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DR-1 GAS LOOP THERMAL AND FLUID FLOW ANALYSES

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INTRODUCTION

Thermal and fluid fluid flow analyses of the DR-1 Gas Loop and machine programs based thereon are reported in Reference 1. Certain portions of the analyses and program descriptions contain information which, when combined with machine calculation results, would identify the magnitude of in-reactor radiation heating rates. These rates are classified, and to avoid classification of the entire report, the affected sections are presented in this supplement to Reference 1.

The sections appearing in this supplement are:

V. In-reactor Tube Assembly

VIII. Over-all Loop Analysis

IX. Machine Programs for Over-all Analysis

APPENDIX A: Program Listing for DR-1 TEST EVAL Executive Routine

APPENDIX B: Program Listing for CALC Subroutine

APPENDIX C: Program Listing for COEFT Subroutine

APPENDIX H: Program Listing for SEARCH Subroutine

APPENDIX I: Program Listing for OUTPUT Subroutine

Sections V and IX are the only sections containing sensitive information. The remaining sections have been included in this supplement for convenience to the reader.

Sections I through IV, plus VI and VII, which present introductory material, general relationships, and analyses of the circulators, loop heat exchanger, and loop pressure drops are contained in Reference 1. Appendices D through G, program listings for the above analyses, are also contained in Reference 1.

V. IN-REACTOR TUBE ASSEMBLY

This section is devoted to a heat transfer and temperature distribution analysis of the in-reactor assembly under steady-state conditions. Pressure drop analysis is reported elsewhere.

A. Component Description

The in-reactor tube assembly consists of two concentric tubes. The in-reactor end of the outer tube is closed (welded end cap). Recirculating gas enters the annulus, flows to the end of the assembly, and returns through the center tube over the specimen. The entire assembly is approximately 25 feet long. The outer one foot is a stagnant region in which shielding is installed. Most of the assembly is located in-reactor in the "C" test hole, a square, horizontal side channel in the DR Reactor moderator. The assembly penetrates the side shield through a water-cooled step plug which is installed in a stepped hole in the shield.

The outer tube is 3-7/8 inches OD with an 0.125-inch wall and is made of Inconel. The inner tube is made of type 316 stainless steel, and has a 2.245-inch ID and an 0.0625-inch wall.

B. Process Description

Figure 7 illustrates the processes involving the assembly. The processes include regenerative heat exchange between the two gas streams, exchange between outer tube and surroundings, exchange between inner and outer tubes, heat generation in assembly materials, and fission heat generation in the test specimen (if one is installed). The tube may be divided into four general zones: out-of-reactor, step-plug, reflector, and active zones. As is noted in Figure 7, not all of the processes are present in all of the zones.

C. Process Analysis

Figure 8 shows a cross-section of the assembly and test channel in the active zone. Making a heat balance on differential lengths of the inner and outer tubes, respectively, yields the following equations:

$$1) \quad Q_H + Q_I = Q_1 + Q_3 \quad (\text{inner tube})$$

$$2) \quad Q_C + Q_0 + Q_3 = Q_2$$

Using coefficients per unit length,

$$3) \quad Q_H = H_H (T_H - T_I)$$

$$4) \quad Q_1 = H_C (T_I - T_C)$$

$$5) \quad Q_2 = H_0 (T_S - T_C)$$

$$6) \quad Q_C = H_S (T_S - T_0)$$

$$7) \quad Q_3 = H_X (T_I - T_0)$$

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- ① Transfer from hot to cold stream
 - ② Transfer from inner to outer tube
 - ③ Radiation heating of assembly materials
 - ④ Exchange between moderator and outer tube
 - ⑤ Exchange between step plug and outer tube
 - ⑥ Fission heating of test specimen
- > Direction of gas flow
 —————> Direction of energy processes

FIGURE 7

PROCESS DIAGRAM OF IN-REACTOR ASSEMBLY

- Q_I - Radiation heating per foot, inner tube
- Q_0 - Radiation heating per foot, outer tube
- Q_H - Heat transferred to inner tube from center gas stream, per foot
- Q_C - Heat transferred to outer tube from surrounding, per foot
- Q_1 - Heat transferred from inner tube to annulus gas stream, per foot
- Q_2 - Heat transferred from outer tube to annulus gas stream, per foot
- Q_3 - Heat transferred from inner tube to outer tube, per foot

→ Indicates positive direction for process.

T_H = Center stream gas temperature
 T_C = Annulus stream gas temperature
 T_I = Inner tube wall temperature
 T_0 = Outer tube wall temperature
 T_S = Surroundings surface temperature

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FIGURE 8

CROSS-SECTION PROCESS DIAGRAM - IN-REACTOR ASSEMBLY

The positive directions of transfer are defined in Figure 8, as are the symbols. Similarly, heat balances on the flowing gas streams yield:

$$-WC_p dT_H = -Q_H dL \quad (\text{exit stream})$$

$$WC_p dT_C = (Q_1 + Q_2) dL \quad (\text{annulus stream})$$

$$8) \text{ or, } \frac{dT_H}{dL} = \frac{Q_H}{WC_p}$$

$$9) \quad \frac{dT_C}{dL} = \frac{(Q_1 + Q_2)}{WC_p}$$

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The distance L is measured into the reactor. The symbols W and C_p represent the flow rate and the specific heat, respectively, for the gas. Equations 1) through 9) can be combined to yield second order differential equations in T_H and T_C . However, explicit equations in just T_H or T_C cannot be obtained, and in any event, the coefficients are not independent of T_H and T_C . A trial-and-error, finite-difference approach is used instead.

The finite forms of equations 8) and 9) are:

$$T_H' - T_H = Q_H \Delta L / WC_p$$

and

$$T_C' - T_C = (Q_1 + Q_2) \Delta L / WC_p$$

or for unit length,

$$10) T_H' - T_H = Q_H / WC_p \quad \text{and}$$

$$11) T_C' - T_C = (Q_1 + Q_2) / WC_p$$

The tube is divided into increments of unit length; Q_H , Q_1 , and Q_2 are determined at the beginning of the increment and are assumed constant across the increment. T_H' and T_C' at the end of the increment can then be computed; the procedure is repeated for each increment in order.

To determine the correct values of Q_H , Q_1 , and Q_2 for each increment, a trial and error process is necessary. Given T_H , T_C , T_S , Q_1 , and Q_0 , T_I and T_O are estimated. The coefficients and transfer rates are calculated using these temperatures. The transfer rates are then substituted in equations 1) and 2). If the equations are not satisfied, then T_I and T_O are re-estimated and the calculation repeated until agreement is obtained. One additional condition must be satisfied: T_H and T_C must be equal at the in-reactor end of the assembly. This

follows because they are one and the same temperature. Ordinarily, the starting point for the calculation will be elsewhere than this location. Thus, only one of the two temperatures (T_C and T_H) can be arbitrarily specified. To satisfy this condition, the second trial and error process must be used. One of the two temperatures, T_C or T_H , is specified at the starting point and the other is estimated. The repetitive calculation is carried to the in-reactor end from the starting point, and the two temperatures at this location are compared. If not equal, the process is repeated with revised estimates of the one until agreement is obtained.

Once the condition is satisfied, the calculation is completed to the other end of the assembly from the starting point. The right hand members of equations 10) and 11) must be multiplied by -1 to proceed in the out-of-reactor direction.

The above procedure and analysis is generally representative of all zones; however, some modifications must be made to reflect process differences. The above analysis is for the active zone, and represents the general case. In the other three zones, the radiation heating of assembly materials is nil. This is reflected by setting Q_I and Q_O equal to zero. The out-of-reactor zone is insulated from the surroundings; this condition is reflected by setting H_S equal to zero.

With the test specimen in place, the active zone must be divided into three regions; upstream of the specimen, at the specimen, and downstream of the specimen. The first and last regions are treated the same. They must be distinguished, however, since they are not adjacent to each other and the downstream geometry for the inner tube is altered by the lead rod attached to the specimen. The hot or center gas stream passes through the specimen. In this region, the stream is assumed to be insulated from the tube assembly. Heating of this stream by the specimen is treated separately. The condition of insulation is reflected by setting H_H equal to zero in this region.

D. Determination of Coefficients

The forced convection coefficients H_O , H_C , and H_H are calculated using the equation developed in Reference (1). The purely radiative coefficient, H_X , is also calculated using the pertinent equation developed in Reference (1).

H_S is the symbol used for the coefficient of transfer between the surroundings and the outer tube. For the out-of-reactor region, H_S is zero. For the step plug region, H_S is 12 BTU/hr-°F-ft of tube. This value is based on experimental data, using the inlet water temperature as the sink temperature. Hence T_S is specified to be the inlet water temperature in this region.

In the moderator region H_S , T_S , Q_I and Q_O are inseparably bound parameters. There is no practical way to measure individually the radiation heating or the local transfer rate to the moderator, nor is there a practical way to measure the effective moderator surface temperature seen by the outer

tube. The complicated round-in-square, three-dimensional geometry, coupled with uncertainties of clearances and of contact between the tube and the moderator, effectively prevent analytical estimates of H_S . Further, the depressant effects of the assembly on local tube powers, and hence upon local graphite temperatures, make it almost certain that the effective values of T_S will be well below maximum moderator temperatures.

The approach which has been taken is one of gross simplifying assumptions. T_S is assumed constant at one value for the active zone, and at another value for the reflector zone. Q_I and Q_O are assumed to be constant throughout the active zone and to be zero in the reflector and all other zones. H_S is calculated as a combination radiative and constant coefficient.

Originally, T_S was assumed to be 600 F in the active zone. This assumption was based on the no-energy-interchange, local moderator temperature determined in an electrical analogue study by J. Muroaka ⁽²⁾ for a similar installation. H_S was calculated as a purely radiative coefficient using emissivities of 0.8 for the moderator and 0.5 for the outer tube surface. Q_I and Q_O were estimated on the basis of a one-half-watt-per-gram heating rate. Using these values for T_S , Q_I and Q_O , and calculating H_S as described, excellent agreement was obtained with loop experimental data taken shortly after the in-reactor tube assembly was installed. ⁽³⁾

A check of loop data sometime later showed that marked changes must have taken place in the in-reactor tube assembly processes. There were strong indications that 1) the coefficient H_S was much less temperature dependent than in the above procedure and had definitely increased, and 2) that the effective values of T_S or Q_I and Q_O , or both, had increased.

