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AUTOMATED POSTATTACK DAMAGE ASSESSMENT SYSTEM (APUDAS) FOR SEWAGE AND MISSION-CRITICAL HVAC SYSTEMS

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
APUDAS stands for Automated Postattack Utilities Damage Assessment System. Currently, there is no automated, real-time, consolidated monitoring system to accomplish a timely, comprehensive, postattack status assessment of overseas air base utilities. These utilities include the electrical distribution, potable water, POL, sewerage, and mission-critical HVAC systems. Neither is there a formal Air Force requirement for an APUDAS, although the need for it was clearly demonstrated in the Airbase Operability exercise, SALTY DEMO, at Spangdahlem AF, FRG in 1985.

An APUDAS consists of sensors distributed throughout a utility network, plus a data communication and processing system. The sensors measure whatever quantities are necessary to determine the utility's operational status. Each sensor signal is fed into a nearby small radio transceiver, which in turn transmits the sensor signal to a central base radio. The base radio feeds all the sensor signals into a central computer, which processes the information for display in such a fashion that it permits a trained observer to quickly determine the utility's operational status, plus locate and assess damage. (Continued)

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19. ABSTRACT (Concluded)

Design concepts for a sewerage system APUDAS, and for an HVAC system APUDAS are described in this report. Both are quite feasible, but neither is cheap. The 20-year life cycle cost for a Tyndall AFB sewerage system APUDAS is approximately 3 million dollars. It will permit an operational status assessment within 20 minutes, allowing 10 minutes for data handling and 10 minutes for human assessment.

Current APUDAS design concepts do not include system control, so an APUDAS is not a full fledged Supervisory Control and Data Acquisition (SCADA) system. However, the potential for making an APUDAS be a SCADA system certainly exists. The barriers are cost, survivability, and reliability.

EXECUTIVE SUMMARY

A. OBJECTIVE: The objective of the effort reported herein was to develop conceptual designs and cost analyses for an automated postattack utilities damage assessment system (APUDAS) for airbase sewerage systems, and for heating, ventilating, and air conditioning (HVAC) systems in mission-critical airbase facilities. Similar work had recently been done for electrical, potable water, and petroleum, oil and lubricant (POL) systems. An APUDAS senses and locates weapon-induced damage to a utility network, so a damage assessment team will not have to search for the damage to assess it.

B. BACKGROUND: The Air Force's current method for locating airbase utility attack damage is to have people manually search for it. This is time-consuming and dangerous, and can be avoided by automation.

C. SCOPE: The scope of the effort reported herein included performing a literature review, then identifying, evaluating, and recommending APUDAS conceptual designs, including sensors, communication links, and control logic for airbase sewerage and mission-critical HVAC systems. The conceptual designs are compatible with the Air Force's Survivable Base Recovery After Attack (BRAAT) Communication System (SBCS).

D. METHODOLOGY: State of the art sensor and data system technology was applied.

E. TEST DESCRIPTION: N/A

F. RESULTS: The required APUDAS conceptual designs were developed, and are described herein.

G. CONCLUSIONS: Automated postattack utility damage assessment is possible within the current state of the art in sensor and data system technology.

H. RECOMMENDATIONS: Conduct an APUDAS field demonstration at a CONUS Air Force base.

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PREFACE

This report was prepared by Applied Research Associates, Inc. (ARA), P.O. Box 40128, Tyndall AFB FL 32403, under contract F08635-88-C-0067, for the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall Air Force Base, Florida 32403-6001.

This report summarizes work done between October 1988 and May 1989. Mr Thomas Hardy was the AFESC/RDCE project officer.

This report has been reviewed by the public affairs office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of the work described herein was to develop conceptual designs and cost analyses for an automated postattack utilities damage assessment system (APUDAS) for air base sewerage systems, and for heating, ventilating, and air conditioning (HVAC) systems in mission-critical air base facilities. Reference 1 describes similar work for electrical, potable water, and petroleum, oil and lubricant (POL) systems. An APUDAS senses and locates weapon-induced damage to a utility network, so a damage assessment team will not have to search for the damage to assess it.

