ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

SINCLAIR RADIATION PROGRAM

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Project 2437

SINCLAIR RESEARCH LABORATORIES, INC.
HARVEY, ILLINOIS

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PREFACE

The purpose of this report is to compile the results of preliminary information, data and calculations which have been completed prior to June 1, 1956, for the development of a continuous flow reactor unit to study the effects of gamma radiation on petroleum fractions.

Acknowledgments are extended to Sinclair Research Laboratories, Inc. for the use of a continuous flow reactor unit and for their valuable assistance and advice in making available information basic to the design, construction, operation, and analysis of results of the continuous flow reaction system referred to in this report.

R. H. Dilley, T. R. Johnson, R. A. Mulcahy, and G. M. Marcus have completed much of the experimental work and calculations upon which this report is based.

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ABSTRACT

This report describes the progress of the construction of a continuous flow chemical reactor unit to study the effect of gamma radiation on petroleum fractions. Information concerning the available gamma sources and the experimental location is also included. Batch irradiation test observations are discussed, and preliminary calculations involving the irradiation variables are presented.

INTRODUCTION

This is a progress report on a research project sponsored by Sinclair Research Laboratories, Inc., and conducted by the University of Michigan, Engineering Research Institute, covering investigations of the effect of gamma radiation on petroleum fractions. Studies are being made of the influence on radiation reactions of a number of operating variables previously found to be of importance in thermal and catalytic petroleum reactions.

Present studies involve the use of normal heptane, toluene, and methylcyclohexane as feeds to a continuous flow reactor unit operating at a pressure of 1000 psi and temperatures of 620° to 900°F as previously outlined by R. L. Smith and A. I. Snow.

Further investigation will include the use of high pressure hydrogen gas and the effects of catalytic materials and surfaces. Analysis of the product will be performed by the Sinclair Research Laboratories, Inc. in a method similar to that suggested by L. D. Norris, memorandum on the *Analytical Scheme, Normal Heptane Reforming Tests*, February 15, 1956, and some preliminary analysis will be conducted by the ERI project group.

The progress of the construction of a pilot plant unit to investigate these variables and to obtain pertinent data of these effects is discussed in this report.

CONSTRUCTION OF THE CONTINUOUS FLOW REACTOR UNIT

The flow diagram for the continuous flow pilot plant appears as Figure 1 and indicates the relative position for the various units and auxiliary equipment. All of the major items for the pilot plant have been received and most of high pressure fittings and related equipment will be on hand within the next 10 days.

There are a few items which require machining, threading or minor alteration. The materials for these changes are on hand or should be received within this same 10-day period. Table I is a list of the major equipment received and those items which were fabricated for use in the continuous flow reactor pilot plant. Items which are being fabricated and will be completed and received by June 10th are listed in Table II.

The equipment which has been assembled on the pilot plant equipment rack located at space number 1, Figure 7, includes the Ruska pump, dryer, filter and piping through to the mixing valve on the feed line. The rupture disk and the 1/8-inch to 1/4-inch tube connector on this line are still to be completed.

On the high pressure hydrogen line, the inlet and exit valves to the blowcases, heater, dryer, sight glass, filter and rotameter are connected through to the mixing valve. Piping for the blowcases and the three-section sight glass are to be completed. The dryer will be filled and the heater on the Deoxo unit will be wound after all units have been assembled and the system checked for leaks. A cylinder rack-carrier will be positioned at point D, Figure 7.

When the Hot Cave plugs are completed the process lines will be continued through to the reactor and back to the equipment rack. Electrical power leads and the thermocouple leads will be drawn at the same time.

The assembled equipment after the process return line includes the product cooler, sight glass, pressure control valve and the connecting valves and fittings. The vent line from the wet test meter has been completed and the level control system is about half completed. The glassware for the product receiver and the sampling bulbs is being constructed by the glass blower. Cold traps and other tubing will be assembled in two weeks' time.

The powerstats for the reactor heaters are mounted beneath the equipment rack next to the Ruska pump. Overhead process and pressure lines are contained in the raceway over the Gamma Room doorway.

The equipment for pressure and temperature instrumentation, shown on Figure 2, has been completed and tested, but will require further calibration checks when the thermocouples and the pressure pickup systems are completed.

Product analysis equipment has been assembled as it was being used on the batch reactor test runs. Most of this equipment is portable, but will be used in the laboratory, room 1066.

TABLE I

MAJOR EQUIPMENT RECEIVED BEFORE JUNE 1, 1956

Ruska liquid proportioning pump

Liquid and gas line filters

Liquid and gas line dryers

Gas line Deoxo unit

Mixing valve to reactor

Reactor, Hoke type, (2)

Modified sight glass for liquid level

Sensing element

Line cooler

Relay and Solonoid valve for product receiver

Wet test meter

Pressure control valve

Pressure recorder-controller

Temperature recorder-controller

Temperature indicator, multi-point

High pressure rotameter

Dryer-Deoxo indicator sight glass

3-Section sight glass for blowcases

H_2 and N_2 pressure regulators

Reactor heater control powerstats (4)

All piping and most valves and fittings

Pilot plant equipment rack

Podbielniak column and accessories

Refractometer and constant temperature bath

ASTM distillation apparatus

Gas feed blowcases (2)

TABLE II

EQUIPMENT BEING FABRICATED

Continuous reactor holding rack

Transfer plugs for process lines

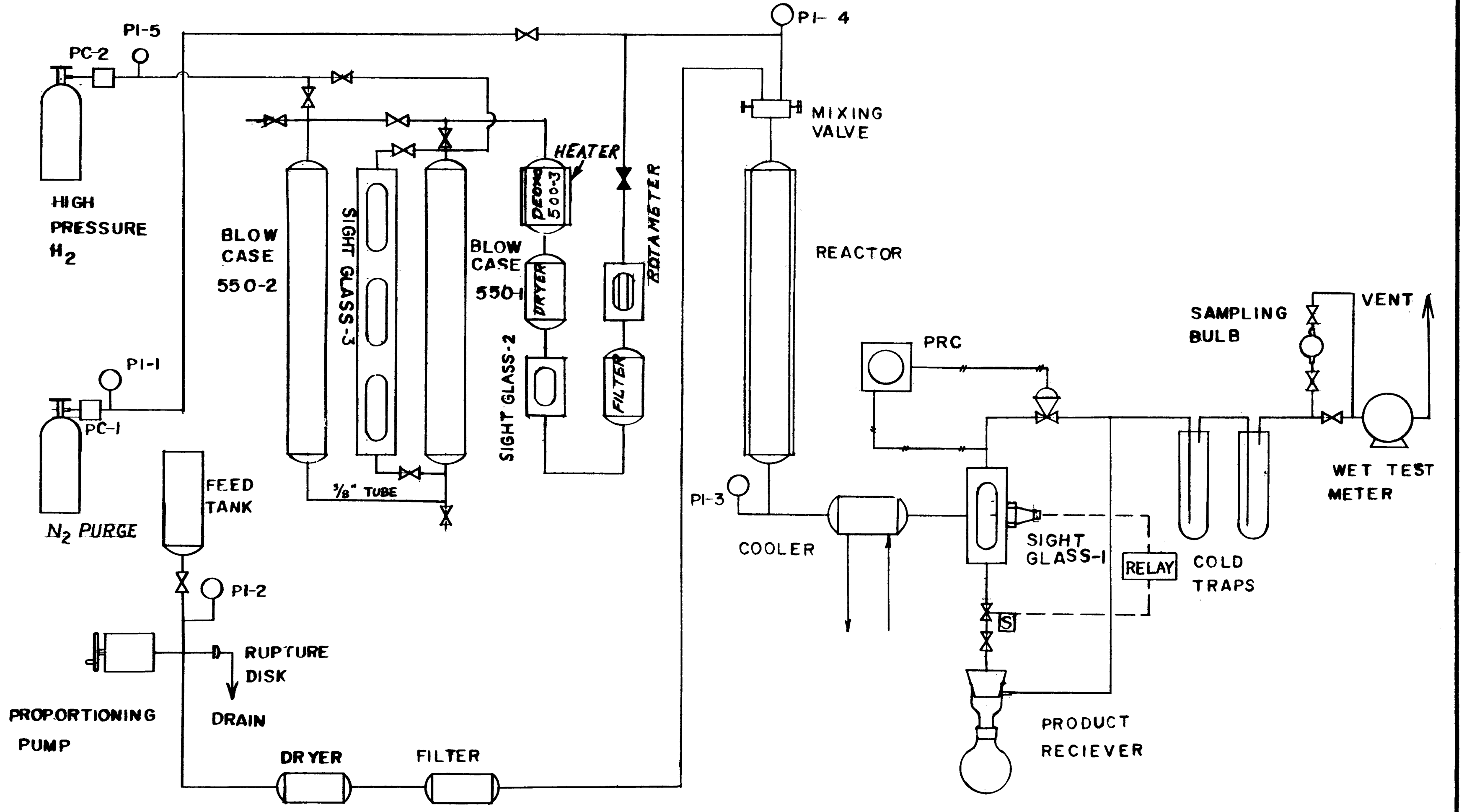
Cold traps

Product receiver

Reactor, Sinclair type (requests for bids are out)

Reactor thermocouples

Stainless steel elbows and tees (8)



ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64" DECIMAL ± .005" ANGULAR ± 1/2°