A series of calculations were made for comparison with loop data over a variety of loop flow rates and inlet temperatures to the in-reactor assembly, with and without a test specimen in place. The values of T_S , Q_I , and Q_O were adjusted as appeared reasonable and H_S was calculated with varying proportions of radiative and constant components. Rather excellent agreement with data was obtained over the full range of conditions using the following parameters:

1. T_S in the active zone was assumed to be 700 F, and in the reflector zone, to be 150 F.
2. Values of Q_I and Q_O corresponding to an irradiation heating rate of approximately 0.7 watts per gram, were assumed.
3. H_S was assumed to be wholly constant, with a value of 15 BTU/hr-°F-ft of tube.

These values of the respective parameters are the ones currently being used. It is recommended that periodic check calculations be made against experimental data to discern any further process changes.

None of these parameters, T_S , Q_S , Q_O , or H_S , can be considered truly constant. However, excellent agreement with existing data is obtained using the above approach. In any event, the present state of knowledge does not justify more refined treatment.

E. Adaptations to Machine Computation

The calculation of tube temperature distribution is carried out by means of executive routine direction of two subroutines, COEFT 1 and CALC 1. Programs listings for the two subroutines are given in the Appendix.

The tube is divided into 24 one-foot increments. There are 25 sets of temperatures (T_H , T_C , T_I , and T_O are a set), one set at each junction between increments and one at each end of the assembly. These are indexed by K , with K ranging in order from one for the set at the out-of-reactor end to 25 for the set at the in-reactor end.

In the iterative loop used for the calculation, the set of temperatures being calculated is always indexed by K . Thus, when the direction of iteration is into the reactor, the set of temperatures on which the calculation is based is indexed by $K-1$, and for the other direction, by $K+1$. Two of the heat transfer rates (corresponding to Q_H and Q_C) are indexed to save them for later read-out and summarization. In the iterative loop, these are indexed the same as the temperature set being calculated; that is, by K . Thus, when the calculation starts between the ends of the assembly, these rates will be indexed from 1 to $K_I - 1$ and from $K_I + 1$ to 25, where K_I is the index of the temperature set at the starting point.

The iterative loop and some of the calculations are affected by the direction of iteration. The index must be defined so that regardless of the direction of iteration, the loop index always increases. The K index of the set of temperatures upon which the calculation is based for each increment differs according to the direction of iteration. Finally, the temperature difference across an increment for each gas stream is added to the base temperature of the stream when proceeding inward and subtracted when proceeding outward.

To handle these aspects, the calculation has been divided into the two subroutines, CALC 1 and COEFT 1. The calculation of coefficients, heat transfer rates, and gas stream heat transport capacities, and the trial and error determination of T_I and T_O for each increment, is carried out by COEFT 1.

The iterative machinery and all calculations affected by the direction of iteration are contained within CALC 1. The iterative loop in CALC 1 uses the symbol MM as index. For inward iteration, MM is defined as follows:

$$MM = K$$

The loop limits are specified directly in values of K as appropriate. For outward iteration, MM is defined as:

$$MM = K_I - K + 1$$

where K_I is the K index for the starting set of temperatures. The loop limits are determined by substituting the pertinent value of K in the

above equation. On each pass through the loop, the value of K corresponding to MM is calculated using the above equation solved for K.

The symbol M, used for specifying the base set of temperatures to be used by COEFT 1, is defined as follows:

1. For outward iteration: $M = K + 1$
2. For inward iteration: $M = K - 1$

The CALC 1 program is divided into two portions, one for inward iteration and one for outward iteration. Each time through the loop, the magnitude of the logic factor J1 is tested; the program proceeds to that portion directed by the value of J1.

The subroutine COEFT 1 is called within CALC 1 for each increment. It calculates the coefficients and heat transfer rates, determines the correct values of T_I and T_O , then calculates the gas stream heat transport capacities.

The determination of T_I and T_O is carried out as follows: After calculating the coefficients and heat transfer rates, COEFT 1 computes the quantities TST1 and TST2 as defined below:

$$TST1 = \frac{Q_H + Q_I - Q_3 - Q_1}{2 H_C}$$

$$TST2 = \frac{Q_C + Q_O + Q_3 - Q_2}{2 H_O}$$

These are rearrangements of equations 1) and 2), divided by twice the coefficients H_C and H_O , respectively. If the magnitudes of both TST1 and TST2 are within ± 1 , then the conditions of equations 1) and 2) are approximately satisfied, and T_I and T_O are correct. If either or both are not within ± 1 , then TST1 is added to T_I , and TST2 to T_O , and the entire calculation is repeated until both TST1 and TST2 satisfy the above condition.

The COEFT 1 call list consists of G, LL, JJ, and M. The pertinent flow geometry factor ($Z1, Z2$ or zero) for calculation of the coefficient between the center gas stream and the inner tube (H_H) is substituted for G. The proper choice of the three alternatives for the coefficient between the outer tube and its surroundings (H_S) is specified by the value of LL. A negative number is substituted to specify zero for H_S . Zero is substituted for H_S to be calculated as a coefficient with radiative and constant components. If debug output from COEFT 1 is desired, zero is substituted for JJ; otherwise some other number is substituted. The proper set of base temperatures to be used by COEFT 1 is specified by substituting the corresponding value of the K index for M.

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The CALC 1 call list consists of G, Ll, J, KX, KY, and J1. Substitution for G, Ll and J are made as described in the case of COEFT 1 for G, Ll, and JJ. The upper and lower limits for the CALC 1 iterative loop are specified by substituting the appropriate values for KY and KX, respectively. The direction of iteration (in or out-of-reactor) is specified by substituting a number other than zero, or zero, respectively, for J1.

CALC 1 automatically makes all substitutions in the COEFT 1 call list. G and Ll are never used in CALC 1 - they are included in CALC 1's call list in order to make the substitution in COEFT 1. The value substituted for J in calling CALC 1 is automatically substituted for JJ in the COEFT 1 call list; thus, J effectively controls debug output from both routines. Normally, a fixed point variable name is substituted for J rather than an actual number. The value of the variable is then read in as data. This arrangement permits debug control by data read-in rather than having to recompile the executive routine.

The executive routine calls CALC 1 once for each of the regions into which the in-reactor assembly has been divided. Before the first calling of CALC 1, all factors involving the weight flow and constants are calculated. T_H at the starting point is either calculated or estimated; corresponding values of T_C , T_I , and T_O are estimated. T_S , Q_I , and Q_O are specified as appropriate for the first region to be calculated. CALC 1 is then called, proceeding inward, for each region in order to the in-reactor end of the assembly. The magnitude of the difference between T_H and T_C at the end of the assembly is checked. If outside ± 1 , the difference is added to T_C at the starting point and the calculation repeated until the difference is within ± 1 . Once this condition is satisfied, the program returns to the starting point and calculates outward to the out-of-reactor end of the assembly (if necessary), calling CALC 1 as required. Appropriate respecifications of T_S , Q_I , and Q_O are made as required between callings of CALC 1.

All data used by the subroutines (except those specified above for the call list) and all calculated results are available to and between subroutines and the executive routine via listing in COMMON. Data which must be supplied to the subroutines (considering the two as a unit, and excluding those supplied to one by the other,) are:

<u>Name</u>	<u>Quantities</u>
TC	Bulk gas temperature, annulus stream, °F Bulk gas temperature, center stream, °F Inner tube wall temperature, °F Outer tube wall temperature, °F
TH	
TI	
TO	
TS	Temperature of surroundings, °F

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<u>Name</u>	<u>Quantities</u>
Z0	Geometry factor times weight flow factor for heat transfer coefficient between outer tube and annulus gas stream.
ZC	Same as Z0, but for transfer between inner tube and annulus stream
Z1	Same as Z0, but for transfer between center stream and inner tube, or for an empty inner tube.
Z2	Same as for Z1, but for inner tube with lead rod installed.
KX	Lower index limit for D0 loop.
KY	Upper index limit for D0 loop
J1	Logic factor specifying direction of iteration.
J	Logic factor controlling debug output.
HSP	Heat transfer coefficient between step plug and outer tube.
HSC	Constant component of coefficient between moderator and outer tube.
HST	Geometry-emissivity factor for radiative component of coefficient between moderator and outer tube.
HIO	Same as HST, but for coefficient between inner and outer tubes.
UL	Weight flow rate times constant in defining equation for temperature-dependent specific heat.
U	Weight flow rate times constant specific heat.
CEX	Exponent (constant) for temperature factor in defining equation for temperature-dependent specific heat.
HXT	Exponent (constant) for temperature factor in forced convection coefficient equation.
QI	Radiation heat generation per foot of inner tube.

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<u>Name</u>	<u>Quantities</u>
QO	Radiation heat generation per foot of outer tube.
L1	Logic factor, directing designation of co-efficient between surroundings and outer tube.
KG	Logic factor, directing computation of heat transport capacity according to the type of gas.

Quantities computed, and which are available to other routines:

<u>Name</u>	<u>Quantities</u>
HO	Heat transfer coefficient between annulus stream and outer tube, per unit length of assembly.
HC	Same as HO, but between inner tube and annulus stream.
HH	Same as HO, but between center stream and inner tube.
HS	Same as HO, but between surroundings and outer tube.
HX	Same as HO, but between inner and outer tube.
QH	Rate of heat transfer between center stream and inner tube.
QC	Rate of heat transfer between surroundings and outer tube.
Q1	Rate of heat transfer between inner tube and annulus stream.
Q2	Rate of heat transfer between outer tube and annulus stream.
Q3	Rate of heat transfer between inner tube and outer tube.
UH	Heat transport capacity, center stream.
UC	Heat transport capacity, annulus stream.
TC TX TI TO	As previously defined, K-indexed array for the entire assembly.

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Name

Quantities

QR

K-indexed values of QH and QC, respectively,
converted to kilowatts.

