175
4-27-81
①
UCC-ND

NUCLEAR
DIVISION

UNION
CARBIDE

①
R3851
MASTER
Y-2564
Y-2225

LIQUID-PHASE DETECTION INSTRUMENT
TO RECORD AND ANNUNCIATE PROCEDURAL
DEVIATIONS IN SINTERING RUNS

D. K. Mee
D. M. Darby
T. M. Sims, Jr.

April 1981

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A02
Microfiche copy: A01

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Date of Issue: April 15, 1981
Distribution Category: UC-37

Y-2225

LIQUID-PHASE DETECTION INSTRUMENT TO RECORD AND ANNUNCIATE PROCEDURAL DEVIATIONS IN SINTERING RUNS

D. K. Mee
D. M. Darby
T. M. Sims, Jr.

Instrumentation and Characterization Department
Y-12 Development Division

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Oak Ridge Y-12 Plant

P. O. Box Y, Oak Ridge, Tennessee 37830

Prepared for the Department of Energy
Under US Government Contract W-7405-eng-26

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

A liquid-phase detection instrument (LPDI) has been developed to aid in making consistently accurate alloy sintering runs. The LPDI displays the furnace temperature, detects the alloy's liquid-phase arrest temperature, calculates the necessary hold temperature from the arrest temperature (i.e., calibrates the system), and provides a digital record for quality assurance purposes. In field tests, the instrument's detected arrest temperature was within $+1^{\circ}$ to -0°C of an operator's assessment of the actual arrest temperature.

CONTENTS

SUMMARY	4
INTRODUCTION	5
LIQUID-PHASE DETECTION INSTRUMENTATION	6
Theory of Operation	6
Concept	6
Considerations	6
Implementation	7
Instrument Description	8
Hardware	8
Software	9
Error Analysis	12
Performance Tests	15
Software	15
Cooling System	15
Signal Buffering and Measurement	15
Liquid-Phase Detection	15
Conclusions	16
REFERENCES	19
ACKNOWLEDGMENTS	20

SUMMARY

A highly accurate temperature measurement is required in the sintering of alloys. The temperature measurement is calibrated at the alloy's liquid-phase arrest temperature to obtain this degree of accuracy. Furnace operators are presently required to make this calibration by observing the liquid-phase arrest temperature on a strip-chart recorder and calculating the necessary hold temperature from it, which effectively calibrates the system. Since errors can easily be made in this process, a liquid-phase detection instrument (LPDI) has been developed with the following objectives: (1) to aid personnel in detecting the liquid-phase arrest temperature, (2) to alert personnel to procedural deviations, and (3) to make automatic control of sintering furnaces possible in the future.

The LPDI, as does the previous method, identifies the alloy's liquid-phase arrest by detecting the point at which the temperature of an alloy sample lags behind the temperature of a pure-metal sample which does not undergo a phase change. The microcomputerized LPDI displays the alloy-sample temperature, prints the arrest temperature, calculates and prints the hold temperature, alarms when the run is out of specifications, and provides a digital record for Quality Assurance (QA) purposes.

Calculations show that the "worst case" LPDI theoretical error is $+4.6^{\circ}$ to -2.6°C . Field tests were conducted which were in agreement with the calculated results. Presently, the LPDI is installed on a production sintering furnace.

INTRODUCTION

In alloy sintering at the Oak Ridge Y-12 Plant,^(a) pressed metal powder is heated on a furnace hearth until melting occurs throughout the powder. If the temperature of the hearth is held a few degrees above or below the specified limits, the run fails; and in the first case, the powder is ruined. Since accuracy is so critical in this application, the thermocouple temperature measurement must be calibrated at the alloy's liquid-phase arrest temperature before the hold period begins. This calibration must be done by a furnace operator who observes the liquid-phase arrest temperature on a strip-chart recorder and calculates the necessary hold temperature from it (effectively calibrates the system for temperatures near the arrest temperature). Since errors can easily be made during this process, an LPDI has been developed with the following objectives: (1) to aid personnel in detecting the liquid-phase arrest temperature, (2) to alert personnel to procedural deviations, and (3) to make automatic control of sintering furnaces possible in the future.

(a) Operated by the Union Carbide Corporation, Nuclear Division, for the Department of Energy.