Revised	5-28-56 JSB
ISSUE	DATE

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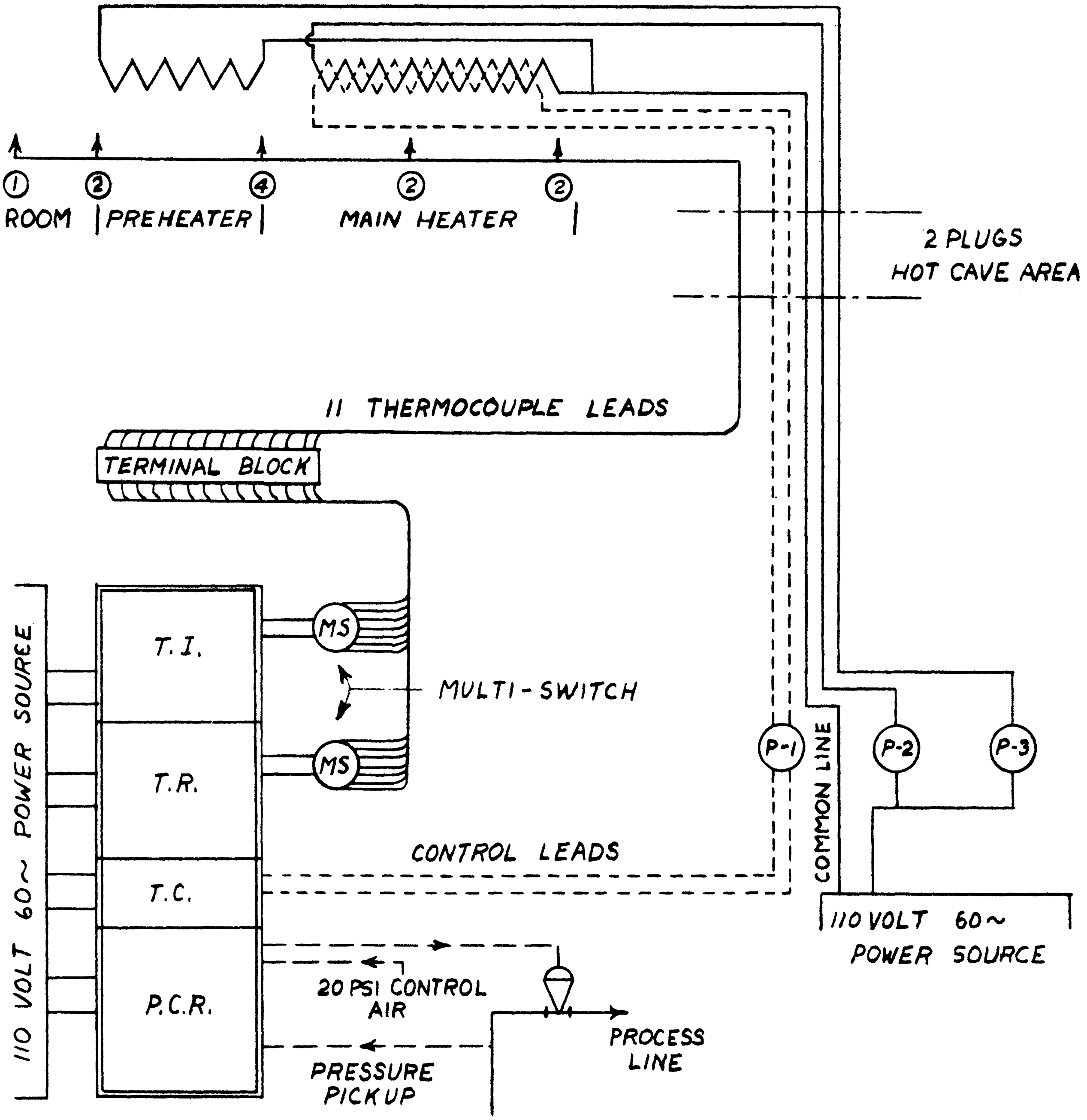
PROJECT 2437

CLASSIFICATION Figure 1

DESIGNED BY T. C. Johnson
DRAWN BY C. L. Willems
CHECKED BY J. S. Boegli
APPROVED BY
SCALE NONE
DATE 12/13/55

TITLE FLOW SHEET

DWG. NO. B- 2437A-1



P-1	POWERSTAT	CONTROL	1 KVA
P-2	POWERSTAT	MAIN HEATER	2 KVA
P-3	POWERSTAT	PREHEATER	1 KVA
TI	TEMPERATURE	INDICATOR	
TR	TEMPERATURE	RECORDER	
TC	TEMPERATURE	CONTROLLER	
PCR	PRESSURE	CONTROLLER - INDICATOR	

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SCALE NONE
CHECKED BY
DATE 5-29-56

TITLE
ELECTRICAL SYSTEM

PROJECT
2437

CLASSIFICATION
Figure 2

DWG. NO. A- 2437A-3

ISSUE
DATE

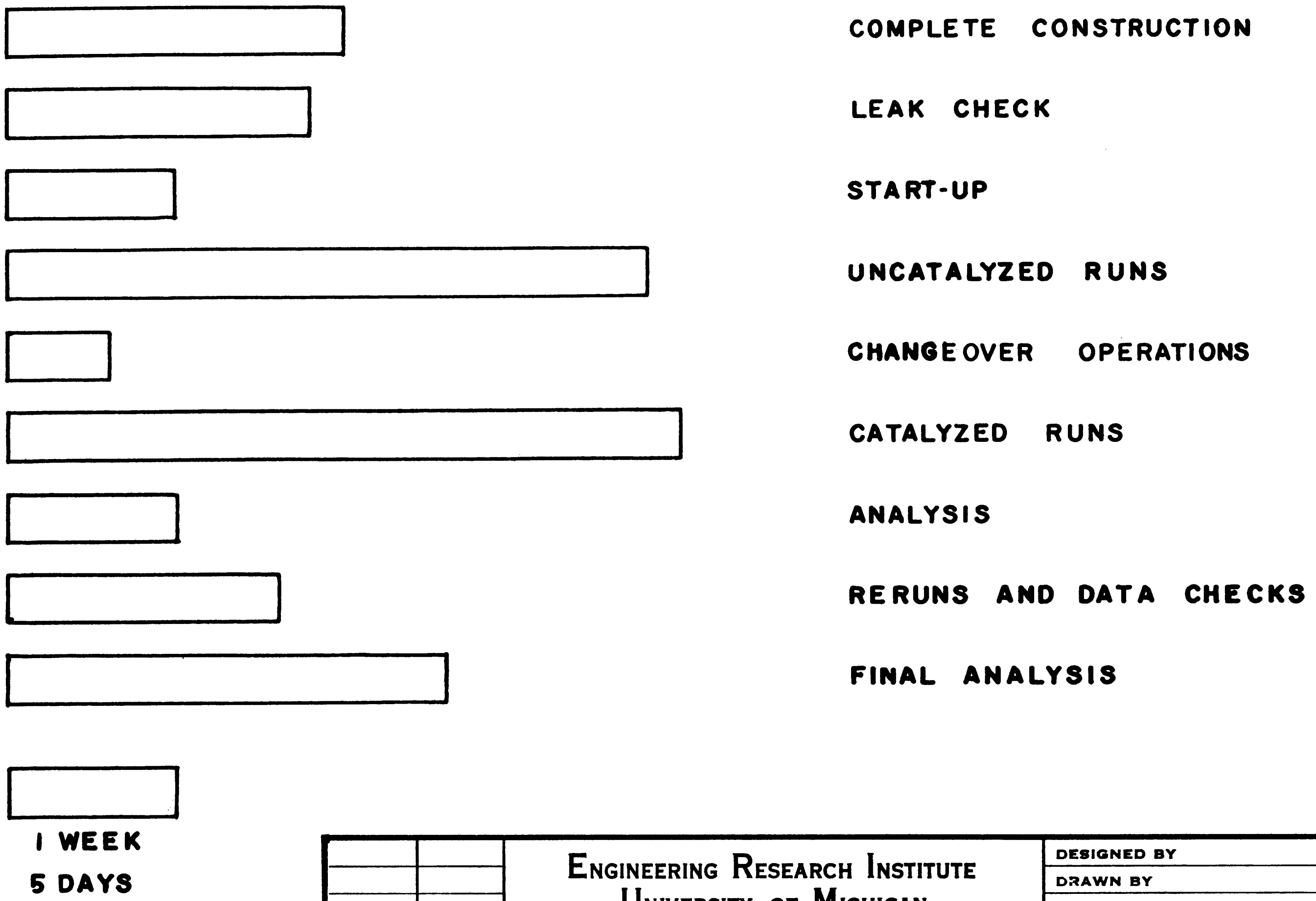
ESTIMATION FOR FUTURE OPERATIONS

At this time it appears that the equipment for the continuous flow reactor system will be completed in construction and fabrication about the 20th of June. The period required for leak detection, checking and repair will be about four days so that calibration tests and operating set point determinations can be made during the following week June 25th to 29th.

Start up with the equipment will probably begin the first of July and it is estimated that if the test runs are made on a 24-hour - day basis, three days per week, that the complete series of testing can be completed in about 7 to 8 weeks time. It is expected that any analysis of the products determined with the laboratory equipment on hand or available through the facilities of the University of Michigan will be made concurrently with normal testing operations. Reruns at various conditions may be required, and thus an additional amount of time may be necessary over-and-above this time allotment

Correlation of data and summarization of the operating variances should require a maximum of five weeks and it is expected that at least one of the personnel will supervise this information during the test operation period. Joint meetings of the project staff will be continued to alleviate long-range complications, and monthly meetings between the project staff and Sinclair Research Laboratories, Inc. will be continued to instrument efficient coordination.

Figure 3 is a breakdown of the estimated time requirement for each phase in the future operations.



ISSUE DATE

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PROJECT

CLASSIFICATION

FIGURE 3

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DATE

TITLE
BAR GRAPH OF TIME
REQUIRED

DWG. NO. A-

BATCH REACTOR OPERATION AND PERFORMANCE

Construction and Operation

In order to obtain a general idea of the effect of radiation and high temperatures on the pure hydrocarbons, it was decided to build a batch reactor. The cobalt-60 source was immediately available for use on these preliminary runs.

The reactor body is a 1-inch type 304 stainless steel tube with 1/8-inch wall thickness and 9 inches in length. One end was sealed by a plug tube fitting and the other end by a tube tee with fabricated plugs designed for the thermocouple tube and pressure gauge side stem. Figure 4 is a photograph of the assembled unit. The completed unit was hydrostatically pressure tested at 1500 psi. The reactor was heated by a chromel resistance wire wrapped around the middle eight inches of the tube. A chromel-alumel thermocouple in a thermowell located in the center of the tube was used to measure the temperature. A calibrated pressure gauge was used to measure the pressure.

In preparation for running, the vessel was cleaned, drained and evacuated and then charged with the desired pure hydrocarbon. The temperature was raised to the operating level and maintained until the pressure was relatively constant. The cobalt-60 source was then raised around the reactor. On the first runs the source was lowered so that the pressure gauge could be read, but on later runs the pressure was estimated continuously by reading the gauge through mirrors.

After several runs the reactor developed leaks which became progressively worse. A second batch reactor was constructed similar to the first. This vessel was pressure tight.

The temperatures existing in the reactor along the axis of the tube were determined by traversing the length of the tube with the thermocouple while the wall temperature was held to a constant value. The tests were obtained with air at atmospheric pressure with the reactor ends sealed. The average temperature is calculated by integrating the temperature profiles at three different temperature levels as shown in Figure 5. The average temperatures of the axis are then plotted against the temperature read by the thermocouple in its usual position, Figure 6. This approximated a straight line. All temperatures reported in other sections of this report are not corrected but are the temperatures read from the thermocouple.

Batch Reactor Data and Conclusions

Table III is an overall summary of the results obtained on the first batch reactor. Only five samples were taken for analysis since the unit developed leaks about the threaded fittings of the tee. It was generally observed that there was a pressure rise after the temperature and pressure attained a steady state and the source was raised around the reactor unit. Runs 8, 12 and 20 indicated that thermal cracking was starting at about 700° to 750°F for normal heptane. Runs 15, 18, 19 indicated that there was a pressure rise after the hydrocarbon was exposed to gamma radiation. Toluene and methylcyclohexane feeds were used for runs 16 and 17.

The poor recoveries of the feed hydrocarbon due to leaks which developed in the reactor fittings and the complications in sampling the product materials decreased the accuracy of product analysis.

