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TOP SHIELD TEMPERATURES - C AND K REACTORS

December 28, 1964

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TOP SHIELD TEMPERATURES - C AND K REACTORS

INTRODUCTION

A modification program is now in progress at the C and K Reactors consisting of an extensive renovation of the graphite channels in the vertical safety rod systems. The present VSR channels are being enlarged by a graphite coring operation and channel sleeves will be installed in the larger channels.

One problem associated with the coring operation is the danger of damaging top thermal shield cooling tubes located close to the VSR channels to such an extent that these tubes will have to be removed from service. If such a condition should exist at one or a number of locations in the top shield of the reactors after reactor startup, the question remains - what would the resulting temperatures be of the various components of the top shields?

This study was initiated to determine temperature distributions in the top shield complex at the C and K Reactors for various top thermal shield coolant system conditions. Since the top thermal shield cooling system at C Reactor is different than those at the K Reactors, the study was conducted separately for the two different systems.

SUMMARY

Three dimensional heat transfer calculations were performed on representative models of the top shield complex at C Reactor and the K Reactors. The calculations were performed by a FORTRAN coded heat transfer program written for the IBM 7090.

The purpose of the calculations was to determine top shield temperatures associated with the loss of top thermal shield cooling tubes next to a VSR channel.

The results of the calculations show that for C Reactor the loss of one pair of cooling tubes will result in a maximum temperature of 1,030°F in the lead surrounding the damaged set of cooling tubes.

The calculated results for the K Reactors show that the loss of one thermal shield cooling tube will result in a maximum temperature of 490°F in the lead surrounding the damaged tube. This temperature is below the melting point of lead; however, the corresponding delta temperature across the top biological shield is about (330 - 114°F) which, in itself, is damaging to concrete.

The loss of two cooling tubes adjacent to the same VSR channel in the K Reactors will result in a maximum temperature of 660°F in the lead surrounding the damaged tubes.

DISCUSSION

Previous calculations were performed at an earlier date* with results that indicated high temperatures would exist at localized regions following the

* Letter - Top Thermal Shield Temperatures - C Reactor, J. D. Agar to F. J. Kempf - May 17, 1963.

[redacted]

removal of a single top thermal shield cooling tube at the K Reactors; high temperatures would also occur in C Reactor following the removal of a single pair of tubes. However, these preliminary calculations were approximations at best.

This study was based upon a more realistic approach to the problem. In reality, the heat generated in the top shield complex is transferred in a three dimensional manner. This third dimension is particularly accentuated with the spatial orientation of the top thermal shield cooling tubes, the top biological shield cooling tubes, and the process channels. The orthogonal relationship between the top biological shield cooling tubes (side to side) and the top thermal shield cooling tubes (front to rear) is shown in Figures 1 and 2.

Each reactor type was handled separately. The top shield complex, including the top reflector and the top row of process tubes of a given reactor, either C or the K Reactors, was reduced to a representative model. This segmental model included that portion of the top shield complex associated with one VSR channel and ball 3-X channel. The poor thermal conductivity through the graphite and the top biological shield concrete, plus the uniformity in the spatial location of the heat sinks in the shield complex, will allow such a model to be representative.

This model was further simplified with the elimination of a VSR channel through the shield. This latter simplification did not significantly alter the final calculated temperatures and the model approximates the volumes between the VSR channels. If failure occurs in a top thermal shield cooling tube or a pair of cooling tubes, the lack of cooling will be sensed all along the coolant channel which will include that portion of the shield complex between the VSR channels.

The calculations were performed with the aid of a FORTRAN heat transfer program* and the maximum number of storage locations allotted by the program limited the size and complexity of the mathematical model.

Figure 1 shows the C Reactor model as used in the calculations. The top thermal shield cooling tubes were originally installed in pairs rather than singularly as at the K Reactors. The distance between the pairs of cooling tubes is longer than at the K Reactors, which introduces a problem in the use of the model. As can be seen, the removal of one pair of top thermal shield cooling tubes from the model, depicting cooling tube damage, results in an unbalance in the heat transfer properties of the model.

To counteract this difficulty of a thermal unbalance, the left and right sides of the thermal shield blocks, as shown in the sketch, were connected together in the heat transfer program. That is, the side temperature nodes that are shown by the dotted lines in Figure 1 were assumed to be connected together to form a continuous thermal shield equipped with usable cooling tubes. Therefore, when one pair of cooling tubes is removed from the mathematical model, the heat generated in the vicinity of the removed tubes is partially transferred to cooling tubes not shown in the model.

* HW-73668, Unclassified, "User's Manual For STHTP - A Steady State Heat Transfer Program For The IBM 7090 Computer," F. J. Mollerus, Jr., May 21, 1962

[redacted]

The nodular arrangement shown in Figures 1 and 2 of the mathematical models used for the top shield complex form a necessary part of the heat transfer program. The calculations are performed by using the relaxation method of heat transfer. A given system is arbitrarily subdivided into a number of smaller parts called temperature nodes. These nodes are treated as separate individual bodies of a given material and each with a constant temperature that must be calculated by making independent and simultaneous heat balances on all nodes.

Varying heat generation rates may be taken into account by simply making the nodes different materials with particular physical properties. The heat generation rates for the shield complex were taken from a study that was done a few years ago.*

The temperature nodes for the models of both C Reactor and the K Reactor types were chosen to accentuate the lead grout around the thermal shield cooling tubes. The process tubes do not appear as nodes in the model because of storage limitations of the program. The top row of process tubes was accounted for as a heat sink. The graphite reflector temperature was calculated at the location of the top row of process tubes and maintained constant for a given power level.

Figure 2, as mentioned earlier, shows the mathematical model for the K Reactors. The discussion for this model is very similar to that for the C Reactor model with the exception of the numbers and location of the top thermal shield cooling tubes. In this model, the tubes are singularly placed and spaced at closer intervals. Therefore, for a given volume more cooling tubes are available. The cooling tubes of interest, i.e., located next to the VSR channels, are located in the center of the model and the heat transfer characteristics of the model are not unbalanced when these tubes are assumed to be damaged and are removed from the model.

In both models, the depth of the volume is subdivided into four layers or rows. This was done to indicate or show the temperature distribution in the front to rear direction through the top shield complex. The results of the study show the temperature distribution in this direction, i.e., around each biological shield cooling tube, to be approximately symmetrical with respect to the center of the model. Therefore, two layers or rows would have been sufficient. However, the use of four layers does not detract from the accuracy of the calculations.

The two modes of heat transfer that were considered are radiation and conduction. Convection heat transfer through the gas gaps was neglected because of the relatively slow gas velocity in the graphite stack and the small gap dimensions that depress natural convection. The main purpose of the pile gas is to prove an inert atmosphere, relatively speaking, and to provide a heat conducting material for the gaps.

The structures of both reactor types were maintained true to form, with the few exceptions mentioned earlier. The presence of an aluminum sheet between the top of the reflector and the thermal shield cast iron blocks was accounted for in the

* HW-67513, Secret, "An Evaluation of Five Possible HCR Sleeve Materials For K Reactor," W. L. Bunch, J. D. Agar, November 23, 1960.

[redacted]

low emissivity factor between the graphite and the cast iron. The heat transfer coefficients between the cast iron blocks and the lead grout around the cooling tubes, and between the biological shield cooling tubes and the concrete were inserted into the program as parameters.

The models were first used in the sense of normal reactor operation with all cooling tubes intact. The calculations were performed with varying heat transfer coefficients until the top shield temperatures as presently measured (current to within one month of this writing) were matched by the calculated temperatures. The resulting data of these cases constituted the base cases for the two reactor types.

The variation of heat generation rates from the process tubes to the top of the biological shield was accounted for by calculating the volumetric average rate for a horizontal layer of nodes and maintaining this rate constant for the calculations. The number of layers used are indicated by the horizontal layers of temperature nodes shown in Figures 1 and 2 as dotted lines.

The final values of the significant system parameters for the base cases are shown below in tables 1 and 2.

