מדינת ישראל

משרד האנרגיה והתשתית

אגף מחקר ופיתוח

צינור חום כימי סולרי

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של אנרגית שמש שתסופק על ידי תנור השמש במכון ויצמן

בוצע ע"י: פרופ' משה לוי, הדסה רוזין ורחל לויתן
מכון ויצמן למדע, רחובות

לפי חוזה מס' 86-1-85

אלול תשמ"ז ספטמבר 1987

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<u>תוכן העניינים:</u>

ת ק צ י ר

בתקופה המתועדת בדו"ח זה הכנו את התשתית לקבלת הקולט/ריאקטור שנבנה ב-SANDIA והגיע ארצה בחודש מאי. בצענו את כל חבורי הצנרת של הגזים, הספקת חשמל במתחים שונים לנקודות ההפעלה והבקרה וכן קווי הבקרה והפיקוד המחברים בין הבקר, המחשב ושאר המערכת. בצענו נסיון ראשוני לחמום דו-תחמוצת הפחמן כשהריאקטור היה במוקד התנור הסולרי. הצלחנו להגיע לטמפרטורות גבוהות ולאחידות בטמפרטורה בריאקטור כולו.

אנו ממשיכים עם בדיקות הקבלה של המערכת כולה ונתחיל בקרוב בנסיונות רפורמציה עצמם, במערכת של מעגל פתוח.

מילות מפתח: אנרגית שמש, צינור טרמוכימי סולרי, קולט שמש לטמפרטורות גבוהות.

Abstract

During the period covered by this report we have prepared all the infrastructure for the acceptance of the SANDIA-Israel receiver/reformer that arrived here in May 1987. We have connected all the tubing, electrical and control lines. We have carried out a preliminary experiment for heating CO_2 in the focal zone of the solar furnace and managed to heat the whole reactor to a uniform temperature. We are continuing with the acceptance tests of all the components and will start the actual reforming experiments, in an open loop mode, very soon.

Key words: Solar energy, solar thermochemical pipe, high-temperature solar receiver.

This project is a joint Israeli/American effort to prove the concept of a solar chemical heat pipe in a real solar experiment. For this purpose a receiver/reformer was designed jointly and built in SANDIA Albuquerque. The infrastructure and the controls were prepared at the WIS and the whole system is now being assembled and tested.

Fig. 1 (which is taken from the computer display - Screen R1) is a schematic flow diagram of the system which is basically composed of four parts:

1. Reacting gases.
2. Receiver/Reactor.
3. Product gas analysis.
4. Product gas disposal and safety equipment.

1. Reacting gases

The methane is contained in 60 cylinders arranged in two groups of 30 (Picture 1). The methane was pumped from the Ashdod gas field, compressed in the field to 150 atm. and delivered here by truck. Analysis showed that the purity of the methane is higher than 99% and the impurities in the gas will not interfere with the reforming reaction. We have 60 additional containers stored at the Institute. Filling the containers can be done within 24 hours, so that our supply of methane is adequate. At the maximum output we will be working at about 6000 l/h which is the content of one cylinder. That means that we can work about 50 h without change of cylinders.

The CO_2 was obtained from Zinada. It is a large container equipped with a refrigerating unit to keep the pressure under 300 psi (Picture 1). The unit contains about 3 tons liquid CO_2 and it is rented to us by the company with an agreement that it will be refilled on demand within 24 h. Both gases are kept at a distance of 10 meters from the furnace and are led into the building by underground pipes. The CO_2 flow is controlled by a Tylan mass flow controller L41-37 (Fig. 1 and Picture 2). The amount of CO_2 used is measured continuously and substracted from the original amount of CO_2 in the container. An alarm is sounded when the gas approaches a certain low critical value.

The methane line has a safety, normally closed, pneumatically actuated emergency valve L9-78 (Kinetrol limit switch unit) and Tylan mass flow controller (L41-17). The two controllers are connected by a "master-slave" arrangement, to a given ratio of CO_2/CH_4. The flows and the ratio are displayed on the screen as F-37, F-17 and K respectively. The two gas flows combine and go through a 5 liter mixer, into the reactor, through a stainless steel tube at a hight of 6 meters from ground level. The pressure at the entrance before the mixer is measured by a Barton ITT proportional pressure meter (P-101) and the temperature of the gases going in, by a thermocouple (T01). The reacting gases enter the reactor at the top of the first reactor tube and exit through an inner tube. In screen R-1 (Fig. 1), only reactor No. 3 is shown. However, in screen R2a (Fig. 2), all seven reactors connected in series can be seen.

2. Receiver/reactor

The reactor, built in SANDIA Albuquerque, is described in detail in a draft document from SANDIA. It is shown schematically in screen R2a (Fig. 2) and in Pictures 3 and 4. The important parts are: seven inconnel reformer tubes placed in a concave inconel box containing 2 kg sodium metal and a stainless steel wick, to raise the sodium liquid to the solar heated front. The box contains 4 vacuum valves. It was evacuated before introduction of the sodium and then pumped out for a few days before heating. The unit contains a heater for melting the sodium (H090), before starting the solar heating, and a thermocouple (T-90) that controls the temperature of this heater. The whole unit was tested in Albuquerque, before shipping, and it was stated that a uniform temperature of 500°C was obtained with only the bottom heater after 8 hours. The reactor is equipped with a number of thermocouples in the front and in the back of the sodium box as seen in screens R2a and R2b (Figs. 2 and 3). (A number of these thermocouples stopped functioning at an early stage. We have to find the reason and come up with a solution as it may be very critical for the continuation of the work).

Thermocouples are also placed in the reactor tubes at different levels. We have now a multipoint TC that will measure the temperatures at 4 different levels in the reactor. An additional TC was placed through the inner tube near the bottom. The temperature T-100, shown on the screen, is the temperature of the product gases measured directly and continuously by thermocouples T-34 and T-33 through a Ronan TC t smitter, and taken as the average of the two, for additional safety. T is the temperature that will control the flow of reactants to maintain a constant temperature in the reactor, irrespective of the changing insolation conditions.

3. <u>Product gas analysis</u>

A manifold was attached to the exit tubes and the sampling tubes from the different levels in reactors 3 and 4. This manifold is connected to 14 high temperature Nupro valves actuated pneumatically by Bacara solenoid valves (see Picture 4). The sampling valves are opened by control from the computer and lead the gas through a Valco sampling valve in the Tracor Gas Chromatograph (Picture 5). The analysis of each sample lasts 8 minutes. The next sample is injected automatically. The results are calculated and printed by an HP integrator and fed into the computer.

The analysis manifold is also used for measuring any build-up of pressure in any of the reactor tubes. A differential pressure transmitter PD-100 placed at the end of the exit manifold is connected between the entrance and the exit to the GC. After a sample was taken for analysis, the valve L9-75 leading to the GC is closed and the PD-100 measures the pressure differential between the feed and the sampling tube opened. In this way any build-up of pressure can be checked and the spot where build up occured can be identified.

4. Product gas disposal and safety equipment

The product gases are led to a flare system H4-18 placed on the roof of the solar furnace and are burnt away (Picture 6). Before reaching the flare the gases pass through a pressure control valve L91-76, that regulates the rate of exit of gases in order to maintain a constant pressure at the inlet P101. The temperature at the exit tube is also recorded at T-02 to make sure that the gases to not exit at an exceedingly high temperature.