QS

VIII. OVER-ALL LOOP ANALYSIS

Given the loop flow rate and a gas temperature at any particular point between the preheater outlet and the heat exchanger inlet, plus loop and external condition data, it is possible to calculate the corresponding circulator performance, temperatures and pressure drops all around the loop. The procedure begins at the location of the given temperature. The temperature distribution is calculated proceeding in the direction of gas flow using the analyses given heretofore, and winding up with the circulator performance calculation. Then, with the temperatures known, the pressure drops across the loop can be calculated.

The given flow rate and temperature may be arbitrarily specified, or they may be calculated from other conditions to which they are related and which are arbitrarily specified. For instance, the gas temperatures at the outlet of a test specimen may be calculated, given the test specimen power, geometry, and surface temperature at the outlet end, with the flow rate arbitrarily specified. Given these conditions, the inlet gas temperature can also be calculated, and the calculation around the loop can proceed from there.

Thus, almost any type of condition can be investigated. The most pertinent type of analysis is that centered about a particular test specimen. The loop conditions corresponding to a particular test specimen design at some desired reference power temperature and flow rate can be calculated. Other cases are the maximum power for which the desired reference temperature can be maintained, and the minimum test temperature which can be achieved with the reactor in operation.

Both of these cases occur when no preheat is added to the gas, and the flow rate is the maximum possible. At these conditions, the in-reactor assembly inlet temperature is equal to the circulator outlet temperature, and the maximum circulator pressure rise is just equal to the loop pressure drop. For the maximum circulator pressure rise, the condition of single circulator operation is imposed, because the auxiliary loop has only one circulator. Also, it is desired to avoid a reactor scram when one circulator fails in the primary loop.

The maximum power and minimum temperature cases are calculated using a trial-and-error process. Starting with reference specimen power and maintaining the surface temperature constant at the reference condition, the power is adjusted upward and the temperature distribution recalculated for each adjustment until the condition for no preheat is met. The loop pressure drop is then calculated and compared to the maximum single circulator pressure rise which was computed as part of the temperature distribution calculation. The flow is adjusted upward in accordance with the difference. The change in flow affects the temperature distribution. Thus, it is necessary to repeat that process, again adjusting the power until the condition of no preheat is met. The pressure drop

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is again calculated and again compared with the circulator pressure rise. The whole process continues on until both conditions have been satisfied. The temperatures, pressure drops, circulator performance, and test specimen power at this point are those it was desired to determine.

A very similar procedure is used in the minimum test temperature determination, except that here the power is maintained constant at the reference condition and the surface temperature is adjusted downward.

IX. MACHINE PROGRAMS FOR OVER-ALL ANALYSIS

Such procedures as those described in the preceding sections involve lengthy finite difference solutions with numerous trial-and-error processes. Solution by hand calculation would be costly and impractical. They are, however, particularly suited to machine computation. Over-all machine programs using the subroutines previously described have been developed to do the job.

One such routine, which accomplishes the computation described above for maximum power and minimum temperature cases of a specific test specimen design, is the DR-1 TEST EVAL Executive Routine for helium operation. Two similar routines have been developed for carbon dioxide and nitrogen. Deviations of these from the helium routine are described later. Other executive routines can and have been written, but will not be described here. The program listing for DR-1 TEST EVAL is given in the Appendix.

The executive routine for helium performs four major functions:

1. It provides for data read-in.
2. It performs initialization duties before entry to loops and between loop iterations.
3. It directs the flow of computation.
4. It provides for adjustments in trial-and-error cases as later described.

A. General Program Procedure

Calculations for up to ten separate reference cases may be made. Each case provides for specifications of design or reference test power, maximum surface temperature, flow rate, difference between maximum surface temperature and outlet bulk gas temperature at reference conditions, radiation heating rates for inner and outer tubes, and effective moderator temperatures for the reflector and active zones. Each of these must be specified for each reference case, even where there is no change from case to case.

The variable name assigned to each of the above is indexed by I. Progression through successive reference cases is provided by an I-indexed DO loop. Nested within this loop is a J-indexed DO loop which provides for as many as five distinct calculation treatments of each reference case. The J-indexed cases are listed in order below, with the listed number corresponding to the value of the J-index:

1. Over-all analysis of the loop at reference conditions. The temperature distribution, pressure drop, and circulator performance are calculated at reference conditions. Primary loop operation is assumed. The circulator calculation includes the effects of dual or single compressor operation as directed, and the effects of the flow control valve and loop bypass.
2. Determination of maximum test specimen power for which the reference test specimen temperature is not exceeded. Assumes primary loop operation, with a single circulator being used.
3. Determination of minimum achievable test specimen temperature at reference power. Assumes primary loop operation, with a single compressor being used.
- 4 and 5. Identical to cases 2 and 3, respectively, but assuming auxiliary loop operation.

For the initial J-case, the program first computes the outlet and inlet gas temperatures for the test specimen from reference conditions with appropriate adjustments for the current flow rate, test surface temperature and power. Starting at the inlet end of the test specimen, the assembly temperature distribution is calculated using subroutines COEFT 1 and CALC 1 as previously described. HEX subroutine is called to provide the heat exchanger mean and outlet gas temperatures. COMP is then called to provide the maximum pressure rise and corresponding circulator outlet temperature that would be delivered by a single circulator, for the current loop flow rate and heat exchanger outlet temperature.

The procedure described to this point is that followed in all subsequent references to over-all temperature distribution calculations. For the first J-case, however, COMP is called only to provide an estimate of the circulator outlet temperature for the first calling of PRDP and COMPX. For the first J-case, PRDP and COMPX are called as previously described, up to and including the calling for which the circulator outlet temperature before and after calling agree within ± 2.5 F. When this point is reached, the basic calculations for the first J-case are complete.

In each of the other J-cases, the solutions are complete when there is no preheat being added and the flow rate is the maximum achievable. These correspond, respectively, to the following conditions:

1. The circulator outlet temperature is equal to the in-reactor assembly inlet temperature.
2. The loop pressure drop, including that across the test specimen, is just equal to the maximum pressure rise that can be delivered by a single circulator with no flow through the loop bypass and for the current loop flow rate and heat exchanger outlet temperature.

For each case, the procedure is to recompute the over-all temperature distribution, adjusting the pertinent parameter between computations until the first condition is satisfied. PRDP is then called, the loop pressure drop compared with the current circulator pressure rise

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as computed by COMP, the flow adjusted accordingly, and the whole procedure then repeated until both conditions are satisfied. When this has been achieved, the basic calculations for the particular J-case are complete. The program, as written, accepts temperature differences for the first condition of ± 5 F, and for the second condition, pressure differences of 0.1 psi.

For J-cases 2 and 4, the specimen temperature is held constant at the reference condition and the power is adjusted in accordance with the current difference between the condition temperatures. For J-cases 3 and 5, the specimen power is held constant at the reference condition and the surface temperature adjusted directly according to the current magnitude of the temperature difference between TC(I) and TOC.

After the completion of each J-case, various summaries of the calculated results are made by subroutine SEARCH(briefly discussed later). These include summaries of the indexed transfer rates calculated by CALC 1 and COEFT 1, selection of maximum in-reactor assembly temperatures and locations (value of corresponding K-index), and various summaries of the pressure drops calculated by PRDP. Subroutine OUTPUT (briefly discussed later) is then called to read out calculated results as directed. The method of direction is detailed later. The final action in each J-case is initialization for the next J-case. A diagram illustrating the flow of calculations within the J-indexed DO loop is shown in Figure 9.

B. Initialization

Where parameters may vary from case to case, it is necessary to specify the correct values of the parameters before starting the calculation. This process is known as initialization.

All J-indexed variables must be initialized for each specific J-case before its calculation begins. This includes the current flow rate, test specimen power, and test specimen temperature (W, QTS, and TFE, respectively). For the first J-case, initializing is done just prior to the first entry to the J-indexed loop for the particular I-case. Initialization for each of the other J-cases is accomplished as the last action in the immediately preceding J-cases.

Other initializing includes the calculation of the quantities VXX and FC for the PRDP subroutine before entry to the I loop, calculation of the CALC 1 loop limits from KU (I) and KD (I) before entry to the J-loop, specifications of the parameters T_S , Q_I , and Q_0 , for the CALC 1 and COEFT 1 subroutines, and calculation of T_H and estimates of T_C , T_I , and T_0 for the starting point before the first calling of CALC 1.

Another process related to initialization is used throughout the executive routine and subroutines. There are a number of variables, both indexed and non-indexed, that are subject to respecification or recalculation a number of times in the course of a single J-case calculation, due to the numerous trial-and-error processes. In some of these processes satisfaction of the pertinent condition depends upon agreement between

FIGURE 9
CALCULATION FLOW SHEET FOR J-LOOP
DR-1 TEST EVAL

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the values of a certain variable before and after a particular calculation. To test for satisfaction of the condition, it is necessary to have available the previous value of the variable for comparison with the current value after the respecification. In such cases it is necessary to arrange that the two values are not stored in the same place for, if so, the previous value is lost. This is done by defining a new variable name and equating this name to that usually used for the variable before the respecification.

C. Adjustments

As previously mentioned, there are numerous trial-and-error processes throughout the executive and subroutines. The value of one or more variables is assumed. A generally straightforward calculation is then performed and from the results, a condition quantity is calculated, the value of which determines whether or not the condition of the trial-and-error process is satisfied. Normally, the condition quantity is defined so that: 1) it approaches zero when the condition is satisfied, and 2) it can be used as an adjustment to the assumed parameter if the condition is not satisfied. When the latter is the case, then the assumed parameter is adjusted in accordance with a formula using the condition quantity.

Such a procedure amounts to a series type solution. Care must be taken in the adjustment formulation or the series will diverge. When this occurs, the condition will be farther from, rather than closer to satisfaction on successive trials, and the process either will never be satisfied or will yield a trivial solution.

Most of the trial-and-error processes for these routines use a simple difference between calculated and estimated parameters as the condition quantity; algebraically adding the quantity directly to the estimated variable for the next trial. No divergence problems have been encountered with these. However, for the determination of maximum power (J-cases 2 and 4) the adjusted variable (test specimen power) is not the variable involved in either condition quantity. The relation between the condition quantity and the power is quite complex in each case. Considerable difficulty has been encountered in formulating adjustments that do not diverge. The adjustments, as presently formulated, do work and the user is cautioned against tampering with them.

