GEOTHERMAL WELL TESTING AT ROOSEVELT KGRA, BEAVER COUNTY, UTAH

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This paper describes testing procedures used by Phillips Petroleum Company at the Roosevelt KGRA prospect. The equipment and techniques described herein are not all original or new ideas but represent a combination of elements chosen after an intensive review of the state of the art. Special acknowledgment should be given to Jerry Jones of Union Oil Company and Dick Bolton of the New Zealand Ministry of Works for their cooperation and advice.

During the spring of 1975, Phillips Petroleum engaged Loffland Brothers to drill several geothermal exploration wells on the Roosevelt KGRA prospect in Beaver County, Utah. In May we encountered geothermal hot water in our KGRA 3-1 well. A three-hour flow from this well through an open pipe indicated flows in excess of 600,000 pounds per hour of fluid at wellhead pressures approaching 400 psig. The flow was measured using the technique described by Russell James for measuring flow discharging at the speed of sound to the atmosphere.[1] Concern about the accuracy of this type of measurement (flow conditions are well outside the limits described by James) arid the prudence of continued testing with our crude testing facilities led us to seek a safer and more accurate means of flow testing the well.

After reviewing the technology available for measuring two-phase steam/water flow, it was decided that the most accurate method would probably be to separate the steam and water phases and measure them separately. A survey of current practice revealed that the Bottom Outlet Cyclone was the most popular design in current use, and for that reason we chose to use it: for our geothermal testing. Conversations with Dick Bolton of the Ministry of Works and Development, New Zealand, led us to a paper by P. Bangma on the development and performance of a steam-water separator for use on geothermal bores. In it he detailed the development of the steam separator used at Wairakei which incorporates a spiral inlet (as opposed to a tangential inlet) to permit a substantial increase in inlet velocity without a corresponding increase in liquid carried over into the steam phase. Our discussions with Dick Bolton led us to believe that the spiral entry would indeed permit us to nearly double the inlet velocity allowable in the conventional tangential design. As a result of this research we settled on the following design parameters:

Maximum working pressure	550 psig
Design steam flow @ 200 psig	200,000 #/hr.
Design water flow @ 200 psig	800,000 #/hr.
Design temperature	600°F

These parameters result in a 154 ft/sec superficial inlet ve'locity for a 36" I.D. separator with a 12" diameter inlet. (Superficial inlet velocity is the

'Measurement of Steam-Water Mixtures Discharging at the Speed of Sound to the Atmosphere, Russell James, New Zealand Engineering, 21(10):437-31 (Oct. 1966).

velocity calculated considering only the vapor phase in the inlet mixture.) It is important to remember when selecting a separator that increasing flow rates and decreasing flowing pressure each increase the required separator size, i.e., while the vessel must be designed for the maximum expected working pressure it must be sized for the minimum expected flowing pressure. The separator, fabricated by WKM-Brewster, includes an integral water drum separated internally from the separator section. The drum was included to try to minimize flashing of water in the water metering line.

The piping scheme shown for the well testing facility (Figs. 1 & 2) was designed to be simple to erect, able to accommodate anticipated thermal expansion safely, and resistant to erosion at the pipe turns. To accommodate thermal expansion, the system is designed to include a large horizontal loop supported in the vertical direction and free to move in the horizontal plane. In addition, the separator base is free to slide and a WKM-Brewster internal expanding wellhead is used to absorb the expansion of the wellbore casing.

After the initial operation of the facility we added several guy wires to support the vessel and piping. These restraints are kept slack until the system is hot and are then tightened enough to snub any vibration which may occur in the course of operation. Even with the special wellhead design, the wellhead rose about 4 inches when the well got hot and in the initial test appeared to place an undesirable strain on the piping. The use of a one and one-half ton hydraulic jack under the first pipe support off the wellhead appeared to alleviate the problem. As a safety precaution, this was verified by pipe stress calculations using piping displacements actually measured during initial tests. These calculations show that the use of a hydraulic support can provide a safe, inexpensive and reliable means of compensating for pipe displacement due to expansion. Selecting an appropriate size jack for the job allows an operator to support the piping during well tests with a controlled amount of thrust and little fear of overcompensating for thermal expansion.

