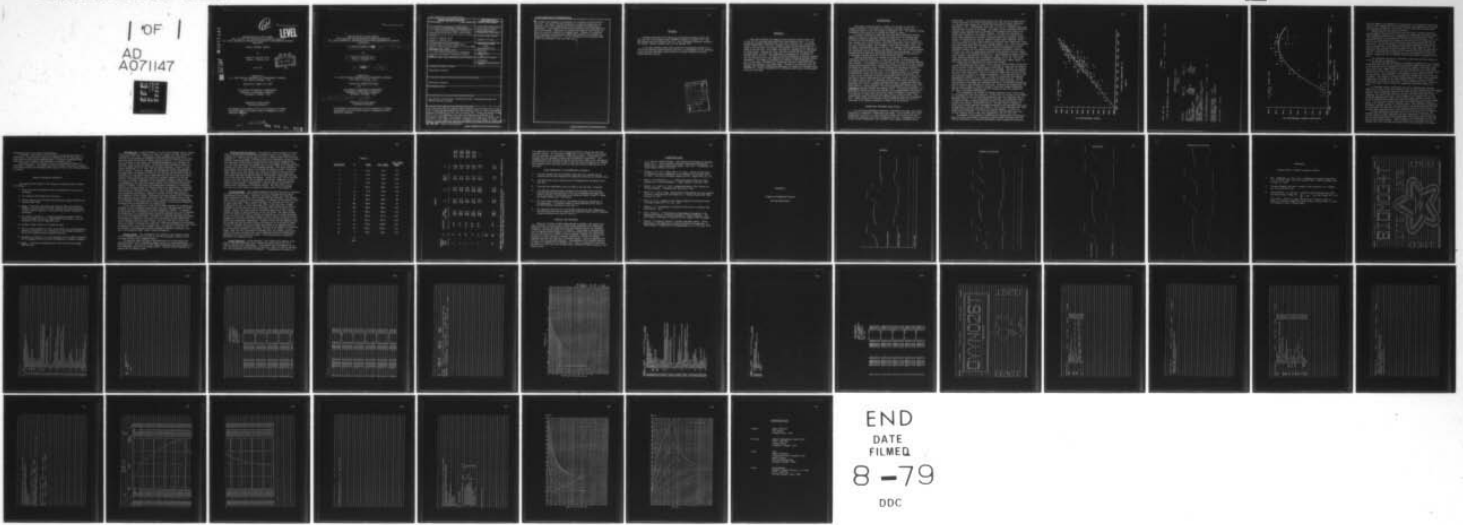


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PREDICTABILITY OF BURN DEPTH:
DATA ANALYSIS AND MATHEMATICAL MODELING BASED ON
U.S. ARMY AEROMEDICAL RESEARCH LABORATORY'S EXPERIMENTAL PORCINE
BURN DATA

ANNUAL SUMMARY REPORT

BY

Francis S. Knox III, Ph.D.
Ransom A. Nockton, M.S.

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LSU SCHOOL OF MEDICINE IN SHREVEPORT
Department of Physiology & Biophysics
Shreveport, Louisiana 71130

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BURN DATA.**

⑨ ANNUAL SUMMARY REPORT. 1 Oct 76-14 Jun 77

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FORWARD

Research discussed in this report was accomplished between October 1976 and June 1977 by the authors under USAMRDC Contract No. DAMD17-77-C-7004. The original data was collected at the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama between June 1972 and January 1973.

In the data collection phase of this project the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences, National Research Council.

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ABSTRACT

This report describes the progress made during the period October 1976 to June 1977 in analyzing experimental burn data collected at the U. S. Army Aeromedical Research Laboratory from June 1972 to January 1973. During this period, October 1976 to June 1977, additional burn data from experiments conducted at the University of Rochester were obtained, reread and are ready to be added to the data base. Burn depths corrected for shrinkage can be 46% deeper in dermal burns. Thermal data (e.g. heat flux) recorded on FM tape during the experiments at USAARL was redigitized in preparation for calculation of thermal input to the skin. The effect of ambient temperature on pig skin temperature was studied to see if skin temperatures could be calculated knowing ambient temperature. The effects of anesthesia and humidity on this relationship have yet to be included. Refinement of a preliminary empirical model awaits the heat flux data now resident on the digital tapes. Sections of an analytical model employing Crank-Nicholson differencing techniques are runnable on computers using FORTRAN IV. Further development of the analytical model awaits the finalization of the burn data base.

INTRODUCTION

This report covers the period 1 October 1976 through 14 June 1977. A complete description of the project can be found in the first annual report covering the period 1 July 1975 through 30 September 1976¹. The general working hypothesis of the project can be summarized briefly as follows:

It should be possible to define the cause and effect relationships between exposure of skin to an excessive thermal environment and the resulting tissue damage by analyzing experimental exposures of pig skin to a well-controlled JP-4 fuel fire and recording furnace wall temperature, heat flux as a function of time, exposure time, skin condition, initial skin temperature, water content of the skin as a function of depth, burn damage on gross and microscopic scales, and the effects of protecting the skin by fabrics. The analysis of these experimental data should allow the development of an empirical or "black box" model describing the relationship between the thermal environment and tissue damage. The understanding that this empirical model imparts should make possible development of a reasonable analytical model for the fire-fabric-skin system.

Extensive experiments were carried out during 1972 at the U. S. Army Aeromedical Research Laboratory. In these experiments, 95 anesthetized pigs were exposed to a well-controlled JP-4 fuel fire, and the above mentioned observations recorded. The purpose of the present project is to analyze the data collected during those experiments and to develop both an empirical and an analytical model describing the response of skin, whether protected or unprotected by fabrics, to a severe thermal environment, e.g. a simulated post-crash fire. The primary accomplishments of the first year were (1) to organize the data, (2) to attempt to ascertain the validity and consistency of the experimental observations, (3) to make certain corrections for known experimental error, and (4) to extend the data base to include measurements of the depth of damage in such a way that corrections could be made for shrinkage or swelling of the tissue subsequent to the initial thermal injury. Another accomplishment was to present the data base graphically as a way of dramatizing the cause and effect relationships which might exist between or among variables. The final accomplishment was to develop a preliminary empirical (multiple discriminant) model. The technical objectives were generally met during the first year although as the accomplishments presented in more detail in the first annual report show model development was hampered by not being able to finalize the data base upon which to build the model. This second annual report summarizes the continued progress made since 30 September 1976. Before moving to a discussion of the technical objectives for Phase II, a discussion of the problems arising out of Phase I will be presented.

UNRESOLVED PROBLEMS FROM PHASE I

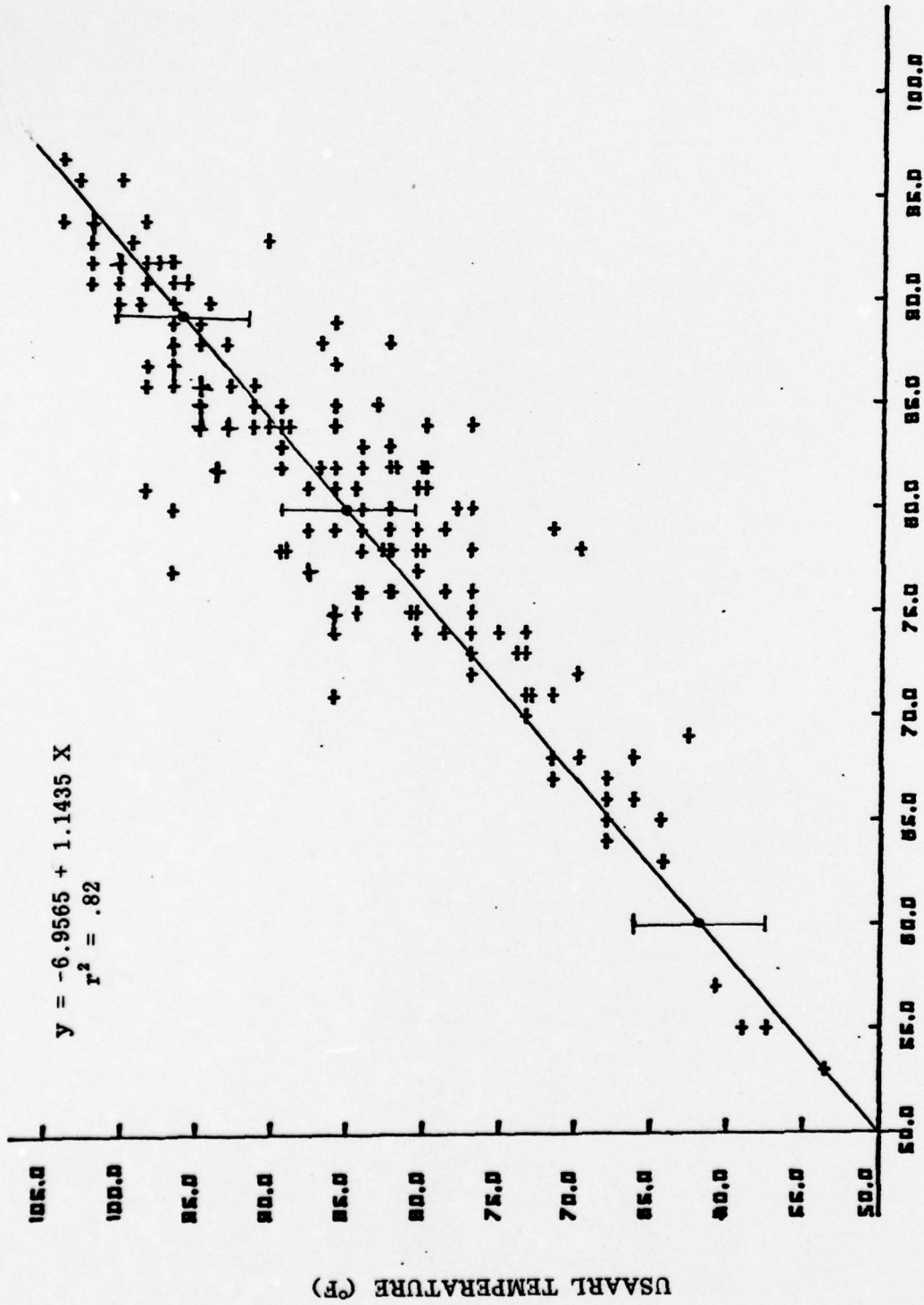
It is clear from experiments conducted at Rochester² that initial skin surface temperature is important in determining burn depth. In the USAARL study, pigs burned prior to 9/5/72 (i.e. about one half the pigs) did not have their skin temperatures measured at the time of exposure to the fire. Subsequent to 9/5/72 all skin surface temperatures were measured with a copper-constantan ribbon