Because of the difficulties encountered with divergence, the following provisions have been built into the program. A fixed point parameter, J1 (not the same as is used in the CALC 1 subroutine), is defined so that it increases by one on each successive temperature distribution trial. After completion of each trial, the magnitude of J1 is compared with that of JT, the value of which is read in as data. If J1 exceeds JT, the program proceeds without further trials. This prevents the machine from grinding out numerous meaningless trials in case of divergence. A maximum execution time can be specified to avoid endless repetition. However, the minimum time that can be specified is one minute, which is quite long for the machine. On one such occasion, before the limit on the number of trials was built in, the machine calculated approximately five hundred trials. Of these, only the first four or five yielded any useful information on the problem.

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The parameter J1 is set back to zero each time the flow adjustment is made and on each successive J iteration. Thus, the limit for temperature distribution trials is for each flow adjustment trial.

A similar limit is built in for the number of flow adjustments, using the names J2 for the accumulated number of trials and JW for the limit parameter. This limit is for each J-case. Thus, a maximum of JT times JW power adjustment trials is permitted for each J-case.

To provide information on the behavior of successive adjustments, provisions are built in for debugging output. If the parameter JX0 has the value zero, the current values of the adjusted parameter, of J1 or J2, and of the condition quantity are read out before adjustment is made. The value of JX0 is read in as data; when this output is no longer needed, JX0 is set equal to some value other than zero.

D. Data Input

Data input to the program may be divided into three classes as follows:

<u>Class</u>	<u>Format</u>
1. Data concerned with loop and gas property characteristics and certain loop operating conditions.	8E9.3
2. Fixed point data on indexing information and logic factors.	24I3
3. Reference case data.	8F8.1, F8.4

Each class is read in by a separate READ INPUT TAPE statement. The first class is tabulated below, in the order in which it is read in:

<u>Name</u>	<u>Quantity and Remarks</u>
EKO(L)	Sum of expansion - contraction and acceleration coefficients at outlet of pressure drop region L, for L = 1 through 5 and L = 16. In regions L = 6 through 15, it has no significance.
EKI(L)	Same as EKO for inlet to pressure drop regions L = 1 through 5 and L = 16. In regions L = 6 through 15 it represents the sum of the expansion-contraction coefficients at inlet and outlet.
AZ(L)	Flow area for pressure drop region L, except for L = 3. Here it represents the product of:

$$\frac{R}{gA^2 P} \times 2.72 \times 10^{-12} \text{ for the test specimen.}$$

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<u>Name</u>	<u>Quantity and Remarks</u>
DE(L)	Equivalent diameter of pressure drop region L, except for L = 3. For this region DE(L) represents the value of the equivalent length times $\frac{K_F}{2}$ for the test specimen, where K_F is defined by equation (38), Section III. (1)
EL(L)	Equivalent length for pressure drop region L, including that of fittings, except for regions L = 1 through 4. For regions 1, 2, and 4, it represents the equivalent length of a one-foot increment. Fittings for these regions are handled separately. For region 3, it represents the exponent applied to the mean temperature for the friction pressure drop across the test specimen.
<p><u>Note:</u> Data cards 4000 through 4090 carry the above data. They are listed in the order named for region 1, then region 2, etc. There should be no reason for altering these data, excepting region 3 and those regions affected when the loop is modified. Region 3 is devoted to the test specimen.</p>	
EL9	Equivalent length for a 90° square bend.
EL18	Equivalent length for a 180° square bend.
ZZ0	Geometry factor for unit length heat transfer coefficient, outer tube to annulus stream.
ZZC	Same as ZZ0, but for inner tube to annulus stream.
ZZ1	Same as ZZ0, but for center stream to inner tube when the inner tube is empty.
ZZ2	Same as ZZ1, but for inner tube downstream of test specimen with a 3/4 inch OD specimen lead rod.
HX1	Reciprocal of K_h , where K_h is defined by equation (13), Section VI. (1)
HX2	Exponent of temperature for loop heat exchanger gas side coefficient. Equal to d divided by 2, where d is defined by equation (4b), Section III. (1)
HD	First approximation of circulator bypass exchanger modified coefficient, HK.
TSP	Temperature of inlet water, °F.
HSC	Value of constant component of heat transfer coefficient between moderator and outer tube.

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<u>Name</u>	<u>Quantity and Remarks</u>
HSP	Heat transfer coefficient between step plug and outer tube.
D, E	Constants in approximate equation for modified circulator bypass exchanger coefficient, HK. See equation (14) (1) Section IV.
AD,BD,CD	Constants in circulator performance equation (equation (5), Section IV). (1)
CP	Specific heat of gas in non-temperature dependent region.
P	Power input per circulator, BTU/hr.
PI	Inlet pressure to circulators in psia.
PK	Fixed flow resistance constant for circulator bypass. Same as K_{PA} in equation (11), Section IV. (1)
WW	Water flow rate to first pass of loop heat exchanger, gpm.
HIO	Emissivity-geometry constant for inner to outer tube radiative coefficient. Analogous to K_r as defined by equation (11), Section III. (1)
HXT	Exponent applied to temperature for gas heat transfer coefficient. Equivalent to d, as defined by equation (4b), Section III. (1)
CEX	Exponent applied to temperature for temperature-dependent specific heat. Equivalent to a_x for specific heat, equation (2), Section III. (1)
XSC1	Geometry-temperature factor (latter evaluated at 100F) for gas side coefficient of loop bypass exchanger.
XSC2	Geometry factor for water side coefficient, loop bypass exchanger.
XQ2	Water flow rate to loop bypass exchanger.
XHC1	Fixed flow resistance constant for full open loop port of flow control valve, times 2500. Equivalent to K_{VL} , equation (9), Section IV. (1)
XHC2	Same as XHC1, but for diverting port. Equivalent to K_{VLP} , equation (10), Section IV. (1)
XQ1	Fixed flow resistance constant, loop bypass. Equivalent to K_{LP} , equation (12), Section IV. (1)

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Excepting AZ(L), DE(L), ZZ1, and ZZ2, all of the above data are listed in COMMON in the DR-1 TEST EVAL executive routine, and are available to all subroutines without further action. Proper values of all data listed above, excluding CEX and CCP, must be included. CEX and CCP, concerned with calculating temperature-dependent specific heat, are not used in this executive routine. Spaces must be allowed for both, however, to avoid incorrect storage of the data following them. Zero must be read in as the value of EKO(L) for L = 6 through 15.

The non-indexed data above are located on cards 4110 through 4126, following cards 4000 through 4090. Normally, only WK should have to be changed, unless some portion of the loop is modified.

The second class of data (fixed point) includes:

<u>Name</u>	<u>Quantity</u>
II	Number of reference cases to be calculated. Must be specified to set upper limit on I-indexed loop. Any value from 1 to 10, inclusive.
JX	Number of J-indexed cases to be calculated. Sets limit on J-indexed loop. Any value from 1 to 5 inclusive.
JJ	Logic factor. When JJ equals zero or less, all J-indexed cases up to and including JX will be calculated. When JJ equals one or greater, only cases J = 1 and J = 5 are calculated, unless JX is less than five, in which event only the case for J = 1 is calculated.
JX1-6	Logic factors controlling output from CALC1 - COEFT 1 sub-routines. Each of the six factors correspond to one calling of CALC 1. They are used in order of calling, that is, for upstream of specimen, at specimen, downstream of specimen, reflector, step plug, and out-of-reactor regions.
JJ,JK,JL	Logic factors controlling three classes of output from sub-routine OUTPUT. They refer, respectively, to the array of K-indexed results from the tube temperature distribution calculation; the array of pressure drop, L-indexed, and to selected over-all results of each J-case. All are discussed later.
JX0	Logic factor controlling output concerning the behavior of adjustments in the J-case trial-and-error procedure.
JXC	Logic factor controlling output from COMFX subroutine.
JM	Logic factor controlling which of three alternatives are used for JL controlled output. The choice depends upon the gas for which the calculation is conducted. Assign values as for KG, with which it is interchangeable.

<u>Name</u>	<u>Quantity</u>
KG	Logic factor used for those portions of the program (sub-routines included) where the type of gas used makes a difference. Use minus 1 for nitrogen, zero for carbon dioxide, and plus 1 for helium.
JT,JW	Logic factors setting limits on the number of trials for each sequence of the temperature balancing and flow adjustment portions, respectively, of J-indexed cases. Any value from plus one up, as desired.
JPS	Logic factor directing COMFX to compute for single or dual circulator operation. Use one for single, zero for dual operation.

For any of the logic factors controlling output, use zero if the particular output is desired, and one if it is not desired. Normally JX1-6, JX0 and JXC are used only to obtain debug information. For a debugged program, these will normally be set at one. All of these data are contained on the first 5000 series data cards.

The reference case data, indexed by I, include:

<u>Name</u>	<u>Quantity</u>
KD(I)	K-index most closely corresponding to the downstream end of the specimen.
KU(I)	K-index most closely corresponding to the upstream end of the specimen.

Note: The quantity KU(I) minus KD(I) corresponds to the length of the specimen rounded off to the nearest foot. Because most specimens are quite short, the rounding off error relative to the actual specimen length is appreciable. However, the error would affect only the specimen pressure drop, for which the actual length is used.

<u>Name</u>	<u>Quantity</u>
QTSR(I)	Reference test specimen power, KW.
DTR(I)	Difference between test specimen surface and outlet bulk gas temperatures at the outlet end of the test specimen (°F). Valid only at reference power and flow rate.
QIR(I)	Rate of radiation heating per foot of inner tube-BTU/hr.
QOR(I)	Same as QIR(I), but for outer tube.
TLS(I)	Moderator temperature, reflector region.

<u>Name</u>	<u>Quantity</u>
TFER(I)	Reference specimen surface temperature, outlet end.
T2S(I)	Moderator temperature, active region.
HGT(I)	Geometry-emissivity factor, for calculation of radiation component of moderator to outer tube coefficient. Anologous to K_r as defined by equation (11), Section III.

