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K AREA HYDRAULIC WORKING CURVES
AND NUMERICAL RESULTS OF PT IP-130A
K REACTOR TRIP-OUT TEST DOWN TO CROSS-TIE BACKUP

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K AREA HYDRAULIC WORKING CURVES
AND NUMERICAL RESULTS OF PT IP-130A
"K REACTOR TRIP-OUT TEST DOWN TO CROSS-TIE BACKUP"

PURPOSE

The purpose of this document is:

1. To collect together and record graphically hydraulic data obtained from various documents, tests, and calculations in the course of process engineering work at the K Reactors.

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2. To list the numerical results of the recent trip-out and cross-tie backup test (PT IP-130-A)⁽¹⁾ at KW Reactor.

INTRODUCTION

During the course of process engineering work at the K Reactors, a wide variety of problems have been encountered where hydraulic information was required. This information was obtained from various documents, from calculations, and from actual tests run specifically to obtain the information. In order to simplify work of this nature in the future and to present a convenient means of obtaining information, the data so collected are summarized and graphed in this document.

The reader should use these data realizing that the numbers may not be exact and that the method of obtaining them may not be theoretically precise. The basic idea in doing this work was to obtain numbers which would be adequate in actual application to conditions at the reactor facilities.

In the Discussion below, each figure will be listed in turn and a summarized explanation given on the construction of the curve. More detailed information can be obtained from the author.

PT IP-130-A, "K Reactor Trip-Out Test Down to Cross-Tie Backup"⁽¹⁾ was recently performed at KW Reactor. The production test specified that the "stricken" reactor trip-out all of its high-lifts, low-lifts, and service water pumps simultaneously, and measure the pressure decay down to the point where cross-tie backup flow was initiated. Cross-tie backup flow for various pumping configurations at the "aiding" reactor was then determined. These data are listed in tables below, but no interpretations or conclusions will be made in this document.

DISCUSSION

Figures 1 and 2 (Reactor characteristic with a KIIN and KIIE load (KE Reactor at present), and reactor characteristic with a KIIN and KIIE load (KW Reactor at present and KE Reactor by about 3/60).

These two curves are based on the following actual flow-pressure data:

1. Hot equilibrium operating conditions at KE and KW in October, 1959. ($T_A = 51^\circ\text{C}$ for KE and 52°C for KW).
2. Cold full flow conditions at KW in October, 1959. ($T_A = 16^\circ\text{C}$).
3. Cold startup flow conditions at KE in October, 1959. ($T_A = 16^\circ\text{C}$).
4. Cold low flow conditions at KW obtained during the trip-out test on 10/8/59⁽¹⁾ when 1, 2, 3, 4, 5, and 6 low lifts were supplying the pile in turn. ($T_A = 16^\circ\text{C}$).

A flow calculation was made as follows:

$$F = K P^{1/1.8}$$

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where P is the reactor riser pressure at the bottom of the rear crossover elevation and where K was determined for the two higher temperature curves on each graph by plugging in the known values of F and P from data obtained as listed in items 1, 2, and 3 above. After obtaining K, subsequent pressures were calculated for any particular flow and the resultant points plotted to obtain the curve presented. Base F and P data to calculate K for the 50C cases were obtained by plotting P vs. T_A for a given flow on semi-log paper and extrapolating to 50C to obtain a new P. T_A is defined as follows:

$$T_A = \frac{T_0 - T_1}{2} + T_1$$

Where t_0 = reactor bulk outlet temperature, and
 t_1 = reactor bulk inlet temperature.

Subsequent pressures were calculated for chosen flows as before. Data obtained as listed in item 4 above were near the calculated curve but crossed it and had a different slope. Although this indicated that the bottom part of the curves should be shaped differently, other data obtained during the same test would not have been consistent with a curve so obtained. A possible source of error lies in the indication of the Foxboro flow transmitters at such a low flow (about 10,000 gpm). Future efforts should be aimed at obtaining intermediate data to check the rest of curve and at rechecking the lower portion of the curve with more accurate flow instrumentation (Mercury manometers parallel to the Foxboro flow transmitters have worked well in the past).