B. BACKGROUND

In a postattack scenario the Air Base Commander needs an accurate and timely assessment of base utilities to carry out a military response to enemy action which may have damaged mission-critical utilities. Among those mission critical utilities are electrical, POL, HVAC, potable water, and sewerage systems. No automated, real-time, consolidated monitoring system is now available to accomplish a timely, comprehensive, postattack status assessment of these utilities. Such a monitoring system would substantially enhance the Base Commander's ability to respond to enemy action. Timely and comprehensive information speeds both the assessment process and the prioritized allocation of personnel, equipment and material to repair/reactivate/replace damaged utilities. At present, information is transmitted over radio and landlines, by assessment teams (with varying degrees of experience and ability) who physically assess the extent of damage. The overall status of mission-critical utilities is not known until the last team reports its findings and all information is consolidated. Furthermore, the volume and complexity of information to be digested is more than people without a computerized monitoring system can handle. For example, the SALTY DEMO damage scenario at Spangdahlem Air Base, FRG in 1985 predicted 253 craters involving major utilities for an eight-attack war, including 153 electrical cable repairs, 29 waterline repairs, and 13 POL repairs. The large amount of information caused widespread confusion, and brought the damage assessment process to a virtual halt. With an automated, postattack utilities damage assessment system (APUDAS), consolidation of information would be rapid and thorough, allowing timely response and prioritized repair resource allocation.

An APUDAS monitors the host system status, provides a damage alert, and displays information from which the approximate locations and extent of damage can quickly be determined. The information displayed by an APUDAS is used to dispatch damage assessment teams to known damage locations, rather than to visually search for damage and then assess it. Thus the number of damage assessment teams, as well as their exposure to hazardous environments can be minimized, and the use of their time optimized. However, an APUDAS will not completely eliminate the need for utility damage assessment teams (DATs). The information displayed by an APUDAS is used to devise a strategy for minimizing the operational impact of utility damage, such as by sealing off a damaged area and routing flow around it, when that is possible. Finally, the displayed information, together with that obtained by damage assessment teams, is used to devise an expedient repair strategy based on repair resource availability.

An APUDAS must interface with the Survivable Base Recovery After Attack (BRAAT) Communication System (SBCS). As of June 1989, the configuration of SBCS had not been well defined. References 2 and 3 are draft specifications and a statement of work for a contract to produce a prototype SBCS. The major concern of many potential SBCS users, including Air Force Civil Engineering, is that the SBCS development schedule will be so compressed that there will be insufficient time for a thorough requirements definition phase. Thus, the prototype may be incapable of servicing all its users.

C. SCOPE

AFESC SETA Subtask 2.04 defined the scope of the effort reported herein to include performing a comprehensive literature review, then identifying, evaluating, and recommending APUDAS conceptual designs, including sensors, communication links, and control logic for airbase sewerage and mission-critical HVAC systems, that will be compatible with SBCS. The end products of this effort were to be APUDAS design concepts and life cycle cost (LCC) analyses for sewerage and mission-critical HVAC systems, together with a statement of the necessary conditions for APUDAS automation on a Wang or equivalent programmable computer. The following five tasks were to be accomplished:

1. Survey the utility industry and commercial equipment sources to identify utility flow and status sensors and equipment that have potential for application in an APUDAS for sewerage systems, and for HVAC systems. Survey four primary equipment functions: utility system flow (voltage/amperage) metering and sensing; *in situ* data recording and transmission; data acquisition; and data processing, storage, and display. Obtain all relevant product data for evaluation, including technical features and performance, cost, vendor information, and delivery lead time.

2. Accomplish a preliminary, first-order assessment of the 20-year life cycle costs of those technically and operationally acceptable APUDAS concepts for sewerage and mission-critical HVAC systems at Tyndall AFB, FL.