LIQUID-PHASE DETECTION INSTRUMENTATION

THEORY OF OPERATION

Concept

A concept presently used by the production personnel is the basis for this instrument's liquid-phase detection. Sample blocks of the pure metal and the alloy are placed side by side on the hearth's perimeter, and their temperatures are measured. Figure 1 (top) illustrates an ideal temperature measurement of these blocks. As the alloy enters its liquid phase, a temperature differential, ΔT , is created by the temperature lag of the alloy block. By plotting ΔT versus time, Figure 1 (bottom), it is apparent that the peak of this curve occurs immediately after the alloy has melted; and therefore, the temperature of the alloy at the peak of ΔT is the liquid-phase arrest temperature ($+1^\circ$ to -0°C).

Considerations

Several factors need to be considered in the implementation of the liquid-phase detection instrument. First, temperature gradients caused by large power changes and changes in gas flow cause peaks in ΔT which are similar to the peak at the alloy's liquid-phase arrest temperature. For the present application, these perturbations in ΔT occur at the beginning of the run and at 1310°C . To eliminate the effect of extraneous peaks in ΔT , the search for the alloy's liquid phase is delayed until the alloy's temperature reaches 1420°C .

Second, steady-state gradients across the hearth are detected by placing a second alloy block in the center of the hearth, Alloy C (center), and comparing its temperature to the temperature of the perimeter alloy block, Alloy O (outside), which is used for the liquid-phase detection. Since W-3Re versus W-25Re thermocouples with an accuracy of only $\pm 1\%$ are used, errors in the gradient measurement between the Alloy C and Alloy O thermocouples as large as $\pm 29^\circ\text{C}$ (at 1450°C) may occur if care is not taken in the thermocouple selection. This error is decreased to approximately $\pm 3^\circ\text{C}$ by specifying the use of thermocouples from the same batch of wire.

Pairing of the pure-metal sample thermocouple and the Alloy O sample thermocouple is not necessary for this instrument, since the errors introduced by using unmatched thermocouples do not affect the time at which the ΔT peak occurs. Using an unmatched thermocouple for the pure-metal sample would normally cause an error in the displayed ΔT ; however, this error is significantly reduced by zeroing the measurement at a point where ΔT is known to be small (1420°C).

Finally, each thermocouple must be electrically isolated from the other thermocouples. The initial method of measuring ΔT was to short the negative thermocouple leads used in the pure metal and the Alloy O samples and to measure the difference in electromotive force

Figure 1. METHOD OF LIQUID-PHASE DETECTION.

(emf), from the positive leads, which was converted to temperature. When this method was tested, a current loop was formed through the short and the low impedance between the thermocouples' hot junctions, causing as much as $\pm 100^{\circ}\text{C}$ error. To eliminate this loop, each thermocouple is measured separately, and the temperature difference is obtained digitally. It is important to note that all connections to ground or guard must also be eliminated unless these connections are multiplexed along with the signal leads.

Implementation

An LSI-11^(b) microcomputer is used in this application because of the large amount of necessary data reduction and manipulation. After the thermocouple signals are digitized, the microcomputer software averages 20 consecutive readings to reduce noise and then linearizes the signals. The ΔT is calculated and monitored by a peak-detection routine which automatically stores the liquid-phase arrest temperature at the peak. Once the arrest temperature has been defined, the hold temperature is calculated from it; and is printed. Throughout the liquid-phase hold period, the temperatures of Alloy O and Alloy C are monitored, and out-of-tolerance alerts or hold time-temperature updates are provided when necessary.

INSTRUMENT DESCRIPTION

Hardware

The LPDI hardware (Figure 2) can be divided into four basic parts: the analog circuitry, the LSI-11 microcomputer, the control panel, and the printer. These parts will be discussed in this section.

Figure 2. BLOCK DIAGRAM OF THE LIQUID-PHASE DETECTOR.

(b) Digital Equipment Corporation.

Analog Circuitry - Thermocouple signals are inputted to the LPDI on an isothermal connection block; then they are digitized using a low level digitizer which has cold-junction compensation and is compatible with the LSI-11 bus. The thermocouple signals are also relayed to the existing analog recorders through specially developed unity-gain buffer amplifiers. These amplifiers prevent current pulses from the analog recorder from creating error in the LPDI measurement.

Microcomputer - The LSI-11 microcomputer handles all the data manipulation and controls the printer and the control panel. All of the interface cabling from the front-panel controls and the printer is routed through an internal-junction panel before entering the microcomputer. The junction panel allows any section of the instrument to be removed easily and provides a place for interface connections and electronics.

Because of the contaminated operating environment, the microcomputer must be cooled with the instrument air which enters the enclosure at 70 psi through 3/8-in. tubing. Air mufflers are installed on this tubing to prevent the irritating noise which would otherwise be generated. The LPDI is also equipped with muffin fans for easy maintenance; however, these fans must be switched off during normal operation with instrument air.

