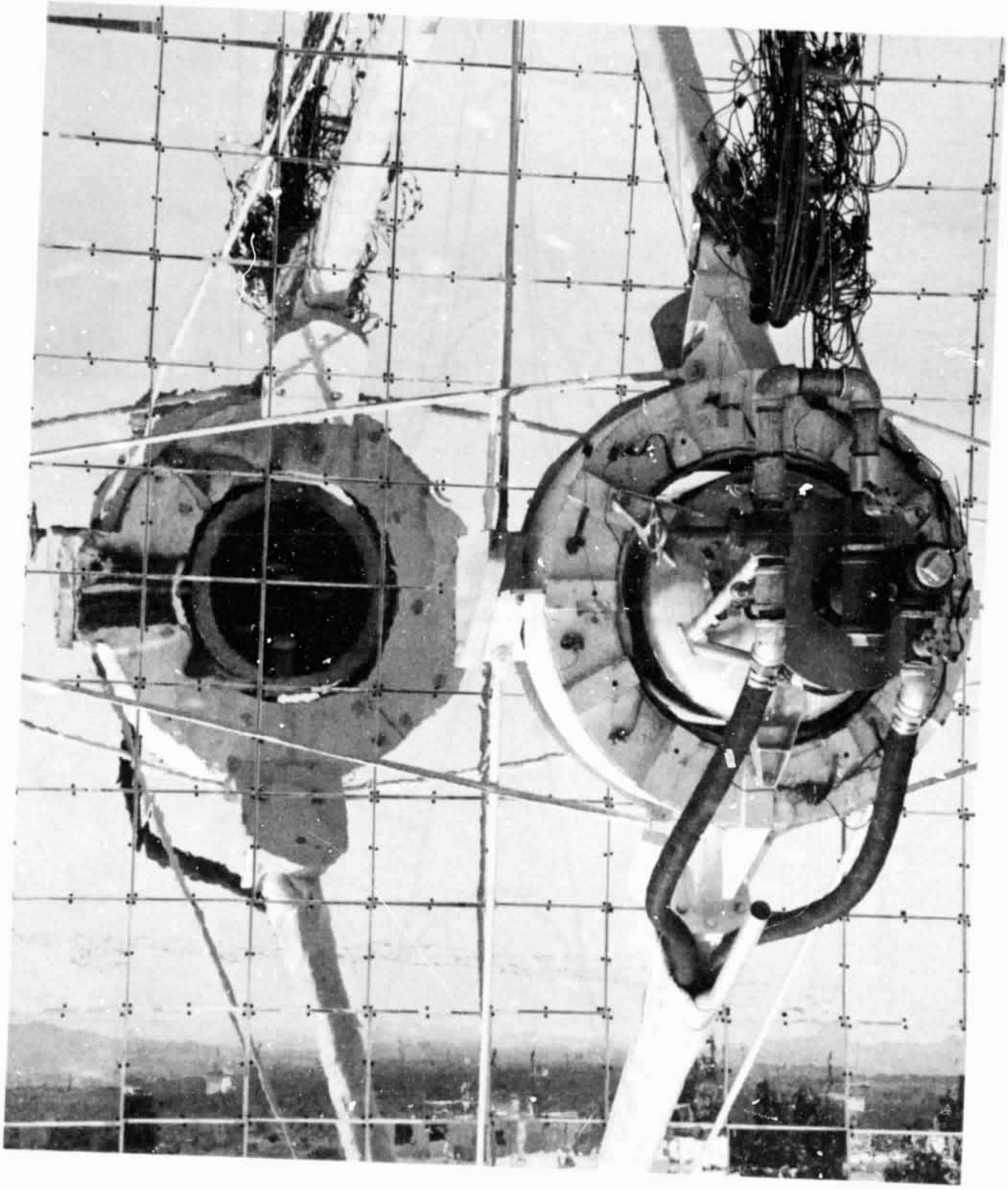


Picture 2: CLOSE-UP OF FLUX MAPPER FROM OUTER END



Picture 3: CLOSE-UP OF FLUX MAPPER FROM INNER END



Picture 4: COLD-WATER CALORIMETER INSTALLED ON TBC