Changes in tube resistances because of film buildup or sloughing can change these types of curves also. For instance, curves drawn as a result of tests run last spring were accurate until late this summer when a sudden film buildup occurred. The new pile hydraulic demand curve not only shifted back in flow, but the shape of the curve was changed, i.e., a curve drawn using the equation $F = K P^{1/1.8}$ as described above did not fit the data obtained and adjustments to account for this had to be made in constructing the curve. The curve presented in figure 1 should fit KE Reactor and those in figure 2 should fit KW Reactor as of 10/16/59, and should be good until another change in film condition or some other hydraulic change occurs. Curves at other temperatures can be constructed as described for the 50C curve above.

Figure 3 (K Area old high lift pump characteristics)

1700, 1680, and 1500 rpm curves were obtained by taking the TDH (total dynamic head) vs. flow curves as obtained at startup and reported in HW-39237(2) for the high-lift pumps and low-lift pumps and calculating high-lift pump discharge pressures for any particular flow as follows:

$$P.D.P.H.L. = TDH_{H.L.} + TDH_{L.L.} - C$$

Where C is a combination of friction, elevation, and velocity losses from the clear well to the high-lift pump discharge. Intermediate RPM curves, as shown on the figure, were calculated by means of the affinity laws which state that:

$$\frac{n_1}{n_2} = \frac{Q_1}{Q_2} \text{ and } \frac{n_1^2}{n_2^2} = \frac{TDE_1}{TDE_2}$$

where n is the pump speed in RPM and Q is the pump flow in GPM, and where 1 subscripts refer to known conditions. Data taken during operation of the pumps were close to the curves shown. The cavitation limit and cutoff points were plotted on this graph from figures 7 and 8.

Figure 4 (CG-775 pump characteristics)

These curves were obtained by plotting data from tests run by members of Reactor Modification Design Sub-Section on the prototypical CG-775 pump installed in KE Reactor. The 1650 rpm curve was obtained by the affinity laws (explained under figure 3) as were additional points on the 1600 rpm curve. The prototype currently installed in KE has a 32-inch impeller while a 33-inch impeller will probably be the one used to fulfill the requirements of CG-775. The arbitrary maximum operating flow for the 32-inch impeller was then picked temporarily after consultation with M. H. Schack⁽³⁾, Reactor Modification Design Sub-Section, for use in case of five-pump operation with the prototype.

Figure 5 (Friction drops, high lift pump discharge to riser and low lift pump discharge to high lift pump suction)

Actual data points were obtained during operation and lines were drawn through them with a slope of 1/1.8 on log-log paper. However, it was noted that, according to instruments, there was apparently no pressure drop between the high lift pump discharge and the pump flow venturis. Since the pump discharge pressure taps were quite close to the pump casing and in only one position, it was concluded that there was an unequal velocity distribution around the circumference of the pipe which meant that the actual average pressure may have been higher than that indicated. A standard friction loss calculation was then performed which agreed with data obtained from the pump venturis to the risers. This calculation was then applied to the line between the pump venturi and pump discharge to obtain an "actual" average pump discharge pressure. The point so obtained was also plotted on this graph and a line with a slope of 1/1.8 drawn through it. The distance between the three operating pumps-per-side line and the two operating pumps-per-side line was obtained from S. S. Jones⁽⁴⁾, Process and Reactor Development Sub-Section, and is assumed to be the same for both cases. Use of the "calculated" data fits the reactor conditions obtained from this and the pump curves as depicted in figure 6. However, the author did not check back on the original startup pump tests to see if the curves obtained had this possible "error" built in (i.e., tests run to obtain the curves might have utilized the same pressure taps with the same possible "error"). The same type of situation exists in the friction drop between the low lift pumps and the high lift pumps where use of a "calculated" friction drop fits actual indirect data obtained from pump performance. This calculation agrees with data taken during the CG-775 prototypical pump tests.

Figure 6 (100-K Pump and Reactor Characteristic Curves)

The curves from the previous figures have been combined on this graph in a composite picture of various reactor operating conditions. They are especially useful in obtaining five-pump cavitation and bulk outlet temperature limits and corresponding reactor operating points.

Figure 7 (Cavitation Cutoff Points - Old High Lifts)

A plot of cavitation cutoff points from unpublished startup data is plotted as shown. The curve was a "best fit" of five points covering the range shown and is probably not as accurate as would be indicated by the scale of the graph. The cavitation limit as determined from the test of 2/58⁽⁵⁾⁽⁶⁾ and shown in figure 9 is also plotted to show its relationship to the cutoff points and is an accurate relation.