TABLE 1

C REACTOR BASE CASE
SYSTEM PARAMETERS

ITEM	LOCATION	VALUE
Contact Coefficients	Thermal Shield - between Lead and Cast Iron	1,000 BTU/hr ft^2 °F
Contact Coefficients	Thermal Shield - between Lead and Cooling Tubes	75 BTU/hr ft^2 °F
Contact Coefficients	Biological Shield - between Cooling Tubes and Concrete	3,000 BTU/hr ft^2 °F
Reactor Power Level		2,310 Mw
Emissivity	Top of Reflector	0.20
Emissivity	Cast Iron	0.50
Emissivity	Lead Grout	0.28
Emissivity	Copper Cooling Tubes	0.78
Thermal Conductivities	Graphite Reflector	Variable
Thermal Conductivities	Pile Gas (70% He-30% CO_2)	Variable
Thermal Conductivities	Cast Iron	26.0 BTU/hr ft °F
Thermal Conductivities	Lead	20.0 BTU/hr ft °F
Thermal Conductivities	Copper	220.0 BTU/hr ft °F
Thermal Conductivities	Biological Shield Concrete	0.50 BTU/hr ft °F

TABLE 2

K REACTOR BASE CASE
SYSTEM PARAMETERS

ITEM	LOCATION	VALUE
Contact Coefficient	Thermal Shield - between Lead and Cast Iron	4,000 BTU/hr/ft^2/°F
Contact Coefficient	Thermal Shield - between Lead and Cooling Tubes	1,000 BTU/hr/ft^2/°F
Contact Coefficient	Biological Shield - between Cooling Tubes and Concrete	5,000 BTU/hr/ft^2/°F
Reactor Power Level		4,400 Mw
Emissivity	Same as C Reactor	
Thermal Conductivity	Same as C Reactor	

The two tables below present the variable thermal conductivities used in the calculations for both the C Reactor and the K Reactors.

TABLE 3

GRAPHIC THERMAL CONDUCTIVITY

Temperature (°F)	Value (BTU/hr ft °F)
140	15.0
356	17.0
464	17.5
572	18.0
662	18.0
752	18.0
842	18.0
1,110	17.0
2,160	15.0

TABLE 4

PILE GAS THERMAL CONDUCTIVITY

	Value (BTU/hr ft °F)	
Temperature (°F)	70% He-30% CO_2	70% He-30% N_2
212	.0449	.0575
392	.0543	.0687
572	.0640	.0801
752	.0734	.0913
932	.0832	.1030
1,110	.0926	.1140
1,290	.1020	.1260

[redacted]

The results of the calculations are presented in Figures 3 through 14. Figures 3 through 6 present the calculated temperatures for C Reactor base case and for the case of removal of the shaded thermal shield cooling tubes. The temperatures for the base case are the non-circled temperatures. The temperatures shown in the parentheses on the biological shield nodes are the temperatures for the second layer of nodes in the same row. This arrangement is necessary only for the biological shield and is shown in Figures 1 and 2.

The circled temperatures are those calculated for the hypothetical removal of the cooling tubes that are shaded in the figures.

The temperatures that are prefixed with an asterisk are those that were measured at the reactor in question. These are the temperatures that were matches in determining the base case.

The temperatures shown on Figures 7 through 10 are those for the K Reactors' base case. The reference or measured temperatures are shown prefixed by an asterisk. Here again, the temperatures shown in the parentheses are for the nodes behind the nodes shown for the biological shield.

The temperatures shown on Figures 11 through 14 are those calculated for the removal of one or two cooling tubes. The temperatures shown as enclosed are associated with the removal of one cooling tube and this one is shown as shaded. The temperatures not enclosed are associated with the removal of two cooling tubes, one shaded and the other cross hatched. The reason for one or two tubes in the case of the K Reactors is the physical locations of the VSR channels and the top thermal shield cooling tubes. There are cooling tubes in close proximity of both sides of the VSR channel and might possibly be damaged in the channel enlarging process. On the other hand, there is a greater possibility of damaging one cooling tube if the VSR hole is enlarged eccentrically to the given channel center line, hence the extra set of calculations for the K Reactor model.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the calculations that were performed:

1. For C reactor, if one pair of cooling tubes is permanently damaged, then the temperature of the lead around the damaged cooling tubes will exceed the melting point (621.5°F).
2. For K Reactor, if one cooling tube next to a VSR channel is permanently damaged, then the temperature of the lead surrounding that tube will not exceed the melting point of lead. However, the temperature gradient through the top biological shield will be significantly increased.
3. For K Reactor, if two cooling tubes next to the same VSR channel are lost to future use, the temperature of the lead surrounding these tubes will be at or above the melting point of lead.

The following recommendations pertain to the calculations:

1. If damage occurs to one pair of thermal shield cooling tubes next to a VSR channel during channel enlargement at C Reactor, top fringe poison should be charged in the appropriate process tubes to lower the anticipated top shield temperatures.

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2. If damage occurs to either one or two top thermal shield cooling tubes next to a VSR channel at the K Reactors during channel enlargement, appropriate top fringe poison should be charged in the top process tubes prior to startup.

ACKNOWLEDGMENT

The author is indebted to Mr. G. H. Dickerson for handling the time-consuming task of setting up the FORTRAN program input data and successfully debugging the three-dimensional array of data.

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Reactor Design Analysis
N-Reactor Project

JD Agar:bw

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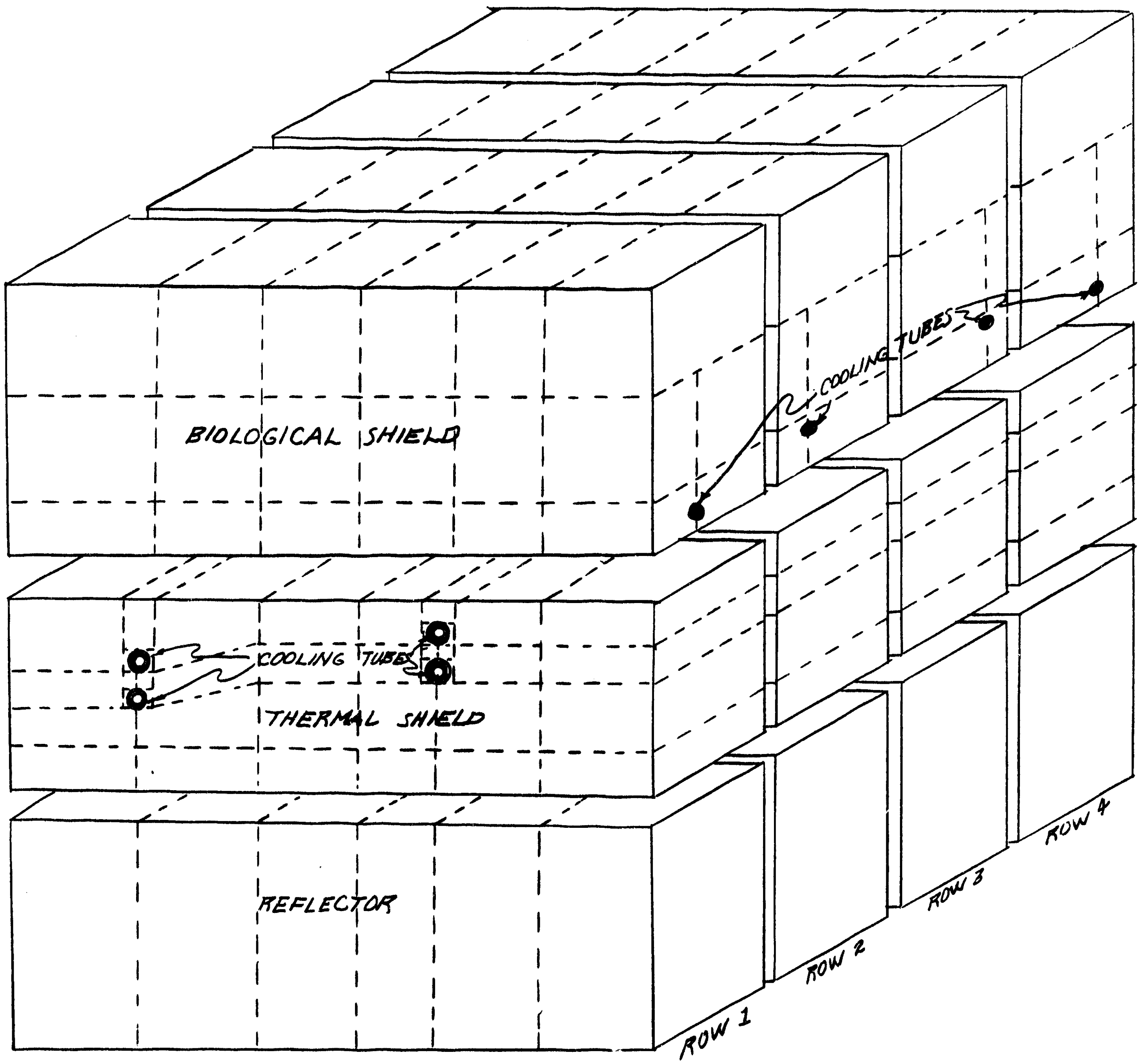
FIGURE 1
"C" REACTOR TOP SHIELD COMPLEX