Eight further runs were made after the batch reactor was modified and the leaks completely sealed. Runs A-103, A-104 and A-105, Table IV, using normal heptane as feed, were operated at temperatures below 750°F and resulted in no large pressure rise during the period of radiation. Runs A-106 and A-108 on normal heptane resulted in a 250 psia pressure rise during the period of radiation where the temperature of the hydrocarbon was maintained at a fairly constant value of 800°F. Similar test runs (A-107, A-109 and A-110) were conducted at the same temperature range and at similar pressures with a moderate rise in pressure during the test run.

It is concluded from these results that at the elevated temperatures studied there is an increase of the reaction rate of normal heptane when exposed to gamma radiation compared with the reaction rate without radiation. Further tests should indicate the effect of radiation on methylcyclohexane and toluene feeds. Full evaluation of the results should await further testing of these hydrocarbons and the corresponding product analyses. Full records of the data are being kept and are available to the Sinclair Research Laboratories, Inc.

TABLE III

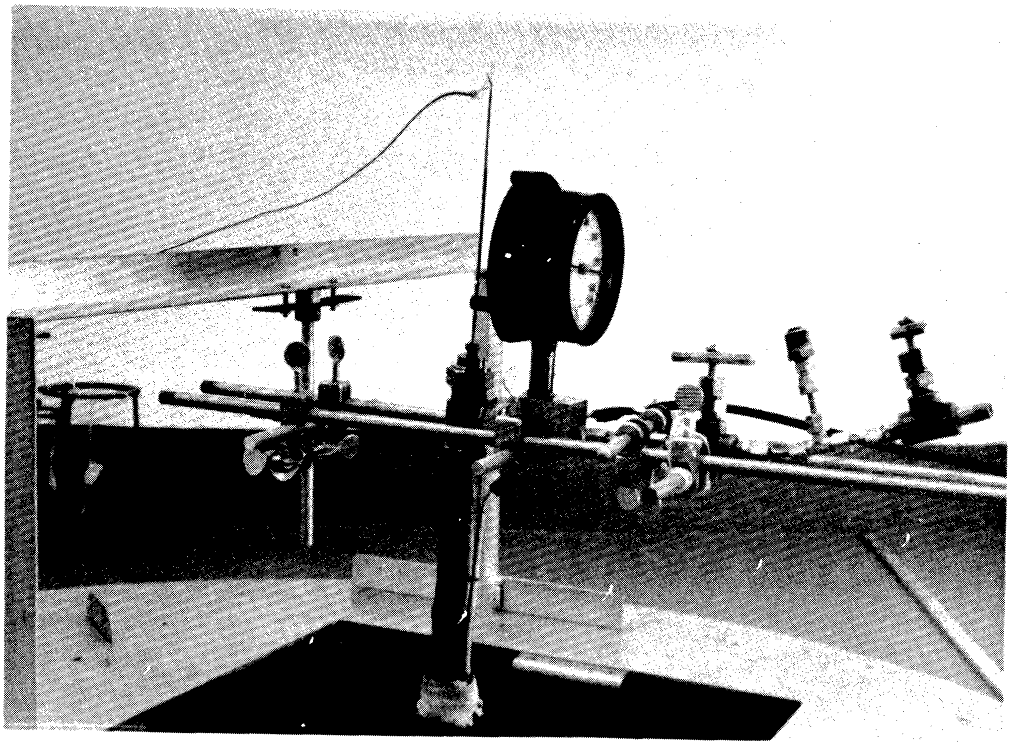
SUMMARY OF RUNS WITH FIRST BATCH REACTOR

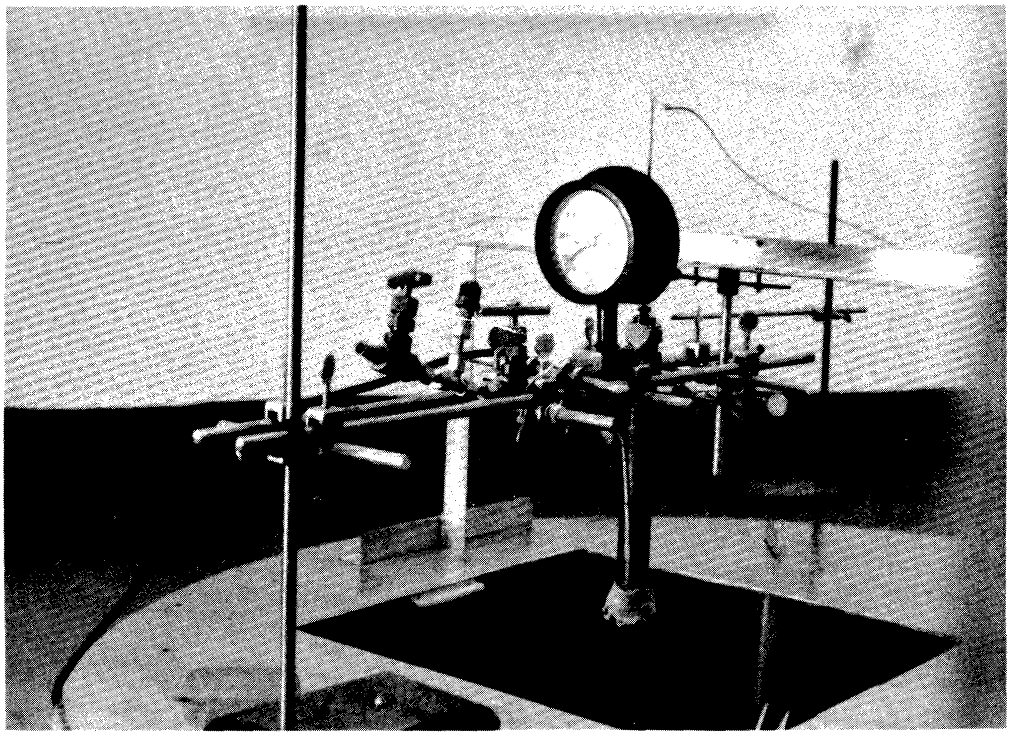
Run No.	Date of Run	Charge	Recovery	Ave. Max. Temp.	Ave. Pressure	Duration of Irradiation	Liquid Sample	Results & Comments
		cc	cc	^{o}F	psia	minutes	Sinclair Sample No.	
1	2-2-56	18 nC_7	--	680	--	--	--	pressure test - low pressure
2	2-3-56	38 nC_7	24	825	580	--	--	carbon deposits on wall - some thermal cracking
3	2-7-56	air	--	--	--	--	--	pressure test - low pressure
4	2-8-56	30 nC_7	28	750	150	--	--	slight pressure rise-thermal cracking
5	2-9-56	45 nC_7	30	580	300	--	--	leaked
6	2-10-56	20 nC_7	16	750	--	--	--	low pressure
7	2-10-56	20 nC_7	--	700	70	--	--	pressure test to find leak around gauge
8	2-10-56	45 nC_7	43	700	950	--	--	held pressure
9	2-14-56	35 nC_7	22.5	800	500	--	--	leaked
10	2-14-56	35 nC_7	26	700	580	--	--	leaked
	2-15 to 21	Temperature gradient measurements and dosimetry of cobalt-60 source.						
11	2-22-56	35 nC_7	--	--	--	--	--	bad leak
12	2-22-56	35 nC_7	24	760	650	--	--	thermal cracking
13	2-22-56	45 nC_7	--	850	900	--	--	thermal cracking
14	2-28-56	45 nC_7	--	--	--	--	--	bad leak
	2-29-56	Pressure tests to find leaks in reactor.						
15	3-1-56	45 nC_7	40	650	770	25	240K-1	reaction - a 100 psi pressure rise during radiation
16	3-2-56	45 toluene	--	655	770	30	--	leak during last few minutes of run
17	3-5-56	45 MCH	--	655	580	6	240K-2	bad leak
18	3-7-56	45 nC_7	--	650	770	50	240K-3	no pressure rise - no apparent leak (gas sample) - 240K-5
19	3-8-56	35 nC_7	--	750	770	50	240K-4	small pressure rise - leak lost 20 psi in 15 min.
20	4-9-56	45 nC_7	--	750	1270	--	--	no leak - no evidence of thermal cracking
100	4-20-56	35 nC_7	--	850	280	--	--	low pressure
101	4-23-56	40 nC_7	--	750	400	--	--	bad leak
102	4-26-56	30 nC_7	--	790	210	20	--	bad leak

TABLE IV

SUMMARY OF RUNS WITH SECOND BATCH REACTOR

Run No.	Date of Run	nC_7 Charge	Recovery	Ave. Max. Temp.	Max. Pressure	Duration of Irradiation	Liquid Sample	Gas Sample	Results & Comments
		cc	cc	°F	psia	minutes			
A-103	4-10-56	40	37	745	1150	60	Yes	No	fluctuating pressure, net rise
A-104	4-11-56	40	32.5	750	1000	60	Yes	No	pressure rise
A-105	4-12-56	45	42	700	1200	60	Yes	Yes	no pressure rise
A-106	4-16-56	35	10.5	790	1400	8	Yes	Yes	very steep pressure rise
A-107	4-18-56	35	28	800	1400	0	Yes	No	steep pressure rise
A-108	4-19-56	35	24	800	1420	7	Yes	Yes	steep pressure rise
A-109	4-23-56	35	19	825	1420	0	Yes	Yes	small pressure rise
A-110	4-24-56	35	25	800	1300	0	Yes	Yes	moderate pressure rise