3. Recommend to AFESC/RDCE the applicable technology for an airbase sewerage system APUDAS, and for an HVAC system APUDAS. Consider such issues as: peak power requirements, reliability, maintainability, serviceability, safety, spares, survivability, technical risk, security, frequency spectrum availability, development/acquisition time, operation and maintenance (O&M) training requirements, and LCC. Problems unique to the recommended technology (e.g., frequency allocation) shall be singled out for analysis, discussion, and resolution.

4. Develop conceptual designs for an air base sewerage system APUDAS, and for an HVAC system APUDAS, based on the information developed under Tasks 1 through 3 above. A conceptual design consists of a description of the system architecture, sensor/metering hardware installation parameters, telemetry hardware, and data processing, storage and display components. Base the conceptual designs on the following operational concept: maximum use of buried (or overhead for Pacific Air Force (PACAF) electrical distribution) sensing devices, located to clearly define utility operational status; maximum use of radio frequency (RF) data transmission from sensors to the data receiving station; data receiving station and data processing equipment located in the Wing Survival/Recovery Center (SRC) and/or Base Civil Engineer (BCE) Damage Control Center (DCC); and maximum use of ruggedized components for all APUDAS elements. The design of customized instrumentation housings may be specified/required.

5. Prepare a technical report documenting all work accomplished under Tasks 1 through 4 above.

The following sections of this report describe the results of the above effort. Section II discusses APUDAS requirements. Section III deals with sewerage systems, and Section IV with HVAC systems. For both sewerage and HVAC systems, the APUDAS design concept discussion begins with a brief explanation of system function and operational state parameters. Then follows a description of possible damage modes, and definition of the measurements required to detect, locate, and describe damage. Emphasis is on the techniques and equipment recommended for obtaining the necessary measurements. Section V deals with data transmission from individual sensors to the APUDAS host computer, and with the display and analysis of APUDAS data in the SRC and the BCE DCC. Section VI contains a preliminary LCC assessment for the above APUDAS design concepts, for Tyndall AFB, FL. Section VII summarizes the results of the entire effort. As intended by the RDCE Project Officer, the effort reported herein used Reference 1 as a point of departure.

SECTION II

REQUIREMENTS

A. PROGRAMMATIC REQUIREMENTS

There is no Air Force Statement of Need (SON) or Program Management Directive (PMD) for developing or fielding an APUDAS, in either USAFE or PACAF. However, Troubleshooting/Damage Assessment of Utilities is listed as Priority Need 17 in the 1987 Air Force Engineering and Services Needs and Operational Requirements (ESRB) booklet (Reference 4). The OPR is AFESC/DEM. Page 98 of Reference 4 reads as follows:

TITLE: 0204 TROUBLESHOOTING & DAMAGE ASSESSMENT OF UTILITIES

DESCRIPTION: Provide automated technique for assisting in utility damage assessment in combat environment, as well as troubleshooting during peacetime.

MAJCOMs: 1986 ESRB, USAFE, AFCC, AFSC

BASIS OF NEED

- CHANGE IN THREAT
  - COLLATERAL DAMAGE
  - NONNUCLEAR THREAT TO AIR BASES
- DETERIORATION IN PERFORMANCE
  - ACCIDENTAL UTILITY DISRUPTION
- OPPORTUNITIES FOR INCREASED OPERATIONAL EFFECTIVENESS
  - MOS SELECTION
  - COMPREHENSIVE DATABASE FOR PEACETIME EXCAVATION
  - WARTIME RECOVERY
  - RAPID ORIENTATION FOR MOBILITY TEAMS
- OPPORTUNITY FOR REDUCED O&M COSTS
  - COST AND TIME TO REPAIR
  - TIMELY LOCATION OF DAMAGE
  - BETTER UTILIZATION OF ASSETS

CURRENT CAPABILITY/ASSESSMENT

- PEACEKEEPER (RIOT CONTROL VEHICLE)/TIME CONSUMING, COSTLY, VULNERABLE, MANPOWER INTENSIVE
- PLANT-IN-PLACE RECORD /NONCURRENT, DOES NOT INCLUDE COMM