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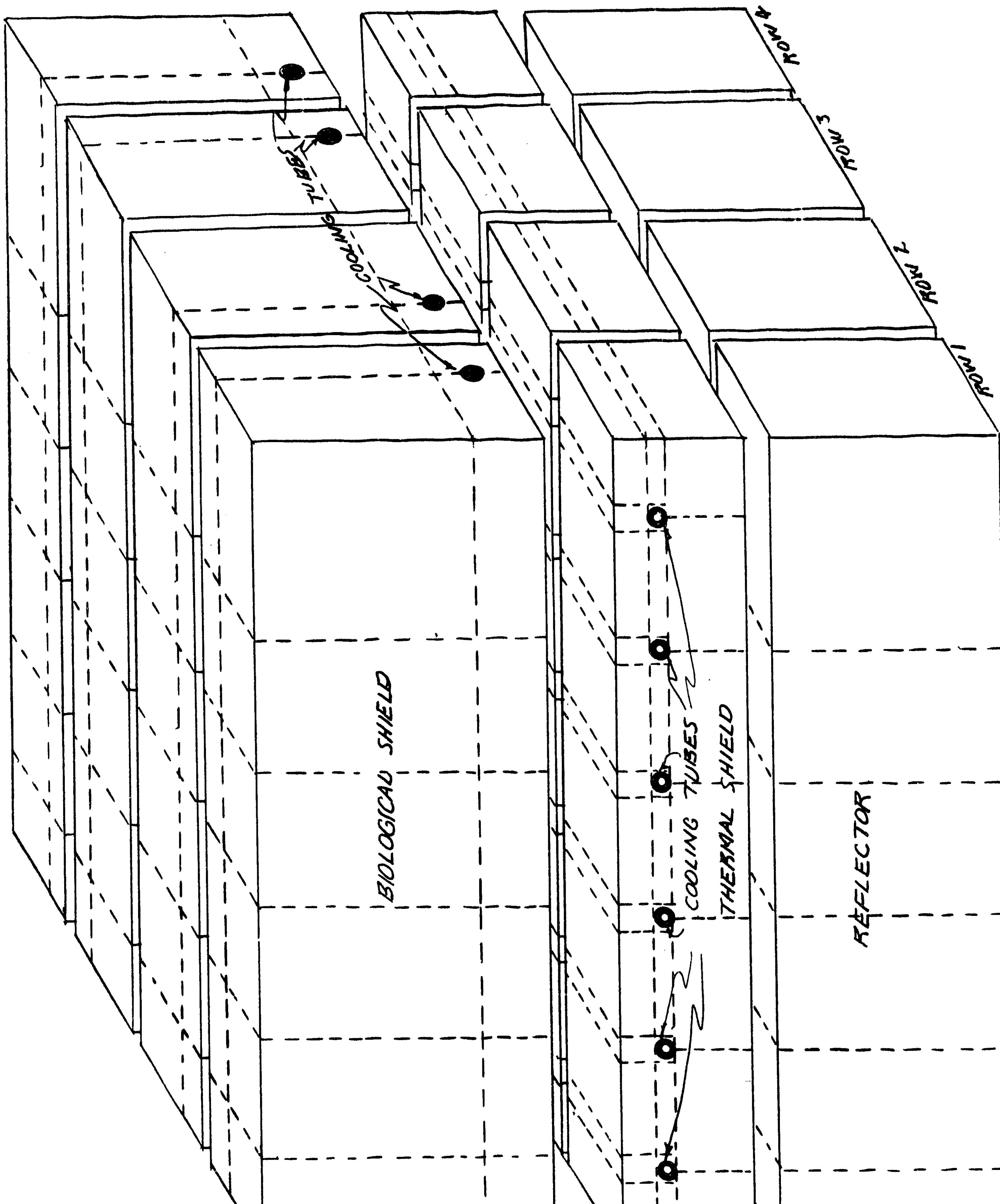

K REACTOR TOP SHIELD COMPLEX

FIGURE 2

[redacted]

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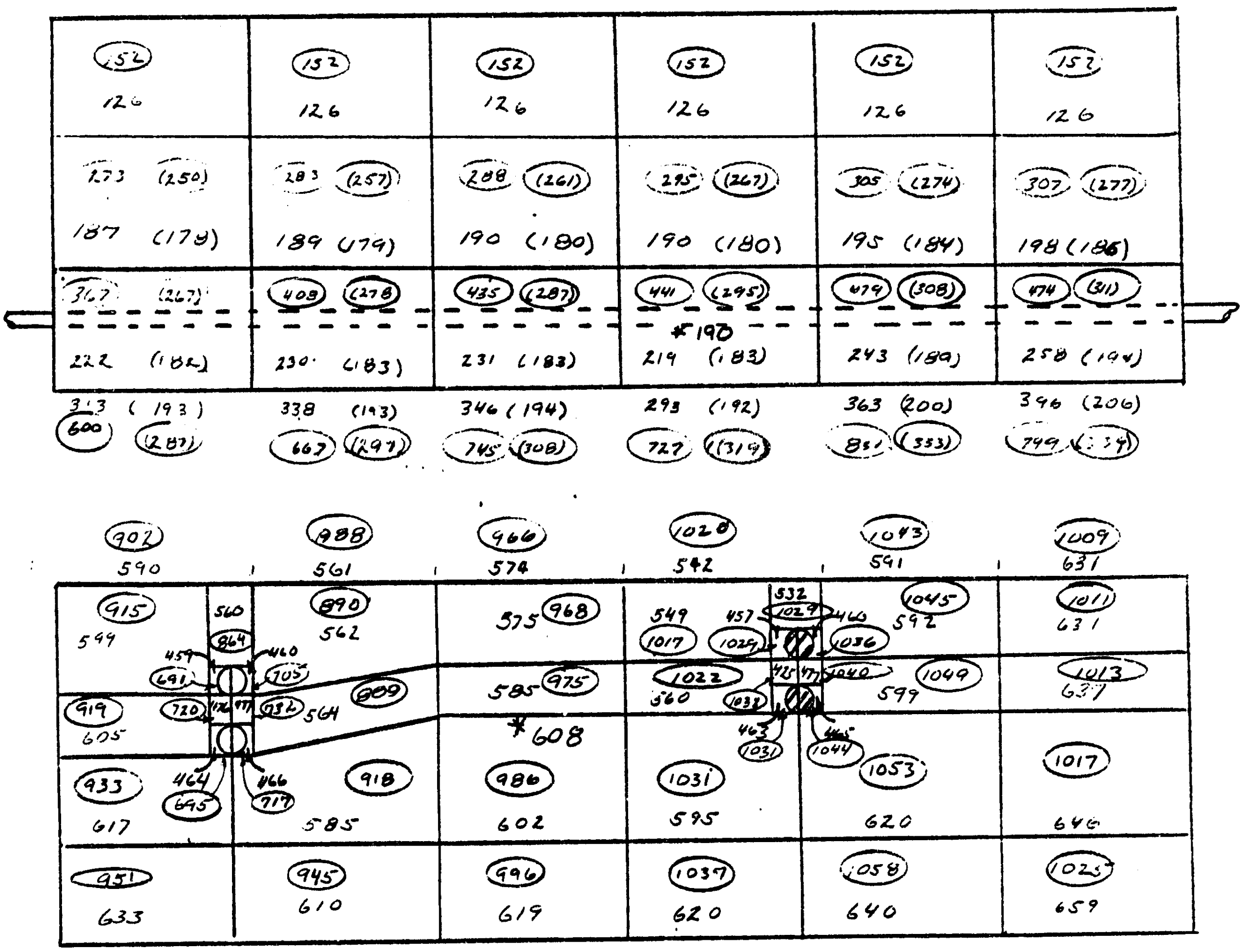
FIGURE 3

C-REACTOR

ROW 1



TEMPERATURES WITH ○ AROUND THEM ARE FOR TWO TUBES TAKEN OUT. TUBES MARKED ⊘ THE OTHER TEMPERATURES ARE THE BASE CASE

[redacted]

