AD-A090 828 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CA F/G 9/3

EMCS MODULES/INTELLIGENT TIME CLOCK (ITC).(U)

SEP 80 D SHIROMA

UNCLASSIFIED CEL-TN-1588 NL

1 OF 1

END

DATE FILMED

12-80

DTIC

LEVEL II

AD A090828

Technical Note

CEL

TN no. N-1588

DDC FILE COPY

title: EMCS MODULES/INTELLIGENT TIME CLOCK (ITC)

author: Dallas Shiroma

date: September 1980

DTIC ELECTE OCT 28 1980 S D E

sponsor: Chief of Naval Material

program nos: Z0371-01-221C

CIVIL ENGINEERING LABORATORY

NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

Approved for public release; distribution unlimited.

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

80 10 9 122

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TN-1588
2. GOVT ACCESSION NO.: AD-A090828 DN887052
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): EMCS MODULES/INTELLIGENT TIME CLOCK (ITC)
5. TYPE OF REPORT & PERIOD COVERED: Final; FY77 - FY80
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Dallas Shiroma
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: CIVIL ENGINEERING LABORATORY, Naval Construction Battalion Center, Port Hueneme, California 93043
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 64710N, Z0371 01 221C
11. CONTROLLING OFFICE NAME AND ADDRESS: Chief of Naval Material, Washington, D.C. 20360
12. REPORT DATE: Sept[redacted]80
13. NUMBER OF PAGES: 18
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): EMCS, microprocessors, energy conservation, HVAC controls, time clock
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The CEL has developed a microprocessor-based intelligent time clock (ITC) for control of HVAC equipment. The ITC has the capability of operating as a stand-alone controller, or as part of a distributed large-scale Energy Monitoring and Control System (EMCS). The ITC has "intelligence" to monitor actual environmental conditions and to base actual control functions on these data. Evaluation of the ITC has demonstrated

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued

that such "intelligent" control devices can provide significant energy savings over conventional control devices.

Library Card

Civil Engineering Laboratory
EMCS MODULES/INTELLIGENT TIME CLOCK (ITC) (Final),
by Dallas Shiroma

TN-1588 18 pp illus September 1980 Unclassified

1. Microprocessors 2. HVAC controls 3. Z0371-01-221C

The CEL has developed a microprocessor-based intelligent time clock (ITC) for control of HVAC equipment. The ITC has the capability of operating as a stand-alone controller, or as part of a distributed large-scale Energy Monitoring and Control System (EMCS). The ITC has "intelligence" to monitor actual environmental conditions and to base actual control functions on these data. Evaluation of the ITC has demonstrated that such "intelligent" control devices can provide significant energy savings over conventional control devices.

CONTENTS

INTRODUCTION

The Intelligent Time Clock (ITC) was developed as a cost-effective alternative for conventional time clocks with the added capability of operating as a stand-alone Energy Management and Control System (EMCS) device as well as expanding to become an integral part of a base-wide control network. The ITC has the capability to monitor actual environmental conditions and to use this data to determine which control function to perform. Such a device meets the specialized requirements of many Navy buildings for the present as well as for the future.

The prototype ITCs were developed on a contract. This report describes the development of the ITCs, their capabilities and performance.

BACKGROUND

As a result of the energy crisis of 1973, energy conservation targets were established for Navy shore activities. To meet these targets, many large activities are considering installation of computerized energy monitoring and control systems (EMCS) for their promise of long-term energy controls with limited manpower resources. The main disadvantage is the high initial cost of these systems.

Considerable work in the area of large scale EMCS has been done, leading to the development of the Inter Agency Guide Specifications for EMCS. However, on a lesser scale, smaller activities where a large EMCS would not be economically feasible, have had to look elsewhere to achieve their conservation goals. In this area, such devices as electromechanical time clocks or demand and cycling controllers have been applied. If properly maintained, conventional time clocks and controllers provide energy savings, but all too often these controls malfunction or lose their effectiveness due to tampering or by setting them for worst case conditions to eliminate complaints. In addition, many of these devices are not designed to be expanded or integrated into a larger EMCS, if one is to be instituted at a later date.

Having identified a need for such a device, the Civil Engineering Laboratory initiated a development program in FY-77 and a contract was awarded for the development of two ITCs. These microprocessor based ITCs would provide energy efficient control of HVAC equipment while maintaining the building's temperature within predetermined limits. They would have the "intelligence" to monitor temperatures, on/off status of equipment, time of day, day of week and would optimally start-up and shut-down the HVAC equipment based on this information.

CURRENT STATUS OF ITC

The ITC is alive and well today, despite considerable delays in its delivery by the contractor. Originally scheduled for delivery in the spring of 1978, the first unit was shipped to CEL in early 1979, almost a year behind schedule. The delay was due in part to the unavailability of component hardware due to an industry-wide shortage of certain integrated circuit chips, and in part to the overcommitment of contractor personnel to other projects. Another contributing factor was the decision to provide each unit with an ASCII display, a feature which compounded the problems associated with software development.

In evaluating the initial ITC, several significant errors were discovered, requiring the units to be returned to the manufacturers. The contractor completely redid the software and after "thorough testing" shipped the units to CEL in April of 1979. The units failed to operate satisfactorily. Several months passed before the contractor provided software corrections, and by late summer, the ITC was "semi-intelligent." Unfortunately, its operation was now excruciatingly slow, requiring almost an hour to input the 25 control parameters! In addition several more errors were detected in the control routine. By the end of calender year 1979, while still not correcting all the software bugs, the contractor provided upgraded hardware for the ITC's, replacing most of the wire-wrapped cards with printed circuit boards, and also a fairly comprehensive though outdated software listing. At this time too, CEL, with the purchase of a microprocessor development system, acquired the capability to develop microprocessor software. Thus it was decided, with the ITCs almost 2 years behind schedule and still mired in prolonged delays due to software bugs, to accept delivery of the units and to complete final software modifications in-house at CEL.

By April 1980, after extensive software debugging and rewriting at CEL, the units were operational. One unit was installed in Bldg. 560 at the Civil Engineering Laboratory, Port Hueneme, California, (Figure 1) to control the steam-heating system. The other unit is scheduled to be installed at NWC China Lake, CA.

In summary, despite the prolonged delays and the less than exceptional performance of the contractor, the ITCs are operational and have demonstrated that significant energy savings are possible with intelligent control devices.

ITC Features

The ITC is based on the National Semiconductor SC/MP microprocessor. It has the capability of 32 anolog inputs (for temperature sensing or other analog signal sensing), 64 digital inputs (for sensing on/off conditions), and can control 16 loads. The ITC has a real-time clock, a calendar, and a day-of-week counter, which allows it to automatically recognize weekends.

Holidays can be set from the front panel. The ITC will enter the holiday mode at midnight for the number of days specified, and will automatically revert to its normal schedule upon expiration of the holiday period.