A gas monitoring system with 8 sensors: one for CH_4, at the site where the methane cylinders are stored outside, another one for CH_4, at the site of the flow controlers inside the building, two sensors for H_2 and CO, on top of the receiver/reactor, another two sensors, for H_2 and CO, on top of the GC, and two sensors for H_2 and CO, in the control room where the operators sit. The sensors are connected to the computer with alarm systems and special procedures for stopping the reaction in case of leaks or malfunction.

Special counters were added in the back of the doors of the solar furnace. They count the number of metal protrusions attached to the doors and thus can determine the position of the doors. This will be used for sending commands to the motors, operating the doors, to open or close according to the changing solar insolation.

The programmed controller and the IBM personal computer are shown in Picture 7. A general view of the reactor, with the pipes leading the gases the electrical and the signal connections in front of the spherical concentrator of the solar furnace is shown in Picture 8.

Initial testing

The reactor was first checked at the Institute after arrival in order to map the TC positions and to check the inlets and outlets of the tubes. It was realized that the reactor tubes cannot be closed because of some steric interference of the connectors. The reactor was then shipped to Kamag where it was taken apart, the thermocouples and the inlet and outlet tubes were fitted and the connectors were machined to close properly. A manifold system was built for the analysis with the valves and the solenoids placed on the back side of the reactor. The whole system was sealed and tested for pressures of up to 20 atmospheres. It was then shipped back to the Institute. A team from Kamag came and installed the system in the solar furnace. This included the inlet and outlet of gases, sampling to the GC, all the electrical connections and signals from the TC's, pressure and flow controllers, output from the GC integrator, gas sensors and the flare unit.

The whole system was checked for leaks and we are still in the process of calibrating and adjusting PID's for flows, pressures and temperature regulation. An additional independent temperature measurement device was added; a pyrometer from Galai that has a separate display as well as a continuous feed into the computer.

A vacuum gauge was attached to the valves at the exit of the sodium box. It was found that the vacuum in the box was maintained at a level lower than 0.2 torr and therefore there was no need for additional pumping at this stage.

The reactor was heated with the internal heater. After a few hours it arrived to equilibrium. When left overnight with a voltage of about 150 Volts the temperature of the heater itself was about 813°C and the temperature in the box was 300-350°C (Figs. 2,3). There is some temperature drop from top to bottom as could be expected. Moreover, the temperature in the front of the box T94 is lower than inside the reactor tubes because that is where the losses through the aperture is the largest.

Attempts to arrive at higher temperatures with an external electric heater placed inside the aperture (Picture 3), were not very successful. We managed to raise it only to 550°C after a few hours of heating. It seems that the geometry of the heater was not suitable for efficient heating of the reactor.

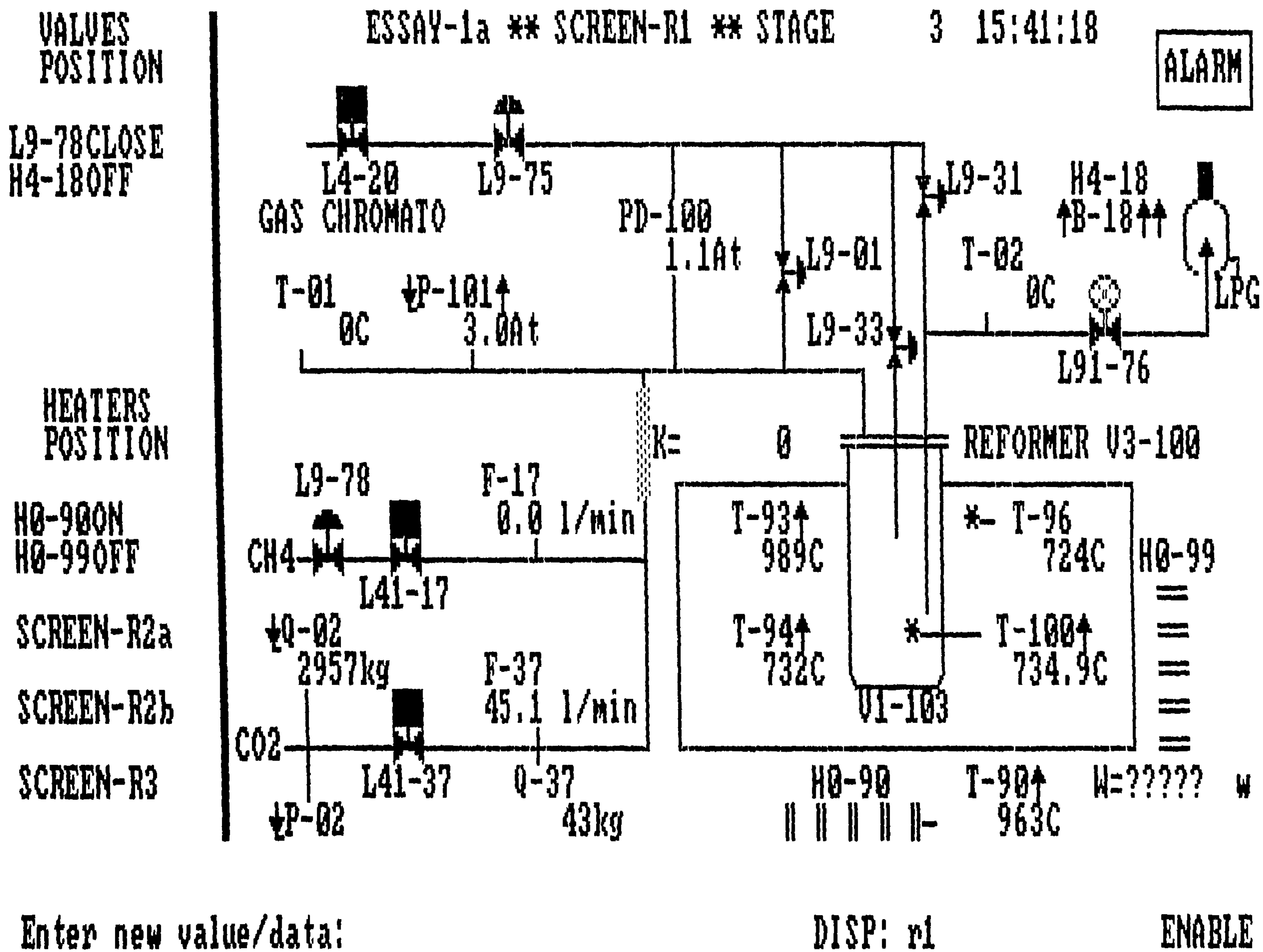
We therefore decided to use the solar furnace directly. The heat-up was rather slow because it was late in the afternoon, but we managed to get to temperatures of 750°C.

The next day we started in the morning and arrived at high temperatures fairly easily. We then started passing CO_2 through the reaction tubes at rather high flows. Figures 1, 4 and 5 show a flow of 44.9 l/min CO_2 and the temperature at the exit of tube 3 is 734°C. The exit temperature from all the tubes is quite uniform, proving that the sodium reflux is working rather well. Another point of interest is that the exit temperature from tube 2 is 728°C, while the first TC in tube 3 shows a temperature of 713°C. That means that the connection between the tubes that protrudes out of the sodium box does not lead to exessive cooling of the gas.