Control Panel - The control panel (Figure 3) basically consists of two thumb-wheel inputs, a light-emitting diode (LED) display, alarms, power and program-initiation switches, and a printer (discussed later). The desired printing rate (1 to 99 min) and the type of alloy to be sintered are selected via the PRINT INTERVAL and PROGRAM SELECT thumb-wheel switches. The LED display indicates ΔT and the temperature of the alloy block selected on the switch below the display. Personnel are alerted to a liquid-phase condition or to a procedural violation by an audible alarm (silenced by depressing an indicator) and the appropriate indicator (LIQUID PHASE or ALARM indicators). Finally, data collection is halted and initiated by depressing the RESET/RUN button (illuminated during data collection).

Printer - The printer is used to provide a clock for microcomputer-program timing, to provide information for personnel during the run, and to provide a digital record for QA purposes. Modifications in the printer allow the time-of-day clock to remain current with the LPDI power switch (on or off) and allow the fanfold paper to be loaded without removal of the printer's front panel.

Software

Software Overview - The software for the LPDI is in four levels: (1) the BASIC program, (2) the REBEL BASIC interpreter which is in machine language, obtained from Lawrence Livermore National Laboratory,¹⁻³ (3) the software patch, and (4) the power-up bootstrap. All of the instrument's software is stored on programmable read-only memories (PROM) and transferred to the LPDI's random access memory (RAM) when the power switch is turned on (Figure 4).

Figure 3. FRONT PANEL OF THE LIQUID-PHASE DETECTION INSTRUMENT.

188351

Figure 4. LIQUID-PHASE DETECTION INSTRUMENT PATCH AND BOOTSTRAP.

Software Patch - To program the PROMs, the REBEL BASIC interpreter and the BASIC program are loaded into the RAM of an LSI-11 microcomputer; and the program is initiated. Program execution is immediately halted in a delay loop (first line of the program), and the volatile contents of seven general-purpose registers are recorded (for later use in the power-up bootstrap). The content of the LSI-11 RAM at this time is the memory image that needs to be stored on PROM. This transfer is accomplished by typing the software patch into an empty portion of RAM which transfers blocks of the RAM (1K words) into the PROM programmer. A 1K word PROM is programmed following each block transfer until the entire memory image has been programmed on PROMs.

PROM Bootstrap - A power-up bootstrap is also loaded onto PROMs via the PROM programmer's keyboard. This bootstrap is used to transfer the memory image from the bootstrap board (contains the PROMs) to the LPDI RAM and restore the contents of the seven general-purpose registers. When the LPDI is turned on in the field, the bootstrap is automatically executed causing the BASIC program to be executed from the point at which it was previously halted.

BASIC Program - The BASIC program (5K words) is the portion of developed software which controls the LPDI. Figure 5 is a simplified flow chart of the BASIC program showing its major sections. After completion of the delay loop, all of the front-panel controls and the program variables are initialized.

Data Collection - Data collection begins when the operator depresses the RESET/RUN button. Each thermocouple signal is first averaged over 20 consecutive measurements and then linearized with a subroutine containing eight parabola segments (accuracy is $\pm 0.5^{\circ}\text{C}$ from -18° to 1693°C).

Program Logic - The program logic controls the display of all necessary data and searches for the peak of ΔT after the temperature of Alloy O (T_{AO}) reaches 1420°C . During the search for the peak of ΔT , the current value of T_{AO} is stored each time ΔT exceeds a previously stored maximum (Figure 6). A positive identification of the peak of ΔT is made when ΔT becomes less than the maximum (ΔT_3) by a selectable amount of hysteresis (ΔT_h). At this time, the liquid-phase arrest temperature (T_{lp}) is defined to be T_{AO3} ; the LIQUID PHASE light is illuminated; and the necessary hold temperature is calculated (T_{lp} , the hold temperature, and the hold time will be printed). If the procedure is violated during the

Figure 5. BASIC-PROGRAM FLOW CHART.

liquid-phase hold portion of the run, the ALARM light is illuminated ($\geq 1^\circ\text{C}$ violation), and an audible alarm is sounded ($\geq 2^\circ\text{C}$ violation). If the audible alarm is silenced, it will be reactivated when T_{AO} is within specifications.