Figure 8 (Cavitation Constants - K Old High Lifts)

A cavitation test was run in 2/58⁽⁵⁾ to determine the severest cavitation conditions in which the high lift pumps could be run without sustaining undue cavitation damage. The results of the test are plotted in this figure and reported in greater detail in HW-56672⁽⁶⁾. In addition, the beginning of severe cavitation as determined from tests at startup and reported in HW-39237⁽²⁾ is plotted along with a cavitation cutoff curve as obtained from figure 7. The construction of the graph and the cavitation curves as presented here are actually an algebraic simplification of the familiar plot of NPSH/TDH vs. specific speed⁽⁷⁾ and has only been used for the old K high lifts as far as the author knows.

Figure 9 (Friction Drop, Riser to Header)

This curve was obtained from a test run at various flows in 2/59. The header pressure at the K Reactors is measured in the center of the header where at full flow the static pressure is about 7 psig higher than it is at the ends of the headers. This is due to the decrease in velocity from the ends to the center. The "actual" curve is compared on the graph with a theoretical curve with velocity effects accounted for and with a straightforward $F = K P^{1/1.8}$ friction calculation. An actual data point at 15°C is also plotted and an estimated 15°C curve is drawn through the point.

Figure 10 (K Tube Characteristics, EOAS (End-Of-Active-Section) to Rear Header)

Pressure drops through the rear tube fittings at the K Reactors are plotted in this graph for both thick and thin wall perms in the rear dummy charge. These are copied from other documents⁽⁸⁾⁽⁹⁾ as noted on the graph and are included here as a convenience for obtaining Panellit pressure as explained below.

Figure 11 (K Tube Characteristics, Front Header to Tube Inlet)

Pressure drops through the front face tube fittings at the K Reactors are plotted in this graph for all flow zones. The pressure drop curve for the present size 0.419 inch venturi is a slight extrapolation of data reported in reference ⁽¹⁰⁾ at 22°C. A calculation was made to 5°C using a method as outlined in HW-54590⁽¹¹⁾. Zones 2,⁽³⁾ and 4 pressure drops were obtained at startup and are reported in HW-38373⁽¹²⁾.

Figures 12, 13 and 14 (Tube Characteristics, Tube Inlet to End-Of-Active-Section)

The curves on these graphs were obtained from hydraulic tests run in 2/59. The methods used was to monitor a large number of Panellit and associated header pressures for each type of charge and flow zone during a startup and equilibrium

run. The results were averaged and at the average flow obtained, the tube inlet to EOAS pressure drop for each type of charge and flow zone was obtained for both the hot and cold conditions by subtracting the average rear header pressure, the front header to tube inlet pressure drop, and the EOAS to rear header pressure drop all from the averaged front header pressure. Lines were drawn through the points so obtained parallel to a similar pressure drop curve obtained from HW-54590(11). Pressure drops at other temperatures were obtained by plotting pressure drop versus T_a (T_a defined under figures 1 and 2) at a particular flow on semi-log paper. Specifically, the pressure drops at 50° and 40° were plotted from figures 12, 13, and 14 and a straight line drawn between the two points so an extrapolation or interpolation to other temperatures could be made.

This method of obtaining pressure drops may seem somewhat devious compared to the use and extrapolation of laboratory data. However, application of laboratory data to reactor use does not always give accurate enough results for predicting Panellit pressures. This is due, perhaps, to the difficulties of simulating average tube conditions exactly in the lab. (e.g. 550° graphite surrounding reactor tubes may cause some expansion affects affecting the pressure drop through the tube which can't be duplicated in the lab. Also, it would be difficult to obtain an average charge in terms of slug sizes and charge length as it affects pressure drop without running numerous tests.) Another factor affecting this pressure drop significantly is the amount of film deposit. Anytime a change in film conditions occurs, a new test and calculations must be made. Unfortunately, all the pressure drops and pressures graphed in figures 12 through 21 are not correct at present because of a film buildup which occurred late in the summer in both areas. New tests and calculations have not been made as yet; however, this film may slough off later and cause the tube characteristics to return to near their original value; also, corrections can be made fairly easily by using flow data from the IBM ROL report to calculate new pressures at that particular flow and temperature and then scaling other values up or down proportionately.