PLANNED CAPABILITY/ASSESSMENT

- AIRFIELD DAMAGE ASSESSMENT SYSTEM/NOT ADAPTED FOR UTILITIES

- MOBILE ARMORED RECONNAISSANCE VEHICLE/IMPROVED SURVIVABILITY, TIME CONSUMING, MANPOWER INTENSIVE

AUTOMATED POSTATTACK UTILITIES DAMAGE ASSESSMENT SYSTEM (APUDAS)/
REAL-TIME ASSESSMENT, PRIORITIZES REPAIR (AFESC/RD)

ALTERNATIVE SOLUTIONS/ASSESSMENT:

NONE

REQUIREMENT

DEVELOP A UTILITY SYSTEM LOCATION, DOCUMENTATION, AND ASSESSMENT SYSTEM FOR USE IN WARTIME AND PEACETIME ENVIRONMENT. SHOULD INCLUDE INTERFACE WITH COMMUNICATIONS FUNCTIONAL ELEMENTS.
(OPR: AFESC/DEM OCR: AFWL/NTE, AFSC AD/YQ)

GRAPHICS DISPLAY TECHNIQUES (AFESC/DEM)

AUTOMATED SENSING AND CONTROL OF UTILITY SYSTEMS (AFESC/DEM)

As noted in Reference 1 (p. 75), a coordinated PMD for APUDAS is required to ensure that total program budget for research, development, acquisition, and installation is identified and programmed. Advocacy and system requirements must originate within operational commands, with strong Airbase Operability support from the Air Force Secretariat (SAF/AQ), The Air Staff (AF/LEE/XOO), AD/YQ, and AFESC.

B. OPERATIONAL REQUIREMENTS

Because APUDAS has no PMD, it also has no system level or interface specification. The functions of APUDAS have been described in Section I. There appears to be no reason to change the APUDAS operational requirements established judgmentally in Reference 1, except for the spatial resolution requirement. They are:

1. APUDAS will be fully operational 24 hours a day.

2. An APUDAS must enable the status of its utility to be assessed within 20 minutes.

3. During peacetime, utility status will be assessed in the BCE Operations Facility.

4. During exercises or wartime, utility status will be assessed in both the BCE DCC, which may be the same as the BCE Operations Facility, and in the SRC or the Alternate Survival/Recovery Center (ASRC).

5. In the event of hostilities, APUDAS must be able to operate without maintenance and with little sunlight for 30 consecutive days.

6. APUDAS battery service life must be at least 6 months, i.e. the battery power system must last at least 6 months before being recharged or replaced.

7. APUDAS components must have at least a 180-day mean time between failure (MTBF).

8. APUDAS must be compatible with the SBCS (References 2 and 3).

9. APUDAS data communication components must be survivable.

10. APUDAS must handle multiple damage locations, and multiple attacks.

11. Pipeline (water, POL, and sewer) damage location spatial resolution must be no coarser than 1/3 mile. This requirement had to be relaxed from the 500 foot requirement stated in Reference 1, to be consistent with Requirement 2 above. See Section V, C for details.

12. Commonality among the APUDAS data communication hardware for the five utilities should be maximized.

SECTION III

SEWERAGE SYSTEM APUDAS DESIGN CONCEPT

A. SEWERAGE SYSTEM FUNCTION

The function of a sewerage system is to convey sanitary and storm sewage (contaminated water) from many collection points to a single or at most a very few treatment plants. There the sewage undergoes physical, biological, and/or chemical treatment until its condition is compatible with the anticipated uses of the body of water into which the treated sewage is released.