thermocouple. The skin temperatures listed in the data base for the pigs burned during the summer of 1972 were extrapolated from a plot of ambient temperature vs. measured skin temperature using the data collected from September 5 to September 8, 1972. Unfortunately, only early a.m. and p.m. ambient temperatures were available to construct this graph. An analysis of this extrapolation procedure depended upon obtaining hourly temperatures and humidities from Cairns Army Airfield Weather Station, Fort Rucker, Alabama. The data were unavailable at Cairns Army Airfield but were finally found to be resident on microfiche at the United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Nashville, North Carolina. Complete hourly weather reports on microfiche were obtained for Cairns Army Airfield for the period July, 1972 through January, 1973. From these records the hourly temperatures and humidities were extracted for those days on which experiments were conducted. From this list of hourly temperatures, a linear regression analysis was run between those temperatures recorded at Cairns and the early a.m. and p.m. temperatures recorded at the USAARL vivarium. Figure 1 shows a plot of the USAARL temperatures vs. the temperatures recorded at Cairns Army Airfield at approximately the same time. Table 1 shows the results of the linear regression analysis with a correlation coefficient (R) of .90. The linear regression equation shows that temperatures at USAARL were slightly higher, on the average, than the temperatures at Cairns Army Airfield.

Considering the location of the vivarium and the terrain between Cairns Army Airfield and the USAARL burn facility, it is reasonable to expect that the temperatures at USAARL would be slightly higher on the average. Consider, for instance, the fact that the vivarium is placed between two buildings, which would attenuate any wind while Cairns Field, which is on relatively higher and more open terrain, would have quite different air mixing characteristics. The initial plan was to use this regression equation ($y = -6.9565 + 1.1435X$) to calculate the environmental temperatures at the lab at hours other than those recorded at the lab. Having thus obtained hourly temperatures, albeit calculated, at the laboratory site, we next proposed to investigate the relationship between the environmental temperature and the measured skin temperatures of the pigs. Using just the temperatures, the data, as seen in Figure 2, seems to indicate a much more complex relationship between environmental temperature and skin temperature than that proposed by Dr. Lum in the original extrapolation¹.

The investigation into possible underlying mechanisms which could account for the dispersion of the data continues. At this time it is too early to say whether the relationship between environmental temperature and skin temperature can be adequately defined. It will most probably be nonlinear. One approach would be to subject the data to multiple regression analysis including the humidity, and possibly wind velocity, as additional factors. The pigs would be expected to adopt various thermo-regulatory strategies depending on environmental factors such as temperature, humidity, and wind velocity. The fact that these pigs were under halothane anesthesia may have altered their normal response. As shown in earlier work at Rochester¹, the use of an anesthetic (chlorpromazine plus Dial in Urea-urethane) tends to allow skin temperature to fall in a cool room.

Investigation of the problem of predicting skin temperatures in anesthetized pigs when given environmental temperatures and humidities has begun and will include consideration of all possible physiological thermo-regulatory mechanisms.



CAIRNS AAF TEMPERATURE (°F)

Figure 1

TABLE 1

NAME: KNOX, TED ID# 32 DATE: 06-JUN-77 TIME: 13:32:40

CAIRNS AAF TEMPERATURES VS. USAARL TEMPERATURES

LINEAR REGRESSION, Y UPON X
RESULTS

STATISTIC	GROUP 1 (X)	GROUP 2 (Y)
SAMPLE SIZE	174	174
SUM	14024.	14827.
SUM OF SQUARES	0.11426E 07	0.12830E 07
MEAN	80.598	85.210
STANDARD ERROR OF MEAN	0.63849	0.80681
STANDARD DEVIATION	8.4223	10.643

SUM OF PRODUCTS = 0.12090E 07
 SLOPE COEFFICIENT = 1.1435
 INTERCEPT = -6.9565
 COEFFICIENT OF DETERMINATION (R**2) = 0.81898
 CORRELATION COEFFICIENT (R) = 0.90497

THE LINEAR REGRESSION EQUATION IS: Y = -6.9565 + 1.1435 X

STANDARD ERROR OF ESTIMATE = 4.5412
 ERROR VARIANCE = 20.622
 STANDARD DEVIATION OF SLOPE = 0.40993E-01
 DEGREES OF FREEDOM = 172

TEST STATISTIC, T = 27.896

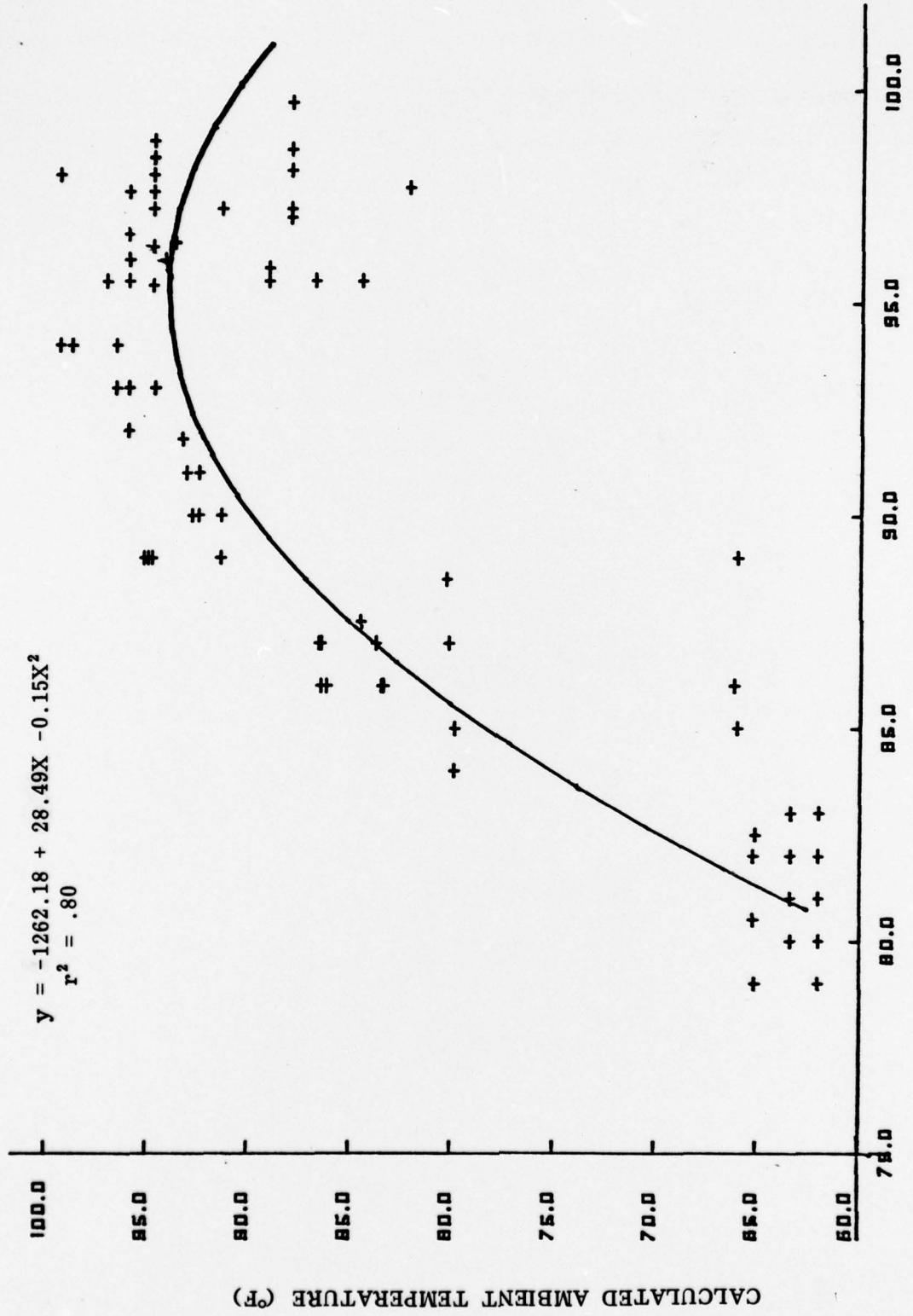


FIG SKIN TEMPERATURE (°F)

Figure 2

This investigation will continue but it is too early to tell whether the final result will be a more adequate formula for predicting the skin temperatures of the pigs burned prior to September 5 or whether it will be impossible to predict their skin temperatures with any degree of accuracy.

