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STUDY OF MINE FIRES AND MINE VENTILATION
Part I
Computer Simulation of Ventilation Systems Under the Influence of Mine Fires

Rudolf E. Greuer

Principal Investigator

Michigan Technological University

College of Engineering

Department of Mining Engineering

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FOREWORD

This report was prepared by Michigan Technological University, College of Engineering, Department of Mining Engineering, Houghton, Michigan, under USBM Contract No. S0241032. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PMSRC with Dr. R. F. Chaiken acting as the technical project officer. Mr. D. J. Askin was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 4, 1974 to October 14, 1977. This report was submitted by the author on September 14, 1977. This technical report has been reviewed and approved.

It is hereby certified that no inventions have been made on this project.

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies of the Interior Department's Bureau of Mines or of the U.S. Government.

SUMMARY

The existing computer programs for the simulation of ventilation systems under normal ventilation conditions are reviewed and a suitable program for including the influence of mine fires is selected. New program parts are written for the consideration of methane productions in coal mines, heat and gas productions of mine fires, temperature and air composition changes in ventilation systems, and the ventilation forces resulting from the latter. Other program parts are provided for the detection of danger zones and reversed air currents and for the inclusion of recirculated air currents in the network analysis. Existing program and new program parts are combined.

The resulting new program can be used for a multitude of assignments. It is designed for the practical ventilation engineer and should be applicable to all types of ventilation emergency plans, in particular mine fire plans.

The organization of the program and its mathematical basis are described. A FORTRAN IV listing and several flow diagrams are included. Eight executed examples are discussed, input and output for these examples explained. Storage requirements and execution times are estimated.

TABLE OF CONTENTS

1. INTRODUCTION

Most of the major mine disasters have throughout the history of mining been caused by explosions and fires and both causes remain among the greatest potential hazards in mining. The greatest hazard of mine fires is the poisonous and sometimes explosive combustion products which are carried through the mines by their ventilation.

To combat this hazard, the paths which the combustion products take, must be known for the proper designation of escape routes and the safe and economical performance of fire fighting activities. To predict these paths is complicated by the fact that the fires themselves can cause considerable ventilation disturbances. The volume expansion of the air as it passes through the fire has a constriction or throttle effect. Density differences in non-horizontal communicating airways create buoyancy effects similar to chimney drafts. The intensity of the fires, on the other hand, depends on their oxygen supply, i.e. the airflow rates and oxygen concentration which are provided by the ventilation system.

The conventional analog computers and digital computer programs for ventilation network (airflow distribution) calculations are not capable of taking this mutual interaction between fires and ventilation systems into account. They cannot distinguish between air of different qualities (concentrations, temperatures) either. The preferred compromise has been until now to use these conventional analog computers or digital computer programs and to support them with manual calculations.

This approach can be satisfying when no recirculation of air occurs and the fire generated ventilation forces are relatively small. Concentration of methane and combustion products can in these cases be determined by a sequence of simple mixing processes in the network nodes once the airflow distribution is known. The fire generated ventilation forces, which depend on the air temperature downstream of the fire, can be calculated for an estimated airflow rate through the fire and then inserted in the network calculation. Unchanged temperatures and natural ventilation pressures are assumed for all other air currents. If the airflow rate through the fire, which is then obtained in the network calculation, is too far off the estimate, the process is repeated with a new, better estimate. The amount of manual work involved in this procedure may be cumbersome but is manageable, if, as in the preparation of emergency plans, sufficient time is available.

With recirculation, temperatures and concentration of several of the air currents, which enter network nodes, are not known and the calculation of the state of the mixture leaving the nodes is therefore not possible. To overcome this difficulty some method of describing the network configuration mathematically or of applying an iterative approximation method has to be used. Recirculation is common in hardrock mines and can be caused by the fire itself in coal mines even though it is not permitted under normal ventilation conditions. With large fire generated ventilation forces the ventilation disturbances become such that the assumption of unchanged temperatures and natural ventilation pressures in all airways except for those immediately downstream of the fire does no longer hold either. In such cases the amount of manual work becomes excessive, or so many simplifying assumptions have to be made that the results of the calculations have only a limited value.

Due to its great importance for escape and fire fighting plans, mining engineers have studied the interaction between ventilation systems and fires for several decades. The large amount of conducted theoretical and experimental work was recently reviewed (7), the still existing gap for coal mine fires is in the process of being closed (3,5). Ventilation network calculations with digital computers are becoming more and more common and with them the availability of reliable data on ventilation systems. In the same way as suitable computer programs for ventilation network calculations have led to considerable improvements in the ordinary ventilation planning work, it can be expected that suitable programs for fire emergencies will lead to improvements in this field also. This report describes such a program and demonstrates its application with a number of examples.

The here introduced program can fulfill the following functions:

a) it starts with a conventional network calculation for the state of the mine before the emergency;

b) next, it simulates the production of heat and contaminants in designated locations;

c) next, it calculates the resulting temperature and concentration distribution based on the airflow obtained in step a, if recirculation occurs it makes use of an iterative approximation method;
d) next, it calculates the fire generated ventilation forces;
e) next, it inserts these forces into the network and repeats the network calculation to determine the changed airflow distribution;
f) next, it repeats steps b through e until an equilibrium is reached;
g) finally, it analyzes the results for danger zones caused by instable airways, airflow reversals, high temperatures, high concentrations of methane or combustion products.

As this sequence indicates, it was attempted to determine an equilibrium under steady state conditions. The crucial heat exchange between rock and air is, however, calculated under non-steady state conditions, taking the changing rock temperature into account. If the change of the ventilation system with time shall be investigated, it is necessary to execute a series of calculations for different time intervals since the beginning of the emergency event.

The program has the options to execute network, temperature, and concentration calculations combined or separately. It has been made as flexible as possible to make it useful for a multitude of assignments. Methane concentrations are, however, always determined when a change in the airflow distribution takes place, since this is indispensable for coal mines. In its organization the program has been divided into two parts, labeled "network part" (for functions a and e) and "concentration part" (for all the other functions). The network part contains basically an earlier existing program for conventional network calculations. It was attempted to change this existing program and its input data as little as possible in order to make the use of the new program, for users of the conventional network program, as simple as possible.

It has been attempted to keep the amount of input data in the new program small and to extract as much information as possible from these data. Input data are furthermore analyzed for completeness and for such mistakes that occur most frequently. When possible, incomplete data are amended by average values and incorrect data are corrected.

The formulation of heat and combustion products as a function of the oxygen supply to the fire has intentionally been kept very simple. There is no difficulty in amending the program with fire characteristics of any desired properties. But to introduce these, in a form that they are applicable to all types of mines and fuels, would require so many additional explanations and input data that at this stage the introduction of the new program for practical emergency planning would be impeded.

On the whole, this program has been drafted with routine application by practical ventilation engineers in mind. It is, as far as the author knows, the first program of its kind and the necessity of some changes will certainly be felt after it has been exposed to some practical use.

2. REVIEW OF EXISTING PROGRAMS FOR VENTILATION NETWORK CALCULATIONS

Ventilation network calculations, whose goal is the determination of airflow and pressure distributions in mine ventilation systems, have been performed routinely and at a large scale with computers for approximately two and a half decades. Throughout the fifties and the first half of the sixties, analog computers were mainly used for this purpose. They were almost completely replaced by digital computers, after the latter became more and more available, larger, cheaper, and faster. Digital computers, being all purpose computers, can usually perform network calculations more economically than the single purpose analog computers. The first reported ventilation network calculations with digital computers were performed in 1958 and since 1960 they have become routine in West Germany, where large ventilation problems necessitated the wide use of analog computers before. From the mid-sixties on, digital computers were in all major mining countries, either routinely used for network calculations or their use was being investigated. To date such calculations have become a self-understanding part of all ventilation planning. A review of the history of ventilation network calculations with computers and the different programs in use has been given by the author in an earlier report (7).

Normal environmental factors, like concentrations of contaminants or temperatures, are heavily influenced by the airflow distribution. On the other hand, it is quite possible that the airflow distribution is influenced by these environmental factors. There exists an increasing number of attempts to combine ventilation network calculations in digital computer programs with the precalculation of environmental conditions (1,6,8,10,16,19). None of these efforts have, however, progressed far enough to be useful for the simulation of fire emergency situations.

All programs for ventilation network calculations which are presently used employ the CROSS iteration method of balancing pressures around loops. Its principles are described in a large number of earlier papers on network calculations (e.g. 6,20). Experience has shown that this method allows working with the most simple program and organization of the input data and does not pose any difficulties, time or storagewise, for average sized modern computers. Previous limitations in computer capacity, which led to other programs with lower storage requirements or higher execution speeds, do practically no longer exist. It was, therefore, decided to use for this contract the CROSS method of balancing pressures. It was furthermore decided to utilize and modify a program which already had a large number of users in the U.S. This would make the understanding of the new program, at least for some people, easier. It would, furthermore, allow them to use existing network calculation data for the new program.

There seem to be two different programs for ventilation network calculations in wide use in the U.S. (6); the so-called Pennsylvania State University program (6,20), and the so-called Michigan Technological University program (7). The last published version of the Penn State program (20) was written before 1970. It was described in great detail in 1972 (6). The Michigan Tech program originated in West Germany around 1965 as a new, more compact, version of older existing programs and is widely used by German ventilation engineers. It is very similar to the standard program of the British National Coal Board, which was issued in 1967, since both programs have the same source. Since this program was not a genuine novelty and a large number of copies together with manuals are in circulation, no detailed description of this program was published.

The Penn State and Michigan Tech programs are not very different. They use the same mathematical description of ventilation networks and use essentially the same solution method. Judgment of the quality of a computer program is to a large part based on how familiar one is with the program and the way in which input and output are organized. As long as programs give correct results with the same amount of computer and user effort, they must be considered as being equally useful.

The author, having participated in writing the Michigan Tech program and having carefully studied the Penn State program feels, however, that the former program is simpler to use and it seems to have a better convergence also. The reason is, perhaps, that it was written by practical ventilation engineers who had to perform large numbers of network calculations for their planning purposes. The features which the author thinks should be changed in the Penn State program are the following:

Airways (branches) should obtain identification numbers, not just sequence numbers; if input cards are placed in a different sequence or if the network changes, these sequence numbers will change also, which is a great inconvenience.

The use of a junction marker array in the "tree building process" limits the junction numbers to a few places or causes a lot of storage waste.

The natural ventilation pressure has to be calculated and inserted manually.

The approximation of the fan characteristic requires 90 statements. The feared undulations of polynomials which led to this occurs, however, only at both ends of the fan characteristic curve.

To use only the airflow rates of fixed quantity airways and the highest flow rates from indicated fan characteristics, or to use for all airways of the first mesh a rate of 100,000 cfm for the calculation of the initial airflow distribution, gives a poor start.

The output comprises a lot of actually unneeded information.

Since the distribution of the Penn State and Michigan Tech programs seem to be of the same order of magnitude, it was decided to use the Michigan Tech network program for the new program.

3. MATHEMATICAL DESCRIPTION OF VENTILATION NETWORKS FOR AIRFLOW AND PRESSURE DISTRIBUTION CALCULATIONS

The mathematical description of ventilation networks is not uniform and considerable confusion exists among practical ventilation engineers in this respect. It seems, therefore, advantageous to explain the principles which have been used in this report.

The networks are considered to be in a steady state. The forces acting on the ventilation system do not change very rapidly so that inertia forces of the air can be neglected. The response of the ventilation system to changing forces is considered as a sequence of equilibrium states to which the steady state mathematical description of network applies.

The mathematical description of ventilation networks can be based on mass flow rates or volume flow rates of air. Ventilation engineers prefer to work with volume flow rates because these flow rates, being the product of cross sectional area and measured airflow speed, are easy to visualize. Moreover, energies (ft-lb) per unit volume (ft^3) have the dimensions of pressures ($ft\text{-}lb/ft^3 = lb/ft^2$) and can, like fan pressures or the pressure losses in airways, be directly read from manometers or barometers. Problems arise from the fact that due to density changes of the air the volume flow rates change also, even when the mass flow rates remain constant. This makes it, in ventilation surveys, difficult to detect genuine air leakage currents. In network calculations, suitable allowances have to be made for the fact that the volume flow rates entering airways are not necessarily equal to the volume flow rates leaving them. Energy balances are distorted by the fact that equal energy quantities (ft-lb/lb) can be expressed by different pressures ($ft\text{-}lb/ft^3$), which in ventilation pressure surveys usually leads to an overestimate of natural ventilation pressures and requires, in network calculations, suitable adjustments.

The network calculations in this report will, therefore, be based on mass flow rates, but since these and the pertinent energy quantities per unit mass (ft-lb/lb = ft, heads) are unfamiliar to many ventilation engineers, they are with the help of reference densities d_r

converted into quantities with the dimensions of volume flow rates and pressures. The reference densities are nothing more than constant factors which are carried through the calculations with the sole aim of obtaining results in familiar units. For their magnitude a value close to the average density in that part of the mine, for which the results of the network calculation are most important, is chosen. They are stated at the beginning of the program together with a reference temperature which corresponds to this density.

This approach requires preparing the input data of the network calculation in the following way. The measured actual flow rates Q, having an average density of d, are converted to the reference volume flow rate Q_r according to

$$Q_r = Q \frac{d_r}{d}$$

The pressure loss H_L which has been obtained from an altimeter survey (15) or read from the manometer of a trailing hose (9) is converted to the reference pressure loss

$$H_{Lr} = H_L \frac{d_r}{d}$$

If pressure losses have been calculated from the formula

$$H_L = \frac{K\ L\ O}{5.2\ A^3} \left(\frac{Q}{10^5}\right)^2$$

where K = friction factor
L = airway length
O = airway perimeter
A = airway cross sectional area

and if the Bureau of Mines schedule of friction factors has been used (11), the conversion is

$$H_{Lr} = H_L \frac{d_r}{0.075}$$

Measured fan pressure H_F are converted to

$$H_{Fr} = H_F \frac{d_r}{d}$$

Fan pressures obtained from fan characteristics based on a density of 0.075 lb/ft^3 are converted to

$$H_{Fr} = H_F \frac{d_r}{0.075}$$

Natural ventilation heads h_N, which as heat energy converted into mechanical work are represented by the area enclosed in a pressure-volume (p-v) diagram ($h_N = - \oint v\, dp = - \oint dp/d$), are expressed as natural ventilation pressure

$$H_{Nr} = - \frac{d_r}{5.2} \oint \frac{dp}{d}$$

If resistance factors R have been determined from measured pressure losses H_L and airflow rates Q according to

$$R = H_L/(Q/10^5)^2$$

they have to be converted to

$$R_r = R \left(\frac{d_r}{d}\right)^3$$

in order to make the equation $H_{Lr} = R_r\ (Q_r/10^5)^2$ fit.
If they have been calculated from Bureau of Mines friction factors (11) with the help of the formula $R = K\ L\ O/(5.2\ A^3)$, they have for the same purpose to be converted to

$$R_r = R \frac{d_r^{\ 3}}{0.075\ d^2}$$

It is, in this report, from now on assumed that volume flow rates Q, pressures H and resistance factors R are based on a constant reference density and the subscripts r are, therefore, from now on omitted.

With this agreement and the assumption of steady state flow conditions, ventilation networks can be described by three different sets of equations: resistance equations or equivalents, junction equations, and mesh equations.

Every airway with a flow resistance obeys the resistance equation $H_L = R\,Q^2$. If the airway has no flow resistance but contains a pressure source H_F, an equation $H_F = f(Q)$ is substituted. If the resistance is made variable in order to keep the airflow rate Q constant (fixed quantity airway) an equation

$$Q = \text{constant}$$

takes the place of the resistance equation.
The law of mass conservation applies to every junction.

$$\Sigma\, Q = 0$$

The airflow rate entering a junction must be equal to the airflow rate leaving it. These are the junction equations of networks.
The first law of thermodynamics applies to every mesh, which can be written as

$$\Sigma\, H_L - \Sigma\, H_F - H_N = 0$$

The sum of all pressure losses in the airways of a mesh is equal to the sum of all pressures generated by pressure sources plus the natural ventilation pressure in this mesh.

If the number of airways in a network is n_b, the number of junctions n_j, and the number of meshes is n_m, there are

n_b resistance or equivalent equations,

$n_j - 1$ junction equations, and

$n_m = n_b - n_j + 1$ mesh equations.

4. PROGRAM DESCRIPTION

4.1 NETWORK PART OF PROGRAM

4.1.1 Section "Read Input Data"

The input data for this program part comprise: one network control card; airway cards; junction cards; fan characteristic cards; and additional airway cards.

Junction and fan characteristic cards may be omitted if the information contained in them is not considered essential to the expected result of the calculation. The option of additional airway cards has been introduced to be capable of using already existing decks or files of airway cards from conventional ventilation network calculations, which do not contain all the information needed for the use of this program.

The network control card has to state:

NB	number of airways
NJ	number of junctions
NFNUM	number of fan characteristics to be read in
NADBC	number of additional airway cards
NVPN	marker; NVPN > 0 indicates that NJ junction cards shall be read in and that natural ventilation pressures shall be calculated from junction card data
NETW)	(values larger than 0 indicate that network, concentration,
NCONC)	marker (and temperature calculations shall be performed; these
NTEMP)	(can be executed independently of each other
MADJ	maximal number of times a network calculation shall be performed in one program run
ITN	maximal number of iterations permitted within network and concentration parts of program
DR	reference density
TR	reference temperature

The two numbers MADJ and ITN are safety switches against endless computer runs with meaningless data.

NB airway cards are needed which can be arranged in any arbitrary sequence. There are three types of airway cards: regular airway cards, marked by NWTYP = 0; fixed quantity airway cards, marked by NWTYP = -1; fan cards, marked by NWTYP = 1.

All airway cards have to state:

NO airway number
JS junction number of airway beginning
JF junction number of airway end

Regular airway cards have to state:

R resistance factor of airway when computer is not expected to calculate this figure

Fan cards have to state (in the R-column) the fan pressure. This will be the acting fan pressure, when no fan characteristics are given.

Fixed quantity cards have to state:

Q desired constant airflow rate

In regular airway and fan cards the statement of an estimated Q is optional. When it is in the right order of magnitude it is helpful for obtaining a fast solution.

The airway properties:

KF friction factor
LA airway length
A cross sectional area
O perimeter

may be stated at this place in the airway cards. They may be stated later in the NADBC additional airway cards, or average properties, read into the computer at the beginning of the concentration part, may be used.

For NVPN > 0, NJ junction cards have to be provided. Each one has to state:

JNO junction number
T temperature of junction
Z elevation of junction

Since this information is used for the calculation of the natural ventilation pressure only, the data do not have to be very accurate. The statement of:

CH4C methane concentration in junction

is optional. It is used in the concentration part to estimate the methane evolution of airways if no better information has been given. It can be stated later with the input data of the concentration part, if so desired. The possibility to state it here was introduced because the junction cards provide ample space.

NFNUM sets of fan characteristic cards have to be provided. Every set comprises one fan identity card, stating:

NOF	airway number of fan
MPTS	number of points which shall be used to define the fan characteristic

and as many curve point cards as are needed to state:

QF	airflow rate at point of fan characteristic
PF	fan pressure at point of fan characteristic

for all of the MPTS points. Ten points contained in two cards will usually be sufficient.

4.1.2 Complete Input Data, Output of Input

In this section the NADBC additional network airway cards are read in. They contain:

NOX	airway number
KX	friction factor K
LX	airway length
AX	cross sectional area
OX	perimeter

A check is made to see if all the additional cards refer to airways which are part of the network. If not, their content is disregarded and a message printed. It is then checked to see if the resistance factor R for every regular airway has been stated. If not, it is checked to see if R can be calculated from the stated airway dimensions, but a stated R always overrides a calculated value. If R has not been stated and cannot be calculated, a network calculation is impossible. The computer shows where data are lacking, prints out the received input data together with the message that no network calculation has been performed and moves on to the concentration part of the program. It does the same if no network calculation is desired (NETW $\leq$ 0). As a preparation for the network calculation the counters MADJC and ITCT as well as the markers NSW, NSNVP, NNVP, and MARKN are set to zero.

4.1.3 Arrange Airways to Size and Magnitude R*Q

Numerical values of resistance factors are small and are traditionally stated as $R*10^{10}$. In order to make the resistance equation

$H_L = R Q^2$ fit, Q is, in this formula, expressed in units of 10^5 cfm. This conversion is done in the first pass through this program part when NSW $\leq$ 0.

Theoretical investigations have shown that the convergence of the CROSS iteration method is improved when airways with high resistance factors are made so-called "primary" airways, which occur in one mesh only (18). It has been shown by earlier experiences with digital computers that when meshes are formed in this way, an acceptable rate of convergence can be achieved altogether (7) and many existing programs follow this route. Additional practical experience has shown that an even better convergence can be reached when airways with high products R*Q appear in as few meshes as possible, i.e. are made primary airways. This makes the denominator of the CROSS correction formula small and the corrections consequently large.

In preparation for the selection of primary airways, an INU-list is formed. This contains, in its lowest places, the fans for which no fan characteristic has been given (constant pressure fans). The regular airways follow in the order of their increased magnitude R*Q. The list is completed with the fixed quantity airways and the fans, for which a fan characteristic has been given (variable pressure fans). The positions of these fans in the airway list is at this time put into a special NFREG-list in order to be able to locate them later on when fan pressures have to be determined.

The reason for this arrangement is that, in the next program section, primary airways are selected from the top of the INU-list. Fixed quantity airways can, according to their definition, have no airflow rate corrections. They should, therefore, occur in as few meshes as possible. Variable pressure fans have to adjust their pressures after every airflow rate correction. To make them primary airways, which are corrected only once in every iteration, keeps the computing effort low. It prevents, furthermore, oscillations of the system, which can occur when a large number of variable pressure fans are cooperating.

4.1.4 Set Up Base System

As with all computer sorting processes, the principles employed in this section are not complicated but are hard to explain. The best way to understand the procedures, if one desires, is to go through a numerical example. Since the procedures are not new or unique they shall not be discussed in detail here.

Starting out with the airway in the lowest place of the INU-list, the base system or a tree of N_j - 1 "secondary" airways is assembled in such a way that all junctions of the network are connected, but no meshes are formed. The number of remaining primary airways is ($N_b - N_j + 1 = N_m$) equal to the number of meshes. Everyone of the remaining branches will, therefore, when added to the base system, close a mesh. All airways which become part of the base system are entered into a list of secondary airways, the KNO-list. The remaining primary airways are marked by giving their finishing junctions JF a negative sign.

In assembling the base system the airways are scrutinized in ascending order of their places in the INU-list. This means that the KNO-list of secondary airways contains the fixed pressure fans and the airways with the lowest possible products R*Q. If a fixed quantity airway has to be entered into the KNO-list, which usually means that all airways entering and leaving a junction are fixed quantity airways, a message is printed and this airway is treated like a regular airway. If an airway, like a dead-end working, is only connected to the network at one end, a message is printed out also.

4.1.5 Form Meshes

Every primary airway, which is either a fixed quantity airway, variable pressure fan, or a regular airway with a high product R*Q, will form a mesh with secondary airways. As one can visualize from connecting two branches of a tree (secondary airways), there is only one possibility to form a mesh. The meshes are found by adding to both ends of a primary airway a sequence of secondary airways from the KNO-list until the ends meet. Two lists are used to describe the meshes. The MSL-list contains the whole sequence of primary and secondary airways which forms all the meshes in the network. The MEND-list contains the places of the secondary airways in the MSL-list, which closed a mesh when it was formed. Thus, if the first two meshes would comprise 6 and 10 airways, one would have: MEND(1) = 6, MEND(2) = 16. The primary airways in these meshes would have the places MSL(1) and MSL(6+1), the two meshes would occupy the places 1 through 6, and 7 through 16 in the MSL-list.

4.1.6 Satisfy Junction Equations

The CROSS approximation method does not interfere with the junction equations, but these have to be satisfied originally to make the method work. This can be done by placing the airflow rates of every primary airway into all the airways which belong to the mesh of this primary airway. With N_b airflow rates Q existing in the N_b airways and $N_j - 1$ junction equations, $N_b - (N_j - 1) = N_m$ airflow rates can be arbitrarily chosen. N_m is equal to the number of primary airways.

This can be visualized in the following way. If we assume that in every mesh a certain airflow rate is circulated, the junction equations must be satisfied. Whatever flows into the junctions, through which this mesh passes, must flow out of them again. The primary airways, being part of one mesh only, carry this specific airflow rate. The secondary airways carry the airflow rates of all the meshes of which they are a part.

The program accomplishes this by setting the airflow rates of all secondary airways, found from the MSL and MEND-lists, initially to zero. It then takes the airflow rates, which have been indicated for the primary airways in the airway cards, and puts them into the airways of the pertinent meshes. The directions, in which the airflow rates circulating in the meshes pass through the airways, have to be noted. All airflow rates are then for every individual airway summed up, and the result is an airflow distribution which satisfies the junction equations.

4.1.7 Calculate Natural Ventilation Pressure

This section of the program is executed in the first network calculation (NSNVP $\leq$ 0) only where junction cards with temperature and elevation data were read in (NVPN > 0). If it has to be assumed that heat sources or changed surface temperatures have altered the temperature distribution in the mine, the pertinent natural ventilation pressures are calculated in a different way in another section of the program.

Natural ventilation pressures are caused by the conversion of heat into mechanical energy, which is then available to propel the air and to overcome friction losses. Under steady-state conditions cyclic processes which are provided by every mesh of the ventilation system are necessary for such a conversion. The amount of heat converted into work per unit weight of air h_N is indicated by the area enclosed by the mesh in a pressure (p) volume (v) diagram ($h_N = - \oint v \, dp$). Data on specific volumes and pressures are usually not available at mines and are tedious to determine. Data on temperatures and elevations can, however, be easily obtained. The author suggested, therefore, in the early sixties, determining the natural ventilation from:

$$h_N = \frac{1}{T_m} \oint T \, dZ$$

where: T = absolute temperature
Z = elevation
T_m = average absolute temperature in the mesh under consideration

and to let the computer calculate h_N and incorporate it in the network calculation from information on temperatures and elevations of the network junctions. The error which is caused by substituting $1/T_m \oint T \, dZ$ for $- \oint v \, dp$ has been investigated (7) and is comparatively small. This method of considering natural ventilation network calculations is a very convenient one, is part of the Michigan Tech program, and has found its way into many other programs also.

For lack of other information, a linear temperature change between junctions is assumed, which is accurate enough for the normal state of mines. The natural ventilation pressure H_N based on a reference density DR can then be calculated from:

$$H_N = \frac{DR}{5.2} \, \frac{n \, \Sigma \, (T_s * Z_f - T_f * Z_s)}{\Sigma \, (T_s + T_f)}$$

where: n = number of airways in mesh
T_s, Z_s = temperatures and elevations of starting junctions of airways in mesh
T_f, Z_f = temperatures and elevations of finishing junctions of airways in mesh

The computer performs this calculation and stores the natural ventilation pressure, which has been obtained for the meshes of the network in a FNVP-list.

4.1.8 Iteration

The CROSS correction, which is used in this program is:

$$Q = - \frac{\Sigma R_i |Q_i| Q_i - \Sigma H_{Fi} - H_N}{\Sigma (2 R_i |Q_i| - dH_{Fi}/dQ_i)}$$

where: R_i, Q_i = resistance and airflow rate of regular airways contained in the mesh

H_{Fi} = pressure of fans contained in the mesh

H_N = natural ventilation pressure of the mesh

dH_{Fi}/dQ_i = gradient of the fan pressure characteristic at airflow rate Q

This correction is applied to every mesh in the network except for those which have a fixed quantity airway as primary airway, and this process is reiterated until either a specified number of iterations has been performed or a specified threshold is no longer exceeded.

For variable pressure fans, the estimated fan pressure contained in the airway card and a gradient RGRAD = $dH_F/dQ = 0$ is assumed in the first iteration. In the following iterations, values determined in the next program section are used. Calculated at first is the numerator of the CROSS correction DPSUM - FNVP, then the denominator RQSUM, then the correction DQ, then the corrected flow rates Q of the airways in the mesh, finally the sum of all corrections in one iteration DQSUM = Σ ABS(DQ).

4.1.9 Fan Characteristic

The fan characteristics were read into the computer with the fan characteristic cards, in which, for every fan with the airway number NOF for MPTS points, the airflow rates QF and fan pressures PF had been stated. Intermediate fan pressure values FANP, at the airflow rate FANQ, are determined with the help of LAGRANGE's interpolation formula:

$$FANP = PF_1 \frac{(FANQ-QF_2)(FANQ-QF_3)\ldots.(FANQ-QF_n)}{(QF_1-QF_2)\ (QF_1-QF_3)\ \ldots.(QF_1-QF_n)}$$

$$+ PF_2 \frac{(FANQ-QF_1)(FANQ-QF_3)\ldots.(FANQ-QF_n)}{(QF_2-QF_1)\ (QF_2-QF_3)\ \ldots.(QF_2-QF_n)} +$$

$$+ PF_n \frac{(FANQ-QF_1)(FANQ-QF_2)\dots(FANQ-QF_{n-1})}{(QF_n-QF_1)\ (QF_n-QF_2)\ \dots(QF_n-QF_{n-1})}$$

This formula permits very simple programming and gives a smooth fit of the fan curves. Exceptions are the boundary regions where undulations can occur. Beyond the last stated point of the characteristic one can have steep extensions. To avoid difficulties in the boundary region, into which the fan might enter during the iteration process, the fan pressure is, for the region to the left of the second point and to the right of the second last point, made equal to the pressures in these points. Fans, which in the last iteration before the output of a result are still in these regions, are entered into a NFCW-list which is later used for printing a warning.

For the gradient of the characteristic RGRAD = dH_f/dQ, the slope of a straight connection between the two stated points to the left and the right of the operating point FANQ, FANP is used. This approach is good enough since the justification of RGRAD in CROSS' correction formula is questioned anyway (14).

The calculated fan pressures FANP replace the estimated pressures in the R-list of the input data. The counter of iterations, which have been performed with a particular assembly of meshes (IT), and the counter of the total number of iterations performed in the network calculation (ITCT), are raised by one.

4.1.10 Continue in Appropriate Program Section

At least two iterations (IT = 2) have to be performed, otherwise the fan characteristics would remain unconsidered. After the second iteration, a check is made to see if the sum of all corrections DQSUM is smaller than $0.002*10^5$. If it is, and for NSNVP $\leq$ 0, control passes to the next program section. NSNVP is a marker which indicates with NSNVP $\leq$ 0, that this is the first network calculation of the program run, and that the sections "calculate natural ventilation pressure" and "calculate resistance of regulators" have to be executed. For DQSUM $\geq 0.002*10^5$, a check is made to see if ITCT does not exceed the limit ITN set in the control card. If it does in the last network calculation of the program run, the marker MARKN will cause the printing of a warning. For ITCT $\leq$ ITN, a check is made to see if the number of iterations with the present mesh assembly approaches twenty. This indicates a poor convergence and a new mesh assembly is made by giving control to the section "arrange airways to size and magnitude R*Q". The marker NSW, which prevents a renewed division of Q by 10^5, is made positive; the marker NSFLOW is set to zero. NSFLOW $\leq$ 0 indicates that a new mesh selection has been made in the network part of the program and that a new flow scheme in the concentration part of the program is therefore necessary.

If this was not the first network calculation of the computer run (NSNVP > 0), the next two program sections would be omitted. In preparation for the concentration part of the program, the airflow rates are multiplied by 10^5. A check is made to determine if, during the last network calculation which the computer was assigned to make (MADJC $\geq$ MADJ), an airflow reversal has taken place. If it has, it is an indication that an airway changes its airflow direction in every network calculation. This means that the airway is so unstable that the minute adjustments of temperature and airflow distribution, which are made in consecutive steps, did let the airflow in the airway oscillate. Since the magnitude of the adjustments is well below the perennial changes which occur in real mines, it seemed important to detect these airways rather than to suppress the oscillations by finer adjustment procedures.

4.1.11 Calculate Resistance of Regulators

The concept of fixed quantity airways is a valuable planning aid for the simulation of such airways through which, in the reality of a mine, a certain fixed quantity is allowed to flow irrespective of the state of the rest of the ventilation system. This concept is as old as the use of computers for network calculations and was already part of the first digital computer programs. The adjustment of regulators by mine personnel, with which the airflow rate is kept constant, will not happen in the case of an emergency. The fixed quantity airways have, therefore, to be converted into regular airways to obtain a realistic simulation of their behavior. This can cause problems with fixed quantity airways which are used to simulate the outflow of compressed air. They should be put in series with a pressure source in the same way as, in reality, the compressed air lines are connected to a compressor.

Fixed quantity airways are, therefore, in this program only treated as fixed quantity airways in the first network calculation of the computer run. After its completion, their resistance is calculated and they are converted into regular airways. This section of the program is consequently executed only once (NSNVP = 0). If the changes in the ventilation system are such that new network calculations become necessary (NSNVP $\neq$ 0), this section is omitted.

The determination of the resistance of fixed quantity airways proceeds in the way that meshes containing them are sorted out with the help of the MSL and MEND-lists. The pressures H_L, acting on the fixed quantity airways, are determined by summing up the pressures in all other airways of these meshes. The resistance is calculated from $R = H_L/Q^2$. Subsequently NWTYP of the fixed quantity airways is changed from -1 to 0, which means they are converted into regular airways.

4.1.12 Output of Results

This output contains the results of the first network calculation. If temperature and concentration calculations are subsequently desired (NCONC > 0, NTEMP > 0), the output will show on which initial network data they were based. If they are not desired (NCONC $\leq$ 0, NTEMP $\leq$ 0), this will be the only output and the computer will print information to that effect. Printed are, for the regular and fixed quantity airways, the airway numbers NO, their junction numbers JS, JF, calculated airflow rates Q, and pressure losses P, resistance factors R, and the stated airway dimension lengths LA, cross sectional areas A, friction factors KF, and perimeters O. A separate table is provided for fans with numbers NO, junctions JS, JF, airflow rates Q, and fan pressures P. Since ventilation planning comprises, frequently, the selection of suitable fans, the characteristics, which were used in the network calculation, are indicated also. Finally, the number of airways and the number of junctions is printed because they may be needed in future plannings, and experience shows that, in their statement, errors occur frequently.

In preparation for the next network part, the markers NSFLOW and ITCT are set to zero.

4.2 CONCENTRATION PART OF PROGRAM

4.2.1 Read and Complete Input Data

The input data for this program part comprise: one concentration control card; one average value card; additional airway cards; additional junction cards; and contamination cards. All cards except for the control card are optional. The computer must, however, receive the input data, which it needs for the assigned calculations somehow, either as average data or as detailed airway data. The concentration control card has to state:

NDIM	additional number of concentration airway cards to follow
NCH4C	additional number of concentration junction cards to follow
NAV	marker for presence of average value card (> 0 yes)
MAXJ	highest junction number used in network
INFLOW	number of cards specifying contamination
JSTART	number of junctions from which concentration calculations shall start; normally this will be the atmosphere
TSTART	temperature in JSTART
TIME	time which has elapsed since beginning of contamination; this is necessary for the temperature calculation where non-steady state conditions have to be assumed, only
CRITSM CRITGS CRITHT	accuracy with which the results for smoke, methane, and temperature are expected; when recirculation occurs, an iteration method has to be used and these are the threshold values at which iterations stop
WRNPR WRNSM WRNGS WRNHT	pressure losses, smoke concentrations, methane concentrations, and temperatures which shall be considered to be critical, so special attention should be drawn to them in output

The average value card contains average values for:

TAVR	rock temperature
HAAVR	rock diffusivity
HKAVR	rock thermal conductivity
KFAVR	friction factor of airways
LAAVR	airway length
AAVR	airway cross sectional area
OAVR	airway perimeter

This card is optional. It was introduced to keep the amount of input data as small as possible. Rock temperatures, diffusivities, conductivities, and airway friction factors can in many cases be assumed to be the same for many airways of the mine. Many airways exist in hardrock mines, like raises between levels, which have, essentially, all the same dimensions. If detailed, accurate information is needed, it can always be entered with the airway cards and override the average values. Another reason for the introduction of average values was to prevent the termination of a computer run due to lack of, perhaps, rather insignificant airway properties.

If additional concentration airway cards are wanted, NDIM in the concentration control card has stated how many of them. They contain:

NOX	airway number
CH4VX	methane volume production rate in airway
CH4PAX	methane volume production rate per unit surface area in airway
TROCKX	average rock temperature in airway
HAX	thermal diffusivity of rock in airway
HKX	thermal conductivity of rock in airway
DZRDX	elevation change in airway

Except for NOX, all of this information is optional. DZRDX must, however, be unequal to zero if it shall override elevation changes calculated from junction elevations, because the computer cannot decide if it is equal to zero or if it has been forgotten. If it is equal to zero, it should be given a small positive or negative value close to zero.

If additional concentration junction cards are wanted, NCH4C in the concentration control card has stated how many of them. They contain only:

JNOX	junction number
CH4CX	methane concentration in junction

and are used if one wants to determine the methane evolution from concentrations in junctions and this was not entered into the junction cards in the network part of the program.

If contamination enters the ventilation system, INFLOW contamination cards have to be used. Besides the airway number they contain three sections: the first one with a specified contamination which can be anything; the second one applying to oxygen rich fires; the third one applying to fuel rich fires or any type of fire. As discussed in the introduction, this is a preliminary stage which can be improved once the necessity exists. The contamination cards contain:

NCENT number of airways into which the contaminants enter

Section 1

CONT volume flow rate of contaminated inflow
CONC concentration of contaminant in inflow
HEAT heat entering airway

Section 2

O2MIN oxygen concentration with which fumes leave fire zone

Section 3

SMPO2 smoke production per ft^3 of oxygen delivery

HTPO2 heat production per ft^3 of oxygen delivery

Section 2 overrides section 1, section 3 overrides section 1 and 2.

Control card, optional average value card, and optional additional airway cards are read in. Methane evolution rate per airway CH4VX and per unit area of airway CH4PAX, rock temperature TROCKX, thermal diffusivity HAX and conductivity HKX, and elevation change DZRDX, are placed in the airway files CH4V, CH4PA, TROCK, HA, HK, and DZRD. A check is made to see if the number of airway cards in the input was equal to the stated number of cards NDIM. If not, a message is printed and the calculation terminated.

The airway files are then completed. For every airway a check is made to see if data for thermal diffusivity HA and conductivity HK from the just received additional airway cards, and if data for the friction factor KF, the airway length LA, the cross sectional area A, and the perimeter O from the network part of the program exist. If they don't, average values from the average value card are substituted. If this card does not exist, a message is printed and the calculation terminated. The elevation change DZRD cannot be checked because it may in reality be equal to zero. Before an average value is substituted for the rock temperature TROCK, it is first checked to see if junction cards exist in the network part (NVPN > 0). If yes, the airway is marked by giving its airway number NO a different sign than the rest of the airways. Temperatures T and elevations Z of starting and finishing junctions of these airways are then retrieved from the junction files of the network part of the program. Rock temperatures are calculated from these in the following way. When the assumption is made that the increase of rock temperature with depth has, due to the heat exchange between rock and air, become the same as the increase of rock temperature with depth, the air temperature change can, for steady state heat transfer, be described by (7):

$$t = t_{r0} - g_a \, LAsin\, \beta + (t_1 - t_{r0}) \exp(-\alpha \, O \, LA/G \, CP)$$

where: t_{r0} = rock temperature at beginning of airway
t_1 = air temperature at beginning of airway
g_a = autocompression gradient
β = slope angle (positive for ascending, negative for descending ventilation)
α = convection coefficient
G = weight flow rate
CP = specific heat of air

If, for the convection coefficient, the approximation:

$$\alpha = 0.4 \, V^{0.8}$$

(7) where: α = convection coefficient (Btu/ft^2-hr-$^\circ$F)
V = air speed (ft/sec)

is used, the exponent can be converted to:

$$X*LA = \alpha \, O \, LA/G \, CP = 0.014 \, O \, LA/(A^{0.8} \, Q^{0.2})$$

With DZRD = LA sin β and the definition of an average rock temperature

$$TROCK = t_{r0} - \frac{g_a}{2} DZRD$$

one obtains for the rock temperature

$$TROCK = \frac{t_2 - t_1 * \exp(-X*LA) + DZRD*g_a}{(1 - \exp(-X*LA)} - \frac{g_a}{2} DZRD$$

Elevation changes DZRD are calculated as the difference between the two elevations if DZRD, in the files, is equal to zero. It is for this reason that DZRDX in the input data should not be made exactly equal to zero, even for a horizontal airway, which it usually isn't anyway in so-called level airways.

4.2.2 Set Up JNO List

If no junction number cards were, in the network part of the program, read into the computer, no junction number list (JNO-list) yet exists.