In spite of our satisfactory operation of this facility as designed, operators considering testing wells at rates in excess of one million pounds per hour would be well advised to consider rigidly anchoring all major pieces of the facility and using some form of expansion joint. Barco Division of Aeroquip Corporation has a series of ball-type joints for steam service that might be suited for this type of service. All changes of direction in the piping except those immediately upstream of the separator and the meter runs are accomplished using tees with the run end enclosed with a plate. This provides a hydraulic cushion at each turn and it is believed that this will minimize the erosion normally associated with elbows used in this type of system.

System Controls

The system is controlled by regulating the pressure with a pressure control valve on the steam line and by regulating the level in the separator with a level control operating a diaphragm-actuated valve in the water line. In sizing the water control valve, one has to be careful to size the valve for flashing liquid across the valve. In our application, the use of an 8" Fisher type 657ED with an equal percentage, 3" travel cage has provided very satisfactory service and appears to offer a reasonable margin for capacity in excess of design.

Flow Measurement

The facility includes equipment to measure pressures and temperatures at the wellhead, the steam meter line and the water meter line. In addition, pressures are measured at the separator and downstream of the steam and water control valves (measure back pressure of muffler). Steam and water flows are measured using standard orifice plates in the meter runs and recorded on American Meter Recorders. The quality of the separated steam is measured using a throttling calorimeter as described in the ASME Power Test Code PTC 19:11-1940. Connections for taking samples are provided at the wellhead for total flow and downstream from the separator for the separated steam and water.

Flow Discharge

. Steam and water in the system are discharged to a pit through the muffler shown in Fig. 3. Design is based upon mufflers used by Union Oil at Valles Caldera and does an exce lent job of silencing and dissipating the flow. The total open area of the s ots is approximately four times the area of the pipes feeding it. It is espec ally important to place the slots on the sides of the pipe only and to arrange them so that the thrusts are balanced during use.

Facility Operations

In operation thus far, the facility has provided us with accurate measurements and reliable service. One area which is still not providing us with totally satisfactory information, however, is the measurement of water flow. The small pressure drop experienced between the separator and the meter and the pressure drop across the meter is sufficient to cause flashing of small amounts of water into steam in the system. This flashing causes a 10 to 20 percent error in the separated water measurement. At the present time we are producing with a relatively constant enthalpy up the wellbore so an accurate calculation of the total flow can be made from our separated steam flow measurement. In the future, however, it may become necessary to lower the elevation of the water meter piping relative to the separator to eliminate this flashing. In tests run to date the facility has provided satisfactory operation over the following range of conditions:

Wellhead pressure	385 psig	294 psig
Pressure drop wellhead to separator outlet	20 psi	35 psi
Total flow rate	720,000 #/hr	925,000 #/hr
Separated steam quality	100%	99%
Muffler back pressure	25 psi	

Measuring Reservoir Pressure

All flow testing using this facility has been performed on Well 54-3 in the Roosevelt KGRA prospect. This well was drilled adjacent to the 3-1 well when 3-1 was judged to be unsuitable for flow testing due to casing problems. KGRA 3-1 was used as an observation well for these flow tests and provided us with information concerning the reservoir. This well was instrumented with a Sperry-Sun Permagauge recording system. The Permagauge surface recorder was connected to a downhole system consisting of a Permagauge concentric expandable chamber suspended to the well bottom by a .020" I.D x .094" OD stainless steel capillary tube. This tube and chamber were filled with nitrogen and the Permagauge recorder measures the surface pressure of this column and calculates the corresponding bottom hole (reservoir) pressure. This test resulted in agreement between a wellhead monitor and the recorder tied to the downhole system within a range of less than .2 psi. The data we were able to gather using this system were of excellent quality and provided plots for the various solutions of reservoir calculations which required virtually no adjustments to the measured data. The system is capable of providing the quality of data needed to perform accurate reservoir calculations but not without some difficulties:

1. The elements of the system are not entirely reliable. Leaks in the gas column and calibration problems brought on by the harsh environment are the major factors causing unreliable operation.