Another problem which was held over from Phase I revolves around the original digitized records which were found to be inadequate for further analysis. This inadequacy necessitated our redigitizing the entire experimental record. This redigitization was accomplished at Fort Rucker during February, 1977. The process of writing programs to access the data, to strip out the pertinent data from the total record and convert that data to appropriate engineering units is under way. The new temperatures and heat fluxes resulting from this process will be incorporated into the statistical (empirical) model begun last year. In addition to data recorded during the exposure of the pigs, there are also data on these tapes concerning the response of the Aerotherm and Fabric Research Lab sensors. These data will be accessible as soon as the programs to access the data are complete and will be analyzed when the data base is reasonably free of error.

The redigitized records are considerably cleaner than previous records as shown by the plots in Appendix A.

The primary problem encountered in writing the programs to access the data automatically has been that the multi-level calibration signal employed on a number of the channels was not consistent from channel to channel or from tape to tape. There were twelve voltage levels built into the step sequence but not all twelve are present on each of the records. The reason for this is that in setting the gain and bias levels of the recordings to accommodate the output signals from the various sensors, certain subsets of the calibration voltages were used at one time or another. The program, currently being developed, will look at the calibration voltage steps and check for the ratios between the steps in order to identify which steps are present on that record. Having identified the steps, it should be a relatively simple matter to extract the appropriate calibration voltage from a table.

An additional problem encountered was that the supplemental calibration signals on the tapes (which were introduced from a battery operated four-step voltage source) were not employed consistently and often during the experimentation. For instance, these records often appear at the end of the tape rather than at the beginning, and there appear to be some changes in the voltage level over time during the experiments. Finally, the four-step battery operated calibrator was not itself calibrated sufficiently often to give one confidence in most of the voltage levels. The data on the channel connected to the HyCal Asymptotic Calorimeter appear to be unusable, since for electrical reasons, only calibration voltages from the battery operated calibrator were introduced on the HyCal Calorimeter channel. For the present, the data from the other channels will be retrieved using the automatic step calibration source and the HyCal Calorimeter data will be ignored.

In those experiments conducted prior to 9/5/72 in which heat flux was recorded using the HyCal Calorimeter and wall temperature of the furnace was recorded using a Chromel-Alumel Thermocouple, the written records of heat flux can be cross-checked using a correlation between wall temperature and the heat flux from the slug calorimeter. This correlation will be calculated from data obtained after 9/5/72 and then heat fluxes will be back-calculated for the earlier

experiments based on recorded wall temperatures.

In summary, there remains work to be done to bring the data base to a usable state. This includes 1) better skin temperatures for the early pigs; 2) better heat flux data from the digitized tapes; 3) inclusion of additional water profile data; and 4) detection and elimination of erroneous values.

What follows will be a discussion of the work proceeding in Phase II to meet Phase II objectives. The reader will notice, however, that there is considerable overlap between the development which began in Phase I and is being continued in Phase II.

PHASE II TECHNICAL OBJECTIVE

Test empirical model (Phase I) and develop an analytical model to predict burn damage.

- 1) Obtain raw data from Rochester study and hopefully correct them for shrinkage.
- 2) Test empirical model against this data base.
- 3) Further optimize model to obtain best performance against USAARL and Rochester data basis.
- 4) Result - Draft paper describing final empirical model and submit for critique to project monitors and other workers from whom constructive criticism might be expected; revise draft and consider submission for publication.
- 5) Re-evaluate in parallel in 1-4 above the analytical models of Stoll^{3,4}, Mehta and Wong⁵, Morse et al (AEROTHERM)⁶ and Takata⁷, as to the assumptions made and the algorithms used.
- 6) Establish design criteria for an analytical model.
- 7) Review all data necessary for input to the model, e.g. skin absorptivity, diffusivity, conductivity, etc. to ascertain the underlying distributions and the 95% confidence limits associated with each.
- 8) Implement the model at L.S.U. and Louisiana Tech for initial development and de-bugging followed by further development on USAARL's computer.
- 9) Result - A preliminary analytical model which predicts burn damage from heat flux.

Rochester Data. In early November, Dr. Knox held meetings with Dr. Charles Yuile, Dr. Hinshaw, Dr. Kingsley, Dr. Bale, Dr. Adolph, and Mrs. Doris Nash, in Rochester, New York. The purpose of these meetings was to discuss the extensive set of experiments conducted at the University of Rochester in the 1950's and early 1960's on the effect of radiant energy on pig skin. Dr. Charles Yuile, now a consultant on this project and consulting pathologist at the University of Rochester, acted as host and guide. He had previously confirmed by phone that all of the biopsy slides from this project had been destroyed. However, it was further established, by Dr. Yuile, that the original tissue blocks were available and in storage. During the meetings it became apparent that the identification of the tissue blocks was going to be difficult, but that some 390-450 blocks could be identified with a pig number and an experiment and that the results of the experiments had been recorded in two University of Rochester reports, UR-338² and UR-553⁸. University of Rochester Report 338 entitled "Studies of Flash Burns: The Influence of Skin Temperature in the Production of Cutaneous Burns in Swine" is represented by the bulk of the biopsy material, while University of Rochester Report 553 entitled "A Theoretical and Experimental Investigation of Temperature Response of Pig Skin Exposed to Thermal Radiation" is represented by a relatively small number of biopsy specimens. However, the latter report, which constituted the major portion of Thomas P. Davis' Ph.D. thesis, includes pigs which had silver-palladium thermocouples implanted in the skin so direct measurements of skin temperature could be made. Fortunately this biopsy material was in relatively good condition and was collected towards the end of the Rochester study so that the experimental methods were well in hand. Further, the particular experiments on the influence of skin temperature in the production of burns and the temperature response of skin are important for the present study.

At Dr. Knox's request, Dr. Yuile had the biopsy specimens re-embedded and sectioned and has subsequently graded each of the over 400 specimens in a manner consistent with the re-grading of the material collected at USAARL. In addition, he has graded some 127 specimens from the USAARL data base as a way of checking the consistency of his grading procedure against the grading procedures carried out by Drs. McCormick and Duffy. Moreover, Dr. Yuile has made some observations concerning the variability of burns and these observations will be expanded into a short technical report later this summer. All in all, some 400 or more burns from the Rochester study in which a carbon arc-clamp was employed as the radiation source are ready to be added to the data base. Any observed differences in the burns resulting from the use of a pure radiation source as opposed to a fuel fire will be important in developing the equations coupling the thermal environment to the skin in the analytical model, which is under development.

Empirical Model. The development of the empirical model started in Phase I will be expanded as soon as the data on heat flux and sensor response can be recovered from the newly redigitized tapes.

The empirical model will help in detecting errors in the data base as discussed previously¹ and in establishing design criteria for a second generation analytical model. Three sources of skin thermal properties have been obtained^{3,8,9} and a MEDLARS search will be initiated shortly. Accurate thermal properties are essential for an analytical model.

Analytical Model Development. The analytical model developed at the end of Phase I and reported in the first annual progress report is now running on the Louisiana Tech computer facility and at the L.S.U. Medical Center PDP 11/40 (see Appendix B). This program calculates in-depth skin temperatures using the Crank-Nicholson differencing method but incorporates only the initial heating period. The subsequent cool-off period, damage rate and total damage calculations based on a first order chemical reaction model have now been added to the Louisiana Tech computer code under CSMP, an IBM simulation package. With some modification, this computer code should allow us to simulate the models of Stoll^{3,4}, Mehta and Wong⁵, Morse et al⁶, and Takata⁷, since they are all based on the use of first order kinetics to calculate damage from calculated in-depth tissue temperature. The primary difference among the models is the selection of coefficients and exponents in the first order damage calculations. Shortly this model will be converted to run on the PDP 11/40 so that the selection of heat flux, integration interval, exposure time, skin thermal characteristics, and the like, can be entered interactively via the terminal. Subsequently, a printer "plotting" module will be added to allow visualization of the tabular results. This interactive package will allow us to more easily re-evaluate the models based on this approach.