TLS(I), T2S(I), QOR(I), QIR(I), and HGT(I) are not concerned with the test specimen. However, they are parameters occasionally subject to change, and it has been convenient to include them as I-indexed variables. It is pointed out that no I-indexed variables are included for test specimen pressure drop characteristics. These are read in under the L-indexed EKI, EKO, AZ, DE and EL for $L = 3$, and as the non-dimensioned WK. Thus, only one test specimen at a time may be investigated from the aspect of pressure drop characteristics.

The values of KU(I) and KD(I) are read in with the second class of data on 5000 series data cards because they are fixed point numbers. All of the non-indexed fixed point data are read in, then the KU(I) and KD(I) data. The balance of the I-indexed data are contained on 6000 series data cards, following the 5000 series cards. Each 6000 series card contains data for a single I-case.

As a general rule, incorrect results or program execution difficulties are due most likely to incorrect or misarranged data. A few extra minutes spent double-checking the data may save many wasted dollars of machine time charges. The following is a check list of items on the data:

1. Always be sure that one but no more than one DATA control card immediately precedes the data cards.
2. Be sure that all 4000 series cards are present, and in the correct order.
3. Be sure that at least as many sets of KU(I) and KD(I) data, and at least as many 6000 series cards are included as the value specified for II. More may be included, provided this does not result in more 5000 series cards than corresponds to the value of II. The extra data are simply ignored.
4. If the values of KD(I) and KU(I) change from case to case, be sure that they are arranged in the same order as the corresponding 6000 series cards. Otherwise, the arrangement of the 6000 series cards is of no importance to the correctness of results.
5. However, some thought should be given to the arrangement of the I-indexed data so that results appear in a logical order.
6. Always doublecheck new or corrected cards to be certain that they are correct.
7. Last but not least, be sure that the data is arranged in strict agreement with the READ INPUT TAPE statements.

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E. Output

Immediately following the statements that accomplish the read-in of data, at the first of the program, all of the first class of data is read out under appropriate headings. This array will appear as the first output and only once for each execution run. None of the fixed point data, including KU(I) and KD(I) are read out.

Following the above data output, the I-indexed data for I = 1 appears. The READ OUTPUT TAPE statement for this output is located after entry to the I-DO loop, but before entry to the J-DO loop. After the I-indexed data the debug and results output for each successive J-case will appear. When this is complete, the output for other I-cases will appear in order.

The read-out of results for each J-case is accomplished within subroutine OUTPUT, for which the program listing appears in the Appendix. The results output consists of three optional arrays.

The first of these is the K-indexed array of TC, TH, TI, and TO, QR, and QS, calculated for the in-reactor tube assembly. The value of each set preceded by its K-index appears on successive lines following the heading for the array.

The second array is that of the pressure drops, DP, calculated for the 16 regions into which the loop has been divided. This appears as two double lines of output. The upper line of each pair is preceded by the letter L, and the lower line of each by the letters DP. The upper line of numbers are the values of the L-index corresponding to pressure drops in the lower line.

The third array consists of four lines of miscellaneous, selected results giving an over-all picture of loop operation for the particular J-case. Each line is preceded by an appropriate heading to identify the results. The array read-out is tabulated below:

<u>Name</u>	<u>Quantity</u>
First Line:	
QTS	Test specimen power.
QIP	Net rate of energy carry-off from in-reactor assembly.
QRT	Net rate of heat transfer from center stream to inner tube, for the entire in-reactor assembly.
QSK	Net rate of heat exchange with moderator for the entire in-reactor assembly.
QSP	Net rate of heat exchange between the outer tube and the step plug.
QST	Over-all exchange with surroundings (QSK plus QSP) for the entire in-reactor assembly.

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<u>Name</u>	<u>Quantity</u>
W	Loop flow rate.
WBA	Circulator flow rate.
WPA	Circulator bypass flow rate.
Second Line:	
TXI-TX25	Temperatures of the in-reactor assembly gas streams. Annulus stream temperatures are on upper row, center stream temperatures on lower row. The number indicates the K-index of the temperatures. One corresponds to the out-of-reactor end of the assembly, seven to the in-reactor end of the step plug, K1 and K2 to downstream and upstream ends of the test specimen, and 25 to the in-reactor end of assembly.
TCM	Upper number is the maximum annulus stream temperature, lower number the K-index associated with it (approximate location).
THM	Same as TCM for center stream temperature.
TIM	Same as for TCM for inner tube wall temperature.
TOM	Same as TCM for outer tube wall temperature.
Third Line:	
TFE	Surface temperature of test specimen at outlet end.
TL	Outlet gas temperature from loop heat exchanger.
TB	Circulator inlet temperature.
TBP	Circulator bypass outlet temperature.
TOC	Circulator outlet temperature.
Fourth Line:	
DPA	Pressure rise across the circulator.
DPT	Total loop pressure drop, excluding flow valve but including test specimen.
DPL	Total loop pressure drop (DPT) minus test specimen pressure drop (DPF). DPL is the pressure drop across the loop proper.
DPF	Test specimen pressure drop.
DPV	Permanent flow meter pressure drop.
DPFL	Particulate filter pressure drop.

SECRET

<u>Name</u>	<u>Quantity</u>
DPIT	Pressure drop across the in-reactor assembly, excluding the test specimen.
DPTS	Pressure drop across in-reactor assembly including the test specimen but excluding the pressure drop from the test specimen on out. (Region 4). Same as is measured for test specimen by loop instrumentation.

All temperatures are in °F, flows in lbs/hr, pressure drops in psi, and powers in KW.

Negative values of QIP, QSK, QSP, and QST, indicate net losses with respect to the in-reactor assembly. A negative value of QRT indicates that the net transfer is to, rather than from, the center gas stream and QSK, QSP, and QST, are obtained by appropriate summations of QS(K), QRT, by summation of QR(K). DPL is obtained by subtracting DP(3) from DPT. DPIT, DPTT, and DPTS are obtained by appropriate summations of DP(1), DP(2), DP(3), and DP(4). QIP is calculated by algebraically adding QST, QTS, and the product of 16 times the sum of QIR(I) and QOR(I). The latter quantity is the estimated radiation heating of the entire in-reactor assembly.

All of these summation operations are carried out in subroutine SEARCH, for which the program listing appears in the Appendix.

The output described above for one J-case is shown for a typical instance in Figure 10. Subroutine OUTPUT formats have been constructed so that results fit on an 8-1/2 inch by 11 inch sheet, permitting them to be reproduced directly from the machine listing.

F. NITROGEN AND CARBON DIOXIDE EXECUTIVE ROUTINES

Both of these executive routines are very similar to the DR-1 TEST EVAL routine for helium. The program for the latter was used to formulate these two, making changes only where necessary. In fact, when the helium routine was developed, it was generalized where possible to minimize changes for the nitrogen and carbon dioxide routines. As a result, all three differ principally in detail and each contains features that would not be included otherwise.

The most basic difference between the nitrogen and carbon dioxide routines and the helium routine is that the latter is oriented toward specific test specimens of known details. The former two are more oriented toward general parametric studies of over-all loop operation.

Nitrogen Routine

This routine is named DR-1 NIT EVAL. It differs from the helium routine as follows:

1. Only power and outlet gas temperature plus KU(I) and KD(I) data on length and position are included as test specimen data.

FIGURE 10

TYPICAL RESULTS OUTPUT

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RESULTS FOR I # 6, J # 1

K	TC	TH	TI	TO	QR	QS
1	796.8	1036.2	917.4	815.2	1.558	-0.
2	807.1	1046.5	927.7	825.5	1.802	-2.280
3	803.9	1058.5	921.2	696.8	1.888	-2.276
4	801.4	1071.1	927.3	695.8	2.001	-2.275
5	799.6	1084.5	932.2	695.3	2.088	-2.275
6	798.5	1098.4	939.7	695.6	2.204	-2.277
7	797.9	1113.1	945.8	696.1	2.316	-2.379
8	797.5	1128.5	952.9	691.6	2.418	-2.388
9	797.8	1144.6	961.4	693.6	1.932	-0.867
10	819.3	1157.5	1011.3	897.4	1.893	-0.941
11	840.1	1170.1	1027.0	914.1	1.856	-1.011
12	860.2	1182.5	1042.2	930.3	1.822	-1.080
13	879.5	1194.6	1057.1	945.9	1.790	-1.147
14	898.3	1206.5	1071.5	961.1	1.761	-1.211
15	916.4	1218.3	1085.6	975.7	1.734	-1.274
16	933.9	1229.8	1099.3	990.0	1.709	-1.334
17	950.8	1241.2	1112.6	1003.8	1.686	-1.393
18	967.3	1252.4	1125.7	1017.1	1.666	-1.450
19	983.2	1263.5	1138.4	1030.1	1.648	-1.506
20	998.6	1274.5	1150.8	1042.8	1.633	-1.561
21	1013.6	1285.4	1162.8	1055.4	-0.	-1.476
22	1018.1	1032.2	1054.6	1036.1	0.	0.
23	1021.8	1031.2	1046.6	1038.2	-0.148	-1.470
24	1025.3	1030.0	1048.2	1040.9	-0.173	-1.486
25	1028.6	1028.7	1051.5	1044.2	-0.204	-1.498

REGIONAL PRESSURE DROPS

L	1	2	3	4	5	6	7	8
DP	0.185	0.118	2.229	0.182	0.159	0.130	0.138	0.
L	9	10	11	12	13	14	15	16
DP	0.032	0.	0.055	0.	0.141	0.	0.002	0.009

QTS	QIP	QRT	QSK	QSP	QST	W	WBA	WPA
38.00	36.14	36.88	-25.47	-11.38	-36.85	410.0	729.9	231.8

TX1	TX7	TXK1	TXK2	TX25	TCM	THM	TIM	TOM
796.8	797.9	1013.6	1018.1	1028.6	1028.6	1285.4	1162.8	1055.4
1036.2	1113.1	1285.4	1032.2	1028.7	25	21	21	21

TFE	TL	TB	TBP	TOC
1650.0	194.2	152.4	103.7	168.9

DPA	DPT	DPL	DPF	DPV	DPFL	DPIT	DPTT	DPTS
5.822	3.840	1.611	2.229	0.136	0.324	0.485	2.714	2.532

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2. As described in Section VII, the test specimen pressure drop at reference conditions is assumed to be the difference between maximum single circulator pressure rise and the loop pressure drop (DPL) for the reference case. Thus COMPX is never used with the nitrogen routine.
3. For J-cases, two through five, the specimen outlet gas temperature is used in place of the specimen outlet surface temperature.
4. The temperature dependence of the specific heat for nitrogen at higher temperatures, and the use of gas rather than surface temperature for the test specimen thermal parameter results in some differences in calculating the value of TH at the starting point of the temperature distribution calculation.
5. VXX(L) and FC(L) are calculated by hand and read in as data under the names AZ(L) and DE(L), respectively. After data read-in, they are transferred to the correct names, VXX(L) and FC(L).