For operation during normally off hours, a manual override for up to 1 hr is provided.

A programmable low-temperature override prevents interior temperatures from dropping below some interior temperature limit (ITL) to protect pipes from freezing.

The ITC utilizes linear thermistors to sense temperatures. To minimize effects of spurious fluctuations in the sensor readings, ITC measures each sensor at 5 discrete times and then averages these readings to determine the channel temperature for each sensor, the 5 min average temperature.

The ITC can be programmed to monitor up to 5 zones, with each zone being assigned up to a maximum of 6 temperature sensors. For each zone, the ITC calculates a 15 min space-weighted average temperature. This is done by assigning a weight factor to each sensor. The ITC then incorporates the weights in determining the zonal 15 min-space-weighted temperature. Thus zonal decisions are based on a time average as well as a space-weighted average. In most applications then, temperature sensors in colder areas can be weighed proportionally higher in heating applications, while warmer areas can be weighed to have greater influence in cooling applications.

The ITC has the capability of communications over phone lines via an auto-answer/auto-call modem. Communications is in ASCII coding at 300 baud rate. The ITC also has a printer port through which the accumulated data may be printed out.

In addition to analog and digital monitoring, the ITC stores a considerable amount of data. For each channel, it records the current 5 min average temperature, the maximum and minimum temperatures and times of occurrence, the temperatures at start of work (SOW) and at close of work (COW), and the zone profile for the past 24 hr. The ITC monitors the operation of the equipment it controls, recording the cumulative hours of operation and number of ON/OFF transitions of the equipment. This information may be printed out on a local printer or transmitted via phone lines and can be useful in determining building performance. This amount of information may not be required for all situations.

The front panel provides an alphanumeric display for local readout of input and output parameters. Toggle and push-button switches on the front panel are used to program the input parameters. Once the input function is selected, the ITC prompts the operator for the necessary information.

Control Algorithm

The optimized start/stop control algorithm is accomplished by sampling interior and outside air temperature, and using this data to determine when the HVAC system needs to be on or off. The general control algorithm is shown in Figure 2.

To determine optimum start-up time, ITC looks at the interior zone temperatures during a predefined time interval between ETO (earliest turn on) and LTO (latest turn on). If the zone space-weighted temperature is above the upper limit or below the lower limit, the HVAC is turned on. The earlier we are before the time of building occupancy, the wider is the allowable temperature range. The actual slope of the upper- and lower-temperature limits, which will be a function of the particular building and HVAC equipment, essentially being dependent on how long it will take the HVAC equipment to change the interior temperature from some given temperature to meet occupied comfort conditions, is defined by two times (ETO and LTO) and four temperatures (THI, TLI, THF and TLF), which are programmable.

Outside air temperature is sensed and used to determine the optimum shutdown time. The rate at which the building will lose or gain heat is a function of the temperature gradient between the outside environment and the interior space. With small temperature gradients, the building's interior temperature should not change rapidly, and thus the HVAC can be turned off earlier in the day. Conversely, with large temperature gradients (on very hot or very cold days) the HVAC will have to be kept on longer. ITC monitors outside air temperature and uses this information to determine when in the interval between ESD (earliest shutdown) and LSD (latest shutdown) to turn off the HVAC. The parameters (OHI, OLI, OHF, OLF, ESD and LSD) are programmable from the front panel.

The control algorithm provides the flexibility of handling severe weather conditions as well as mild conditions, accordingly minimizing the HVAC equipment operation while maintaining the required temperature range for normal working hours.

ITC Hardware

The ITC is designed around the National Semiconductor SC/MP microprocessor, a rugged but extremely limited unit. Due to its limited features, SC/MP software support is not easily available. It was found during debugging that development of machine language programs for the SC/MP can be difficult and frustrating due to its limited instruction set.

The ITC has three memory cards, each card containing 10K of memory composed of 8K of programmable read only memory (PROM) and 2K of random access memory (RAM). The total memory can be expanded with additional memory cards available only from the contractor. This is due to the unique bus structure used in the prototype ITCs. The 24K PROM space is made up of 4K for the RPL interpreter (a BASIC-like interpreter), 2K for machine language subroutines, and 18K for the RPL programs. Of the 18K of RPL program, approximately 6K are programs relating to the ASCII display, a significant memory overhead for the use of the display. Of the 6K of RAM, less than 4K are used for scratch pad and parameter storage.

The overall hardware of the ITC reflected extremely poor quality control on the part of the contractor. Although both ITCs were supposed to be identical, several cards differed from one unit to the other, and some of the pc cards worked in one unit and not the other. Also several boards operated in one position of the back plane but not another for no apparent reason. The difficulty of hardware debugging, which also included detecting some bad IC chips, was compounded by the woeful lack of documentation. An underrated power supply (rated at 5v, 3a but operating at 4.5a) which caused overheating and intermittent failures was another frustrating problem. In addition, one unit did not have a power supply for its ASCII display. The ITC, although capable of handling 32 analog inputs, 64 digital inputs and 16 digital controls, had connectors for only 16 analog inputs, 32 digital inputs and 8 digital controls. In spite of these hardware deficiencies and in view of the long delays, and problems experienced, we were indeed fortunate to have even two semi-operational units.

ITC Software

The ITC operates with a BASIC-like interpreter, a feature which greatly simplified software development and debugging. With the amount of software, debugging would have been nearly impossible if it was in machine language. Documentation on the software was poor, however the use of the BASIC-like interpreter allowed anyone with some rudiments of programming experience to write and modify control routines of ITC. The ITC software itself was awkward in structure, owing to the many fixes required to correct software bugs. To help alleviate the problem, CEL completely rewrote many of the control subroutines.

Although awkward in structure, the software reflects the basic concept of modular software. With modular software, each control function is contained in a separate module or subroutine. Thus, by additions of more software modules, the control functions of the ITC can be augmented without extensive software modifications.

ITC Field Operation and Monitoring

One ITC was installed on 28 April 1980 in Building 560 at the Civil Engineering Laboratory, Port Hueneme, Ca 93043, to control the steam heating system. Eight temperature sensors were used, seven for interior spaces and one for outside air temperature. A motorized valve in the steam line is controlled based on the space weighted average interior temperature and outside air temperature. The installation is shown in Figure 3. The ITC replaced a mechanical time clock which was set to turn on the steam at 0530 and off at 1230 (seven hours each day.)

The control algorithm that was programmed in at CEL is shown in Figure 4. Since CEL has only a heating system, no cooling, just the lower limit of temperature was implemented with the upper limits set at some arbitrarily high values. With the mild climate at CEL and due to the particular characteristics of Building 560, LTO and ESD were defined to be the same. Thus between ETO and LTO, the ITC will monitor interior temperatures to determine when the heating should be turned on; and between ESD and LSD, it will check to determine when to turn the heat off. If, by LTO, the heat has not been turned on (ITC has determined heating is not required), then the heating system will be off for the entire day, i.e., there is not a period of time when the heating is defined as being "on" as with the general control algorithm (Figure 2).