It is set up in this program section together with a check, if the stated number of junctions is equal to the actual number, and, when necessary, with a correction. This is a frequent source of error when concentration calculations are performed only. The reason is that the number of junctions must be obtained by marking them in a check-list, whereas the number of airways can simply be obtained by counting the airway cards. It can be disputed whether junction cards and information on junctions serve a useful purpose. The calculation of the natural ventilation pressure in this way is, however, so widespread that in this program junction cards were retained. The occasionally made comment of storage waste is not true. Since the number of junctions is, with at least three airways entering or leaving a junction, equal to or smaller than 2/3 of the airway number, it takes, at the most, the same space to store temperature and elevation data junction-wise with a special junction number list than to do it airway-wise.

4.2.3 Calculate Methane Evolution

With a junction number list established, potential additional NCH4C junction cards can be read in. They contain, besides the junction number, only methane concentrations CH4C in junctions, which are placed into the pertinent list. A check is made again to see if all cards refer to junctions of the network. When not, a message is printed but no termination of calculations takes place since information on methane evolution is provided from several sides.

For all ventilation planning in coal mines, it is very important to assess the methane evolution since changes in the airflow distribution will cause changes in the methane concentration distribution also. Airflow reductions can lead to dangerous concentrations, the main concern in all fire fighting operations. It is justified to consider the rate of methane release from coal faces, ribs, and pillars as roughly constant over short time periods. Even the increased methane production caused by mining operations will, when the operations stop, only gradually taper off (2,12).

The rate of methane evolution per airway CH4V is introduced into this program in three different ways. It is in the additional airway cards either stated directly (CH4VX) or stated per unit surface area (CH4PAX) and then multiplied by the surface area LA*O. If both statements have not been given, it is calculated from the methane concentrations in junctions by assuming that the concentration change between starting and finishing junction of an airway multiplied by its airflow rate is equal to its methane production.

This last approach is a convenient one since methane concentrations in junctions, like temperatures, are, by most ventilation engineers, known by heart for their mine. It is, however, a crude approach since it is accurate only when merging air currents have the same concentrations. If the printout of the input data for concentrations and temperature calculations shows that the methane production obtained in this way is unrealistic for some airways, it has to be stated directly. Methane evolutions CH4V obtained from direct statements CH4VX override all other values; those indirectly obtained from CH4PAX override the ones derived from junction concentrations.

At the end of this section, the contamination cards are read in.

4.2.4 Output of Input

To allow a critical assessment of the quality of results obtained with the help of this program, all important input data, which are not contained in the network output, are printed out. These data comprise a table with airway numbers NO, starting and finishing junctions JS, JF, elevation differences DZRD, rock temperatures TROCK, methane evolution CH4V, thermal conductivity HK, and thermal diffusivity HA. The time after the beginning of the contamination TIME, number JSTART and temperature TSTART of that junction, from which the calculation starts, are given also. Finally, the contamination with NCENT, CONT, CONC, HEAT, O2MIN, SMPO2, and HTPO2 is listed, or, if no contamination occurs, a relevant message is printed.

4.2.5 Flowscheme

All airways are checked for negative airflow rates. If any are detected, the flow is made positive by exchanging starting and finishing junctions. This makes a new mesh selection necessary in following network calculations and the marker NSFLOW is, therefore, set equal to zero. With the exchange of junctions, the sign of the elevation change DZRD has to be changed also.

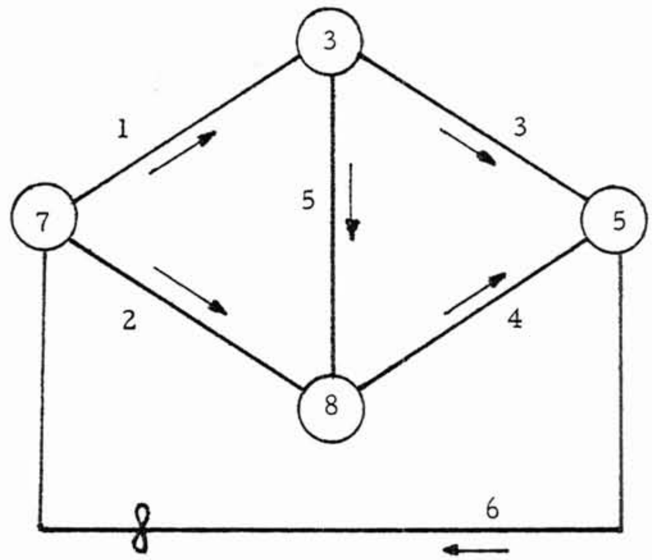
For the purpose of identifying airways with airflow reversals in the output, they are placed into a NREV file and their total number is counted by NRCT. Since the possibility exists that in the iteration process between the network and concentrations parts of the program, an airway experiences airflow reversal repeatedly, it is checked to see if this airway is not already in the NREV file. If it is, this means that an even number of reversals has taken place and that the airflow in this airway has its original direction again. It is therefore removed from the NREV file. After all airways have been checked, the NREV file is compacted and NRCT set to its proper value.

For the purpose of calculating temperatures and concentrations, one has to know which air currents go into the same junction and are mixed there and which air currents leave from the same junction and have consequently the same properties. Since the number of airways connected to a junction can change in wide limits, it is not advisable to compile this information in a multidimensional array in which many places could remain empty. Instead a series of one-dimensional arrays is used, which was, for the same reasons, the approach with the mesh-lists in the network part of the program also. The procedures chosen for assembling these arrays are similar to the ones used by GEIGER (6). The following 5 arrays are set up:

JNOL	list of all junction numbers arranged according to magnitude of numbers
NGOUT	list of all airways going away from junctions
LOUT	list of last place occupied in NGOUT-list by a series of airways leaving a particular junction
NGIN	list of all airways entering junctions
MIN	list of last places occupied in NGIN-list by a series of airways entering a particular junction

The example given in Fig. 1 may make this procedure clearer. The first junction number considered is JNOL(1) = 3. LOUT(1) = 2 indicates that airways NGOUT(1) = 3 and NGOUT(2) = 5 leave this junction. MIN(1) = 1 indicates that airway NGIN(1) = 1 enters it. The second junction number

Fig. 1: Flowscheme of a simple network described with the help of onedimensional arrays



JNOL	NGOUT	LOUT	NGIN	MIN
3	3	2	1	1
5	5	3	3	3
7	6	5	4	4
8	1	6	6	6
	2		2	
	4		5	

JNOL	JNO	JLR
3	8	4
5	7	3
7	5	2
8	3	1

is JNOL(2) = 5. Airways leaving this junction occupy the places LOUT(1) + 1 = 3 through LOUT(2) = 3 in the NGOUT-list, consequently NGOUT(3) = 6 is the only airway leaving this junction. Airways entering this junction occupy the places MIN(1) + 1 = 2 through MIN(2) = 3 in the NGIN-list, consequently NGIN(2) = 3 and NGIN(3) = 4 are entering this junction. The procedures for all other junctions are the same.

4.2.6 Relate JNO- and JNOL-Lists

In the JNOL-list the junction numbers are arranged according to their magnitude. If a JNO-list has been created by (NVPN >0) reading junction cards in the network part of the program into the computer, the junction numbers in this list can be in any arbitrary sequence which is convenient for input and output. Both lists are correlated by the JLR-list which indicates in which place a junction from the JNOL-list is contained in the JNO-list. Fig. 1 shows, for instance, that the junction JNOL(1) = 3 can from JLR(1) = 4 be located as JNO(4) = 3.

In this section the contaminant concentrations in junctions PROP and PRCH4 are set equal to zero also.

4.2.7 Indices of Starting Junction (Atmosphere)

The indices of the junction at which one wants the temperature and concentration calculation to begin are determined. They are MSTART for the JNOL-list and ISTART for the JNO-list. The temperature of this junction is set to TSTART, which had been stated in the control card. The counter MRC and the marker MARKC are set to zero.

4.2.8 Conditions at Roadway Ends

4.2.8.1 General Remarks

Determined with the help of this program are: contaminant concentrations; methane concentrations; and temperatures.

Changes of concentrations and temperatures can occur in roadways due to contaminants, methane, and heat entering or leaving the air. They can occur in junctions due to mixing of air currents with different concentrations and temperatures. Since the processes in roadways and junctions are completely different, two different program sections have been provided.

Contaminant concentrations in roadways have received the name RDPROP, in junctions PROP, at roadway beginnings PROPJS. Methane concentrations have received the names RDCH4, PRCH4, and CH4JS. Temperatures have received the names TRD, T, and TJS.

Temperature calculations are performed only when demanded (NTEMP > 0). Concentration calculations are performed when demanded (NCONC > 0), but also when only temperature calculations were desired, since varying temperatures can cause varying airflow distributions and, therefore, varying methane concentrations.

The concentration calculations have, at this stage, been kept quite simple since the program requires that entering or leaving contaminants be specified. The temperature calculations have, however, become relatively comprehensive and complicated. On the one hand, the techniques for precalculating mine temperatures are more advanced than those for precalculating contaminant productions. On the other hand, the author attached more importance to these temperature precalculations since ventilation disturbances are mainly caused by thermal forces, not by concentration changes.

Roadway calculations start out with setting the properties PROPJS, CH4JS, TJS at the beginning of roadways, leaving a junction equal to the equivalent properties PROP, PRCH4, T in this junction when the properties are known. For the first calculations this junction will be the starting junction JSTART, later on every junction, for which the calculations of the program section "conditions in junctions", could be completed. The roadways coming out of the junctions are found from the LOUT- and NGOUT-lists and identical calculations are performed for all of them. At the start of every calculation the counter ICFTM is set to zero.

4.2.8.2 Concentration Changes and Added Heat in Airways

A check is made to see if contaminants or heat enter the airway (NO = NCENT). If not, the volume flow rate of the pure (100% concentration) contaminant CONTAM, the volume flow rate of the gas current carrying the contaminant CONTQ, and the heat addition HEATAD are set equal to zero. If a contaminant or heat enters the mine air, it can be specified in the contamination cards in several ways. In section 1 the volume flow rate of the gas current carrying the contaminant CONT, its concentration CONC (%), and the heat HEAT are specified. CONTAM, CONTQ and HEATAD are determined from:

CONTAM = CONT*CONC/100

CONTQ = CONT

HEATAD = HEAT

CONT and HEAT can have negative signs for gas absorptions and heat sinks. If the inflow CONT is so large that it influences the airflow distribution, which will very rarely be the case, a fixed quantity airway similar to compressed air discharges should be provided for it.

Section 2 of the contamination card applies to oxygen rich fires and states the oxygen concentration O2MIN with which the fumes leave the fire zone. The assumption is made that all consumed oxygen is converted into CO_2. The oxygen concentration entering the fire zone is 0.21 - PROPJS, the oxygen consumption is 0.21 - PROPJS - O2MIN/100, the volume flow rate of CO_2 consequently:

CONTAM = (0.21 - PROPJS - O2MIN/100) * Q

No additional gas enters the mine:

CONTQ = 0

The rate of heat generation is, with 437 Btu/ft^3 of consumed oxygen:

HEATAD = CONTAM * 437

Section 3 applies to fuel rich fires and contaminant and heat production, SMPO2 and HTPO2 per ft^3 of oxygen delivery, have to be stated. One obtains:

CONTAM = (0.21 - PROPJS)*Q*SMPO2

HEATAD = (0.21 - PROPJS)*Q*HTPO2

CONTQ = 0

At this place, a suitable function relating contaminant and heat production with the oxygen supply can easily be introduced, if so desired and such a function is available.

Contamination and methane concentration at the end of the roadway can then be calculated from:

RDPROP = [PROPJS(Q-CONTQ) + CONTAM]/Q

RDCH4 = [CH4JS(Q-CH4V) + CH4V]/Q

If a temperature calculation is desired (NTEMP > 0), the heat addition HEATAD finds use; if it is not desired TRD is set equal to zero, JF made negative to mark the completed roadway calculation, and the rest of this program section is omitted.

4.2.8.3 Temperature Changes in Airways

The air temperature is increased by heat addition and subsequently reduced again by heat transfer to the airway walls. The temperature increase:

$\Delta t = t - t_1$ is

$\Delta t = \text{HEATAD}/(Q*DR*CP)$

where: t_1 = temperature before heat addition
DR = reference density
CP = specific heat of air

If for CP a temperature function CP = a + b*t is assumed, one obtains:

$$t = -(a/b - t_1)/2 + \sqrt{((a/b - t_1)/2)^2 + a*t_1/b + \text{HEATAD}/(Q*DR*b)}$$

and with a = 0.2376 Btu/lb°F, b = 0.000024 Btu/lb°F°F,

$$t = -4950 - t_1/2 + \sqrt{(4950 - t_1/2)^2 + 9900\, t_1 + \text{HEATAD}*10^6/(Q*24*DR)}$$

This equation is based on pure air. One might dispute if the assumption of temperature variable specific heats is necessary, since the influence of the air composition is neglected, but the introduction of variable specific heats causes no great difficulties.

Heat transfer to the airway walls lets the air temperature drop from an initial value of t_1 to t, which for horizontal airways can be calculated from (7):

$$t = t_r + (t_1 - t_r) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0))$$

where: t_r = rock temperature
R_0 = 2 A/O = hydraulic radius

K(α), the so-called "coefficient of age", is a dimensionless scale for the thickness of the insulating rock layer surrounding airways which increases with age. Its use allows treating non-steady state heat transfer like a steady state process and has, therefore, in mine ventilation become common practice.

In non-horizontal airways, the change of rock temperature with depth and the so-called "autocompression heat", the increase of air temperature with air pressure, have to be included. If one makes the justified assumption that the rock immediately surrounding an airway has, with some age of the airway, assumed the same temperature as the air ordinarily passing through it, geothermal and autocompression gradients become the same and the temperature can be calculated from (7):

$$t = t_{r0} - g_a \, LA \sin\beta + (t_1 - t_{r0}) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0))$$

where: g_a = autocompression gradient
β = slope angle (positive for ascending, negative for descending ventilation)
t_{r0} = rock temperature at airway beginning

If an average rock temperature TROCK = $t_{r0} - g_a$*DZRD/2 is defined, one obtains with DZRD = LA*sin β:

$$t = TROCK + (t_1 - TROCK) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0))$$

$$- g_a*DZRD/2 * (1 + \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0)))$$

The autocompression gradient g_a can be calculated from the mechanical heat equivalent 778.26 ft-lb/Btu and CP as:

$$g_a = 1/(778.26*CP) \; ^{\circ}F/ft$$

The coefficient of age $K(\alpha)$ is a function of the dimensionless Fourier (FO) and Biot (BI) numbers. They are defined as:

$$FO = TIME * HA/R_0^2$$

$$BI = HC * R_0/HK$$

where HA and HK are the previously introduced thermal diffusivity and conductivity and HC is the convection coefficient.

$K(\alpha)$ has been calculated by several researchers whose results are in good agreement (7). A solution for short periods of heat exchange has been provided by SCERBAN and Kremnev (17) which reads:

$$K(\alpha) = BI - BI^2 *f(x)/(0.375 + BI)$$

$$\text{where } f(x) = [1 - \exp(x^2)*(1 - \frac{2}{\sqrt{\pi}} \int_0^x \exp(-x^2)dx)]$$

$$\text{and } x = (0.375 + BI)\sqrt{FO}$$

For the calculation of the error function

$$\phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-x^2)dx$$

in this computer program, the author introduced the power series:

$$\phi(x) \approx \frac{2}{\sqrt{\pi}} \sum_{n=0}^{\infty} \frac{(-1)^n}{n} * \frac{x^{2n+1}}{2n+1} \qquad \text{for } x \leqq 2.5$$

$$\frac{\sqrt{\pi}}{2}[1 - \phi(x)] \approx \frac{\exp(-x^2)}{2x}[1 - \frac{1}{2x^2} + \frac{1*3}{(2x^2)^2} - \frac{1*3*5}{(2x^2)^3} + \cdots]$$

$$\text{for } x > 2.5$$

Development of the series is stopped when the terms in the brackets become smaller than 10^{-5}.

The convection coefficient HC is a function of air thermal conductivity HKA, Reynolds number RN, Prandtl number PR, and airway dimensions. A formula proposed by KREITH (13) for the turbulent flow in smooth ducts seems to be an average among the many suggestions found in the literature (7). It reads:

$$HC = 0.023 \frac{HKA}{2R_0} \; RN^{0.8} \; PR^{0.333}$$

With the Prandtl number being essentially independent of the air temperature, and having a value of 0.70 between 0 and 1600°F and with $R_0 = 2A/O$, this becomes:

$$HC = 0.005 \frac{HKA*O}{A} \quad RN^{0.8}$$

A correction for rough walls can be made by introducing the correction factor (7):

$$COR = \left(\frac{f}{f_0}\right) (100/RN)^{0.125}$$

where: f = friction coefficient of rough wall
f_0 = friction coefficient of hydraulically smooth wall

The friction coefficient f is proportional to the friction factor KF. For a density of 0.075 lb/ft^3 the relationship is f = KF/809, for a reference density DR it is f = KF*0.075/(809*DR).

f_0 (FRO in the program) can be obtained from:

$$f_0 = 0.032 + 0.221/RN^{0.237}$$

The thermal conductivity of air can be approximated by:

$$HKA = 0.015 \; (T/492)^{0.81} \qquad Btu/ft\ h\ ^{\circ}F$$

where: T = absolute air temperature (°R)

The temperature dependence of air viscosity VISC and weight WT, both of which are needed for the Reynolds number, can be expressed by:

$$VISC = 10^{-4} * 1.43 \left(\frac{T}{492}\right)^{1.75} \qquad ft^2/sec$$

$$WT = DR * (TR + 460)/T$$

where: TR = reference temperature

and the Reynolds number:

$$RN = V\ D_o/Visc$$

where: D_o = hydraulic diameter = 4 A/O
V = air velocity

with V = Q*DR/(60*A*WT)

RN = DR * Q/(15*WT*O*VISC)

The program starts the temperature calculation by setting the temperature at the beginning of the airway TJS equal to the pertinent junction temperature T. If a heat addition takes place (HEATAD = 0), the temperature behind the heat source is determined and made equal to TJS. It is stored in the TFSI file also because it is needed in later program sections.

For the calculation of WT, VISC, CP, and HKA, the average temperature in the roadway is needed. It is tentatively (ICFTM = 0) assumed to be the arithmetic mean between starting and rock temperature (TM = (TJS + TROCK)/2). If after the completion of the temperature calculation the result shows that the temperature at the end of the roadway TRD is more than 50^oF different from TROCK, a new TM is assumed (ICFTM = 1). Since the temperature along an airway follows an exponential curve of the type:

$$TRD = TROCK + (TJS - TROCK)\ \exp(-X*LA)$$

the factor X can be calculated from the last calculated TRD value as:

$$X = \frac{1}{LA}\ [\ln\ (TJS - TROCK)/(TRD - TROCK)]$$

and TM can be determined as the integral mean $1/LA \int TRD*dLA$ as:

$$TM = TROCK + \frac{(TJS - TROCK)}{LA*X}\ (1 - \exp(-X*LA))$$

This procedure of assuming a new TM is repeated until the calculated values for TRD vary less than 50^oF. Since TM is, at this place, only needed to take the changes of the air properties WT, VISC, CP, and HKA with temperature into account, this threshold of 50^oF seems to be stringent enough. After these properties have been determined, Reynolds number RN, convection coefficient HC, Fourier number FO, Biot number BI, and coefficient of COAGE are calculated. The exponent in the temperature formula:

$$HK*LA*O*COAGE/(Q*DR*CP*R_0)$$

becomes with R_0 = 2 A/O and the factor 60 min/hr, when HK is, as customary, expressed per hour but Q is stated per minute:

$$XNEW = HK*LA*O^2*COAGE/(120*DR*Q*CP*A)$$

and TRD can be calculated. XNEW is placed in a file for future use. After the calculation has been completed, the roadway is marked by making its finishing junction JF negative.

4.2.9 Conditions in Junctions

Junctions, for which the junction calculations have been completed, receive a negative number JNO. They are disregarded in this program section. For the other junctions with a positive JNO, the airways going into a junction are located from the MIN- and NGIN-lists. In order to be able to perform a junction calculation the roadway calculations for these airways must have been completed, which means that they must all have negative finishing junctions. If they don't, the junction is disregarded. For the rest, the air quantities Q flowing into the junction (SUMAIR), the contaminant quantities RDPROP * Q (SUMPR), the methane quantities RDCH4 * Q, and the enthalpies TRD * Q * CP (SUMHT) are all summed up. Contaminant and methane concentrations in the junction are calculated from:

$$PROP = SUMPR/SUMAIR$$

$$PRCH4 = SUMCH4/SUMAIR$$

the temperatures from:

$$T = SUMHT/(SUMAIR*CP)$$

which with CP = 0.2376 + 0.000024 * T results in:

$$T = -4950 + \sqrt{4950^2 + SUMHT/(SUMAIR*0.000024)}$$

The program returns to the section "conditions at roadway ends" where the number JNO of the junctions, with completed junction calculations, is made negative.

4.2.10 Recirculation, First Approximation

If, in the previous section, no junctions with a positive JNO can be found for which all entering airways have negative finishing junctions

JF, recirculation occurs in the network. The alternating roadway and junction calculations cannot be continued since concentrations and temperature of recirculated air entering a junction are not known. This difficulty is overcome by introducing estimated concentrations and temperatures for all recirculated airflows, with which the junction and roadway calculations are completed. The results obtained for the recirculated airflows are then taken as new, better estimates and the concentration and temperature calculations for the network are repeated. This process is continued until the differences between results and estimates are smaller than the thresholds CRITSM, CRITGS, CRITHT stated in the control card.

A variety of methods was tried to overcome the recirculation problem. With the complexity of most ventilation networks, only iteration methods seem to be practical. The herein described procedure, which is similar to the adjustment of trigonometric height measurements, showed the best convergence.

The program section starts by setting NREC = 1. NREC helps in searching for junctions where the ratio of recirculated air QREC to not recirculated air QIN is $QREC/QIN \leqq NREC/2$. If no such junction can be found, NREC is stepwise increased.

All junction numbers JNO are then checked for their signs. Negative junction numbers are counted by L and then disregarded because the junction calculations have been completed for them. Positive junction numbers JNO are one after the other compared with the finishing junctions JF of airways. Junctions JNO, for which no negative JF can be found ($JNO + JF \neq 0$, $N \leqq 0$), are disregarded because no airway with a complete roadway calculation exists for them. The remaining junctions JNO are the ones where recirculated air enters the intake air.

To find reasonable first estimates for the recirculated air, concentrations RDPROP, RDCH4, and temperatures TRD for the airways with completed roadway calculations ($JNO + JF = 0$) as well as their airflow rates Q are summed up (SRPR, SRCH4, STRD, QIN) and average values AVRPR, AVRCH4, AVTRD are calculated. The airways with recirculated air are entered into a temporary file (MEMREC) first and their airflow rates are summed up also (QREC). If a comparison shows that the recirculated airflow rate QREC for an airway is smaller than one half of the not recirculated air QIN (QREC*2/QIN - NREC $\leqq$ 0), the airway and the first estimates for its concentrations and temperature are entered into the permanent recirculation files. If QREC is larger than 1/2 QIN, the next positive junction JNO is tried. If no junction with QREC $\leqq$ 1/2 QIN could be found, NREC is increased by 1 which changes the criterion to QREC $\leqq$ QIN. If again no junction can be found, NREC is increased to 3 and so on.

The recirculation files have been introduced to avoid the repetition of this search procedure in every step of the iteration process, in which concentrations and temperatures of recirculated airflows are determined. Airways with recirculation are counted with MRC, their place in the airway list is transcribed from the temporary file MEMREC into NOREC, and the first estimates for their concentrations and temperatures are entered into ESTPR, ESTCH4, ESTTR. After this, they receive these estimated values as their roadway end properties RDPROP, RDCH4, TRD, and their finishing junctions are made negative as if the roadway calculation had been completed. The place of the pertinent junction in the JNOL-list is located and the junction calculation for this junction completed. The program statements for doing this are essentially the same as in the program section "conditions in junctions". The program returns to the section "conditions at roadway ends".

4.2.11 Recirculation, Preparation for Iteration

If in the previous program section it has been found that all junction numbers JNO are negative (L $\geqq$ NJ), the calculation of concentrations and temperatures is complete. All finishing junctions JF and junction numbers JNO are made positive again. If the counter MRC for the recirculation files indicates that no recirculation exists (MRC = 0), the rest of this program section is omitted. For MRC > 0 the differences DIFPR, DIFCH4, DIFTRD between last estimated values ESTPR, ESTCH4, ESTTR and last calculated results RDPROP, RDCH4, TRD are determined for every airway with recirculation. If these differences are larger than the thresholds CRITSM, CRITGS, CRITHT, a marker L is made > 0. The last calculated properties RDPROP, RDCH4, TRD are made the new estimates ESTPR, ESTCH4, ESTTR, and the finishing junctions JF are made negative. If this was the last iteration, these junctions will be the only negative ones in the JF-list and can be used to identify recirculation paths. The iteration counter ITCT is raised by one. If a positive marker L indicates that more iterations are necessary, it is checked to see if the maximum number ITN, which had been stated in the control card, is not exceeded. If not, the computer goes back to the beginning of the section "conditions at roadway ends" to start another iteration. If ITN would be exceeded, the marker MARKC is made positive for an appropriate message. If temperature and network calculations were demanded, the next program section is entered, if not, this section is omitted and a message printed.

4.2.12 Calculation of Natural Ventilation Pressure

This section determines the thermal forces which are caused by changed temperature distributions and introduces them into the ventilation system.

The energy per unit mass, which is required to overcome the flow resistance of an airway, is proportional to the velocity of the air in the airway. The same applies to the pressure loss when the latter is based on a constant reference density. If the density of the air changes, energy or pressure losses will change inversely proportional to the square of the density ratios. If the density change is caused by temperature changes, energy or pressure losses will change proportional to the square of the absolute temperature ratios. This change can, in a mass flow rate based network calculation, be accounted for by multiplying the resistance factor R by a factor $(T_2/T_1)^2$, where the subscripts 1 and 2 denote the old and new temperatures.

Since temperatures along the length LA of an airway vary, it is necessary to use a mean square temperature Tm^2, which for accurate calculations should be:

$$T_m^{\ 2} = \frac{1}{LA} \int T^2 \, dLA$$

With the previously quoted formula (section "conditions at roadway ends"):

$$t = t_r + (t_1 - t_r) \exp(-X*LA) - \frac{g_a DZRD}{2} (1 + \exp(-X*LA))$$

one obtains with the abbreviations:

$$E = g_a * DZRD/2, \; B = (t_1 - t_{rock}), \; XNEW = X*LA$$

$$T_m^2 = (T_{rock} - E)^2 + \frac{(E - B)^2}{2*XNEW}(1 - \exp(-2*XNEW))$$

$$+ \frac{2}{XNEW}(T_{rock} - E)*(B - E)*(1 - \exp(-XNEW))$$

The natural ventilation pressure can be calculated from:

$$H_N = \frac{DR}{5.2} * \frac{1}{T_m} \oint T\, dZ$$

$\oint T\, dZ$ can be replaced by $\Sigma\, t_m$*DZRD when one assumes airways with constant slopes. This requires knowing the mean temperature $t_m = 1/LA \int t\, dLA$ in the airways. It can be calculated from the above formula for t as:

$$t_m = t_{rock} + \frac{B}{XNEW}(1 - \exp(-XNEW)) - E(1 + (1 - \exp(-XNEW))/XNEW)$$

The program starts this section by setting the temperature at the beginnings of airways T1 equal to the temperature T of the starting junction JS. If contamination in an airway occurs (NCENT = NO), T1 is set equal to the calculated temperature TFSI behind the contamination source. The mean temperature TMRD (i.e. t_m) and mean square absolute temperature TMSQR (i.e. T_m^2) are calculated next for every airway. To account for the pressure loss changes with temperature, the resistance factor R is set to new adjusted values which are the product of RSTD and the ratio TMSQR/(TR + 460)^2. RSTD is the resistance factor of the airways based on the reference temperature TR.

If the marker NSFLOW $\leq$ 0 indicates that an airflow reversal has taken place, a new mesh selection is necessary before the natural ventilation pressure can be calculated. The rest of this program section is, therefore, omitted. With NSFLOW > 0, the natural ventilation pressures are calculated for all meshes of the network.

Since it is the thermal forces (i.e. the changed flow resistances and natural ventilation pressures and among these mainly the latter) which can alter the temperature distribution and with it the thermal forces again, the changes of natural ventilation pressures from one iteration to the next one are made the threshold for the decision whether more iterations should be performed. The natural ventilation pressure FNVP of the last iteration is therefore preserved as ONVP before a new value FNVP is calculated. $\oint T\, dZ = \Sigma\, t_m$*DZRD is calculated by summing up in HSU the products FRNVP = TMRD*DZRD for all airways of a mesh. The direction in which the computer progressed in forming the mesh is accounted for by FACT (+1 for direction JS to JF, -1 for direction JF to JS). The average temperature in the mesh is calculated as the weighed arithmetic mean by summing up in TSU all absolute values of FRNVP and dividing them by two times the total elevation change in the mesh.

Errors in the statement of DZRD can make the sum of all elevation changes around a mesh unequal to zero. This means that the temperature-elevation plot of the mesh is not closed which can, even for small errors in DZRD, cause very large errors for the natural ventilation pressure. The sum of all positive elevation changes ZUP and all negative changes ZDOWN in traversing around the mesh is, therefore, determined. For ZUP $\neq$ ZDOWN the mesh is closed by substituting the reference temperature for the gap.

The differences between old and new natural ventilation pressures are calculated and their absolute values summed up in DNVP.

4.2.13 Reroute to Appropriate Program Section

Calculations of the natural ventilation pressure are necessary at two places in the program: within the network calculation; at the completion of the temperature calculation in order to find out if such significant changes have taken place that a new network calculation is required.

If the former is the case and the natural ventilation pressures are wanted for a network calculation, this is indicated by the marker NNVP > 0 and the program returns to the section "iteration" of the network part. The marker NNVP and the counter ITCT are set to zero. If the latter is the case, it is checked to see if the average change in the natural ventilation pressure between the last two iterations was larger than 0.001 inches watergage per mesh. If it was smaller, the calculation is considered to be completed and the section "output of results" is entered. If it was larger, it is checked to see if the maximum number of iterations MADJ between network and concentration part, which had been stated in the control card, has been reached (MADJC - MADJ $\geq$ 0). In this case a message is printed before the output section is entered also. For (MADJC - MADJ < 0, the counter MADJC is raised by one, the counter ITCT and the marker MARKN are reset to zero, the marker NSNVP is set to one, all finishing junctions JF are made positive and the airflow rates Q are divided by 10^5 again. If NSFLOW $\leq$ 0 indicates that a new mesh selection is necessary, NSW is made equal to one and the section "arrange airways to size and magnitude R*Q" is entered. For NSFLOW > 0, the calculation is continued in the section "iteration".

4.2.14 Output of Results

The pressure losses for the regular airways are calculated and the fan pressure extracted from the R-file. If the stated maximum number of iterations ITN was exceeded in the network part (MARKN > 0) or in the concentration part (MARKC > 0), warnings are printed.

A table with the results of the calculations for the states of the airway ends comes next. It lists airway numbers NO, junctions JS and JF, calculated airflow rates Q, temperatures TRD, smoke concentrations RDPROP, methane concentrations RDCH4, and pressure losses P. The term "smoke" stands for "contaminant" because it is shorter and this program will mainly be used for fire emergency plans. Airflow rates and pressures are based on reference densities.

Another table with the results of the calculations for the junctions follows. It contains junction numbers JNO, temperatures T, smoke concentrations PROP, and methane concentrations PRCH4. The number of iterations MADJC between network and concentration parts of the program is printed next.

The list of all finishing junctions JF is then scrutinized for negative values which indicate recirculation. The pertinent airways and their junctions are printed out together with an explanation that a recirculation path is closed at this place.

Next, it is checked to see if any threshold limits for critical states (WRNPR, WRNGS, WRNSM, WRNHT) were specified. If not, a message is printed. If yes, all airways are checked for critical states and if any are detected they are placed in a printed list of airways together with the critical conditions. The same is done for junctions.

With the help of the counter NRCT and the NREV-list, which were both established at the beginning of the section "flowscheme", airways with airflow reversal are finally printed out. To make the airways in the printed list appear in the same sequence as in all other airway lists, they have to be extracted in this sequence from the NREV-list. With this last list, the output is complete.

4.3 COOPERATION OF PROGRAM SECTIONS

The cooperation of the different program sections is shown in Figs. 2a - 2e. The computer nomenclature, which has been used in these figures, is listed in Table 1.

Fig. 2a shows all existing major connections between program sections. Fig. 2b indicates which connections are used when only a network calculation is desired. Fig. 2c does the same for a concentration or temperature calculation without a network calculation. Fig. 2d refers to a combined network, concentration, and temperature calculation (NETW=1, NCONC=1, NTEMP=1), where the stated number of iterations is sufficient (ITCT < ITN, MADJC < MADJ), where no airflow reversals occur in the iteration process (which would make new mesh selections necessary), and where no recirculation occurs. Fig. 2e shows the same for the case of airflow reversals during the iteration process.

Figs. 2d and 2e are simplifications. Normally airflow reversals will happen at some stages of the iteration process and not happen at others. The reversals, in turn, can cause or remove recirculation. An insufficient number of iterations will be the rule at the start of the calculations also. The usual flowchart will, therefore, resemble Fig. 2a more than Figs. 2d or 2e.

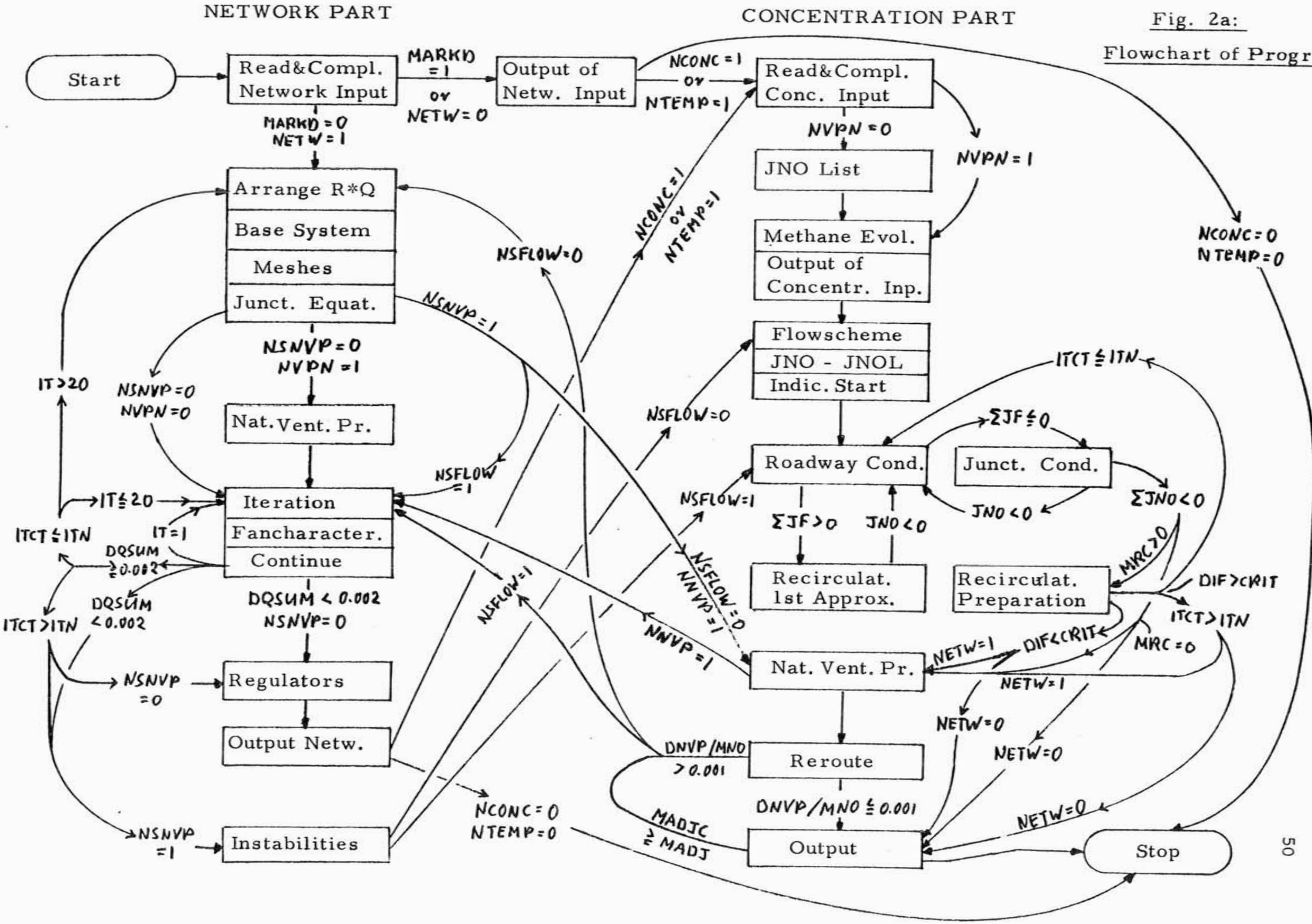
4.4. EXAMPLES FOR PROGRAM USE

4.4.1 General Remarks

The program has been designed in such a way that it can be used for all mine ventilation systems, coal mines and hardrock mines alike. It

Fig. 2a:

Flowchart of Program



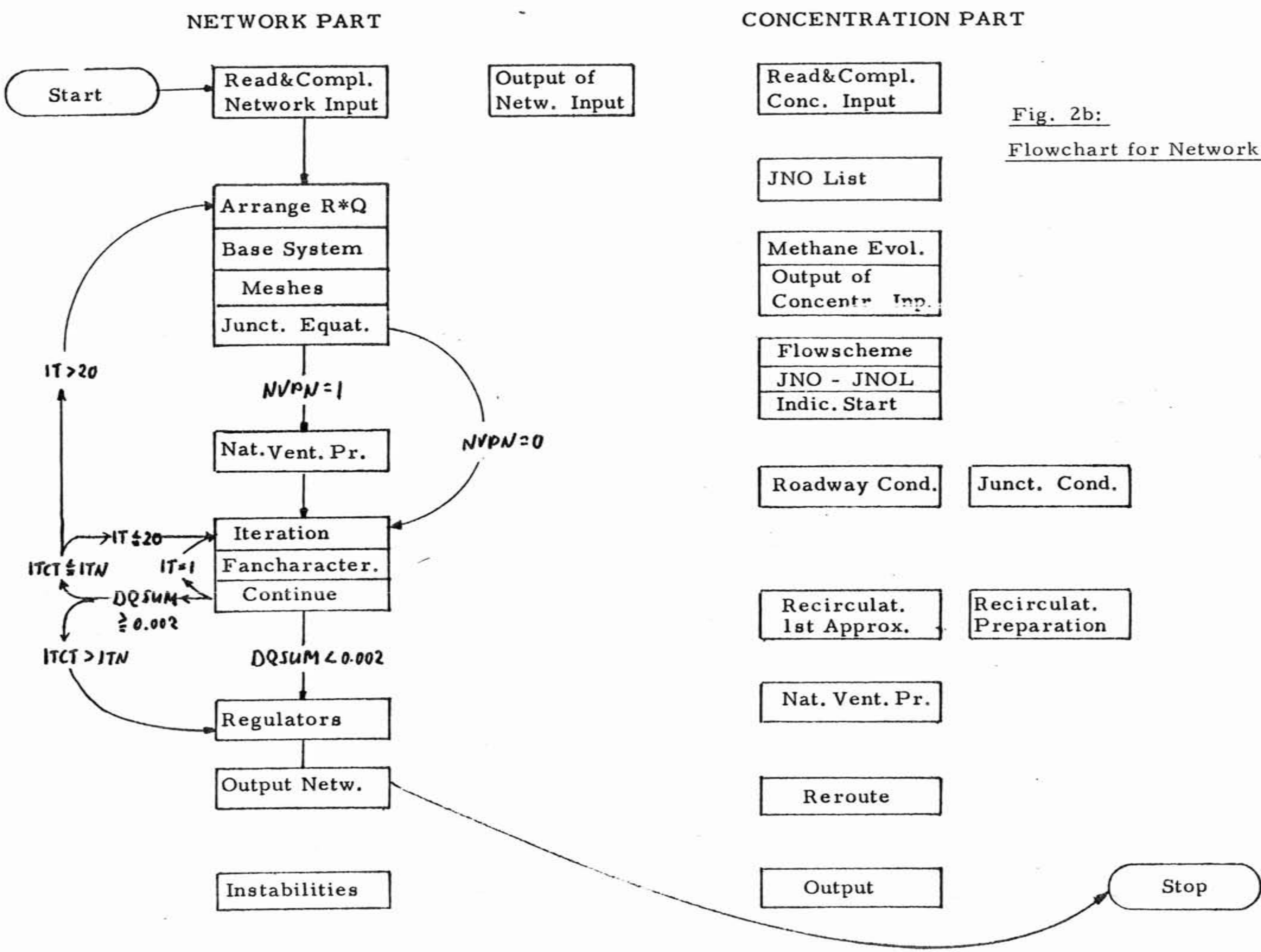


Fig. 2b:

Flowchart for Network Calculation

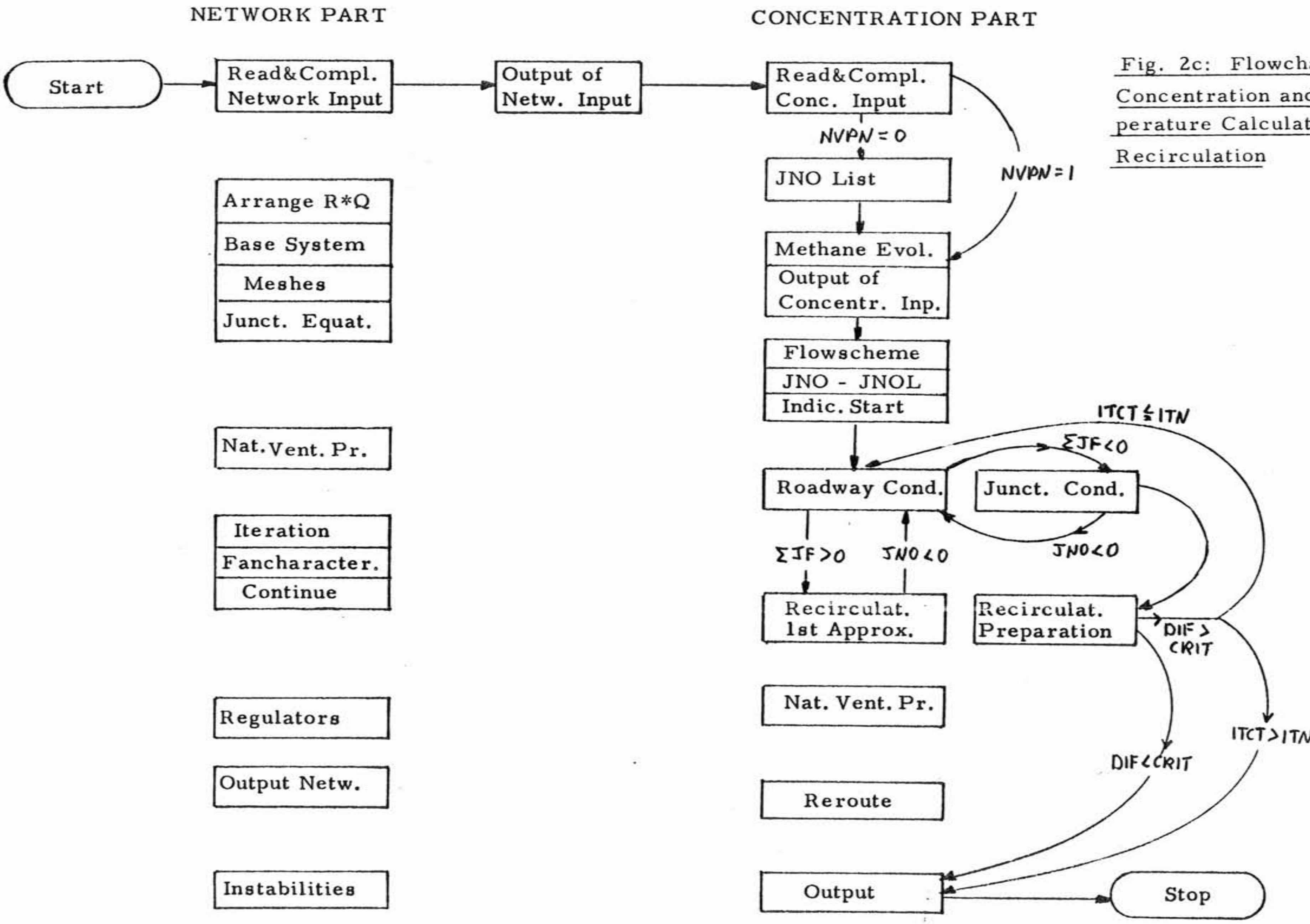


Fig. 2c: Flowchart for Concentration and Temperature Calculation with Recirculation

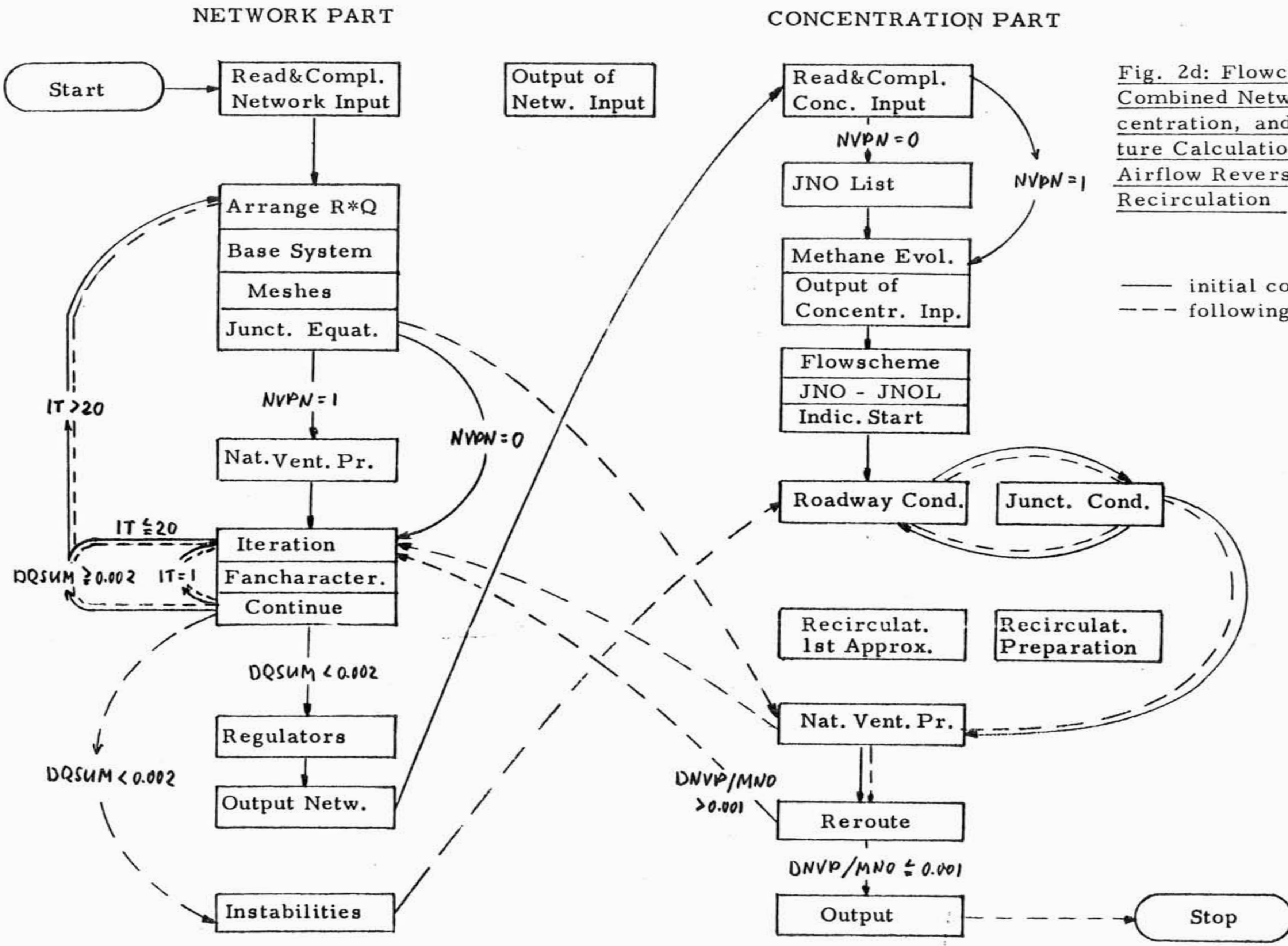


Fig. 2d: Flowchart for Combined Network, Concentration, and Temperature Calculations Without Airflow Reversals or Recirculation

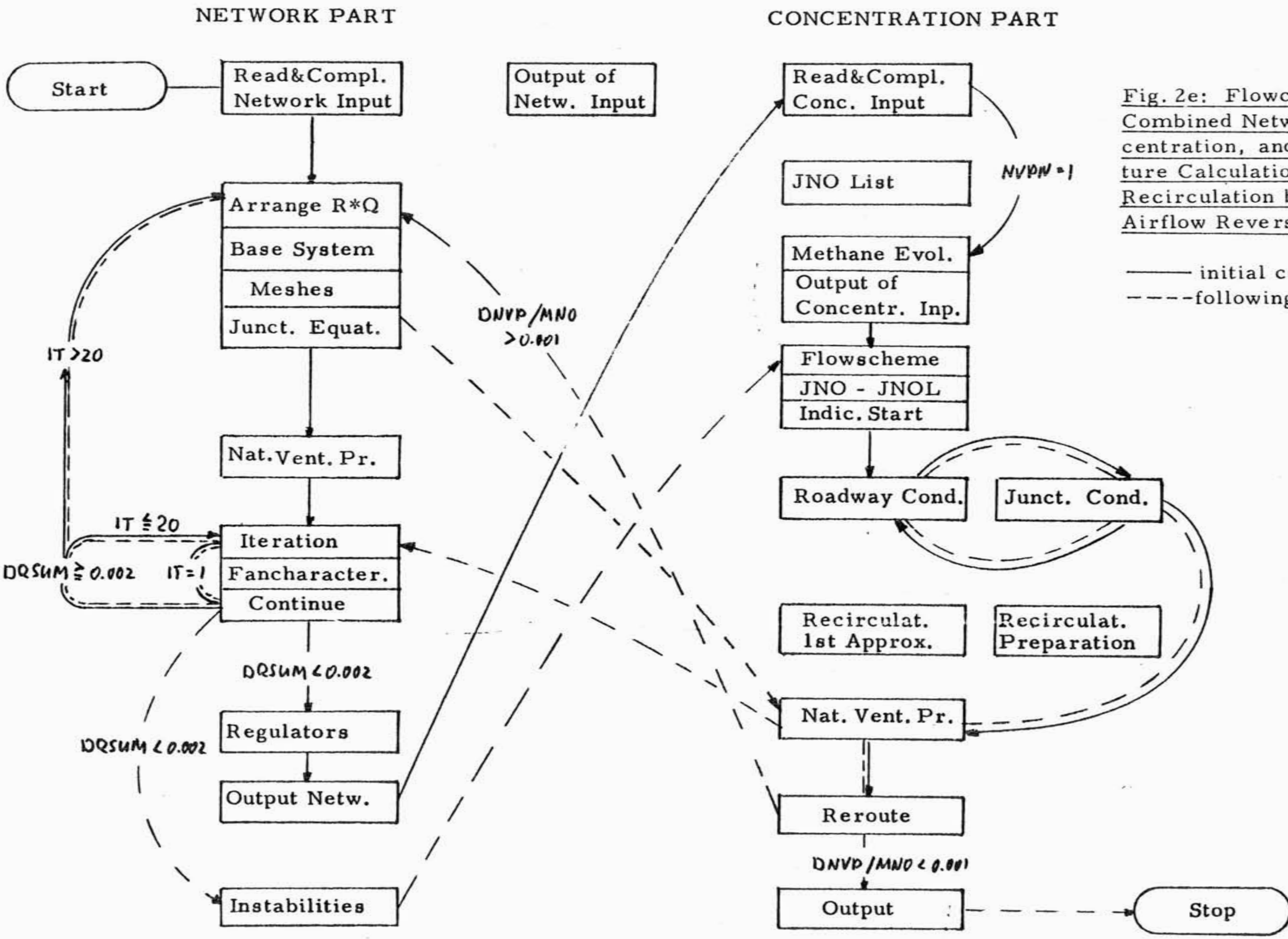


Fig. 2e: Flowchart for Combined Network, Concentration, and Temperature Calculations without Recirculation but with Airflow Reversals

——— initial course

- - - - following courses

Table 1: Computer Nomenclature for Cooperation of Program Sections

CRITGS CRITHT CRITSM	thresholds for corrections in iterations of concentration part of program
DIFCH4 DIFPR DIFTRD	change in properties between last two iterations of concentration part of program
DNVP/MNO	average change of natural ventilation pressure per mesh
0.001	threshold for adjustment of natural ventilation pressure to changed temperature distribution (0.001 inches watergage)
CQSUM	sum of all corrections in one network iteration
0.002	threshold for corrections in network iterations (200 cfm)
IT	counter of iterations in network part for every given mesh assmebly
ITCT	counter of iterations in network and concentration parts of program
ITN	maximal allowed number of iterations
JF	finishing junction of airway; a negative sign of JF is used as marker for completed roadway calculations
ΣJF<0	roadway calculations for all airways going into one particular junction have been completed
JNO	junction number; a negative sign of JNO is used as marker for completed junction calculations
ΣJNO<0	all junction calculations have been completed
MADJ	maximal allowed number of exchanges between network and concentration parts of program
MADJC	counter of exchanges between network and concentration parts
MARKD>0	no resistance nor dimensions were stated for an airway
MRC	counter of airways closing recirculation paths
NCONC>0	a concentration calculation shall be performed

Table 1 (continued)

NETW>0	a network calculation shall be performed
NNVP>0	this is a natural ventilation pressure calculation within the network part of the program
NVPN>0	junction cards were used and read into the computer
NTEMP>0	a temperature calculation shall be performed

can perform network (flow distribution), concentration, and temperature calculations separately as well as combined. Concentration calculations can be performed for methane and other contaminants, separately or combined. The quantities of contaminants entering the ventilation system can be stated directly as flow rates and concentrations or, as for fires, as a function of the oxygen supply.

Rather than demonstrating all possible combinations, a number of examples shall be given which are all different from each other but still relatively close to mine ventilation realities. The examples have been selected for an easy understanding of how to use the program rather than for a demonstration of the program capabilities. All examples are based on the same comparatively small ventilation network to make the understanding simple and not to burden this report with too much input and output information. The program has been used so far for mines with up to 180 airways.

The selected ventilation system is that of a small multilevel coal mine with single entries and longwall faces. This type of mine was chosen because it represents something like a blend of hardrock and coal ventilation systems. Sufficient nonhorizontal airways, like in many hardrock mines, exist for the development of large thermal drafts and at the same time methane evolution is taking place. Fig. 3 shows the ventilation plan of this system. Those input data, which were used in all examples, are compiled in Tables 2 through 6.

The data from Tables 2 through 4 are read into the computer in the network part of the program. Table 2 lists the contents of the airway and additional airway cards, table 3 the contents of the junction cards. Information on temperatures and elevations of junctions is required only when a network calculation with natural ventilation pressures, based on actually observed temperatures, is desired. If not, elevation differences can be stated and temperatures can be calculated in the concentration part of the program and can be entered here or later via additional junction cards. Table 4 lists the points of the fan characteristic which are entered with the fan characteristic cards. Fig. 4 shows a plot of these fan characteristics.

The input, which during the concentration part of the program is read into the computer has been kept to a minimum. Table 5 lists methane

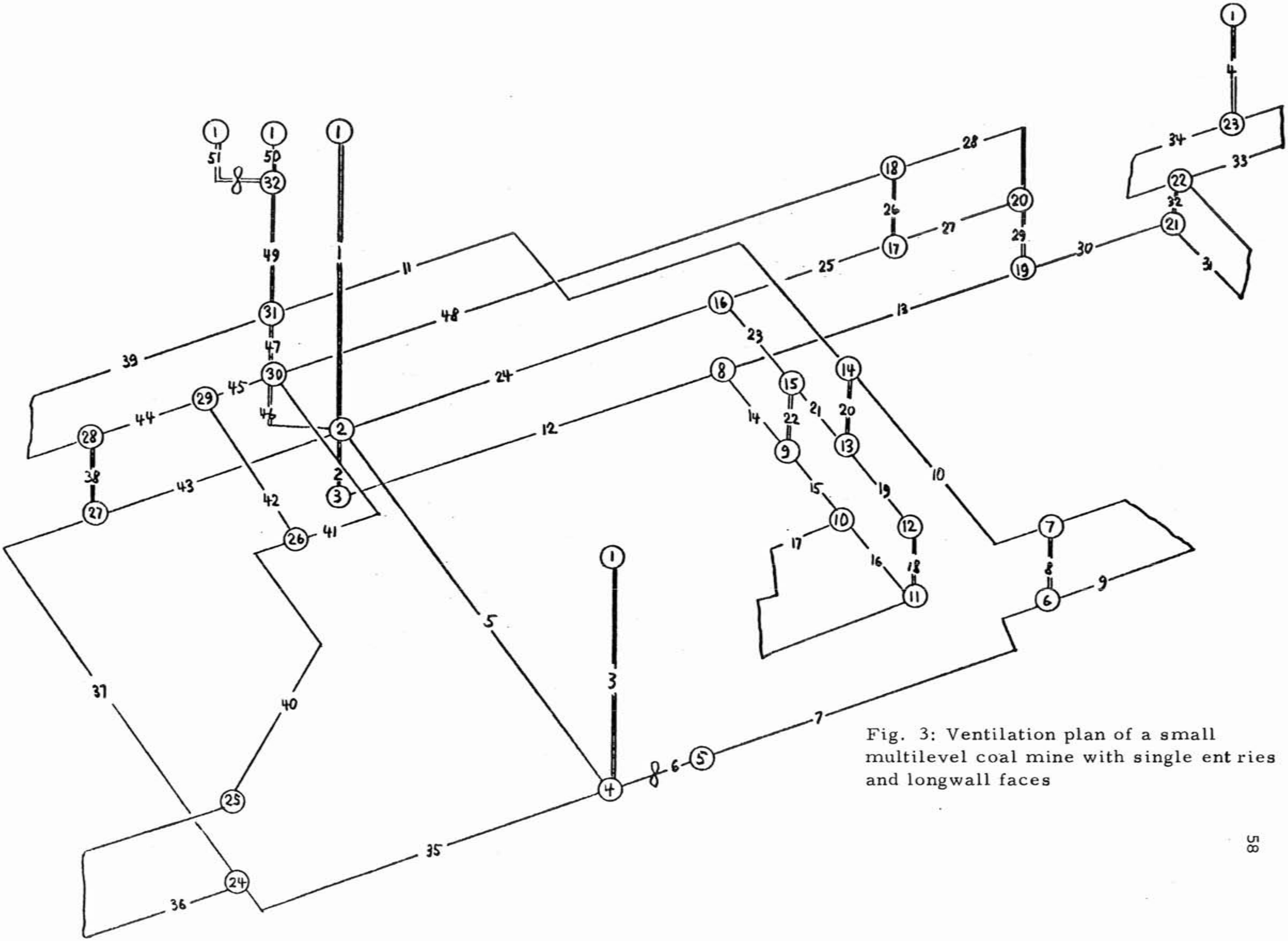


Fig. 3: Ventilation plan of a small multilevel coal mine with single ent ries and longwall faces

Fig. 4: Fancharacteristics

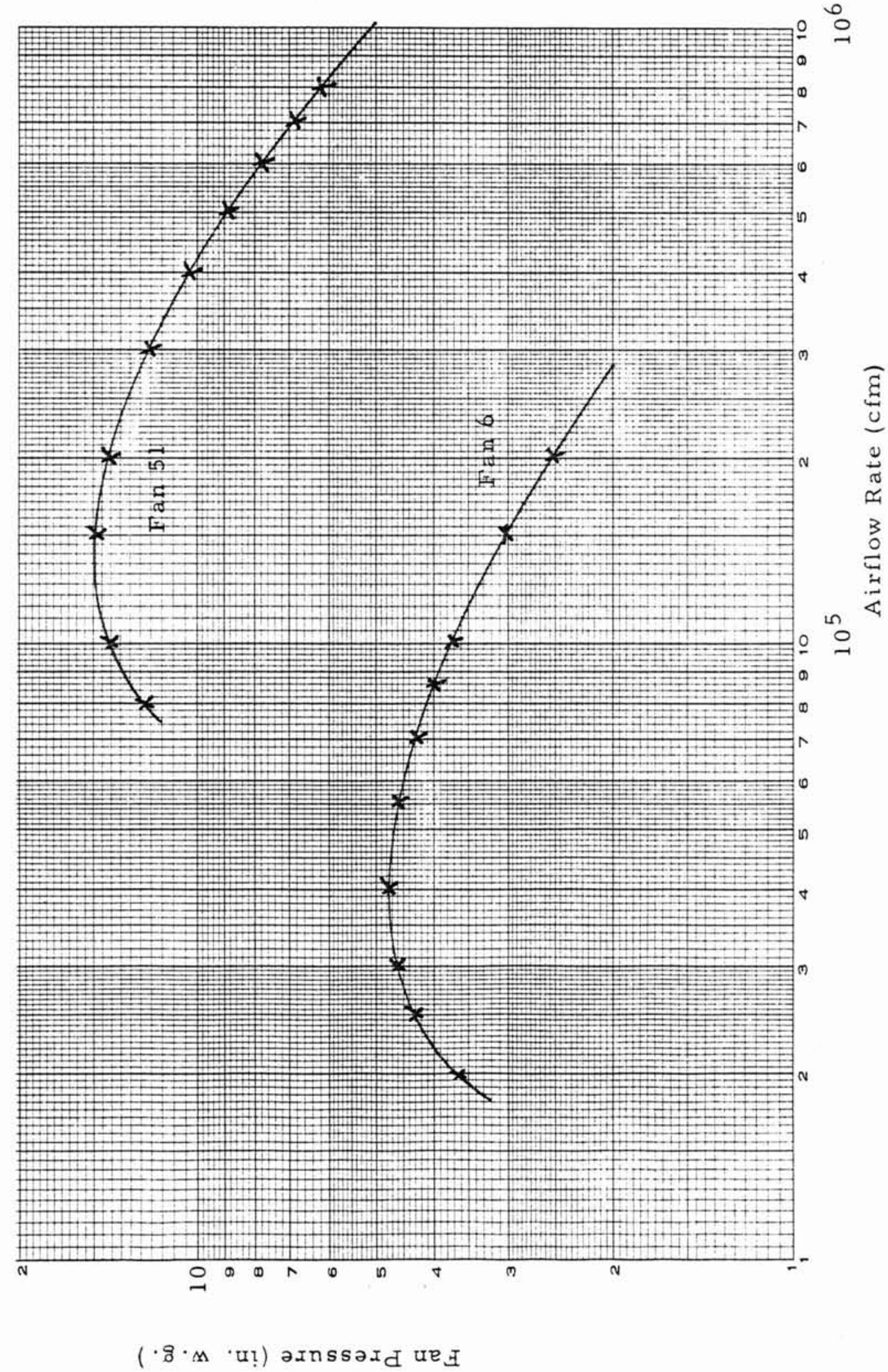


Table 2: Input Data for Airways

NO NETWORK CALCULATION HAS BEEN PERFORMED, THESE ARE THE INPUT DATA

AIRWAY	FROM	TO	AIRFLOW	AIRWAY TYPE	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	200000.	0	2597	200.0	.156	250	50.0
2	2	3	60000.	0	325	200.0	.048	250	50.0
3	1	4	100000.	0	27	200.0	.479	250	50.0
4	1	23	30000.	0	2580	200.0	.995	250	50.0
5	2	4	35000.	0	2900	80.0	2.400	100	35.0
6	4	5	60000.	1	100	80.0	4.000	100	35.0
7	5	6	60000.	0	2700	80.0	2.307	100	35.0
8	6	7	5000.	0	524	120.0	1888.233	350	44.0
9	6	7	60000.	0	1700	80.0	9.923	100	35.0
10	7	14	70000.	0	1650	80.0	3.239	100	35.0
11	14	31	70000.	0	4500	80.0	20.002	100	35.0
12	3	8	53600.	0	2700	80.0	.360	100	35.0
13	8	19	20000.	0	2050	80.0	41.490	100	35.0
14	8	9	50000.	0	600	80.0	.821	100	35.0
15	9	10	35000.	0	600	80.0	1.437	100	35.0
16	10	11	6000.	0	600	80.0	124.385	100	35.0
17	10	11	30000.	0	1100	80.0	5.500	100	35.0
18	11	12	35000.	0	319	120.0	3.900	350	44.0
19	12	13	35000.	0	600	80.0	3.772	100	35.0
20	14	13	6000.	0	524	120.0	4.000	350	44.0
21	13	15	35000.	0	550	80.0	1.108	100	35.0
22	9	15	6000.	0	318	120.0	474.065	350	44.0
23	15	16	30000.	0	600	80.0	2.047	100	35.0
24	2	16	14800.	0	2600	80.0	77.702	100	35.0
25	16	17	60000.	0	1050	80.0	2.285	100	35.0
26	17	18	60000.	0	228	120.0	2.966	350	44.0
27	20	17	2000.	0	800	80.0	3.500	100	35.0
28	20	18	50000.	0	1217	80.0	4.931	100	35.0
29	19	20	50000.	0	333	120.0	4.565	350	44.0
30	21	19	31300.	0	1100	80.0	.475	100	35.0
31	22	21	40000.	0	1313	80.0	13.375	100	35.0
32	22	21	3000.	0	313	120.0	1234.019	350	44.0
33	23	22	20000.	0	1800	80.0	14.500	100	35.0
34	23	22	20000.	0	1800	80.0	14.500	100	35.0
35	4	24	110000.	0	2400	80.0	4.324	100	35.0
36	24	25	45000.	0	2600	80.0	5.572	100	35.0
37	24	27	20000.	0	3200	80.0	5.450	100	35.0
38	27	28	100000.	0	230	120.0	1.066	350	44.0
39	28	31	40000.	0	2292	80.0	14.000	100	35.0
40	25	26	45000.	0	2000	80.0	18.360	100	35.0
41	26	30	38000.	0	1700	80.0	3.630	100	35.0
42	26	29	5000.	0	1050	80.0	1.385	100	35.0
43	2	27	35449.	-1	1650	80.0	65.065	100	35.0
44	28	29	73000.	0	750	80.0	1.260	100	35.0
45	29	30	80000.	0	300	80.0	.854	100	35.0
46	2	30	44000.	0	525	80.0	46.882	100	35.0
47	30	31	203000.	0	297	200.0	.072	250	50.0
48	18	30	100000.	0	4100	80.0	6.265	100	35.0
49	31	32	288350.	0	2031	200.0	.610	250	50.0
50	1	32	20000.	0	30	200.0	441.000	250	50.0
51	32	1	450000.	1	100	80.0	10.000	100	35.0

Table 3: List of Junction Cards Containing Junction Numbers JNO, Temperatures T, elevations Z, and methane concentrations CH4C

JNO	T	Z	CH4C	JNO	T	Z	CH4C
1	50.0	+114	-	17	77.9	-2463	-
2	65.0	-2465	-	18	78.3	-2235	-
3	67.3	-2790	-	19	82.5	-2785	0.80
4	64.3	-2463	-	20	80.9	-2452	-
5	64.5	-2462	0.12	21	82.8	-2786	0.85
6	69.8	-2462	0.20	22	73.2	-2473	0.70
7	75.6	-1938	0.80	23	65.2	-2466	-
8	72.5	-2787	0.12	24	69.9	-2462	0.15
9	75.6	-2785	0.25	25	80.6	-2245	0.90
10	77.0	-2785	0.30	26	86.5	-2247	0.95
11	78.8	-2287	0.90	27	70.5	-2465	-
12	79.3	-2468	0.95	28	68.5	-2235	-
13	82.4	-2465	0.90	29	72.0	-2239	-
14	81.6	-1942	0.85	30	76.8	-2240	-
15	83.2	-2467	0.90	31	76.4	-1943	-
16	78.5	-2466	0.90	32	65.7	+88	-

Table 4: Fan Characteristics

Fan No 6

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52

Fan No 51

80000.	10.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

Table 5: List of Additional Airway Cards in Concentration Part of Program

Airway Number	Methane Production
9	320.0
33	120.0
34	20.0
36	250.0

Table 6: List of Additional Junction Cards in Concentration Part of Program

Junction Number	Methane Concentration
27	0.60
28	0.60

Table 7

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.7	.0	3.0	.1000
3	1	4	-2577.0	76.2	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	72.0	3.0	.1000
7	5	6	.0	69.9	48.0	3.0	.1000
8	6	7	524.0	80.3	30.0	3.0	.1000
9	6	7	524.0	77.6	320.0	3.0	.1000
10	7	14	-4.0	82.1	35.0	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	3	8	3.0	72.6	64.3	3.0	.1000
13	8	19	2.0	82.7	136.0	3.0	.1000
14	8	9	2.0	77.4	65.0	3.0	.1000
15	9	10	.0	77.7	17.5	3.0	.1000
16	10	11	-2.0	79.3	36.0	3.0	.1000
17	10	11	-2.0	79.1	90.0	3.0	.1000
18	11	12	319.0	83.3	17.5	3.0	.1000
19	12	13	3.0	84.0	.0	3.0	.1000
20	14	13	-523.0	80.2	3.0	3.0	.1000
21	13	15	-2.0	83.7	.0	3.0	.1000
22	9	15	318.0	92.4	39.0	3.0	.1000
23	15	16	1.0	76.2	.0	3.0	.1000
24	2	16	-1.0	78.5	133.2	3.0	.1000
25	16	17	3.0	77.8	.0	3.0	.1000
26	17	18	228.0	82.9	.0	3.0	.1000
27	20	17	-11.0	77.6	.0	3.0	.1000
28	20	18	217.0	78.7	.0	3.0	.1000
29	19	20	333.0	82.1	.0	3.0	.1000
30	21	19	1.0	82.5	.0	3.0	.1000
31	22	21	-313.0	82.8	60.0	3.0	.1000
32	22	21	-313.0	87.9	4.5	3.0	.1000
33	23	22	-7.0	73.4	120.0	3.0	.1000
34	23	22	-7.0	73.4	20.0	3.0	.1000
35	4	24	1.0	70.1	165.0	3.0	.1000
36	24	25	217.0	81.3	250.0	3.0	.1000
37	24	27	-3.0	70.5	90.0	3.0	.1000
38	27	28	230.0	67.0	.0	3.0	.1000
39	28	31	292.0	77.3	.0	3.0	.1000
40	25	26	-2.0	86.7	22.5	3.0	.1000
41	26	30	7.0	76.3	.0	3.0	.1000
42	26	29	8.0	71.1	.0	3.0	.1000
43	2	27	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.5	.0	3.0	.1000
45	29	30	-1.0	85.0	.0	3.0	.1000
46	2	30	225.0	86.2	.0	3.0	.1000
47	30	31	297.0	81.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	430.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

productions for the active longwall faces, Table 6 some additional methane concentrations in junctions. Methane productions in other airways, elevation differences, and rock temperatures have not been stated. They are calculated from methane concentrations, elevations, and temperatures in junctions, which are contained in the junction cards. Thermal conductivities and diffusivities have not been stated for individual airways either, instead average values from the average value card are used. Table 7 gives a summary of the input which was used in this way for the concentration part of the program.

The output has, in all examples, been organized in the same way. It starts (Table -a) with the results of a conventional network calculation executed with the Michigan Tech program. This network calculation is always performed as a check if the input data for the network description are correct and complete. In many cases these data will already exist from previous network calculations. A list of fan operating points in the network calculations comes next (Table -b). Additionally used input is listed in Table -c. The results of the concentration and temperature calculations and of the new network calculation, which takes the thermal forces developed by the new temperature distribution into account, are shown in Tables -d and -e. Table -d list temperatures, smoke (contaminant) concentrations, methane concentrations, air flow rates and pressure losses for airway ends. The two last quantities are based on reference densities. Pressure losses in airways were added because their magnitude is a criterion for the stability of airways. Table -e contains temperatures, smoke and methane concentrations for junctions. Table -f lists airways and junctions with critical conditions and airways with airflow reversals to draw the attention of the program user to these. The number of iterative adjustments between network and concentration parts of the program is stated in Table -e. If this number has been too small for completion of the calculation, a message is printed out in Table -b.

4.4.2 Executed Examples

4.4.2.1 Example 1: Simulation of a Normal Ventilation State

This example brings a simulation of the normal ventilation system without any contamination. The results are contained in Tables 8 a - f.

Table 8a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	157212.	.387	2597	200.0	.156	250	50.0
2	1	3	42317.	.009	325	200.0	.048	250	50.0
3	2	3	114804.	.631	2577	200.0	.479	250	50.0
4	1	4	26777.	.071	2580	200.0	.995	250	50.0
5	1	23	30374.	.221	2900	80.0	2.400	100	35.0
7	5	4	58908.	.801	2700	80.0	2.307	100	35.0
8	6	6	3982.	2.994	524	120.0	1888.233	350	44.0
9	6	7	54926.	2.994	1700	80.0	9.923	100	35.0
10	7	7	58908.	1.124	1650	80.0	3.239	100	35.0
11	14	14	55708.	6.207	4500	80.0	20.002	100	35.0
12	3	31	42317.	.064	2700	80.0	.360	100	35.0
13	8	8	13885.	.800	2050	80.0	41.490	100	35.0
14	8	19	28432.	.066	600	80.0	.821	100	35.0
15	9	9	24224.	.084	600	80.0	1.437	100	35.0
16	10	10	4205.	.220	600	80.0	124.385	100	35.0
17	10	11	20019.	.220	1100	80.0	5.500	100	35.0
18	11	11	24224.	.229	319	120.0	3.900	350	44.0
19	12	12	24224.	.221	600	80.0	3.772	100	35.0
20	14	13	3200.	.004	524	120.0	4.000	350	44.0
21	13	15	27424.	.083	550	80.0	1.108	100	35.0
22	9	15	4208.	.840	318	120.0	474.065	350	44.0
23	15	16	31633.	.205	600	80.0	2.047	100	35.0
24	2	16	11723.	1.068	2600	80.0	77.702	100	35.0
25	16	17	43356.	.430	1050	80.0	2.285	100	35.0
26	17	17	47108.	.658	228	120.0	2.966	350	44.0
27	20	18	3751.	.005	800	80.0	3.500	100	35.0
28	20	18	36910.	.672	1247	80.0	4.931	100	35.0
29	19	20	40661.	.755	333	120.0	4.565	350	44.0
30	21	19	26777.	.034	1100	80.0	.475	100	35.0
31	22	21	24251.	.787	1313	80.0	13.375	100	35.0
32	23	21	2526.	.787	1313	120.0	1234.019	350	44.0
33	23	22	13388.	.260	1800	80.0	14.500	100	35.0
34	24	22	13388.	.260	1800	80.0	14.500	100	35.0
35	24	24	86269.	3.218	2400	80.0	4.324	100	35.0
36	24	25	34110.	.648	3600	80.0	5.572	100	35.0
37	27	27	52159.	1.483	3200	80.0	5.450	100	35.0
38	28	28	87608.	.818	2530	120.0	1.066	350	44.0
39	25	31	27897.	1.090	2592	80.0	14.000	100	35.0
40	26	26	34110.	2.136	2000	80.0	18.360	100	35.0
41	26	30	30705.	.342	1700	80.0	3.630	100	35.0
42	27	29	3405.	.002	1050	80.0	1.385	100	35.0
43	28	27	35449.	4.923	1650	80.0	39.173	100	35.0
44	28	29	59711.	.449	750	80.0	1.260	100	35.0
45	29	30	63116.	.340	300	80.0	.854	100	35.0
46	2	30	37348.	6.540	525	80.0	46.882	100	35.0
47	30	31	215187.	.333	297	200.0	.072	250	50.0
48	18	30	84018.	4.422	4100	80.0	6.265	100	35.0
49	31	32	298792.	5.448	2031	200.0	.610	250	50.0
50	1	32	16299.	11.715	30	200.0	441.000	250	50.0

Table 8b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58908.	4.495
51	32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

```
 20000.  3.60    25000.  4.30    30000.  4.60    40000.  4.78    55000.  4.58
 70000.  4.29    85000.  3.96   100000.  3.70   150000.  3.00   200000.  2.52

 80000. 12.25   100000. 14.00   150000. 14.90   200000. 14.05   300000. 12.00
400000. 10.25   500000.  8.85   600000.  7.80   700000.  6.90   800000.  6.20
```

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 2.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

Table 8c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.6	.0	3.0	.1000
3	1	4	-2577.0	57.5	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	70.7	3.0	.1000
7	5	6	.0	69.9	47.1	3.0	.1000
8	6	7	524.0	80.1	23.9	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	29.5	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	3	8	3.0	72.6	50.8	3.0	.1000
13	8	19	2.0	82.6	94.4	3.0	.1000
14	8	9	2.0	77.1	37.0	3.0	.1000
15	9	10	.0	77.6	12.1	3.0	.1000
16	10	11	-2.0	79.2	25.2	3.0	.1000
17	10	11	-2.0	79.0	90.0	3.0	.1000
18	11	12	319.0	85.0	12.1	3.0	.1000
19	12	13	3.0	83.8	.0	3.0	.1000
20	14	13	-523.0	80.3	1.6	3.0	.1000
21	13	15	-2.0	83.6	.0	3.0	.1000
22	9	15	318.0	91.6	27.4	3.0	.1000
23	15	16	1.0	78.5	.0	3.0	.1000
24	2	16	-1.0	78.5	105.5	3.0	.1000
25	16	17	3.0	77.8	.0	3.0	.1000
26	17	18	228.0	80.7	.0	3.0	.1000
27	20	18	-11.0	77.5	.0	3.0	.1000
28	20	18	217.0	78.7	.0	3.0	.1000
29	19	20	333.0	82.0	.0	3.0	.1000
30	21	19	1.0	82.5	.0	3.0	.1000
31	22	21	-313.0	82.6	36.4	3.0	.1000
32	22	21	-313.0	87.6	3.8	3.0	.1000
33	23	22	-7.0	73.3	120.0	3.0	.1000
34	23	22	-7.0	73.3	20.0	3.0	.1000
35	4	24	1.0	70.1	129.4	3.0	.1000
36	24	25	217.0	81.3	250.0	3.0	.1000
37	24	27	-3.0	70.5	234.7	3.0	.1000
38	27	28	230.0	67.0	.0	3.0	.1000
39	28	31	292.0	77.3	.0	3.0	.1000
40	25	26	-5.0	80.7	17.1	3.0	.1000
41	26	30	7.0	76.4	.0	3.0	.1000
42	26	29	8.0	71.3	.0	3.0	.1000
43	2	29	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.4	.0	3.0	.1000
45	29	30	-1.0	84.5	.0	3.0	.1000
46	2	30	225.0	85.7	.0	3.0	.1000
47	30	31	297.0	81.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	415.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 8d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	149241.	64.95	.0000	.00	.340
2	2	3	41241.	67.32	.0000	.00	.008
3	1	4	113363.	64.32	.0000	.00	.602
4	1	23	25533.	65.27	.0000	.00	.064
5	2	4	31591.	64.30	.0000	.00	.235
6	4	5	58344.	64.46	.0000	.12	4.507
7	5	6	58344.	69.61	.0000	.20	.780
8	6	7	3948.	77.74	.0000	.81	2.992
9	6	7	54396.	74.89	.0000	.79	2.960
10	7	14	58344.	80.97	.0000	.84	1.140
11	14	31	54594.	76.42	.0000	.84	6.126
12	3	8	41241.	72.41	.0000	.12	.061
13	8	19	13665.	82.49	.0000	.81	.805
14	8	9	27576.	75.31	.0000	.26	.063
15	9	10	23450.	76.81	.0000	.31	.081
16	10	11	4069.	78.84	.0000	.93	.212
17	10	11	19381.	78.74	.0000	.77	.213
18	11	12	23450.	79.81	.0000	.85	.221
19	12	13	23450.	82.39	.0000	.85	.216
20	14	13	3750.	81.90	.0000	.88	.006
21	13	15	27200.	83.10	.0000	.85	.086
22	9	15	4126.	87.04	.0000	.92	.844
23	15	16	31326.	79.14	.0000	.86	.209
24	2	16	11525.	78.50	.0000	.92	1.056
25	16	17	42850.	78.07	.0000	.88	.433
26	17	18	46085.	78.54	.0000	.87	.648
27	20	17	3235.	77.80	.0000	.74	.004
28	20	18	35963.	78.40	.0000	.74	.659
29	19	20	39198.	80.93	.0000	.74	.730
30	21	19	25533.	82.53	.0000	.70	.032
31	22	21	23158.	82.60	.0000	.70	.745
32	22	21	23375.	86.24	.0000	.71	.728
33	23	22	12766.	73.19	.0000	.94	.238
34	23	22	12766.	73.19	.0000	.16	.238
35	4	24	86610.	69.40	.0000	.15	3.216
36	24	25	32873.	80.46	.0000	.91	.620
37	24	27	53737.	70.48	.0000	.59	1.375
38	27	28	81604.	68.53	.0000	.65	.707
39	28	31	26464.	76.31	.0000	.65	.996
40	25	26	32873.	86.36	.0000	.96	2.096
41	26	30	28614.	77.02	.0000	.96	.308
42	26	29	4259.	71.90	.0000	.96	.003
43	2	27	27867.	70.39	.0000	.76	5.029
44	28	29	55140.	71.42	.0000	.65	.383
45	29	30	59399.	75.20	.0000	.67	.305
46	2	30	37017.	75.02	.0000	.00	6.926
47	30	31	207079.	75.40	.0000	.65	.315
48	18	30	82048.	76.83	.0000	.81	4.333
49	31	32	288137.	65.34	.0000	.68	4.973
50	1	32	16734.	70.31	.0000	.00	11.904
51	32	1	304871.	65.63	.0000	.65	11.909