Generally, sewer pipeline networks allow the sewage to flow by gravity, so the sewage has a free surface as it undergoes open-channel flow on its way to a treatment plant. At some points a pump (sewage lift station) may be required to force the sewage over a high point in the terrain, but even then the pressurized segments of sewer pipe are generally short with respect to the unpressurized (open-channel) segments. Even under storm conditions, when the pipes are flowing full and surcharged (hydraulic grade line above the pipe crown), the variation of fluid particle velocity over the flow cross-section is more characteristic of open-channel flow than of highly pressurized flow. This means that in sewers, contours of constant fluid particle velocity are generally not circular and concentric about the pipe centerline. The relation between the fluid particle velocity at a particular point in the flow cross-section and the mean velocity (flow rate divided by pipe cross-sectional area) varies with flow depth. This relation is discussed at length in texts dealing with open-channel flow (References 5 through 12).

B. WASTEWATER TREATMENT

Wastewater treatment typically consists of preliminary processes such as screening and grit removal, primary settling to remove heavy solids, and secondary biological aeration to metabolize and flocculate colloidal and dissolved organics. The waste sludge withdrawn during these operations is thickened and processed for safe disposal.

A schematic diagram of a typical wastewater treatment facility is shown in Figure 1. Most modern wastewater treatment facilities can be adequately represented by this schematic. The most significant difference between wastewater treatment facilities centers on the chosen method of biological aeration: trickling filtration versus activated-sludge aeration. Consequently, most modern wastewater treatment facilities can be classified as either trickling-filter plants or activated-sludge plants. Each of the treatment processes indicated in Figure 1 is briefly described below.

Preliminary treatment of municipal wastewater may consist of processes such as screening, comminution or shredding, grit removal, preaeration, flotation, flocculation, and chemical addition. The latter three processes