In 3 weeks (15 working days) of operation, the ITC turned the steam on for a cumulative time of 25 hr, 30 min, or an average of 2 hr, 22 min per day. This compares favorably with the 7 hr per day that the mechanical time clock would have turned on the steam. During the period, the lowest temperature recorded during working hours was 67°.

Also, in the 3 weeks of ITC control, the amount of natural gas usage by the boiler plant at the CEL complex, decreased on the average 18.6% as compared to the weekly average for the previous 2 months. This decrease is directly attributable to the decrease in steam load due to the shutting off of steam to Building 560. It should be noted that maximum savings obtained from an intelligent control device would occur in the spring and fall when climatic conditions are not severe. Less savings would be expected during the cold winter months.

It is impossible to generalize the specific amount of savings that would be obtained from the installation of an ITC in any particular buildings. This would be dependent on many conditions such as climate, building characteristics, HVAC properties, actual control performed, etc. However, the programmable nature of the ITC makes it flexible enough for use in a wide range of applications, where it can save significant amounts of energy.

CONCLUSIONS

The ITC project was a pioneer effort to develop a low-cost, fixed-algorithm, "intelligent" control device with the capability of stand-alone operation as well as operation as part of a larger control network. Despite the problems experienced during the contract in getting the prototypes operational, the ITCs are operational today, and have demonstrated that significant energy savings can be achieved over conventional control units.

Particular amounts of savings from the use of an intelligent control device will be dependent on a variety of factors such as weather, building and HVAC characteristics, control function performed, etc. However, the ITC is programmable to allow use in a wide range of applications. In addition, it provides monitoring and data acquisition features which allow the user to iteratively determine the optimum input parameters for any particular applications.

During field evaluation at the Civil Engineering Laboratory, Port Hueneme, CA in the spring of 1980, the ITC provided a savings of 18.6% in natural gas usage while controlling the steam heating system. This savings was achieved over the performance of a conventional mechanical time clock.

An intelligent control device must possess certain features to perform effectively in any control application. It must have a real time clock to do time of day control. In addition, the real time clock should have a backup power capability to operate during power outages. Analog and digital input capability to monitor actual conditions such as temperature, on/off status, are required in addition to digital output control capability (to turn equipment on and/or off). The device must be programmable, to allow application in diverse environments and situations. It must have monitoring and data acquisition capability to allow optimizing of the operation of the device in any particular operation. Documentation on both software and hardware is required, which includes software listing and description, memory and I/O mapping, and hardware schematics. For added flexibility and ease of software modification, software should be modular in nature.

For expansion capability, i.e., to be able to incorporate the device into a large-scale system, additional features are desired. The device should have a standard interface connection such as RS-232, IEEE-488, 20 ma, etc., to be able to communicate with other devices. It should be based on an industry standard microprocessor as the 8080 family, Z-80 family, 6800 family etc., such that software support may be obtained from a variety of sources. Also, for ease of hardware expansion, the device should utilize a recognized industry standard bus, such as the Multi-bus, S-100, etc.

Intelligent control devices such as the Intelligent Time Clock have demonstrated significant energy savings over conventional control devices in many control applications. These devices are the forerunners of single building EMCS. Single building EMCS are being developed to effectively control single buildings or clusters of buildings with the capability of being incorporated into a larger EMCS at a later date.

BIBLIOGRAPHY

1. Civil Engineering Laboratory, TDS 77-15: Selecting an energy management system, by Dr. Roger Staab, Port Hueneme, Calif., Jul 1977.

2. __________. TM No. M-62-77-06: Selecting an energy management system, by Dr. Roger Staab, Port Hueneme, Calif., Feb 1977.

3. __________. TM No. M-62-77-21: Localized energy control systems for Navy buildings, by Dr. Roger Staab, Port Hueneme, Calif., Sep 1977.

4. __________. TM No. M-62-78-13: Microprocessor timeclock for localized energy control, by Dallas Shiroma, Dr. Roger Staab, Port Hueneme, Calif., Sep 1978.

5. Staab, R. I., and D. Shiroma (1978), "Microprocessor timeclock for localized energy control," presented at 5th Annual UMR-DNR Conference and Exposition on Energy, University of Missouri-Rolla, Oct 10-12, 1978.