Table 8e:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	2	64.95	.0000	.0000
3	67.32	.0000	.0000	4	64.32	.0000	.0000
5	64.46	.0000	.1212	6	69.61	.0000	.2018
7	75.08	.0000	.7901	8	72.41	.0000	.1231
9	75.31	.0000	.2570	10	76.81	.0000	.3085
11	78.75	.0000	.7984	12	79.81	.0000	.8496
13	82.32	.0000	.8542	14	80.97	.0000	.8401
15	83.62	.0000	.8626	16	78.97	.0000	.8768
17	78.06	.0000	.8674	18	78.48	.0000	.8127
19	82.52	.0000	.7426	20	80.93	.0000	.7426
21	82.94	.0000	.7048	22	73.19	.0000	.5483
23	65.27	.0000	.0000	24	69.40	.0000	.1494
25	80.46	.0000	.9088	26	86.36	.0000	.9602
27	70.45	.0000	.6462	28	68.53	.0000	.6462
29	71.45	.0000	.6687	30	76.07	.0000	.6465
31	75.68	.0000	.6832	32	65.61	.0000	.6457

NUMBER OF ITERATIONS 1

Table 8f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS

(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
2	2	3	.00	.0000	67.3	.008
20	14	13	.88	.0000	81.9	.006
27	20	17	.74	.0000	77.8	.004
42	26	29	.96	.0000	71.9	.003

Table 9a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	157212.	.386	2597	200.0	.156	250	50.0
2	2	3	42317.	.009	325	200.0	.048	250	50.0
3	1	4	114804.	.631	2577	200.0	.479	250	50.0
4	1	23	26777.	.071	2580	200.0	.995	250	50.0
5	2	4	30374.	.221	2900	80.0	2.400	100	35.0
7	5	6	58908.	.801	2700	80.0	2.307	100	35.0
8	6	7	3982.	2.994	524	120.0	1888.233	350	44.0
9	6	7	54926.	2.994	1700	80.0	9.923	100	35.0
10	7	14	58908.	1.124	1650	80.0	3.239	100	35.0
11	14	31	55708.	6.207	4500	80.0	20.002	100	35.0
12	3	8	42317.	.064	2700	80.0	.360	100	35.0
13	8	19	13885.	.800	2050	80.0	41.490	100	35.0
14	8	9	28432.	.066	600	80.0	.821	100	35.0
15	9	10	24224.	.084	600	80.0	1.437	100	35.0
16	10	11	4205.	.220	600	80.0	124.385	100	35.0
17	10	11	20019.	.220	1100	80.0	5.500	100	35.0
18	11	12	24224.	.229	319	120.0	3.900	350	44.0
19	12	13	24224.	.221	600	80.0	3.772	100	35.0
20	14	13	3200.	.004	524	120.0	4.000	350	44.0
21	13	15	27424.	.083	550	80.0	1.108	100	35.0
22	9	15	4208.	.840	318	120.0	474.065	350	44.0
23	15	16	31633.	.205	600	80.0	2.047	100	35.0
24	2	16	11723.	1.068	2600	80.0	77.702	100	35.0
25	16	17	43356.	.430	1050	80.0	2.285	100	35.0
26	17	18	47108.	.658	228	120.0	2.966	350	44.0
27	20	17	3751.	.005	800	80.0	3.500	100	35.0
28	20	18	36910.	.672	1217	80.0	4.931	100	35.0
29	19	20	40661.	.755	333	120.0	4.565	350	44.0
30	21	19	26777.	.034	1100	80.0	.475	100	35.0
31	22	21	24251.	.787	1313	80.0	13.375	100	35.0
32	25	21	2526.	.787	313	120.0	1234.019	350	44.0
33	23	22	13388.	.260	1800	80.0	14.500	100	35.0
34	23	22	13388.	.260	1800	80.0	14.500	100	35.0
35	4	24	86269.	3.218	2400	80.0	4.324	100	35.0
36	24	25	34110.	.648	2600	80.0	5.572	100	35.0
37	24	27	52159.	1.483	3200	80.0	5.450	100	35.0
38	27	28	87608.	.818	230	120.0	1.066	350	44.0
39	28	31	27897.	1.090	2292	80.0	14.000	100	35.0
40	25	26	34110.	2.136	2000	80.0	18.360	100	35.0
41	26	30	30705.	.342	1700	80.0	3.630	100	35.0
42	26	29	3405.	.002	1050	80.0	1.385	100	35.0
43	2	27	35449.	4.923	1650	80.0	39.173	100	35.0
44	28	29	59711.	.449	750	80.0	1.260	100	35.0
45	29	30	63116.	.340	300	80.0	.854	100	35.0
46	2	30	37348.	6.540	525	80.0	46.882	100	35.0
47	30	31	215187.	.333	297	200.0	.072	250	50.0
48	18	30	84018.	4.422	4100	80.0	6.265	100	35.0
49	31	32	298792.	5.448	2031	200.0	.610	250	50.0
50	1	32	16299.	11.715	30	200.0	441.000	250	50.0

Table 9b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58908.	4.495
51	32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 6.00 HOURS

A TEMPERATURE OF 90.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

Table 9c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.6	.0	3.0	.1000
3	1	4	-2577.0	57.5	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	70.7	3.0	.1000
7	5	6	.0	69.9	47.1	3.0	.1000
8	6	7	524.0	80.1	23.9	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	29.5	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	3	8	3.0	72.6	50.8	3.0	.1000
13	8	19	2.0	82.6	94.4	3.0	.1000
14	8	9	2.0	77.1	37.0	3.0	.1000
15	9	10	.0	77.6	12.1	3.0	.1000
16	10	11	-2.0	79.2	25.2	3.0	.1000
17	10	11	-2.0	79.0	90.0	3.0	.1000
18	11	12	319.0	83.0	12.1	3.0	.1000
19	12	13	3.0	83.8	.0	3.0	.1000
20	14	13	-523.0	80.3	1.6	3.0	.1000
21	13	15	-2.0	83.6	.0	3.0	.1000
22	5	15	318.0	91.6	27.4	3.0	.1000
23	15	16	1.0	78.2	.0	3.0	.1000
24	2	16	-1.0	78.5	105.5	3.0	.1000
25	16	17	3.0	77.8	.0	3.0	.1000
26	17	18	228.0	82.7	.0	3.0	.1000
27	20	17	-11.0	77.5	.0	3.0	.1000
28	20	18	217.0	78.7	.0	3.0	.1000
29	19	20	333.0	82.0	.0	3.0	.1000
30	21	19	1.0	82.5	.0	3.0	.1000
31	22	21	-313.0	84.6	36.4	3.0	.1000
32	22	21	-313.0	87.6	3.8	3.0	.1000
33	23	22	-7.0	73.3	120.0	3.0	.1000
34	23	22	-7.0	73.3	20.0	3.0	.1000
35	4	24	1.0	70.1	129.4	3.0	.1000
36	24	25	217.0	81.3	250.0	3.0	.1000
37	24	27	-3.0	70.5	234.7	3.0	.1000
38	27	28	230.0	67.0	.0	3.0	.1000
39	28	31	292.0	77.3	.0	3.0	.1000
40	25	26	-2.0	86.7	17.1	3.0	.1000
41	26	30	7.0	76.4	.0	3.0	.1000
42	26	29	8.0	71.3	.0	3.0	.1000
43	2	27	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.4	.0	3.0	.1000
45	29	30	-1.0	84.5	.0	3.0	.1000
46	2	30	225.0	85.7	.0	3.0	.1000
47	30	31	297.0	81.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	415.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 9d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	134267.	74.06	.0000	.00	.298
2	2	3	34014.	73.33	.0000	.00	.006
3	1	4	110970.	71.87	.0000	.00	.621
4	1	23	29336.	66.40	.0000	.00	.088
5	2	4	28806.	64.49	.0000	.00	.197
6	4	5	57646.	69.94	.0000	.12	4.522
7	5	6	57646.	69.87	.0000	.20	.766
8	6	7	3902.	77.64	.0000	.82	2.922
9	6	7	53744.	74.30	.0000	.80	2.884
10	7	14	57646.	80.33	.0000	.85	1.110
11	14	31	52284.	76.45	.0000	.85	5.620
12	3	8	34014.	72.57	.0000	.15	.042
13	8	19	10367.	82.49	.0000	1.06	.464
14	8	9	23647.	75.23	.0000	.31	.047
15	9	10	20056.	76.72	.0000	.37	.059
16	10	11	3484.	78.82	.0000	1.09	.156
17	10	11	16572.	78.69	.0000	.91	.156
18	11	12	20056.	79.64	.0000	1.00	.162
19	12	13	20056.	82.22	.0000	1.00	.158
20	14	13	5362.	81.91	.0000	.88	.012
21	13	15	25418.	82.97	.0000	.97	.075
22	9	15	3591.	87.00	.0000	1.06	.639
23	15	16	29009.	79.43	.0000	.98	.180
24	2	16	10307.	78.52	.0000	1.02	.650
25	16	17	39317.	78.21	.0000	.99	.365
26	17	18	44284.	78.35	.0000	.96	.399
27	20	17	4967.	77.92	.0000	.73	.009
28	20	18	34736.	78.47	.0000	.73	.615
29	19	20	39703.	80.87	.0000	.73	.749
30	21	19	29336.	82.46	.0000	.61	.043
31	22	21	26605.	82.10	.0000	.61	.981
32	22	21	2731.	85.86	.0000	.62	.962
33	23	22	14668.	73.11	.0000	.82	.314
34	23	22	14668.	73.11	.0000	.14	.314
35	4	24	82130.	70.11	.0000	.16	2.919
36	24	25	31183.	80.30	.0000	.96	.557
37	24	27	50947.	70.49	.0000	.62	1.417
38	27	28	77238.	68.87	.0000	.68	.634
39	28	31	25044.	76.19	.0000	.68	.891
40	25	26	31183.	86.18	.0000	1.01	1.884
41	26	30	27090.	77.28	.0000	1.01	.277
42	26	29	4092.	71.96	.0000	1.01	.002
43	2	27	26291.	71.11	.0000	.81	4.532
44	28	29	52195.	71.23	.0000	.68	.344
45	29	30	56287.	74.45	.0000	.71	.274
46	2	30	34849.	78.66	.0000	.00	5.825
47	30	31	197245.	75.61	.0000	.69	.286
48	18	30	79019.	76.88	.0000	.86	4.021
49	31	32	274573.	65.31	.0000	.72	4.517
50	1	32	15750.	107.32	.0000	.00	12.161
51	32	1	290323.	67.52	.0000	.68	12.184

Tables 9e and 9f:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	90.00	.0000	.0000	2	74.06	.0000	.0000
3	73.33	.0000	.0000	4	70.35	.0000	.0000
5	69.94	.0000	.1226	6	69.87	.0000	.2043
7	74.52	.0000	.7996	8	72.57	.0000	.1493
9	75.33	.0000	.3054	10	76.72	.0000	.3656
11	78.71	.0000	.9380	12	79.64	.0000	.9978
13	82.16	.0000	.9730	14	80.33	.0000	.8503
15	83.47	.0000	.9843	16	79.19	.0000	.9946
17	78.18	.0000	.9649	18	78.41	.0000	.8615
19	82.47	.0000	.7297	20	80.87	.0000	.7297
21	82.45	.0000	.6135	22	73.11	.0000	.4772
23	66.40	.0000	.0000	24	70.11	.0000	.1576
25	80.30	.0000	.9580	26	86.18	.0000	1.0122
27	70.70	.0000	.6827	28	68.87	.0000	.6827
29	71.28	.0000	.7067	30	76.56	.0000	.6858
31	75.83	.0000	.7169	32	67.60	.0000	.6780

NUMBER OF ITERATIONS 5

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS

(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
2	2	3	.00	.0000	73.3	.006
13	8	19	1.06	.0000	82.5	.464
16	10	11	1.09	.0000	78.8	.156
22	9	15	1.06	.0000	87.0	.639
24	2	16	1.02	.0000	78.5	.850
27	20	17	.73	.0000	77.9	.009
40	25	26	1.01	.0000	86.2	1.884
41	26	30	1.01	.0000	77.3	.277
42	26	29	1.01	.0000	72.0	.002
50	1	32	.00	.0000	107.3	12.161

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 95.0 DEGREES
26	1.0	.0000	96.2

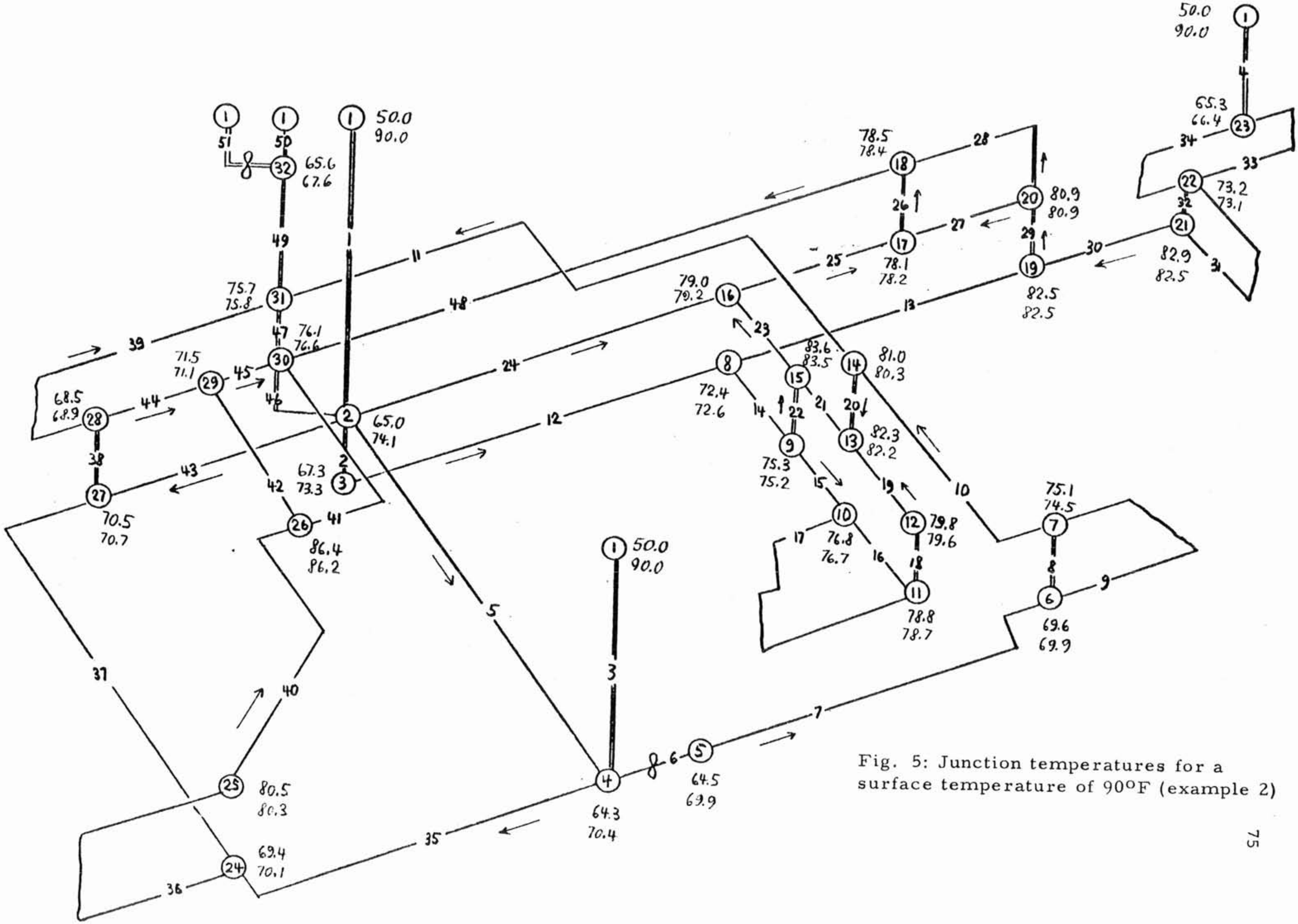


Fig. 5: Junction temperatures for a surface temperature of 90°F (example 2)

A comparison of the junction temperatures and junction methane concentrations from Table 8e with the input data from Table 3 shows good agreement. A comparison between airflow rates in Table 8a and Table 8d shows an acceptable but not complete agreement. The reason is that the Michigan Tech program assumes, for the temperatures on which the calculation of natural ventilation pressures are based, linear changes along the airways whereas the change in reality is exponential.

4.4.2.2 Example 2: Changed Surface Temperature

This example investigates how a change in the surface temperature from $50^{o}F$ to $90^{o}F$ has after 6 hours effected the airflow distribution. The results are contained in Tables 9 a - f. A comparison of calculated temperatures with those from example 1 shows that the temperatures increase mainly in the intake airways whereas in the return airways they remain virtually unchanged. This reduces the natural ventilation in the meshes going through the intake shafts and subsequently the airflow entering the mine. The result is a slight increase in methane concentrations which at several places rise to above 1%.

Junction temperatures based on $50^{o}F$ and $90^{o}F$ (lower placed figures) from Tables 8 and 9 have been plotted into Fig. 5. In some places the calculated temperatures for $90^{o}F$ surface temperature are lower than those for $50^{o}F$. The explanation is that for the $90^{o}F$ an elapsed time period of 6 hrs instead of 2 hrs was assumed. This allows the buildup of a thicker layer of insulating rock around the airways.

For airway 50 (the leakage from the surface into the fan drift), a temperature of $107^{o}F$ has been calculated. The reason is that the rock temperature for this airway was determined from the temperature difference between junctions 1 and 32. The genuine temperature rise in airway 50, which has no practical importance, would have been obtained by stating the genuine rock temperature of this airway in the input data.

4.4.2.3 Example 3: Main Fan Failure

It is assumed that the surface fan fails (airway 51) but that the underground booster fan continues to work. The surface temperature is $50^{o}F$, the time after the event 15 minutes.

Table 10a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	46381.	.034	2597	200.0	.156	250	50.0
2	2	3	-5877.	-.000	325	200.0	.048	250	50.0
3	1	4	45091.	.097	2577	200.0	.479	250	50.0
4	1	23	1615.	.000	2580	200.0	.995	250	50.0
5	2	4	12796.	.039	2900	80.0	2.400	100	35.0
7	5	6	52280.	.631	2700	80.0	2.307	100	35.0
8	6	7	3534.	2.358	524	120.0	1888.253	350	44.0
9	6	7	48746.	2.358	1700	80.0	9.923	100	35.0
10	7	14	52280.	.885	1650	80.0	3.239	100	35.0
11	14	31	22287.	.993	4500	80.0	20.002	100	35.0
12	3	8	-5877.	-.001	2700	80.0	.360	100	35.0
13	8	19	4429.	.081	2050	80.0	41.490	100	35.0
14	8	9	-10306.	-.009	600	80.0	.821	100	35.0
15	9	10	-9204.	-.012	600	80.0	1.437	100	35.0
16	10	11	-1596.	-.032	600	80.0	124.385	100	35.0
17	10	11	-7608.	-.032	1100	80.0	5.500	100	35.0
18	11	12	-9204.	-.033	319	120.0	3.900	350	44.0
19	12	13	-9204.	-.032	600	80.0	3.772	100	35.0
20	14	13	29993.	.360	524	120.0	4.000	350	44.0
21	13	15	20789.	.048	550	80.0	1.108	100	35.0
22	9	15	-1102.	-.058	318	120.0	474.065	350	44.0
23	15	16	19687.	.079	600	80.0	2.047	100	35.0
24	2	16	-3643.	-.103	2600	80.0	77.702	100	35.0
25	16	17	16044.	.059	1050	80.0	2.285	100	35.0
26	17	18	12217.	.044	228	120.0	2.966	350	44.0
27	20	17	-3827.	-.005	800	80.0	3.500	100	35.0
28	20	18	9871.	.048	1217	80.0	4.931	100	35.0
29	19	20	6044.	.017	333	120.0	4.565	350	44.0
30	21	19	1615.	.000	1100	80.0	.475	100	35.0
31	22	21	1457.	.003	1313	80.0	13.375	100	35.0
32	22	21	158.	.003	313	120.0	1234.019	350	44.0
33	23	22	807.	.001	1800	80.0	14.500	100	35.0
34	23	22	807.	.001	1800	80.0	14.500	100	35.0
35	4	24	5608.	.014	2400	80.0	4.324	100	35.0
36	24	25	9236.	.048	2600	80.0	5.572	100	35.0
37	24	27	-3628.	-.007	3200	80.0	5.450	100	35.0
38	27	28	31821.	.108	230	120.0	1.066	350	44.0
39	28	31	8586.	.103	2292	80.0	14.000	100	35.0
40	25	26	9236.	.157	2000	80.0	18.360	100	35.0
41	26	30	10611.	.041	1700	80.0	3.630	100	35.0
42	26	29	-1375.	-.000	1050	80.0	1.385	100	35.0
43	2	27	35449.	.046	1650	80.0	.369	100	35.0
44	28	29	23235.	.068	750	80.0	1.260	100	35.0
45	29	30	21860.	.041	300	80.0	.854	100	35.0
46	2	30	7655.	.275	525	80.0	46.882	100	35.0
47	30	31	62214.	.028	297	200.0	.072	250	50.0
48	18	30	22088.	.306	4100	80.0	6.265	100	35.0
49	31	32	93086.	.529	2031	200.0	.610	250	50.0
50	1	32	-1686.	-.125	30	200.0	441.000	250	50.0
51	32	1	91401.	.125	100	80.0	.150	100	35.0

Table 10b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	52280.	4.638

THESE CHARACTERISTICS WERE STORED FOR FANS 6

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT .25 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

NO TEMPERATURE DETERMINATION WAS DEMANDED

Table 10c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.1	.0	3.0	.1000
3	1	4	-2577.0	57.4	.0	3.0	.1000
4	1	23	-2580.0	58.3	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.6	62.7	3.0	.1000
7	5	6	.0	69.9	41.8	3.0	.1000
8	6	7	524.0	79.9	21.2	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	26.1	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	3	8	3.0	72.5	-7.1	3.0	.1000
13	8	19	2.0	82.5	30.1	3.0	.1000
14	8	9	2.0	76.6	-13.4	3.0	.1000
15	9	10	.0	77.4	-4.6	3.0	.1000
16	10	11	-2.0	79.1	-9.6	3.0	.1000
17	10	11	-2.0	78.9	90.0	3.0	.1000
18	11	12	319.0	82.4	-4.6	3.0	.1000
19	12	13	3.0	83.4	.0	3.0	.1000
20	14	13	-523.0	79.6	15.0	3.0	.1000
21	13	15	-2.0	83.6	.0	3.0	.1000
22	5	15	318.0	89.1	-7.2	3.0	.1000
23	15	16	1.0	76.5	.0	3.0	.1000
24	2	16	-1.0	78.5	-32.8	3.0	.1000
25	16	17	3.0	77.8	.0	3.0	.1000
26	17	18	228.0	81.7	.0	3.0	.1000
27	20	17	-11.0	77.5	.0	3.0	.1000
28	20	18	217.0	78.8	.0	3.0	.1000
29	19	20	333.0	81.9	.0	3.0	.1000
30	21	19	1.0	82.5	.0	3.0	.1000
31	22	21	-313.0	82.1	2.2	3.0	.1000
32	22	21	-313.0	84.2	.2	3.0	.1000
33	23	22	-7.0	73.2	120.0	3.0	.1000
34	23	22	-7.0	73.2	20.0	3.0	.1000
35	4	24	1.0	69.9	8.4	3.0	.1000
36	24	25	217.0	81.2	250.0	3.0	.1000
37	24	27	-3.0	70.5	-16.3	3.0	.1000
38	27	28	230.0	67.5	.0	3.0	.1000
39	28	31	292.0	77.5	.0	3.0	.1000
40	25	26	-2.0	86.5	4.6	3.0	.1000
41	26	30	7.0	76.6	.0	3.0	.1000
42	26	29	8.0	71.6	.0	3.0	.1000
43	2	27	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.0	.0	3.0	.1000
45	29	30	-1.0	82.7	.0	3.0	.1000
46	2	30	225.0	82.3	.0	3.0	.1000
47	30	31	297.0	80.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	284.9	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 10d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	46381.	.00	.0000	.00	.034
2	3	-2	5877.	.00	.0000	1.35	-.000
3	1	4	45091.	.00	.0000	.00	.097
4	1	23	1615.	.00	.0000	.00	.000
5	2	4	12796.	.00	.0000	.14	.039
6	4	5	52280.	.00	.0000	.15	4.638
7	5	6	52280.	.00	.0000	.23	.631
8	6	7	3534.	.00	.0000	.83	2.358
9	6	7	48746.	.00	.0000	.89	2.358
10	7	14	52280.	.00	.0000	.93	.885
11	14	31	22287.	.00	.0000	.93	.993
12	8	3	5877.	.00	.0000	1.35	-.001
13	8	12	4429.	.00	.0000	2.14	.081
14	9	8	10306.	.00	.0000	1.47	-.009
15	10	9	9204.	.00	.0000	1.75	-.012
16	11	10	1596.	.00	.0000	.34	-.032
17	11	10	7608.	.00	.0000	2.10	-.032
18	12	11	9204.	.00	.0000	.93	-.033
19	13	12	9204.	.00	.0000	.98	-.032
20	14	13	29993.	.00	.0000	.98	.360
21	13	15	20789.	.00	.0000	.98	.048
22	15	9	1102.	.00	.0000	.34	-.058
23	15	16	19687.	.00	.0000	.98	.079
24	16	-2	3643.	.00	.0000	.09	-.103
25	16	17	16044.	.00	.0000	.98	.059
26	17	18	12217.	.00	.0000	.98	.044
27	17	20	3827.	.00	.0000	.98	-.005
28	20	18	9871.	.00	.0000	2.78	.048
29	19	20	6044.	.00	.0000	3.92	.017
30	21	19	1615.	.00	.0000	8.81	.000
31	22	21	1457.	.00	.0000	8.81	.003
32	22	21	158.	.00	.0000	8.81	.003
33	23	22	807.	.00	.0000	14.86	.001
34	23	22	807.	.00	.0000	2.48	.001
35	4	24	5608.	.00	.0000	.18	.014
36	24	25	9236.	.00	.0000	2.93	.048
37	27	24	3628.	.00	.0000	.30	-.007
38	27	28	31821.	.00	.0000	.74	.108
39	28	31	8586.	.00	.0000	.74	.103
40	25	26	9236.	.00	.0000	2.48	.157
41	26	30	10611.	.00	.0000	2.69	.041
42	29	26	1375.	.00	.0000	.74	-.000
43	2	27	35449.	.00	.0000	.74	.046
44	28	29	23235.	.00	.0000	.74	.068
45	29	30	21860.	.00	.0000	.74	.041
46	2	30	7655.	.00	.0000	.14	.275
47	30	31	62214.	.00	.0000	1.37	.028
48	18	30	22088.	.00	.0000	1.79	.306
49	31	32	93086.	.00	.0000	1.21	.329
50	32	1	1686.	.00	.0000	1.21	-.125
51	33	1	91401.	.00	.0000	1.21	.125

Table 10e:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	2	.00	.0000	.1427
3	.00	.0000	1.3516	4	.00	.0000	.0315
5	.00	.0000	.1515	6	.00	.0000	.2314
7	.00	.0000	.8825	8	.00	.0000	1.4699
9	.00	.0000	1.5978	10	.00	.0000	1.7977
11	.00	.0000	.9321	12	.00	.0000	.9816
13	.00	.0000	.9816	14	.00	.0000	.9321
15	.00	.0000	.9816	16	.00	.0000	.9816
17	.00	.0000	.9816	18	.00	.0000	1.7859
19	.00	.0000	3.9212	20	.00	.0000	2.7814
21	.00	.0000	8.8073	22	.00	.0000	8.6703
23	.00	.0000	.0000	24	.00	.0000	.2261
25	.00	.0000	2.9269	26	.00	.0000	2.6860
27	.00	.0000	.7418	28	.00	.0000	.7418
29	.00	.0000	.7418	30	.00	.0000	1.3704
31	.00	.0000	1.2075	32	.00	.0000	1.2075

NUMBER OF ITERATIONS 0

WITH AIRWAY NO 2 INTO JUNCTION NO 2

WITH AIRWAY NO 24 INTO JUNCTION NO 2

A RECIRCULATION PATH IS BEING CLOSED

Table 10f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS
(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
2	3	2	1.35	.0000	.0	-.000
4	1	23	.00	.0000	.0	.000
12	8	3	1.35	.0000	.0	-.001
13	8	19	2.14	.0000	.0	.081
14	9	8	1.47	.0000	.0	-.009
15	10	9	1.75	.0000	.0	-.012
16	11	10	.34	.0000	.0	-.038
17	11	10	2.10	.0000	.0	-.032
18	12	11	.93	.0000	.0	-.033
19	13	12	.98	.0000	.0	-.032
22	15	9	.34	.0000	.0	-.056
24	16	2	.09	.0000	.0	-.103
27	17	20	.98	.0000	.0	-.005
28	20	18	2.78	.0000	.0	.048
29	19	20	3.92	.0000	.0	.017
30	21	19	8.81	.0000	.0	.000
31	22	21	8.81	.0000	.0	.003
32	22	21	8.81	.0000	.0	.003
33	23	22	14.86	.0000	.0	.001
34	23	22	2.48	.0000	.0	.001
36	24	25	2.93	.0000	.0	.048
37	27	24	.30	.0000	.0	-.007
40	25	26	2.98	.0000	.0	.157
41	26	30	2.69	.0000	.0	.041
42	29	26	.74	.0000	.0	-.000
47	30	31	1.37	.0000	.0	.028
48	18	30	1.79	.0000	.0	.306
49	31	32	1.21	.0000	.0	.529
50	32	1	1.21	.0000	.0	-.125
51	32	1	1.21	.0000	.0	.125

Table 10f:

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 75.0 DEGREES
3	1.4	.0000	.0
8	1.5	.0000	.0
9	1.6	.0000	.0
10	1.8	.0000	.0
18	1.8	.0000	.0
19	3.9	.0000	.0
20	2.8	.0000	.0
21	8.8	.0000	.0
22	8.7	.0000	.0
25	2.9	.0000	.0
26	2.7	.0000	.0
30	1.4	.0000	.0
31	1.2	.0000	.0
32	1.2	.0000	.0

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

```
AIRWAY    2  IS NOW CARRYING AIR FROM     3  TO     2
AIRWAY   12  IS NOW CARRYING AIR FROM     8  TO     3
AIRWAY   14  IS NOW CARRYING AIR FROM     9  TO     8
AIRWAY   15  IS NOW CARRYING AIR FROM    10  TO     9
AIRWAY   16  IS NOW CARRYING AIR FROM    11  TO    10
AIRWAY   17  IS NOW CARRYING AIR FROM    11  TO    10

AIRWAY   18  IS NOW CARRYING AIR FROM    12  TO    11
AIRWAY   19  IS NOW CARRYING AIR FROM    13  TO    12
AIRWAY   22  IS NOW CARRYING AIR FROM    15  TO     9
AIRWAY   24  IS NOW CARRYING AIR FROM    16  TO     2
AIRWAY   27  IS NOW CARRYING AIR FROM    17  TO    20
AIRWAY   37  IS NOW CARRYING AIR FROM    27  TO    24
AIRWAY   42  IS NOW CARRYING AIR FROM    29  TO    26
AIRWAY   50  IS NOW CARRYING AIR FROM    32  TO     1
```

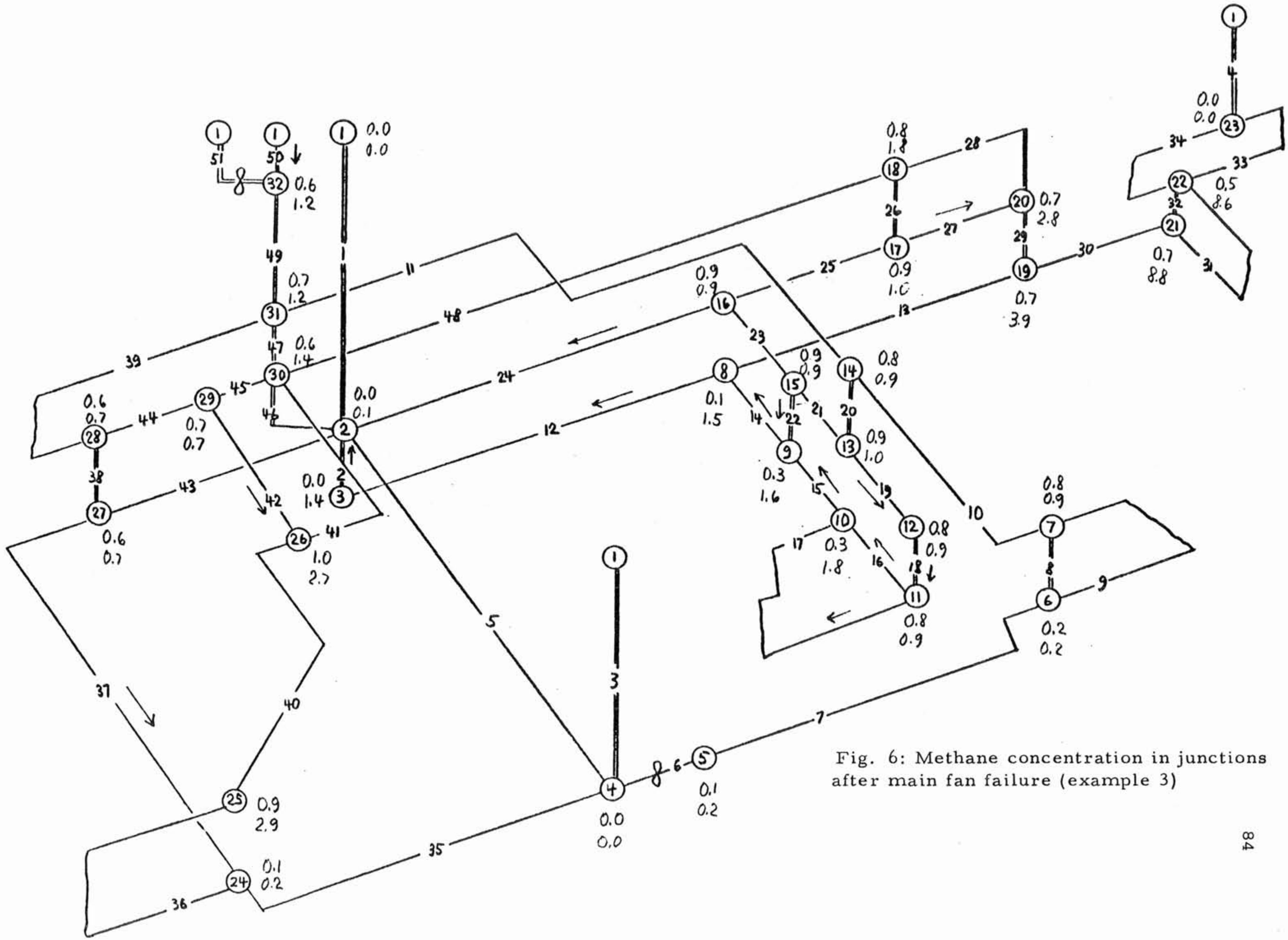


Fig. 6: Methane concentration in junctions after main fan failure (example 3)

A problem of this type, where a large part of the mine is ventilated by small natural ventilation pressures only, can give problems to the program in its herein presented form. These pressures are smaller than the tolerances which have been allowed in the CROSS approximation method in order to keep the number of iterations low. This means that the CROSS method can, for the same input data, come up with different answers for the airflow directions. This has no practical importance. Airways with pressure losses lower than the chosen tolerances are so unstable that a precalculation of their airflow rates or directions makes little practical sense.

In this program, every time that an airflow reversal takes place in a computer run, a new flowscheme and mesh assembly has to be set up, followed by a new network calculation with the help of the CROSS method. The result can be a continuous oscillation of airflow directions in the unstable airways. The obvious remedy, to make the tolerances smaller, offers little advantage. One does no longer get convergence problems, but the results are no more convincing.

A better way for problems of this type is to assume that the temperature distribution remains constant and to perform only one network calculation followed by a concentration calculation but not by a temperature calculation. Tables 10 a - f show the results. In judging these, one should keep in mind that the airways with low pressure losses must be considered unstable. The output draws special attention to recirculation and the airways with airflow reversals also. Fig. 6 shows the methane concentration of junctions before (Table 8) and after (lower placed figures) (Table 10) the main fan failure. Arrows mark airways with airflow reversal.