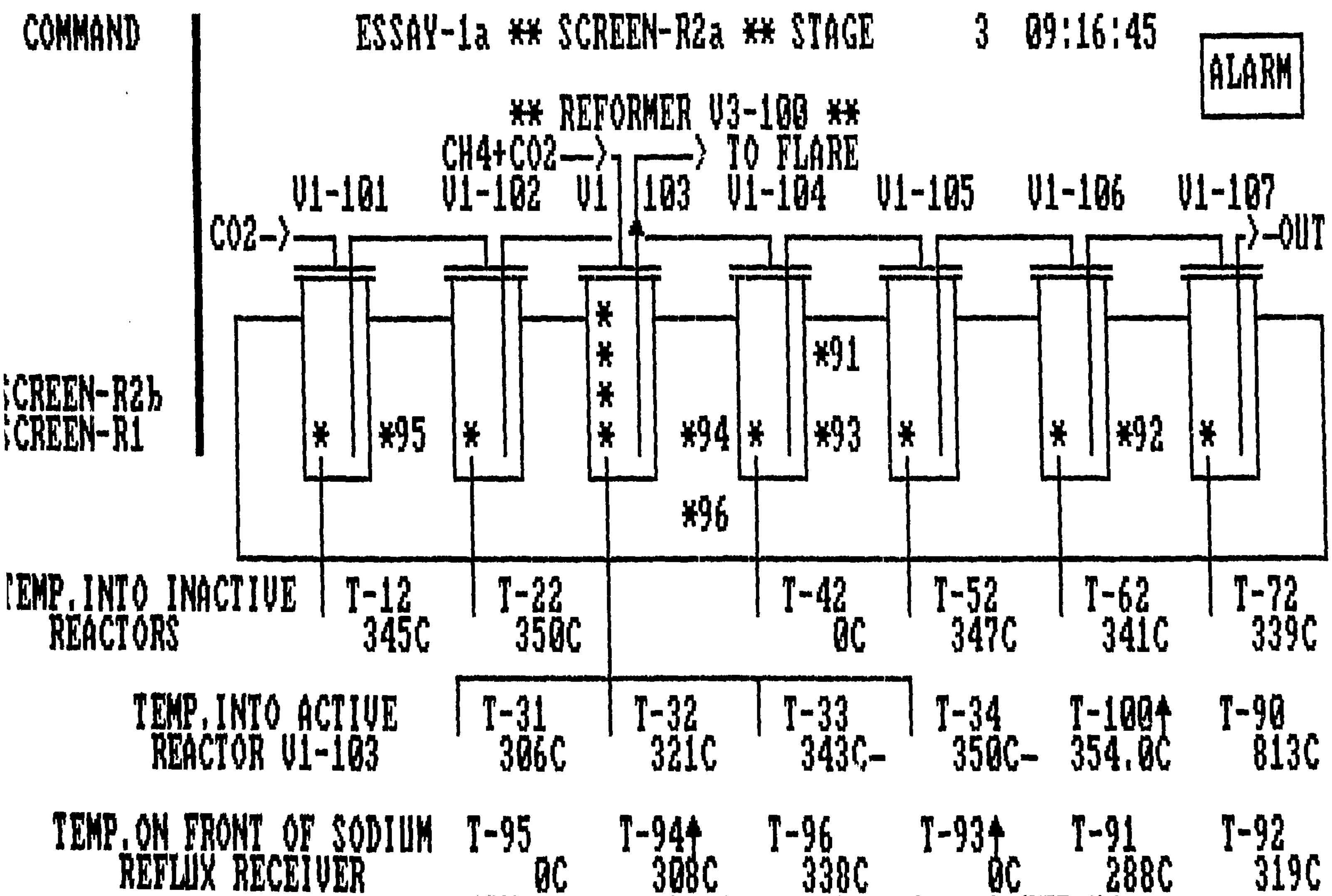
Conclusions

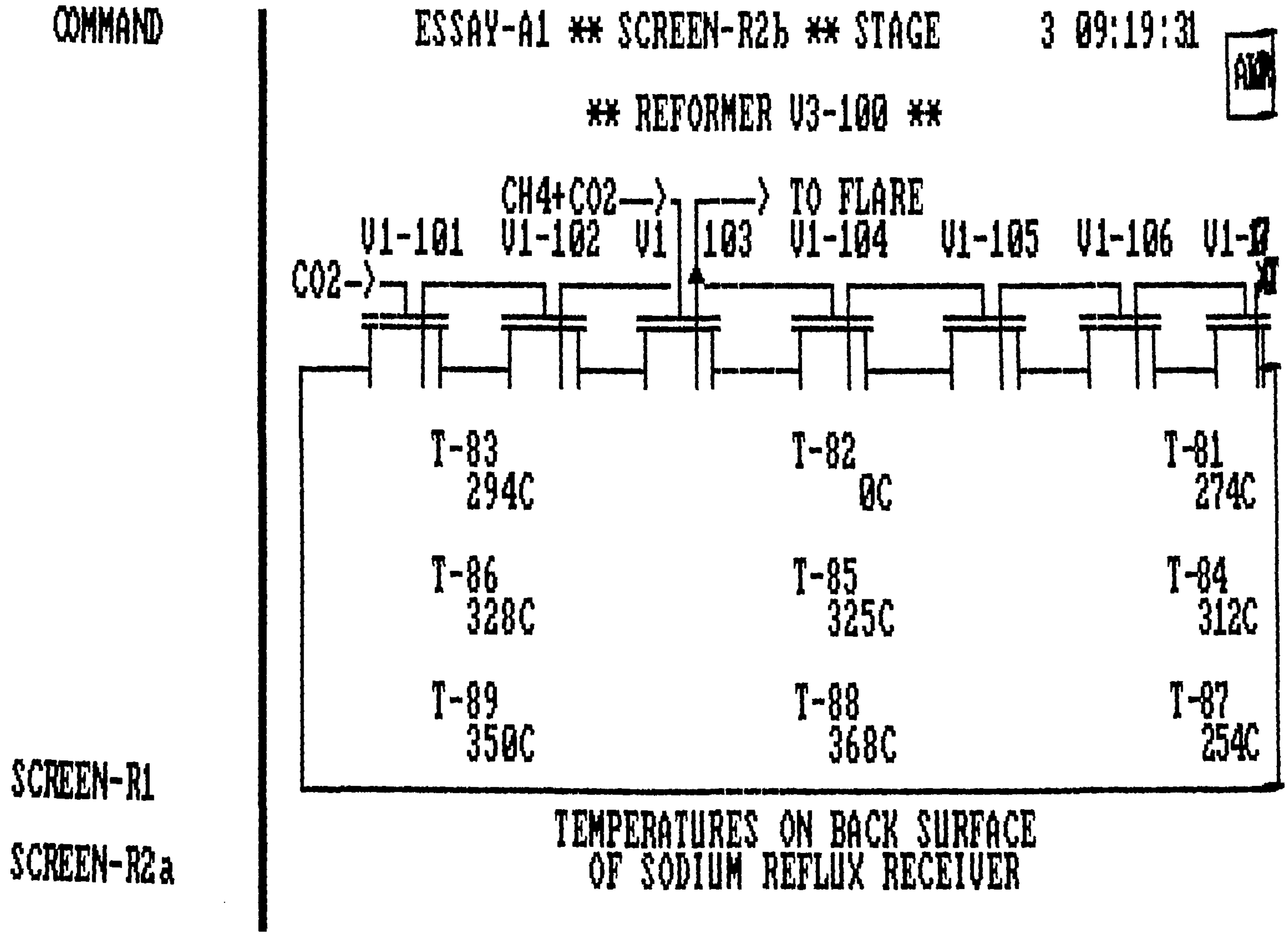
We are now at a stage when we can start testing the methane/CO_2 reforming reaction in a methodic form in the solar environment. After initial testing procedures we will first measure the heat losses and efficiency in heating CO_2 gas. We will then fill reactor tubes number 3 and 4 and carry the reaction to it's maximum capacity. We will obtain the temperature as well as the composition profile along this double length tube. After these experiments we will be in a position to decide about the operation of all the seven reactors in series or in parallel.