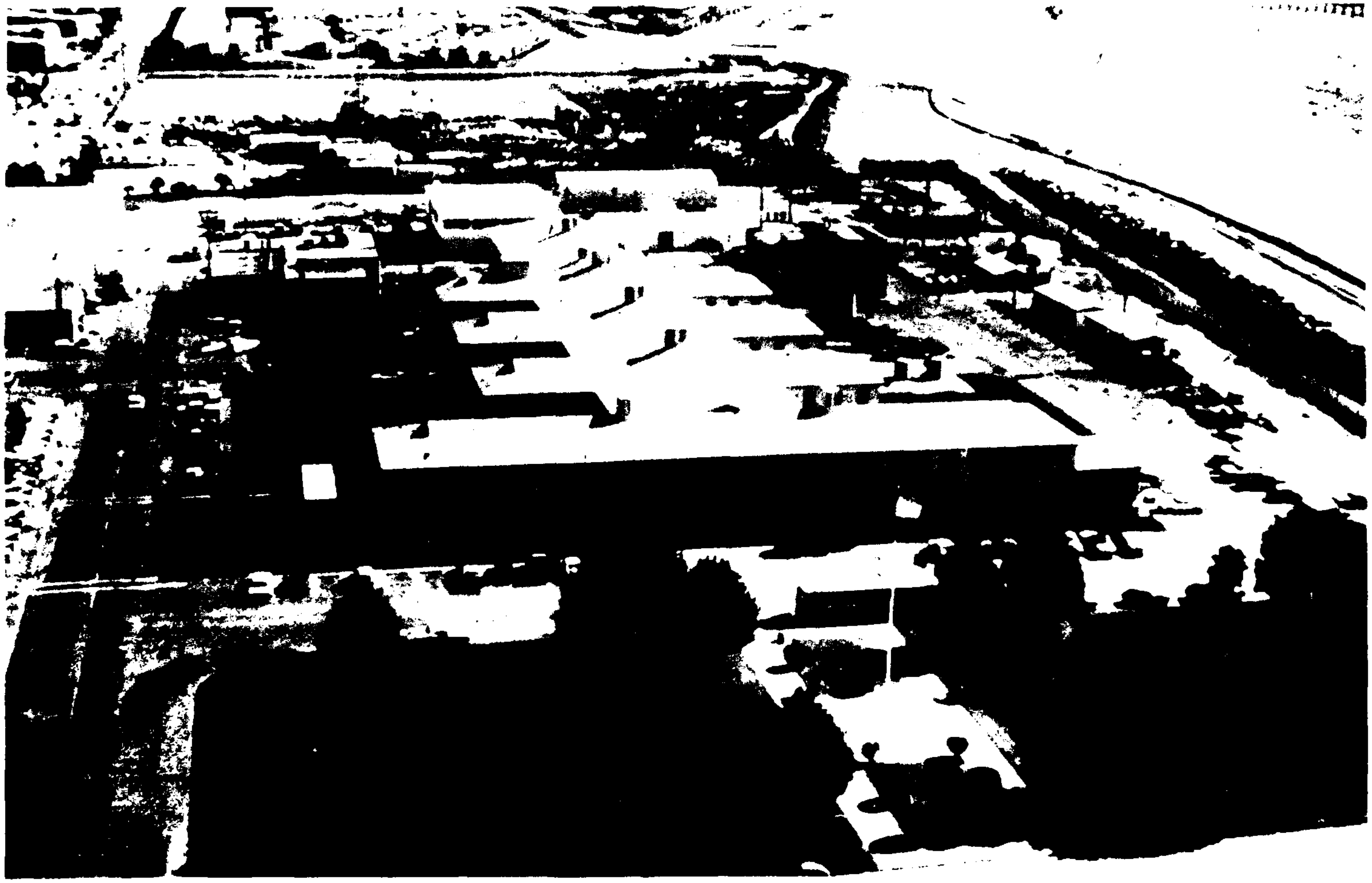

Figure 1. Aerial view of Building 560 at Civil Engineering Laboratory, Port Hueneme, CA.

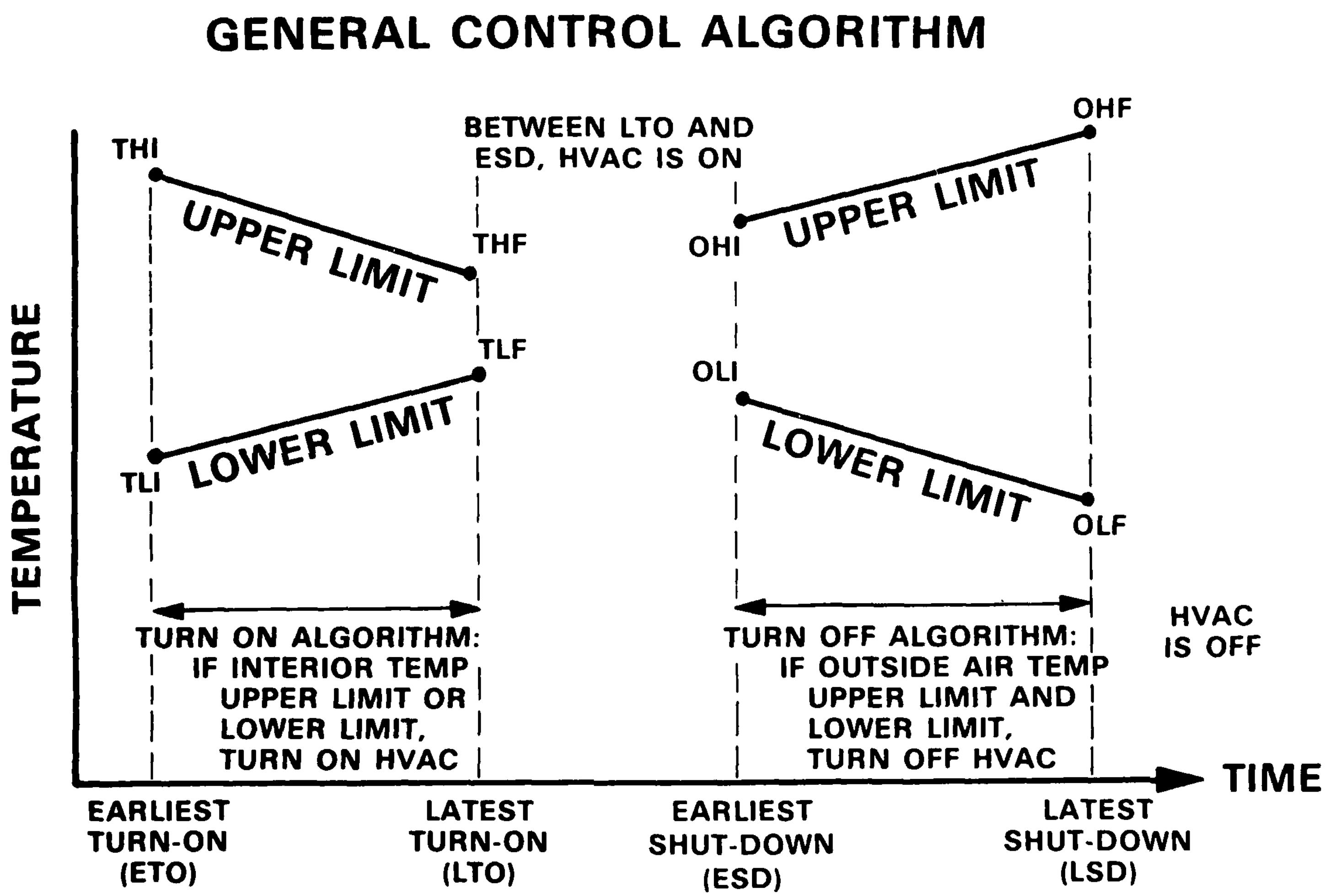

Figure 2. Optimized start/stop control algorithm.

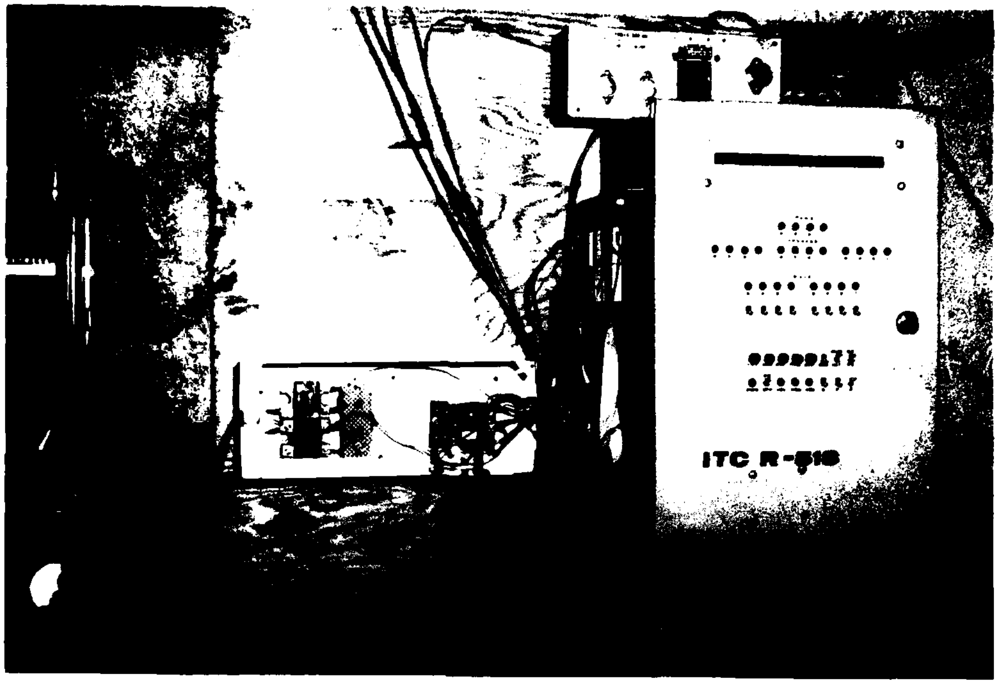

Figure 3a. ITC installation at CEL.