Apart from these points, the nitrogen routine is identical to the helium routine. Many of the data have different magnitudes, of course.

Carbon Dioxide Routine

This executive routine is named DR-1 CARBON DIOXIDE EVAL. It differs from the helium routine more than does the nitrogen routine. The differences are:

1. The same test specimen data are read in as for nitrogen.
2. Because the present circulators are not adaptable to carbon dioxide operation, it is not possible to calculate circulator performance. Thus, COMP and COMPX are never used. Also, for this reason, it is not possible to calculate a maximum flow rate, and so the flow rate is always maintained constant. There is no basis upon which to calculate or estimate a test specimen pressure drop.
3. Because of the restrictions imposed by (2), the program is limited to calculations for J-cases one and five, at the most.
4. The same values of VXX(L) are read-in as for nitrogen, again under the name of AZ(L). After read in, the values are transferred to the correct name, VXX(L).
5. Mean, constant friction factors are used for all L-indexed pressure drop regions except for regions 5 and 16. The mean factor divided by two is read in as data under the name DE(L), excluding the above two regions. For these two regions, the data read-in under DE(L) has the same significance as for nitrogen. After read-in, all DE(L) values are transferred to the name FC(L).

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6. Because of the assumption of constant friction factors, the entrance-exit and friction pressure drops do not receive different flow or temperature treatment in the iso-thermal regions. Thus, for pressure drop regions 6 through 15, the sum of $EKI(L)$ plus $FC(L)$ times $EL(L)$, quantity times $VXX(L)$, is calculated in the executive routine and stored in COMMON under the name $VXX(L)$. Also, the sum of EL 18 plus $EL(1)$ and of $EL9$ plus $EL(2)$ is calculated and stored in COMMON under the names $EKO(3)$ and $EKI(3)$. The L-indexed names for $L = 3$ are not used otherwise.

Again, most data for carbon dioxide have different magnitudes from the other two routines. None of the names associated with circulator calculations are used in this routine; however, spaces for them on the data cards must be maintained since they are listed in the pertinent READ INPUT TAPE statements.

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Irradiation Testing

RE Baars:bmr

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REFERENCES:

1. Baars, RE, DR-1 Gas Loop Thermal and Fluid Flow Analyses,
HW-69882, June 16, 1961
2. Muroaka, J., Graphite Temperature - KAPL-120 Loop, HW-49566,
April 5, 1957
3. Baars, RE, Stack To Tube Interchange For The DR Gas Loop,
HW-60784, June 18, 1959.

APPENDIX A: PROGRAM LISTING FOR DR-1 TEST EVAL EXECUTIVE ROUTINE

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DIMENSION TC(26), TH(26), TI(26), TO(26), QR(26), QS(26), QIR(10), 50
XQOR(10), TFER(10), QTSR(10), DTR(10), T1S(10), T2S(10), WR(10), 51
XHGT(10), EKI(16), EKO(16), AZ(16), DE(16), EL(16), DP(16), VXX(16) 52
X, FC(16), W(10), TH3(10), TFE(10), QTS(10), KD(10), KU(10) 53
COMMON HSP, HST, ZO, ZC, HIO, TS, QI, QO, U, HO, HH, HC, HS, HX, 60
XXSC1, XSC2, XHC1, XHC2, XQ1, XQ2, HSC, TC, TH, TI, TO, QR, QS, 61
XVXX, FC, EL, EKI, EKO, TLM, W, TFE, QTS, DP, DPA, DPL, DPT, DPFL, 62
XDPV, WBA, WPA, TB, TBP, TOC, TL, DPTT, DPTS, DPIT, TOM, TIM, TCM, 63
XTHM, KC, KH, KI, KO, QSK, QIP, QSP, QST, QRT, K2, K1, EL9, EL18, 64
XV2, UW, TSP, PK, D, E, AD, BD, CD, P, PI, CP, HD, TOR, TLR, HX1, HX2 65
X, U1, UH, UC, CEX, CCP, WK, KG, Q1, Q2, Q3, QC, QH, HXT 66
1 FORMAT (8E9.3) 170
2 FORMAT (24I3) 180
3 FORMAT (8F8.1, F8.4) 190
4 FORMAT (87H 200
X AZ DE EL) EKI EKO
5 FORMAT (26H ,5E13.4) 201
6 FORMAT (26H ,5E13.4/ ///) 205
7 FORMAT (107H EL9 EL18 ZZO ZCC ZZ1 ZZ2 210
X HX1 HX2 HD TSP HSC HSP D E/F14.1, F6.1, 211
X6F8.4, F7.1, F6.1, F6.2, F7.2, F7.1, F8.4/ /110H AD 212
X BD CD CP P PI PK WW HIO 213
X WK HXT /8H ,3E12.4, F6.2, F9.1, F7.1, E12.4, F6.1, 214
X3F8.4/110H CEX CCP XSC1 XSC2 XQ2 XHC1 215
X XHC2 XQ1 /10H 216
X ,5F8.4, 3E11.3/ ///) 217
8 FORMAT (98H I QIR QOR TFER Q 220
XTSR DTR T1S T2S WR HGT/21H 221
X ,I2, 3F9.1, 5F8.1, F9.4/ ///) 222
352 FORMAT (45H J1 =13,8H, QT 223
XS =F7.2, 9H, TST2 =F6.1) 224
353 FORMAT (47H J2 =13,6H, 225
XW =F6.1, 9H, TST3 =F6.3) 226
READ INPUT TAPE 2,1,(EKI(L), EKO(L), AZ(L), DE(L), EL(L), L=1,16), 280
XEL9, EL18, ZZO, ZCC, ZZ1, ZZ2, HX1, HX2, HD, TSP, HSC, HSP, D, E, 281
XAD, BD, CD, CP, P, PI, PK, WW, HIO, WK, HXT, CEX, CCP, XSC1, XSC2, 282
XXQ2, XHC1, XHC2, XQ1 283
READ INPUT TAPE 2, 2, II, JX, JJ, JX1, JX2, JX3, JX4, JX5, JX6, JI, 290
XJK, JL, JM, KG, JX0, JT, JW, JXC, JPS, 291
X (KD(I), KU(I), I = 1, II) 292
READ INPUT TAPE 2,3, (QTSR(I), DTR(I), QIR(I), QOR(I), T1S(I), 300
XTFER(I), WR(I), T2S(I), HGT(I), I = 1, II) 301
WRITE OUTPUT TAPE 3, 4 310
WRITE OUTPUT TAPE 3,5,(EKI(L), EKO(L), AZ(L), DE(L), EL(L), L=1,15) 311
WRITE OUTPUT TAPE 3,6,(EKI(L), EKO(L), AZ(L), DE(L), EL(L), L=16,16) 312
WRITE OUTPUT TAPE 3, 7, 313

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APPENDIX A: PROGRAM LISTING FOR DR-1 TEST EVAL EXECUTIVE ROUTINE (continued)

XEL9,EL18, ZZO, ZZC, ZZ1, ZZ2, HX1,HX2,HD, TSP, HSC, HSP, D, E,	314
XAD,BD, CD, CP, P, PI, PK,WW ,HIO, WK , HXT, CEX, CCP, XSC1, XSC2,	9315
XXQ2, XHC1, XHC2, XQ1	X315
DO 15 L = 1,16	315
IF (L-3)12,92,12	320
92 VXX(L) = AZ(L)	325
FC(L) = DE(L)	326
GO TO 15	327
12 VXX(L) = 2.08E-13/AZ(L)**2	330
IF (L - 5)14,13,93	340
93 IF (L-16)14,13,15	345
13 FC(L) = 0.755*(6.814E-04*AZ(L)/DE(L))**0.43	350
GO TO 15	360
14 FC(L) = 0.1*(6.814E-04*AZ(L)/DE(L))**0.2	370
15 CONTINUE	380
V2= WW**0.8	390
UW = WW*501.0	400
DO 51 I = 1,I1	410
QTS(1) = QTSR(I)	420
W(1) = WR(I)	430
TFE(1)= TFER(I)	440
WRITE OUTPUT TAPE 3,8, I, QIR(I), QOR(I), TFER(I), QTSR(I), DTR(I)	450
X, T1S(I), T2S(I), WR(I), HGT(I)	451
QO = QOR(I)	460
QI = QIR(I)	470
TS = T2S(I)	480
HST = HGT(I)	490
K1 = KD(I)	520
K2 = KU(I)	530
K3 = K2 + 1	540
M2 = K2 - K1 + 1	550
M3 = M2 + 1	560
M4 = K2 - 8	570
M5 = M4 + 1	580
KX3 = K2 - 1	590
M6 = M5 + 1	600
M7 = M6 + 1	610
A1 = 25 - K2	620
DO 51 J = 1,JX	630
J2 = 0	630
IF (JJ -1)103,101,101	640
101 IF (J - 1)103,103,102	650
102 IF (J - 5)51,103,103	660
103 U = W(J)*CP	670
V = W(J)**0.8	690
ZO = ZZO*V	720
ZC = ZZC*V	730

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APPENDIX A: PROGRAM LISTING FOR DR-1 TEST EVAL EXECUTIVE ROUTINE (continued)