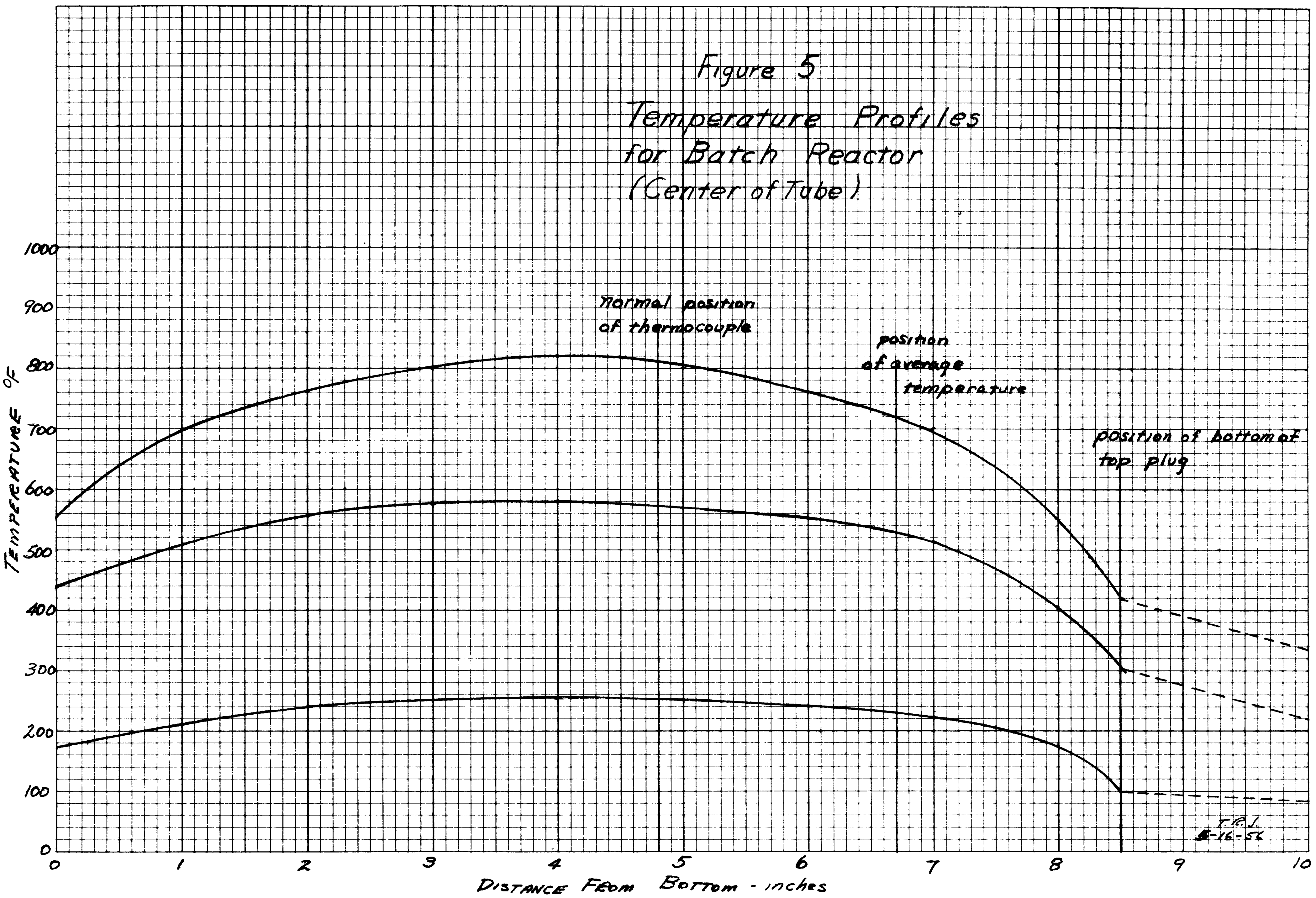


Figure 5

Temperature Profiles for Batch Reactor (Center of Tube)

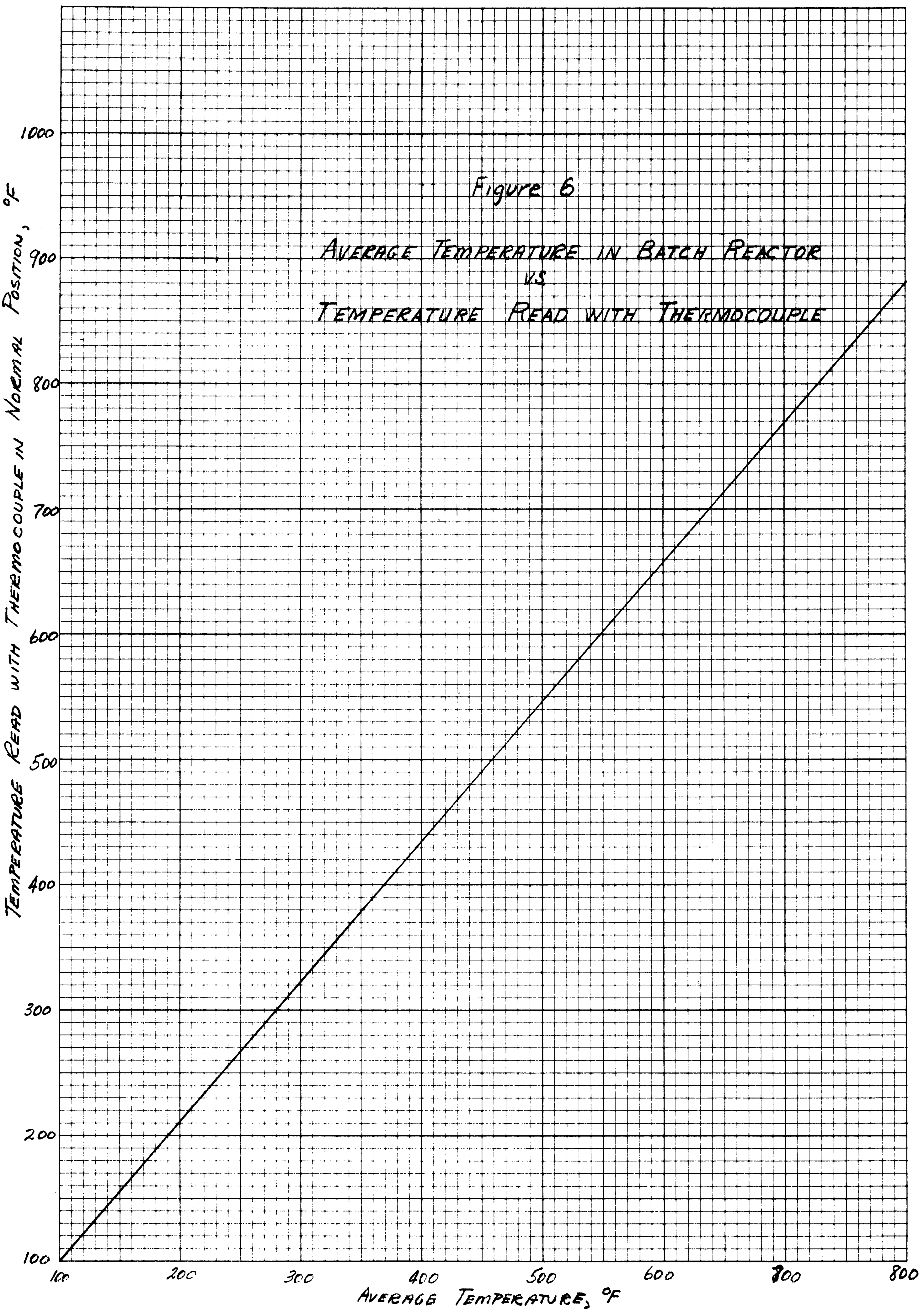


Figure 6

AVERAGE TEMPERATURE IN BATCH REACTOR
VS
TEMPERATURE READ WITH THERMOCOUPLE

FACILITIES AVAILABLE IN THE PHOENIX MEMORIAL LABORATORY

The University of Michigan Phoenix Project has made facilities available for the Engineering Research Institute Project 2437 in the Phoenix Memorial Laboratory. Four locations on the ground floor of the Laboratory are to be used to give the required operating and testing equipment floor space necessary for the project. The following will describe the size, utilities and general description of each of these locations as shown on Figure 7.

Operating Room 1069

The available floor space in room 1069 is divided into two areas on either side of the Gamma Room doorway. Space number 1 will be used for the major part of the apparatus. The dimensions of this space are 64 x 28 inches with a wall clearance height of 7 feet. Space number 2 is located along the east wall of room 1069 next to the edge of a support column. The floor space here is 22 x 18 inches and has been designed for the instrument panel rack.

The utilities available in the Operating Room will be discussed under the following headings: air, vacuum, water, electricity, ventilation, and drains.

Compressed air is available at points B and C as shown on Figure 7, beneath the Hot Cave windows. The outlet valves are recessed in the wall and are positioned 16 inches above the floor. This compressed air is available at 76-84 psia and has been prefiltered at the pump.

Two vacuum sources are available in the same recess as the compressed air source. The vacuum is rated at 18 inches of mercury.

Water is also available at these recessed outlets under the Hot Cave windows. The water is rated at 25 GPM at 60 psi from a 3/4-inch source.

Electrical outlets are located at points A and E. There are five receptacles on the panel at point A delivering 110 volts and 15 amperes, and one unit delivering 120/208 volts, 3 phase, 20 amperes. At point E there are two receptacles delivering 110 volts and 15 amperes.

A raceway 4 x 3 inches in cross section is available to carry utility lines for air, water and electricity from points A and B to point E. It runs over the doorway to the High Gamma Room at a height of 7 feet on the south and east walls.

The ventilating system in room 1069 is capable of 40 to 60 air changes per hour. Process off gases will be vented through a special 3/4-inch copper vent line which enters the room above the High Gamma Room doorway and exhausts through a flame arrestor on the roof of the building.

A drain is available for the cooling water in the recessed opening under the Hot Cave window. The diameter of the drain is 1-3/8 inches and will require a special siphon breaker.

Hot Cave Number 1 - Room 1069-A

The Hot Cave Room will be used as a means of passage for the process lines from the Operating Room to the High Gamma Room. These process lines will pass through special lead plugs called an "A" transfer plug and a "B" transfer plug. A "B" plug on the east wall between points A and B will contain three spiraled 3/4-inch tubes equally spaced within the 5-3/4-inch diameter of the plug. The process lines, thermocouple leads and the electrical power lines will be drawn through these 3/4-inch tubes.

Between the Hot Cave and the High Gamma Room two "A" plugs will be used, and the process lines will be divided between the two 3/4-inch tubes spiraled in each of these plugs. The diameter of the "A" plugs is 4 inches.

The method of fabricating these plugs will be to coil 3/4-inch copper tubing on a 1-1/2-inch radius making at least 1-1/2 complete turns in a total length of 22 inches. These tubes will then be equally spaced within the plug shell and molten lead poured to fill the inner space.

The process lines will have unions on both ends of the plugs to facilitate cleanup and repair. The electrical leads will have at least two receptacle units at each end for the same purpose.

High Gamma Room 1069-C

The main part of the High Gamma Room is 10 x 12 feet, and the source well plate cover is mid-center and 6 inches above the floor. The diameter of the well is about 5 feet and the chemical reactor test equipment will be suspended from rack straddling the well.

Electricity is available in room 1069-C delivered through seven explosion-proof elements equally spaced around the room. The delivery is 110 volts at 15 amperes and can be controlled through the service box at point D in the Operating Room.

Compressed air, vacuum and cold water is available at point F in the northwest corner of the High Gamma Room. The air ventilating system is capable of maintaining 40 to 60 air changes per hour.

High Level Chemistry Room 1066

Bench and hood space is available for analysis and testing in the High Level Chemistry Room. Work space and storage room measures 11 x 2 feet, and equipped with the necessary utilities.

Compressed air at 76-84 psi is available at three sources equally spaced along the upper shelf of the laboratory bench. Vacuum at 18 inches of mercury is available at two points.

Both hot and cold water is supplied at two positions and a drain exists midway on the bench top beneath the shelf.

There are five electric outlets for both 110 volts and 15 amperes and 220 volts and 20 amperes. The 220 volt line requires a special safety plug.

The ventilating system in the room is adequate, but testing and experimentation involving organic vapors should be carried out under the hoods. There are two hoods; one is a walk-in type and the other at bench top height. Both hoods have glass window covers. Water, vacuum and compressed air are available in both of these hoods. The venting system is capable of drawing 100 linear feet per minute across the face of the hood. Both hoods have two 2-inch drains of a funnel type.