Tissue Shrinkage. One working hypothesis has been that if skin is subjected to a high thermal input it will shrink and that this shrinkage distorted earlier measurements of burn depth. Therefore, the biopsy material was reread and depth measurement recorded to allow correction for this shrinkage. The question arises whether, in fact, there was shrinkage. An analysis was conducted in which the ratio of corrected depth to uncorrected depth was calculated for each of the 16 gross grade levels. These results, see Table 2, show that there is slight shrinkage at the low end of the scale followed by slight swelling of the tissue at moderate burn levels and fairly severe shrinkage, up to 46%, at high levels of damage. Clearly, the models based on uncorrected depth would tend to underestimate the depth of dermal damage by as much as 40-50%. The slight swelling seen in the middle level burns is evident on examination of the biopsy specimens. At this level the tissue is damaged enough to result in edema, but not so severely damaged as to have the tissue water boiled off or have the microcirculation in the upper dermal appendages compromised. Attempts to show that the regression lines for relating total flux and depth of burn were improved by correcting the depths indicate that although there is only slight improvement at the exposure times of 1, 5 and 7 seconds, the addition of depth correction did not degrade the sensitivity of the regression calculation in most cases, see Table 3 for results. It would appear, then, that while correction for shrinkage does not markedly improve the scatter of the data, corrections may still be necessary because of marked tissue shrinkage at the more severe burn levels. This correction may be especially important in the analytical model.

Sensor Experiment. In late December, 1972, sensors were exposed to the furnace, both with and without fabric between the sensor and the fire, in a study to determine their performance. At the present time there appears not to have been an FM tape recording made of these data. Thus, in order to use these data, the stripcharts will have to be digitized. A digitizing device using the A

TABLE 2

<u>Gross Grade</u>	<u>N</u>	<u>Depth</u>	<u>Corr. Depth</u>	<u>Corr. Depth Depth</u>
1	5	67.5	74.2	1.10
2	5	97.5	104.5	1.07
3	4	78.1	82.4	1.06
4	1	37.5	43.3	1.15
5	7	355.4	385.9	1.09
6	21	67.9	66.6	.98
7	16	135.9	131.1	.96
8	24	147.9	144.9	.98
9	129	320.8	312.1	.97
10	146	550.9	549.5	1.00
11	30	486.3	544.9	1.12
12	74	670.6	871.3	1.30
13	56	691.3	957.4	1.38
14	41	784.2	1148.6	1.46
15	67	901.3	1180.7	1.31
16	2	537.5	754.0	1.40

TABLE 3

Exposure Time (Sec)	N	Total Flux	Depth		a	SE(b)	t
			Depth	Corr. Depth			
1	75	3.08	346.5	133.2	-63.2	23.9	5.58
			379.9	161.8	-117.8	26.7	6.06
3	94	7.91	585.2	76.4	-18.8	15.0	5.10
			818.4	122.4	-148.9	24.1	5.07
5	65	13.12	845.8	50.9	178.4	12.3	4.13
			981.5	64.7	-133.0	14.7	4.40
7	9	16.63	1016.7	45.9	253.6	15.9	2.89
			1448.0	101.4	-238.1	21.2	4.78
9	17	15.97	739.0	16.6	1004.6	19.9	-.84
			1008.7	12.0	1200.3	27.4	-.44
260							
All	260	8.65	606.5	43.4	231.0	4.2	10.4
			766.9	59.8	249.6	5.6	10.7

Regression Analysis showing the effect of correcting the burn depth. e.g. at 1 second exposure the "t" statistic improved with depth correction from 5.58 to 6.06.

to D capabilities of our PDP 11/40 is being constructed to extract the data from stripchart records. The calibration voltages for this set of data have been located and the conversion from millimeters to microvolts is known. These data will be extracted from the stripchart records when the digitizer is operational. The remaining sensor data collected during the course of this study, are in the digitized records which can be retrieved as soon as the data recovery programs are finished but correlations with burn data should be made only when the data base is in its final state.

WORK REMAINING TO BE COMPLETED IN PHASE II

- 1) The data obtained from the Rochester study need to be entered into the computer data file and compared with comparable data from the USAARL study.
- 2) The heat fluxes must be extracted from the digitized data and added to the data base.
- 3) Corrected skin temperatures must be added to the data base, if possible.
- 4) The analytical model currently running on the Louisiana Tech University computer and the Department PDP 11/40 must be expanded and made interactive to facilitate a re-evaluation of the analytical models of Stoll^{3,4}, Mehta and Wong⁵, Morse et al⁶, and Takata⁷.
- 5) The tissue water profile must be recalculated using data collected late in the experiments. (A literature search is being conducted at this time to provide additional information on this topic.)
- 6) The empirical model must be re-evaluated using the new skin temperatures and heat fluxes and both the empirical and analytical models must be optimized using the Rochester data base as a test set.

SUMMARY AND PROBLEMS

There are a number of tasks being pursued in parallel at the present time. With the addition of the data base of water profile information, skin temperature information, and heat flux information from the digitized records, the remainder of Phase II will proceed rapidly to a conclusion. The problem of extracting data from the digitized records appears to be the most difficult and was delayed some three or four months by a delay in contract funding. Progress was made during the period 1 October through 30 January, primarily in the area of obtaining pathology data from the University of Rochester studies. Since the signing of the contract, work has proceeded normally. Accomplishment of the technical objective for Phase II is expected by 30 September 1977. After a somewhat slow start then, the project is on the track and all tasks under the Phase II objective should be completed on time.

LITERATURE CITED

1. F. S. Knox III, Ransom Nockton. Data Analysis and Mathematical Modeling Based on U. S. Army Aeromedical Research Laboratories Experimental Porcine Burn - Phase I Data Annual Report 1 July 1975 - 30 September 1976 under Contract DABT01-75-C-0257.
2. Berkley, K. M., H. E. Pearse and T. P. Davis. Studies of Flash Burns: The Influence of Skin Temperature in the Production of Cutaneous Burns in Swine. University of Rochester Report UR-338. August 1954, pp. 1-60.
3. Stoll, A. M. and Greene, L. C. Relationship between Pain and Tissue Damage Due to Thermal Radiation, J. Appl. Physiol. 14:373-382, 1959.
4. Weaver, J. A. and A. M. Stoll. Mathematical Model of Skin Exposed to Thermal Radiation. Aerospace Med. 40(1):24-30, 1969.
5. Mehta, A. K. and F. Wong. Measurement of Flammability and Burn Potential of Fabrics, Fuels Research Laboratory M.I.T. Summary Report DSR 73884, February 15, 1973.
6. Morse, H. et al. Analysis of the Thermal Response of Protective Fabrics Tech Report AFML-TR-73-17, Jan., 1973.
7. Takata, A. N. Development of Criterion for Skin Burns, Aerospace Med. 45(6):634-637, 1974.
8. Davis, Thomas P. A Theoretical and Experimental Investigation of the Temperature Response of Pig Skin Exposed to Thermal Radiation. AEC Rad D Report, University of Rochester UR-553, August, 1959, 262 pages.
9. Bowman, H. Frederick, Ernest G. Cravalho and Monty Woods. Theory, Measurement, and Application of Thermal Properties of Biomaterials, in Annual Review of Biophysics and Bioengineering, Vol. 4, 1975, pp. 43-80.

APPENDIX A

Original and Redigitized Records

Showing Improvements

ORIGINAL



ORIGINAL CONTINUED



REDIGITIZED

(19)

SLUG CALORIMETER

CONTROL CHANNEL

CLOCK CHANNEL



REDIGITIZED CONTINUED

(20)



APPENDIX B

Analytical Model - Program Listings and Results.