Print - The print section shown in Figure 5 controls the printing of all data. The printout (Figure 7) begins with the printing of the time of day, PRINT INTERVAL (in minutes), ΔT_h ($^\circ\text{C}$), and the PROGRAM SELECT. This information is printed in red, and will be reprinted in a contrasting color each time a thumb-wheel setting is modified. After the switch conditions are printed, T_{AO} will be printed in black at the selected print intervals. ΔT will be printed in the third column from the time T_{AO} reaches 1420°C until a peak in ΔT is detected. Upon detection of the ΔT peak, T_{Ip} will be printed in red, followed by printings of T_{AO} and the temperature of Alloy C (T_{AC}) at the selected intervals. When T_{AO} reaches the hold temperature calculated from T_{Ip} , the hold temperature and the hold time are printed and outlined in dots. If a new hold time or temperature is later required (because of unacceptable gradients across the hearth), this information will be printed in a similar manner. Throughout the liquid-phase hold period, data are printed in red if they meet specifications and in black if they do not. The completion of the hold time is indicated by a double row of dots.

Figure 6. THE ΔT PEAK-DETECTION METHOD.

Error Analysis

The effective LPDI error (E_{LPDI}) described in this section is the deviation of the true Alloy O sample temperature from the ideal Alloy O sample temperature during the hold period (assuming no operator error). The measured Alloy O sample temperature (T_{AO_i}) can be described as

$$T_{AO_i} = T_{ao_i} + E_{TO_i} + E_{AO_i} + E_{DO_i}, \quad (1)$$

where the subscript, i , defines when the measurement occurred; T_{ao_i} is the true Alloy O sample temperature; E_{TO_i} is the Alloy O thermocouple calibration error; E_{AO_i} is the Alloy O analog circuitry error; and E_{DO_i} is the Alloy O digital circuitry error. During the hold period, T_{AO_i} is to be held at a temperature increment T_δ above the liquid-phase arrest temperature. Assuming that this is true (i.e., no operator error),

$$T_{AO_h} = T_{AO_p} + T_{\delta}, \quad (2)$$

where the subscripts h and p describe T_{AO_i} measurements during the hold period and when ΔT is at its peak, respectively. The true temperature of the Alloy O sample during the hold period can be found by substituting Equation (1) into Equation (2) and is:

$$T_{ao_h} = T_{ao_p} + T_{\delta} + (ET_{Op} - ET_{Oh}) + (EAO_p - EAO_h) + (EDO_p - EDO_h). \quad (3)$$

Figure 7. LIQUID-PHASE DETECTION INSTRUMENT PRINTOUT. (Highlighted numbers are printed in red on the printout.)

For Equation (3) to be useful, the actual Alloy O sample temperature, T_{aoh} , must be in terms of the actual liquid-phase arrest temperature (T_{lp}) instead of T_{aop} . Since T_{aop} only approximates T_{lp} , these quantities must be related as:

$$T_{aop} = T_{lp} + E_p, \quad (4)$$

where E_p is the error existing in the T_{aop} approximation of T_{lp} . Equation (3) can now be rewritten as:

$$\begin{aligned} T_{aoh} = & T_{lp} + T_\delta + E_p + (ETOp - ETOh) + (EAO_p - EAO_h) \\ & + (EDO_p - EDO_h). \end{aligned} \quad (5)$$

The calculated LPDI error, E_{LPDI} , as mentioned previously, is the difference between the actual temperature of Alloy O during the hold period (T_{aoh}) and the ideal Alloy O hold temperature ($T_{lp} + T_\delta$). The ideal hold temperature appears on the right side of Equation (5) with the associated error terms; so, from Equation (5):

$$E_{LPDI} = E_p + (ETOp - ETOh) + (EAO_p - EAO_h) + (EDO_p - EDO_h). \quad (6)$$

The right side of Equation (6) can be evaluated as follows, assuming that T_δ is small (22°C in the present application). E_p is estimated from experimental results to be $+1^\circ$ to -0°C ; $ETOp - ETOh$ will be $+1^\circ$ to -0°C (estimated from calibration plots); and $EAO_p - EAO_h$ will be negligible. $EDO_p - EDO_h$ is a function of the digital circuitry resolution and the thermocouple linearization and is $\pm 2.6^\circ\text{C}$ in the range of interest. The effective LPDI error (E_{LPDI}) is then $+4.6^\circ$ to -2.6°C for this application.