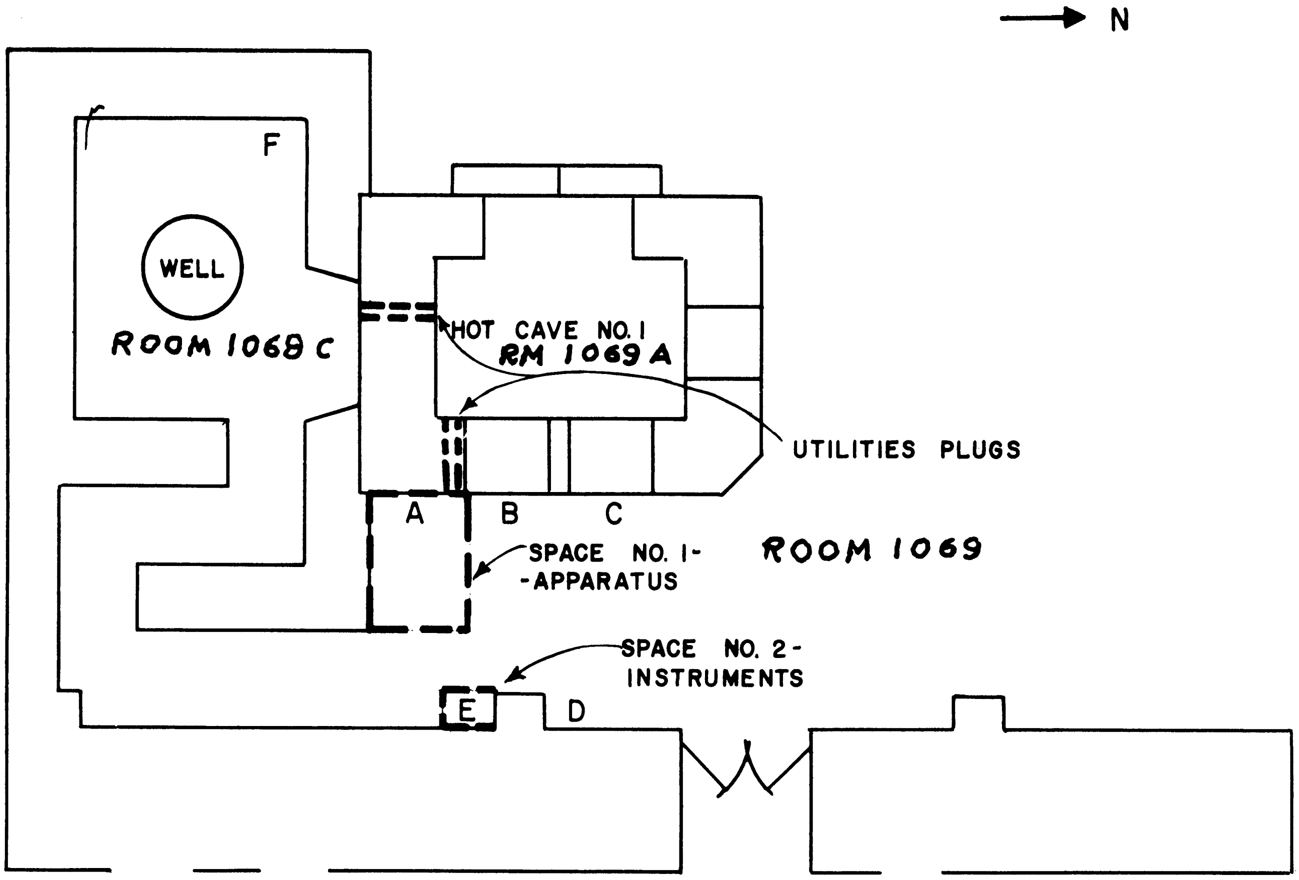
There are six storage cabinets under the bench. The complete laboratory bench is coated with an organic chemical-resistant paint and the fixtures are chrome plated.

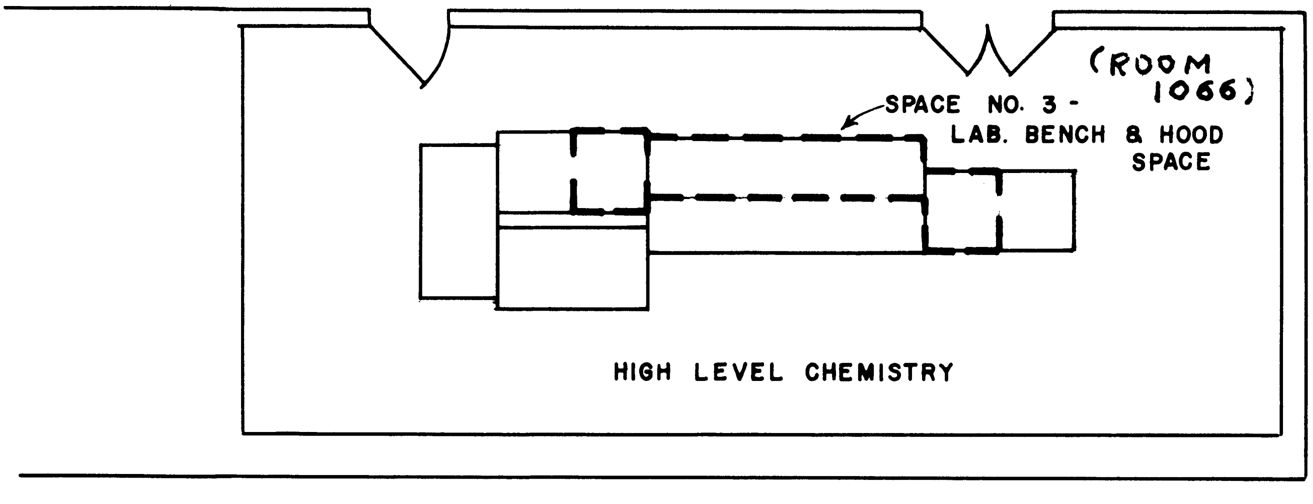
TABLE V

A Tabulation of Utilities Available in the Phoenix Memorial Laboratory.

ROOM	UTILITY	GROUP	CAPACITY
1069	air	BC	76-84 PSI
	vacuum	BC	vacuum of 18" Hg
	water	BC	60 PSI with 3/4" outlet
	electricity	A	4 110 volts, 15 amperes 1 120/208 volts, 15 amperes
		B	4 110 volts, 15 amperes 1 120/208 volts, 15 amperes
		C	4 110 volts, 15 amperes 1 120/208 volts, 15 amperes
		D	2 110 volts, 15 amperes
		E	2 110 volts, 15 amperes
1069-C	air	F	76-84 PSI
	vacuum	F	vacuum of 18" Hg
	water	F	60 PSI with 3/4" outlet
	electricity	located around Gamma Room	100 volts, 15 amperes 120 volts, 20 amperes

SCHEMATIC DIAGRAM, GROUND FLOOR
PHOENIX MEMORIAL LABORATORY
SHOWING SPACE REQUESTED





ANALYSIS OF THE AVAILABLE RADIATION SOURCES

The Radiation Laboratory at the University of Michigan Phoenix Memorial Laboratory at present has available a 3,000 curie gamma radiation source of cobalt-60 which has been used by the Engineering Research Institute for this project on preliminary test runs. This source is composed of forty-two cobalt 60 rods, 10 inches in length and 3/8 inches in diameter, completely clad in aluminum. The rods are held in a cylindrical array by an aluminum spacement rack which has a 4-inch inside diameter. Other spacement racks are possible depending on the desired gamma flux and the limitations on the inside diameter.

The 4-inch diameter spacement rack now being used has 28 rods in the inner row and 14 rods in the second row. The rods in the inner ring are 3/8-inch from the center hole and there is about 1/8-inch between adjacent rods. The mean radius for the source rods then is 2-1/2 inches.

A second support rack has been suggested with a center hole of about 2-1/2 to 3 inches inside diameter and with 20 rods in the inner ring and 22 in the second ring. This rack would increase the gamma power equivalent by decreasing the radial distance between the source and the chemical reactor.

The use of nuclear reactor fuel elements as a source of gamma radiation will be available at the Phoenix Laboratory in the near future. Four of these elements from the Materials Testing Reactor would provide an initial source strength of above 10,000 curies if the elements are received 250 days after removal from the MTR core. Receipt of younger elements is anticipated.

The dimensions of a fuel element of the MTR type are 3.2 x 3 inches in cross section and about 25-1/2 inches in length. A spacing rack for these elements has been considered with 3 inches between element faces making a 3 x 3 x 25-1/2 inch center test hole.

Several factors should be expressed here concerning the cobalt-60 and the MTR fuel element as sources of gamma radiation. Cobalt-60 emits two gamma-ray photons with energies of 1.16 Mev and 1.32 Mev, whereas the fuel elements emit many gamma-ray photons of many energies between 2.9 and 0.3 Mev. The shielding in the High Gamma Room 1069-C is adequate for the cobalt-60 source but the elements may require additional shielding. Calculations for this increased shielding requirement are presented in the following section.

Calculations for the maximum axial dose rate (Rep/hr) using the MTR elements indicates that drop of approximately 10% for each 10 days of usage may be expected. The cobalt-60 source, in comparison, offers a more nearly constant maximum axial dose rate for a longer period of operation. The advantage of the MTR element, therefore, is in the higher power, available during the early stages of cooling and in the length of the source and its application as a gamma radiation facility for the continuous chemical reactor.

SHIELDING FOR THE HIGH GAMMA ROOM

The High Gamma Room 1069-C shown on Figure 7, was originally designed to contain gamma radiation in the energy range of cobalt-60 sources. The shielding walls on south and west sides were constructed of 30-inch thick barytes concrete with a minimum distance between the walls and the well of 3-1/2 feet.

In view of the proposed use of fuel elements from the Materials Testing Reactor as a source of gamma radiation and the more penetrating gamma associated with this source, additional shielding may be required. Lead and barytes concrete were considered and calculations based on four elements irradiated under normal operating conditions in the MTR and removed for a 120-day period, would require 1-1/2 inches lead or 5-1/3 inches of barytes concrete increased thickness.

Plans are being made to install lead bricks and sheet which can be replaced or removed according to experimental changes in the laboratory.