- 1) JOB - BIOMO34T; La. Tech. Univ.; Calculation of In-Depth Temperatures for a $3 \text{ CAL}\cdot\text{CM}^{-2}\cdot\text{SEC}^{-1}$ Fire ($150 \text{ CAL}\cdot\text{CM}^{-3}\cdot\text{SEC}^{-1}$) With No Cooling. Plot of Temp. vs. Depth.
- 2) The same program with minor changes in skin parameters as it compiled and run on the PDP 11/40.
- 3) JOB-OYYNO26T; La. Tech Univ.; Analytical Model Running Under CSMP including cooling, damage rate $\frac{dw}{dt} = DW$ and total damage (W) at the skin surface. Plots of 1) Temp, DW and W as a function of time; 2) Temp. as a function of Depth from Skin Surface at various times; 3) Temp. as a function of time at various depths.


```

3JOB      RENEAU,KP=29,TIME=30
1  DIMENSION(T(250),E(250),G(250),H(250),Z(250),J(250),U(250))
2  DIMENSION(SV(250),M(250),CP(250),BK(250))
3  READ(5,901)TEMPIO,DENS,Q1,BL,AK
4  READ(5,904)JINC,JTIME
5  901  FORMAT(6F10.5)
6  904  FORMAT(2I10)
7  READ(5,902)(CP(J),J=1,JINC)
8  READ(5,903)(BK(J),J=1,JINC)
9  902  FORMAT(7F10.5)
10 903  FORMAT(7F10.5)
11  AJ=JINC
12  HI=BL/(AJ-1.0)
13  DO6J=1,JINC
14  6  T(J)=TEMPIO
15  WRITE(6,910)
16  910  FORMAT(1H1,52X,'SKIN DIFFUSION DATA',52X,'INPUT PARAMETER LIST',/)
17  WRITE(6,911)TEMPIO,DENS,Q1,BL,AK,JINC,JTIME
18  911  FORMAT(1X,53X,8H TEMPIO=,E16.8/54X,5H DENS=,E16.8/54X,3H Q1=,E16.8/
19  154X,3H BL=,E16.8/54X,3H AK=,E16.8/54X,5H JINC=,E16.8/54X,6H JTIME=,E16.8/54X,
20  JJJ=0
21  F(1)=-BK(2)/(2.0*HI*HI)-BK(1)/(2.0*HI*HI)
22  G(1)=[BK(1)+BK(2)]/(2.0*HI*HI)*DENS*CP(1)/AK
23  H(1)=0.0
24  M=1
25  11 Z(1)=-F(1)*I(2)-([BK(1)+BK(2)]/(2.0*HI*HI)-(DENS*CP(1)/AK))*T(1)
26  1*Q1
25  N=JINC-1
26  DO10J=2,N
27  F(J)=-BK(J+1)/(2.0*HI*HI)
28  G(J)=[BK(J)+BK(J+1)]/(2.0*HI*HI)+DENS*CP(J)/AK
29  H(J)=-[BK(J)]/(2.0*HI*HI)
30  10 Z(J)=-F(J)*T(J+1)-([BK(J)+BK(J+1)]/(2.0*HI*HI)-DENS*CP(J)/AK)*T(J)
31  1-H(J)*T(J)-1)
32  F(JINC)=0.0
33  G(JINC)=[BK(JINC)+BK(JINC-1)]/(2.0*HI*HI)+DENS*CP(JINC)/AK
34  H(JINC)=-[BK(JINC)+BK(JINC-1)]/(2.0*HI*HI)
35  Z(JINC)=-([BK(JINC)+BK(JINC-1)]/(2.0*HI*HI)-(DENS*CP(JINC)/AK))*T(
36  JINC)-H(JINC)*T(JINC-1)
37  M(1)=G(1)
38  U(1)=Z(1)/M(1)
39  DO40J=2,JINC
40  JM1=J-1
41  SV(JM1)=F(JM1)/M(JM1)
42  H(J)=G(J)-H(J)*SV(JM1)
43  U(J)=(Z(J)-H(J)*U(JM1))/M(J)
44  T(JINC)=U(JINC)
45  KK=JINC-1
46  DO50J=1,KK
47  KMJ=JINC-J
48  T(KMJ)=U(KMJ)-SV(KMJ)*T(KMJ+1)
49  50  JJJ=JJJ+1
50  TIME=JJJ*AK
51  IF(JJJ.EQ.M*1001.GO TO 1Z
52  GO TO 11
53  1Z  WRITE(6,901)TIME
54  801  FORMAT(1X,53X,5HTIME=,F10.6)
55  WRITE(6,914)(T(J),CP(J),BK(J),J=1,JINC)
56  914  FORMAT(2X,'T=',F20.5,2X,'CP=',F20.5,2X,'BK=',F20.5,
57  M=M+1

```

42.

36 IF(M.EQ.11) GO TO 100
57 GO TO 11
58 100 STOP
59 END

SENTRY

52

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMP10= 0.32500000E 02
DENS= 0.10000000E 01
G1= 0.15000000E 03
BL= 0.19999900E 00
AK= 0.10000000E 01
JINC= 10
JTIME= 1000

TIME= 1.000000

T=	105.23230	CP=	1.00000	BK=	0.00055
T=	60.49109	CP=	1.00000	BK=	0.00065
T=	41.97743	CP=	1.00000	BK=	0.00075
T=	35.51010	CP=	1.00000	BK=	0.00090
T=	33.44914	CP=	1.00000	BK=	0.00110
T=	32.79047	CP=	1.00000	BK=	0.00125
T=	32.58453	CP=	1.00000	BK=	0.00135
T=	32.52220	CP=	1.00000	BK=	0.00138
T=	32.50542	CP=	1.00000	BK=	0.00140
T=	32.50212	CP=	0.50000	BK=	0.00040

TIME= 2.000000

T=	138.05600	CP=	1.00000	BK=	0.00055
T=	87.46121	CP=	1.00000	BK=	0.00065
T=	59.21147	CP=	1.00000	BK=	0.00075
T=	48.08310	CP=	1.00000	BK=	0.00090
T=	38.47607	CP=	1.00000	BK=	0.00110
T=	35.30952	CP=	1.00000	BK=	0.00125
T=	33.79741	CP=	1.00000	BK=	0.00135
T=	33.09074	CP=	1.00000	BK=	0.00138
T=	32.80992	CP=	1.00000	BK=	0.00140
T=	32.72934	CP=	0.50000	BK=	0.00040

TIME= 3.000000

T=	161.83630	CP=	1.00000	BK=	0.00055
T=	108.81080	CP=	1.00000	BK=	0.00065
T=	75.61357	CP=	1.00000	BK=	0.00075
T=	56.51752	CP=	1.00000	BK=	0.00090
T=	46.10341	CP=	1.00000	BK=	0.00110
T=	40.22231	CP=	1.00000	BK=	0.00125
T=	36.89119	CP=	1.00000	BK=	0.00135
T=	35.05223	CP=	1.00000	BK=	0.00138
T=	34.21620	CP=	1.00000	BK=	0.00140
T=	33.94997	CP=	0.50000	BK=	0.00040

TIME= 4.000000

T=	181.13520	CP=	1.00000	BK=	0.00055
T=	126.70110	CP=	1.00000	BK=	0.00065
T=	90.45967	CP=	1.00000	BK=	0.00075
T=	68.01793	CP=	1.00000	BK=	0.00090
T=	54.75513	CP=	1.00000	BK=	0.00110
T=	46.60541	CP=	1.00000	BK=	0.00125
T=	41.58542	CP=	1.00000	BK=	0.00135
T=	38.59229	CP=	1.00000	BK=	0.00138
T=	37.15021	CP=	1.00000	BK=	0.00140
T=	36.67099	CP=	0.50000	BK=	0.00040

TIME= 5.000000

T=	197.65200	CP=	1.00000	BK=	0.00055
T=	142.28700	CP=	1.00000	BK=	0.00065

T=	103.97690	CP=	1.00000	BK=	0.00075
T=	79.17052	CP=	1.00000	BK=	0.00050
T=	63.79472	CP=	1.00000	BK=	0.00110
T=	53.87827	CP=	1.00000	BK=	0.00125
T=	47.47980	CP=	1.00000	BK=	0.00135
T=	43.50800	CP=	1.00000	BK=	0.00138
T=	41.53944	CP=	1.00000	BK=	0.00140
T=	40.87202	CP=	0.50000	BK=	0.00040
TIME= 6.000001					
T=	212.26800	CP=	1.00000	BK=	0.00055
T=	156.24760	CP=	1.00000	BK=	0.00065
T=	116.46640	CP=	1.00000	BK=	0.00075
T=	89.93794	CP=	1.00000	BK=	0.00090
T=	72.99091	CP=	1.00000	BK=	0.00110
T=	61.73143	CP=	1.00000	BK=	0.00125
T=	54.26392	CP=	1.00000	BK=	0.00135
T=	49.51934	CP=	1.00000	BK=	0.00138
T=	47.12949	CP=	1.00000	BK=	0.00140
T=	46.31056	CP=	0.50000	BK=	0.00040
TIME= 7.000001					
T=	225.52370	CP=	1.00000	BK=	0.00055
T=	169.02770	CP=	1.00000	BK=	0.00065
T=	128.17110	CP=	1.00000	BK=	0.00075
T=	100.37440	CP=	1.00000	BK=	0.00090
T=	82.25777	CP=	1.00000	BK=	0.00110
T=	69.98824	CP=	1.00000	BK=	0.00125
T=	61.70993	CP=	1.00000	BK=	0.00135
T=	56.37576	CP=	1.00000	BK=	0.00138
T=	53.65260	CP=	1.00000	BK=	0.00140
T=	52.72649	CP=	0.50000	BK=	0.00040
TIME= 8.000001					
T=	237.78460	CP=	1.00000	BK=	0.00055
T=	180.93830	CP=	1.00000	BK=	0.00065
T=	139.28720	CP=	1.00000	BK=	0.00075
T=	110.55050	CP=	1.00000	BK=	0.00090
T=	91.56192	CP=	1.00000	BK=	0.00110
T=	78.53607	CP=	1.00000	BK=	0.00125
T=	69.64632	CP=	1.00000	BK=	0.00135
T=	63.86949	CP=	1.00000	BK=	0.00138
T=	60.91187	CP=	1.00000	BK=	0.00140
T=	59.86737	CP=	0.50000	BK=	0.00040
TIME= 9.000001					
T=	249.30990	CP=	1.00000	BK=	0.00055
T=	192.20420	CP=	1.00000	BK=	0.00065
T=	149.96310	CP=	1.00000	BK=	0.00075
T=	120.52690	CP=	1.00000	BK=	0.00090
T=	100.88950	CP=	1.00000	BK=	0.00110
T=	87.29767	CP=	1.00000	BK=	0.00125
T=	77.55367	CP=	1.00000	BK=	0.00135
T=	71.84140	CP=	1.00000	BK=	0.00138
T=	68.70078	CP=	1.00000	BK=	0.00140
T=	67.60971	CP=	0.50000	BK=	0.00040
TIME= 10.000001					
T=	260.26410	CP=	1.00000	BK=	0.00055
T=	202.98940	CP=	1.00000	BK=	0.00065
T=	160.31010	CP=	1.00000	BK=	0.00075
T=	130.35290	CP=	1.00000	BK=	0.00090
T=	110.22980	CP=	1.00000	BK=	0.00110
T=	96.21748	CP=	1.00000	BK=	0.00125
T=	86.53262	CP=	1.00000	BK=	0.00135