2. The system requires extensive attention prior to, during and after the test to provide continuous operation.

3. Some means of protecting the surface elements of the system from the environment must be provided.

4. The system requires an external power source to sustain operation during the measuring period.

In conclusion, the facility used by Phillips at the Roosevelt KGRA has demonstrated the capability of providing accurate data in a safe fashion in the testing done to date. Further testing will no doubt result in refinement of the equipment and methods used. The most important single factor to be considered in designing and operating such a facility must be the safety of the people involved in the testing. Every effort should be made to insure the integrity and safety of the system.

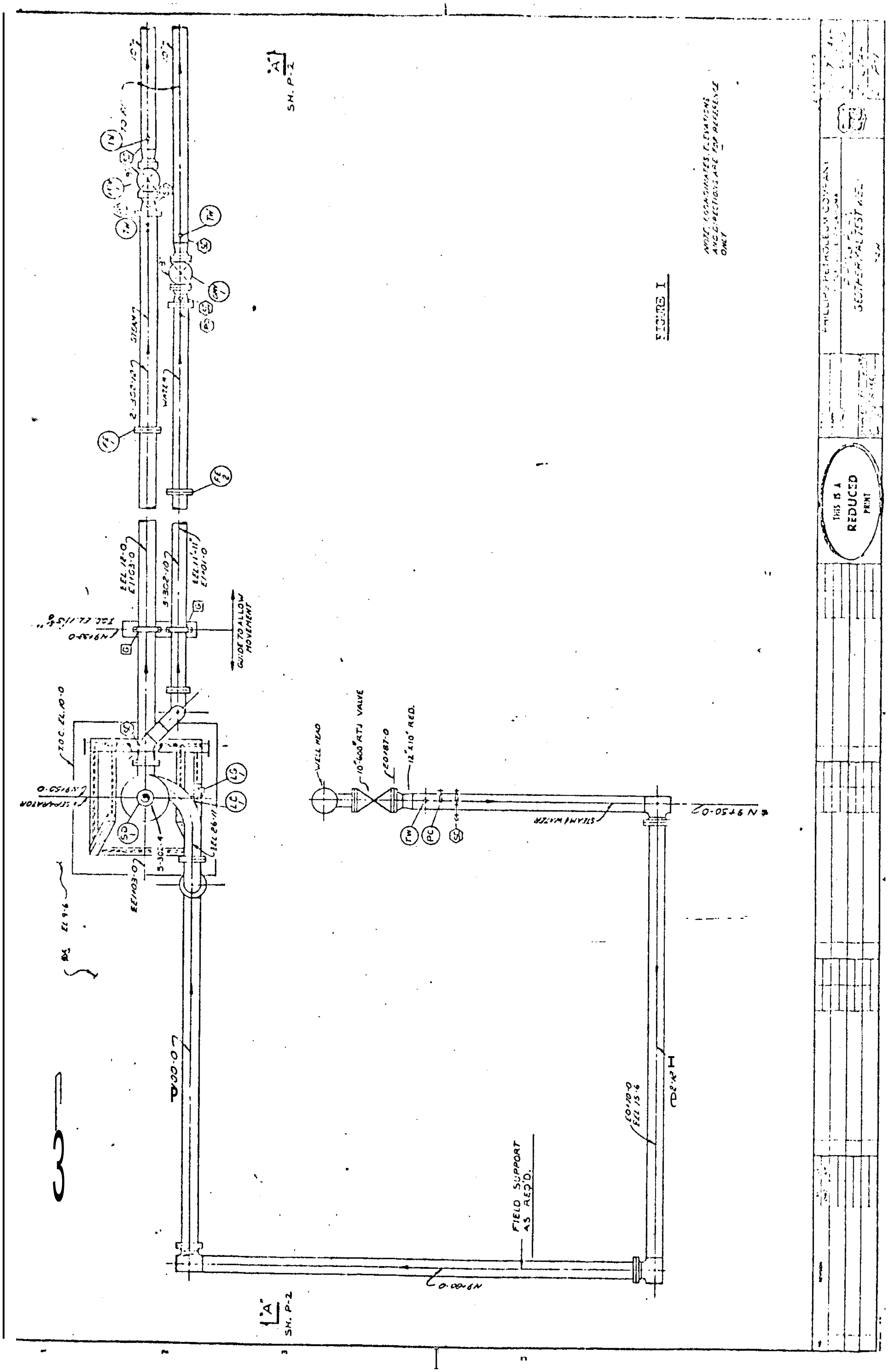
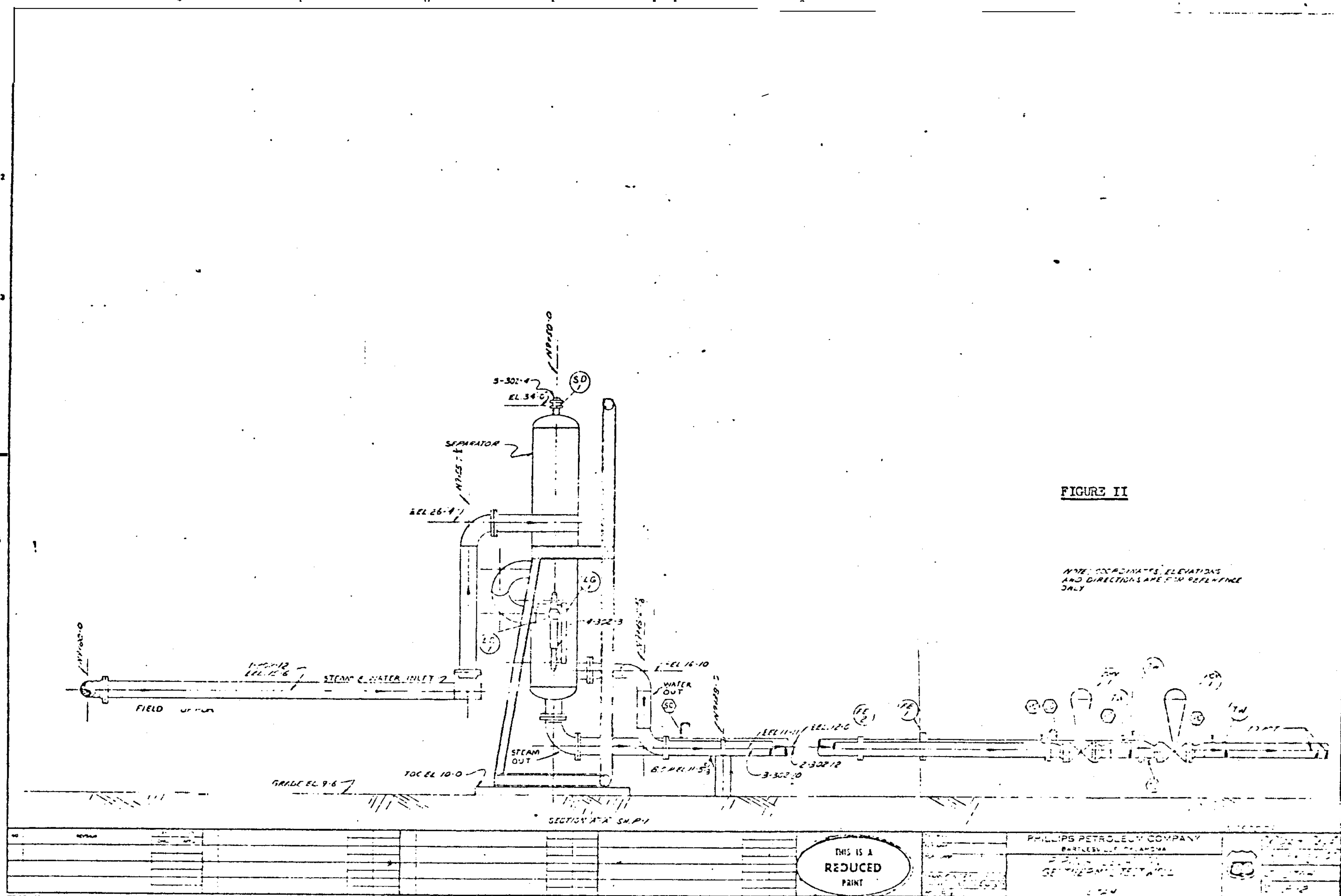