4.4.2.4 Example 4: Fire In a Horizontal Airway

A fire is assumed at the beginning of airway 5 (NCENT). It is estimated that 30,000 cfm of air (CONT) travels through the fire zone, leaves a smoke (carbon dioxide) concentration of 1.00% (CONC), and produces a heat of $15*10^4$ Btu/min (HEAT). The results of the calculations are shown in Tables 11 a - f. One sees that the fumes coming from the fire have cooled down to almost normal temperatures before they leave

Table 11a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	157212.	.386	2597	200.0	.156	250	50.0
2	2	3	42317.	.009	325	200.0	.048	250	50.0
3	1	4	114804.	.631	2577	200.0	.479	250	50.0
4	1	23	26777.	.071	2580	200.0	.995	250	50.0
5	2	4	30374.	.221	2900	80.0	2.400	100	35.0
7	5	6	58908.	.801	2700	80.0	2.307	100	35.0
8	6	7	3982.	2.994	524	120.0	1888.233	350	44.0
9	6	7	54926.	2.994	1700	80.0	9.923	100	35.0
10	7	14	58908.	1.124	1650	80.0	3.239	100	35.0
11	14	31	55708.	6.207	4500	80.0	20.002	100	35.0
12	8	8	42317.	.064	2700	80.0	.360	100	35.0
13	8	19	13885.	.800	2050	80.0	41.490	100	35.0
14	8	9	28432.	.066	600	80.0	.821	100	35.0
15	9	10	24224.	.084	600	80.0	1.437	100	35.0
16	10	11	4205.	.220	600	80.0	124.385	100	35.0
17	10	11	20019.	.220	1100	80.0	5.500	100	35.0
18	11	12	24224.	.229	319	120.0	3.900	350	44.0
19	12	13	24224.	.221	600	80.0	3.772	100	35.0
20	12	13	3200.	.004	324	120.0	4.000	350	44.0
21	14	15	27424.	.083	550	80.0	1.108	100	35.0
22	13	15	4208.	.840	318	120.0	474.065	350	44.0
23	15	16	31633.	.208	600	80.0	2.047	100	35.0
24	15	16	11423.	1.068	2600	80.0	77.702	100	35.0
25	16	17	43356.	.430	1050	80.0	2.285	100	35.0
26	17	18	47108.	.658	228	120.0	2.966	350	44.0
27	17	17	3751.	.005	800	80.0	3.500	100	35.0
28	20	18	36910.	.672	1217	80.0	4.931	100	35.0
29	20	20	40661.	.755	333	120.0	4.565	350	44.0
30	19	19	26777.	.034	1100	80.0	.475	100	35.0
31	21	21	24251.	.787	313	80.0	13.375	100	35.0
32	22	21	2526.	.787	313	120.0	1234.019	350	44.0
33	22	22	13388.	.260	1800	80.0	14.500	100	35.0
34	23	22	13388.	.260	1800	80.0	14.500	100	35.0
35	24	24	86269.	3.218	2400	80.0	4.324	100	35.0
36	24	25	34110.	.648	2600	80.0	5.572	100	35.0
37	24	25	52159.	1.483	3200	80.0	5.450	100	35.0
38	27	27	87608.	.818	230	120.0	1.066	350	44.0
39	28	28	27897.	1.090	2592	80.0	14.000	100	35.0
40	25	31	34110.	2.136	2000	80.0	18.360	100	35.0
41	26	26	30705.	.342	1700	80.0	3.630	100	35.0
42	26	30	3405.	.005	1050	80.0	1.385	100	35.0
43	28	29	35449.	4.925	1650	80.0	39.173	100	35.0
44	28	27	59711.	.449	750	80.0	1.260	100	35.0
45	29	29	63116.	.340	300	80.0	.854	100	35.0
46	22	30	37348.	6.540	525	80.0	46.882	100	35.0
47	30	31	215187.	.333	297	200.0	.072	250	50.0
48	18	30	84018.	4.422	4100	80.0	6.265	100	35.0
49	31	32	298792.	5.448	2031	200.0	.610	250	50.0
50	1	32	16299.	11.715	30	200.0	441.000	250	50.0

Table 11b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58908.	4.495
51	32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION CONCENTRAT.	HEAT	OXYGEN CONCENTRATION BEHIND FIRE	PRODUCTION PER % OXYGEN SMOKE	PRODUCTION PER % OXYGEN HEAT
5	30000.0	1.00	150000.00	.00	.00	.00

Table 11c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.6	.0	3.0	.1000
3	1	4	-2577.0	57.5	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	70.7	3.0	.1000
7	5	6	.0	65.9	47.1	3.0	.1000
8	6	7	524.0	80.1	23.9	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	29.5	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	5	8	3.0	75.6	50.8	3.0	.1000
13	8	19	2.0	85.6	94.4	3.0	.1000
14	8	9	2.0	77.1	37.0	3.0	.1000
15	9	10	.0	77.9	12.1	3.0	.1000
16	10	[illegible]	-2.0	[illegible]	18.2	3.0	.1000
17	10	[illegible]	-2.0	[illegible]	25.0	3.0	.1000
18	[illegible]	[illegible]	319.0	[illegible]	90.0	3.0	.1000
19	[illegible]	[illegible]	3.0	[illegible]	12.1	3.0	.1000
20	[illegible]	[illegible]	-523.0	80.3	1.0	3.0	.1000
21	[illegible]	[illegible]	-6.0	[illegible]	.0	3.0	.1000
22	[illegible]	[illegible]	318.0	91.6	27.4	3.0	.1000
23	15	[illegible]	1.0	[illegible]	.0	3.0	.1000
24	[illegible]	[illegible]	-4.0	78.8	105.5	3.0	.1000
25	[illegible]	[illegible]	[illegible]	77.8	.0	3.0	.1000
26	16	[illegible]	228.0	86.7	.0	3.0	.1000
27	[illegible]	[illegible]	-11.0	[illegible]	.0	3.0	.1000
28	20	[illegible]	217.0	78.0	.0	3.0	.1000
29	19	20	333.0	[illegible]	.0	3.0	.1000
30	[illegible]	19	1.0	[illegible]	.0	3.0	.1000
31	21	[illegible]	-311.0	[illegible]	36.4	3.0	.1000
32	[illegible]	[illegible]	-313.0	87.6	3.8	3.0	.1000
33	[illegible]	[illegible]	-7.0	73.3	120.0	3.0	.1000
34	[illegible]	[illegible]	-7.0	[illegible]	20.0	3.0	.1000
35	[illegible]	[illegible]	1.0	70.1	129.4	3.0	.1000
36	24	[illegible]	217.0	[illegible]	[illegible]	3.0	.1000
37	24	[illegible]	-3.0	80.0	234.7	3.0	.1000
38	[illegible]	28	230.0	87.0	.0	3.0	.1000
39	[illegible]	[illegible]	292.0	77.5	.0	3.0	.1000
40	25	[illegible]	-2.0	86.7	17.0	3.0	.1000
41	26	[illegible]	7.0	76.4	.0	3.0	.1000
42	[illegible]	[illegible]	8.0	71.3	.0	3.0	.1000
43	[illegible]	27	.0	70.5	212.7	3.0	.1000
44	28	29	-4.0	73.4	.0	3.0	.1000
45	29	30	-1.0	84.5	.0	3.0	.1000
46	2	30	225.0	85.7	.0	3.0	.1000
47	30	31	297.0	[illegible]	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	22	-26.0	415.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 11d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	147749.	65.00	.0000	.00	.334
2	2	3	41379.	67.39	.0000	.00	.008
3	1	4	114874.	64.33	.0000	.00	.618
4	1	23	25527.	65.27	.0000	.00	.064
5	2	4	29891.	66.03	1.0037	.00	.258
6	4	5	58259.	64.80	.2072	.12	4.509
7	5	6	58259.	69.70	.2072	.20	.778
8	6	7	3942.	77.80	.2072	.81	2.984
9	6	7	54318.	75.16	.2072	.79	2.955
10	7	14	58259.	81.23	.2072	.84	1.138
11	14	31	54620.	76.41	.2072	.84	6.131
12	3	8	41379.	72.45	.0000	.12	.062
13	8	19	13700.	82.51	.0000	.81	.810
14	8	9	27679.	75.45	.0000	.26	.064
15	9	10	23539.	76.91	.0000	.31	.082
16	10	11	4085.	78.87	.0000	.96	.214
17	10	11	19454.	78.78	.0000	.77	.215
18	11	12	23539.	79.96	.0000	.85	.223
19	12	13	23539.	82.53	.0000	.85	.218
20	14	15	3640.	81.90	.2072	.88	.006
21	13	15	27179.	83.18	.0278	.85	.086
22	9	15	4140.	87.20	.0000	.92	.850
23	15	16	31319.	78.85	.0241	.86	.209
24	2	16	11556.	78.51	.0000	.91	1.063
25	16	19	42875.	78.01	.0176	.87	.433
26	17	18	46120.	78.65	.0164	.87	.650
27	10	17	3245.	77.79	.0000	.74	.004
28	20	18	35982.	78.36	.0000	.74	.660
29	19	20	39227.	80.95	.0000	.74	.732
30	21	19	25527.	82.54	.0000	.70	.032
31	22	21	23151.	82.73	.0000	.70	.745
32	23	22	2376.	86.31	.0000	.71	.729
33	23	22	12763.	73.22	.0000	.94	.237
34	4	24	12763.	73.22	.0000	.16	.237
35	24	25	86505.	69.62	.2072	.15	3.212
36	24	26	32843.	80.55	.2072	.91	.619
37	27	27	53366.	70.49	.2072	.59	1.571
38	28	28	81558.	68.46	.1364	.65	.706
39	25	31	26441.	76.36	.1364	.65	.994
40	25	30	32844.	80.43	.2072	.96	2.093
41	26	30	28615.	76.90	.2072	.96	.308
42	26	29	4227.	71.86	.2072	.96	.003
43	3	27	27896.	70.46	.0000	.76	5.042
44	28	29	55117.	71.59	.1364	.65	.383
45	29	30	59344.	75.70	.1414	.67	.305
46	2	30	37027.	75.72	.0000	.00	6.441
47	30	31	207089.	75.75	.0728	.65	.315
48	18	30	82102.	76.82	.0092	.81	4.338
49	31	32	288149.	65.49	.1041	.68	4.978
50	1	34	16723.	71.01	.0000	.00	11.904
51	32	1	304872.	65.85	.0984	.65	11.909

Table 11e:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	2	65.00	.0000	.0000
3	67.39	.0000	.0000	4	64.68	.2072	.0000
5	64.80	.2072	.1213	6	69.70	.2072	.2021
7	75.34	.2072	.7912	8	72.45	.0000	.1227
9	75.45	.0000	.2561	10	76.91	.0000	.3074
11	78.79	.0000	.7954	12	79.96	.0000	.8465
13	82.45	.0278	.8516	14	81.23	.2072	.8414
15	83.72	.0241	.8600	16	78.83	.0176	.8743
17	77.99	.0164	.8650	18	78.52	.0092	.8111
19	82.53	.0000	.7420	20	80.95	.0000	.7420
21	83.06	.0000	.7049	22	73.22	.0000	.5484
23	65.27	.0000	.0000	24	69.62	.2072	.1496
25	80.53	.2072	.9097	26	86.43	.2072	.9611
27	70.48	.1364	.6466	28	68.46	.1364	.6466
29	71.61	.1414	.6690	30	76.31	.0728	.6461
31	75.93	.1041	.6831	32	65.79	.0984	.6457

NUMBER OF ITERATIONS 1

Table 11f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS
(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
2	2	3	.00	.0000	67.4	.008
5	2	4	.00	1.0037	66.0	.258
6	4	5	.12	.2072	64.8	4.509
7	5	6	.20	.2072	69.7	.778
8	6	7	.81	.2072	77.8	2.984
9	6	7	.79	.2072	75.2	2.955
10	7	14	.84	.2072	81.2	1.138
11	14	31	.84	.2072	76.4	6.131
20	14	13	.88	.2072	81.9	.006
27	20	17	.74	.0000	77.8	.004
25	4	24	.15	.2072	69.6	3.212
26	24	25	.91	.2072	80.5	.619
36	24	27	.59	.2072	70.5	1.571
37	27	28	.65	.1364	68.5	.706
38	28	31	.65	.1364	76.4	.994
39	25	26	.96	.2072	86.4	2.093
40	25	30	.96	.2072	76.9	.308
41	26	29	.96	.2072	71.9	.003
42	26	29	.65	.1364	71.6	.383
44	28	30	.67	.1414	75.7	.305
45	29	31	.65	.0728	75.7	.315
47	30	32	.68	.1041	65.5	4.978
51	32	1	.65	.0984	65.8	11.909

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 95.0 DEGREES
4	.0	.2072	64.7
5	.1	.2072	64.8
6	.2	.2072	69.7
7	.8	.2072	75.3
14	.8	.2072	61.2
24	.1	.2072	69.6
25	.9	.2072	80.5
26	1.0	.2072	86.4
27	.6	.1364	70.5
28	.6	.1364	68.5
29	.7	.1414	71.6
30	.6	.0728	76.3
31	.7	.1041	75.9
32	.6	.0984	65.8

Table 12a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	157212.	.386	2597	200.0	.156	250	50.0
2	2	3	42317.	.009	325	200.0	.048	250	50.0
3	1	4	114804.	.631	2577	200.0	.479	250	50.0
4	1	23	26777.	.071	2580	200.0	.995	250	50.0
5	2	4	30374.	.221	2900	80.0	2.400	100	35.0
7	5	6	58908.	.801	2700	80.0	2.307	100	35.0
8	6	7	3982.	2.994	524	120.0	1888.233	350	44.0
9	6	7	54926.	2.994	1700	80.0	9.923	100	35.0
10	7	14	58908.	1.124	1650	80.0	3.239	100	35.0
11	14	3	55708.	6.207	4500	80.0	20.002	100	35.0
12	5	8	42317.	.064	2700	80.0	.360	100	35.0
13	8	19	13885.	.800	2050	80.0	41.490	100	35.0
14	8	9	28432.	.066	600	80.0	.821	100	35.0
15	9	10	24224.	.084	600	80.0	1.437	100	35.0
16	10	11	4205.	.220	600	80.0	124.365	100	35.0
17	10	11	20019.	.220	1100	80.0	5.500	100	35.0
18	11	12	24224.	.229	319	120.0	3.900	350	44.0
19	12	13	24224.	.221	600	80.0	3.772	100	35.0
20	14	13	3200.	.004	524	120.0	4.000	350	44.0
21	13	15	27424.	.083	550	80.0	1.108	100	35.0
22	13	15	4208.	.840	318	120.0	474.065	350	44.0
23	15	16	31633.	.205	600	80.0	2.047	100	35.0
24	16	14	11723.	1.068	2600	80.0	77.702	100	35.0
25	16	17	43356.	.430	1050	80.0	2.285	100	35.0
26	17	18	47108.	.658	228	120.0	2.966	350	44.0
27	20	17	3751.	.005	800	80.0	3.500	100	35.0
28	20	18	36910.	.692	1217	80.0	4.931	100	35.0
29	19	20	40661.	.758	333	120.0	4.565	350	44.0
30	21	19	26777.	.034	1100	80.0	.475	100	35.0
31	21	21	24251.	.787	1313	80.0	13.375	100	35.0
32	22	22	2526.	.787	313	120.0	1234.019	350	44.0
33	22	22	13388.	.260	1800	80.0	14.500	100	35.0
34	23	22	13388.	.260	1800	80.0	14.500	100	35.0
35	23	24	86269.	3.218	2400	80.0	4.324	100	35.0
36	24	25	34110.	.648	2600	80.0	5.572	100	35.0
37	24	25	52159.	1.483	3200	80.0	5.450	100	35.0
38	24	27	87608.	.818	330	120.0	1.066	350	44.0
39	27	28	27897.	1.090	2292	80.0	14.000	100	35.0
40	25	31	34110.	2.136	2000	80.0	18.360	100	35.0
41	25	26	30705.	.342	1700	80.0	3.630	100	35.0
42	26	30	3405.	.002	1050	80.0	1.385	100	35.0
43	26	29	35449.	4.923	1650	80.0	39.173	100	35.0
44	28	27	59711.	.449	750	80.0	1.260	100	35.0
45	29	29	63116.	.340	300	80.0	.854	100	35.0
46	2	30	37348.	6.540	525	80.0	46.882	100	35.0
47	30	31	215187.	.333	297	200.0	.072	250	50.0
48	18	30	84018.	4.426	4100	80.0	6.265	100	35.0
49	31	32	298792.	5.448	2031	200.0	.610	250	50.0
50	1	32	16299.	11.715	30	200.0	441.000	250	50.0

Table 12b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58908.	4.495
51	32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.40

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION CONCENTRAT.	HEAT	OXYGEN CONCENTRATION BEHIND FIRE	PRODUCTION PER % OXYGEN SMOKE	PRODUCTION PER % OXYGEN HEAT
18	.0	.00	.00	16.00	.00	.00

Table 12c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	1	3	-325.0	67.6	.0	3.0	.1000
3	2	4	-2577.0	57.5	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	1	4	2.0	64.3	.0	3.0	.1000
6	2	5	1.0	65.7	70.7	3.0	.1000
7	4	6	.0	69.9	47.1	3.0	.1000
8	5	7	524.0	80.1	23.9	3.0	.1000
9	6	7	524.0	77.5	350.0	3.0	.1000
10	6	14	-4.0	82.0	29.5	3.0	.1000
11	14	31	-1.0	75.4	.0	3.0	.1000
12	3	8	3.0	72.6	50.8	3.0	.1000
13	8	19	2.0	82.6	94.4	3.0	.1000
14	8	9	2.0	77.1	37.0	3.0	.1000
15	9	10	.0	77.6	12.1	3.0	.1000
16	10	11	-2.0	79.2	25.2	3.0	.1000
17	10	11	-5.0	79.0	90.0	3.0	.1000
18	11	12	319.0	83.0	12.1	3.0	.1000
19	12	13	3.0	83.8	.0	3.0	.1000
20	12	14	-523.0	80.3	1.6	3.0	.1000
21	13	15	-2.0	83.6	.0	3.0	.1000
22	13	15	318.0	91.6	27.4	3.0	.1000
23	13	16	1.0	78.2	.0	3.0	.1000
24	15	16	-1.0	78.5	105.5	3.0	.1000
25	15	17	3.0	77.8	.0	3.0	.1000
26	16	18	228.0	82.7	.0	3.0	.1000
27	17	17	-211.0	77.5	.0	3.0	.1000
28	20	18	217.0	78.7	.0	3.0	.1000
29	20	20	333.0	82.0	.0	3.0	.1000
30	19	19	1.0	82.5	.0	3.0	.1000
31	21	21	-331.0	82.6	36.8	3.0	.1000
32	21	21	-311.0	83.6	3.8	3.0	.1000
33	25	22	-7.0	73.3	120.0	3.0	.1000
34	23	22	-7.0	73.1	20.0	3.0	.1000
35	24	24	1.0	70.1	129.4	3.0	.1000
36	24	25	217.0	81.3	250.0	3.0	.1000
37	24	27	-3.0	70.5	234.7	3.0	.1000
38	27	28	230.0	72.0	.0	3.0	.1000
39	28	31	229.0	77.3	.0	3.0	.1000
40	25	26	-2.0	86.7	17.1	3.0	.1000
41	26	30	7.0	76.4	.0	3.0	.1000
42	26	29	8.0	71.3	.0	3.0	.1000
43	28	27	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.4	.0	3.0	.1000
45	29	30	-1.0	84.5	.0	3.0	.1000
46	29	30	225.0	85.7	.0	3.0	.1000
47	30	31	227.0	81.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	415.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 12d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	156454.	64.99	.0000	.00	.374
2	2	3	55868.	67.32	.0000	.00	.015
3	1	4	109854.	64.34	.0000	.00	.365
4	1	23	25012.	65.27	.0000	.00	.061
5	2	4	26252.	64.30	.0000	.00	.162
6	4	5	50308.	64.49	.0000	.14	4.677
7	5	6	50308.	69.73	.0000	.23	.580
8	6	7	3409.	77.90	.0000	.93	2.233
9	6	7	46900.	75.30	.0000	.91	2.205
10	7	14	50308.	81.35	.0000	.97	.849
11	14	31	59996.	76.43	.8074	.90	7.419
12	3	8	55868.	72.39	.0000	.09	.113
13	8	19	12532.	82.52	.0000	.84	.678
14	8	9	43335.	75.12	.0000	.18	.156
15	9	10	40344.	76.61	.0000	.21	.239
16	10	11	7008.	78.71	.0000	.57	.629
17	10	11	33336.	78.62	.0000	.48	.630
18	11	12	40344.	614.13	5.0000	.52	3.999
19	12	13	40344.	288.10	5.0000	.52	1.733
20	13	14	9688.	107.29	5.0000	.54	.053
21	13	15	30656.	162.49	5.0000	.52	.170
22	9	15	2992.	87.70	.0000	1.09	.445
23	15	16	33647.	106.03	4.5555	.57	.284
24	2	16	10486.	78.51	.0000	1.01	.875
25	16	17	44133.	82.50	3.4731	.67	.477
26	17	18	46114.	81.44	3.3239	.68	.058
27	20	17	1981.	77.73	.0000	.76	.001
28	20	18	35563.	78.36	.0000	.76	.645
29	19	20	37544.	80.95	.0000	.76	.070
30	21	19	25012.	82.54	.0000	.72	.031
31	22	21	22686.	82.74	.0000	.72	.715
32	22	22	2326.	86.33	.0000	.72	.699
33	23	22	12503.	73.22	.0000	.96	.228
34	23	24	12509.	73.22	.0000	.16	.228
35	4	25	85798.	69.60	.0000	.15	5.159
36	24	25	32545.	80.53	.0000	.92	.608
37	24	27	53255.	70.49	.0000	.59	1.547
38	27	28	80660.	68.46	.0000	.65	.690
39	28	21	26159.	76.36	.0000	.65	.973
40	25	26	32543.	86.43	.0000	.97	2.055
41	26	30	28321.	76.90	.0000	.97	.302
42	26	29	4222.	71.86	.0000	.97	.003
43	22	27	27405.	70.47	.0000	.78	4.866
44	28	29	54501.	71.60	.0000	.65	.375
45	29	30	58723.	75.72	.0000	.68	.299
46	2	30	36444.	75.77	.0000	.00	6.241
47	30	31	205165.	75.77	.7471	.61	.309
48	18	30	81678.	76.84	1.8766	.71	4.299
49	31	32	291320.	65.50	.6924	.68	5.088
50	1	32	16686.	71.02	.0000	.00	11.852
51	32	1	308006.	65.85	.6549	.04	11.850

<u>Table 12e:</u>

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	2	64.99	.0000	.0000
3	67.32	.0000	.0000	4	64.33	.0000	.0000
5	64.49	.0000	.1405	6	69.73	.0000	.2341
7	75.48	.0000	.9160	8	72.39	.0000	.0909
9	75.12	.0000	.1761	10	76.61	.0000	.2061
11	78.63	.0000	.4911	12	614.13	5.0000	.5210
13	288.10	5.0000	.5210	14	85.55	.0074	.9035
15	155.89	4.5555	.5715	16	99.51	3.4731	.6748
17	82.30	3.3239	.6785	18	80.10	1.8766	.7143
19	82.53	.0000	.7609	20	80.95	.0000	.7609
21	83.07	.0000	.7194	22	73.22	.0000	.5597
23	65.27	.0000	.0000	24	69.60	.0000	.1508
25	80.53	.0000	.9179	26	86.43	.0000	.9698
27	70.48	.0000	.6538	28	68.46	.0000	.6538
29	71.62	.0000	.6765	30	76.34	.7471	.6119
31	75.96	.6924	.6757	32	65.80	.6549	.6391

NUMBER OF ITERATIONS 4

Table 12f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS
(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
11	14	31	.90	.8074	76.4	7.419
18	11	12	.52	5.0000	614.1	3.999
19	12	13	.52	5.0000	288.1	1.733
20	13	14	.54	5.0000	107.3	.053
21	13	15	.52	5.0000	162.5	.170
22	9	15	1.09	.0000	87.7	.445
23	15	16	.57	4.5555	106.0	.284
24	2	16	1.01	.0000	78.5	.875
25	16	17	.67	3.4731	82.5	.477
26	17	18	.68	3.3239	81.4	.658
27	20	17	.76	.0000	77.7	.001
46	26	29	.97	.0000	71.9	.003
47	30	31	.61	.7471	75.8	.309
48	18	30	.71	1.8766	76.8	4.299
49	31	32	.68	.6924	65.5	5.088
51	32	1	.64	.6549	65.9	11.850

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 95.0 DEGREES
12	.5	5.0000	614.1
13	.5	5.0000	288.1
14	.9	.8074	65.5
15	.6	4.5555	155.9
16	.7	3.4731	79.5
17	.7	3.3239	82.3
18	.7	1.8766	80.1
30	.6	.7471	76.3
31	.7	.6924	76.0
32	.6	.6549	65.8

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

AIRWAY 20 IS NOW CARRYING AIR FROM 13 TO 14

Table 13a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	157212.	.386	2597	200.0	.156	250	50.0
2	2	3	42317.	.009	325	200.0	.048	250	50.0
3	1	4	114804.	.631	2577	200.0	.479	250	50.0
4	1	23	26777.	.071	2580	200.0	.995	250	50.0
5	1	4	30374.	.221	2900	80.0	2.400	100	35.0
7	5	6	58908.	.801	2700	80.0	2.307	100	35.0
8	5	7	3982.	2.994	524	120.0	1888.233	350	44.0
9	6	7	54926.	5.994	1700	80.0	9.923	100	35.0
10	7	14	58908.	1.124	1650	80.0	3.239	100	35.0
11	14	31	55708.	6.207	4500	80.0	20.002	100	35.0
12	3	8	42317.	.064	2700	80.0	.360	100	35.0
13	8	19	13885.	.800	2050	80.0	41.490	100	35.0
14	8	9	28432.	.066	600	80.0	.821	100	35.0
15	9	10	24224.	.084	600	80.0	1.437	100	35.0
16	10	[illegible]	4205.	.220	600	80.0	124.385	100	35.0
17	10	[illegible]	20019.	.220	1100	80.0	3.500	100	35.0
18	[illegible]	[illegible]	24224.	.229	319	120.0	3.900	350	44.0
19	[illegible]	[illegible]	24554.	.221	600	80.0	3.772	100	35.0
20	[illegible]	[illegible]	3200.	.004	524	120.0	4.000	350	44.0
21	[illegible]	[illegible]	27424.	.083	550	80.0	1.108	100	35.0
22	[illegible]	15	4208.	.840	318	120.0	474.065	350	44.0
23	15	16	31633.	.205	600	80.0	2.047	100	35.0
24	[illegible]	16	11723.	1.068	2600	80.0	77.702	100	35.0
25	16	17	43356.	.430	1050	80.0	2.285	100	35.0
26	17	18	47108.	.650	228	120.0	2.966	350	44.0
27	20	17	3751.	.006	800	80.0	3.500	100	35.0
28	19	18	36910.	.672	1217	80.0	4.931	100	35.0
29	[illegible]	20	40661.	.755	333	120.0	4.565	350	44.0
30	21	19	26777.	.034	1100	80.0	.475	100	35.0
31	[illegible]	21	24251.	.787	1313	80.0	13.375	100	35.0
32	25	25	2526.	.787	313	120.0	1234.019	350	44.0
33	25	21	13388.	.260	1800	80.0	14.500	100	35.0
34	23	26	13388.	.260	1800	80.0	14.500	100	35.0
35	24	24	86269.	3.218	2400	80.0	4.324	100	35.0
36	24	25	34110.	.648	3600	80.0	5.572	100	35.0
37	24	27	52159.	1.483	3300	80.0	5.450	100	35.0
38	27	28	87608.	.818	2530	120.0	1.066	350	44.0
39	28	31	27897.	1.090	2592	80.0	14.000	100	35.0
40	25	26	34110.	2.136	2000	80.0	18.360	100	35.0
41	26	30	30705.	.345	1700	80.0	3.630	100	35.0
42	26	29	3405.	.002	1050	80.0	1.385	100	35.0
43	[illegible]	27	35449.	4.925	1650	80.0	39.173	100	35.0
44	28	29	59711.	.449	1950	80.0	1.260	100	35.0
45	29	30	63116.	.340	300	80.0	.854	100	35.0
46	2	30	37348.	6.540	525	80.0	46.882	100	35.0
47	30	31	215187.	.333	297	200.0	.072	250	50.0
48	18	30	84018.	4.422	4100	80.0	6.265	100	35.0
49	31	32	298792.	5.448	2031	200.0	.610	250	50.0
50	1	32	16299.	11.715	30	200.0	441.000	250	50.0

Table 13b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	68908.	4.495
51	32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	4.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION CONCENTRAT.	HEAT	OXYGEN CONCENTRATION BEHIND FIRE	PRODUCTION PER % OXYGEN SMOKE	PRODUCTION PER % OXYGEN HEAT
20	.0	.00	.00	.00	1.00	300.00

Table 13c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.6	.0	3.0	.1000
3	1	4	-2577.0	57.5	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	70.7	3.0	.1000
7	5	6	.0	69.9	47.1	3.0	.1000
8	6	7	524.0	80.1	23.9	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	29.5	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	8	8	3.0	76.6	50.8	3.0	.1000
13	8	19	2.0	85.6	64.4	3.0	.1000
14	8	9	2.0	77.1	37.0	3.0	.1000
15	9	10	.0	77.6	12.1	3.0	.1000
16	10	11	-2.0	79.2	25.2	3.0	.1000
17	10	11	-2.0	79.0	90.0	3.0	.1000
18	11	12	319.0	83.0	12.1	3.0	.1000
19	12	13	3.0	83.8	.0	3.0	.1000
20	13	15	-523.0	80.3	1.6	3.0	.1000
21	14	15	-2.0	83.6	.0	3.0	.1000
22	15	15	318.0	91.6	27.4	3.0	.1000
23	15	16	1.0	76.6	.0	3.0	.1000
24	15	16	-1.0	78.5	105.5	3.0	.1000
25	16	17	3.0	71.8	.0	3.0	.1000
26	17	18	228.0	82.7	.0	3.0	.1000
27	18	18	-11.0	77.5	.0	3.0	.1000
28	20	20	217.0	78.7	.0	3.0	.1000
29	19	18	333.0	82.0	.0	3.0	.1000
30	19	20	1.0	82.5	.0	3.0	.1000
31	21	19	-313.0	83.6	36.4	3.0	.1000
32	22	21	-313.0	87.6	3.8	3.0	.1000
33	22	21	-7.0	73.3	120.0	3.0	.1000
34	23	22	-7.0	73.3	20.0	3.0	.1000
35	23	22	1.0	70.1	129.4	3.0	.1000
36	24	24	217.0	81.3	250.0	3.0	.1000
37	24	25	-3.0	70.5	234.7	3.0	.1000
38	27	27	230.0	69.1	.0	3.0	.1000
39	28	28	292.0	77.3	.0	3.0	.1000
40	25	31	-2.0	86.7	17.1	3.0	.1000
41	26	26	7.0	76.4	.0	3.0	.1000
42	26	30	8.0	71.3	.0	3.0	.1000
43	26	29	.0	70.8	212.7	3.0	.1000
44	28	27	-4.0	73.4	.0	3.0	.1000
45	29	29	-1.0	74.3	.0	3.0	.1000
46	22	30	225.0	85.7	.0	3.0	.1000
47	30	30	297.0	81.2	.0	3.0	.1000
48	18	31	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	415.2	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000

Table 13d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	157471.	64.99	.0000	.00	.379
2	2	3	59625.	67.31	.0000	.00	.017
3	1	4	100910.	64.34	.0000	.00	.477
4	1	23	30436.	65.27	.0000	.00	.090
5	2	4	17122.	64.30	.0000	.00	.069
6	4	5	30551.	64.53	.0000	.23	4.621
7	5	6	30551.	69.81	.0000	.39	.214
8	6	7	2090.	78.18	.0000	1.52	.841
9	6	7	28461.	75.66	.0000	1.51	.813
10	7	14	30551.	81.65	.0000	1.60	.314
11	14	3	61526.	77.53	10.5724	1.07	9.890
12	3	8	59625.	72.37	.0000	.09	.128
13	8	19	16306.	82.48	.0000	.66	1.146
14	8	9	43319.	75.11	.0000	.17	.156
15	9	10	37176.	76.64	.0000	.20	.203
16	10	11	6459.	78.73	.0000	.59	.535
17	10	11	30716.	78.64	.0000	.50	.535
18	11	12	37176.	79.52	.0000	.54	.556
19	12	13	37176.	82.12	.0000	.54	.543
20	13	14	30975.	774.98	21.0000	.55	6.117
21	13	15	6201.	83.31	.0000	.54	.004
22	9	15	6143.	86.36	.0000	.61	1.866
23	15	16	12344.	78.36	.0000	.58	.032
24	2	16	16162.	78.48	.0000	.65	2.077
25	16	17	28505.	77.89	.0000	.62	.191
26	17	18	41315.	78.71	.0000	.62	.521
27	20	17	12810.	78.10	.0000	.62	.059
28	20	18	33935.	78.35	.0000	.62	.587
29	19	20	46742.	80.93	.0000	.59	1.039
30	21	19	30436.	82.53	.0000	.59	.046
31	22	21	27596.	82.60	.0000	.59	1.058
32	22	22	2840.	86.08	.0000	.59	1.041
33	23	22	15218.	73.19	.0000	.79	.337
34	23	24	15218.	73.19	.0000	.13	.337
35	4	25	87481.	69.58	.0000	.15	3.284
36	24	25	33168.	80.53	.0000	.90	.631
37	24	27	54313.	70.49	.0000	.58	1.609
38	27	28	81992.	68.47	.0000	.64	.713
39	28	31	26369.	76.36	.0000	.64	.989
40	25	26	33168.	86.42	.0000	.95	2.135
41	26	30	28894.	76.91	.0000	.95	.314
42	26	29	4274.	71.86	.0000	.95	.003
43	2	27	27679.	70.47	.0000	.77	4.964
44	28	29	55623.	71.59	.0000	.64	.390
45	29	30	59897.	75.68	.0000	.67	.311
46	2	30	36883.	75.73	.0000	.00	6.391
47	30	31	200922.	75.74	.0000	.57	.296
48	18	30	75247.	76.81	.0000	.62	3.644
49	31	32	288817.	65.57	2.2522	.68	5.004
50	1	32	16721.	71.01	.0000	.00	11.901
51	32	1	305537.	65.92	2.1290	.64	11.896

Table 13e:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.70	.0000	.0000	2	64.99	.0000	.0000
3	67.31	.0000	.0000	4	64.34	.0000	.0000
5	64.53	.0000	.2314	6	69.81	.0000	.3853
7	75.83	.0000	1.5066	8	72.37	.0000	.0852
9	75.11	.0000	.1704	10	76.64	.0000	.2029
11	78.66	.0000	.5123	12	79.52	.0000	.5447
13	82.13	.0000	.5447	14	441.86	10.5724	1.0721
15	84.82	.0000	.5797	16	78.43	.0000	.6211
17	77.96	.0000	.6197	18	78.55	.0000	.6183
19	82.51	.0000	.6166	20	80.93	.0000	.6166
21	85.93	.0000	.5913	22	73.19	.0000	.4600
23	65.27	.0000	.0000	24	69.58	.0000	.1479
25	80.53	.0000	.9005	26	86.42	.0000	.9515
27	70.48	.0000	.6432	28	68.47	.0000	.6432
29	71.61	.0000	.6652	30	76.29	.0000	.5667
31	76.18	2.2522	.6814	32	65.87	2.1290	.6441

NUMBER OF ITERATIONS 4

Table 13f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS
(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
8	6	7	1.52	.0000	78.2	.841
9	6	7	1.51	.0000	75.7	.813
10	7	14	1.60	.0000	81.6	.314
11	14	31	1.07	10.5724	77.5	9.890
20	13	14	.55	21.0000	775.0	6.117
21	13	15	.54	.0000	83.3	.004
42	26	29	.95	.0000	71.9	.003
49	31	32	.68	2.2522	65.6	5.004
51	32	1	.64	2.1290	65.9	11.896

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 95.0 DEGREES
7	1.5	.0000	75.8
14	1.1	10.5724	441.9
31	.7	2.2522	76.2
32	.6	2.1290	65.9

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

AIRWAY 20 IS NOW CARRYING AIR FROM 13 TO 14

airway 5. Consequently, there is no substantial change in the air flow or temperature distribution. Since airway 5 is an intake airway, almost the whole mine is filled with smoke except for the part ventilated from intake shaft 4.

4.4.2.5 Example 5: Oxygen Rich Fire at Bottom of Timbered Raise

A fully developed fire burns at the bottom of raise airway 18. This raise is timbered and it is assumed that the fumes leave the fire zone with an oxygen concentration of 16% (O2MIN). The results of the calculation are shown in Tables 12 a - f. The natural ventilation of the fire will increase the air flow in airway 18 from approximately 24,000 cfm to 40,000 cfm (based on the reference density). Raise 20, which is an unstable descensionally ventilated airway, will experience a stable air flow reversal and transport approximately 10,000 cfm of fumes up to the next higher level, where an additional contamination of airway 11 takes place.

4.4.2.6 Example 6: Fuel Rich Fire in a Descensionally Ventilated Raise

A smoldering fire is assumed in raise airway 20. Since the raise is poorly ventilated, the possibility of considerable preheating shall be considered, leading to a fuel rich fire. In this, all of the oxygen in the air supply is consumed. The smoke production (SMPO2) per ft^3 of oxygen is estimated to be 1 ft^3, the heat production (HTPO2) 300 Btu. The results are shown in Tables 13 a - f. Raise 20 develops a very powerful natural draft, transporting approximately 31,000 cfm of smoke up into airway 11. Since 11 is the return for airways 8, 9, and 10, these airways will experience air flow reduction and methane concentration increases to above 1%.

In the design of the program it has been assumed that the location of a fire is at the beginning of the airway in which the fire occurs. If an air flow reversal in an airway with fire occurs, the program will move the fire zone from one end of the airway to the other end. This feature had been introduced to assume, for the detection of instabilities, the worst possible conditions. If this approach becomes unrealistic, one has to consider the fire zone as a separate airway whose location is fixed. This shall be demonstrated with the next example.

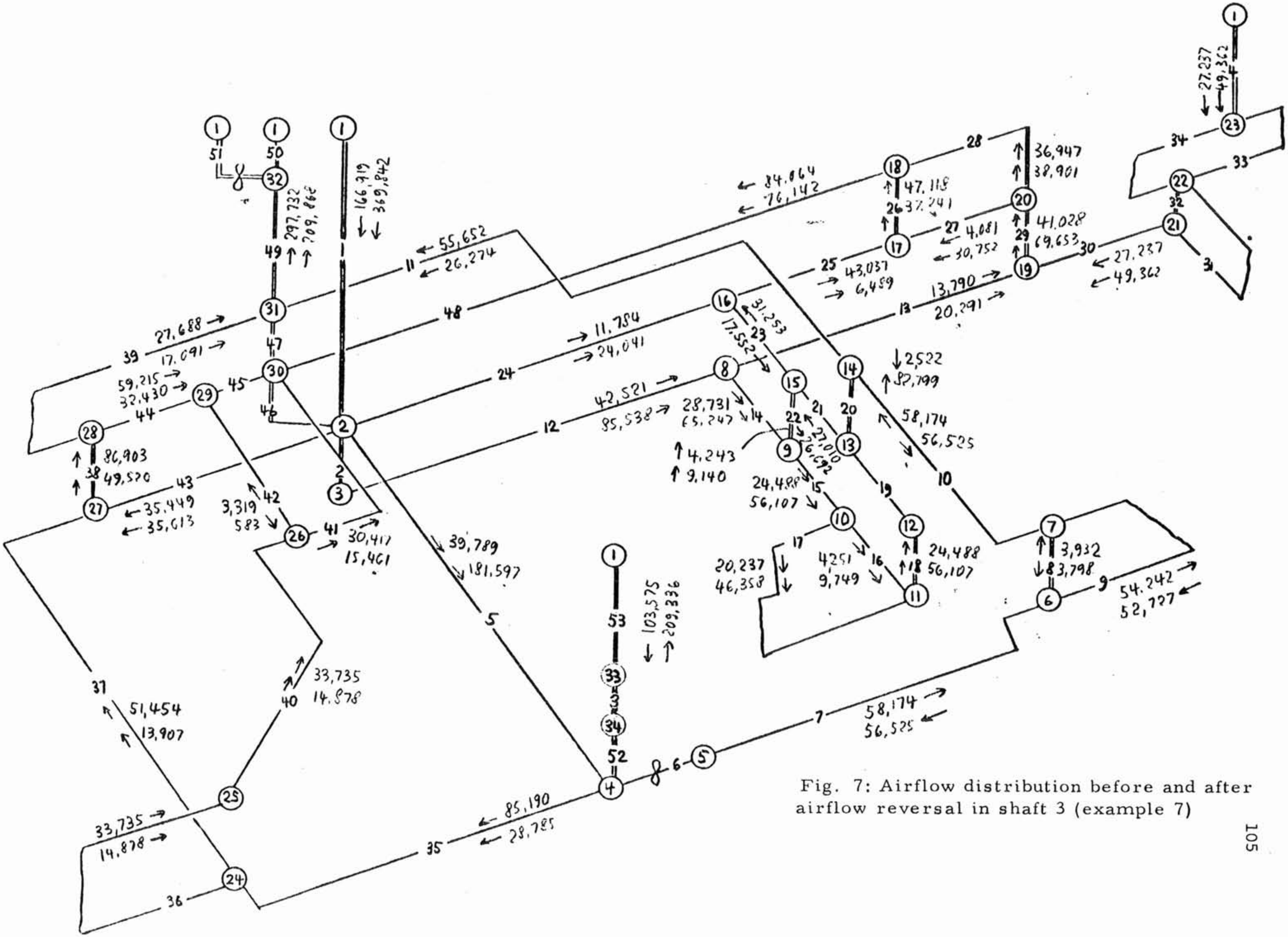


Fig. 7: Airflow distribution before and after airflow reversal in shaft 3 (example 7)

Table 14a:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	206873.	64.98	.0000	.00	.654
2	2	3	45002.	67.38	.0000	.00	.010
3	33	34	40386.	1110.87	5.0000	.00	.012
4	1	23	29120.	65.27	.0000	.00	.083
5	2	4	81712.	64.32	.0000	.00	1.569
6	4	5	51680.	352.63	1.6538	.14	4.650
7	5	6	51680.	74.63	1.6538	.23	.796
8	6	7	3500.	78.22	1.6538	.90	2.368
9	6	7	48180.	75.81	1.6538	.89	2.343
10	7	14	51680.	81.50	1.6538	.94	.897
11	14	31	54613.	76.40	1.5650	.94	6.128
12	3	8	45002.	72.47	.0000	.11	.073
13	8	19	13669.	82.52	.0000	.80	.806
14	8	9	31333.	75.48	.0000	.23	.082
15	9	10	26736.	76.93	.0000	.28	.105
16	10	11	4651.	78.86	.0000	.83	.277
17	10	11	22085.	78.78	.0000	.68	.277
18	11	12	26736.	79.98	.0000	.75	.288
19	12	13	26736.	82.55	.0000	.75	.281
20	13	14	2933.	79.04	.0000	.80	.004
21	13	15	23802.	83.26	.0000	.75	.066
22	9	15	4597.	87.13	.0000	.83	1.048
23	15	16	28400.	78.76	.0000	.77	.172
24	2	16	12561.	78.51	.0000	.84	1.256
25	16	17	40961.	77.95	.0000	.79	.395
26	17	18	46907.	78.74	.0000	.78	.672
27	20	17	5946.	77.88	.0000	.68	.013
28	20	18	36843.	78.33	.0000	.68	.692
29	19	20	42789.	80.96	.0000	.68	.870
30	21	19	29120.	82.54	.0000	.62	.042
31	22	21	26403.	82.74	.0000	.62	.969
32	22	21	2717.	86.22	.0000	.62	.953
33	23	22	14560.	73.22	.0000	.82	.309
34	23	22	14560.	73.22	.0000	.14	.309
35	4	24	70418.	83.59	1.6538	.18	3.078
36	24	25	27676.	80.72	1.6538	1.08	.445
37	24	27	42742.	70.59	1.6538	.72	1.007
38	27	28	72356.	68.39	.9769	.72	.556
39	28	31	23789.	76.41	.9769	.72	.805
40	25	26	27676.	86.51	1.6538	1.14	1.488
41	26	30	24809.	76.76	1.6538	1.14	.231
42	26	29	2867.	71.70	1.6538	1.14	.001
43	2	27	29614.	70.49	.0000	.72	5.683
44	28	29	48568.	71.82	.9769	.72	.298
45	29	30	51435.	76.34	1.0147	.74	.230
46	2	30	37983.	76.16	.0000	.00	6.786
47	30	31	197977.	76.09	.4709	.65	.288
48	18	30	83750.	76.81	.0000	.73	4.514
49	31	32	276379.	65.60	.7306	.71	4.582
50	1	32	16882.	71.46	.0000	.00	12.142
51	32	1	293260.	66.03	.6886	.67	12.128
52	34	4	40386.	1023.70	5.0000	.00	.020
53	1	33	40386.	64.19	.0000	.00	.120