FIGURE 4
C-REACTOR
ROW 2

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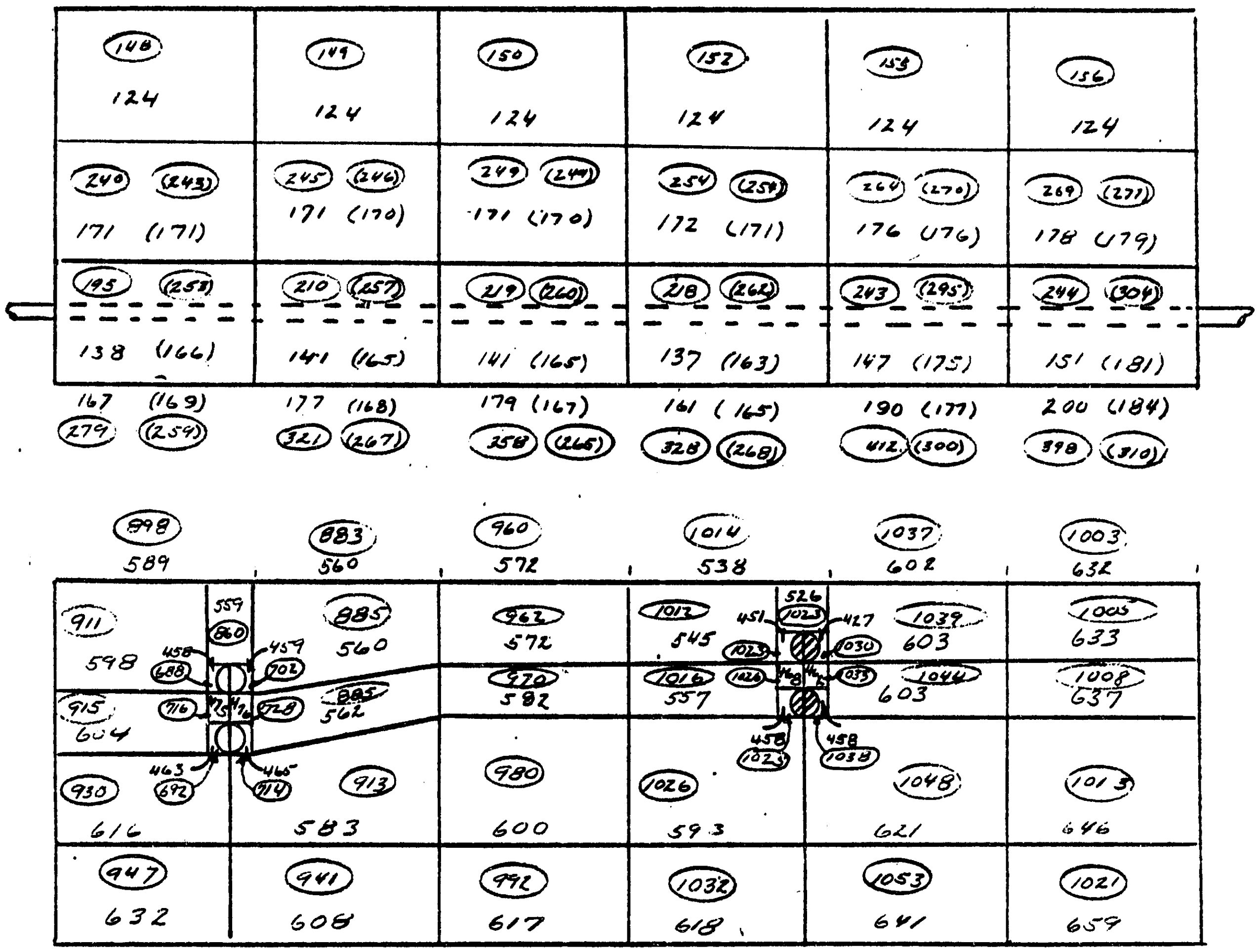
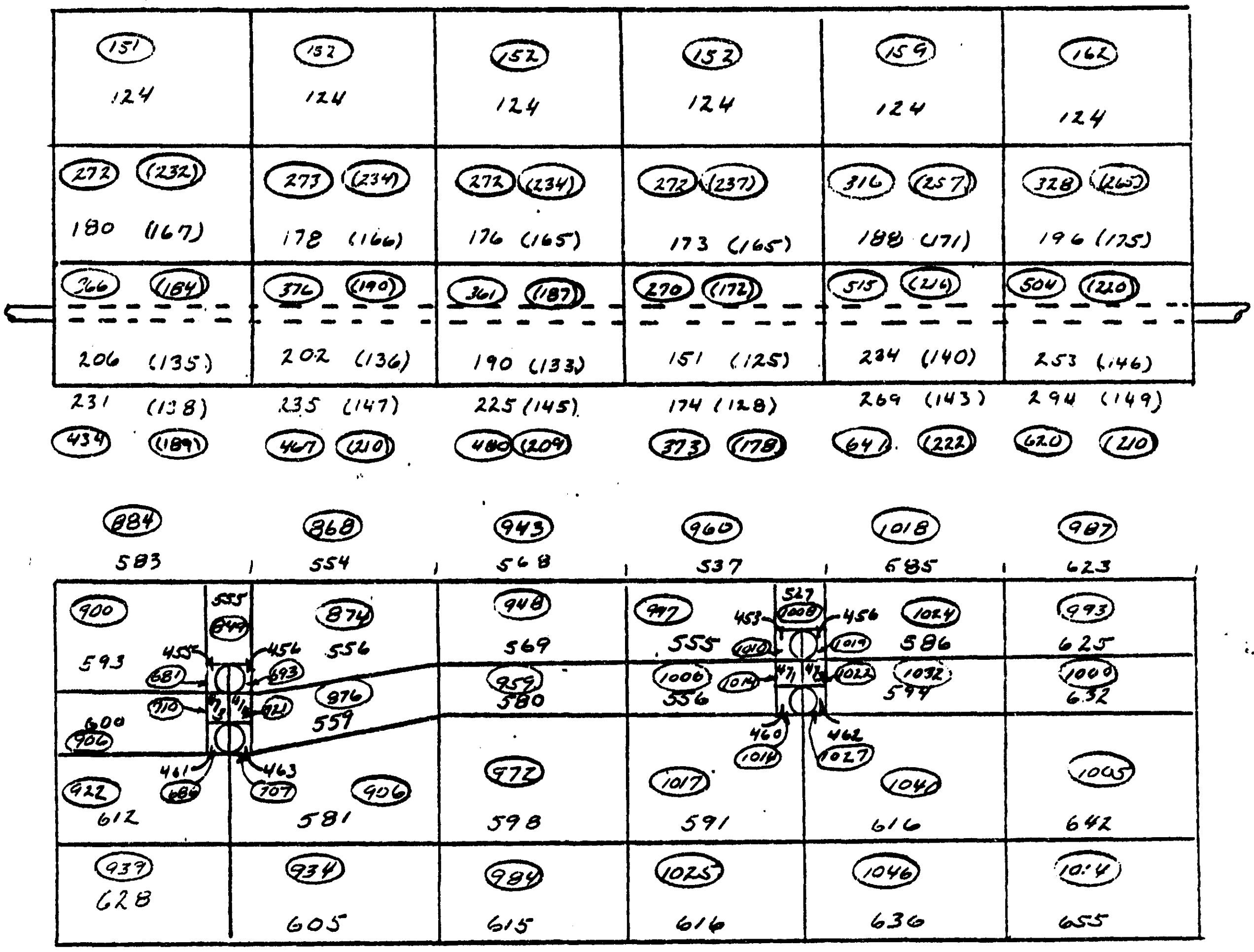


TEMPERATURES WITH ◯ AROUND THEM ARE FOR TWO TUBES TAKEN OUT, TUBES MARKED ⊘ THE OTHER TEMPERATURES ARE THE BASE CASE

TEMPERATURES IN °F

[redacted]