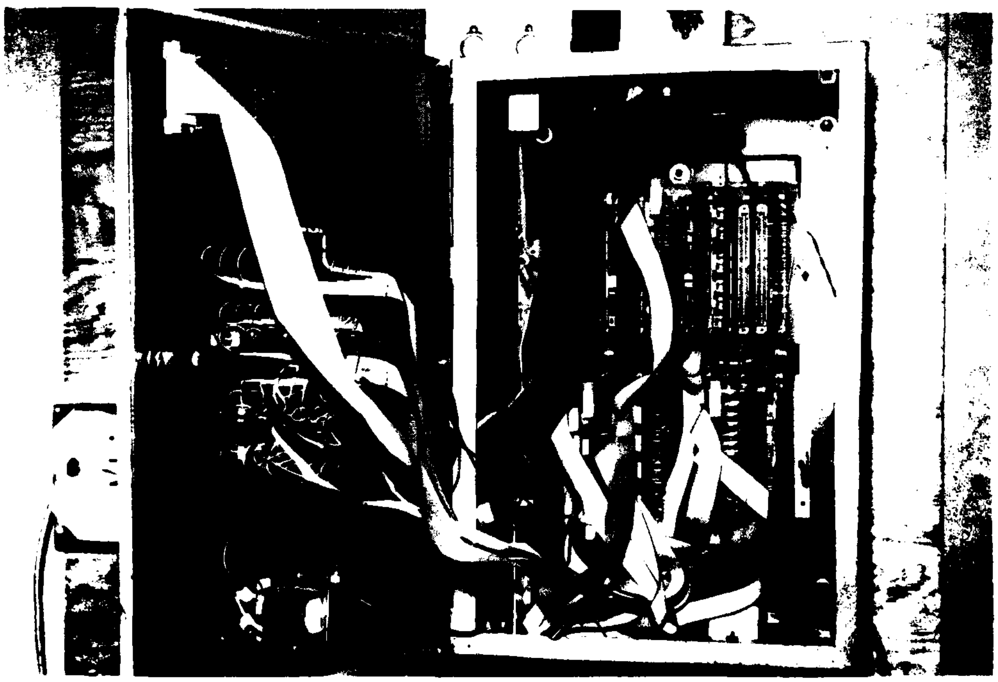

Figure 3b. Interior view of ITC.

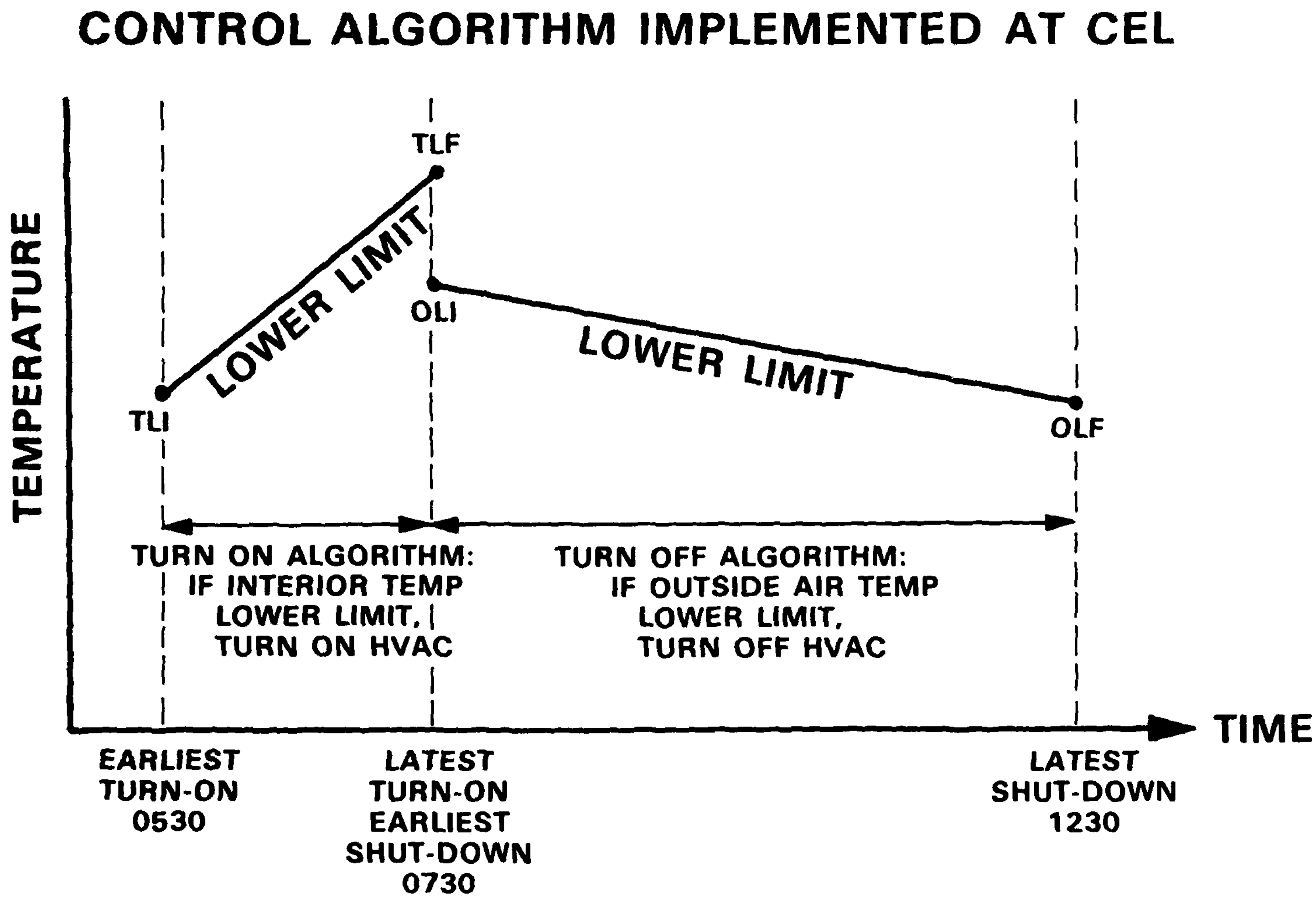

Figure 4. Steam-heating system control at CEL.