Table 14b:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	217687.	64.97	.0000	.00	.724
2	2	3	45519.	67.38	.0000	.00	.010
3	33	34	27989.	1103.67	5.0000	.00	.006
4	1	23	29719.	65.27	.0000	.00	.086
5	2	4	91966.	64.32	.0000	.00	1.988
6	4	5	49859.	255.22	1.1666	.14	4.686
7	5	6	49859.	72.92	1.1666	.23	.678
8	6	7	3378.	78.12	1.1666	.43	2.201
9	6	7	46481.	75.69	1.1666	.92	2.176
10	7	14	49859.	81.50	1.1666	.98	.835
11	14	31	54360.	76.40	1.0700	.96	6.071
12	3	8	45519.	72.47	.0000	.11	.075
13	8	19	13544.	82.53	.0000	.80	.792
14	8	9	31975.	75.47	.0000	.23	.085
15	9	10	27308.	76.92	.0000	.27	.110
16	10	11	4742.	78.85	.0000	.81	.288
17	10	11	22566.	78.78	.0000	.67	.289
18	11	12	27308.	79.96	.0000	.74	.300
19	12	13	27308.	82.54	.0000	.74	.294
20	13	14	4501.	79.05	.0000	.77	.008
21	13	15	22807.	83.26	.0000	.74	.060
22	9	15	4667.	87.10	.0000	.82	1.080
23	15	16	27474.	78.74	.0000	.75	.161
24	2	16	12690.	78.51	.0000	.84	1.281
25	16	17	40165.	77.95	.0000	.78	.380
26	17	18	46697.	78.74	.0000	.76	.666
27	20	18	6533.	77.90	.0000	.67	.015
28	20	18	36730.	78.33	.0000	.67	.688
29	19	20	43263.	80.96	.0000	.67	.890
30	21	19	29719.	82.54	.0000	.61	.044
31	22	21	26945.	82.73	.0000	.61	1.009
32	22	21	2774.	86.19	.0000	.61	.994
33	23	22	14860.	73.22	.0000	.81	.322
34	23	22	14860.	73.22	.0000	.13	.322
35	4	24	70095.	79.14	1.1666	.18	2.706
36	24	25	27526.	80.68	1.1666	1.09	.438
37	24	27	42570.	70.56	1.1666	.73	.996
38	27	28	72157.	68.38	.6883	.72	.553
39	28	31	23714.	76.41	.6883	.72	.800
40	25	26	27526.	86.51	1.1666	1.15	1.471
41	26	30	24718.	76.76	1.1666	1.15	.230
42	26	29	2808.	71.69	1.1666	1.15	.001
43	2	27	29588.	70.49	.0000	.72	5.673
44	28	29	48443.	71.81	.6883	.72	.296
45	29	30	51251.	76.35	.7145	.75	.228
46	2	30	37924.	76.16	.0000	.00	6.765
47	30	31	197321.	76.09	.3317	.64	.286
48	18	30	83428.	76.81	.0000	.72	4.479
49	31	32	275395.	65.60	.5082	.71	4.550
50	1	32	16882.	71.46	.0000	.00	12.143
51	32	1	292277.	66.04	.4788	.67	12.146
52	34	4	27989.	959.88	5.0000	.00	.014
53	1	33	27989.	64.10	.0000	.00	.057

Table 14c:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	226688.	64.96	.0000	.00	.785
2	2	3	46138.	67.37	.0000	.00	.010
3	33	34	17236.	1093.44	5.0000	.00	.002
4	1	23	30310.	65.27	.0000	.00	.090
5	2	4	100129.	64.32	.0000	.00	2.356
6	4	5	48132.	173.98	.7343	.15	4.716
7	5	6	48132.	71.54	.7343	.24	.587
8	6	7	3262.	78.06	.7343	.46	2.050
9	6	7	44870.	75.61	.7343	.95	2.025
10	7	14	48132.	81.51	.7343	1.01	.778
11	14	31	54129.	76.40	.6529	.98	6.020
12	3	8	46138.	72.46	.0000	.11	.077
13	8	19	13502.	82.53	.0000	.80	.787
14	8	9	32637.	75.46	.0000	.22	.089
15	9	10	27887.	76.91	.0000	.27	.114
16	10	11	4845.	78.85	.0000	.79	.301
17	10	11	23042.	78.77	.0000	.66	.301
18	11	12	27887.	79.94	.0000	.73	.313
19	12	13	27887.	82.52	.0000	.73	.306
20	13	14	5997.	79.07	.0000	.75	.015
21	13	15	21890.	83.26	.0000	.73	.056
22	9	15	4750.	87.07	.0000	.80	1.119
23	15	16	26640.	78.72	.0000	.74	.151
24	2	16	12863.	78.51	.0000	.82	1.316
25	16	17	39502.	77.94	.0000	.77	.368
26	17	18	46586.	78.74	.0000	.75	.663
27	20	17	7084.	77.92	.0000	.66	.018
28	20	18	36728.	78.33	.0000	.66	.088
29	19	20	43812.	80.95	.0000	.66	.413
30	21	19	30310.	82.54	.0000	.60	.046
31	22	21	27480.	82.72	.0000	.60	1.049
32	22	21	2830.	86.16	.0000	.60	1.034
33	23	22	15155.	73.21	.0000	.79	.335
34	23	22	15155.	73.21	.0000	.13	.335
35	4	24	69233.	75.52	.7343	.18	2.379
36	24	25	27205.	80.65	.7343	1.10	.427
37	24	27	42027.	70.53	.7343	.73	.968
38	27	28	71655.	68.36	.4307	.73	.545
39	28	31	23557.	76.41	.4307	.73	.790
40	25	26	27205.	86.51	.7343	1.16	1.437
41	26	30	24494.	76.76	.7343	1.16	.226
42	26	29	2711.	71.68	.7343	1.16	.001
43	2	27	29628.	70.49	.0000	.72	5.689
44	28	29	48099.	71.82	.4307	.73	.292
45	29	30	50810.	76.36	.4469	.75	.224
46	2	30	37931.	76.16	.0000	.00	6.767
47	30	31	196549.	76.09	.2070	.64	.284
48	18	30	83314.	76.81	.0000	.71	4.467
49	31	32	274234.	65.60	.3143	.72	4.511
50	1	32	16897.	71.46	.0000	.00	12.165
51	32	1	291131.	66.04	.2960	.67	12.168
52	34	4	17236.	879.42	5.0000	.00	.007
53	1	33	17236.	63.90	.0000	.00	.021

Table 15a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

REGULAR AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	166919.	.435	2597	200.0	.156	250	50.0
2	2	3	42521.	.009	325	200.0	.048	250	50.0
3	33	34	103575.	.009	27	200.0	.008	250	50.0
4	1	23	27237.	.074	2580	200.0	.995	250	50.0
5	2	4	39789.	.380	2900	80.0	2.400	100	35.0
7	5	6	58174.	.781	2700	80.0	2.307	100	35.0
8	6	7	3932.	2.920	524	120.0	1888.233	350	44.0
9	6	7	54242.	2.920	1700	80.0	9.923	100	35.0
10	7	14	58174.	1.096	1650	80.0	3.239	100	35.0
11	14	31	55652.	6.195	4500	80.0	20.002	100	35.0
12	3	8	42521.	.065	2700	80.0	.360	100	35.0
13	8	19	13790.	.789	2050	80.0	41.490	100	35.0
14	8	9	28731.	.068	600	80.0	.821	100	35.0
15	9	10	24488.	.086	600	80.0	1.437	100	35.0
16	10	11	4251.	.225	600	80.0	124.385	100	35.0
17	10	11	20237.	.225	1100	80.0	5.500	100	35.0
18	11	12	24488.	.234	319	120.0	3.900	350	44.0
19	12	13	24488.	.226	600	80.0	3.772	100	35.0
20	14	13	2522.	.003	524	120.0	4.000	350	44.0
21	13	15	27010.	.081	550	80.0	1.108	100	35.0
22	9	15	4243.	.853	318	120.0	474.065	350	44.0
23	15	16	31253.	.200	600	80.0	2.047	100	35.0
24	2	16	11784.	1.079	2600	80.0	77.702	100	35.0
25	16	17	43037.	.423	1050	80.0	2.285	100	35.0
26	17	18	47118.	.658	228	120.0	2.966	350	44.0
27	20	17	4081.	.006	800	80.0	3.500	100	35.0
28	20	18	36947.	.678	1217	80.0	4.931	100	35.0
29	19	20	41028.	.768	333	120.0	4.565	350	44.0
30	21	19	27237.	.035	1100	80.0	.475	100	35.0
31	22	21	24608.	.814	1313	80.0	13.375	100	35.0
32	22	21	2569.	.815	313	120.0	1234.019	350	44.0
33	23	22	13619.	.269	1800	80.0	14.500	100	35.0
34	23	22	13619.	.269	1800	80.0	14.500	100	35.0
35	4	24	85190.	3.138	2400	80.0	4.324	100	35.0
36	24	25	33735.	.634	2600	80.0	5.572	100	35.0
37	24	27	51454.	1.443	3200	80.0	5.450	100	35.0
38	27	28	86903.	.805	230	120.0	1.066	350	44.0
39	28	31	27688.	1.073	2292	80.0	14.000	100	35.0
40	25	26	33735.	2.090	2000	80.0	18.360	100	35.0
41	26	30	30417.	.336	1700	80.0	3.630	100	35.0
42	26	29	3319.	.002	1050	80.0	1.385	100	35.0
43	2	27	35449.	4.761	1650	80.0	39.481	100	35.0
44	28	29	59215.	.442	750	80.0	1.260	100	35.0
45	29	30	62534.	.334	300	80.0	.854	100	35.0
46	2	30	37377.	6.550	525	80.0	46.882	100	35.0
47	30	31	214392.	.331	297	200.0	.072	250	50.0
48	18	30	84064.	4.427	4100	80.0	6.265	100	35.0
49	31	32	297732.	5.410	2031	200.0	.610	250	50.0
50	1	32	16311.	11.733	30	200.0	441.000	250	50.0
52	34	4	103575.	.040	125	200.0	.038	250	50.0
53	1	33	103575.	.782	2425	200.0	.729	250	50.0

Table 15b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58174.	4.511
51	32	1	314043.	11.738

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

THE STATED NUMBER OF AIRWAYS WAS 53 THE STATED NUMBER OF JUNCTIONS WAS 34

TIME AFTER BEGINNING OF EVENT .50 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION CONCENTRAT.	HEAT	OXYGEN CONCENTRATION BEHIND FIRE	PRODUCTION PER % OXYGEN SMOKE	PRODUCTION PER % OXYGEN HEAT
3	.0	.00	.00	16.00	.00	.00

Table 15c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	.0	3.0	.1000
2	2	3	-325.0	67.6	.0	3.0	.1000
3	33	34	-27.0	58.4	.0	3.0	.1000
4	1	23	-2580.0	58.4	.0	3.0	.1000
5	2	4	2.0	64.3	.0	3.0	.1000
6	4	5	1.0	65.7	69.8	3.0	.1000
7	5	6	.0	69.9	46.5	3.0	.1000
8	6	7	524.0	80.1	23.6	3.0	.1000
9	6	7	524.0	77.5	320.0	3.0	.1000
10	7	14	-4.0	82.0	29.1	3.0	.1000
11	14	31	-1.0	76.4	.0	3.0	.1000
12	3	8	3.0	72.6	51.0	3.0	.1000
13	8	19	2.0	82.6	93.8	3.0	.1000
14	8	9	2.0	77.1	37.3	3.0	.1000
15	9	10	.0	77.6	12.5	3.0	.1000
16	10	11	-2.0	79.2	25.5	3.0	.1000
17	10	11	-2.0	79.0	90.0	3.0	.1000
18	11	12	319.0	83.1	12.2	3.0	.1000
19	12	13	3.0	83.8	.0	3.0	.1000
20	14	13	-523.0	80.4	1.3	3.0	.1000
21	13	15	-2.0	83.6	.0	3.0	.1000
22	9	15	318.0	91.6	27.6	3.0	.1000
23	15	16	1.0	76.2	.0	3.0	.1000
24	2	16	-1.0	78.5	106.1	3.0	.1000
25	16	17	3.0	77.8	.0	3.0	.1000
26	17	18	228.0	82.7	.0	3.0	.1000
27	20	17	-1.0	77.5	.0	3.0	.1000
28	20	18	217.0	78.7	.0	3.0	.1000
29	19	20	333.0	82.0	.0	3.0	.1000
30	21	19	1.0	85.5	.0	3.0	.1000
31	22	21	-313.0	85.6	37.0	3.0	.1000
32	22	21	-313.0	87.7	3.9	3.0	.1000
33	23	22	-7.0	73.3	120.0	3.0	.1000
34	23	22	-7.0	73.3	20.0	3.0	.1000
35	4	24	1.0	70.1	127.8	3.0	.1000
36	24	25	217.0	81.3	250.0	3.0	.1000
37	24	27	-3.0	79.5	231.5	3.0	.1000
38	27	28	230.0	67.0	.0	3.0	.1000
39	28	31	292.0	77.3	.0	3.0	.1000
40	25	26	-5.0	86.7	16.9	3.0	.1000
41	26	30	7.0	76.4	.0	3.0	.1000
42	26	29	8.0	71.3	.0	3.0	.1000
43	2	27	.0	70.8	212.7	3.0	.1000
44	28	29	-4.0	73.4	.0	3.0	.1000
45	29	30	-1.0	84.5	.0	3.0	.1000
46	2	30	225.0	85.7	.0	3.0	.1000
47	30	31	297.0	81.2	.0	3.0	.1000
48	18	30	-5.0	76.8	.0	3.0	.1000
49	31	32	2031.0	71.2	.0	3.0	.1000
50	1	32	-26.0	415.3	.0	3.0	.1000
51	32	1	26.0	70.0	.0	3.0	.1000
52	34	4	-125.0	63.5	.0	3.0	.1000
53	1	33	-2425.0	57.3	.0	3.0	.1000

Table 15d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	369842.	64.85	.0000	.00	2.090
2	2	3	85538.	67.18	.0000	.00	.035
3	34	33	209336.	1137.89	5.0000	.30	.328
4	1	23	49362.	65.25	.0000	.00	.238
5	2	4	181597.	64.35	.0000	.00	7.751
6	5	4	56525.	69.50	.0000	1.25	4.547
7	6	5	56525.	70.08	.0000	1.13	.744
8	7	6	3798.	81.67	.0000	1.06	2.853
9	7	6	52727.	79.41	.0000	1.04	2.875
10	14	7	56525.	81.72	.0000	.44	1.078
11	14	31	26274.	76.40	.0000	.39	1.416
12	3	8	85538.	72.33	.0000	.06	.264
13	8	19	20291.	82.46	.0000	.52	1.775
14	8	9	65247.	74.94	.0000	.12	.355
15	9	10	56107.	76.48	.0000	.14	.462
16	10	11	9749.	78.62	.0000	.40	1.217
17	10	11	46358.	78.55	.0000	.33	1.217
18	11	12	56107.	79.28	.0000	.37	1.266
19	12	13	56107.	81.87	.0000	.37	1.236
20	13	14	82799.	79.08	.0000	.39	2.838
21	15	13	26692.	82.27	.0000	.43	.082
22	9	15	9140.	85.65	.0000	.42	4.121
23	16	15	17552.	76.83	.0000	.44	.065
24	2	16	24041.	78.45	.0000	.44	4.591
25	16	17	6489.	77.82	.0000	.44	.010
26	17	18	37241.	79.09	.0000	.42	.424
27	20	17	30752.	78.35	.0000	.41	.343
28	20	18	38901.	78.34	.0000	.41	.771
29	19	20	69653.	80.90	.0000	.41	2.306
30	21	19	49362.	82.49	.0000	.37	.121
31	22	21	44731.	82.34	.0000	.37	2.776
32	22	21	4631.	85.47	.0000	.37	2.762
33	23	22	24681.	73.10	.0000	.49	.887
34	23	22	24681.	73.10	.0000	.08	.887
35	4	24	28785.	69.99	.0000	.74	.357
36	24	25	14878.	80.67	.0000	2.41	.127
37	24	27	13907.	70.50	.0000	2.39	.106
38	27	28	49520.	68.18	.0000	1.10	.260
39	28	31	17091.	76.45	.0000	1.10	.416
40	25	26	14878.	86.59	.0000	2.52	.430
41	26	30	15461.	76.60	.0000	2.46	.090
42	29	26	583.	71.33	.0000	1.10	.000
43	2	27	35613.	70.43	.0000	.60	8.215
44	28	29	32430.	72.03	.0000	1.10	.133
45	29	30	31847.	77.15	.0000	1.10	.088
46	2	30	43053.	75.74	.0000	.00	8.707
47	30	31	166502.	76.19	.0000	.63	.204
48	18	30	76142.	76.81	.0000	.41	3.731
49	31	32	209868.	65.63	.0000	.64	2.643
50	1	32	17781.	71.12	.0000	.00	13.461
51	32	1	227648.	66.19	.0000	.59	13.454
52	4	34	209336.	64.74	.0000	.30	.161
53	33	1	209336.	206.07	5.0000	.30	11.808

Table 15e:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.60	.0000	.0000	2	64.85	.0000	.0000
3	67.18	.0000	.0000	4	65.57	.0000	.2965
5	70.08	.0000	1.1271	6	79.57	.0000	1.0456
7	81.72	.0000	.4405	8	72.33	.0000	.0597
9	74.94	.0000	.1169	10	76.48	.0000	.1387
11	78.56	.0000	.3442	12	79.28	.0000	.3660
13	82.00	.0000	.3877	14	79.08	.0000	.3892
15	79.85	.0000	.4333	16	78.45	.0000	.4411
17	78.26	.0000	.4166	18	78.70	.0000	.4139
19	82.48	.0000	.4114	20	80.90	.0000	.4114
21	85.64	.0000	.3662	22	73.10	.0000	.2836
23	65.25	.0000	.0000	24	69.99	.0000	.7391
25	80.67	.0000	2.4070	26	86.02	.0000	2.4043
27	70.45	.0000	1.1012	28	68.18	.0000	1.1012
29	72.03	.0000	1.1012	30	76.58	.0000	.6288
31	76.24	.0000	.6372	32	66.06	.0000	.5875
33	1137.89	5.0000	.2965	34	64.74	.0000	.2965

NUMBER OF ITERATIONS 6

Table 15f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS
(THE STATED NUMBERS REFER TO AIRWAY ENDS)

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILAT. PRESSURE LOWER THAN .010 INCHES WG
3	34	33	.30	5.0000	*****	.328
6	5	4	1.25	.0000	69.5	4.547
7	6	5	1.13	.0000	70.1	.744
8	7	6	1.06	.0000	81.7	2.853
9	7	6	1.04	.0000	79.4	2.875
25	16	17	.44	.0000	77.8	.010
26	24	25	2.41	.0000	80.7	.127
37	24	27	2.39	.0000	70.5	.106
38	27	28	1.10	.0000	68.2	.260
39	28	31	1.10	.0000	76.4	.416
40	25	26	2.52	.0000	86.6	.430
41	26	30	2.46	.0000	76.6	.090
42	29	26	1.10	.0000	71.3	.000
44	28	29	1.10	.0000	72.0	.133
45	29	30	1.10	.0000	77.1	.088
53	33	1	.30	5.0000	206.1	11.808

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATIONS HIGHER THAN .050 PERCENT	TEMPERATURE MORE THAN 95.0 DEGREES
5	1.1	.0000	70.1
6	1.0	.0000	79.6
25	2.4	.0000	80.7
26	2.5	.0000	86.0
27	1.1	.0000	70.4
28	1.1	.0000	68.2
29	1.1	.0000	72.0
33	.3	5.0000	*****

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

AIRWAY 3 IS NOW CARRYING AIR FROM 34 TO 33
AIRWAY 6 IS NOW CARRYING AIR FROM 5 TO 4
AIRWAY 7 IS NOW CARRYING AIR FROM 6 TO 5
AIRWAY 8 IS NOW CARRYING AIR FROM 7 TO 6
AIRWAY 9 IS NOW CARRYING AIR FROM 7 TO 6
AIRWAY 10 IS NOW CARRYING AIR FROM 14 TO 7

AIRWAY 20 IS NOW CARRYING AIR FROM 13 TO 14
AIRWAY 21 IS NOW CARRYING AIR FROM 15 TO 13
AIRWAY 23 IS NOW CARRYING AIR FROM 16 TO 15
AIRWAY 42 IS NOW CARRYING AIR FROM 29 TO 26
AIRWAY 52 IS NOW CARRYING AIR FROM 4 TO 34
AIRWAY 53 IS NOW CARRYING AIR FROM 33 TO 1

Table 16a:

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION CONCENTRAT.	HEAT	OXYGEN CONCENTRATION BEHIND FIRE	PRODUCTION PER % OXYGEN SMOKE	PRODUCTION PER % OXYGEN HEAT
17	100.0	100.00	.00	.00	.00	.00

Table 16b:

TEMPERATURES AND CONCENTRATIONS OF SMOKE AND METHANE IN JUNCTIONS

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.60	.0000	.0000	2	65.07	.0000	.0000
3	67.49	.0000	.0000	4	64.34	.0000	.0000
5	64.53	.0000	.1211	6	69.79	.0000	.2018
7	75.72	.0000	.2900	8	72.50	.0000	.1230
9	75.69	.0000	.2566	10	77.08	.0000	.3080
11	78.86	.4256	.7969	12	80.23	.4256	.8480
13	85.66	.3674	.8528	14	81.58	.0000	.8400
15	83.86	.3190	.8612	16	78.58	.2332	.8755
17	77.90	.2167	.8661	18	78.65	.1218	.8116
19	82.24	.0000	.7417	20	80.98	.0000	.7417
21	83.35	.0000	.7035	22	73.26	.0000	.5473
23	65.58	.0000	.0000	24	69.85	.0000	.1494
25	80.62	.0000	.9084	26	86.52	.0000	.9597
27	70.53	.0000	.6461	28	68.28	.0000	.6461
29	71.92	.0000	.6683	30	76.80	.0483	.6462
31	76.44	.0347	.6829	32	66.04	.0328	.6455

NUMBER OF ITERATIONS 1

Table 16b:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	149032.	65.07	.0000	.00	.540
2	2	3	41295.	67.49	.0000	.00	.008
3	1	4	113633.	64.36	.0000	.00	.605
4	1	23	25579.	65.28	.0000	.00	.064
5	2	4	31357.	64.30	.0000	.00	.231
6	4	5	58352.	64.53	.0000	.12	4.507
7	5	6	58352.	69.79	.0000	.20	.781
8	6	7	3947.	77.89	.0000	.81	2.994
9	6	7	54405.	75.57	.0000	.79	2.971
10	7	14	58355.	81.58	.0000	.84	1.144
11	14	31	54635.	76.40	.0000	.84	6.131
12	3	8	41295.	72.50	.0000	.12	.062
13	8	19	13663.	82.54	.0000	.81	.006
14	8	9	27632.	75.69	.0000	.26	.064
15	9	10	23496.	77.08	.0000	.31	.081
16	10	11	4078.	78.91	.0000	.92	.213
17	10	11	19419.	78.84	.5150	.77	.214
18	11	12	23496.	80.23	.4256	.65	.223
19	12	13	23496.	82.78	.4256	.65	.218
20	14	13	3720.	81.91	.0000	.88	.006
21	13	15	27217.	83.31	.3674	.89	.086
22	9	15	4136.	87.47	.0000	.92	.049
23	15	16	31352.	78.60	.3190	.86	.209
24	2	16	11536.	78.52	.0000	.91	1.060
25	16	17	42889.	77.91	.2338	.88	.433
26	17	18	46146.	78.93	.2167	.87	.651
27	20	17	3257.	77.78	.0000	.74	.004
28	20	18	35985.	78.29	.0000	.74	.660
29	19	20	39242.	80.98	.0000	.74	.732
30	21	19	25579.	82.54	.0000	.70	.035
31	22	21	23195.	82.92	.0000	.70	.749
32	22	21	2384.	86.42	.0000	.71	.734
33	23	22	12790.	73.26	.0000	.94	.239
34	23	22	12790.	73.26	.0000	.16	.239
35	4	24	86638.	69.85	.0000	.15	3.226
36	24	25	32889.	80.62	.0000	.91	.622
37	24	27	53749.	70.50	.0000	.59	1.577
38	27	28	81618.	68.28	.0000	.65	.707
39	28	31	26435.	76.42	.0000	.65	.995
40	25	26	32889.	86.52	.0000	.96	2.101
41	26	30	28689.	76.72	.0000	.96	.309
42	26	29	4200.	71.80	.0000	.96	.002
43	2	27	27868.	70.58	.0000	.76	5.036
44	28	29	55182.	71.93	.0000	.65	.384
45	29	30	59382.	76.69	.0000	.67	.306
46	2	30	36976.	77.02	.0000	.00	6.446
47	30	31	207178.	76.45	.0483	.65	.316
48	18	30	82130.	76.80	.1218	.81	4.340
49	31	32	288245.	65.68	.0347	.68	4.987
50	1	32	16701.	72.26	.0000	.00	11.903
51	32	1	304946.	66.22	.0328	.65	11.907

4.4.2.7 Example 7: Oxygen Rich Fire in an Intake Shaft

It shall be investigated if a fire in the timbered shaft airway 3 is capable of reversing the air flow in this shaft. For this purpose the shaft simulation is divided into three parts: an upper section airway 53; a lower section airway 52; and the fire zone airway 3. A length of 27 ft is assumed for the fire zone, the remaining shaft length is 2550 ft (Fig. 7). Tentatively different locations are selected for the fire zone until an air flow reversal occurs. With the section below the fire zone being 50, 75, or 100 ft long, not sufficient natural ventilation pressure is developed for a reversal, although the air flow rate through the shaft drops from approximately 103,000 cfm normal to 40,000, 27,000, and 17,000 cfm (Table 14 a - c). With the section below the fire zone being 125 ft long, the reversal in the shaft has taken place (Tables 15 a - f) and a large air flow rate of 207,000 cfm is exhausting. This in turn causes reversals and high methane concentrations in a number of other airways. Fig. 7 shows a plot of original air flow rates (Table 15a) and final air flow rates (Table 15d) with the lower placed figures indicating the latter state.

Should the fire start at the top of the shaft, one will have a somehow different phenomenon. Air flow reversal will occur fast but will be maintained only when the fire zone is more than 100 ft below the surface. Otherwise the natural ventilation pressure will, after the reversal, be too weak to maintain this flow direction and a very unstable state with fluctuations of the air flow will develop.

4.4.2.8 Example 8: Layout of Fire Warning System

It shall be investigated if a fire warning system installed at the upcast shaft airway 49 can detect spontaneous combustion in the gob area of longwall face airway 17. For this purpose one releases 100 cfm of contaminant (CONT) with a concentration (CONC) of 100.00% into airway 17. Table 16 shows that this results in a concentration of 0.0347% in upcast shaft 49 and of 0.1218% in return airway 48. If a detection of 5 ppm CO can be accomplished, the spontaneous combustion source must release at least 100*5/347 = 1.44 cfm of CO for an instrument installation at the surface and 100*5/1218 = 0.41 cfm for an installation in airway 48.

4.5 ORGANIZATION OF INPUT

4.5.1 Common Input Cards

The sequence of input data is: 1 network control card; NB airway cards; NJ junction cards (optional); NFNUM sets of fan characteristic cards (optional), each set comprising 1 fan identity card, 1 or more curve point cards; NADBC additional network airway cards (optional).

If a concentration or temperature calculation is desired, these cards are followed by: 1 concentration control card; 1 average value card (optional); NDIM additional concentration airway cards; NCH4C additional concentration junction cards (optional); INFLOW contamination cards (optional).

The term "optional" does not mean that all of the optional cards can be omitted. There must be sufficient input information for the given assignment. Otherwise a message will state what is lacking and the calculation will be terminated.

The network control card contains:

NB NJ NFNUM NADBC NVPN NETW NCONC NTEMP MADJ ITN DR TR

FORMAT (10I5,2F10.5)

These symbols have been explained in the program description. In example 1 this control card reads:

51 32 2 3 1 1 1 1 10 30 .075 70.0

The NB airway cards contain:

NO JS JF NWTYP R Q KF LA A O

FORMAT (4I5,F10.3,F10.0,2I10,2F10.1)

For instance, airway card 1, which remained unchanged in all examples, reads:

1 1 2 0 0.156 200000 250 2597 200.0 50.0

The NJ junction cards contain:

JNO T Z CH4C (optional)

FORMAT (I5,T11,F5.1,T20,F6.0,F5.2)

For instance, junction card 1 read in all described examples:

1 50.0 114

The NFNUM sets of fan characteristic cards contain the fan identity card with:

NOF MPTS

FORMAT (2I5)

and the curve point cards with:

QF PF QF PF QF PF QF PF QF PF

FORMAT (5(F8.0,F6.2))

For instance, the set for fan No. 6, which was used throughout all examples, reads:

6 10

20000 3.60 25000 4.30 30000 4.60 40000 4.78 55000 4.58
70000 4.19 85000 3.96 100000 3.70 150000 3.00 200000 2.52

The NADBC additional airway cards contain:

NOX KX LX AX OX

FORMAT (I5,T41,2I10,2F10.1)

For instance, card 45 reads in all described examples:

45 100 300 80.0 35.0

The concentration control card contains:

NDIM NCH4C NAV MAXJ INFLOW JSTART TSTART TIME CRITSM CRITGS
CITHT WRNPR WRNSM WRNGS WRNHT

FORMAT (6I5,F5.1,F8.2,F7.5,F5.3,F6.3,F4.2,F6.4,F4.1,F5.0)

In example 1 this control card reads:

5 2 1 32 0 1 50.0 2.0 0.005 0.10 0.20 0.01 0.05
1.0 95.0

The magnitude of the iteration thresholds CRITSM, CRITGS, CRITHT is a matter of personal preference. Low values will require more iterations but give more accurate results and vice versa. The selection of the warning thresholds depends on what one considers to be a state requiring special attention.

The average value card contains:

TAVR HAAVR HKAVR KFAVR LAAVR AAVR OAVR

FORMAT (3F10.5,2I10,2F10.2)

It reads in the calculations of this report:

70.0 0.10 3.0 100 1000 100.0 100.0

Only HAAVR and HKAVR were used in the calculations.

The NDIM additional concentration cards contain:

NOX CH4VX CH4PAX TROCKX HAX HKX DZRDX

FORMAT (I5,F10.2,4F10.5,F10.1)

In the described examples, 5 such cards were used stating the methane production CH4VX of the longwall faces only. Card 1 reads, for instance:

9 320.0

The NCH4C additional concentration junction cards contain:

JNOX CH4CX

FORMAT (I5,T26,F5.2)

These calculations used two such cards for the input of two additional junction concentrations. The first of the cards reads, for instance:

27 0.60

The INFLOW contamination cards contain:

NCENT CONT CONC HEAT O2MIN SMPO2 HTPO2

FORMAT (I5,F10.0,F10.5,F10.2,3F10.5)

Patterns for these cards will be given later.

In all of the described examples all input cards, except for the network and concentration control cards, and the contamination cards, did not change, since the network did not change either. Two new airway and two new junction cards were added, only in example 7.

4.5.2 Control and Contamination Cards

In example 1 a simulation of the normal ventilation system without any contamination was demanded. This requires a network, concentration, and temperature calculation. It was assumed that the surface temperature is 50.0°F. The time after the ventilation change (which in this case did not take place) was arbitrarily set to 2 hrs.

The network control card states in this case:

51 32 2 3 1 1 1 1 10 30 0.075 70.0

and the concentration control card states:

5 2 1 32 0 1 50.0 2.0 0.005 0.10 0.20 0.01 0.05
1.0 95

There are no contamination cards since INFLOW = 0.

In example 2 the normal ventilation system, without contamination but with a surface temperature of 90.0°F 6 hrs after the temperature change, was simulated. This requires a network, concentration, and temperature calculation.

The network control card remains the same as in example 1, the concentration control card changes to:

5 2 1 32 0 1 90.0 6.0 0.005 0.10 0.20 0.01 0.05 1.0 95

No contamination cards are needed.

In example 3 a failure of the surface fan 51 was assumed. The surface temperature is 50°F, the time after the fan failure 0.25 hrs. Only a network and concentration calculation, but no temperature calculation, was performed. To indicate the fan failure the network airway card 51 has to be changed from NWTYP = 1 to NWTYP = 0. Into the R column, which for the airway cards of NWTYP = 1 states the fan pressure, the flow resistance of the idling fan has to be inserted. The set of fan characteristic cards for fan 51 has to be removed.

The network control card reads consequently:

51 32 1 3 1 1 1 0 10 30 0.075 70.0

the concentration control card reads:

5 2 1 32 0 1 50.0 0.25 0.005 0.10 0.20 0.01 0.05 1.0 95

No contamination cards are needed.

In example 4 a fire was assumed at the beginning of airway 5, producing 30,000 cfm of contaminated air (CONT) with a smoke concentration of 1.0% (CONC) and $15*10^4$ Btu/min heat production (HEAT). Of interest is a time period 1 hour after the event. The network control card remains the same as in examples 1 and 2, the concentration control card reads:

5 2 1 32 1 1 50.0 1.0 0.005 0.10 0.20 0.01 0.05 1.0 95

The contamination card reads:

5 30000. 1.0 150000.00 0. 0. 0.

In example 5 an oxygen rich timber fire was assumed at the bottom of raise 18 which reduces the oxygen concentration of the air traveling through the fire zone to 16.0% (O2MIN). Network and concentration control cards remain the same as in example 4, but the contamination card changes to:

18 0. 0. 0. 16.0 0. 0.

In example 6 a fuel rich fire in raise 20 is assumed which produces 1 cfm of smoke with 100% concentration and 300 Btu of heat per cfm of oxygen. The network and concentration control cards remain the same as in the previous example, the contamination card changes to:

20 0. 0. 0. 0. 1.00 300.00

In example 7, O_2-rich timber fires are assumed at different locations in shaft 3. Two new airways, 52, 53, and two new junctions, 33, 34, are introduced. Their network airway and junction cards have to be added. The number of airways NB, and the number of junctions NJ, and the highest junction number MAXJ, change. The network control card reads, therefore:

53 34 2 3 1 1 1 1 10 30 0.075 70.0

the concentration control card reads:

5 2 1 34 1 1 50.0 0.5 0.005 0.10 0.20 0.01 0.05
1.0 95

and the contamination card reads:

3 0. 0. 0. 16.0 0. 0.

In example 8 a contaminant volume of 100.00 cfm (CONT) with a concentration of 100.0% (CONC) is released into airway 17. No heat is added. The network control card reads:

51 32 2 3 1 1 1 1 10 30 0.075 70.0

the concentration control card reads:

5 2 1 32 1 1 50.0 0.1 0.005 0.10 0.20 0.01 0.05
1.0 95

and the contamination card reads:

17 100. 100.00 0. 0. 0. 0.

4.6 STORAGE REQUIREMENTS

The storage requirements for the execution of this program are not small, but not excessive either. NB (number of airways) places are needed for the arrays:

NO, JS, JF, Q, NGOUT, NGIN, RDPROP, TRD, LA, A, O, KF, CH4V, CH4PA, TROCK, HA, HK, DZRD, RDCH4, XNEW, R, RST, FRNVP, NWTYP, P, RQ, INU, KJS, KJF, KNO. These are 30 arrays which, with the EQUIVALENCE (P,RQ), (CH4PA,RDCH4), (NGOUT,INU), (NGIN,KJF), (MIN,KNO), can be reduced to 26.

NJ (number of junctions) places are needed for the arrays:
LOUT, MIN, JNOL, JNO, JLR, PROP, CH4C, T, Z, PRCH4
These are 10 arrays which with EQUIVALENCE (CH4C,PRCH4), (Z,PROP), (LOUT, KJS) can be reduced to 6.

NFNUM (number of fans) places are needed for the arrays:
NOF, MPTS, NFREG, NFCW, RGRA

MPTS (number of curve points) * NFNUM places are needed for the arrays:
QF, PF

NB - NJ + 1 places are needed for the arrays:
FNVP, MEND

How large the array MSL has to be is hard to predict, since the number of airways in meshes depends very much on the network configuration. A figure of 5 to 10 times the number of airways NB will usually be sufficient.

As many places as recirculation paths exist, are needed for the arrays:
MEMREC, NOREC, ESTPR, ESTCH4, ESTTR
A number of 1/5*NB should be sufficient even for bad cases.

As many places as airways with inflow of contaminants exist are needed for the arrays:
HEAT, NCENT, CONT, CONC, O2MIN, SMPO2, HTPO2, TFSI

How many places the array NREV requires depends on the type of calculations. This array registers the airways with airflow reversal. In the worst case this can be all NB airways, but normally a smaller number of 1/3*NB should be sufficient.

With the assumption of NJ = 2/3*NB, NFNUM = 1/30*NB and MPTS = 10 this adds up to approximately 40*NB. Few network calculations use more than NB = 200 airway simulations.

4.7 EXECUTION TIME

This depends on the number of iterations, which have to be performed. In the described examples it never exceeded 10 seconds with a UNIVAC 1110. As a safeguard against excessive time consumptions, which can happen in unstable networks with oscillating air currents, the thresholds ITN and MADJ are stated in the network control card.