DOSE RATE CALCULATIONS

To determine the dose rate or the energy absorbed per unit mass per unit time within a chemical reactor situated in the center of a radiation source, a theoretical approach is suggested for preliminary calculations. J. G. Lewis has derived Equation 1 for the expected dose rate within a hollow, transparent, cylindrical source of no thickness with a gamma energy of 0.75 Mev per disentegration and a 20 day source activation period.

$$\begin{aligned} I = {} & 2\alpha\pi\left[\tan^{-1}\left(\frac{Z_1}{r}\right) + \tan^{-1}\left(\frac{L-Z_1}{r}\right)\right] \\ & - 2\alpha\pi b\mu\rho \ln \frac{\left[(L-Z_1)+\sqrt{r^2+(L-Z_1)^2}\right]\left[Z_1 + \sqrt{r^2+Z_1^2}\right]}{r^2} \\ & + \frac{\alpha\pi L\mu^2 b^2\rho^2}{r} - \cdots\cdots\cdots\cdots \quad \text{Equation 1} \end{aligned}$$

where,

$$\tan^{-1}\left(\frac{Z_1}{r}\right) \geq 0, \qquad \tan^{-1}\left(\frac{L-Z_1}{r}\right) < \frac{\pi}{2}$$

I = Rep per hour

b = thickness of reactor shell equivalent to steel, inches

Z_1= height from base to point source, inches

r = radius of source, inches

L = length of source, inches

μ = absorption coefficient, cm^2/gm

ρ = density of reactor wall material, steel at 7.98 gm/cm^3

$$\alpha = \left(\frac{\text{activity of source, curies}}{\text{area, cm}^2}\right)\left(\frac{\text{1000 millicuries}}{\text{curie}}\right)\left(\frac{\text{roentgen equivalent at 1 cm}}{\text{hour-millicurie point source}}\right)$$

$$\alpha = \frac{(C)}{(A)}$$

The first three terms in this expansion have been treated independently and nomographs are available for estimating the dose rate within a pressurized chemical reactor under the following conditions:

1) Gamma ray energy of 0.75 Mev per disentegration

2) Twenty day activation period of the source

3) Reactor walls, insulation and heating wire can be expressed as an equivalent steel thickness

4) The source offers no self absorption to radiation

Calculations based on the first term of the expansion were made for fuel elements of the Materials Testing Reactor type based on 20 days in the reactor and at periods of 90, 120 and 170 days after removal from the active core. The value of M was obtained from W. E. Siri, Isotopic Tracers and Nuclear Radiations, page 427, as 3780 Rep/hour - point Curie source at one centimeter.

Figures 8, 9 and 10 complete the results of these calculations where R is the radial distance in inches from the centerline of the element and Z is the height in inches above the base of the element. The curves indicate the position of equal-valued dose rates in units of Rep/hour.

Equation 1 does not consider build-up; therefore, the sum of this series must be multiplied by the appropriate build-up factor given by J. Moteff, Miscellaneous Data for Shielding Calculations, APEX 176.

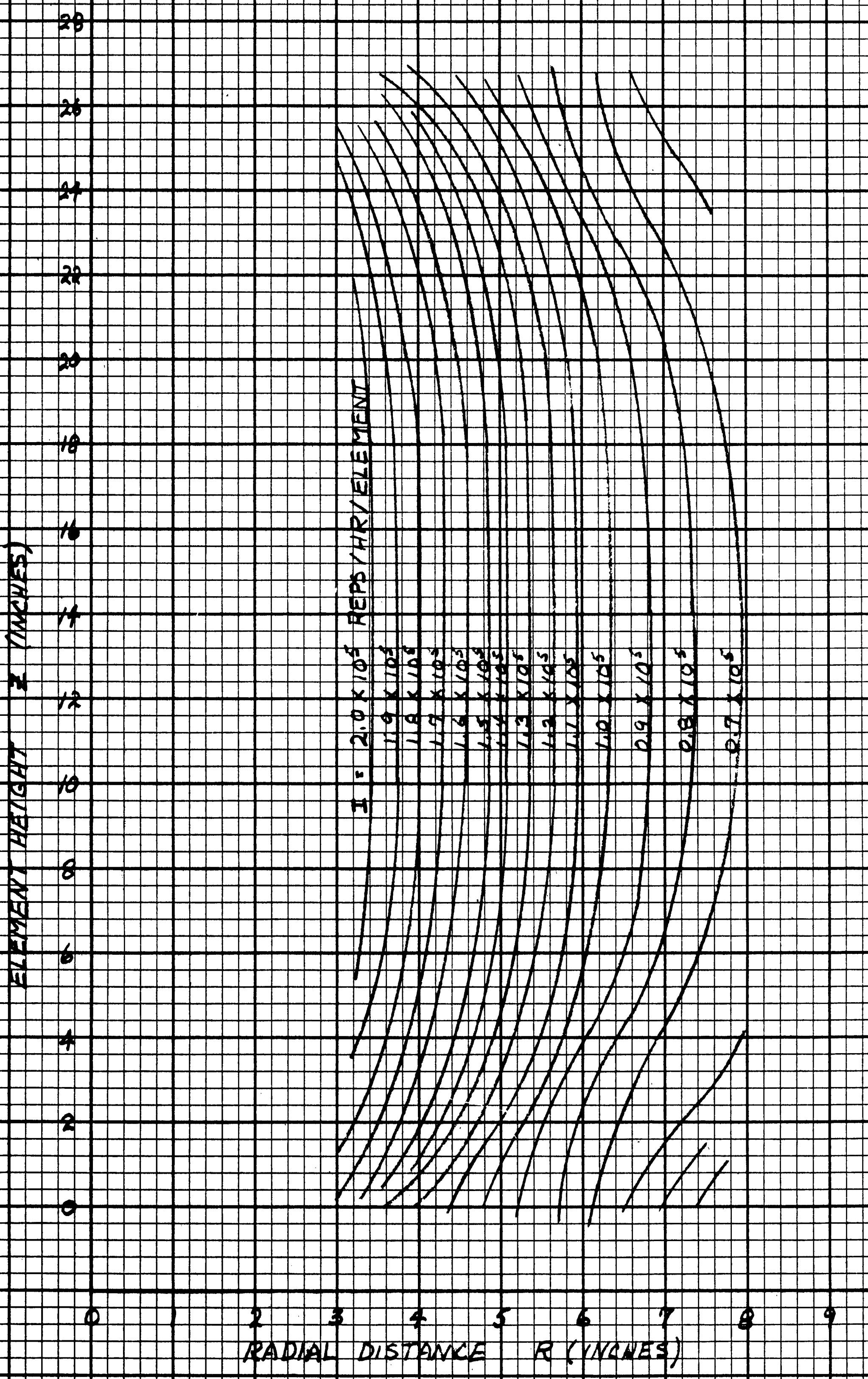


FIGURE 8

ISODOSE CURVES AS A FUNCTION OF MTR
ELEMENT HEIGHT AND RADIAL DISTANCE

BASED ON 20 DAY IRRADIATION, 90 DAYS COOLING (12,800 CURIES)

I (DOSE RATE) = REP/HR/ELEMENT

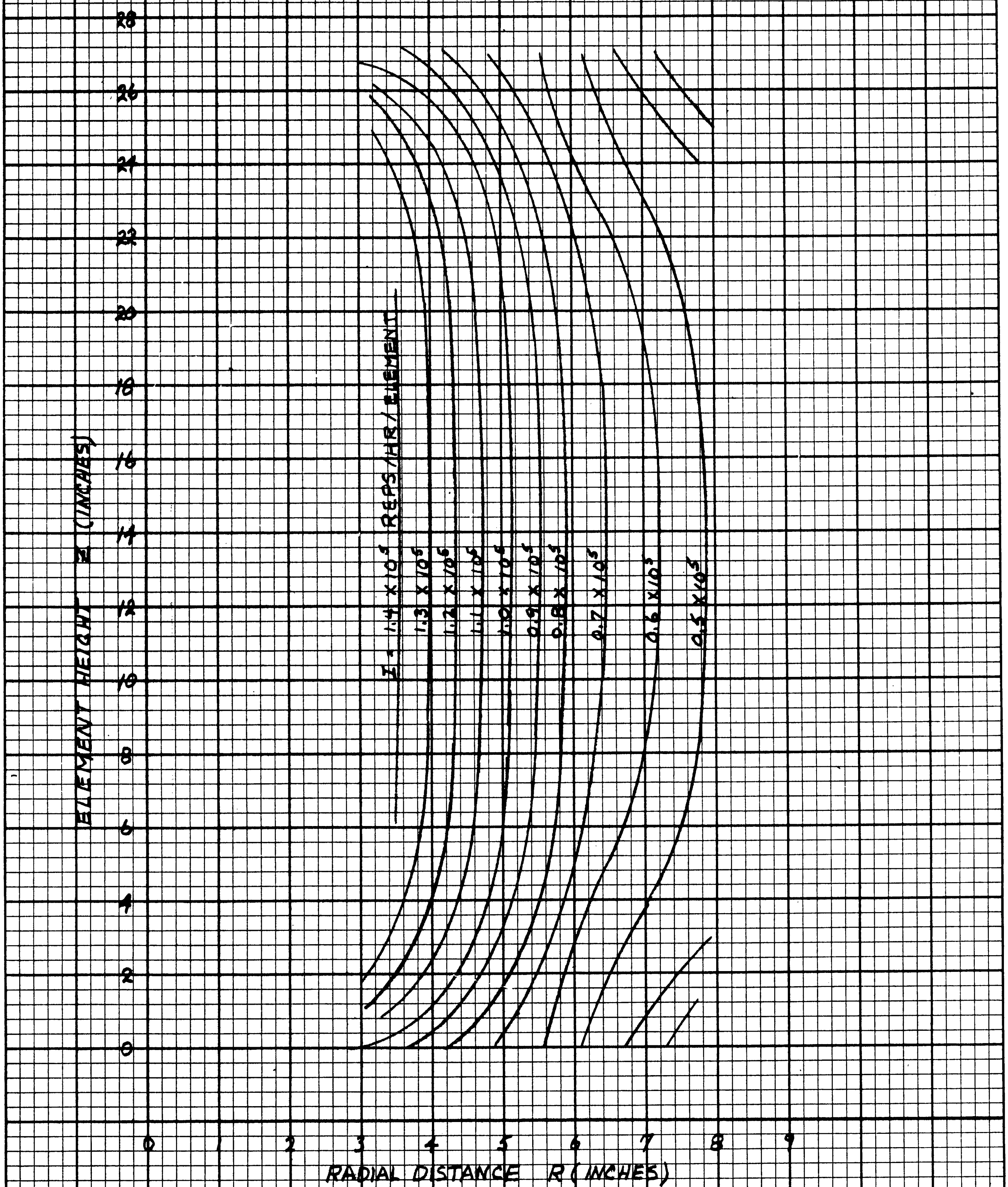


FIGURE 9

ISODOSE CURVES AS A FUNCTION OF MTR ELEMENT HEIGHT AND RADIAL DISTANCE.