DECLASSIFIED

Z1 = ZZ1*V	740
Z2 = ZZ2*V	750
J1 = 0	671
104 TH3(J) = TFE(J) - DTR(I)*(QTS(J)/QTSR(I))*(WR(I)/W(J))**.8	760
TH(K2) = TH3(J) - QTS(J)*3415.0/U	780
TI(K2) = TH(K2)	790
TC(K2) = TH(K2) - A1*(QI +QO)/U	800
TO(K2) = TC(K2)	810
105 CALL CALC1 (Z1, 1, JX1, K3, 25, 1)	830
TST = TH(25) - TC(25)	1190
IF (TST - 1.0)111,113,112	1200
111 IF (TST + 1.0)112,113,113	1210
112 TC(K2) = TC(K2) + TST	1220
GO TO 105	1230
113 CALL CALC1 (0.0,1, JX2, 2, M2, 0)	1250
TH(K1) = TH3(J)	1260
CALL CALC1 (Z2, 1, JX3, M3, M4, 0)	1280
QO = 0.0	1290
QI = 0.0	1300
TS = T1S(I)	1310
CALL CALC1 (Z2, 1, JX4, M5, M6, 0)	1330
TS = TSP	1340
CALL CALC1 (Z2, 0, JX5, M7, KX3, 0)	1360
CALL CALC1 (Z2,-1, JX6, K2, K2, 0)	1380
TS = T2S(I)	1390
QO = QOR(I)	1400
QI = QIR(I)	1410
CALL HEX(J)	1420
CALL COMP(J)	1430
IF (J -1)27,17,27	2770
17 CALL PRDP(J)	2780
TCO = TOC	2782
CALL COMPX(J, JXC, JPS)	2784
IF (TOC - TCO - 2.5)80,81,17	2786
80 IF (TOC - TCO + 2.5)17,81,81	2788
81 CALL SEARCH(J)	2790
CALL OUTPUT(JI, JK, JL, JM, J, I)	2800
IF (JJ -1)18,16,16	2810
16 TFE(5) = TFE(J) + TOC -TC(1)	2830
W(5) = W(J)*(DPA /DPT)**0.5	2840
QTS(5) = QTS(1)	2845
GO TO 51	2850
18 UX1 = 3415.0/U	2880
DQTS = (TC(1) - TOC + UX1*QST)/(DTR(I)/QTS(J) + 2.0*UX1)	2890
QTS(2) = QTS(1) + DQTS	2895
W(2) = W(1)	2900
TFE(2) = TFE(1)	2910

APPENDIX A: PROGRAM LISTING FOR DR-1 EVAL EXECUTIVE ROUTINE (continued)

DECLASSIFIED

TFE(3) = TFE(1) - TC(1) + TOC	2915
GO TO 51	2915
27 TST2= TC(1) - TOC	2920
J1 = J1 + 1	2120
IF (JX0)21,10,21	2915
10 WRITE OUTPUT TAPE 3, 352, J1 ,QTS(J), TST2	X2122
21 IF (J1 - JT) 20,20,201	2920
20 IF (TST2- 5.0)56,201,22	2920
56 IF(TST2+ 5.0)22,201,201	2930
22 IF(J -2)25,25,24	2940
24 IF(J -4)26,25,26	2950
25 DRT = TFE(J) - TH(K1)	2960
UX1 = 3415.0/U	2962
DQTS = (TC(1) - TOC	2964
QTS(J) = QTS(J) + DQTS/2.0	2965
GO TO 104	2970
26 TFE(J) = TFE(J) - TST2	2980
GO TO 104	2990
201 CALL PRDP(J)	2995
TST3 = DPA-DPT	3000
J2 = J2 +1	2800
IF (JX0)11,9,11	
9 WRITE OUTPUT TAPE 3, 353, J2 ,W(J), TST3	X2801
11 IF (J2 -JW)40,40,33	
40 IF (TST3)31,33,28	3010
28 IF (TST3- 0.1)33,33,31	3020
31 UD1 = U/3415.0	3030
WX1 = W(J)	3040
W(J) = W(J)*(DPA/DPT)**0.5	3050
IF(J-3)32,103,34	
34 IF(J-5)32,103,32	
32 DRT = TFE(J)-TH(K1)	3060
WX2 = W(J)	3071
UD2 = WX2*CP/3415.0	3072
FA =(WX1/WX2)**0.8	3073
QTS(J) = QTS(J)*(2.0*QTS(J) +(TFE(J) - TOC)*(UD2-UD1) + DRT*UD1)/	3076

APPENDIX A: PROGRAM LISTING FOR DR-1 TEST EVAL EXECUTIVE ROUTINE (continued)

X(2.0*QTS(J) + DRT*UD2*FA)
GO TO 103
33 CALL SEARCH(J)
CALL OUTPUT(JI, JK, JL, JM, J, I)
IF (J - 3) 90,91,91
90 W(3) = W(2)
QTS(3) = QTS(1)
GO TO 51
91 W (J + 1) = W (J - 1)
QTS(J+1) = QTS(J-1)
TFE(J+1) = TFE(J-1)
51 CONTINUE
CALL EXIT
END

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3077
3080
3090
2800
3105
3130
3120
3140
3150
3160
3170
3800
3810
3820

APPENDIX B: PROGRAM LISTING FOR CALC 1 SUBROUTINE

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SUBROUTINE CALC1 %G, L1, J, KX, KY, J1+	C10
DIMENSION TC%26+, TH%26+, TI%26+, TO%26+, QR%26+, QS%26+	C20
X ,VXX%16+, FC%16+,EKI%16+,EKO%16+,EL%16+,DP%16+,W%10+,QTS%10+,	C21
XTFE%10+	C22
COMMON HSP, HST, ZO, ZC, HIO, TS, QI, QO, U, HO, HH, HC, HS, HX,	60
XXSC1, XSC2, XHC1, XHC2, XQ1, XQ2, HSC, TC, TH, TI, TO, QR, QS,	61
XVXX,FC,EL,EKI,EKO,TLM , W, TFE, QTS, DP, DPA,DPL,DPT, DPFL,	62
XDPV, WBA, WPA, TB, TBP, TOC, TL, DPTT, DPTS, DPIT, TOM, TIM, TCM,	63
XTHM, KC, KH, KI, KO, QSK, QIP, QSP, QST, QRT, K2, K1,EL9,EL18,	64
XV2,UW, TSP, PK, D, E, AD, BD, CD, P, PI, CP, HD,TOR,TLR,HX1,HX2	65
X,U1, UH, UC, CEX, CCP, WK, KG, Q1, Q2, Q3, QC, QH, HXT	66
3 FORMAT %72H K TC TH TI TO	
X QR QS/	
XI15, 4F8.1, 11H ,2F9.2+	
4 FORMATT %47H CALC1 INPUT-OUTPUT, KX #I3,6H K	C60
XY #I3//+	C61
IF %J+12, 11, 12	C68
11 WRITE OUTPUT TAPE 3, 4, KX, KY	C69
12 DO 1 MM # KX,KY	C70
IF %J1+5,6,5	C71
5 K # MM	C72
M # K - 1	C80
CALL COEFT1%G, L1, J, M+	C90
8 TC%K+ # TC%M+ & %Q1 &Q2+/UC	C130
TH%K+ # TH%M+ & %QH+/UH	C140
GO TO 10	C141
6 K # K2 - MM &1	C82
M # K & 1	C83
CALL COEFT1%G, L1, J, M+	C90
9 TC%K+ # TC%M+ - %Q1 &Q2+/UH	C142
TH%K+ # TH%M+ - %QH+/UH	C143
10 TI%K+ # TC%K+ & Q1/HC	C150
TO%K+#TC%K+ & Q2/HO	C160
QR%K+ # QH/3415.0	170
QS%K+ # QC/3415.0	C180
IF %J+ 1,2,1	C190
2 WRITE OUTPUT TAPE 3,3, K, TC%K+, TH%K+, TI%K+, TO%K+, QR%K+, QS%K+	
1 CONTINUE	C220
RETURN	C230
END%0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0+	