5. TABLE OF TEXT NOMENCLATURE

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
A	A	12	ft^2	airway cross sectional area
α	HC	29	$\frac{Btu}{ft^2\ hr\ ^oF}$	convection coefficient
β		29		slope angle
BI	BI	39		Biot Number
COR	COR	40		correction of convection coefficient for rough walls
CP	CP	29	Btu/lb ^oF	specific heat of air
D_o		40	ft	hydraulic diameter of airway
d		12	lb/ft^3	actual average air density in airway
d_r	DR	12	lb/ft^3	reference air density
FO	FO	39		Fourier Number
f		40		friction coefficient for rough walls
f_o	FRO	40		friction coefficient for hydraulically smooth wall
G		29	lb/hr	weight flow rate of air
g_a		29	$^oF/ft$	auto compression gradient
H_F		12	in. wg.	actual fan pressure
H_{Fr}	FANP	12	in. wg.	reference fan pressure
H_L		12	in. wg.	actual pressure loss
H_{Lr}	P	12	in. wg.	reference pressure loss
h_N		13	ft	natural ventilation head
H_N		14	in. wg.	natural ventilation pressure

Table of Text Nomenclature (continued)

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
H_{Nr}	FNVP	13	in. wg.	reference natural ventilation pressure
K	KF	12	$10^{10} \frac{lb*min^2}{ft^4}$	friction factor
$K(\alpha)$	COAGE	38		coefficient of age
L	LA	12	ft	airway length
n_b	NB	14		number of airways in network
n_j	NJ	14		number of junctions in network
n_m		14		number of meshes in network
O	O	12	ft	airway perimeter
p		13	lb/ft^2	static air pressure
Q		12	ft^3/min	actual volume flow rate
Q_r	Q	12	ft^3/min	reference volume flow rate
R	R	13	$10^{10} \frac{in.\ wg.}{(ft^3/min)^2}$	resistance factor
R_r	RSTD	13		reference resistance factor
R_o		38	ft	hydraulic radius
T		15	^{o}R	absolute air temperature
t	TRD	37	^{o}F	temperature of air in airway
TM	TM	41	^{o}F	estimated average air temperature in airway
T_m	TM	21	^{o}R	average absolute air temperature in airway
t_m	TMRD	46	^{o}F	mean air temperature in airway
T_m^2	TMSQR	45	$(^{o}R)^2$	mean square absolute air temperature in airway
t_r	TROCK	38	^{o}F	rock temperature

Table of Text Nomenclature (continued)

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
TR	TR	40	^{o}F	reference temperature
t_1	TJS	29	^{o}F	air temperature at beginning of airway
t_{ro}	TRS	29	^{o}F	rock temperature at beginning of airway
T_s, T_f	T0,T1	21	^{o}R	absolute temperatures of starting and finishing junctions of airway
v		13	ft^3/lb	specific volume of air
V		29	ft/sec	air velocity
VISC	VISC	40	ft^2/sec	kinematic viscosity of air
WT	WT	40	lb/ft^3	specific weight of air
X	X	29	ft^{-1}	quantity αO/(G*CP)
X	X	39		quantity (0.375 + BI) $\sqrt{FO}$
XNEW	XNEW	42		exponent in formula for air temperature in airways
Z	Z	21	ft	elevation
Z_s, Z_f	Z0,Z1	21	ft	elevations of starting and finishing junctions of airways

6. BIBLIOGRAPHY

1. Amano, K. and Shigeno, S., An underground ventilation network analysis and estimation of temperature of air current. A Decade of Digital Computing in the Mining Industry. AIME, New York, 1969

2. Cervik, J., An investigation of the behavior and control of methane gas. Min. Congr. Journ. 53 (1967), No. 7, pp. 52/57

3. Chaiken, R. F. and Singer, J. M., Experimental coal mine fire research. IV International Symposium on Combustion Processes 1975, Czestochowa, Poland

4. Duerr, H. G., The calculation of ventilation and compressed air networks based on energy principles under consideration of thermal energies with the help of electronic digital computers. Bergbau Wissenschaften 10 (1963), pp. 73/84

5. Edwards, J. C., Perlee, H. E., and Chaiken, R. F., Flame spread in a duct fire. ASME-AICHE Heat Transfer Conference 1976, St. Louis

6. Geiger, G. E., Development of an Air quality simulator for coal mines. NTIS Pb-213 833, 1972

7. Greuer, R., Influence of mine fires on the ventilation of underground mines. NTIS Pb-225 834, 1973

8. Hall, C. J., Wang, F. D., and Wang, Y. J., A thermodynamic based ventilation network digital computer program. International Mine Ventilation Congress Johannesburg, 1975

9. Hartman, H. L., Mine ventilation and air conditioning. The Ronald Press Company, New York, 1960

10. Hitchcock, W. W. and Hoover, T. E., Computer analysis of mine ventilation and environmental control. International Mine Ventilation Congress Johannesburg, 1975

11. Kingery, D. S., Introduction to mine ventilation principles and practice. USBM Bulletin 589, 1960

12. Kissell, F. N., Methane migration characteristics of the Pocohontas No. 3 coal bed. USBM Rep. Inv. 7649, 1972

13. Kreith, F., Principles of heat transfer. International Textbook Company, 1965

14. Maassen, F., Ventilation calculation by digital computer. Bergbau Wissenschaften 9 (1962), pp. 179/190

15. McElroy, G. E. and Kingery, D. S., Making ventilation pressure surveys with altimeters. USBM Inform. Circ. 7809, 1957

16. McPherson, M. J., The simulation of airflow and temperature in the stopes of South African gold mines. International Mine Ventilation Congress Johannesburg, 1975

17. Scerban, A. N. and Kremnev, O. A., The scientific basis of calculations and control of climatic conditions in deep mines. A. N. Ukrain. RSR, Kiev, 1959

18. Scott, D. R. and Hinsley, F. B., Ventilation network theory. Colliery Engrg. 28 (1951), pp. 67/71, 159/166, 229/235, 497/500

19. Stefanko, R. and Ramani, R. V., Computerized planning for mine atmospheric environment. International Mine Ventilation Congress Johannesburg, 1975

20. Wang, Y. J. and Saperstein, L. W., A computer-aided solution of complex ventilation networks. Transact. Soc. Min. Engrs. AIME 247 (1970), pp. 238/250

7. PROGRAM LISTING

```
C     COMBINED PROGRAMS FOR NETWORK, CONCENTRATION, AND TEMPERATURE
C                          CALCULATIONS
C
C
C
      DIMENSION NO(200),JS(200),JF(200),Q(200),NGOUT(200),LOUT(200),
     1NGIN(200),MIN(200),JNOL(150),JNO(150),JLR(150),PROP(150),RDPROP(20
     20),MEMREC(50),NOREC(50),ESTPR(50),ESTCH4(50),ESTTR(50),HEAT(10),TR
     3D(200),LA(200),A(200),O(200),KF(200),CH4V(200),CH4PA(200),CH4C(150
     4),T(150),Z(150),NCENT(10),CONT(10),CONC(10),TROCK(200),HA(200),HK(
     5200),DZRD(200),PRCH4(150),RDCH4(200),O2MIN(10),SMPO2(10),HTPO2(10)
     6,TFSI(10),XNEW(200),R(200),MEND(100),MSL(1500),RSTD(200),FRNVP(200
     7),QF(10,10),PF(10,10),RGRAD(10),NFCW(10),NFREG(10),MPTS(10),
     8FNVP(100),NWTYP(200),P(200),RQ(200),INU(200),KJS(200),KJF(200),KNO
     9(200),NOF(10),NREV(200)
      EQUIVALENCE (P,RQ),(CH4PA,RDCH4),(CH4C,PRCH4),(Z,PROP),(NGOUT,INU)
     1,(LOUT,KJS),(NGIN,KJF),(MIN,KNO)
C
C     NETWORK PART OF PROGRAM
C
C     READ INPUT DATA
      READ (5,402) NB,NJ,NFNUM,NADBC,NVPN,NETW,NCONC,NTEMP,MADJ,ITN,DR,T
     1R
      READ (5,403) (NO(K),JS(K),JF(K),NWTYP(K),R(K),Q(K),KF(K),LA(K),A(K
     1),O(K),K=1,NB)
      IF (NVPN) 2,2,1
    1 READ (5,404) (JNO(K),T(K),Z(K),CH4C(K),K=1,NJ)
    2 IF (NFNUM) 5,5,3
    3 DO 4 K=1,NFNUM
      READ (5,405) NOF(K),MPTS(K)
      INDEX=MPTS(K)
      READ (5,406) (QF(K,I),PF(K,I),I=1,INDEX)
    4 CONTINUE
C     COMPLETE INPUT DATA
    5 IF (NADBC) 11,11,6
    6 L=0
      DO 9 I=1,NADBC
      READ (5,407) NOX,KX,LX,AX,OX
      DO 7 J=1,NB
      IF (NOX-NO(J)) 7,8,7
    7 CONTINUE
      GO TO 9
    8 L=L+1
      KF(J)=KX
      LA(J)=LX
      A(J)=AX
      O(J)=OX
    9 CONTINUE
      IF (NADBC-L) 10,11,10
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```
00242    10   WRITE (6,408)                                                 000214
00244    11   MARKD=0                                                       000222
00245         DO 16 I=1,NB                                                  000222
00250         IF (NWTYP(I)) 16,12,16                                        000227
00253    12   IF (R(I)) 13,13,16                                            000230
00256    13   IF (A(I)) 14,14,15                                            000233
00261    14   WRITE (6,409) NO(I)                                           000236
00264         MARKD=1                                                       000244
00265         GO TO 16                                                      000246
00266    15   R(I)=KF(I)*LA(I)*Q(I)/(5.2*A(I)**3)*DR/0.075                  000250
00267    16   RSTD(I)=R(I)                                                  000266
00271         IF (MARKD) 18,18,17                                           000270
00271    C    OUTPUT OF INPUT                                               000270
00274    17   WRITE (6,410)                                                 000274
00276         WRITE (6,411) (NO(K),JS(K),JF(K),Q(K),NWTYP(K),LA(K),A(K),R(K),KF(   000300
00276        1K),O(K),K=1,NB)                                               000300
00315         GO TO 153                                                     000325
00316    18   IF (NETW) 17,17,19                                            000327
00321    19   NSW=0                                                         000331
00322         MADJC=0                                                       000332
00323         NSNVP=0                                                       000333
00324         NNVP=0                                                        000334
00325         MARKN=0                                                       000335
00326         ITCT=0                                                        000336
00326    C    ARRANGE AIRWAYS TO SIZE AND MAGNITUDE R*Q                     000336
00327    20   NBU=NB                                                        000340
00330         NBL=1                                                         000341
00331         DO 28 K=1,NB                                                  000353
00334         IF (NSW) 21,21,22                                             000353
00337    21   Q(K)=Q(K)/100000.                                             000356
00340    22   DO 23 J=1,NFNUM                                               000364
00343         IF (NOF(J)-NO(K)) 23,24,23                                    000364
00346    23   CONTINUE                                                      000371
00350         IF (NWTYP(K)) 25,26,27                                        000371
00353    24   NFREG(J)=K                                                    000376
00354    25   INU(NBU)=K                                                    000401
00355         NBU=NBU-1                                                     000403
00356         GO TO 28                                                      000406
00357    26   RQ(K)=ABS(R(K)*Q(K))                                          000410
00360         NWTYP(K)=2                                                    000413
00361         GO TO 28                                                      000415
00362    27   INU(NBL)=K                                                    000417
00363         NBL=NBL+1                                                     000421
00364    28   CONTINUE                                                      000427
00366         IF (NBU+1-NBL) 35,35,29                                       000427
00371    29   NRETU=0                                                       000435
00372         DO 34 K=1,NB                                                  000435
00375         IF (NWTYP(K)-2) 34,30,30                                      000443
00400    30   IF (NRETU) 31,31,32                                           000447
00403    31   MMIN=K                                                        000452
```

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00404   100*          NRETU=1                                      000454
00405   101*     32   IF (RQ(MMIN)-RQ(K)) 34,34,33                 000457
00410   102*     33   MMIN=K                                       000463
00411   103*     34   CONTINUE                                     000467
00413   104*          INU(NBL)=MMIN                                000467
00414   105*          NBL=NBL+1                                    000471
00415   106*          NWTYP(MMIN)=0                                000474
00416   107*          IF (NBU+1-NBL) 35,35,29                      000476
00416   108*     C    SET UP BASE SYSTEM                           000476
00421   109*     35   IND=INU(1)                                   000504
00422   110*          KJF(NJ)=JS(IND)                              000505
00423   111*          KJS(NJ-1)=JS(IND)                            000511
00424   112*          JS(IND)=-JS(IND)                             000513
00425   113*          KJF(NJ-1)=JF(IND)                            000515
00426   114*          KNO(NJ-1)=IND                                000517
00427   115*          KNUM=NJ-1                                    000521
00430   116*     36   DO 43 NUC=2,NB                               000525
00433   117*          IND=INU(NUC)                                 000537
00434   118*          IF (JS(IND)) 43,37,37                        000541
00437   119*     37   N1=0                                         000545
00440   120*          N0=0                                         000546
00441   121*          DO 41 K=KNUM,NJ                              000552
00444   122*          IF (JS(IND)-KJF(K)) 39,38,39                 000552
00447   123*     38   N0=1                                         000554
00450   124*     39   IF (JF(IND)-KJF(K)) 41,40,41                 000557
00453   125*     40   N1=1                                         000561
00454   126*     41   CONTINUE                                     000565
00456   127*          IF (N1+N0-1) 43,47,42                        000565
00461   128*     42   JS(IND)=-JS(IND)                             000572
00462   129*          JF(IND)=-JF(IND)                             000574
00463   130*     43   CONTINUE                                     000600
00465   131*          IF (KNUM-1) 44,52,44                         000600
00470   132*     44   DO 46 K=1,NB                                 000606
00473   133*          IF (JS(K)) 46,46,45                          000606
00476   134*     45   WRITE (6,412) NO(K)                          000610
00501   135*     46   CONTINUE                                     000620
00503   136*          GO TO 52                                     000620
00504   137*     47   IF (NWTYP(IND)) 48,49,49                     000622
00507   138*     48   WRITE (6,413) NO(IND)                        000625
00512   139*     49   KNUM=KNUM-1                                  000634
00513   140*          IF (N0) 50,50,51                             000640
00516   141*     50   KJS(KNUM)=JF(IND)                            000643
00517   142*          KJF(KNUM)=JS(IND)                            000645
00520   143*          KNO(KNUM)=-IND                               000647
00521   144*          JS(IND)=-JS(IND)                             000651
00522   145*          GO TO 36                                     000653
00523   146*     51   KJS(KNUM)=JS(IND)                            000655
00524   147*          KJF(KNUM)=JF(IND)                            000660
00525   148*          KNO(KNUM)=IND                                000662
00526   149*          JS(IND)=-JS(IND)                             000664
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00527          GO TO 36                          000666
00530    52    DO 53 K=1,NB                      000670
00533    53    JS(K)=IABS(JS(K))                 000700
00533    C     FORM MESHES                       000700
00535          MESC=0                            000702
00536          MNO=0                             000703
00537          DO 62 K=1,NB                      000707
00542          IF (JF(K)) 54,62,62               000707
00545    54    JF(K)=-JF(K)                      000712
00546          MNO=MNO+1                         000713
00547          JBM=JS(K)                         000716
00550          JEM=JF(K)                         000720
00551          NK=K                              000721
00552    55    MESC=MESC+1                       000724
00553          MEND(MNO)=MESC                    000730
00554          MSL(MESC)=NK                      000731
00555          DO 56 KCO=1,NJ                    000736
00560          IF (JBM-KJF(KCO)) 56,57,56        000736
00563    56    CONTINUE                          000744
00565    57    KB=KCO                            000744
00566          DO 58 KCO=1,NJ                    000750
00571          IF (JEM-KJF(KCO)) 58,59,58        000750
00574    58    CONTINUE                          000756
00576    59    KE=KCO                            000756
00577          IF (KB-KE) 60,62,61               000757
00602    60    NK=KNO(KB)                        000763
00603          JBM=KJS(KB)                       000765
00604          GO TO 55                          000767
00605    61    NK=-KNO(KE)                       000771
00606          JEM=KJS(KE)                       000773
00607          GO TO 55                          000775
00610    62    CONTINUE                          001000
00610    C     SATISFY JUNCTION EQUATIONS        001000
00612          MBEGW=3                           001000
00613          DO 65 K=1,MNO                     001002
00616          MENDW=MEND(K)                     001010
00617          DO 64 J=MBEGW,MENDW               001011
00622          N=MSL(J)                          001015
00623          IF (N) 63,64,64                   001016
00626    63    N=-N                              001020
00627    64    Q(N)=0.                           001022
00631    65    MBEGW=MENDW+2                     001025
00633          MBEGW=1                           001032
00634          DO 70 K=1,MNO                     001037
00637          MENDW=MEND(K)                     001040
00640          N=MSL(MBEGW)                      001042
00641          IF (N) 66,67,67                   001045
00644    66    N=-N                              001047
00645    67    Q1=Q(N)                           001051
00646          M=MBEGW+1                         001053
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```
00647              DO 69 J=M,MENDW                                   001056
00652              N=MSL(J)                                          001062
00653              FACT=1.                                           001063
00654              IF (N) 68,69,69                                   001065
00657   68         N=-N                                              001067
00660              FACT=-1.                                          001070
00661   69         Q(N)=Q(N)+Q1*FACT                                 001072
00663   70         MBEGW=MENDW+1                                     001100
00663   C          CALCULATE NATURAL VENTILATION PRESSURE            001100
00665              IF (NSNVP) 71,71,72                               001105
00670   71         IF (NVPN) 85,85,74                                001110
00673   72         IF (NSFLOW) 73,73,85                              001115
00676   73         NNVP=1                                            001117
00677              GO TO 337                                         001121
00700   74         MBEGW=1                                           001123
00701              DO 84 K=1,MNO                                     001124
00704              MENDW=MEND(K)                                     001135
00705              FNVP(K)=0.                                        001136
00706              NT=0                                              001137
00707              TSU=0.                                            001140
00710              DO 83 J=MBEGW,MENDW                               001145
00713              N=MSL(J)                                          001145
00714              NX=N                                              001146
00715              IF (NX) 75,76,76                                  001147
00720   75         NX=-NX                                            001151
00721   76         DO 80 L=1,NJ                                      001153
00724              IF (JS(NX)-JNO(L)) 78,77,78                       001156
00727   77         T0=T(L)+460.                                      001160
00730              Z0=Z(L)                                           001163
00731   78         IF (JF(NX)-JNO(L)) 80,79,80                       001166
00734   79         T1=T(L)+460.                                      001170
00735              Z1=Z(L)                                           001173
00736   80         CONTINUE                                          001177
00740              H=T0*Z1-T1*Z0                                     001177
00741              IF (N) 81,82,82                                   001205
00744   81         H=-H                                              001210
00745   82         FNVP(K)=FNVP(K)+H                                 001212
00746              TSU=TSU+T0+T1                                     001214
00747   83         NT=NT+1                                           001220
00751              TM=TSU/NT                                         001225
00752              FNVP(K)=FNVP(K)*DR/(5.2*TM)                       001231
00753   84         MBEGW=MENDW+1                                     001236
00753   C          ITERATION                                         001236
00755   85         IT=0                                              001244
00756   86         DQSUM=0.                                          001245
00757              MBEGW=1                                           001245
00760              DO 99 K=1,MNO                                     001262
00763              MENDW=MEND(K)                                     001264
00764              DPSUM=0.                                          001266
00765              RQSUM=0.                                          001267
```

```
00766          N=MSL(MBEGW)                                 001270
00767          IF (N) 87,88,88                              001273
00772   87     N=-N                                         001275
00773   88     IF (NWTYP(N)+1) 89,99,89                     001277
00776   89     DO 96 J=MBEGW,MENDW                          001302
01001          N=MSL(J)                                     001310
01002          FACT=1.                                      001312
01003          IF (N) 90,91,91                              001314
01006   90     N=-N                                         001316
01007          FACT=-1.                                     001317
01010   91     IF (NWTYP(N)) 96,92,93                       001321
01013   92     RQ2=R(N)*ABS(Q(N))**2                        001325
01014          RQSUM=RQSUM+RQ2                              001331
01015          DP=R(N)*Q(N)*ABS(Q(N))                       001333
01016          DPSUM=DPSUM+FACT*DP                          001340
01017          GO TO 96                                     001343
01020   93     DPSUM=DPSUM-FACT*R(N)                        001345
01021          DO 94 L=1,NFNUM                              001354
01024          IF (NFREG(L)-N) 94,95,94                     001354
01027   94     CONTINUE                                     001361
01031          GO TO 96                                     001361
01032   95     RQSUM=RQSUM-RGRAD(L)                         001363
01033   96     CONTINUE                                     001370
01035          DQ=(DPSUM-FNVP(K))/RQSUM                     001370
01036          DO 98 J=MBEGW,MENDW                          001377
01041          N=MSL(J)                                     001377
01042          FACT=1.                                      001400
01043          IF (N) 97,98,98                              001402
01046   97     N=-N                                         001404
01047          FACT=-1.                                     001405
01050   98     Q(N)=Q(N)-(DQ*FACT)                          001407
01052          DQSUM=DQSUM+ABS(DQ)                          001415
01053   99     MBEGW=MENDW+1                                001421
01053   C      FANCHARACTERISTICS                           001421
01055          DO 114 J=1,NFNUM                             001431
01060          NFCW(J)=0                                    001431
01061          DO 100 K=1,NB                                001435
01064          IF (NOF(J)-NO(K)) 100,101,100                001435
01067   100    CONTINUE                                     001442
01071          GO TO 114                                    001442
01072   101    NPTS=MPTS(J)                                 001444
01073          FANQ=Q(K)*100000.                            001446
01074          NBDR=MPTS(J)-1                               001451
01075          QBL=QF(J,2)                                  001455
01076          QBR=QF(J,NBDR)                               001457
01077          IF (FANQ-QBL) 102,103,103                    001461
01102   102    R(K)=PF(J,2)                                 001464
01103          NFCW(J)=1                                    001466
01104          GO TO 114                                    001470
01105   103    IF (FANQ-QBR) 105,105,104                    001472
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01110      104   R(K)=PF(J,NBDR)                                                     001501
01111            NFCW(J)=1                                                           001503
01112            GO TO 114                                                           001505
01113      105   FANP=0.                                                             001507
01114            DO 108 L=1,NPTS                                                     001507
01117            ANUM=1.0                                                            001527
01120            ADEN=1.0                                                            001531
01121            DO 107 M=1,NPTS                                                     001535
01124            IF (M-L) 106,107,106                                                001535
01127      106   ANUM=ANUM*(FANQ-QF(J,M))/10000                                      001540
01130            ADEN=ADEN*(QF(J,L)-QF(J,M))/10000                                   001545
01131      107   CONTINUE                                                            001555
01133            PART=ANUM*PF(J,L)/ADEN                                              001555
01134            FANP=FANP+PART                                                      001561
01135      108   CONTINUE                                                            001573
01137            DO 111 L=1,NPTS                                                     001573
01142            IF (FANQ-QF(J,L)) 109,109,111                                       001573
01145      109   IF (L-2) 112,110,110                                                001577
01150      110   LL=L-1                                                              001603
01151            RGRAD(J)=(PF(J,L)-PF(J,LL))*100000./(QF(J,L)-QF(J,LL))              001606
01152            GO TO 113                                                           001617
01153      111   CONTINUE                                                            001624
01155      112   RGRAD(J)=0.0                                                        001624
01156      113   R(K)=FANP                                                           001625
01157      114   CONTINUE                                                            001632
01161            IT=IT+1                                                             001632
01162            ITCT=ITCT+1                                                         001635
01162      C     CONTINUE IN APPROPRIATE PROGRAM SECTION                             001635
01163            IF (IT-1) 86,86,115                                                 001640
01166      115   IF (DQSUM-0.002) 120,116,116                                        001643
01171      116   IF (ITCT-ITN) 117,117,119                                           001647
01174      117   IF (IT-20) 86,86,118                                                001652
01177      118   NSW=1                                                               001656
01200            NSFLOW=0                                                            001660
01201            GO TO 20                                                            001661
01202      119   MARKN=1                                                             001663
01203      120   IF (NSNVP) 126,126,121                                              001665
01203      C     DETECT INSTABLE AIRWAYS                                             001665
01206      121   DO 125 I=1,NB                                                       001667
01211            IF (Q(I)) 122,122,125                                               001674
01214      122   IF (MADJC-MADJ) 124,123,123                                         001676
01217      123   WRITE (6,414) NO(I)                                                 001702
01222      124   NSFLOW=0                                                            001711
01223      125   Q(I)=Q(I)*100000.                                                   001712
01225            ITCT=0                                                              001715
01226            IF (NSFLOW) 225,225,246                                             001716
01226      C     CALCULATE RESISTANCE OF REGULATORS                                  001716
01231      126   MBEGW=1                                                             001723
01232            DO 137 K=1,MNO                                                      001724
01235            DPSUM=0.                                                            001735
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01236        MENDW=MEND(K)                                                      001736
01237        NX=MSL(MBEGW)                                                      001740
01240        IF (NX) 127,128,128                                                001743
01243  127   NX=-NX                                                             001745
01244  128   IF (NWTYP(NX)) 129,137,137                                         001747
01247  129   M=MBEGW+1                                                          001752
01250        DO 134 J=M,MENDW                                                   001755
01253        N=MSL(J)                                                           001761
01254        FACT=1.                                                            001762
01255        IF (N) 130,131,131                                                 001764
01260  130   N=-N                                                               001766
01261        FACT=-1.                                                           001767
01262  131   IF (NWTYP(N)) 133,133,132                                          001771
01265  132   DP=-R(N)                                                           001774
01266        GO TO 134                                                          001776
01267  133   DP=R(N)*Q(N)*ABS(Q(N))                                             002000
01270  134   DPSUM=DPSUM+DP*FACT                                                002006
01272        IF (NVPN) 136,136,135                                              002013
01275  135   DPSUM=DPSUM-FNVP(K)                                                002016
01276  136   R(NX)=-DPSUM/(Q(NX))**2                                            002021
             RSTD(NX)=R(NX)
01277        NWTYP(NX)=0                                                        002026
01300  137   MBEGW=MENDW+1                                                      002030
01300  C     OUTPUT OF RESULTS                                                  002030
01302        DO 140 L=1,NB                                                      002037
01305        IF (NWTYP(L)) 138,138,139                                          002037
01310  138   P(L)=R(L)*Q(L)*ABS(Q(L))                                           002041
01311        GO TO 140                                                          002046
01312  139   P(L)=R(L)                                                          002050
01313  140   CONTINUE                                                           002053
01315        WRITE (6,415)                                                      002053
01317        WRITE (6,416)                                                      002060
01321        L=0                                                                002065
01322        DO 143 K=1,NB                                                      002071
01325        IF (NWTYP(K)) 142,142,141                                          002071
01330  141   L=L+1                                                              002073
01331        GO TO 143                                                          002076
01332  142   Q(K)=Q(K)*100000.                                                  002100
01333        WRITE (6,417) NO(K),JS(K),JF(K),Q(K),P(K),LA(K),A(K),R(K),KF(K),O( 002102
01333       1K)                                                                 002102
01347  143   CONTINUE                                                           002123
01351        IF (L) 144,144,145                                                 002123
01354  144   WRITE (6,418)                                                      002126
01356        GO TO 150                                                          002133
01357  145   WRITE (6,419)                                                      002135
01361        DO 147 K=1,NB                                                      002141
01364        IF (NWTYP(K)) 147,147,146                                          002146
01367  146   Q(K)=Q(K)*100000.                                                  002150
01370        WRITE (6,420) NO(K),JS(K),JF(K),Q(K),P(K)                          002153
01377  147   CONTINUE                                                           002167
01401        IF (NFNUM) 150,150,148                                             002167
```

```
01404        148    WRITE (6,421) (NOF(K),K=1,NFNUM)                        002172
01412               DO 149 K=1,NFNUM                                        002212
01415               L=MPTS(K)                                               002215
01416        149    WRITE (6,422) (QF(K,I),PF(K,I),I=1,L)                   002217
01426        150    WRITE (6,423) NB,NJ                                     002240
01432               DO 152 K=1,NFNUM                                        002253
01435               NWRN=NFCW(K)                                            002253
01436               IF (NWRN) 152,152,151                                   002254
01441        151    WRITE (6,424) NOF(K)                                    002256
01444        152    CONTINUE                                                002267
01444        C                                                              002267
01444        C                                                              002267
01444        C      CONCENTRATION PART OF PROGRAM                           002267
01444        C                                                              002267
01446        153    IF (NCONC) 154,154,156                                  002267
01451        154    IF (NTEMP) 155,155,156                                  002271
01454        155    WRITE (6,425)                                           002274
01456               GO TO 401                                               002301
01457        156    PI=3.141593                                             002303
01460               NSFLOW=0                                                002304
01461               ITCT=0                                                  002305
01461        C      READ AND COMPLETE INPUT DATA                            002305
01462               READ (5,426) NDIM,NCH4C,NAV,MAXJ,INFLOW,JSTART,TSTART,TIME,CRITSM,  002306
01462              1CRITGS,CRITHT,WRNPR,WRNSM,WRNGS,WRNHT                   002306
01503               IF (NAV) 158,158,157                                    002332
01506        157    READ (5,427) TAVR,HAAVR,HKAVR,KFAVR,LAAVR,AAVR,OAVR     002335
01517        158    IF (NDIM) 164,164,159                                   002352
01522        159    L=0                                                     002354
01523               DO 162 I=1,NDIM                                         002364
01526               READ (5,428) NOX,CH4VX,CH4PAX,TROCKX,HAX,HKX,DZRDX      002364
01537               DO 160 J=1,NB                                           002403
01542               IF (NOX-NO(J)) 160,161,160                              002403
01545        160    CONTINUE                                                002411
01547        161    L=L+1                                                   002411
01550               CH4V(J)=CH4VX                                           002414
01551               CH4PA(J)=CH4PAX                                         002416
01552               TROCK(J)=TROCKX                                         002420
01553               HA(J)=HAX                                               002422
01554               HK(J)=HKX                                               002424
01555               DZRD(J)=DZRDX                                           002426
01556               NO(J)=-NO(J)                                            002430
01557        162    CONTINUE                                                002434
01561               IF (NDIM-L) 163,164,163                                 002434
01564        163    WRITE (6,429)                                           002437
01566               GO TO 401                                               002444
01567        164    DO 185 I=1,NB                                           002446
01572               IF (NO(I)) 168,165,165                                  002461
01575        165    IF (NAV) 166,166,167                                    002464
01600        166    WRITE (6,430)                                           002470
01602               GO TO 401                                               002474
```

```
01603   167   NO(I)=-NO(I)                                        002476
01604         HA(I)=HAAVR                                         002477
01605         HK(I)=HKAVR                                         002501
01606         GO TO 173                                           002503
01607   168   IF (NAV) 166,166,169                                002505
01612   169   IF (HA(I)) 170,170,171                              002507
01615   170   HA(I)=HAAVR                                         002512
01616   171   IF (HK(I)) 172,172,173                              002515
01621   172   HK(I)=HKAVR                                         002517
01622   173   IF (KF(I)) 174,174,175                              002522
01625   174   KF(I)=KFAVR                                         002524
01626   175   IF (LA(I)) 176,176,177                              002527
01631   176   LA(I)=LAAVR                                         002531
01632   177   IF (A(I)) 178,178,179                               002534
01635   178   A(I)=AAVR                                           002536
01636   179   IF (O(I)) 180,180,181                               002541
01641   180   O(I)=OAVR                                           002543
01642   181   IF (TROCK(I)) 182,182,185                           002546
01645   182   IF (NVPN) 183,183,184                               002550
01650   183   TROCK(I)=TAVR                                       002553
01651         GO TO 185                                           002555
01652   184   NO(I)=-NO(I)                                        002557
01653   185   CONTINUE                                            002566
01655         DO 197 J=1,NB                                       002566
01660         IF (NO(J)) 186,186,187                              002566
01663   186   NO(J)=-NO(J)                                        002571
01664         GO TO 197                                           002572
01665   187   ES=0.0                                              002574
01666         EF=0.0                                              002574
01667         TRS=0.0                                             002575
01670         TRF=0.0                                             002576
01671         L=0                                                 002577
01672         M=0                                                 002600
01673         DO 192 I=1,NJ                                       002604
01676         IF (JS(J)-JNO(I)) 189,188,189                       002604
01701   188   ES=Z(I)                                             002607
01702         TRS=T(I)                                            002611
01703         L=1                                                 002613
01704         GO TO 191                                           002615
01705   189   IF (JF(J)-JNO(I)) 191,190,191                       002617
01710   190   EF=Z(I)                                             002621
01711         TRF=T(I)                                            002623
01712         M=1                                                 002625
01713   191   IF (L+M-2) 192,193,192                              002630
01716   192   CONTINUE                                            002635
01720         GO TO 196                                           002635
01721   193   IF (DZRD(J)) 195,194,195                            002637
01724   194   DZRD(J)=EF-ES                                       002640
01725   195   X=0.014*O(J)/(A(J)**0.8*(ABS(Q(J)))**0.2)           002644
01726         TROCK(J)=(TRF-TRS*EXP(-X*LA(J))+DZRD(J)/187.)/(1.-EXP(-X*LA(J)))-D   002665
```

```
01726                 1ZRD(J))(2.*187.)                         002665
01727                  IF (TROCK(J)) 196,196,197                002711
01732         196      TROCK(J)=TAVR                            002714
01733         197      CONTINUE                                 002720
01733         C        SET UP JNO LIST                          002720
01735                  IF (NVPN) 198,198,203                    002720
01740         198      L=1                                      002723
01741                  DO 201 I=1,MAXJ                          002733
01744                  DO 199 J=1,NB                            002733
01747                  IF (JS(J)-I) 199,200,199                 002733
01752         199      CONTINUE                                 002740
01754                  GO TO 201                                002740
01755         200      JNO(L)=JS(J)                             002742
01756                  L=L+1                                    002745
01757         201      CONTINUE                                 002752
01761                  IF (L-1-NJ) 202,203,202                  002752
01764         202      WRITE (6,431)                            002756
01766                  NJ=L-1                                   002763
01766         C        CALCULATE METHANE EVOLUTION              002763
01767         203      IF (NCH4C) 209,209,204                   002767
01772         204      L=0                                      002771
01773                  DO 207 I=1,NCH4C                         003001
01776                  READ (5,432) JNOX,CH4CX                  003001
02002                  DO 205 J=1,NJ                            003013
02005                  IF (JNOX-JNO(J)) 205,206,205             003013
02010         205      CONTINUE                                 003020
02012                  GO TO 207                                003020
02013         206      CH4C(J)=CH4CX                            003022
02014                  L=L+1                                    003024
02015         207      CONTINUE                                 003031
02017                  IF (NCH4C-L) 208,209,208                 003031
02022         208      WRITE (6,433)                            003034
02024         209      DO 220 I=1,NB                            003042
02027                  IF (CH4V(I)) 210,210,220                 003052
02032         210      CH4V(I)=CH4PA(I)*LA(I)*O(I)              003055
02033                  IF (CH4V(I)) 211,211,220                 003063
02036         211      M=0                                      003065
02037                  N=0                                      003066
02040                  DO 216 L=1,NJ                            003072
02043                  IF (JS(I)-JNO(L)) 213,212,213            003072
02046         212      CH4S=CH4C(L)                             003075
02047                  M=1                                      003077
02050         213      IF (JF(I)-JNO(L)) 215,214,215            003102
02053         214      CH4F=CH4C(L)                             003104
02054                  N=1                                      003106
02055         215      IF (M+N-1) 216,216,218                   003111
02060         216      CONTINUE                                 003120
02062         217      CH4V(I)=0.0                              003120
02063                  GO TO 220                                003120
02064         218      IF (CH4F-CH4S) 217,217,219               003122
```