BASED ON 20 DAY IRRADIATION, 120 DAYS COOLING (9,230 CURIES)

I (DOSE RATE) = REPS/HR/ELEMENT

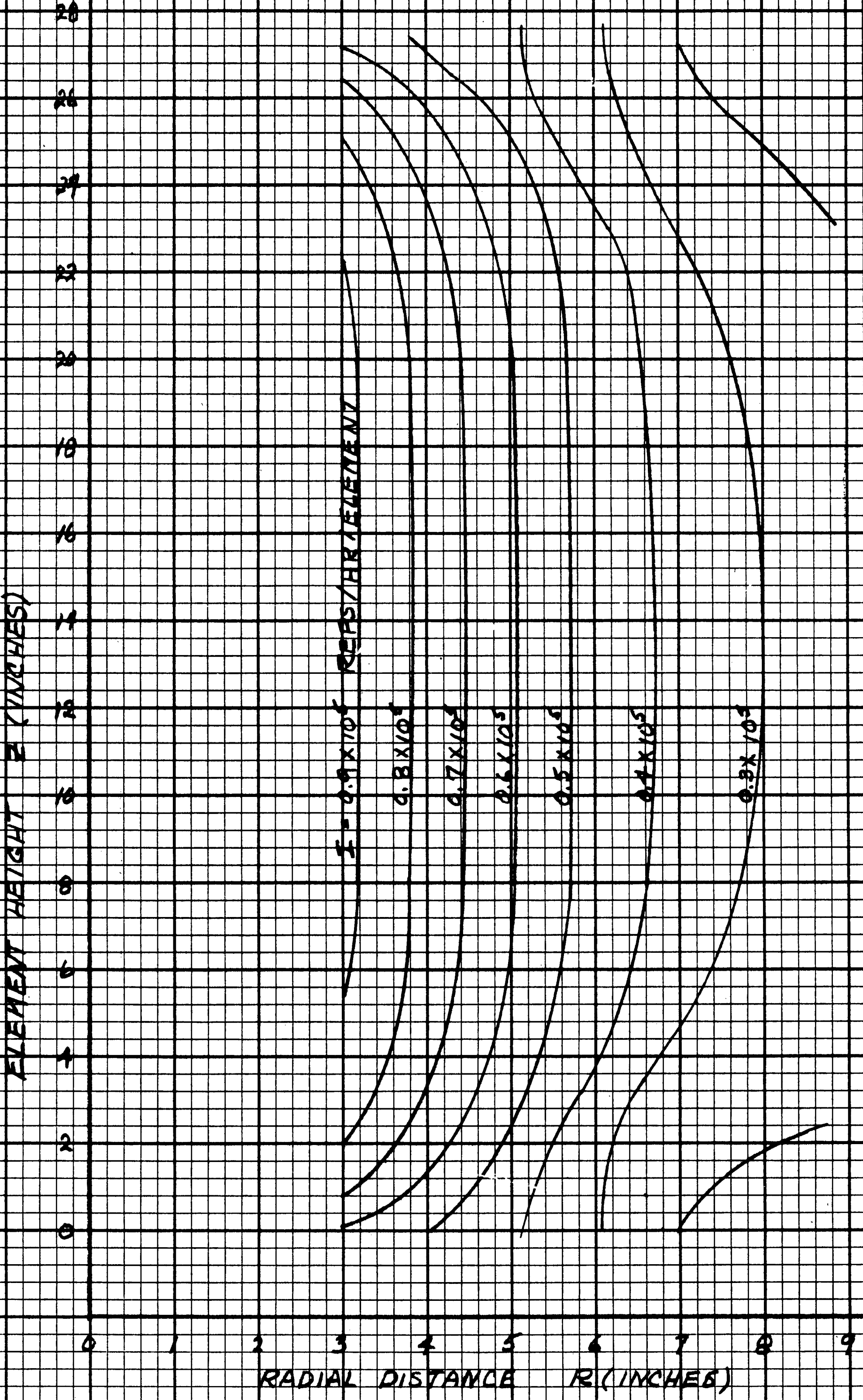


FIGURE 10

ISODOSE CURVES AS A FUNCTION OF MTR ELEMENT HEIGHT AND RADIAL DISTANCE

BASED ON 20 DAY IRRADIATION, 170 DAYS COOLING (5,570 CURIES)

I (DOSE RATE) = REPS/HR/ELEMENT

CALCULATION OF THEORETICAL YIELDS AS A FUNCTION OF DOSE RATE

Preliminary calculations were made to determine the theoretical hydrocarbon yield resulting from a given gamma radiation dose rate. For these calculations it was assumed that all radiation from the source into the chemical reactor was absorbed by the gaseous hydrocarbon. Theoretical yields were based on the effect of gamma radiation only, so that the effect of temperature and pressure was included only as a gas density relationship. Additional yields may result from the temperature and pressure effects. Experiment data may indicate the contribution of each of these variables.

Figures 11, 12, 13 and 14 display the results of these preliminary calculations. The dose rate was taken over a range of 4×10^5 to 70×10^5 Rep/hour corresponding to the dose rate available from four MTR fuel elements. The proper combination of spacing and age of the elements should result in experiment dose rates at inner wall of the chemical reactor between 0.6 to 0.8 million roentgen/hour. Figures 11, 12, 13 and 14 are plotted with dose rate in Rep/hour versus the number of grams of hydrocarbon reacted per hour. Figure 11 has G as a parameter for various reactor volumes. G is defined as the number of molecules reacted per 100 electron volts absorbed. Figures 12, 13 and 14 have both G values and the ratio of hydrogen to hydrocarbon as parameters for various reactor volumes. The equation for the curves may be expressed as:

$$M \times R \times G \times 9.17 \times 10^{-11} = \frac{\text{grams hydrocarbon reacted}}{\text{hour}}$$

where,

R = Dose Rate in Rep/hour

G = Number of molecules reacted per 100 ev absorbed

M = Mass of hydrocarbon in the reactor

The mass of the hydrocarbon in the reactor was calculated from PVT relationships based on reactor volumes for cylinders 24 inches in length, 1-1/2, 3, and 6 inches in diameter. An average value of 95 was used for the molecular weight of the hydrocarbon. The curves, although theoretical and approximate, should give a fair approximation to yields if the radiation is a significant factor in the reaction rates of hydrocarbons.

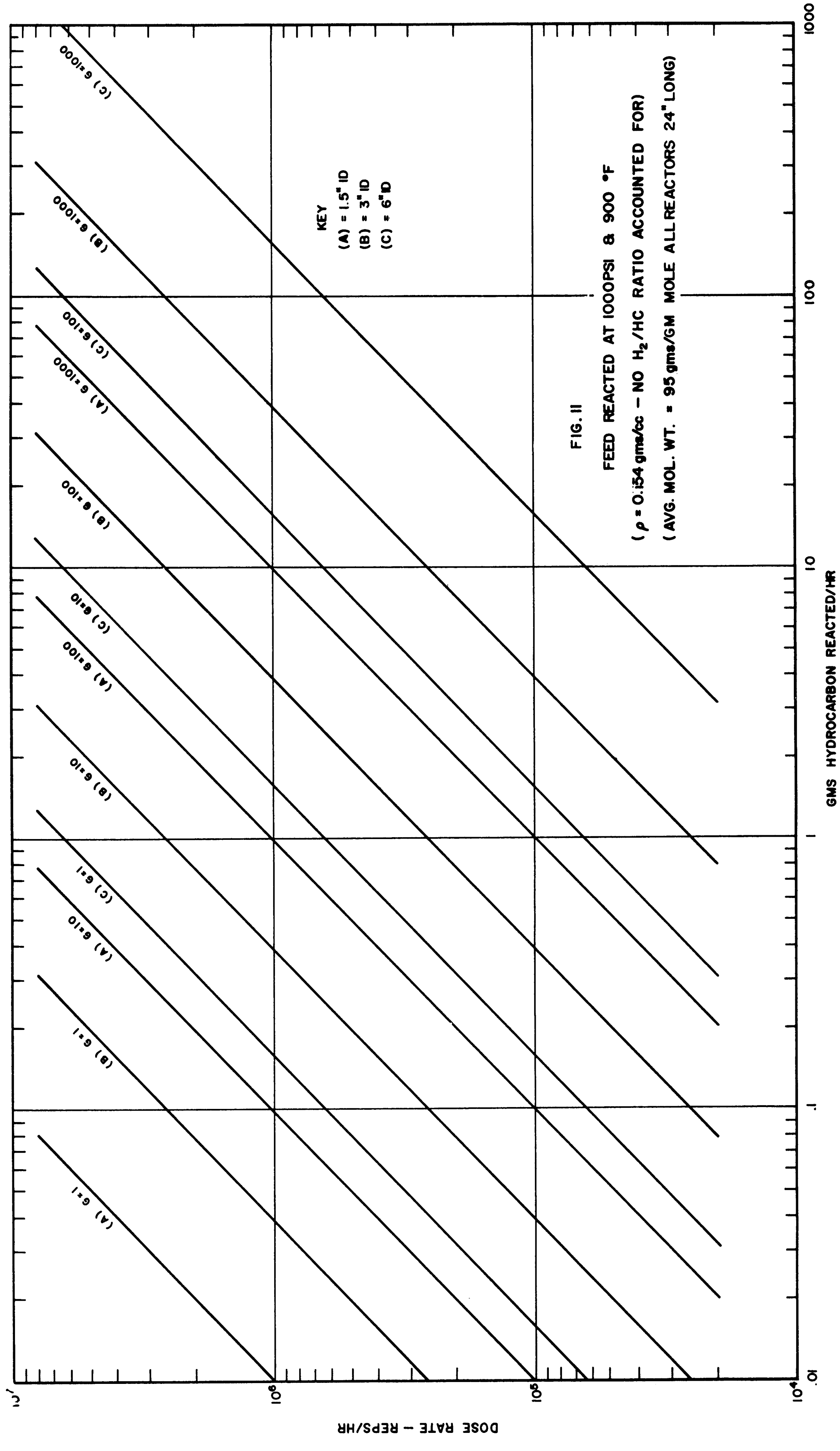


FIG. 11

FEED REACTED AT 1000PSI & 900 °F

(ρ = 0.154 gms/cc – NO H_2/HC RATIO ACCOUNTED FOR)

(AVG. MOL. WT. = 95 gms/GM MOLE ALL REACTORS 24" LONG)