FIGURE 5
C-REACTOR
ROW 3

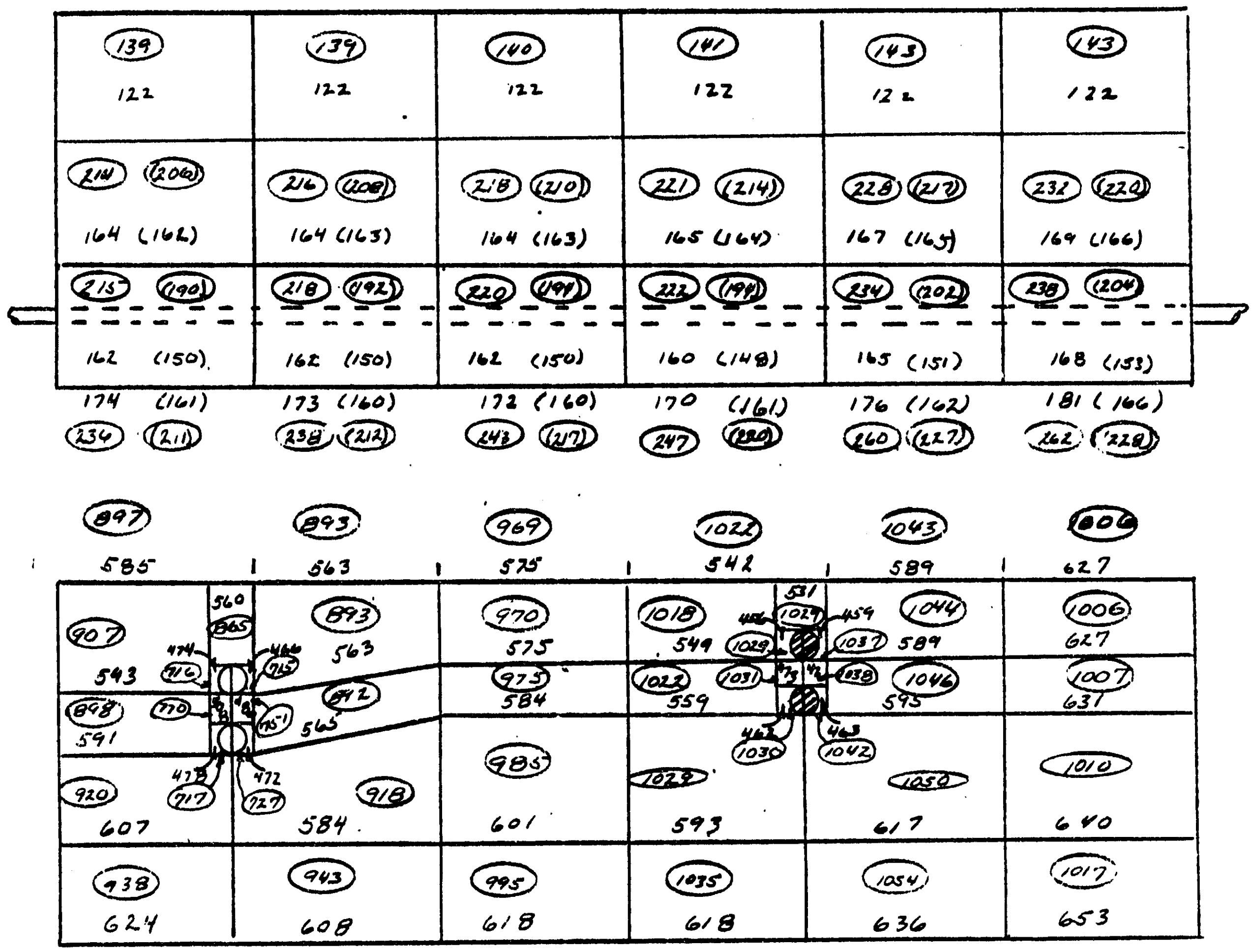


TEMPERATURES WITH ◯ AROUND THEM ARE FOR TWO TUBES TAKEN OUT, TUBES MARKED ⊘
THE OTHER TEMPERATURES ARE THE BASE CASE

TEMPERATURES IN °F

[redacted]

FIGURE 6
C-REACTOR
ROW 4



TEMPERATURES WITH ◯ AROUND THEM ARE FOR TWO TUBES TAKEN OUT. TUBES MARKED ⊘ THE OTHER TEMPERATURES ARE THE BASE CASE

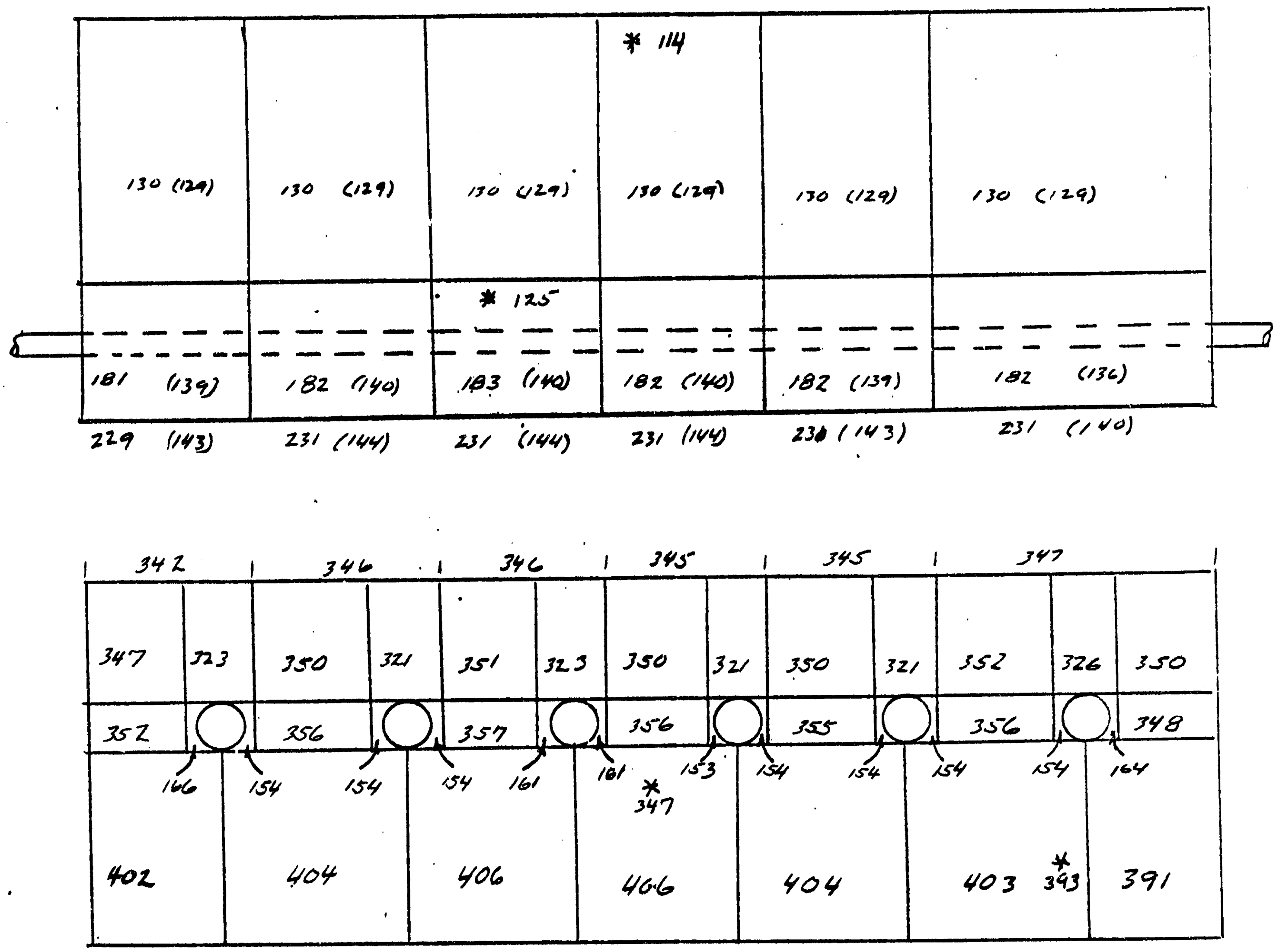
TEMPERATURES IN °F

[redacted]