APPENDIX C: PROGRAM LISTING FOR COEFT 1 SUBROUTINE

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SUBROUTINE COEFT1(G, L1, JJ, M)
  DIMENSION TC(26), TH(26), TI(26), TO(26), QR(26), QS(26)
  X ,VXX(16), FC(16),EKI(16),EKO(16),EL(16),DP(16),W(10),QTS(10),
  XTFE(10)
  COMMON HSP, HST, ZO, ZC, HIO, TS, QI, QO, U, HO, HH, HC, HS, HX,
  XXSC1, XSC2, XHC1, XHC2, XQ1, XQ2, HSC, TC, TH, TI, TO, QR, QS,
  XVXX,FC,EL,EKI,EKO,TLM , W, TFE, QTS, DP, DPA,DPL,DPT, DPFL,
  XDPV, WBA, WPA, TB, TBP, TOC, TL, DPTT, DPTS, DPIT, TOM, TIM, TCM,
  XTHM, KC, KH, KI, KO, QSK, QIP, QSP, QST, QRT, K2, K1,EL9,EL18,
  XV2,UW, TSP, PK, D, E, AD, BD, CD, P, PI, CP, HD,TOR,TLR,HX1,HX2
  X,U1, UH, UC, CEX, CCP, WK, KG, Q1, Q2, Q3, QC, QH, HXT
  TEMF(R) = (R +460.0)**HXT
  CPPF(A) = (A + 460.0)**CEX
  HTSF(R,H,P,S)= R*((H+ 460.0)**2 + (P+ 460.0)**2)*(H + P + 920.0)/
  X1.0E08 + S
4 FORMAT(104H          M      TS      TC      TH      TI      TO      ZO
  X   ZC      G      HSP      HSC      HIO      HST      HXT/
  X17, 5F8.1, 5F7.2, 3F8.4/
  X          108H          HO      HC      HH      HX      HS      QR
  X          QS      Q3      Q1      Q2      QI      QO/
  X          9H          ,5F8.2, 7F9.1/)
29 FORMAT (37H          TI(M) =F7.1,9H,  TST1 =F6
  X.1,10H,  TO(M) =F7.1,9H,  TST2 =F6.1//)
  HO = ZO*TEMF(TC(M))
  HC = HO*ZC/ZO
  HH = G*TEMF(TH(M))
  IF (L1)7,1,2
1 HS = HSP
  GO TO 3
7 HS = 0.0
  GO TO 3
2 HS = HTSF(HST, TS, TO(M), HSC)
3 HX = HTSF(HIO, TI(M), TO(M), 0.0)
  QH = HH*(TH(M) - TI(M))
  QC = HS*(TS - TO(M))
  Q1 = HC*(TI(M) - TC(M))
  Q2 =HO*(TO(M) - TC(M))
  Q3 = HX*(TI(M)-TO(M))
  TST1 = (QH + QI - Q1 - Q3)/(2.0*HC)
  TST2 = (QC + QO +Q3 -Q2)/(HO*2.0)
  IF (TST1 -1.0)15,18,22
15 IF (TST1 +1.0)22,18,18
18 IF (TST2 - 1.0)21, 8,22
21 IF (TST2 + 1.0)22, 8 , 8
22 IF (JJ) 25,24,25
24 WRITE OUTPUT TAPE 3, 29, TI(M), TST1, TO(M), TST2
25 TO(M) = TO(M) + TST2
19 TI(M) = TI(M) + TST1

```

A10

B20

A21

A22

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A50

A51

A61

A62

A63

A64

A65

A66

A67

A70

A80

A90

A100

A110

A120

A125

A126

A130

A140

A93

A145

A92

A135

C120

A95

A150

A96

A97

A155

A160

A165

A99

A171

A1100

APPENDIX C: PROGRAM LISTING FOR COEFT 1 SUBROUTINE (continued)

DECLASSIFIED

GO TO 3	
8 IF (KG) 30,9,10	
30 IF (TC(M) - 440.0) 11,9,9	
11 IF (TH(M) - 440.0) 10,12,12	
9 UC = U1*CPPF(TC(M))	A185
UH = U1*CPPF(TH(M))	A190
GO TO 13	A195
12 UC = U	A200
UH = U1*CPPF(TH(M))	A205
GO TO 13	A210
10 UC = U	A215
UH = U	A220
13 IF (JJ) 6,5,6	A225
5 WRITEOUTPUTTAPE3,4,M, TS,TC(M), TH(M), TI(M), TO(M), ZO,ZC,G,	A235
XHSP,HSC,HIO,HST,HXT, HO,HC,HH,HX,HS,QH,QC,Q3,Q1,Q2,Q1,QO	A236
6 RETURN	A237
END	A240
	A250

APPENDIX H: PROGRAM LISTING FOR SEARCH SUBROUTINE

```

SUBROUTINE SEARCH(J)
  DIMENSION TC(26), TH(26), TI(26), TO(26), QR(26), QS(26), TFE(10)
  X ,VXX(16), FC(16),EKI(16),EKO(16),EL(16),DP(16),W(10),QTS(10)
  COMMON HSP, HST, ZO, ZC, HIO, TS, QI, QO, U, HO, HH, HC, HS, HX,
  XXSC1, XSC2, XHC1, XHC2, XQ1, XQ2, HSC, TC, TH, TI, TO, QR, QS,
  XVXX,FC,EL,EKI,EKO,TLM , W, TFE, QTS, DP, DPA,DPL,DPT, DPFL,
  XDPV, WBA, WPA, TB, TBP, TOC, TL, DPTT, DPTS, DPIT, TOM, TIM, TCM,
  XTHM, KC, KH, KI, KO, QSK, QIP, QSP, QST, QRT, K2, K1,EL9,EL18,
  XV2,UW, TSP, PK, D, E, AD, BD, CD, P, PI, CP, HD,TOR,TLR,HX1,HX2
  X,U1, UH, UC, CEX, CCP, WK, KG, Q1, Q2, Q3, QC, QH, HXT
  TCM = TC(1)
  THM = TH(1)
  TIM = TI(1)
  TOM = TO(1)
  KC = 1
  KH = 1
  KI = 1
  KO = 1
  DO 1 K = 2,25
    IF(TCM - TC(K))2,3,3
  2 TCM = TC(K)
    KC = K
  3 IF (THM - TH(K))4,5,5
  4 THM = TH(K)
    KH = K
  5 IF (TIM - TI(K))6,7,7
  6 TIM = TI(K)
    KI = K
  7 IF (TOM - TO(K))8,1,1
  8 TOM = TO(K)
    KO = K
  1 CONTINUE
    QST = 0.0
    QRT = QR(1)
    DO 9 K = 2,6
      QST = QST + QS(K)
  9 QRT = QRT + QR(K)
    QSP = QST
    KA = K2 - 1
    DO 10 K =7,KA
      QST = QST + QS(K)
  10 QRT = QRT + QR(K)
    K3 = K2 + 1
    DO 11 K =K3,25
      QST = QST + QS(K)
  11 QRT = QRT + QR(K)
    QSK = QST - QSP
    QIP = 16.0*(QO + QI) /3415.0 + QTS(J) +QST

```

X10
 X20
 X21
 60
 61
 62
 63
 64
 65
 66
 X40
 X50
 X60
 X70
 X80
 X90
 X100
 X110
 X120
 X130
 X140
 X150
 X160
 X170
 X180
 X190
 X200
 X210
 X220
 X230
 X240
 X250
 X270
 X280
 X290
 X300
 X310
 X320
 X330
 X340
 X350
 X360
 X370
 X380
 X390
 X400
 X405

APPENDIX E: PROGRAM LISTING FOR SEARCH SUBROUTINE (continued)

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```
DPTT = DP(1)
DO 12 L = 2,4
12 DPTT = DPTT + DP(L)
   DPIT = DPTT - DP(3)
   DPTS = DPTT - DP(4)
   DPL = DPTT - DP(3)
   RETURN
END
```

X410
X420
X430
X440
X450
X460
X470
X480

APPENDIX I: PROGRAM LISTING FOR OUTPUT SUBROUTINE

```

SUBROUTINE OUTPUT (JI, JK, JL, JM, J, I)
  DIMENSION TC(26), TH(26), TI(26), TO(26), QR(26), QS(26), TFE(10)
  X ,VXX(16), FC(16),EKI(16),EKO(16),EL(16),DP(16),W(10),QTS(10)
  COMMON HSP, HST, ZO, ZC, HIO, TS, QI, QO, U, HO, HH, HC, HS, HX,
  XXSC1, XSC2, XHC1, XHC2, XQ1, XQ2, HSC, TC, TH, TI, TO, QR, QS,
  XVXX,FC,EL,EKI,EKO,TLM      , W, TFE, QTS, DP, DPA,DPL,DPT, DPFL,
  XDPV, WBA, WPA, TB, TBP, TOC, TL, DPTT, DPTS, DPIT, TOM, TIM, TCM,
  XTHM, KC, KH, KI, KO, QSK, QIP, QSP, QST, QRT, K2, K1,EL9,EL18,
  XV2,UW, TSP, PK,      D, E, AD, BD, CD, P, PI, CP, HD,TOR,TLR,HX1,HX2
  X,U1, UH, UC, CEX, CCP, WK, KG, Q1, Q2, Q3, QC, QH, HXT
10 FORMAT (86H              K      TC      TH      W90
  X  TI      TO      QR      QS)      W100
11 FORMAT (32H              ,I2,4F9.1,2F9.3 )      W120
12 FORMAT (32H              ,I2,4F9.1,2F9.3///)      W130
13 FORMAT (72H              REGION      W140
  XAL PRESSURE DROPS//33H      L,I5,7I7/33H      W150
  X      DP,8F7.3//33H      W150
  X      L,I5,7I7/33H      DP,8F7.3///)      W152
14 FORMAT (92H      QTS      QIP      QRT      QSK      W160
  X  QSP      QST      W      WBA      WPA/21H      ,      W170
  X6F8.2, 3F8.1///97H      TX1      TX7      TXK1      W180
  X TXK2      TX25      TCM      THM      TIM      TOM/18H      W190
  X      ,9F9.1/18H      ,5F9.1,I7,3I9///78H      W200
  X      TFE      TL      TB      TBP      TOC/      W210
  X39H      ,5F8.1///94H      W220
  X      DPA      DPT      DPL      DPF      DPV      DPFL      DPIT      W230
  X  DPTT      DPTS/22H      ,9F8.3///)      W240
15 FORMAT (61H              RESULTS F      W250
  XOR I =I3,5H, J =I3///)      W260
  WRITE OUTPUT TAPE 3, 15, I, J      W265
  IF (JI)2,1,2      W270
1  WRITE OUTPUT TAPE 3, 10      W280
  WRITE OUTPUT TAPE 3, 11, (K, TC(K), TH(K), TI(K), TO(K), QR(K),
  XQS(K), K =1,24)      W290
  WRITE OUTPUT TAPE 3, 12,(K, TC(K), TH(K), TI(K), TO(K), QR(K),
  XQS(K), K= 25,25)      W300
2  IF (JK)4,3,4      W310
3  WRITE OUTPUT TAPE 3, 13, (L, L =1, 8),(DP(L),L =1, 8),(L,L=9,16)      W320
  X, (DP(L),L =9,16)      W330
4  IF (JL)6,5,6      W340
5  IF (JM)7,8,9      W350
7  TFE(J) = 0.0      W360
  GO TO 9      W370
8  TFE(J)= 0.0      W380
  WBA = 0.0      W390
  WPA = 0.0      W400
  TB = 0.0      W410
  TBP = 0.0      W420

```

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APPENDIX I: PROGRAM LISTING FOR OUTPUT SUBROUTINE (continued)

TOC = 0.0	W440
DPA = 0.0	W450
9 WRITE OUTPUT TAPE 3,14, QTS(J), QIP, QRT, QSK, QSP, QST, W(J),	W460
XWBA,WPA, TC(1), TC(7), TC(K1), TC(K2), TC(25), TCM, THM, TIM, TOM,	W470
XTH(1), TH(7), TH(K1), TH(K2), TH(25), KC, KH,KI, KO, TFE(J), TL,	W480
XTB, TBP, TOC, DPA, DPT, DPL, DP(3), DPV, DPFL, DPIT, DPTT, DPTS	W490
6 RETURN	W500
END	W510