A second error analysis needs to be made on the hearth temperature gradient which is calculated from the Alloy O sample temperature (T_{AO_i}) and the Alloy C sample temperature (T_{AC_i}). The equation for the Alloy C sample temperature is similar to Equation (1) and is:

$$T_{AC_i} = T_{ac_i} + ETC_i + EAC_i + EDC_i, \quad (7)$$

where the subscripts C or c indicate that the parameters are associated with the Alloy C sample. The measured temperature gradient between the Alloy O and the Alloy C samples ($EAC_i - EAO_i$) can be obtained from Equation (1) and Equation (7) and is:

$$\begin{aligned} T_{AC_i} - T_{AO_i} = & T_{ac_i} - T_{ao_i} + ETC_i - ETO_i + EAC_i - EAO_i \\ & + EDC_i - EDO_i. \end{aligned} \quad (8)$$

From Equation (8), the gradient measurement error (E_G) can be identified as all of the terms to the right of the actual gradient ($T_{ac_i} - T_{ao_i}$); therefore:

$$E_G = (ETC_i - ETO_i) + (EAC_i - EAO_i) + (EDC_i - EDO_i). \quad (9)$$

Equation (9) can be evaluated as follows: $ETC_i - ETO_i$ is $\pm 0.2\%$ of T_{ao_i} ($\pm 2.9^\circ\text{C}$ at 1460°C) if the thermocouples are taken from the same batch of wire; $EAC_i - EAO_i$ is negligible; and $EDC_i - EDO_i$ is $\pm 2.6^\circ\text{C}$ making $E_G = \pm 5.5^\circ\text{C}$.

PERFORMANCE TESTS

Software

Tests were conducted on the LPDI's software, cooling system, signal buffering and measurement, and the liquid-phase detection. The software was tested in the laboratory and found to be working properly with the exception of a minor flaw in the thermocouple linearization (error approximately 20°C from 300° to 420°C) which was corrected in the final system.

Cooling System

An evaluation of the cooling system was made by monitoring the air temperatures entering and leaving the LPDI during the months of March and April. The maximum temperature obtained at the exit port next to the microcomputer was 33°C (29°C air input). Similarly, the maximum temperature obtained at the exit port next to the power supply was 42°C (29°C air input). Since the LPDI can operate in temperatures to 50°C , the cooling system is satisfactory (cooling proved satisfactory in the summer months also).

Signal Buffering and Measurement

Large common-mode errors were obtained when the buffer amplifiers were field tested. To correct this problem, the common-mode signals were shunted to ground through $0.1\ \mu\text{F}$ capacitors which were added to the buffer inputs. The calibration accuracy and the long-term accuracy (3 months) were then found to be $\pm 0.5^\circ\text{C}$ and $\pm 2^\circ\text{C}$, respectively. The measurement accuracy of the digitizer was also tested in the field and found to be within tolerances ($EAO_i + EDO_i = \pm 1.7^\circ\text{C}$ at 1460°C).

Liquid-Phase Detection

Two tests were conducted to evaluate the accuracy of the LPDI's detection of T_{lp} relative to the manual detection of T_{lp} by production personnel. Since the analog recorder used to

make the manual detection had several degrees of error in the temperature range of interest, its error was removed in both tests before presenting the data.

Test 1 was made during an actual sintering run. The data taken from this run are plotted in Figure 8 with a vertical line drawn through the peak of ΔT and T_{lp} as indicated by the LPDI. The T_{lp} indicated by the LPDI in the test shown in Figure 8 was identical to the T_{lp} detected manually.

A second test was made in which the furnace was cycled through the liquid-phase arrest temperature four times. The LPDI was reset before each cycle. The T_{lp} detected by the LPDI in this test and in Test 1 are shown in Table 1 with the manually detected arrest temperature (corrected for error) and the LPDI error.

Table 1
EXPERIMENTAL LIQUID-PHASE
DETECTION ERROR

Test	LPDI Detection of T_{lp} (°C)	Manual Detection of T_{lp} (°C)	LPDI Detection Error (°C)
1	1461	1461	0
2a	1462	1462	0
2b	1462	1462	0
2c	1463	1462	+1
2d	1463	1462	+1

The LPDI arrest temperature detection error in these tests ranged from 0° to 1°C and did not exceed $ED_{Op} + E_p$ (+2.3° to -1.3°C) in Equation (6), which was the error components associated with the liquid-phase detection.