It is crucial at this stage, to start designing and building the methanator in order to close the loop.



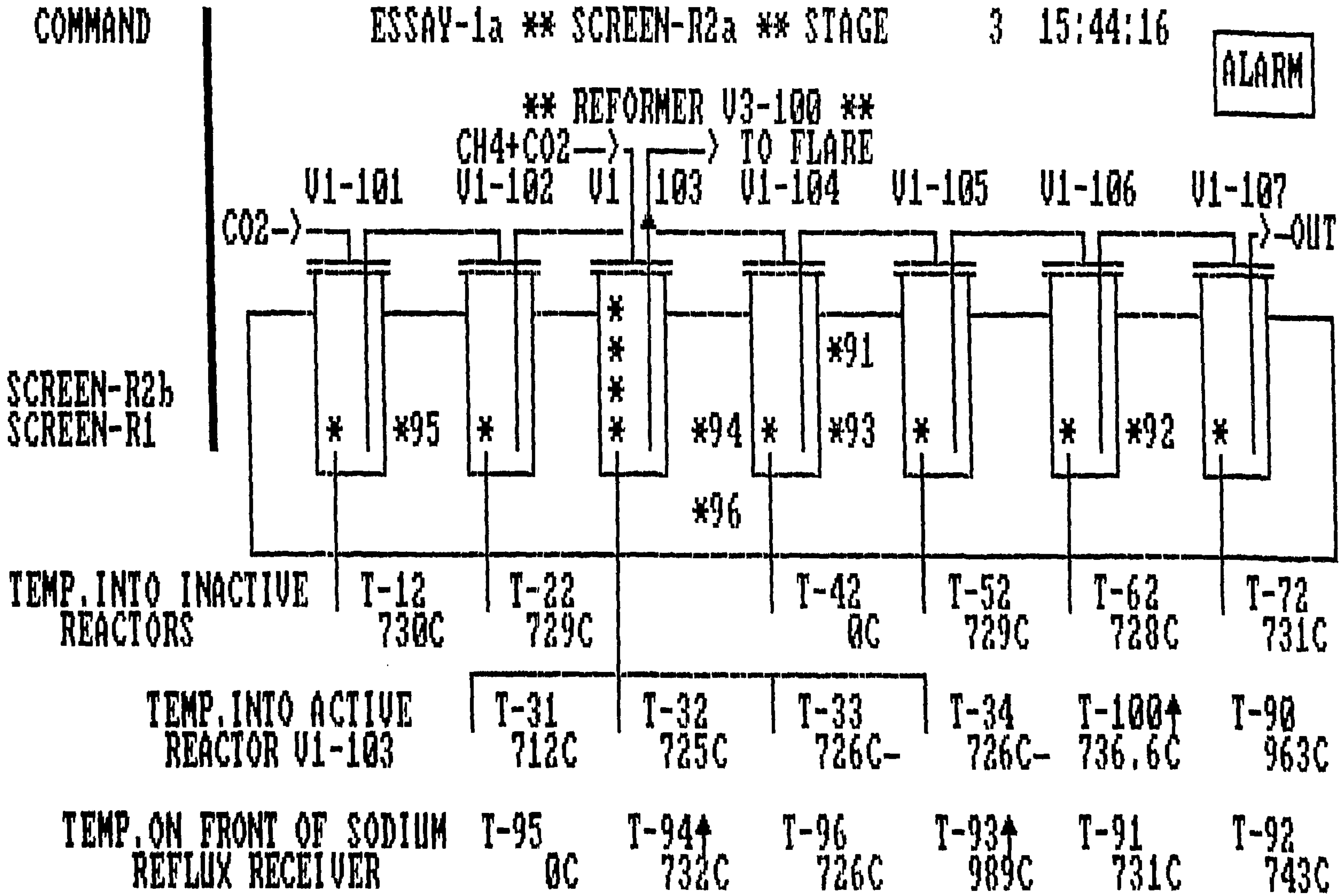
ESSAY-1a ** SCREEN-R1 ** STAGE 3 15:41:18
ALARM
VALUES POSITION
L9-78CLOSE
H4-18OFF
L4-20
L9-75
GAS CHROMATO
PD-100
1.1At
L9-31
H4-18
B-18
L9-01
T-02
0C
LPG
T-01
0C
P-101
3.0At
L9-33
L91-76
HEATERS POSITION
K= 0
REFORMER V3-100
L9-78
F-17
0.0 l/min
H0-90ON
H0-99OFF
CH4
L41-17
T-93
989C
T-96
724C
H0-99
SCREEN-R2a
Q-02
2957kg
T-94
732C
T-100
734.9C
SCREEN-R2b
F-37
45.1 l/min
V1-103
CO2
SCREEN-R3
L41-37
Q-37
43kg
H0-90
T-90
963C
W=????? w
P-02
Enter new value/data:
DISP: r1
ENABLE


COMMAND
ESSAY-1a ** SCREEN-R2a ** STAGE 3 09:16:45
ALARM
** REFORMER V3-100 **
CH4+CO2—> —> TO FLARE
V1-101 V1-102 V1 103 V1-104 V1-105 V1-106 V1-107
CO2-> >-OUT
*91
*95 *94 *93 *92
*96
SCREEN-R2b
SCREEN-R1
TEMP.INTO INACTIVE REACTORS
T-12 345C
T-22 350C
T-42 0C
T-52 347C
T-62 341C
T-72 339C
TEMP.INTO ACTIVE REACTOR V1-103
T-31 306C
T-32 321C
T-33 343C-
T-34 350C-
T-100↑ 354.0C
T-90 813C
TEMP.ON FRONT OF SODIUM REFLUX RECEIVER
T-95 0C
T-94↑ 308C
T-96 338C
T-93↑ 0C
T-91 288C
T-92 319C



COMMAND
ESSAY-A1 ** SCREEN-R2b ** STAGE 3 09:19:31
** REFORMER V3-100 **
CH4+CO2—> —> TO FLARE
V1-101 V1-102 V1 103 V1-104 V1-105 V1-106
CO2->
T-83 294C
T-82 0C
T-81 274C
T-86 328C
T-85 325C
T-84 312C
T-89 350C
T-88 368C
T-87 254C
TEMPERATURES ON BACK SURFACE OF SODIUM REFLUX RECEIVER
SCREEN-R1
SCREEN-R2a