Figures 15, 16, 17, 18, 19, 20, and 21 (Tube Characteristics, KIIN, CIE, KIIN, KIIIE, Zone 2 Solid, Zone 3 Solid, and Zone 4 Solid Type Charges)

These curves are plotted so that once an average reactor header pressure (the average reactor header pressure is defined as the average header pressure from 06 through 53 row) is determined from the previous curves, an average Panellit pressure and an average tube flow can be found for any type of a charge at any particular temperature. This is done as follows:

1. Determine the average reactor header pressure to be considered.
2. Pick the type of charge and temperature to be investigated.
3. From the intersection of the temperature curve (in the "Hdr" curves) and the header pressure from the ordinate read the average tube flow on the abscissa.
4. Where this average tube flow intersects the same temperature curve in the "Pan" curves, read the average Panellit pressure on the ordinate to the left.

In the case of the zone 2, 3, and 4 charges, the header pressure average is higher and can be determined from figure 22. Although these adder factors were calculated for a KII load only, they are only approximate weighted averages, and there will probably be little change with the KIII load. These curves are particularly useful for determining Panellit pressure changes for different temperatures and header pressures such as from cold startup to equilibrium and from summer to winter conditions. They are also useful for determining the header pressure required to obtain a particular tube flow or Panellit pressure for any type of a charge and temperature. The graphs were constructed as follows:

1. One temperature was picked for a particular type charge.
2. All the pressure drops from the front header to the rear header plus the rear header pressure were added up at different tube flows to get the front header pressure for any particular tube flow. These pressure drops were obtained from figures 10 through 14 plus the interpolations described for figures 12, 13 and 14, but not included in this document.
3. Step 2 was repeated for different temperatures for the same type charge.
4. Steps 1, 2, and 3 were repeated for each type of charge.
5. The results were plotted on figures 15 through 21 as the "Hdr" curves.
6. This familiar formula was then taken: $F = K \Delta P^{0.5}$ where
 F = tube flow in gpm
 K = venturi or orifice constant previously determined
 ΔP = front header pressure - Panellit pressure

and rearranged as follows: Pan. pressure = Hdr. pressure - $(F/K)^2$

A Panellit pressure was then calculated for any particular tube flow from each "Hdr" curve plotted in figures 15 through 21 from step 5.

Because of the change in tube characteristics, tube inlet to EOAS, with film formation as described for figures 12, 13, and 14, the "Hdr" and "Pan" curves presented here are not correct at the present time. As mentioned before, new tests and calculations are needed; however, since the film may slough off, temporary corrections could be calculated from IBM ROL flow data at that one condition and proportionate changes made for other conditions.

The accuracy of the curves will probably decrease the further one extends away from the conditions at which they were originally constructed.

Figure 22 (Zone Adder Factors - KII Load)

Since the majority of the zone 2, 3, and 4 tubes are in the top and bottom fringes of the reactor where the header pressures are higher, this graph was constructed to use for figures 19, 20, and 21. This factor should be added to the average reactor header pressure as defined above to obtain the correct "average" header

pressure to use for the zone 2, 3, and 4 header-Paxellit pressure curves.

The curves depicted were obtained by collecting actual header pressure data and calculating a weighted average of the header pressures for each zone from the numbers of zone tubes on each header. This was done at several different flows and the differences between zone 1 and zone 2, zone 1 and zone 3, and zone 1 and zone 4 were plotted on log-log paper. A "best fit" line was then drawn through these points.

Figure 23

PT IP-130-A, K Reactor Tripout Test Down to Crosstie Backup, was run recently at KW Reactor⁽¹⁾. In this production test, all high lifts, low lifts, and two service water pumps at KW were tripped off at the same time while KE was backing up the high pressure crosstie directly with one unthrottled low lift pump and the low pressure crosstie with two service water pumps. The resultant riser pressure decay was monitored by movie cameras and this figure presents that decay as obtained from the films.

Figure 24 (Crosstie Orifice Calibration)

The measuring orifice in the high pressure crosstie was used to measure crosstie flows during PT IP-130-A. This calibration was obtained from S. S. Jones⁽¹³⁾, Process and Reactor Development Subsection, and is presented in this graph.