FIGURE I
THIS IS A REDUCED PRINT
SEPARATOR
WELL HEAD
GUIDE TO ALLOW MOVEMENT
FIELD SUPPORT AS REQ'D.
STEAM WATER
STEAM
WATER



SEPARATOR
EL 34'-0"
SD
LG
STEAM & WATER INLET 2
FIELD
WATER OUT
STEAM OUT
TOC EL 10'-0
GRADE EL 9'-6
SECTION "A"-"A" SH. P-1
NOTE: COORDINATES, ELEVATIONS AND DIRECTIONS ARE FOR REFERENCE ONLY
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FIGURE II

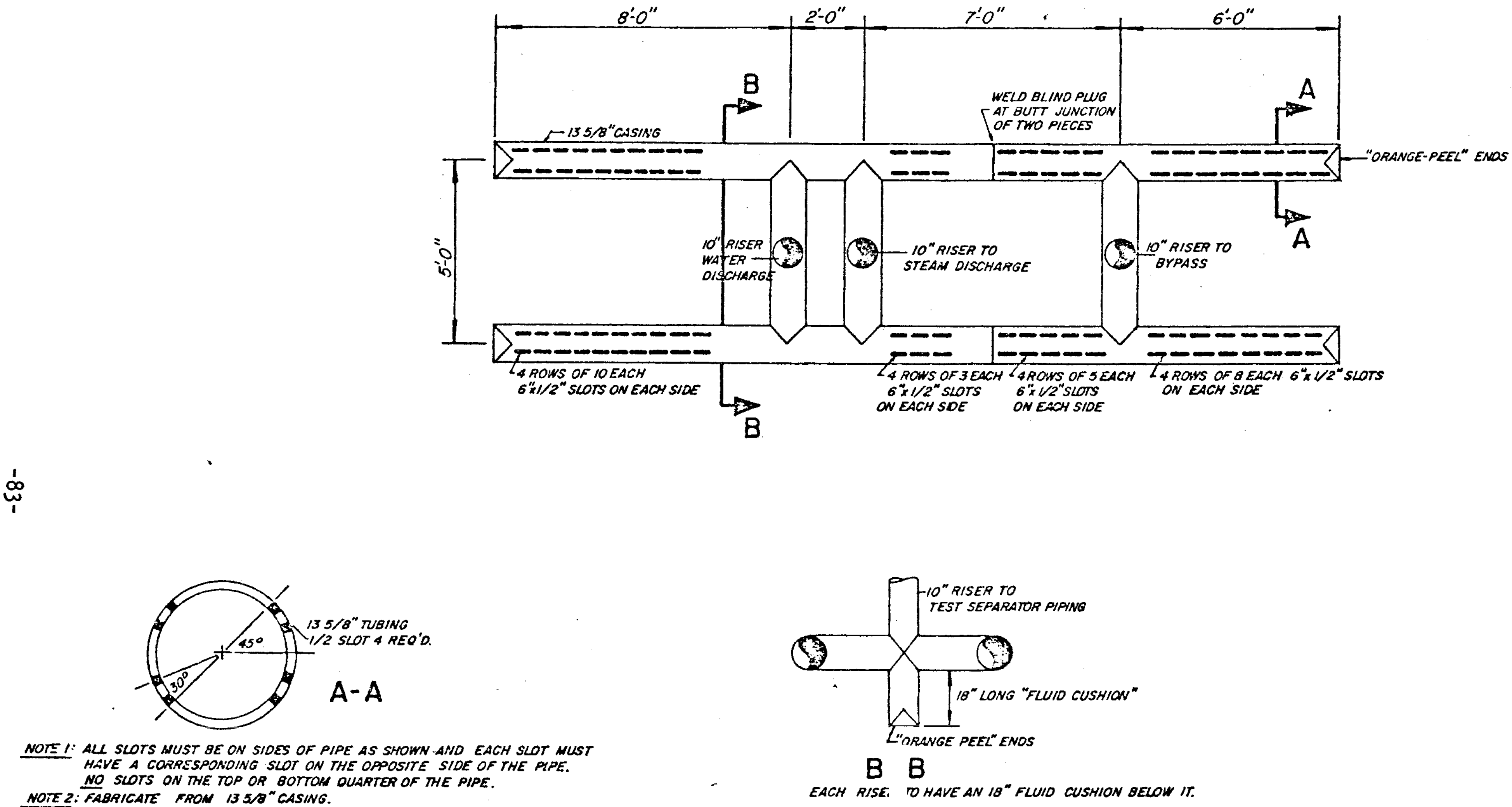

FIGURE III

DIFFUSER ASSEMBLY