10

T=	80.17122	CP=	1.00000	BK=	0.00138
T=	76.89351	CP=	1.00000	BK=	0.00140
T=	79.75278	CP=	0.50000	BK=	0.00040

CORE USAGE OBJECT CODE= 4000 BYTES,ARRAY AREA= 10000 BYTES,TOTAL AREA AVAILABLE= 108160 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0, NUMBER OF EXTENSIONS= 0

COMPILE TIME= 0.70 SEC,EXECUTION TIME= 24.22 SEC, MATFIV - JUL 1973 VIL4 19.52.15 FRIDAY 4 MAR 77

FORTRAN IV MON 13-JUN-77 19:43:24 PAGE 001
CORE=08K, UIC=C120.17 SKINSIM,SY=SKINSIM

```

0001 DIMENSIONT(250),F(250),G(250),H(250),Z(250),U(250)
0002 DIMENSIONSV(250),W(250),CP(250),BK(250)
0003 CALL ASSIGN(1,'SKINSIM,DAT')
0004 READ(1,901)TEMP10,DENS,OL,BL,AK
0005 READ(1,904)JINC,JTIME
0006 901 FORMAT(6F10.5)
0007 904 FORMAT(2I10)
0008 READ(1,902)(CP(J),J=1,JINC)
0009 READ(1,903)(BK(J),J=1,JINC)
0010 902 FORMAT(7F10.5)
0011 903 FORMAT(7F10.5)
0012 AJ=JINC
0013 H1=BL/(AJ-1.0)
0014 DO6J=1,JINC
0015 T(J)=TEMP10
0016 6 WRITE(6,910)
0017 910 FORMAT(1H1,55X,'SKIN DIFFUSION DATA',55X,'INPUT PARAMETER LIST',/)
0018 911 WRITE(6,911)TEMP10,DENS,OL,BL,AK,JINC,JTIME
0019 911 FORMAT(1X,53X,6H,TEMP10=.E16.8/54X,5HDENS=.E16.8/54X,3HOL=.E16.8/
0020 154X,3HBL=.E16.8/54X,3HAK=.E16.8/54X,5HJINC=.E16.8/54X,6HJTIME=.E16.8/54X)
0021 JJJ=0
0022 F(1)=-BK(2)/(2.0*H1*H1)-BK(1)/(2.0*H1*H1)
0023 G(1)=(BK(1)+BK(2))/(2.0*H1*H1)+DENS*CP(1)/AK
0024 H(1)=0.0
0025 M=1
0026 11 Z(1)=-F(1)*T(2)-((BK(1)+BK(2))/(2.0*H1*H1)-(DENS*CP(1)/AK))*T(1)
0027 I=0
0028 N=JINC-1
0029 DO10J=2,N
0030 F(J)=-BK(J+1)/(2.0*H1*H1)
0031 G(J)=(BK(J)+BK(J+1))/(2.0*H1*H1)+DENS*CP(J)/AK
0032 H(J)=-BK(J)/(2.0*H1*H1)
0033 Z(J)=-F(J)*T(J+1)-((BK(J)+BK(J+1))/(2.0*H1*H1)-DENS*CP(J)/AK)*T(J)
0034 1-H(J)*T(J-1)
0035 F(JINC)=0
0036 G(JINC)=(BK(JINC)+BK(JINC-1))/(2.0*H1*H1)+DENS*CP(JINC)/AK
0037 H(JINC)=-((BK(JINC)+BK(JINC-1))/(2.0*H1*H1)
0038 Z(JINC)=-((BK(JINC)+BK(JINC-1))/(2.0*H1*H1)
0039 1-JINC)-H(JINC)*T(JINC-1)
0040 W(1)=G(1)
0041 U(1)=Z(1)/H(1)
0042 DO40J=2,JINC
0043 JMI=J-1
0044 SV(JMI)=F(JMI)/H(JMI)
0045 W(J)=G(J)-H(J)*SV(JMI)
0046 U(J)=(Z(J)-H(J)*U(JMI))/W(J)
0047 T(JINC)=U(JINC)
0048 KK=JINC-1
0049 DO50J=1,KK
0050 KPO=JINC-J
0051 T(KPO)=U(KPO)-SV(KPO)*T(KPO+1)
0052 JJJ=JJJ+1
0053 TIME=JJJ*AK
0054 IF(JJJ.EQ.M*100) GO TO 12
0055 GO TO 11
0056 12 WRITE(6,801)TIME

```

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FORTRAN IV      V01B-02      MON 13-JUN-77 18:43:24      PAGE 002
CORE-00K. UIC-C120.1J      SKINSIM.SY=SKINSIM