```
02067        219   CH4V(I)=(CH4F-CH4S)*Q(I)/100.0                                           003125
02070        220   CONTINUE                                                                 003135
02072              NRCT=0                                                                   003135
02073              IF (INFLOW) 222,222,221                                                  003136
02076        221   READ (5,434) (NCENT(I),CONT(I),CONC(I),HEAT(I),O2MIN(I),SMPO2(I),H       003141
02076             1TPO2(I),I=1,INFLOW)                                                      003141
02076        C     OUTPUT OF INPUT                                                          003141
02112        222   WRITE (6,435)                                                            003164
02114              WRITE (6,436) (NO(I),JS(I),JF(I),DZRD(I),TROCK(I),CH4V(I),HK(I),HA       003170
02114             1(I),I=1,NB)                                                              003170
02131              WRITE (6,437) TIME                                                       003213
02134              WRITE (6,438) TSTART,JSTART                                              003221
02140              IF (INFLOW) 224,224,223                                                  003230
02143        223   WRITE (6,439)                                                            003233
02145              WRITE (6,440) (NCENT(I),CONT(I),CONC(I),HEAT(I),O2MIN(I),SMPO2(I),       003240
02145             1HTPO2(I),I=1,INFLOW)                                                     003240
02161              GO TO 225                                                                003262
02162        224   WRITE (6,441)                                                            003264
02162        C     FLOWSCHEME                                                               003264
02164        225   NSFLOW=1                                                                 003271
02165              DO 231 I=1,NB                                                            003272
02170              IF (Q(I)) 226,231,231                                                    003277
02173        226   NSFLOW=0                                                                 003302
02174              J=JS(I)                                                                  003303
02175              JS(I)=JF(I)                                                              003305
02176              JF(I)=J                                                                  003307
02177              Q(I)=-Q(I)                                                               003310
02200              DZRD(I)=-DZRD(I)                                                         003311
02201              IF (NRCT) 230,230,227                                                    003313
02204        227   DO 229 L=1,NRCT                                                          003316
02207              IF (NREV(L)-I) 229,228,229                                               003322
02212        228   NREV(L)=0                                                                003325
02213              GO TO 231                                                                003326
02214        229   CONTINUE                                                                 003332
02216        230   NRCT=NRCT+1                                                              003332
02217              NREV(NRCT)=I                                                             003335
02220        231   CONTINUE                                                                 003341
02222              IF (NRCT) 235,235,232                                                    003341
02225        232   L=0                                                                      003344
02226              DO 234 I=1,NRCT                                                          003351
02231              IF (NREV(I)) 234,234,233                                                 003351
02234        233   L=L+1                                                                    003353
02235              NREV(L)=NREV(I)                                                          003357
02236        234   CONTINUE                                                                 003362
02240              NRCT=L                                                                   003362
02241        235   L=0                                                                      003365
02242              M=0                                                                      003365
02243              N=1                                                                      003366
02244              DO 240 I=1,MAXJ                                                          003403
02247              K=L                                                                      003405
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02250                 DO 237 J=1,NB                                               003412
02253                 IF (JS(J)-I) 237,236,237                                    003412
02256          236    L=L+1                                                       003415
02257                 NGOUT(L)=J                                                  003420
02260          237    CONTINUE                                                    003425
02262                 LOUT(N)=L                                                   003425
02263                 MM=M                                                        003430
02264                 DO 239 J=1,NB                                               003435
02267                 IF (JF(J)-I) 239,238,239                                    003435
02272          238    M=M+1                                                       003440
02273                 NGIN(M)=J                                                   003444
02274          239    CONTINUE                                                    003450
02276                 MIN(N)=M                                                    003450
02277                 IF ((MM.EQ.M).AND.(K.EQ.L)) GO TO 240                       003452
02301                 JNOL(N)=I                                                   003466
02302                 N=N+1                                                       003470
02303          240    CONTINUE                                                    003501
02303          C      RELATE JNO AND JNQL LISTS                                   003501
02305                 DO 243 I=1,NJ                                               003501
02310                 PROP(I)=0.0                                                 003501
02311                 PRCH4(I)=0.0                                                003502
02312                 DO 241 J=1,NJ                                               003506
02315                 IF (JNOL(I)-JNO(J)) 241,242,241                             003506
02320          241    CONTINUE                                                    003514
02322          242    JLR(I)=J                                                    003514
02323          243    CONTINUE                                                    003523
02323          C      INDICES OF STARTING JUNCTION (ATMOSPHERE)                   003523
02325                 DO 244 I=1,NJ                                               003523
02330                 IF (JNOL(I)-JSTART) 244,245,244                             003523
02333          244    CONTINUE                                                    003531
02335          245    MSTART=I                                                    003531
02336                 ISTART=JLR(I)                                               003533
02337                 T(ISTART)=TSTART                                            003536
02340                 MRC=0                                                       003540
02341          246    MARKC=0                                                     003542
02341          C      CONDITIONS AT ROADWAY ENDS                                  003542
02342          247    L=ISTART                                                    003543
02343                 NSTART=MSTART                                               003544
02344          248    PROPJS=PROP(L)                                              003547
02345                 JX=L                                                        003551
02346                 CH4JS=PRCH4(L)                                              003553
02347                 JNO(L)=-JNO(L)                                              003555
02350                 JY=1                                                        003557
02351                 IF (NSTART-1) 249,250,249                                   003561
02354          249    JY=LOUT(NSTART-1)+1                                         003564
02355          250    JZ=LOUT(NSTART)                                             003570
02356                 DO 288 K=JY,JZ                                              003572
02361                 ICFTM=0                                                     003632
02362                 I=NGOUT(K)                                                  003633
02363                 NM=0                                                        003635
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02364            DO 251 L=1,INFLOW                                          003642
02367            IF (NCENT(L)-NO(I)) 251,252,251                            003642
02372      251   CONTINUE                                                   003647
02374            CONTAM=0.0                                                 003647
02375            CONTQ=0.0                                                  003650
02376            HEATAD=0.0                                                 003651
02377            TFS=0.0                                                    003652
02400            GO TO 262                                                  003653
02401      252   NM=1                                                       003655
02402            IF (CONT(L)) 253,254,253                                   003656
02405      253   CONTAM=CONT(L)*CONC(L)/100.                                003661
02406            CONTQ=CONT(L)                                              003664
02407            GO TO 255                                                  003666
02410      254   CONTAM=0.0                                                 003670
02411            CONTQ=0.0                                                  003670
02412      255   IF (HEAT(L)) 256,257,256                                   003672
02415      256   HEATAD=HEAT(L)                                             003674
02416            GO TO 258                                                  003675
02417      257   HEATAD=0.0                                                 003677
02420      258   IF (O2MIN(L)) 260,260,259                                  003700
02423      259   CONTAM=(0.21-PROPJS-O2MIN(L)/100.)*Q(I)                    003703
02424            CONTQ=0.0                                                  003710
02425            HEATAD=CONTAM*437.                                         003711
02426      260   IF (SMPO2(L)) 262,262,261                                  003714
02431      261   CONTAM=(0.21-PROPJS)*Q(I)*SMPO2(L)                         003717
02432            CONTQ=0.0                                                  003725
02433            HEATAD=(0.21-PROPJS)*Q(I)*HTPO2(L)                         003726
02434      262   RDCH4(I)=CH4JS*(Q(I)-CH4V(I))/Q(I)+CH4V(I)/Q(I)            003732
02435            RDPROP(I)=PROPJS*(Q(I)-CONTQ)/Q(I)+CONTAM/Q(I)             003742
02436            IF (NTEMP) 263,263,264                                     003752
02441      263   TRD(I)=0.0                                                 003755
02442            GO TO 286                                                  003756
02443      264   TJS=T(JX)                                                  003760
02444            IF (NM) 268,268,265                                        003761
02447      265   IF (HEATAD) 267,266,267                                    003764
02452      266   TFSI(L)=TJS                                                003766
02453            GO TO 268                                                  003770
02454      267   VART=(4950.-TJS/2.)**2+9900.*TJS+HEATAD/(Q(I)*0.0000018)   003772
02455            TFS=-4950.-TJS/2.+SQRT(VART)+TJS                           004010
02456            TJS=TFS                                                    004020
02457            TFSI(L)=TFS                                                004021
02460      268   IF (ICFTM) 269,269,270                                     004024
02463      269   TM=(TJS+TROCK(I))/2.                                       004026
02464            GO TO 273                                                  004033
02465      270   ARGMT=(TJS-TROCK(I))/(TRD(I)-TROCK(I))                     004035
02466            IF (ARGMT-1.) 271,271,272                                  004043
02471      271   TM=(TJS+TRD(I))/2.                                         004046
02472            GO TO 273                                                  004052
02473      272   X=ALOG(ARGMT)/LA(I)                                        004054
02474            TM=TROCK(I)+(TJS-TROCK(I))*(1.0-EXP(-X*LA(I)))/(X*LA(I))   004064
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273   WT=DR*(TR+460.)/(TM+460.)                                              004104
      VISC=0.000145*((460.+TM)/492.)**1.75                                   004110
      CP=0.2376+0.000024*TM                                                  004120
      HKA=0.014*((460.+TM)/492.)**0.81                                       004124
      RN=Q(I)*DR/(15.*WT*O(I)*VISC)                                          004132
      FRO=0.0032+0.221/RN**0.237                                             004143
      POT=(100./RN)**0.125                                                   004153
      COR=((KF(I)*0.075)/(809*DR*FRO))**POT                                  004163
      HC=0.005*HKA*O(I)*RN**0.8*COR/A(I)                                     004200
      FO=TIME*HA(I)*O(I)**2/(4.*A(I)**2)                                     004214
      BI=HC*2.*A(I)/(O(I)*HK(I))                                             004226
      X=(0.375+BI)*SQRT(FO)                                                  004234
      IF (X-2.5) 274,277,277                                                 004243
274   N=0                                                                    004246
      SUMT=0.0                                                               004247
      ADDT=X                                                                 004250
275   SUMT=SUMT+ADDT                                                         004253
      N=N+1                                                                  004255
      ADDT=-ADDT*X**2*(2*N-1)/(N*(2*N+1))                                    004260
      IF (ABS(ADDT)-0.00001) 276,275,275                                     004301
276   FX=1.0-(EXP(X**2))*(1.0-(2.0/SQRT(PI))*SUMT)                           004305
      GO TO 281                                                              004316
277   N=0                                                                    004320
      SUMT=0.0                                                               004320
      ADDT=1.0                                                               004321
278   SUMT=SUMT+ADDT                                                         004324
      N=N+1                                                                  004326
      OLADDT=ADDT                                                            004331
      ADDT=-ADDT*(2*N-1)/(2.0*X**2)                                          004333
      IF (ABS(ADDT)-0.00001) 280,279,279                                     004345
279   IF (ABS(OLADDT)-ABS(ADDT)) 280,280,278                                 004351
280   FX=1.0-1.0*SUMT/(SQRT(PI)*X)                                           004357
281   COAGE=BI-FX*BI**2/(0.375+BI)                                           004365
      XNEW(I)=HK(I)*LA(I)*O(I)**2.*COAGE/(120.*DR*Q(I)*CP*A(I))              004374
      IF (ICFTM) 282,282,283                                                 004413
282   TOLD=TROCK(I)                                                          004416
      GO TO 284                                                              004420
283   TOLD=TRD(I)                                                            004422
284   TRD(I)=TROCK(I)+(TJS-TROCK(I))*EXP(-XNEW(I))-(DZRD(I)/(2.*778.26*C     004425
     1P))*(1.+EXP(-XNEW(I)))                                                 004425
      TDM=ABS(TOLD-TRD(I))                                                   004447
      IF (TDM-50.) 286,286,285                                               004452
285   ICFTM=1                                                                004455
      GO TO 270                                                              004457
286   IF (JF(I)) 288,287,287                                                 004461
287   JF(I)=-JF(I)                                                           004464
288   CONTINUE                                                               004472
C     CONDITIONS IN JUNCTIONS                                                004472
      DO 294 I=1,NJ                                                          004472
      L=JLR(I)                                                               004472
```

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02576                IF (JNo(L)) 294,289,289                                   004475
02601     289        JY=1                                                      004500
02602                IF (I-1) 290,291,290                                      004502
02605     290        JY=MIN(I-1)+1                                             004505
02606     291        JZ=MIN(I)                                                 004510
02607                SUMAIR=0.0                                                004513
02610                SUMPR=0.0                                                 004514
02611                SUMCH4=0.0                                                004515
02612                SUMHT=0.0                                                 004516
02613                DO 293 K=JY,JZ                                            004522
02616                J=NGIN(K)                                                 004522
02617                IF (JF(J)) 292,294,294                                    004525
02622     292        SUMAIR=SUMAIR+Q(J)                                        004530
02623                SUMPR=SUMPR+RDPROP(J)*Q(J)                                004533
02624                SUMCH4=SUMCH4+RDCH4(J)*Q(J)                               004537
02625                SUMHT=SUMHT+TRD(J)*Q(J)*(0.2376+0.000024*TRD(J))          004543
02626     293        CONTINUE                                                  004555
02630                NSTART=I                                                  004555
02631                PROP(L)=SUMPR/SUMAIR                                      004557
02632                PRCH4(L)=SUMCH4/SUMAIR                                    004561
02633                RTCONT=4950.**2.+SUMHT/(SUMAIR*0.000024)                  004564
02634                T(L)=-4950.+SQRT(RTCONT)                                  004572
02635                GO TO 248                                                 004577
02636     294        CONTINUE                                                  004602
02636     C          RECIRCULATION, FIRST APPROXIMATION                        004602
02640                NREC=1                                                    004602
02641     295        L=0                                                       004605
02642                DO 303 I=1,NJ                                             004605
02645                IF (JNo(I)) 296,296,297                                   004616
02650     296        L=L+1                                                     004621
02651                GO TO 303                                                 004624
02652     297        N=0                                                       004626
02653                M=0                                                       004626
02654                SRPR=0.0                                                  004627
02655                SRCH4=0.0                                                 004630
02656                STRD=0.0                                                  004631
02657                QIN=0.0                                                   004632
02660                QREC=0.0                                                  004633
02661                DO 301 J=1,NB                                             004637
02664                IF (JNo(I)+JF(J)) 299,298,299                             004637
02667     298        N=N+1                                                     004642
02670                SRPR=SRPR+RDPROP(J)*Q(J)                                  004645
02671                SRCH4=SRCH4+RDCH4(J)                                      004651
02672                STRD=STRD+TRD(J)                                          004654
02673                QIN=QIN+Q(J)                                              004657
02674                GO TO 301                                                 004662
02675     299        IF (JNo(I)-JF(J)) 301,300,301                             004664
02700     300        M=M+1                                                     004666
02701                MEMREC(M)=J                                               004672
02702                QREC=QREC+Q(J)                                            004674
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02703      301   CONTINUE                                              004701
02705            IF (N) 303,303,302                                    004701
02710      302   AVRPR=SRPR/QIN                                        004704
02711            AVRCH4=SRCH4/N                                        004707
02712            AVTRD=STRD/N                                          004714
02713            IF (QREC*2.0/QIN-NREC) 304,304,303                    004721
02716      303   CONTINUE                                              004735
02720            GO TO 311                                             004735
02721      304   DO 305 L=1,M                                          004737
02724            MRC=MRC+1                                             004747
02725            K=MEMREC(L)                                           004751
02726            NOREC(MRC)=K                                          004753
02727            ESTPR(MRC)=AVRPR                                      004755
02730            RDPROP(K)=ESTPR(MRC)                                  004757
02731            ESTCH4(MRC)=AVRCH4                                    004761
02732            RDCH4(K)=ESTCH4(MRC)                                  004763
02733            ESTTR(MRC)=AVTRD                                      004764
02734            TRD(K)=ESTTR(MRC)                                     004766
02735            JF(K)=-JF(K)                                          004767
02736      305   CONTINUE                                              004775
02740            DO 306 J=1,NJ                                         004775
02743            IF (JNO(I)-JNOL(J)) 306,307,306                       004775
02746      306   CONTINUE                                              005003
02750      307   JY=1                                                  005003
02751            IF (J-1) 308,309,308                                  005004
02754      308   JY=MIN(J-1)+1                                         005007
02755      309   JZ=MIN(J)                                             005013
02756            SUMAIR=0.0                                            005015
02757            SUMPR=0.0                                             005016
02760            SUMCH4=0.0                                            005017
02761            SUMHT=0.0                                             005020
02762            DO 310 K=JY,JZ                                        005026
02765            M=NGIN(K)                                             005026
02766            SUMAIR=SUMAIR+Q(M)                                    005030
02767            SUMPR=SUMPR+RDPROP(M)*Q(M)                            005033
02770            SUMCH4=SUMCH4+RDCH4(M)*Q(M)                           005037
02771            SUMHT=SUMHT+TRD(M)*Q(M)*(0.2376+0.000024*TRD(M))      005043
02772      310   CONTINUE                                              005054
02774            NSTART=J                                              005054
02775            L=I                                                   005056
02776            PROP(L)=SUMPR/SUMAIR                                  005060
02777            PRCH4(L)=SUMCH4/SUMAIR                                005063
03000            RTCONT=4950.**2.+SUMHT/(SUMAIR*0.000024)              005066
03001            T(L)=-4950.+SQRT(RTCONT)                              005074
03002            GO TO 248                                             005101
03003      311   IF (L-NJ) 312,313,313                                 005103
03006      312   NREC=NREC+1                                           005106
03007            GO TO 295                                             005111
03007      C     RECIRCULATION, PREPARATION FOR ITERATION              005111
03010      313   DO 314 I=1,NB                                         005113
```

```
03013        314   JF(I)=IABS(JF(I))                                              005122
03015              DO 315 I=1,NJ                                                  005127
03020        315   JNO(I)=IABS(JNO(I))                                            005127
03022              L=0                                                            005131
03023              IF (MRC) 316,326,316                                           005132
03026        316   DO 323 I=1,MRC                                                 005134
03031              K=NOREC(I)                                                     005140
03032              DIFPR=ESTPR(I)-RDPROP(K)                                       005141
03033              DIFCH4=ESTCH4(I)-RDCH4(K)                                      005145
03034              DIFTRD=ESTTR(I)-TRD(K)                                         005150
03035              IF (ABS(DIFPR)-CRITSM/100.) 318,317,317                        005153
03040        317   L=L+1                                                          005161
03041        318   IF (ABS(DIFCH4)-CRITGS/100.) 320,319,319                       005165
03044        319   L=L+1                                                          005172
03045        320   IF (ABS(DIFTRD)-CRITHT) 322,321,321                            005176
03050        321   L=L+1                                                          005201
03051        322   ESTPR(I)=RDPROP(K)                                             005205
03052              ESTCH4(I)=RDCH4(K)                                             005207
03053              ESTTR(I)=TRD(K)                                                005211
03054              JF(K)=-JF(K)                                                   005213
03055        323   CONTINUE                                                       005216
03057              ITCT=ITCT+1                                                    005216
03060              IF (L) 324,326,324                                             005221
03063        324   IF (ITCT-ITN) 247,247,325                                      005223
03066        325   MARKC=1                                                        005226
03067        326   IF (NTEMP) 327,327,328                                         005231
03072        327   WRITE (6,442)                                                  005233
03074              GO TO 359                                                      005240
03075        328   IF (NETW) 359,359,329                                          005242
03075        C     CALCULATION OF NATURAL VENTILATION PRESSURE                    005242
03100        329   DO 336 I=1,NB                                                  005244
03103              DO 330 J=1,NJ                                                  005267
03106              IF (JS(I)-JNO(J)) 330,331,330                                  005267
03111        330   CONTINUE                                                       005275
03113        331   T1=T(J)                                                        005275
03114              DO 332 K=1,INFLOW                                              005302
03117              IF (NCENT(K)-NO(I)) 332,333,332                                005302
03122        332   CONTINUE                                                       005307
03124              GO TO 334                                                      005307
03125        333   T1=TFSI(K)                                                     005311
03126        334   CP=0.2376+0.000012*(TRD(I)+T1)                                 005314
03127              E=DZRD(I)/(2.*778.26*CP)                                       005331
03130              B=T1-TROCK(I)                                                  005341
03131              TMRD=TROCK(I)+B*(1.-EXP(-XNEW(I)))/XNEW(I)-E*(1.+(1.-EXP(-XNEW(I))
03131             1)/XNEW(I))                                                     005345
03132              FRNVP(I)=TMRD*DZRD(I)                                          005357
03133              TMSQR=(TROCK(I)+460.-E)**2.+((E-B)**2.)*(1.-EXP(-2.*XNEW(I)))/(2.*
03133             1XNEW(I))+2.*(TROCK(I)+460.-E)*(B-E)*(1.-EXP(-XNEW(I)))/XNEW(I)    005361
03134              IF (NWTYP(I)) 335,335,336                                      005420
03137        335   R(I)=RSTD(I)*TMSQR/(460.+TR)**2.                               005423
```

```
03140     336   CONTINUE                                                  005431
03142           IF (NSFLOW) 349,349,337                                   005431
03145     337   MBEGW=1                                                   005435
03146           DNVP=0.0                                                  005436
03147           DO 346 K=1,MNO                                            005444
03152           ONVP=FNVP(K)                                              005444
03153           MENDW=MEND(K)                                             005445
03154           FNVP(K)=0.                                                005450
03155           ZUP=0.0                                                   005451
03156           ZDOWN=0.0                                                 005452
03157           HSU=0.                                                    005453
03160           TSU=0.                                                    005454
03161           DO 343 J=MBEGW,MENDW                                      005460
03164           N=MSL(J)                                                  005460
03165           IF (N) 338,339,339                                        005461
03170     338   FACT=-1.                                                  005463
03171           NX=-N                                                     005465
03172           GO TO 340                                                 005466
03173     339   FACT=1.                                                   005470
03174           NX=N                                                      005471
03175     340   HSU=HSU+FACT*FRNVP(NX)                                    005474
03176           TSU=TSU+ABS(FRNVP(NX))                                    005500
03177           IF (DZRD(NX)*FACT) 342,343,341                            005503
03202     341   ZUP=ZUP+DZRD(NX)*FACT                                     005507
03203           GO TO 343                                                 005513
03204     342   ZDOWN=ZDOWN+DZRD(NX)*FACT                                 005515
03205     343   CONTINUE                                                  005523
03207           IF (ZDOWN+ZUP) 344,345,344                                005523
03212     344   HSU=HSU-(ZUP+ZDOWN)*TR                                    005526
03213           TSU=TSU-(ZUP+ZDOWN)*TR                                    005533
03214     345   FNVP(K)=HSU*DR/(5.2*(TSU/(ZUP+ZDOWN)+460.))               005541
03215           DNVP=DNVP+ABS(ONVP-FNVP(K))                               005552
03216     346   MBEGW=MENDW+1                                             005557
03216     C     REROUTE PROGRAM TO APPROPRIATE PROGRAM SECTION            005557
03220           IF (NNVP) 348,348,347                                     005563
03223     347   NNVP=0                                                    005566
03224           ITCT=0                                                    005567
03225           GO TO 85                                                  005570
03226     348   IF (DNVP/MNO-0.001) 355,355,349                           005572
03231     349   IF (MADJC-MADJ) 350,354,354                               005601
03234     350   NSNVP=1                                                   005604
03235           MADJC=MADJC+1                                             005606
03236           ITCT=0                                                    005610
03237           MARKN=0                                                   005611
03240           DO 352 I=1,NB                                             005617
03243           IF (JF(I)) 351,352,352                                    005617
03246     351   JF(I)=-JF(I)                                              005621
03247     352   Q(I)=Q(I)/100000.                                         005623
03251           IF (NSFLOW) 353,353,85                                    005626
03254     353   NSW=1                                                     005631
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03255              GO TO 20                                              005633
03255        C     OUTPUT OF RESULTS                                     005633
03256    354       WRITE (6,443)                                         005635
03260    355       DO 358 L=1,NB                                         005642
03263              IF (NWTYP(L)) 356,356,357                             005650
03266    356       P(L)=R(L)*(Q(L)/100000.)**2.                          005653
03267              GO TO 358                                             005657
03270    357       P(L)=R(L)                                             005661
03271    358       CONTINUE                                              005665
03273    359       IF (MARKN) 361,361,360                                005665
03276    360       WRITE (6,444)                                         005667
03300    361       IF (MARKC) 363,363,362                                005675
03303    362       WRITE (6,445)                                         005677
03305    363       WRITE (6,446)                                         005705
03307              WRITE (6,447) (NO(I),JS(I),JF(I),Q(I),TRD(I),RDPROP(I),RDCH4(I),P(  005711
03307             1I),I=1,NB)                                            005711
03324              WRITE (6,448)                                         005740
03326              WRITE (6,449) (JNO(I),T(I),PROP(I),PRCH4(I),I=1,NJ)   005745
03337              WRITE (6,450) MADJC                                   005762
03342              L=0                                                   005770
03343              DO 365 I=1,NB                                         005774
03346              IF (JF(I)) 364,365,365                                005774
03351    364       JFF=IABS(JF(I))                                       005776
03352              WRITE (6,451) NO(I),JFF                               006000
03356              L=L+1                                                 006007
03357    365       CONTINUE                                              006014
03361              IF (L) 367,367,366                                    006014
03364    366       WRITE (6,452)                                         006017
03366    367       WRNSUM=WRNPR+WRNGS+WRNSM+WRNHT                        006025
03367              IF (WRNSUM) 368,368,369                               006031
03372    368       WRITE (6,453)                                         006033
03374              GO TO 394                                             006040
03375    369       J=0                                                   006042
03376              DO 381 I=1,NB                                         006042
03401              K=0                                                   006047
03402              L=0                                                   006047
03403              M=0                                                   006050
03404              N=0                                                   006051
03405              IF (100.*RDCH4(I)-WRNGS) 371,370,370                  006052
03410    370       K=K+1                                                 006057
03411    371       IF (100.*RDPROP(I)-WRNSM) 373,372,372                 006063
03414    372       L=L+1                                                 006067
03415    373       IF (TRD(I)-WRNHT) 375,374,374                         006073
03420    374       M=M+1                                                 006076
03421    375       IF (P(I)-WRNPR) 376,377,377                           006102
03424    376       N=N+1                                                 006105
03425    377       IF (K+L+M+N) 381,381,378                              006111
03430    378       IF (J) 380,379,380                                    006116
03433    379       WRITE (6,454) WRNGS,WRNSM,WRNHT,WRNPR                 006120
03441              J=J+1                                                 006131
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03442   380   JFF=IABS(JF(I))                                                        006135
03443         WRITE (6,455) NO(Ɨ),JS(I),JFF,RDCH4(I),RDPROP(I),TRD(I),P(I)           006136
03454   381   CONTINUE                                                               006154
03456         IF (J) 382,382,383                                                     006154
03461   382   WRITE (6,456)                                                          006157
03463         GO TO 394                                                              006164
03464   383   J=0                                                                    006166
03465         DO 393 I=1,NJ                                                          006166
03470         K=0                                                                    006173
03471         L=0                                                                    006173
03472         M=0                                                                    006174
03473         IF (100.*PRCH4(I)-WRNGS) 385,384,384                                   006175
03476   384   K=K+1                                                                  006202
03477   385   IF (100.*PROP(I)-WRNSM) 387,386,386                                    006206
03502   386   L=L+1                                                                  006212
03503   387   IF (Ŧ(Ɨ)-WRNHT) 389,388,388                                            006216
03506   388   M=M+1                                                                  006221
03507   389   IF (K+L+M) 393,393,390                                                 006225
03512   390   IF (J) 392,391,392                                                     006231
03515   391   WRITE (6,457) WRNGS,WRNSM,WRNHT                                        006233
03522         J=J+1                                                                  006243
03523   392   WRITE (6,458) JNO(I),PRCH4(I),PROP(I),T(I)                             006247
03531   393   CONTINUE                                                               006262
03533   394   IF (NRCT-1) 401,395,396                                                006262
03536   395   WRITE (6,459)                                                          006266
03540         K=NREV(1)                                                              006273
03541         JFF=IABS(JF(K))                                                        006276
03542         WRITE (6,460) NO(K),JS(K),JFF                                          006300
03547         GO TO 401                                                              006310
03550   396   WRITE (6,459)                                                          006312
03552         L=0                                                                    006316
03553   397   MINREV=NREV(1)                                                         006320
03554         MEMI=1                                                                 006321
03555         DO 399 I=2,NRCT                                                        006330
03560         IF (MINREV-NREV(I)) 399,399,398                                        006330
03563   398   MINREV=NREV(I)                                                         006334
03564         MEMI=I                                                                 006336
03565   399   CONTINUE                                                               006342
03567         L=L+1                                                                  006342
03570         IF (L-NRCT) 400,400,401                                                006345
03573   400   JFF=IABS(JF(MINREV))                                                   006350
03574         WRITE (6,460) NO(MINREV),JS(MINREV),JFF                                006353
03601         NREV(MEMI)=NB+1                                                        006363
03602         GO TO 397                                                              006367
03603   401   STOP                                                                   006371
03603   C                                                                            006371
03603   C     FORMATS                                                                006371
03603   C                                                                            006371
03604   402   FORMAT (10I5,2F10.5)                                                   006374
03605   403   FORMAT (4I5,F10.3,F10.0,2I10,2F10.1)                                   006374
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03606   404   FORMAT (I5,T11,F5.1,T20,F6.0,F5.2)                                      006374
03607   405   FORMAT (2I5)                                                            006374
03610   406   FORMAT (5(F8.0,F6.2))                                                   006374
03611   407   FORMAT (I5,T41,2I10,2F10.1)                                             006374
03612   408   FORMAT (/////,' MISTAKE IN ADDITIONAL AIRWAY CARDS')                    006374
03613   409   FORMAT (/////,' NO RESISTANCE OR DIMENSIONS WERE STATED FOR AIRWAY      006374
03613        1 NO',I10)                                                               006374
03614   410   FORMAT (/////,T17,' NO NETWORK CALCULATION HAS BEEN PERFORMED, THE      006374
03614        1SE ARE THE INPUT DATA',//,' AIRWAY   FROM     TO        AIRFLOW     AI  006374
03614        2RWAY TYPE        LENGTH     AREA    RESISTANCE      K  PERIMETER')      006374
03615   411   FORMAT (I5,I7,I7,F13.0,8X,I5,8X,I7,F9.1,F13.3,I7,F9.1)                  006374
03616   412   FORMAT (/////,' AIRWAY',I5,'   IS ISOLATED FROM NETWORK')               006374
03617   413   FORMAT (/////,' REGULATOR',I5,'   IN BASE SYSTEM')                      006374
03620   414   FORMAT (//,T20,' AIRWAY NO',I7,'   IS AN UNSTABLE AIRWAY WITH CHAN      006374
03620        1GING AIRFLOW DIRECTIONS')                                               006374
03621   415   FORMAT (1H1,'         ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFO   006374
03621        1RE EVENT (BASED ON THE LISTED INPUT DATA)')                             006374
03622   416   FORMAT (1H0,T40,'REGULAR AIRWAYS'//' AIRWAY   FROM      TO      AIRFL   006374
03622        1OW     PRESSURE LOSS        LENGTH     AREA    RESISTANCE       K  PERIME 006374
03622        2TER')                                                                   006374
03623   417   FORMAT (I5,I7,I7,F13.0,F13.3,8X,I7,F9.1,F13.3,I7,F9.1)                  006374
03624   418   FORMAT (/////' NETWORK CONTAINS NO FANS')                               006374
03625   419   FORMAT (1H0,T20,'FANS'//' AIRWAY   FROM       TO        AIRFLOW    FAN P 006374
03625        1RESSURE')                                                               006374
03626   420   FORMAT (I5,I7,I7,F13.0,F13.3)                                           006374
03627   421   FORMAT (////,' THESE CHARACTERISTICS WERE STORED FOR FANS',10I6)        006374
03630   422   FORMAT (//5(F10.0,F6.2)/5(F10.0,F6.2))                                  006374
03631   423   FORMAT (////' THE STATED NUMBER OF AIRWAYS WAS',I7,'      THE STATE     006374
03631        1D NUMBER OF JUNCTIONS WAS',I7)                                          006374
03632   424   FORMAT (////' THE FAN CHARACTERISTIC IS EXCEEDED FOR FAN NO',I5)        006374
03633   425   FORMAT (/////,' NO TEMPERATURE OR CONCENTRATION CALCULATIONS WERE       006374
03633        1DEMANDED')                                                              006374
03634   426   FORMAT (6I5,F5.1,F8.2,F7.5,F5.3,F6.3,F4.2,F6.4,F4.1,F5.0)               006374
03635   427   FORMAT (3F10.5,2I10,2F10.2)                                             006374
03636   428   FORMAT (I5,F10.2,4F10.5,F10.1)                                          006374
03637   429   FORMAT (/////,' MISTAKE IN AIRWAY CONCENTRATION CARDS')                 006374
03640   430   FORMAT (//////,' INSUFFICIENT DESCRIPTION OF AIRWAY PROPERTIES'/'       006374
03640        1(NO AIRWAY CARDS, NO AVERAGE PROPERTIES')                               006374
03641   431   FORMAT (/////,' STATED NUMBER OF JUNCTIONS IS WRONG AND HAS BEEN C      006374
03641        1ORRECTED')                                                              006374
03642   432   FORMAT (I5,T26,F5.2)                                                    006374
03643   433   FORMAT (/////,' MISTAKE IN JUNCTION CONCENTRATION CARDS')               006374
03644   434   FORMAT (I5,F10.0,F10.5,F10.2,3F10.5)                                    006374
03645   435   FORMAT (1H1,T20,' INPUT DATA FOR CONCENTRATION AND TEMPERATURE CAL      006374
03645        1CULATIONS'//' AIRWAY   FROM      TO        ELEVATION DIFF.   ROCK  TEMP. 006374
03645        2    METHANE PROD.      CONDUCTIVITY      DIFFUSIVITY')                  006374
03646   436   FORMAT (I5,2I7,T25,F10.1,T40,F10.1,T56,F10.1,T72,F10.1,T89,F10.4)       006374
03647   437   FORMAT (////,T20,' TIME AFTER BEGINNING OF EVENT',F7.2,'    HOURS')      006374
03650   438   FORMAT (////,T20,' A TEMPERATURE OF',F6.1,'  WAS ASSIGNED TO JUNCT      006374
03650        1ION NO',I7)                                                             006374
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03651      439   FORMAT (////,T25,' THE FOLLOWING CONTAMINATION WAS ASSUMED',//,T18   006374
03651           1,'CONTAMINATION',T43,'OXYGEN CONCENTRATION',T67,'PRODUCTION PER %   006374
03651           2OXYGEN',/,' AIRWAY    FLOWRATE  CONCENTRAT.     HEAT        BEHIND F   006374
03651           3IRE          SMOKE              HEAT')                                006374
03652      440   FORMAT (I6,F11.1,F11.2,F12.2,9X,F6.2,10X,F8.2,7X,F7.2)                 006374
03653      441   FORMAT (/////,T20,' NO CONTAMINATION WAS SPECIFIED')                   006374
03654      442   FORMAT (////,' NO TEMPERATURE DETERMINATION WAS DEMANDED')            006374
03655      443   FORMAT (/////,' THE CALCULATION WAS NOT COMPLETED SINCE THE NUMBER    006374
03655           1 OF EXCHANGES BETWEEN NETWORK AND CONCENTRATION'/' PARTS OF THE PR    006374
03655           2OGRAM BECAME EXCESSIVE')                                              006374
03656      444   FORMAT (/////,' THE NETWORK CALCULATION WAS NOT COMPLETED. MORE IT    006374
03656           1ERATIONS ARE REQUIRED')                                               006374
03657      445   FORMAT (/////,' THE CALCULATION OF CONCENTRATIONS AND TEMPERATURES    006374
03657           1 WAS NOT COMPLETED, MORE ITERATIONS ARE REQUIRED')                    006374
03660      446   FORMAT (/////,T18,'TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS,    006374
03660           1 PRESSURES IN AIRWAYS',//,' AIRWAY',T10,'FROM',T18,'TO',T31,'AIRFL    006374
03660           2OW',T45,'TEMPERATURE',T63,'SMOKE',T77,'METHANE',T93,'PRESSURE',/)    006374
03661      447   FORMAT (' ',I5,2I7,T30,0PF8.0,T46,0PF7.2,T60,2PF8.4,T77,2PF6.2,T93    006374
03661           1,0PF6.3)                                                               006374
03662      448   FORMAT (/////,T18,'TEMPERATURES AND CONCENTRATIONS OF SMOKE AND ME    006374
03662           1THANE IN JUNCTIONS',//,' JUNCTION',T13,'TEMPERATURE',T28,'SMOKE',T    006374
03662           237,'METHANE',T58,'JUNCTION',T69,'TEMPERATURE',T82,'SMOKE',T92,'MET    006374
03662           3HANE'/)                                                               006374
03663      449   FORMAT (I5,T15,0PF7.2,T25,2PF8.4,T36,2PF8.4,T57,I5,T71,0PF7.2,T79,    006374
03663           12PF8.4,T91,2PF8.4)                                                    006374
03664      450   FORMAT (////,T22,'NUMBER OF ITERATIONS',I10)                           006374
03665      451   FORMAT (' ',T18,'WITH AIRWAY NO',I7,'    INTO JUNCTION NO',I5)         006374
03666      452   FORMAT (//,T18,'A RECIRCULATION PATH IS BEING CLOSED')                 006374
03667      453   FORMAT (//////,' NO THRESHOLD LIMITS FOR CRITICAL STATES WERE SPECI    006374
03667           1FIED')                                                                006374
03670      454   FORMAT (/////,T23,'IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITI    006374
03670           1ONS',/,T27,'(THE STATED NUMBERS REFER TO AIRWAY ENDS)',/,' AIRWAY    006374
03670           2 FROM      TO  METHANE CONCENTRATION  SMOKE CONCENTRATION  TEMPERATU    006374
03670           3RE  LOW VENTILAT. PRESSURE',/,T27,'HIGHER THAN',T48,'HIGHER THAN',    006374
03670           4T66,'HIGHER THAN',T85,'LOWER THAN',/,T26,F4.1,' PERCENT',T46,F6.3,    006374
03670           5' PERCENT',T65,F5.0,' DEGREES',T82,F5.3,' INCHES WG',//)              006374
03671      455   FORMAT (I5,I7,I7,T29,2PF6.2,T50,2PF8.4,T69,0PF5.1,T87,0PF6.3)          006374
03672      456   FORMAT (//////,' NO CRITICAL CONDITIONS AT AIRWAY ENDS OR IN JUNCTI    006374
03672           1ONS WERE DETECTED')                                                   006374
03673      457   FORMAT (////,T24,' IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDI    006374
03673           1TIONS',/,' JUNCTION        METHANE CONCENTRATION          SMOKE CONC    006374
03673           2ENTRATIONS',16X,'TEMPERATURE',/,T15,'HIGHER THAN',F4.1,' PERCENT      006374
03673           3       HIGHER THAN',F6.3,' PERCENT           MORE THAN',F6.1,' DEGREES'    006374
03673           4,//)                                                                  006374
03674      458   FORMAT (I5,T23,2PF5.1,T52,2PF8.4,T88,0PF5.1)                           006374
03675      459   FORMAT (/////,T18,'REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWI    006374
03675           1NG PLACES',//)                                                        006374
03676      460   FORMAT (T18,'AIRWAY',I6,'  IS NOW CARRYING AIR FROM',I6,'  TO',I6)    006374
03677            END                                                                   006374
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8. LIST OF COMPUTER SYMBOLS WHICH ARE EXPLAINED IN TEXT

Computer Symbol	Text Page	Definition
A	16	airway cross sectional area
AAVR	26	average airway cross sectional area
AVRCH4	43	average methane concentration of unrecirculated air currents entering junction
AVRPR	43	average contaminant concentration of unrecirculated air currents entering junction
AVTRD	43	average temperature of unrecirculated air currents entering junction
AX	17	airway cross sectional area
CH4C	16	methane concentration in junction
CH4CX	27	methane concentration in junction
CH4JS	35	methane concentration at roadway beginning
CH4PA	28	methane volume production rate per ft^2 of surface area in airway
CH4PAX	27	methane production rate per ft^2 surface area in airway
CH4V	28	methane volume production rate in airway
CH4VX	27	methane production rate in airway
COAGE	41	coefficient of age
CONC	28	concentration of contaminant in gas inflow
CONT	28	volume flow rate of contaminated gas inflow
CONTAM	35	volume flow rate of contaminant
CONTQ	35	volume flow rate of gas inflow carrying the contaminant
COR	40	correction of HC for rough walls
CRITGS	26	accuracy of methane concentration calculation when recirculation occurs
CRITHT	26	accuracy of temperature calculation when recirculation occurs
CRITSM	26	accuracy of contamination calculation when recirculation occurs

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
DNVP	47	difference between natural ventilation pressures in last two iterations
DPSUM	22	sum of pressure losses around mesh
DQ	22	CROSS correction per mesh
DQSUM	22	sum of DQ for all meshes of network
DR	15	reference density
DZRD	28	elevation change in airway
DZRDX	27	elevation change in airway
ESTCH4	44	estimated methane concentration for recirculated air
ESTPR	44	estimated contaminant concentration for recirculated air
ESTTR	44	estimated temperature for recirculated air
FACT	47	factor indicating direction of elevation change
FANP	22	fan pressure at airflow rate FANQ
FANQ	22	airflow rate passing through fan
FNVP	21	list of natural ventilation pressures in meshes
FRNVP	47	product TMRD*DZRD
HA	28	thermal diffusivity of rock in airway
HAAVR	26	average rock diffusivity
HAX	27	thermal diffusivity of rock in airway
HC	39	convection coefficient
HEAT	28	heat entering airway
HEATAD	36	heat addition to air
HK	28	thermal conductivity of rock in airway
HKA	39	thermal conductivity of air

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
HKAVR	26	average rock thermal conductivity
HKX	27	thermal conductivity of rock in airway
HSU	47	sum of quantities FRNVP
HTPO2	28	heat production per ft^3 of oxygen delivery
ICFTM	41	marker
INFLOW	26	number of contamination cards
INU	18	auxiliary list for forming base system
ISTART	34	index of JSTART in JNO-list
IT	22	iteration counter
ITCT	47	iteration counter
ITN	15	maximal number of iterations in network and concentration calculations
JF	16	junction number of airway end
JLR	34	list relating JNO- and JNOL-lists
JS	16	junction number of airway beginning
JSTART	26	number of junction from where concentration calculation shall start
JNO	16	junction number
JNOL	32	list of junction numbers in increasing order
JNOX	27	junction number
KF	16	friction factor
KFAVR	26	average friction number
KNO	19	list of airways in base system
KX	17	friction factor

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
LA	16	airway length
LAAVR	26	average airway length
LOUT	32	list of last airway per junction in NGOUT-list
LX	17	airway length
MADJ	15	maximal number of network calculations in one program run
MADJC	17	iteration counter
MARKC	34	marker
MARKN	17	marker
MAXJ	26	highest junction number
MEMREC	43	temporary list of airways carrying recirculated air
MEND	19	list of mesh ends in MSL-list
MIN	32	list of last airway per junction in NGIN-list
MPTS	17	number of points used to define fan characteristics
MSL	19	list of all independent meshes
MSTART	34	index of JSTART in JNOL-list
NADBC	15	number of additional airway cards
NAV	26	marker for presence of average value card
NB	15	number of airways in network
NCENT	28	number of airways into which contaminants enter
NCH4C	26	additional number of concentration junction cards
NCONC	15	marker for desired concentration calculation
NDIM	26	additional number of concentration airway cards
NETW	15	marker for desired network calculation

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
NFNUM	15	number of fan characteristics to be read into computer
NFREG	18	list of fans with characteristic
NGIN	32	list of airways entering junction
NGOUT	32	list of airways leaving junction
NJ	15	number of junctions in network
NO	16	airway number
NOF	17	airway number of fan
NOREC	44	permanent list of airways carrying recirculated air
NOX	17	airway number
NOX	27	airway number
NNVP	17	marker
NRCT	32	number of airways with airflow reversal
NREC	43	marker
NREV	32	list of airways with airflow reversal
NSFLOW	24	marker
NSNVP	17	marker
NSW	17	marker
NTEMP	15	marker for desired temperature calculation
NVPN	15	marker for presence of junction cards
NWTYP	15	airway type
O	16	airway perimeter
OAVR	26	average airway perimeter
ONVP	47	natural ventilation pressure in last iteration

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
O2MIN	28	oxygen concentration of fumes leaving fire zone
OX	17	airway perimeter
P	25	calculated pressure losses and fan pressures
PF	17	fan pressure at given point of fan characteristic
PR	39	Prandtl number
PRCH4	35	methane concentration in junction
PROP	35	contaminant concentration in junction
PROPJS	35	contaminant concentration at roadway beginning
Q	16	airflow rate
QF	17	airflow rate at given point of fan characteristic
QIN	43	sum of unrecirculated airflow rates entering junction
QREC	43	recirculated air entering junction
R	16	resistance factor of airway
RDCH4	35	methane concentration at roadway ends
RDPROP	35	contaminant concentration at roadway ends
RGRAD	22	slope of fan characteristic
RN	39	Reynolds number
RSTD	46	resistance factor based on reference temperature TR
SMPO2	28	contaminant production per ft^3 of oxygen delivery
SRCH4	43	sum of methane concentrations of unrecirculated airflows entering junction
SRPR	43	sum of unrecirculated contaminant flow rates entering junction
STRD	43	sum of temperatures of unrecirculated airflows entering junction
SUMAIR	42	total airflow rate entering junction

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
SUMCH4	42	total methane flow rate entering junction
SUMHT	42	total enthalpy/reference density entering junction
SUMPR	42	total contaminant flow rate entering junction
T	16	temperature of air in junction
TFSI	46	air temperature behind heat source
TIME	26	time since beginning of contamination
TJS	35	temperature at roadway beginning
TM	41	estimated average air temperature
TMRD	46	mean temperature of air in airway
TMSQR	46	mean square absolute temperature
T1	46	air temperature at beginning of airway
TR	15	reference temperature
TRD	35	temperature at roadway end
TROCK	28	average rock temperature in airway
TROCKX	27	average rock temperature in airway
TSTART	26	temperature in JSTART
TSU	47	sum of absolute quantities FRNVP (in concentration part of program)
WRNGS	26	threshold value for critical methane concentration
WRNHT	26	threshold value for critical temperature
WRNPR	26	threshold value for critical pressure loss
WRNSM	26	threshold value for critical contamination
XNEW	42	exponent in formula for calculation of temperatures in roadways

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
Z	16	elevation of junction
ZDOWN	47	sum of all negative elevation changes in mesh
ZUP	47	sum of all positive elevation changes in mesh

9. LIST OF ADDITIONAL COMPUTER SYMBOLS NOT QUOTED IN TEXT

(This list does not contain some temporary used indices and counters whose meaning and function, when reading the program, can be easily recognized)

Computer Symbol	Definition
ADDT	intermediate quantity for calculation of COAGE
BI	Biot number
CH4S,CH4F	methane concentrations in starting and finishing junctions of airway
CP	specific heat of air
DIFCH4	difference in last two iterations for methane concentration
DIFTRD	difference in last two iterations for air temperatures
ES,EF	elevations of starting and finishing junctions of airway
FO	Fourier number
FRO	coefficient of friction for hydraulically smooth walls
FX	intermediate quantity for calculation of COAGE
KJF	temporary list for assembling base system
KJS	temporary list for assembling base system
MARKD	marker
MBEGW	first airway in mesh
MENDW	last airway in mesh
MESC	mesh counter
MNO	number of meshes in network
NBL	counter

List of Additional Computer Symbols Not Quoted in Text (continued)

Computer Symbol	Definition
NBU	counter
NFCW	list of fans whose characteristic is exceeded
NRETU	marker
POT	exponent for COR
OLADDT	intermediate quantity for calculation of COAGE
QBL	lowest airflow rate used of fan characteristic
QBR	highest airflow rate used of fan characteristic
RQ	product R*Q
RQSUM	sum of all products 2*R*Q
SUMT	intermediate quantity for calculation of COAGE
TO,T1	absolute temperatures of starting and finishing junctions of airway (in network part of program)
TOLD	last calculated temperature at airway end
TRS,TRF	temperatures of starting and finishing junctions of airways
TSU	sum of absolute temperatures of all junctions in mesh (used in network part of program)
VART	content of square root for calculating temperature behind a heat source
VISC	kinematic viscosity of air
WT	specific weight of air
X	quantity ∝0/(G*CP)

List of Additional Computer Symbols Not Quoted in Text (continued)

Computer Symbols	Definition
X	quantity $(0.375 + BI)\sqrt{FO}$
Z0,Z1	elevations of starting and finishing junctions of airway