Fig 3

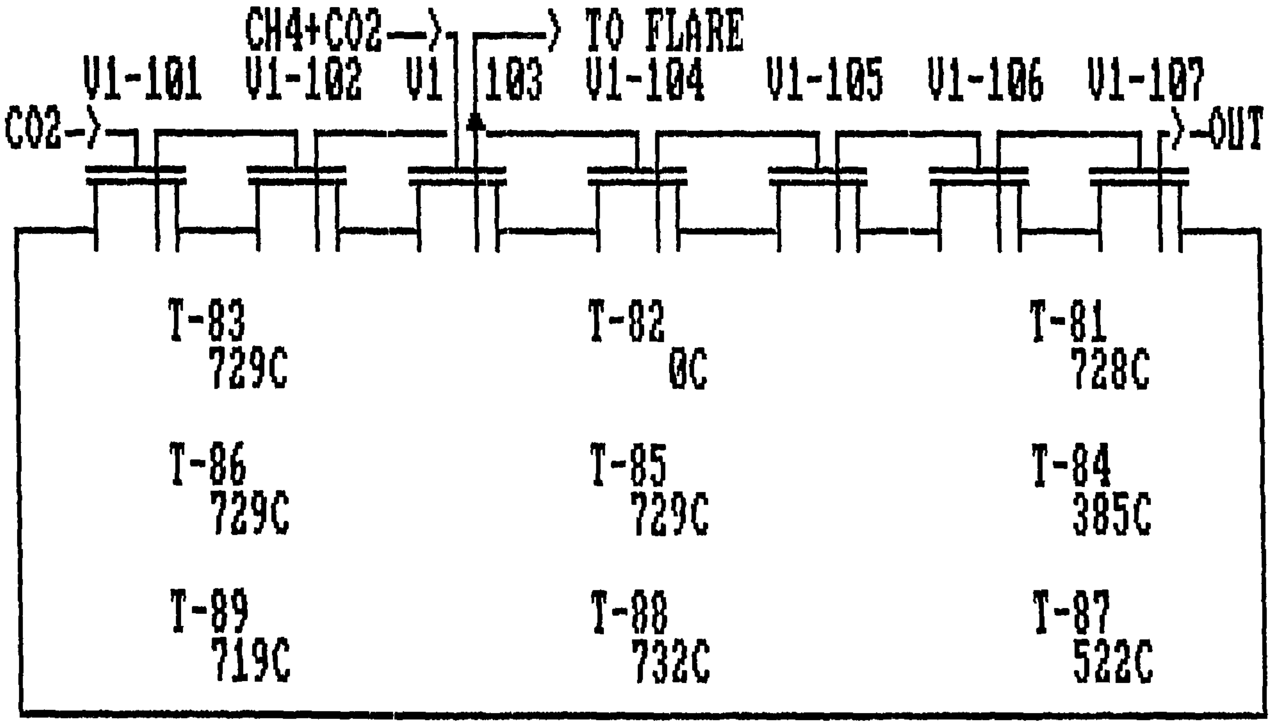

COMMAND
ESSAY-1a ** SCREEN-R2a ** STAGE 3 15:44:16
ALARM
** REFORMER V3-100 **
CH4+CO2—>
> TO FLARE
V1-101
V1-102
V1 103
V1-104
V1-105
V1-106
V1-107
CO2->
>-OUT
SCREEN-R2b
SCREEN-R1
*95
*94
*93
*91
*92
*96
TEMP.INTO INACTIVE REACTORS
T-12 730C
T-22 729C
T-42 0C
T-52 729C
T-62 728C
T-72 731C
TEMP.INTO ACTIVE REACTOR V1-103
T-31 712C
T-32 725C
T-33 726C-
T-34 726C-
T-100 736.6C
T-90 963C
TEMP.ON FRONT OF SODIUM REFLUX RECEIVER
T-95 0C
T-94 732C
T-96 726C
T-93 989C
T-91 731C
T-92 743C