0054      801  FORMAT(1X,53X,5HTIME=,F10.6)
0055      WRITE(6,514)(I(J),CP(J),BK(J),J=1,JINC)
0056      514  FORMAT(2X,'I=',F20.5,2X,'CP=',F20.5,2X,'BK=',F20.5)
0057      M=H+1
0058      IF(M.EQ.11) GO TO 100
0059      GO TO 11
0060      100  STOP
0061      END
0062

```

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

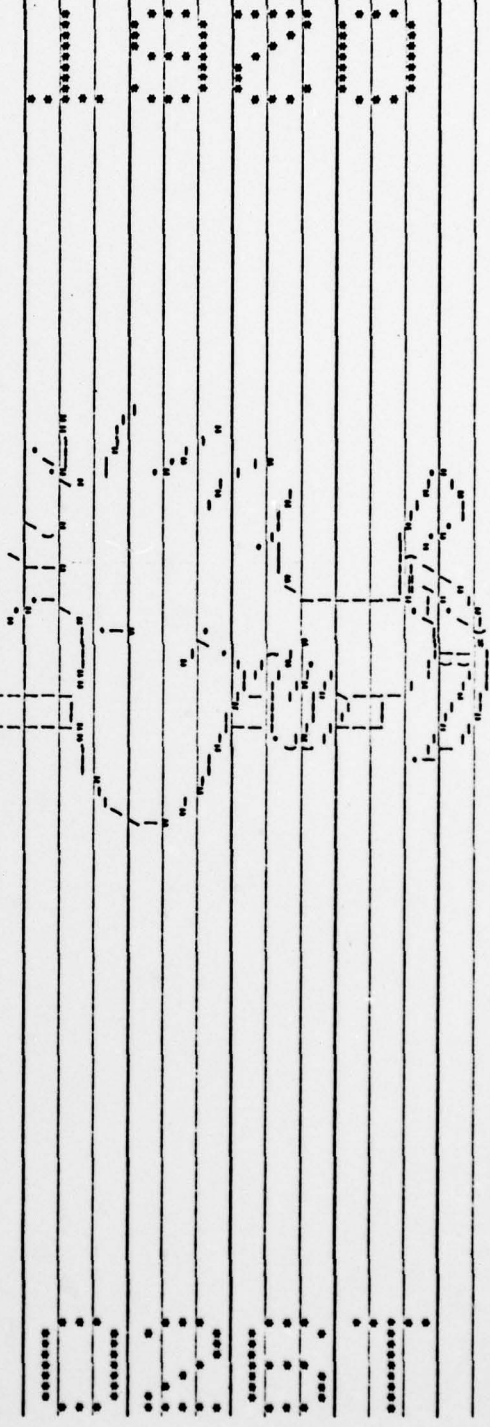
TEMP10= 0.3250000E 02
DENS= 0.1000000E 01
Q1= 0.1500000E 03
R1= 0.2000000E 00
AK= 0.9999999E-02
JINC= 10
JTIME= 1000

TIME	CP	BK
185.23706	CP=	BK=
60.49641	CP=	1.00000
41.90005	CP=	1.00000
35.51235	CP=	1.00000
33.45120	CP=	1.00000
32.79230	CP=	1.00000
32.58630	CP=	1.00000
32.52402	CP=	1.00000
32.50731	CP=	1.00000
32.50386	CP=	0.50000
139.06856	CP=	1.00000
87.47366	CP=	1.00000
59.22236	CP=	1.00000
45.09154	CP=	1.00000
38.48173	CP=	1.00000
35.31398	CP=	1.00000
33.80133	CP=	1.00000
33.09455	CP=	1.00000
32.81379	CP=	1.00000
32.73308	CP=	0.50000
161.05635	CP=	1.00000
108.85046	CP=	1.00000
73.63177	CP=	1.00000
56.58339	CP=	1.00000
46.11629	CP=	1.00000
40.23155	CP=	1.00000
36.05047	CP=	1.00000
35.07069	CP=	1.00000
34.22241	CP=	0.50000
33.95599	CP=	1.00000
181.16206	CP=	1.00000
126.72038	CP=	1.00000
90.48514	CP=	1.00000
68.00060	CP=	1.00000
54.75507	CP=	1.00000
46.62231	CP=	1.00000
41.55800	CP=	1.00000
38.60324	CP=	1.00000
37.10022	CP=	1.00000
36.60057	CP=	0.50000
197.68718	CP=	1.00000
142.32173	CP=	1.00000
104.01218	CP=	1.00000
79.26123	CP=	1.00000
63.82272	CP=	1.00000
53.90331	CP=	1.00000
47.50198	CP=	1.00000
47.50142	CP=	1.00000

AAAAAAAA JOB - DYN026T PRINT DATE - 05/18/77 PRINT TIME - 22.30.27 AAAAAAAAA

CCCCCCCC	YY	YY	YY	NN	NN	00000000	22222222	66666666	TTTTTTTT
CCCCCCCC	YY	YY	YY	NN	NN	00000000	22222222	66666666	TTTTTTTT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CC	YY	YY	YY	NN	NN	00	22	66	TT
CCCCCCCC	YY	YY	YY	NN	NN	00000000	22222222	66666666	TTTTTTTT
CCCCCCCC	YY	YY	YY	NN	NN	00000000	22222222	66666666	TTTTTTTT

LOUISIANA TECH UNIVERSITY
COMPUTING CENTER



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FORTRAN IV G LEVEL 21      BLK DATA      DATE = 77138      21/25/73      PAGE 0001
0001      BLCCK DATA      CSMPECK
0002      COMMON/ZZFOAT/( 80)      CSMPECK
1 /ZZHIST/KEEP,*,ALARM,IZ0000,IZ0001,H( 6)      CSMPECK
2 /ZZISTO/I( 30)      CSMPECK
0003      COMMON/ZZPOIN/PI(16)      CSMPECK
0004      INTEGER NP/ 1, 10, 15, 18, 19, 21, 21CSMPECK
1, 20, 26, 6, 2, 80, 0, 1, 1/      CSMPECK
0005      COMMON/ZZSYMB/S11( 15)      CSMPECK
0006      REAL*8 S11/      CSMPECK
1,*,TIMEDELT,*,ZDELT,*,DELFINZ,*,DELFINFINT,*,IMZZFINT,*,PROEL ZZ,*,CSMPECK
1,*,PROEOUTD,*,ELZCUTC,*,DELMAXZ,*,DELXW ,*,DN ,*,IC FU,*,CSMPECK
1,*,N DHLO,*,G TEMP ,      CSMPECK
1/      CSMPECK
0007      END      CSMPECK

```

PAGE 0002

21/25/23

DATE = 77138

BLK DATA

FORTAN IV G LEVEL 21

OPTIONS IN EFFECT ID=EBODIC SOURCE=NOLIST,NODECK,LCAD,NOMAP
OPTIONS IN EFFECT NAME = BLK DATA, LINECNT = 58
STATISTICS NO. DIAGNOSTICS GENERATED

50

```

FORTRAN IV G LEVEL 21          UPDATE          DATE = 77138          21/25/73          PAGE 0001
0001      SUBROUTINE UPDATE          CSMPECK
0002      COMMON TIME          CSMPECK
0003      1,ZZ000,DELTA,ZZDELTA,ZZDELN,ZZDELN,FINTIM,ZZFINT,PROEL,ZZPROE          CSMPECK
0004      1,OLTDDEL,ZZOUTD,DELTA,X,ZZDELX,M,CM,IC,FUN,DMLOG          CSMPECK
0005      1,TEMP          CSMPECK
0006      COMMON/ZZMIST/KEEP,NALARM,IZ0000,IZ0001          CSMPECK
0007      REAL IC          CSMPECK
0008      REAL*8 ZTIME          CSMPECK
0009      EQUIVALENCE(ZTIME,TIME)          CSMPECK
0010      GC TO(39995,39996,39997,39998),IZ0000          CSMPECK
0011      C SYSTEM SEGMENT CF MODEL          CSMPECK
0012      39995 CONTINUE          CSMPECK
0013      GC TO 39999          CSMPECK
0014      C INITIAL SEGMENT CF MODEL          CSMPECK
0015      39996 CONTINUE          CSMPECK
0016      GC TO 39999          CSMPECK
0017      C DYNAMIC SEGMENT CF MODEL          CSMPECK
0018      39997 CONTINUE          CSMPECK
0019      IC=0          CSMPECK
0020      TEMP=AFGEN(1,FUN,TIME)          CSMPECK
0021      DALCG=226.78474-75000./(273.+TEMP)          CSMPECK
0022      DM=EXP(DMLOG)          CSMPECK
0023      W=INTGRL((IC,DM))          CSMPECK
0024      GC TO 39999          CSMPECK
0025      C TERMINAL SEGMENT CF MODEL          CSMPECK
0026      39998 CONTINUE          CSMPECK
0027      39999 RETURN          CSMPECK
0028      END          CSMPECK

```

FORTRAN IV G LEVEL 21 UPDATE DATE = 77138 21/25/73 PAGE 0002

OPTIONS IN EFFECT ID,EBDC, SOURCE,NOLIST, NODECK,LCAD,NOMAP

OPTIONS IN EFFECT NAME = UPDATE LINECT = 58

STATISTICS SOURCE STATEMENTS = 21, PROGRAM SIZE = 482

STATISTICS NO DIAGNOSTICS GENERATED

STATISTICS NO DIAGNOSTICS THIS STEP 2

\$\$\$ CONTINUOUS SYSTEM MODELING PROGRAM III V1P2 EXECUTION OUTPUT \$\$\$

FUNCTION FUN=(0.,32.50),(1.,105.24),(2.,138.07),(3.,161.86),...
(4.,181.16),(5.,197.69),(6.,139.99),(7.,120.28),(8.,108.70),...
(9.,100.89),(10.,95.33)
TIMER FINTIM=11.
OUTPUT W,DM,TEMP
END

TIMER VARIABLES RKS INTEGRATION START TIME = 0.0 DELMAX
DELT DELMIN FINTIM PROEL OUTCEL 0.11000
6.87500E-03 1.10000E-06 11.000 0.0 0.11000 0.11000
*** INPUT TO FUNCTION FUN ABOVE INPUT DATA CURVE NO. 1 CALL 1 INPUT= 10.010 AT 10.010
\$\$\$ SIMULATION HALTED FOR FINISH CONDITION TIME 11.000