Table I (Summary of Data from PT IP-130-A)

This table summarizes the flow and pressure data from the trip-out test run recently at KW. Besides obtaining the pressure decay (Figure 23), the purpose of the test was to measure the flow capacity of the crosstie lines with the I & E loadings at both reactors under various probable pump and valving configurations. Previous data from solid slug loadings are listed in HW-38373⁽¹²⁾ and HW-42964⁽¹⁴⁾. Riser pressures were obtained by averaging readings from calibrated Heise gauges attached to the riser sensing lines on both sides of the reactors. High pressure crosstie flow rates were obtained from a manometer hooked to sensing lines from the measuring orifice in the crosstie line. The calibration curve is shown in figure 24. The reactor characteristic curve as described for figures 1 and 2 (but plotted on log-log paper for greater accuracy) was used to obtain KW Reactor total flow while it was being supplied by both crosstie lines. Low pressure crosstie flow was obtained by subtracting the high pressure crosstie flow from the total flow. All other flows were obtained by adding up readings from the individual pump Foxboro flow transmitters.

Table II (Elevation Data)

The elevation data listed were those used in the calculations described in this document.

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TABLE I

SUMMARY OF BACKUP FLOW - PRESSURE DATA FROM PT IP-130-A

KE Reactor				KW Reactor						
Flow	BORP	Pumps Running	Valving	Tot Flow	H.P. X-Tie	C.P. X-Tie	BORP	Pumps Running	Valving	Remarks
115,050	226	4 H.L. 4 L.L. 2 S.W. #3 L.L. to X-tie	SE-1, SE-2, V-70, HPC open; V-72, FB-1, FB-2, FB-5 closed.	173,900	-	-	410	6H.L. 6L.L. 2S.W.	SE-1, SE-2 V-72 open V-73 on automatic	Conditions prior to test.
115,575	224.5	No change	No change	17,800	12,900	4,900	30.2	None	V-73 opened.	
115,390	223.5	Added 3rd S.W. pump	No change	19,100	12,800	6,300	31	None	No change	
115,325	223.5	Added 4th S.W. pump	No change	19,800	12,750	7,050	31.5	None	No change	
55,950	69.5	5 (L.L. (#3 off)) 2 S.W.	V-72, SE-1, SE-2 open V-70, HPC, FB-1, FB-2, FB-5, V-73 closed	16,800	11,300	5,500	29.5	None	No change	S.W. pres. = 55 psi thus preventing S.W. flow to KE
63,800	68.5	No change	V-73 opened	18,300	13,500	4,800	30.5	None	No change	S.W. pres. = 57 psi thus preventing S.W. flow to KE
Not certain		No change		7,300	0	7,300	25	None	V-72 closed	V-72 inadvertently closed-not part of test.
				25,800	-	-	38.2	1 L.L.	SE-1, SE-2 V-73 closed	Flow calibration test.
				40,500	-	-	54	2 L.L.	No change	
				48,400	-	-	61.5	3 L.L.	No change	
				53,300	-	-	67.5	4 L.L.	No change	
				57,100	-	-	71.2	5 L.L.	No change	
				59,000	-	-	74.2	6 L.L.	No change	

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TABLE II

Elevation Data

Clearwell level (full)	=	470 ft.
Low-lift pump discharge (centerline)	=	478 ft.
High-lift pump discharge (centerline)	=	474 ft.
105 Building (0 ft. level)	=	465 ft.
Middle of 58 crossheader (used for TORP)	=	506 ft.
Actual top-of-riser (at valve)	=	510.5 ft.
Bottom of rear-face crossover (54 ft. 8 inch level)	=	519.7 ft.

FIG. 1

REACTOR CHARACTERISTICS WITH LOAD - 100%
 $T_R = T_{in} + T_1$ (BUNK TEMP)

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FIG 2

REACTOR CHARACTERISTICS

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WITH KIII LOADING

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$$T_A = \frac{T_D - T_i}{2} + T_i (\text{BULK TEMP})$$

B.O.R.P. AT O'LEVEL IN P.S.I.G.