FIGURE 7

K-REACTOR
BASE CASE

ROW 1



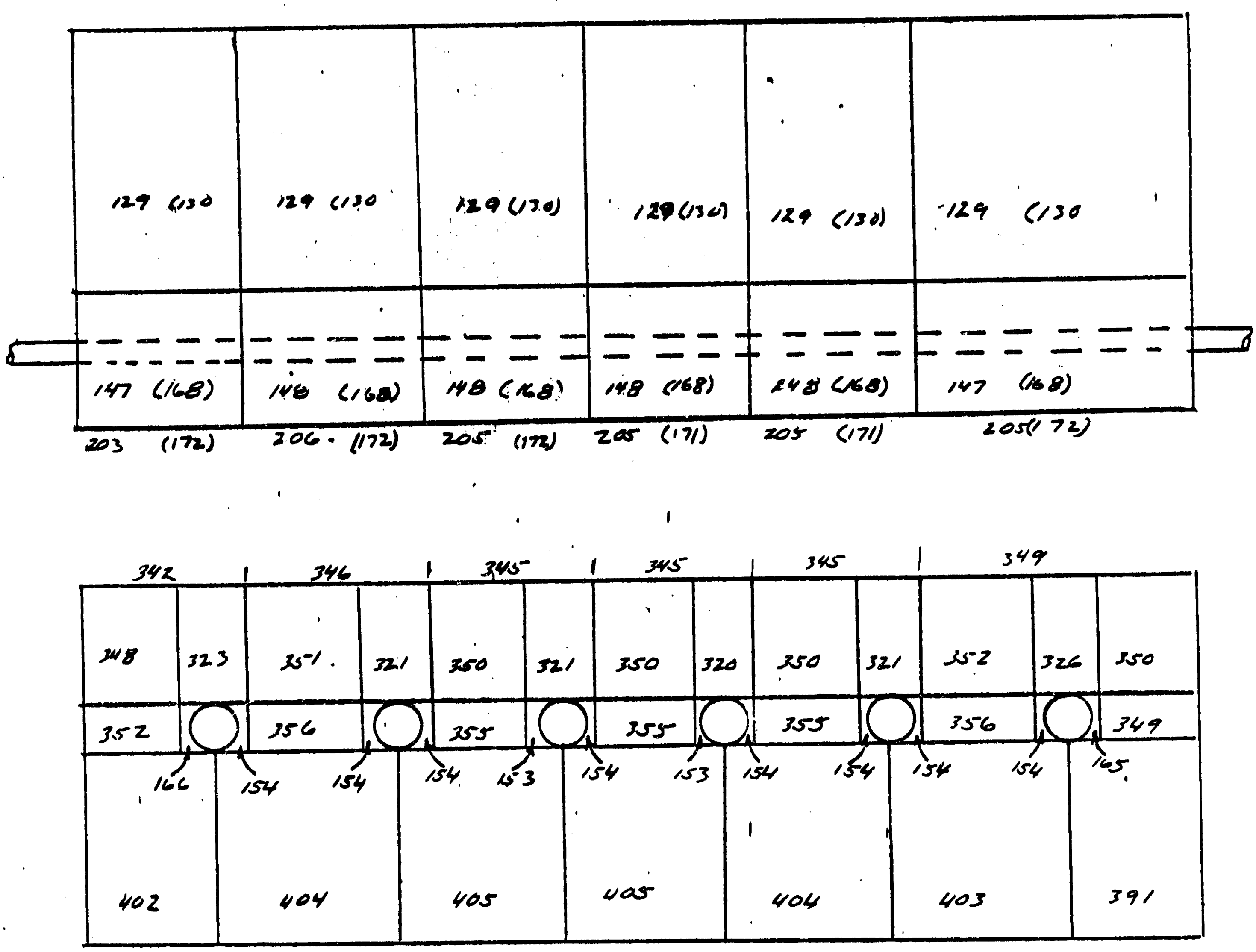
TEMPERATURES IN °F

[redacted]

FIGURE 8

K-REACTOR
BASE CASE

ROW 2



TEMPERATURES IN °F

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FIGURE 9

K-REACTOR
BASE CASE

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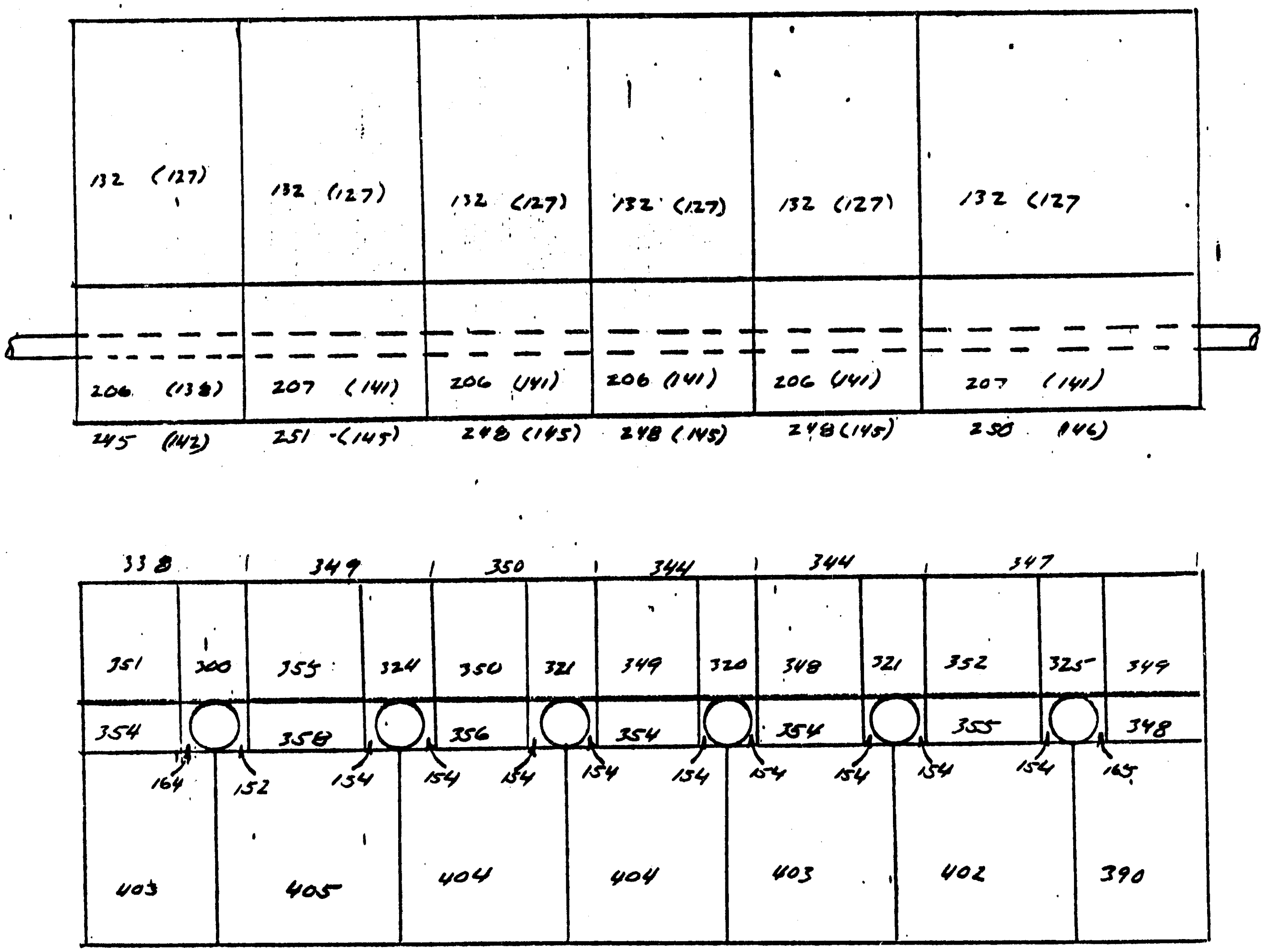
ROW 3



TEMPERATURES IN °F

[redacted]

[redacted]

FIGURE 10

K-REACTOR
BASE CASE

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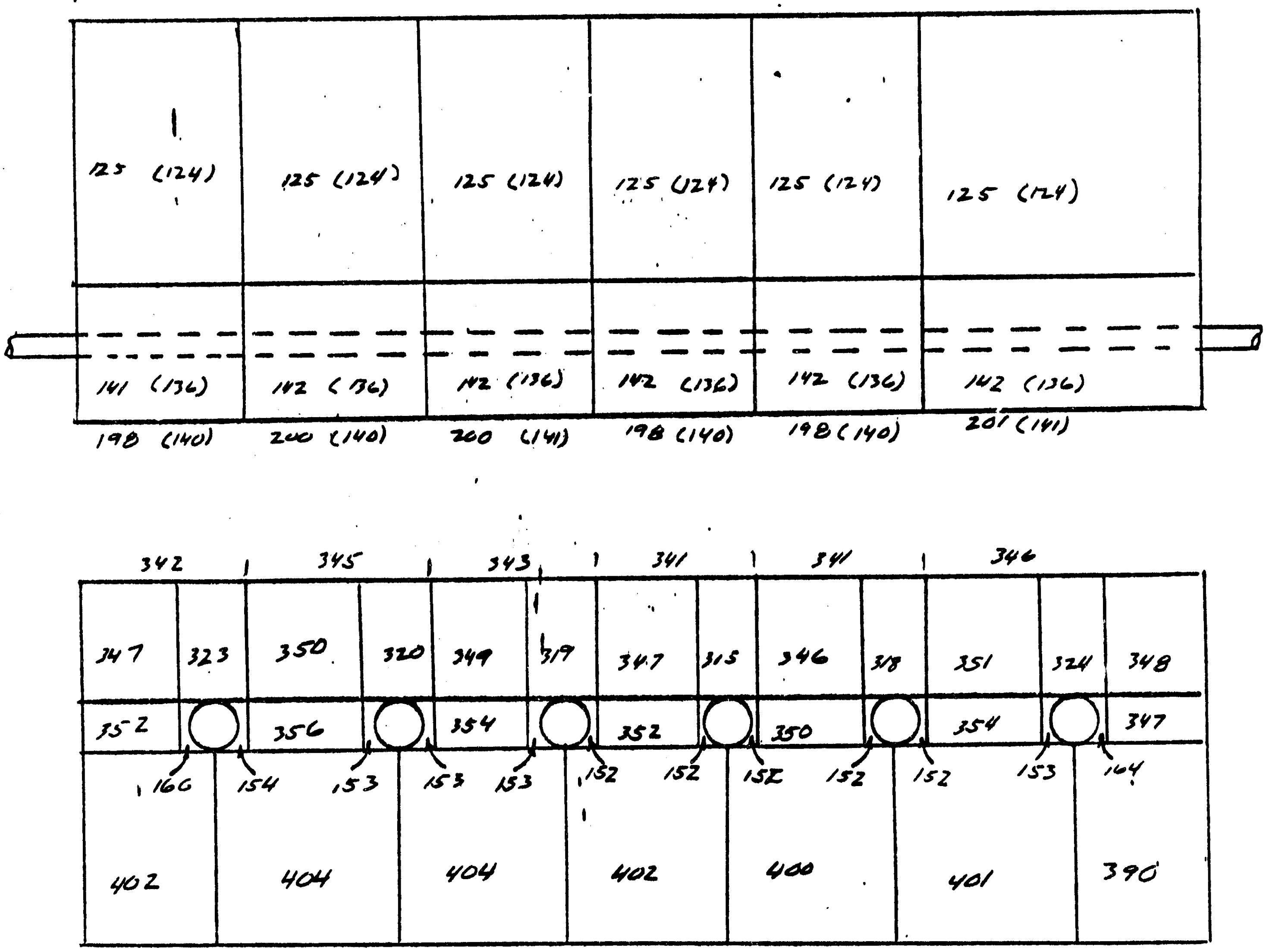
ROW 4