OUTPUT VARIABLE RANGES FOR ALL RUNS IN CASE

VARIABLE	MINIMUM	MAXIMUM	VARIABLE	MINIMUM	MAXIMUM
TIME	0.0	11.0000	W	0.0	4.432482E 28
DM	7.454566E-09	1.475307E 29	TEMP	32.5000	196.863

sf=0 @ t=5 sec.
At skin surface

$\frac{dw}{dt}$

TIME	W	0.0	0.0	0.0	200.0	DW	TEMP
0.11000	7.01417E-08	*	X		1.600CE 29	7.45451E-09	32.500
0.22000	2.89444E-05	*	X		6.0000E 29	3.92252E-08	40.501
0.33000	8.60566E-03	*	X			1.51126E-03	48.503
0.44000	1.9902	*	X			6.43605	56.504
0.55000	358.21	*	X			96.164	64.506
0.66000	51020.	*	X			16520.	72.507
0.77000	5.84036E 06	*	X			2.24820E 06	80.508
0.88000	5.44997E 08	*	X			2.46151E 08	88.510
0.99000	4.19997E 10	*	X			2.15884E 10	96.511
1.1000	6.91959E 11	*	X			1.62381E 12	104.51
1.2100	4.86233E 12	*	X			1.31069E 13	108.52
1.3200	3.06295E 13	*	X			8.27904E 13	112.13
1.4300	1.8959E 14	*	X			5.05407E 14	115.75
1.5400	1.07508E 15	*	X			2.98430E 15	119.39
1.6500	6.06334E 15	*	X			1.70598E 16	122.97
1.7600	3.1601E 16	*	X			9.44967E 16	126.58
1.8700	1.7582E 17	*	X			5.07627E 17	130.19
1.9800	9.07058E 17	*	X			2.64674E 18	133.80
2.0900	3.90961E 18	*	X			1.34046E 19	137.41
2.2000	1.34132E 19	*	X			4.61936E 19	140.21
2.3100	4.29440E 19	*	X			1.44765E 20	142.83
2.4200	1.33421E 20	*	X			4.47244E 20	145.44
2.5300	4.0812E 20	*	X			1.36250E 21	148.06
2.6400	1.2117E 21	*	X			4.09356E 21	150.68
2.7500	3.61871E 21	*	X			1.21353E 22	153.30
2.8600	1.0571E 22	*	X			3.55003E 22	155.91
2.9700	3.05144E 22	*	X			1.02511E 23	158.53
3.0800	8.4444E 22	*	X			2.92248E 23	161.15
3.1900	2.06098E 23	*	X			7.14272E 23	163.40
3.3000	4.86668E 23	*	X			1.64139E 24	165.53
3.4100	1.12338E 24	*	X			3.74172E 24	167.65
3.5200	2.55706E 24	*	X			8.46252E 24	169.77
3.6300	5.76019E 24	*	X			1.89893E 25	171.90
3.7400	1.28629E 25	*	X			4.22887E 25	174.02
3.8500	2.8444E 25	*	X			9.34643E 25	176.14
3.9600	6.26448E 25	*	X			2.05038E 26	178.26
4.0700	1.34723E 26	*	X			4.46495E 26	180.39
4.1800	2.74611E 26	*	X			8.99877E 26	182.52
4.2900	5.43157E 26	*	X			1.73276E 27	184.64
4.4000	1.05623E 27	*	X			3.31920E 27	186.77
4.5100	2.03118E 27	*	X			6.32571E 27	188.89
4.6200	3.97403E 27	*	X			1.19935E 28	189.55
4.7300	7.34305E 27	*	X			2.26277E 28	191.41
4.8400	1.38370E 28	*	X			4.24797E 28	193.23
4.9500	2.59356E 28	*	X			7.93601E 28	195.05
5.0600	4.13366E 28	*	X			1.47531E 29	196.86
5.1700	4.40059E 28	*	X			5.99645E 28	194.23
5.2800	4.42925E 28	*	X			6.57425E 27	187.88
5.3900	4.43213E 28	*	X			6.77627E 26	181.53
5.5000	4.43246E 28	*	X			6.5486CE 25	175.19
5.6100	4.43248E 28	*	X			5.91817E 26	168.86
5.7200	4.43248E 28	*	X			4.96851E 23	162.49
5.8300	4.43248E 28	*	X			3.90502E 22	156.15
5.9400	4.43248E 28	*	X			2.83267E 21	149.80
6.0500	4.43248E 28	*	X			1.85708E 20	143.45

\$\$\$ CONTINUOUS SYSTEM MODELING PROGRAM III VIP2 EXECUTION OUTPUT \$\$\$

\$\$\$CONTINUOUS SYSTEM MODELING PROGRAM III VIM2 TRANSLATOR OUTPUT\$\$\$

FUNCTION FUN(0..32,50), (1..105,24), (2..136,07), (3..161,80)....
(4..181,16), (5..197,68), (6..139,99), (7..120,28), (8..106,70)....
(9..100,89), (10..99,33)

IC=0
TEMP=AFGEN(FUN,TYPE)
DATALOG=226,78474-75000./(273,TEMP)

D=EXPLCMLCG
M=INTEGR(IC,DW)
TIMER FINTIM=11.
OUTPUT N,DW,TEMP

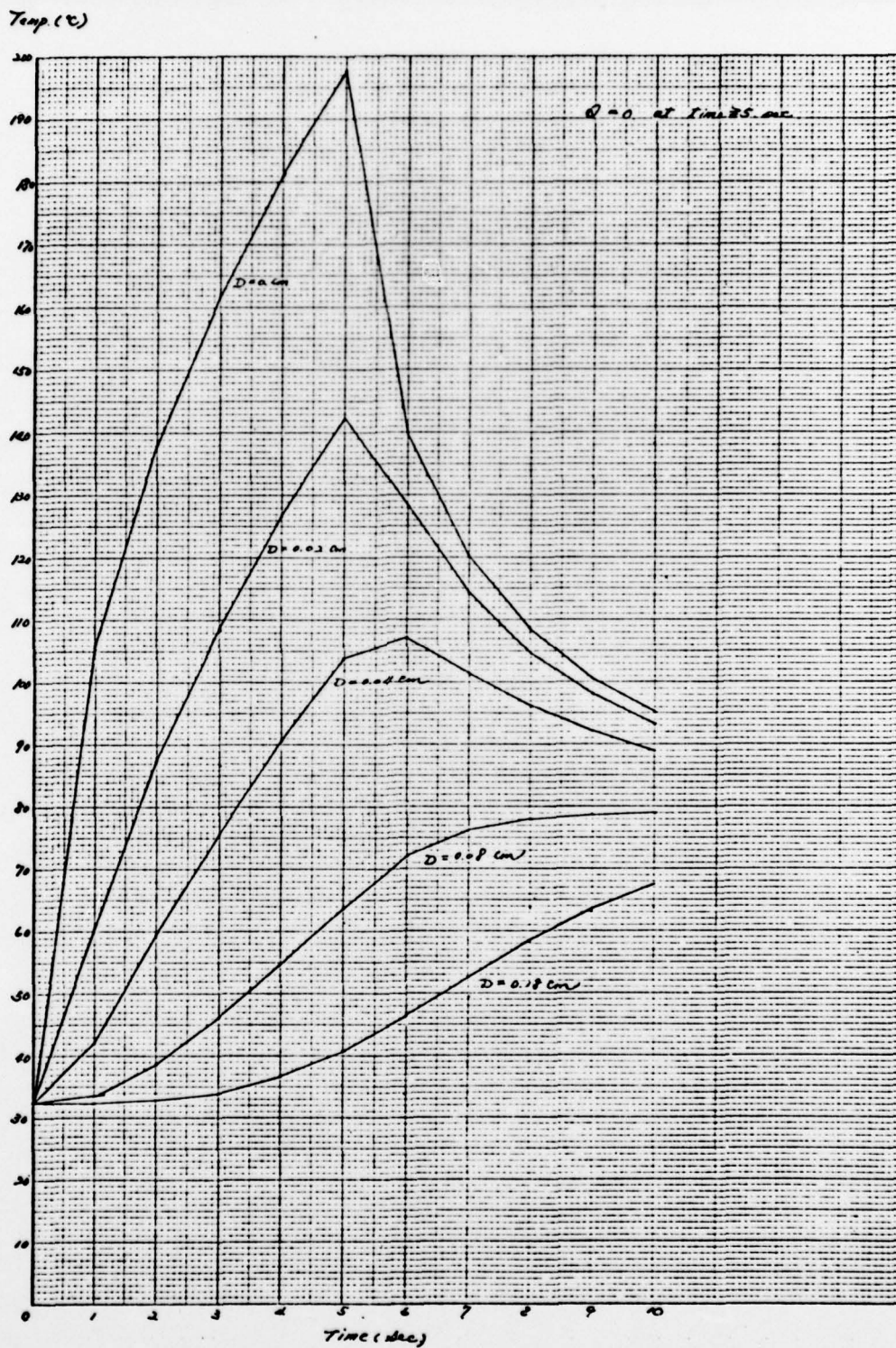
END
STOP

OUTPUT VARIABLE SEQUENCE
IC TEMP CLOGG DW M

\$\$\$ TRANSLATION TABLE CONTENTS \$\$\$

	CURRENT	MAXIMUM
MACRO AND STATEMENT OUTPUTS	11	600
STATEMENT INPL WCRK AREA	37	1900
INTEGRATORS+MEMORY BLOCK OUTPUTS	1 + 0	300
PARAMETERS+FUNCTION GENERATORS	1 + 1	400
STORAGE VARIABLES+INTEGRATOR ARRAYS	0 + 0/2	50
HISTORY AND MEMORY BLOCK NAMES	21	50
MACRO DEFINITIONS AND NESTED MACROS	6	50
MACRO STATEMENT STORAGE	13	125
LITERAL CONSTANT STORAGE	0	100
SORT SECTIONS	1	20
MAXIMUM STATEMENTS IN SECTION	5	600

\$\$\$END OF TRANSLATOR OUTPUT\$\$\$



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