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CG 775 PUMP CHARACTERISTICS

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FIG-4

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FIG: 5

FRICTION DROP

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FIG: 7

CAVITATION CUTOFF POINTS - OLD HIGH LIFTS

CAVITATION CONSTANTS-K HIGH LIFTS (OLD)

FIG-9

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FRICION DROP RISER TO HEADER (KF)

HEADER PRESS. MEASURED IN CENTER OF HEADER

THEORETICAL CURVE BASED ON VELOCITY EFFECT
CENTER TO END OF X-HEADER

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ΔP IN P.S.I.G.

TOTAL REACTOR FLOW

FIG-10

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K PILE CHARACTERISTICS FOAS TO REAR HDR.

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ΔP IN P.S.I.G. (END OF ACTIVE SECTION TO REAR NOZZLE BARREL & REAR NOZZLE BARREL TO REAR HDR)

- ① FROM HW-57743 WITH STANDARD DUMMY CHARGE AT 110°C (~50% INCREASE AT 11°C)
- ② FROM HW-57146 WITH THIN WALL PERFS.
- ③ FROM HW-57146 WITH THICK WALL PERFS.
- ①+② FROM ADDITION OF CURVES ① AND ② THIN WALL PERFS.
- ①+③ FROM HW-57146 WITH THICK WALL PERFS.
- TOP 4 CURVES HAVE NEGLIGIBLE CHANGE WITH TEMPERATURE CHANGE

FLOW

K TUBE CHARACTERISTICS (FRONT HDR. TO TUBE INLET)

(1) EXTRAPOLATED TO 413 VENTURIM (PRESENT F.R. SIZE)
 FROM CONFR UNDER E.D. WATERS TO
 F.W. VAN HORNIER 9-8-58 (RT 22°C)

APPROXIMATELY
 AVERAGE TEMP

(2) CALCULATED TO 5°C

ΔP- FRONT HEADER TO TUBE INLET

TUBE FLOW - G.P.M.

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FIG-14

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TUBE CHARACTERISTICS

TUBE INLET TO END OF ACTIVE SECTION-KIN & CIE

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FIG-13

TUBE CHARACTERISTICS

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TUBE INLET TO END OF ACTIVE SECTION- K_{II}N & K_{III}E PAGE 25

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FIG.-14

TUBE CHARACTERISTICS
TUBE INLET TO END OF ACTIVE SECTION

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FIG-15

TUBE CHARACTERISTIC
K II N SLUGS

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FIG-16 TUBE CHARACTERISTICS

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2 CIE SLUGS

PRESSURE IN PSIG
(ELEVATION + 60")

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FIG.-17

TUBE CHARACTERISTICS
KIII N SLUGS

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FIG.-18

TUBE CHARACTERISTICS
KIII E SLUGS

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FIG.-19

TUBE CHARACTERISTICS

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ZONE 2 SOLIDS

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FIG-20

TUBE CHARACTERISTICS

ZONE 3 SOLIDS

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FIG:21

TUBE CHARACTERISTICS
ZONE 4 SOLID

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FIG-22

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ZONE ADDER FACTORS - KTT LOADING

ADD TO THE AVERAGE ZONE PRESSURE TO GET AVERAGE ZONE HEADER PRESSURE

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ΔP IN P.S.I.G.

100-110591

FORGET SAY IT --- Write It!

DATE June 15, 1960

TO Distribution of INW-59092

FROM J. L. Benson

K AREA HYDRAULIC WORKING CURVES
AND NUMERICAL RESULTS OF PT IP-130A
"K REACTOR TRIP-OUT TEST DOWN TO CROSS-TIE BACKUP"

A recent inquiry concerning the data contained in the subject document led to the discovery that an elevation correction was neglected in drawing the pressure decay curve in Figure 23 on page 35. The data were taken directly from film recordings of Heise gauges located about four feet off the floor of the control room, which means the BORP's drawn on the figure are actually BORP's-2 in psig.

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"SAFETY PAYS WHEN YOU'RE CAREFUL, YOU PAY WHEN YOU'RE NOT"

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KW REACTOR TRIP OUT TEST

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FIG. 23

TIME AFTER POWER LOSS (SECONDS)

B.O.R.P. IN P.S.I.

FIG. 23

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FIG-24 CROSS-TIE ORIFICE CALIBRATION PAGE 36

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END

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