TEMPERATURES IN °F

[redacted]

FIGURE 11
K-REACTOR

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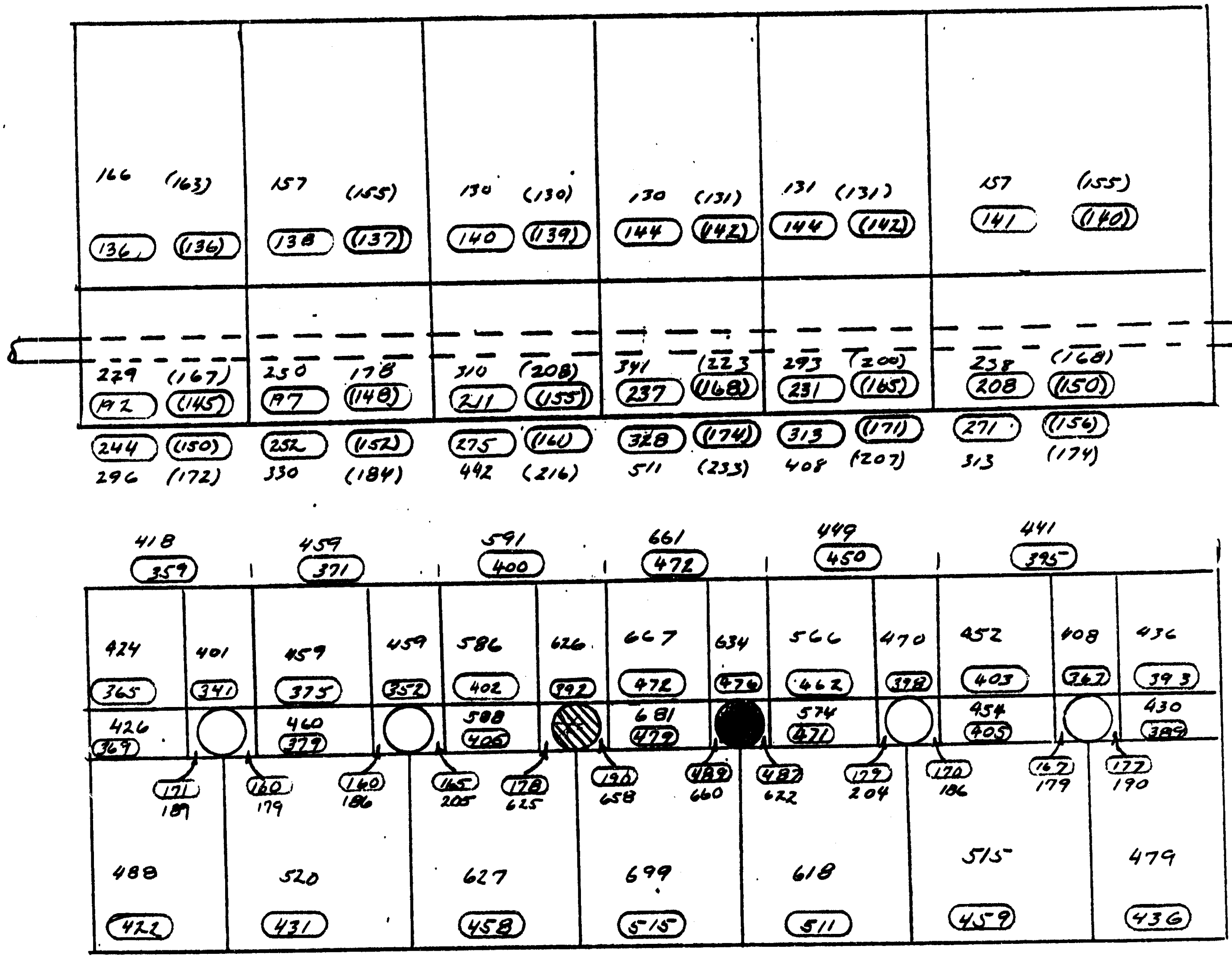
ROW 1



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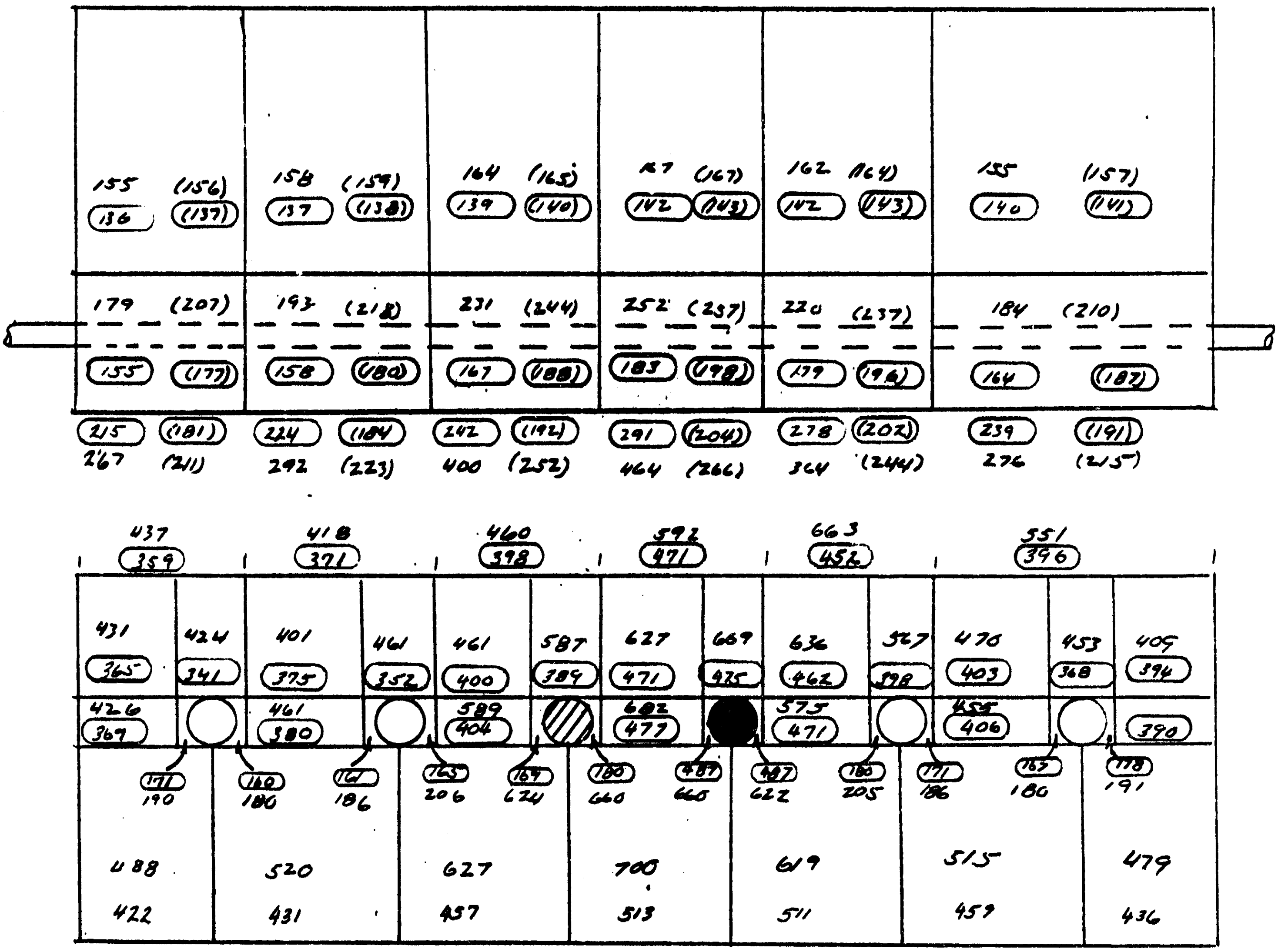
THE OTHER TEMPERATURES ARE FOR BOTH TUBES TAKEN OUT, TUBES MARKED ● ⊘

TEMPERATURES IN °F

[redacted]

[redacted]