DISTRIBUTION LIST

AAP NAVORDSTA IND HD DET PW ENGRNG DIV, McAlester, OK
AFB (AFIT/LD), Wright-Patterson OH; ABG/DEE (F. Nethers), Goodfellow AFB TX; AF Tech Office (Mgt & Ops), Tyndall, FL; AFCEC/XR,Tyndall FL; AUL/LSE 63-465, Maxwell AL; CESCH, Wright-Patterson; HQ Tactical Air Cmd (R. E. Fisher), Langley AFB VA; MAC/DET (Col. P. Thompson) Scott, IL; SAMSO/MNND, Norton AFB CA; Samso, Vandenburg, AFB, CA; Stinfo Library, Offutt NE
ARMY BMDSC-RE (H. McClellan) Huntsville AL; DAEN-CWE-M (LT C D Binning), Washington DC; DAEN-MPE-D Washington DC; DAEN-MPU, Washington DC; ERADCOM Tech Supp Dir. (DELSD-L) Ft. Monmouth, NJ; Engr District (Memphis) Library, Memphis TN; Natick Cen (Kwoh Hu) Natick MA; Tech. Ref. Div., Fort Huachuca, AZ
ARMY - CERL Library, Champaign IL
ARMY AMMUNITION PLANT Sarhw - FEM Hawthorne, NY
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY CRREL G. Phetteplace Hanover, NH
ARMY DARCOM AMCPM-CS (J. Carr), Alexandria VA
ARMY ENG DIV HNDED-CS, Huntsville AL; HNDED-SR, Huntsville, AL
ARMY ENGR DIST. Library, Portland OR
ARMY ENVIRON. HYGIENE AGCY Water Qual Div (Doner), Aberdeen Prov Ground, MD
ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Lenoe, Watertown MA
ARMY MISSILE R&D CMD Redstone Arsenal AL Sci. Info. Cen (Documents)
ASO PWD (ENS J.A. Jenkins), Philadelphia, PA
ASST SECRETARY OF THE NAVY Spec. Assist Energy (Leonard), Washington, DC
BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO
CINCLANT Civil Engr. Supp. Plans. Ofr Norfolk, VA
CNAVRES Code 13 (Dir. Facilities) New Orleans, LA
CNM Code MAT-08T3, Washington, DC
CNO Code NOP-964, Washington DC; Code OP 987 Washington DC; Code OP-413 Wash, DC; Code OPNAV 09B24 (H); OP987J (J. Boosman), Pentagon
COMFLEACT, OKINAWA PWO, Kadena, Okinawa
COMNAVMARIANAS Code N4, Guam
COMOCEANSYSPAC SCE, Pearl Harbor HI
COMSUBDEVGRUONE Operations Offr, San Diego, CA
DEFENSE CIVIL PREPAREDNESS AGENCY J.O. Buchanan, Washington DC
DEFENSE DOCUMENTATION CTR Defense Technical Info Ctr/Alexandria, VA
DOD Staff Spec. Chem. Tech. Washington DC
DOE F.F. Parry, Washington DC; INEL Tech. Lib. (Reports Section), Idaho Falls, ID; Liffick, Richmond, WA; P. Jordan Washington, DC
DTIC Defense Technical Info Ctr/Alexandria, VA
DTNSRDC Code 4111 (R. Gierich), Bethesda MD; Code 42, Bethesda MD
DTNSRDC Code 522 (Library), Annapolis MD
ENVIRONMENTAL PROTECTION AGENCY Reg. VIII, 8M-ASL, Denver CO
FLTCOMBATTRACENLANT PWO, Virginia Bch VA
GSA Fed. Sup. Serv. (FMBP), Washington DC; Office of Const. Mgmt (M. Whitley), Washington DC
KWAJALEIN MISRAN BMDSC-RKL-C
LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)
MARINE CORPS BASE Camp Pendleton CA 92055; Code 43-260, Camp Lejeune NC; M & R Division, Camp Lejeune NC; PWO Camp Lejeune NC; PWO, Camp S. D. Butler, Kawasaki Japan
MARINE CORPS HQS Code LFF-2, Washington DC
MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code PWE, Kaneohe Bay HI; Code S4, Quantico VA; PWD, Dir. Maint. Control Div., Iwakuni Japan; PWO Kaneohe Bay HI; PWO, Yuma AZ; SCE, Futema Japan
MCDEC NSAP REP, Quantico VA
MCLSBPAC B520, Barstow CA; PWO, Barstow CA
MCRD PWO, San Diego Ca
NAF PWD - Engr Div, Atsugi, Japan; PWO Sigonella Sicily; PWO, Atsugi Japan

NALF OINC, San Diego, CA
NARF Code 100, Cherry Point, NC; Code 612, Jax, FL; Code 640, Pensacola FL
NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 187, Jacksonville FL; Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 6234 (G. Trask), Point Mugu CA; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir. Util. Div., Bermuda; ENS Buchholz, Pensacola, FL; Lakehurst, NJ; Lead. Chief. Petty Offr. PW/Self Help Div, Beeville TX; PW (J. Maguire), Corpus Christi TX; PWD Maint. Cont. Dir., Fallon NV; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Maintenance Control Dir., Bermuda; PWD, Willow Grove PA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO Whiting Fld, Milton FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO., Moffett Field CA; ROICC Key West FL; SCE Lant Fleet Norfolk, VA; SCE Norfolk, VA; SCE, Barbers Point HI; Security Offr, Alameda CA
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NATNAVMEDCEN PWO Bethesda, MD
NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVCOASTSYSTCTR CO, Panama City FL; Code 423 (D. Good), Panama City FL; Code 713 (J. Quirk) Panama City, FL; Library Panama City, FL
NAVCOMMAREAMSTRSTA PWO, Norfolk VA; PWO, Wahiawa HI; SCE Unit 1 Naples Italy
NAVCOMMSTA CO (61E) Puerto Rico; Code 401 Nea Makri, Greece; PWO, Exmouth, Australia; PWO, Fort Amador Canal Zone
NAVEDTRAPRODEVCEN Tech. Library
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVENVIRHLTHCEN CO, Norfolk, VA
NAVFAC PWO, Brawdy Wales UK; PWO, Cape Hatteras, Buxton NC; PWO, Centerville Bch, Ferndale CA; PWO, Guam
NAVFAC PWO, Lewes DE
NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0451 Alexandria, VA; Code 0454B Alexandria, Va; Code 046; Code 0461D (V M Spaulding) Alexandria, VA; Code 04B3 Alexandria, VA; Code 081B Alexandria, VA; Code 100 Alexandria, VA; Code 1023 (T. D. Stevens), Alexandria VA; Code 1113 (M. Carr) Alexandria, VA; Code 1113 (T. Stevens) Alexandria, VA; Morrison Yap, Caroline Is.
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 102, (Wildman), Wash, DC; Code 403 (H. DeVoe) Wash, DC; Code FPO-1 Wash, DC
NAVFACENGCOM - LANT DIV. CDR E. Peltier; Code 10A, Norfolk VA; Code 111, Norfolk, VA; Eur. BR Deputy Dir, Naples Italy; European Branch, New York; RDT&ELO 102, Norfolk VA
NAVFACENGCOM - NORTH DIV. CO; Code 09P (LCDR A.J. Stewart); Code 1028, RDT&ELO, Philadelphia PA; Code 111 (Castranovo) Philadelphia, PA; Design Div. (R. Masino), Philadelphia PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC
NAVFACENGCOM - WEST DIV. 102; 112; AROICC, Contracts, Twentynine Palms CA; Code 04B San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACT AROICC, Quantico, VA; Code 05, TRIDENT, Bremerton WA; Code 09E, TRIDENT, Bremerton WA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; Engr. Div. (F. Hein), Madrid, Spain; OICC (Knowlton), Kaneohe, HI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC AF Guam; ROICC, Keflavik, Iceland; ROICC, Pacific, San Bruno CA
NAVMAG SCE, Guam
NAVNUPWRU MUSE DET Code NPU-30 Port Hueneme, CA
NAVOCEANSYSCEN Code 41, San Diego, CA; Code 523 (Hurley), San Diego, CA; Code 6700, San Diego, CA; Code 811 San Diego, CA; Research Lib., San Diego CA; Tech. Library, Code 447
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA
NAVRADRECFAC PWO, Kami Seya Japan