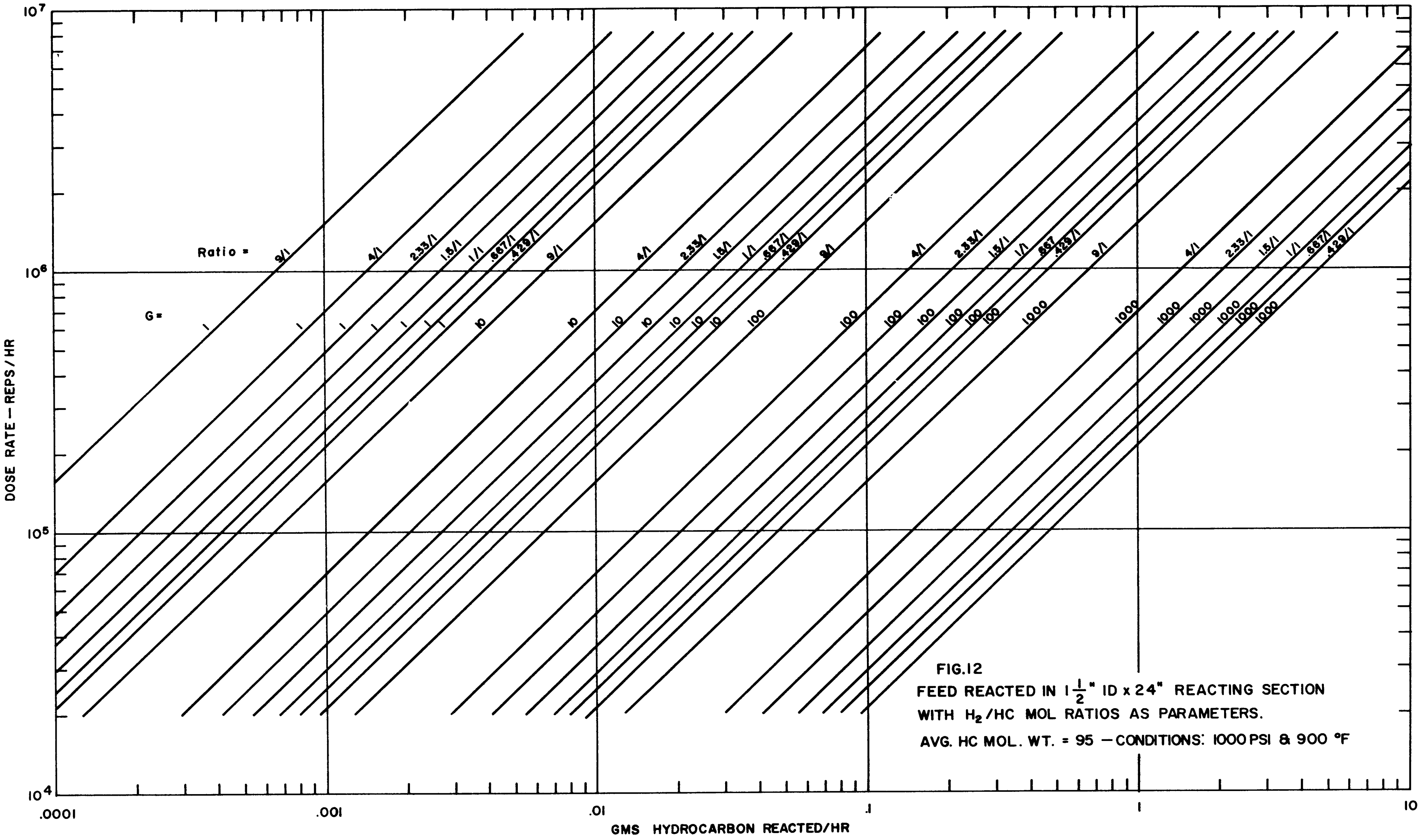


FIG.12
FEED REACTED IN $1\frac{1}{2}$" ID x 24" REACTING SECTION
WITH H_2/HC MOL RATIOS AS PARAMETERS.
AVG. HC MOL. WT. = 95 — CONDITIONS: 1000 PSI & 900 °F

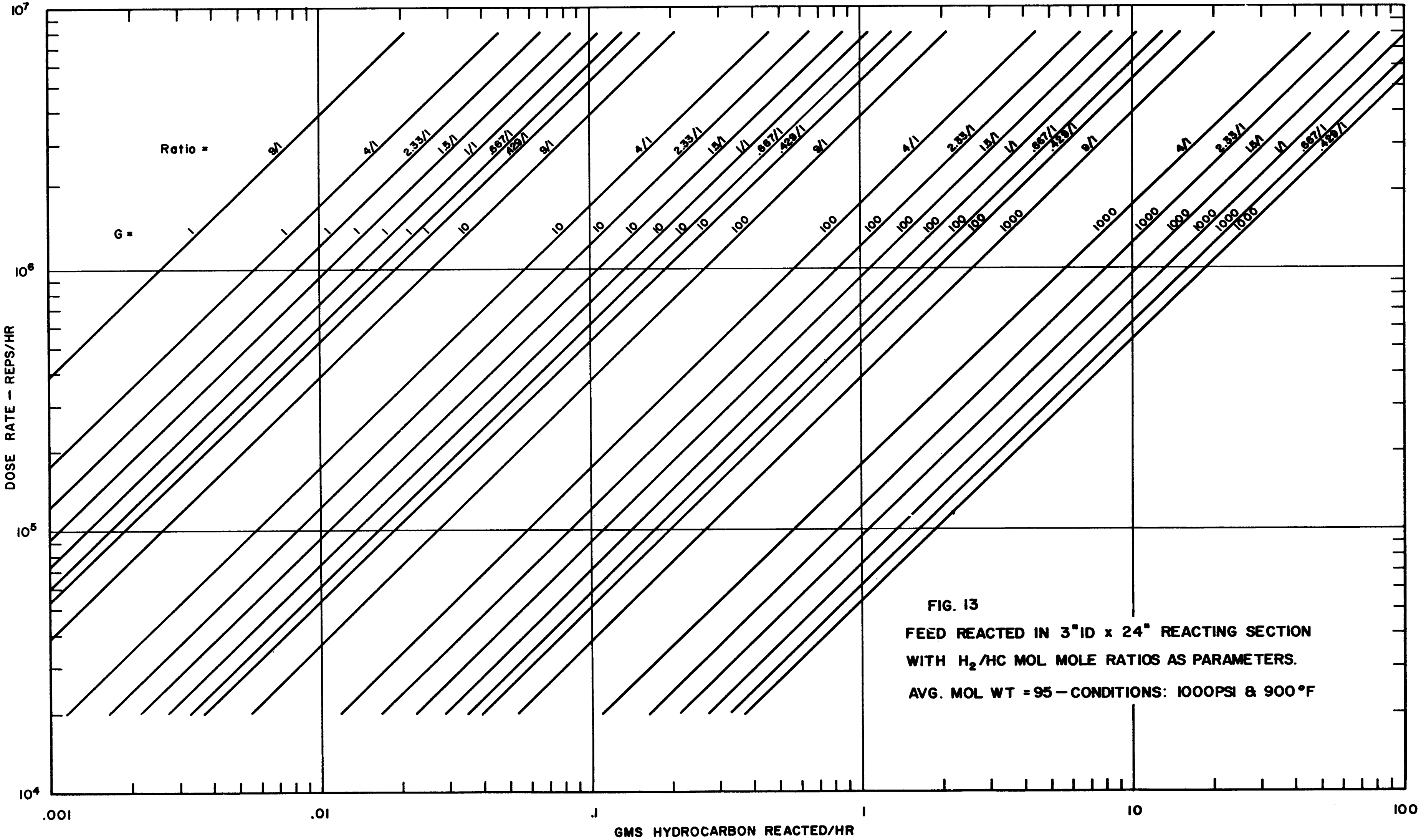


FIG. 13

FEED REACTED IN 3"ID x 24" REACTING SECTION
WITH H_2/HC MOL MOLE RATIOS AS PARAMETERS.
AVG. MOL WT = 95 – CONDITIONS: 1000PSI & 900°F

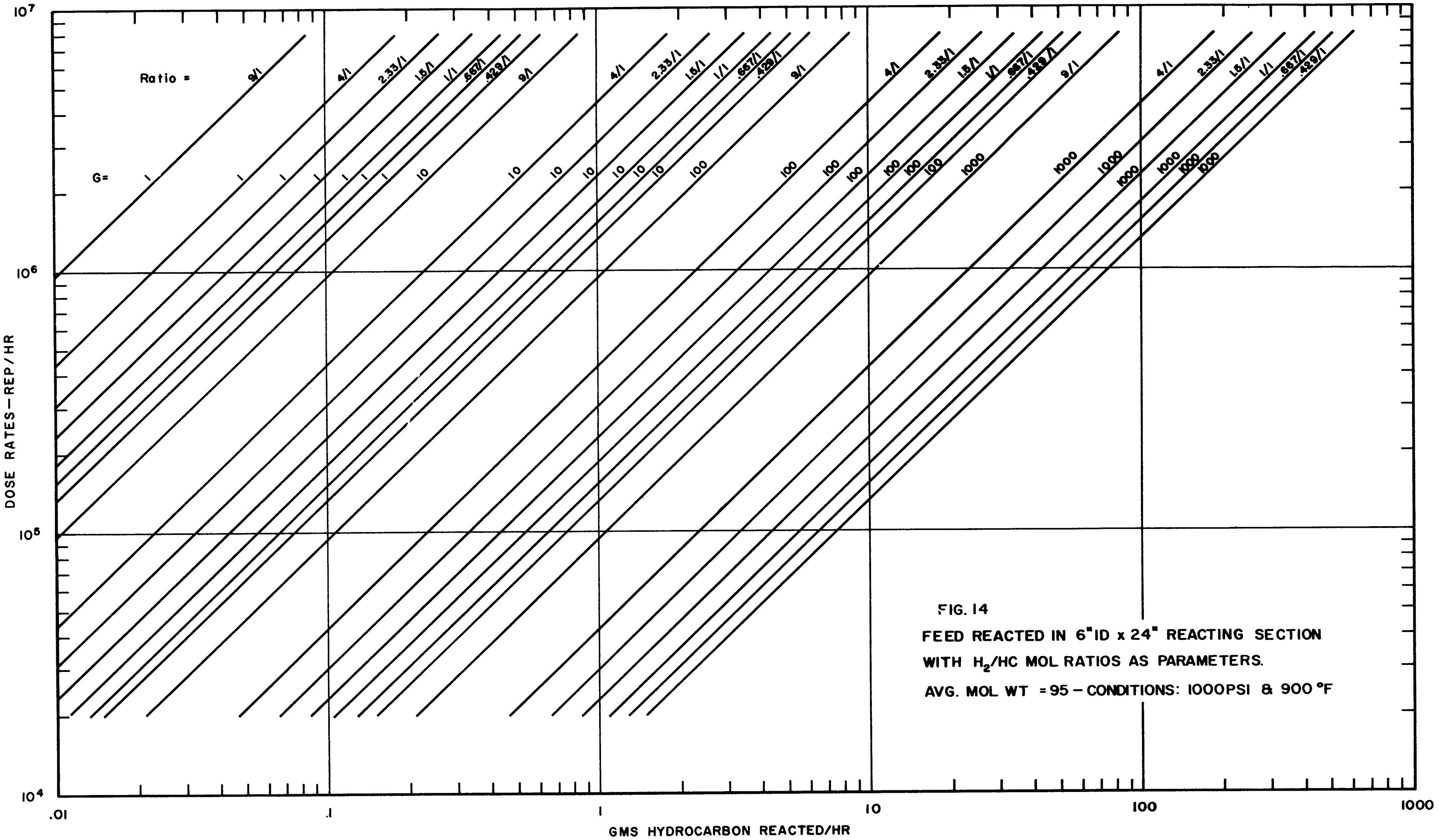


FIG. 14

FEED REACTED IN 6"ID x 24" REACTING SECTION
WITH H_2/HC MOL RATIOS AS PARAMETERS.
AVG. MOL WT = 95 – CONDITIONS: 1000PSI & 900 °F