COMMAND

ESSAY-A1 ** SCREEN-R2b ** STAGE 3 13:12:21

ALARM

** REFORMER V3-100 **

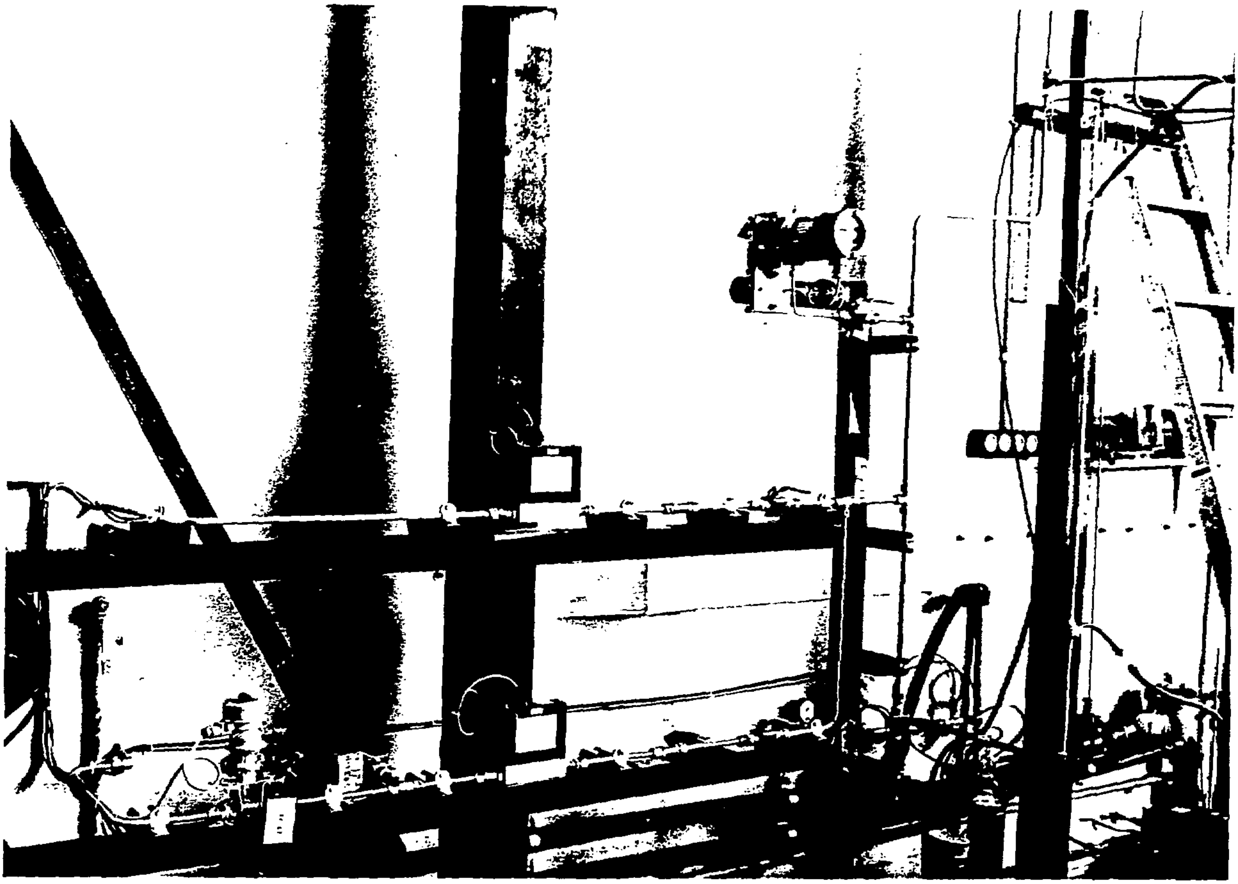


TEMPERATURES ON BACK SURFACE
OF SODIUM REFLUX RECEIVER