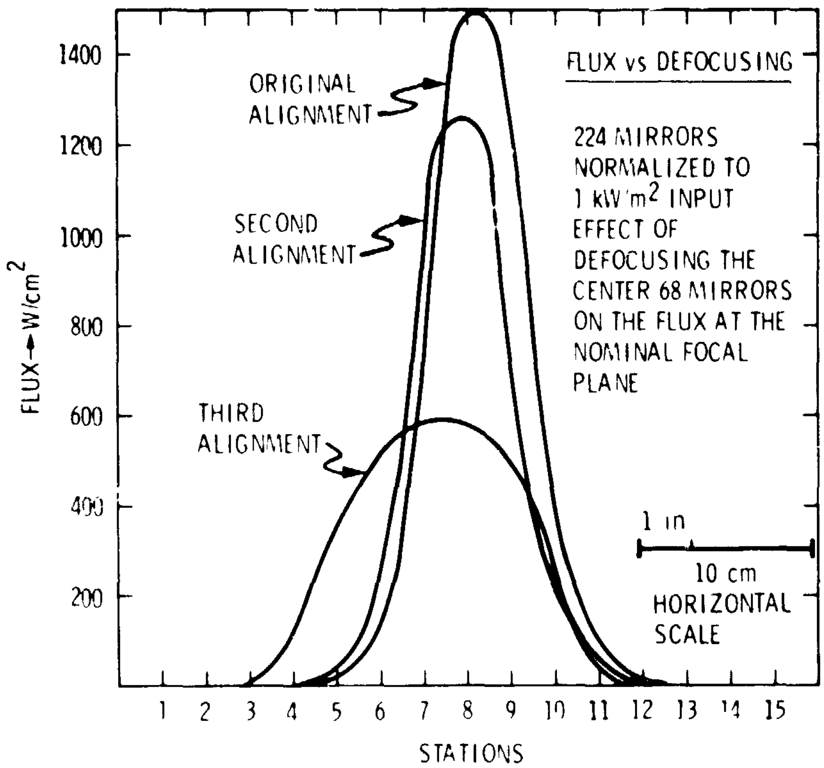


Figure 1. Solar Flux Measurements On Test Bed Concentrators

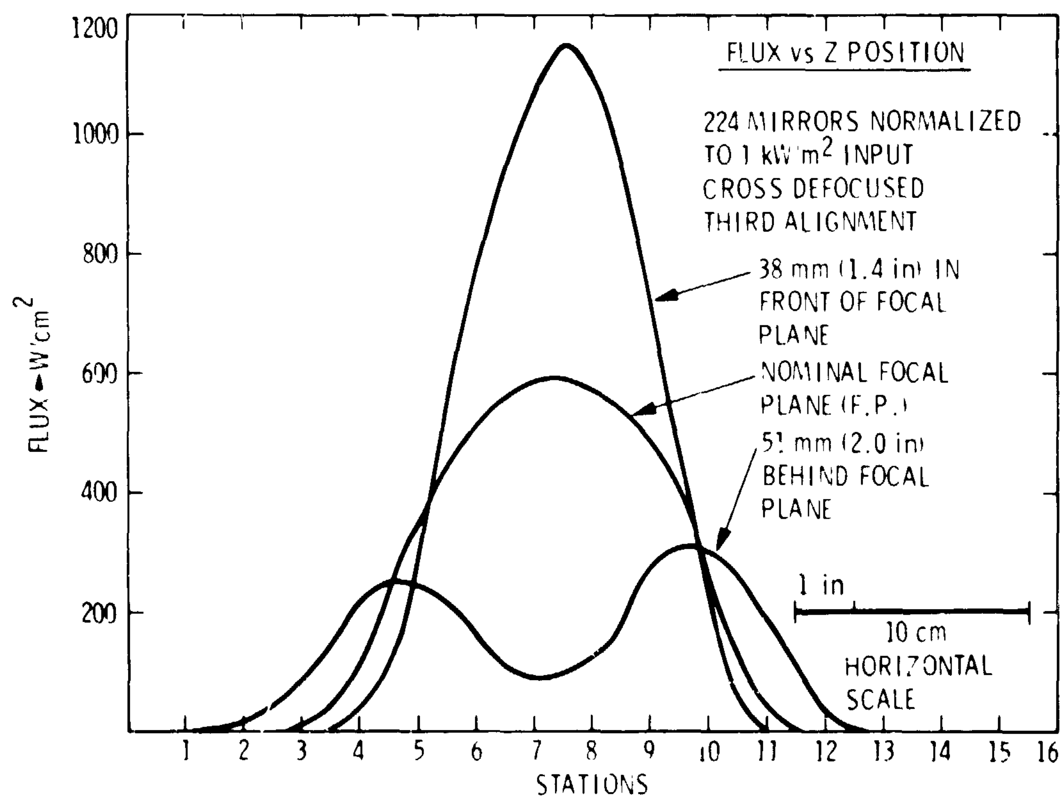


Figure 2. Solar Flux Measurements On Test Bed Concentrators