NAVREGMEDCEN Code 3041, Memphis, Millington TN; PWO Newport RI; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Guam; SCE, Oakland CA
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code OOC (LT R. MacDougal), Washington DC; Code SEA OOC Washington, DC
NAVSEC Code 6034 (Library), Washington DC
NAVSECGRUACT PWO, Adak AK; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSHIPREPFAC Library, Guam
NAVSHIPYD Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, (Woodroff) Norfolk, Portsmouth, VA; Code 400, Puget Sound; Code 400.03 Long Beach, CA; Code 404 (LT J. Riccio), Norfolk, Portsmouth VA; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 450, Charleston SC; Code 453 (Util. Supr), Vallejo CA; L.D. Vivian; Library, Portsmouth NH; PWD (Code 400), Philadelphia PA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI
NAVSTA AROICC, Brooklyn NY; CO Naval Station, Mayport FL; CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY; Dir Mech Engr, Gtmo; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Canal Zone; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWO Midway Island; PWO, Guantanamo Bay Cuba; PWO, Keflavik Iceland; PWO, Mayport FL; ROICC Rota Spain; ROICC, Rota Spain; SCE, Guam; SCE, San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. (A.S. Ritchie), Rota Spain
NAVSUBASE ENS S. Dove, Groton, CT; SCE, Pearl Harbor HI
NAVSUPPACT CO, Seattle WA
NAVSTA Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA
NAVSUPPACT Code 413, Seattle WA; LTJG McGarrah, SEC, Vallejo, CA; Plan/Engr Div., Naples Italy
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVUSEAWARENGSTA Keyport, WA
NAVWPNCEN Code 2636 (W. Bonner), China Lake CA; PWO (Code 26), China Lake CA; ROICC (Code 702), China Lake CA
NAVWPNEVALFAC Technical Library, Albuquerque NM
NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ; Code 092A (C. Fredericks) Seal Beach CA; Maint. Control Dir., Yorktown VA
NAVWPNSTA PW Office (Code 09C1) Yorktown, VA
NAVWPNSTA PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCBU 405 OIC, San Diego, CA
NCBC Code 10 Davisville, RI; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 400, Gulfport MS; NESO Code 251 P.R. Winter Port Hueneme, CA; PW Engrg. Gulfport MS; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI
NCBU 411 OIC, Norfolk VA
NCR 20, Commander
NCSO BAHRAIN Security Offr, Bahrain
NMCB 5, Operations Dept.; Forty, CO; THREE, Operations Off.
NOAA Library Rockville, MD
NRL Code 8400 Washington, DC
NSC Code 54.1 (Wynne), Norfolk VA
NSD SCE, Subic Bay, R.P.
NTC Commander Orlando, FL; OICC, CBU-401, Great Lakes IL
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT; Code S332, B-80 (J. Wilcox); Code SB 331 (Brown), Newport RI
OCEANSYSLANT LT A.R. Giancola, Norfolk VA
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Pentagon (T. Casberg), Washington, DC
ONR Code 221, Arlington VA; Code 700F Arlington VA; Dr. A. Laufer, Pasadena CA
PHIBCB 1 P&E, Coronado, CA
PMTC Code 3331 (S. Opatowsky) Point Mugu, CA; Pat. Counsel, Point Mugu CA
PWC (Lt E.S. Agonoy) Pensacola, FL; ACE Office (LTJG St. Germain) Norfolk VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; Code 10, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 120C, (Library) San Diego, CA; Code 128, Guam; Code 154, Great Lakes, IL;