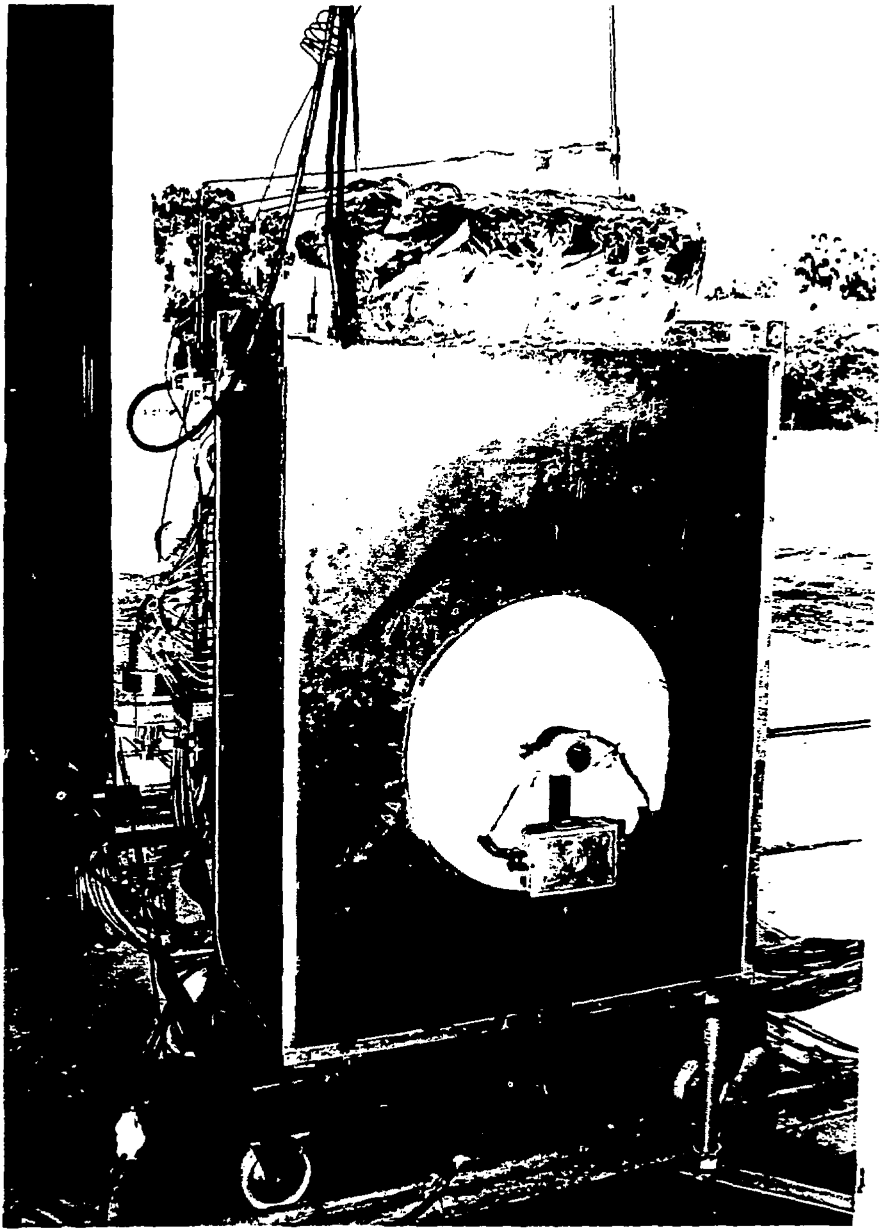
SCREEN-R1

SCREEN-R2a

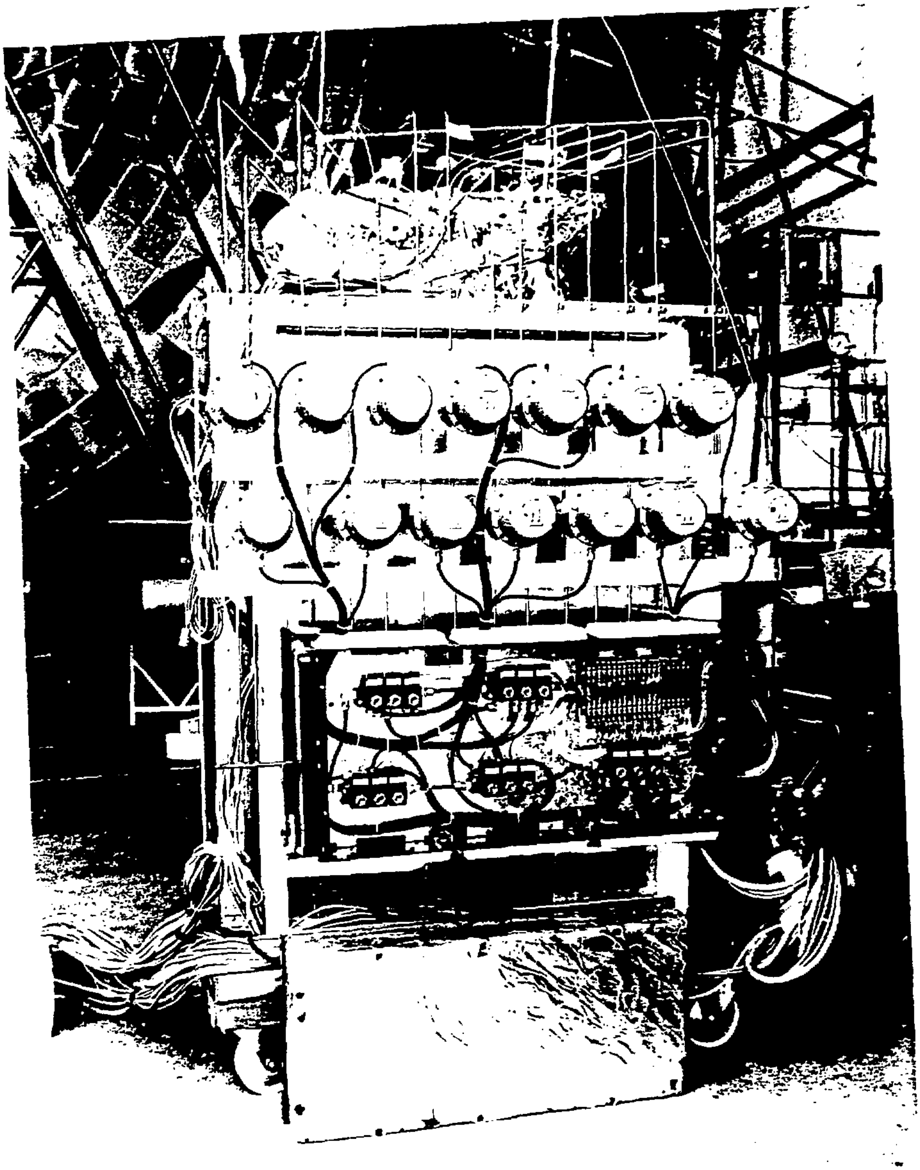
Picture 1



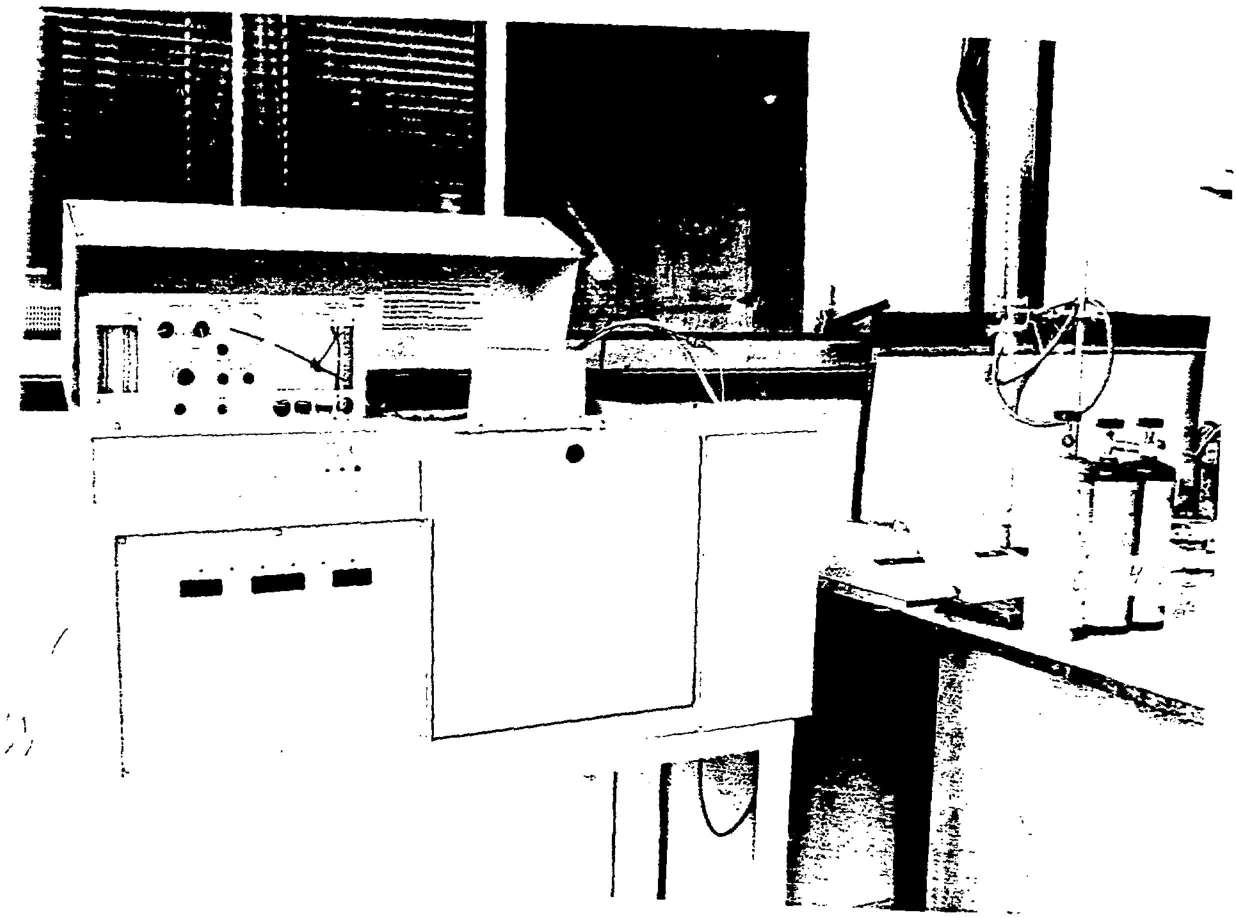
Picture 2

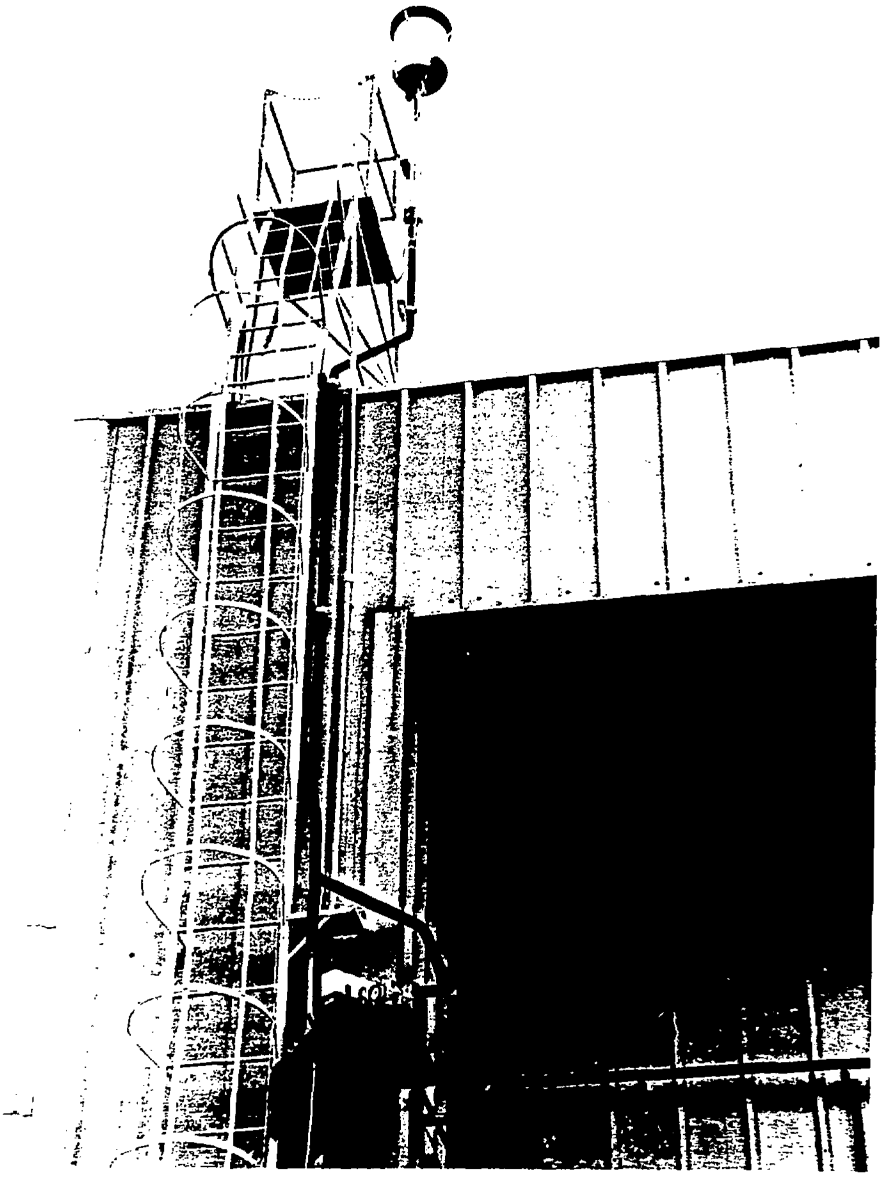