FIGURE 12
K-REACTOR
ROW 2

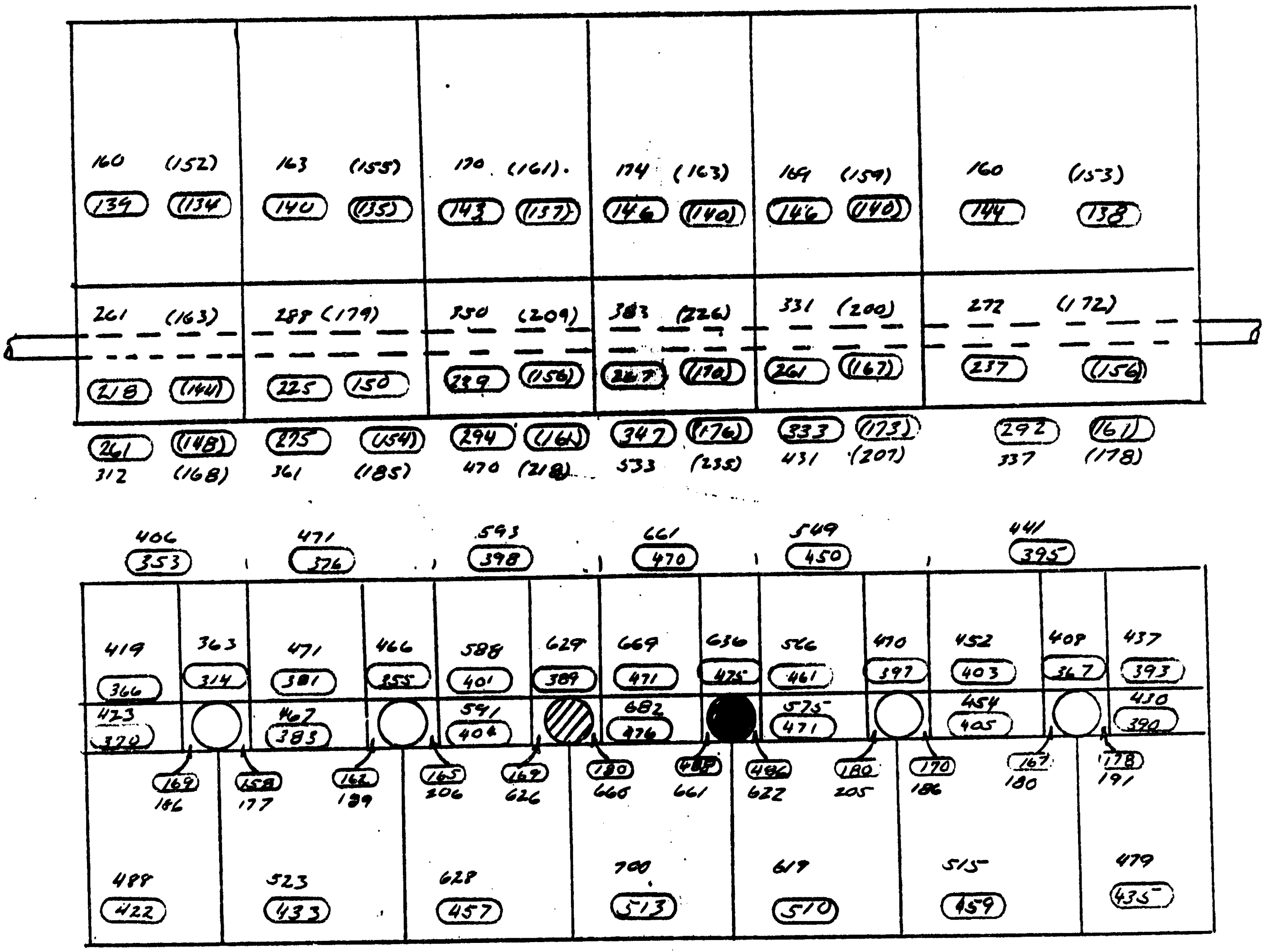


TEMPERATURES WITH ⬭ AROUND THEM ARE FOR THE TUBE MARKED ● TAKEN OUT
THE OTHER TEMPERATURES ARE FOR BOTH TUBES TAKEN OUT, TUBES MARKED ● ⊘

TEMPERATURES IN °F

[redacted]

FIGURE 13
K-REACTOR
ROW 3



TEMPERATURES WITH ⬭ AROUND THEM ARE FOR THE TUBE MARKED ● TAKEN OUT

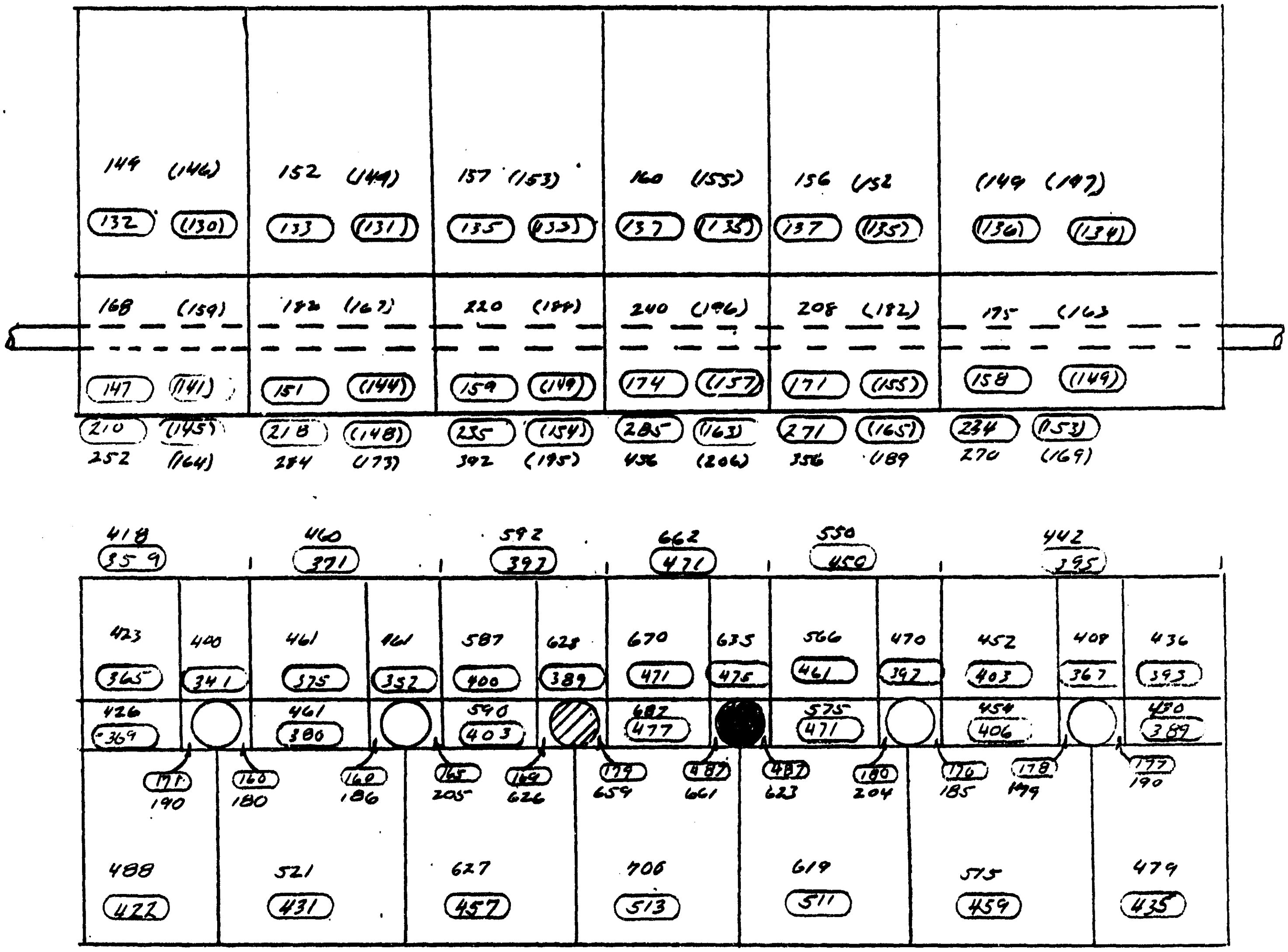
THE OTHER TEMPERATURES ARE FOR BOTH TUBES TAKEN OUT TUBES MARKED ● ⦶

TEMPERATURES IN °F

[redacted]

FIGURE 14
K-REACTOR

ROW 4



TEMPERATURES WITH ⬭ AROUND THEM ARE FOR THE TUBE MARKED ● TAKEN OUT

THE OTHER TEMPERATURES ARE FOR BOTH TUBES TAKEN OUT TUBES MARKED ● ▨

TEMPERATURES IN °F

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