Code 200, Great Lakes IL; Code 200, Guam; Code 220 Oakland, CA; Code 220.1, Norfolk VA; Code 30C, San Diego, CA; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 42B (R. Pascua), Pearl Harbor HI; Code 505A (H. Wheeler); Code 600, Great Lakes, IL; Code 601, Oakland, CA; Code 610, San Diego Ca; Code 700, Great Lakes, IL; LTJG J.L. McClaine, Yokosuka, Japan; Utilities Officer, Guam; XO (Code 20) Oakland, CA
SPCC PWO (Code 120) Mechanicsburg PA
TVA Smelser, Knoxville, Tenn.
NAF PWO (Code 30) El Centro, CA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
US DEPT OF COMMERCE NOAA, Pacific Marine Center, Seattle WA
US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA
USAF Jack S. Spencer, Washington, DC
USAF REGIONAL HOSPITAL Fairchild AFB, WA
USCG (G-ECV) Washington Dc; (Smith), Washington, DC
USCG R&D CENTER D. Motherway, Groton CT; Tech. Dir. Groton, CT
USDA Forest Products Lab, Madison WI; Forest Service, Bowers, Atlanta, GA; Forest Service, San Dimas, CA
USNA Ch. Mech. Engr. Dept Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Engr. Div. (C. Wu) Annaplolis MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; Ocean Sys. Eng Dept (Dr. Monney) Annapolis, MD; PWD Engr. Div. (C. Bradford) Annapolis MD; PWO Annapolis MD
ARIZONA State Energy Programs Off., Phoenix AZ
AVALON MUNICIPAL HOSPITAL Avalon, CA
BONNEVILLE POWER ADMIN Portland OR (Energy Consrv. Off., D. Davey)
BROOKHAVEN NATL LAB M. Steinberg, Upton NY
CALIFORNIA STATE UNIVERSITY LONG BEACH, CA (CHELAPATI)
COLUMBIA-PRESBYTERIAN MED. CENTER New York, NY
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
DAMES & MOORE LIBRARY LOS ANGELES, CA
FLORIDA ATLANTIC UNIVERSITY Boca Raton, FL (McAllister)
FLORIDA TECHNOLOGICAL UNIVERSITY ORLANDO, FL (HARTMAN)
FOREST INST. FOR OCEAN & MOUNTAIN Carson City NV (Studies - Library)
FUEL & ENERGY OFFICE CHARLESTON, WV
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
INDIANA ENERGY OFFICE Energy Group, Indianapolis, IN
WOODS HOLE OCEANOGRAPHIC INST. Woods Hole MA (Winget)
KEENE STATE COLLEGE Keene NH (Cunningham)
LEHIGH UNIVERSITY BETHLEHEM, PA (MARINE GEOTECHNICAL LAB., RICHARDS); Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Dept. of Conservation, Baton Rouge LA
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MICHIGAN TECHNOLOGICAL UNIVERSITY Houghton, MI (Haas)
MISSOURI ENERGY AGENCY Jefferson City MO
MIT Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge, MA (Harleman)
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATL ACADEMY OF ENG. ALEXANDRIA, VA (SEARLE, JR.)
NEW HAMPSHIRE Concord, NH, (Governor's Council On Energy)
NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
NYS ENERGY OFFICE Library, Albany NY
POLLUTION ABATEMENT ASSOC. Graham
PURDUE UNIVERSITY Lafayette, IN (Altschaeffl); Lafayette, IN (CE Engr. Lib)
CONNECTICUT Hartford CT (Dept of Plan. & Energy Policy)
SCRIPPS INSTITUTE OF OCEANOGRAPHY LA JOLLA, CA (ADAMS)
SEATTLE U Prof Schwaegler Seattle WA
STANFORD UNIVERSITY Engr Lib, Stanford CA
STATE UNIV. OF NEW YORK Fort Schuyler, NY (Longobardi)
TEXAS A&M UNIVERSITY W.B. Ledbetter College Station, TX

UNIVERSITY OF CALIFORNIA DAVIS, CA (CE DEPT, TAYLOR); Energy Engineer, Davis CA; LIVERMORE, CA (LAWRENCE LIVERMORE LAB, TOKARZ); La Jolla CA (Acq. Dept. Lib. C-075A)
UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.)
UNIVERSITY OF ILLINOIS URBANA, IL (LIBRARY); URBANA, IL (NEWMARK)
UNIVERSITY OF MASSACHUSETTS (Heronemus), Amherst MA CE Dept
UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
UNIVERSITY OF TEXAS AT AUSTIN AUSTIN, TX (THOMPSON)
UNIVERSITY OF WASHINGTON (FH-10, D. Carlson) Seattle, WA; Dept of Civil Engr (Dr. Mattock), Seattle WA; Seattle WA (E. Linger); Seattle, WA Transportation, Construction & Geom. Div
UNIVERSITY OF WISCONSIN Milwaukee WI (Ctr of Great Lakes Studies)
VIRGINIA INST. OF MARINE SCI. Gloucester Point VA (Library)
ARVID GRANT OLYMPIA, WA
ATLANTIC RICHFIELD CO. DALLAS, TX (SMITH)
BAGGS ASSOC. Beaufort, SC
BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
BRITISH EMBASSY Sci. & Tech. Dept. (J. McAuley), Washington DC
BROWN & CALDWELL E M Saunders Walnut Creek, CA
BROWN & ROOT Houston TX (D. Ward)
CANADA Nova Scotia Rsch Found. Corp. Dartmouth, Nova Scotia; Surveyor, Nenninger & Chenevert Inc., Montreal; Trans-Mnt Oil Pipe Lone Corp. Vancouver, BC Canada
CHEMED CORP Lake Zurich IL (Dearborn Chem. Div.Lib.)
COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)
DESIGN SERVICES Beck, Ventura, CA
DILLINGHAM PRECAST F. McHale, Honolulu HI
DIXIE DIVING CENTER Decatur, GA
DURLACH, O'NEAL, JENKINS & ASSOC. Columbia SC
FORD, BACON & DAVIS, INC. New York (Library)
GRUMMAN AEROSPACE CORP. Bethpage NY (Tech. Info. Ctr)
HONEYWELL, INC. Minneapolis MN (Residential Engr Lib.)
MATRECON Oakland, CA (Haxo)
MCDONNEL AIRCRAFT CO. Dept 501 (R.H. Fayman), St Louis MO
MEDERMOTT & CO. Diving Division, Harvey, LA
MIDLAND-ROSS CORP. TOLEDO, OH (RINKER)
NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
PACIFIC MARINE TECHNOLOGY Duvall, WA (Wagner)
PORTLAND CEMENT ASSOC. SKOKIE, IL (CORLEY; SKOKIE, IL (KLIEGER); Skokie IL (Rsch & Dev Lab, Lib.)
RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ
SANDIA LABORATORIES Albuquerque, NM (Vortman); Library Div., Livermore CA
SCHUPACK ASSOC SO. NORWALK, CT (SCHUPACK)
SEAFOOD LABORATORY MOREHEAD CITY, NC (LIBRARY)
SEATECH CORP. MIAMI, FL (PERONI)
SHELL DEVELOPMENT CO. Houston TX (C. Sellars Jr.)
SWEDEN Cement & Concrete Research Inst., Stockholm; VBB (Library), Stockholm
TEXTRON INC BUFFALO, NY (RESEARCH CENTER LIB.)
TRW SYSTEMS REDONDO BEACH, CA (DAI)
UNITED KINGDOM Cement & Concrete Assoc Wexham Springs, Slough Bucks; Library, Bristol; R. Browne, Southall, Middlesex; Taylor, Woodrow Constr (014P), Southall, Middlesex; Taylor, Woodrow Constr (Smith), Southall, Middlesex; Univ. of Bristol (R. Morgan), Bristol
UNITED TECHNOLOGIES Windsor Locks CT (Hamilton Std Div., Library)
WARD, WOLSTENHOLD ARCHITECTS Sacramento, CA
WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan); Library, Pittsburgh PA
WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)
BRAHTZ La Jolla, CA
BRYANT ROSE Johnson Div. UOP, Glendora CA

ERVIN, DOUG Belmont, CA
KETRON, BOB Ft Worth, TX
KRUZIC, T.P. Silver Spring, MD
CAPT MURPHY Sunnyvale, CA
T.W. MERMEL Washington DC

FILMED

2-8