Picture 3

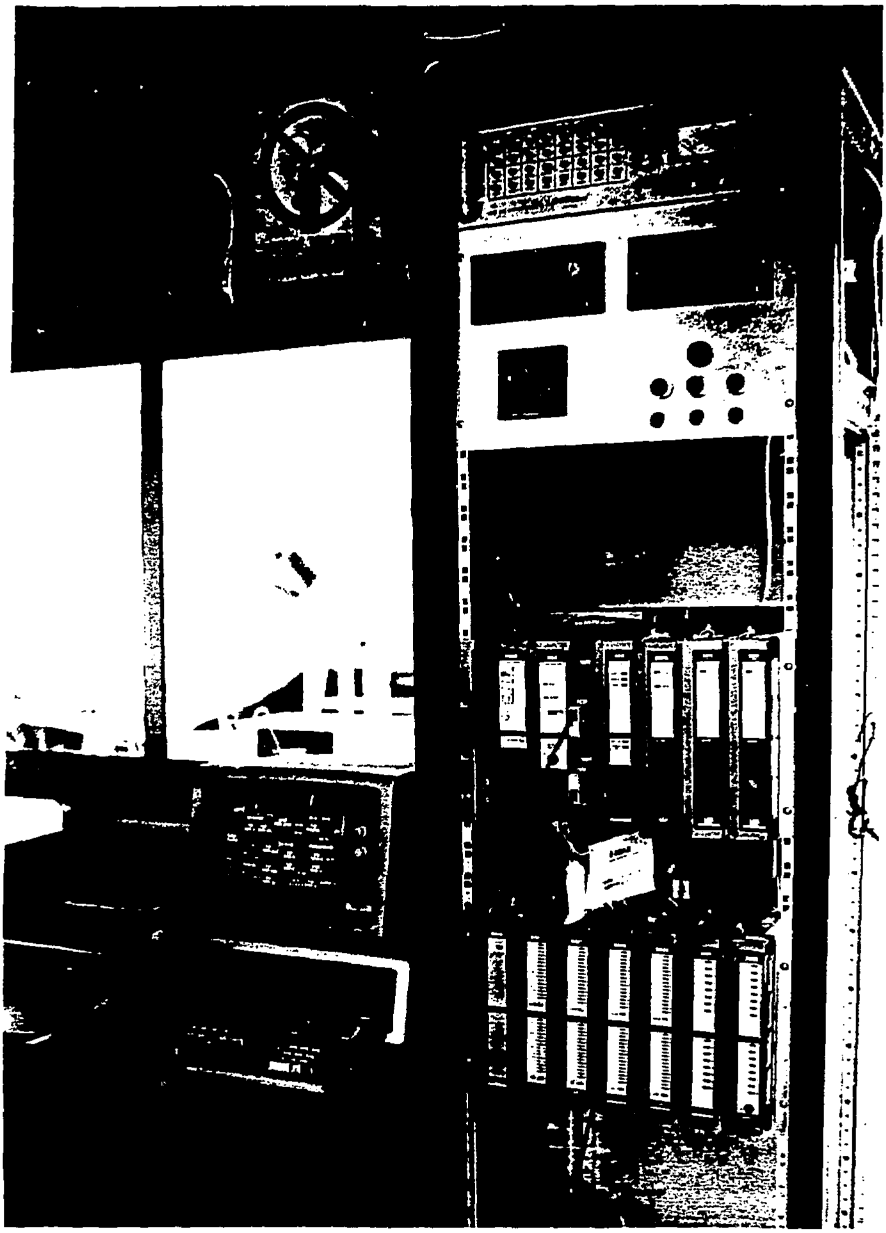


Picture 4

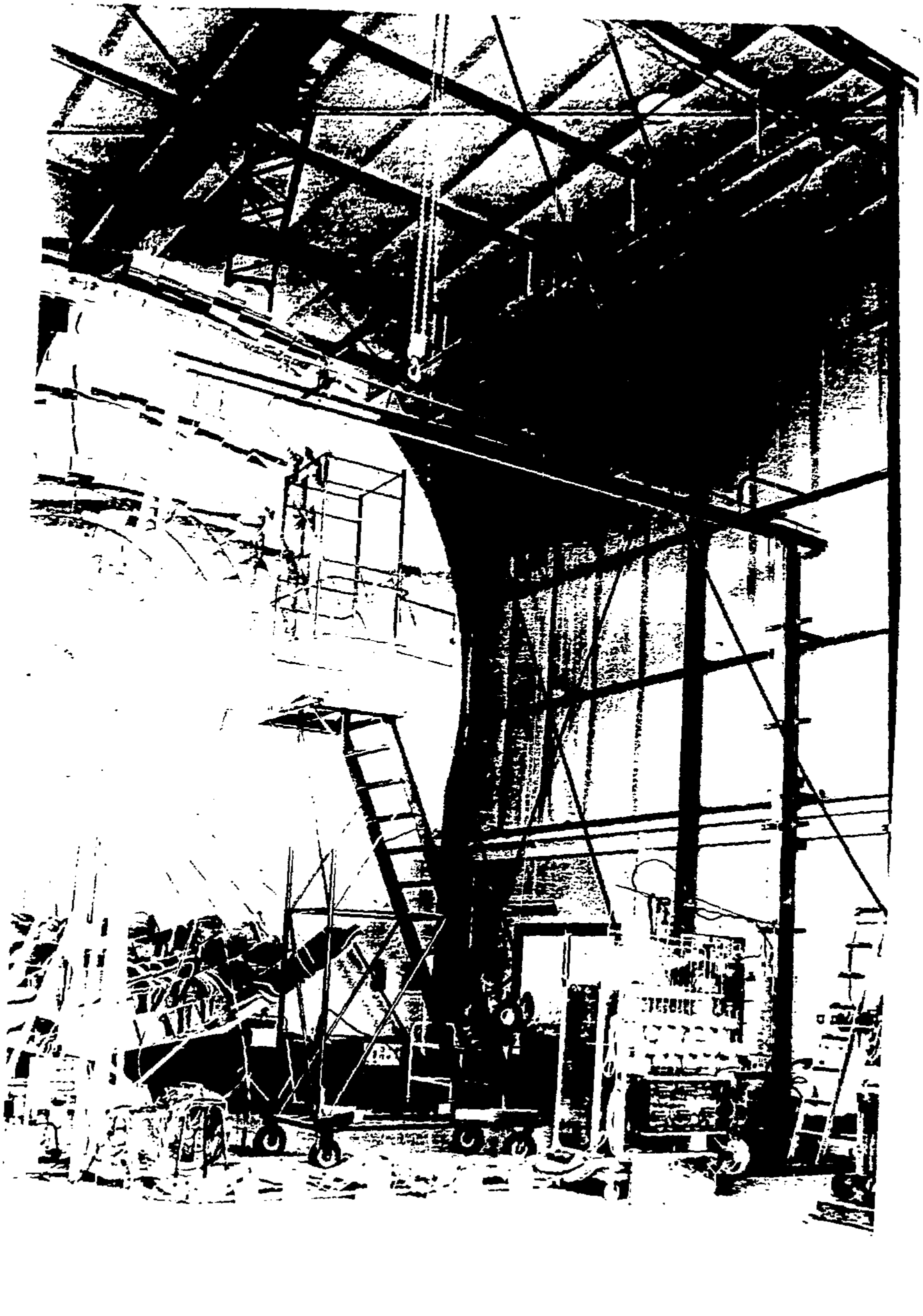




Picture 6



Picture 7



Picture 5

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