CONCLUSIONS

The LPDI prototype has reliably detected the solid-liquid phase transition in sintering runs. By calculating a hold temperature based on the measured-phase transition temperature, many measurement errors are eliminated. Calculations show that the worst case LPDI error is +4.6° to -2.6°C which is a factor of four improvement over the use of W-3Re versus W-25Re thermocouples alone ($\pm 14.6^\circ\text{C}$ error at 1460°C). This accuracy is sufficient to meet the needs of the present application. If greater accuracy were required, it could be attained by: (1) increasing the display and the A/D resolution to 0.1°C and 2 μV , respectively

Figure 8. LIQUID-PHASE DETECTION INSTRUMENT FIELD TEST 1.

(decreases $EDO_p - EDO_h$) and (2) characterizing the slope of the thermocouple error curve, ETO_i , between $T_{AO} = T_{Ip}$ and $T_{AO} = T_{Ip} + T_\delta$ and removing the typical error (decreases $ETO_p - ETO_h$). With these improvements, the LPDI error could be reduced to approximately $+2^\circ$ to -1°C .

REFERENCES

1. J. R. Greenwood and M. C. Zarnstorff, *REBEL/BASIC: COMMANDS*, Lawrence Livermore National Laboratory, Livermore, Calif., UCID-17685 (1977).
2. J. R. Greenwood and M. C. Zarnstorff, *REBEL/BASIC: METHODOLOGY*, Lawrence Livermore National Laboratory, Livermore, Calif., UCID-17686 (1977).
3. M. C. Zarnstorff and J. R. Greenwood, *REBEL/BASIC: LANGUAGE*, Lawrence Livermore National Laboratory, Livermore, Calif., UCRL-52668 (1979).

ACKNOWLEDGMENTS

The authors of this report would like to thank A. E. Stephens, W. A. Pfeiler, W. G. Northcutt, and S. G. Snow of the Y-12 Development Division for background information and for giving direction to the project; J. E. Cheek, W. W. Randles, J. E. Thompson, and many others in the Metal Preparation Division who aided in scheduling and conducting field tests; M. G. Duncan and P. C. Turner of the Y-12 Development Division for providing technical assistance; and R. K. Holbert, W. P. Mattingly, S. F. Sparks, and W. H. Hodgson of the Maintenance Division in the Y-12 Plant for fabricating and installing the hardware.

Distribution

Department of Energy - Oak Ridge

Hickman, H. D.
Poteat, R. M.

Lawrence Livermore National Laboratory

Arnold, W. F.
Dittman, G. L.
McMillan, K.
Moon, D. W.
Nelms, W. S.
Nelson, W. E.

Los Alamos National Laboratory

Hoyt, H. C.

Oak Ridge Gaseous Diffusion Plant

Armstrong, R. C.
Stief, S. S.
Wilcox, W. J., Jr.

Oak Ridge National Laboratory

Hopkins, C. C.
Weir, J. R., Jr.

Oak Ridge Y-12 Plant

Alvey, H. E.
Bailey, H. L.
Barkman, J. R.
Beck, D. E.
Bernander, N. K.
Bostock, D. J.
Bright, G. R.
Briscoe, O. W.
Burditt, R. B.
Burkhardt, J. H., Jr.
Carter, C. C.
Dodson, W. H./Googin, J. M.
Duncan, M. G.
Ferguson, J. E.
Foult, D. L.
Guinn, G. R.
Hackett, D. W.
Holcombe, C. E.
Jackson, V. C.
Jessen, N. C.

Jones, F. W.
Kahl, K. G.
Kaiser, K. W.
Keith, A.
Kite, H. T. (50)
Koger, J. W.
Kollie, T. G.
McLendon, J. D.
Mee, D. K. (15)
Mills, J. M., Jr.
Northcutt, W. G.
Pfeiler, W. A.
Randles, W. W.
Robinette, B. K.
Smith, R. D.
Snow, S. G.
Stephens, A. E.
Stoner, H. H.
Tewes, W. E.
Thompson, J. E., Jr.
Townsend, A. B.
Turner, P. C.
Wilder, E. W.
Williams, R. D.
Y-12 Central Files (master copy)
Y-12 Central Files (route copy)
Y-12 Central Files (Y-12RC)
Y-12 Central Files (5)

Paducah Gaseous Diffusion Plant

Bewley, H. D.

Rockwell International - Rocky Flats

Skulski, R. W.

Sandia National Laboratories - Albuquerque

Neilson, E. W.
Spencer, W. J.

Sandia National Laboratories - Livermore

Willis, A. R.

Union Carbide Corporation - New York

Tinsley, S. W.

In addition, this report is distributed in accordance with the Category UC-37, *Instruments*, as given in the *Standard Distribution for Unclassified Scientific and Technical Reports*, DOE/TIC-4500.