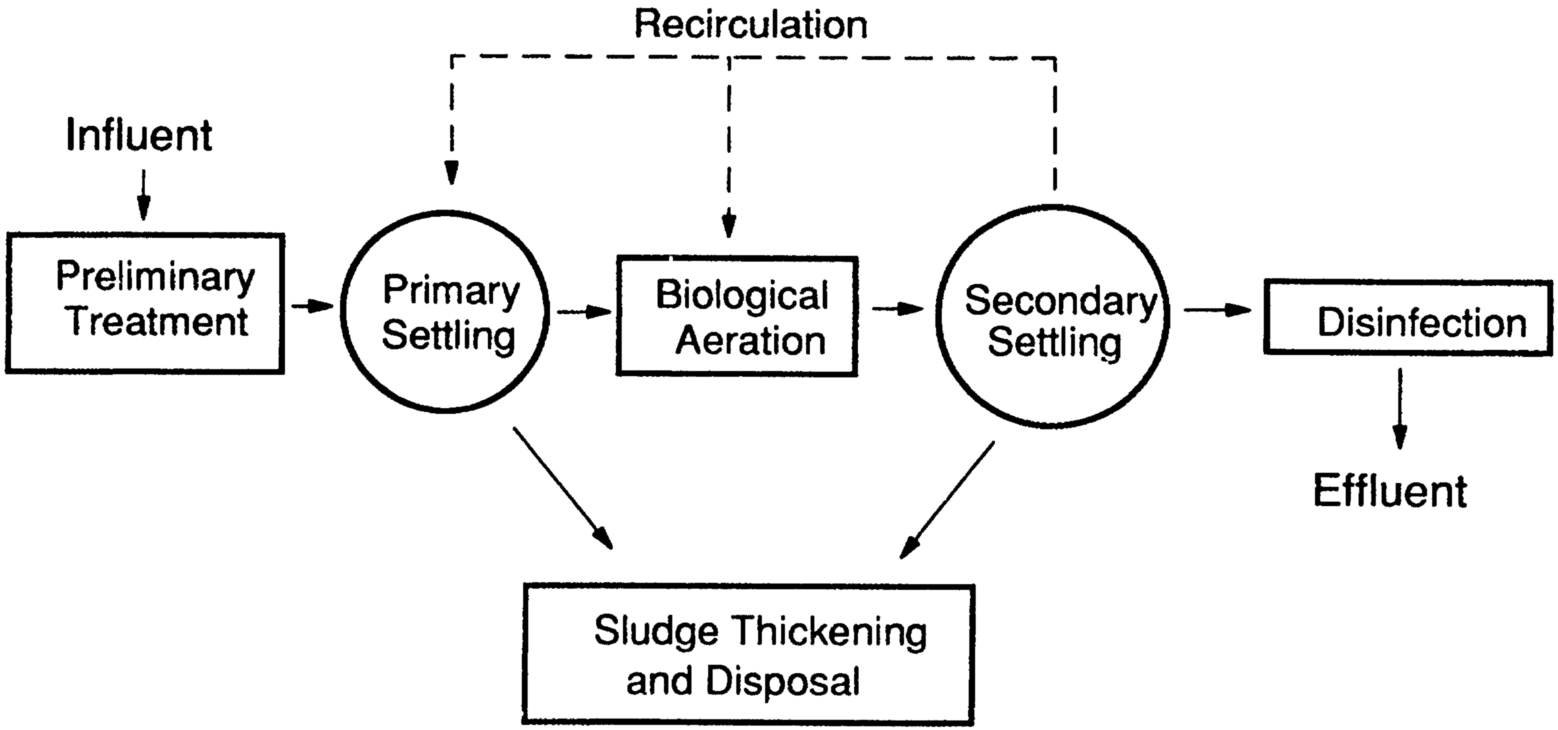

Figure 1. Schematic Diagram of a Typical Wastewater Treatment Facility.

are not required for domestic wastewater treatment, but are required to handle industrial pollutants.

Primary settling is simply sedimentation or settling out of heavy solids in wastewater. The heavy solids settle on the bottom of the primary settling basins. This sediment residue, or sludge, is scraped off the bottom of the settling basins and either pumped to sludge holding tanks or immediately thickened and processed for disposal. Common methods of sludge processing include: digestion, vacuum filtration, and centrifugation. The most common methods of sludge disposal are burial, incineration, and dumping at sea.

Primary sedimentation removes 30-50 percent of the suspended solids from raw municipal wastewater. The remaining organic matter is extracted in the secondary treatment process. Secondary treatment consists of biological aeration and secondary settling. The two most prominent methods of biological aeration are activated-sludge aeration and trickling filtration.

In activated-sludge plants, the effluent from the primary settling basins is fed into an aerated tank, where microorganisms synthesize the organics. The resulting microbial floc, or "activated sludge," is settled from the aerated mixture in the secondary settling basin (secondary clarifier) and returned to the aeration tank.

In trickling-filter plants, the effluent from the primary clarifier "trickles" through a bed of rocks or a synthetic medium supporting microbial film growths. These slime growths extract organics from the wastewater as it trickles through the "filter." Oxygen is supplied from air moving through voids in the medium. Excessive biological growth (humas) washes through the filter and is collected in the secondary clarifier. The excess humas is returned to the primary clarifier.

The effluent from the secondary clarifier may be disinfected or simply discharged. Chlorination is required if the effluent is being discharged to a watercourse used for recreation or water supply.

C. TYNDALL AFB WASTEWATER TREATMENT

The above discussion covers the topic of wastewater treatment in broad terms. Although the basic schematic of Figure 1 applies to all facilities, it is necessary to concentrate on a specific facility in order to discuss the treatment process in detail. Consider the wastewater treatment plant on Tyndall Air Force Base (TAFB), which is a one-stage, trickling-filter plant. A schematic diagram of the TAFB wastewater treatment plant is shown in Figure 2. A summary of the TAFB wastewater treatment process is given below.

The raw wastewater influent entering the plant is deposited at the head of the grit chamber. The channel-type grit chamber (Figure 3) is equipped with a mechanically cleaned bar screen, a comminutor, an aerator, and a mechanical bottom scrapper. The purpose of the bar screen is to prevent large objects from entering the plant. The collected screenings are disposed of by land burial. The comminutor is usually inactive. It is activated only when

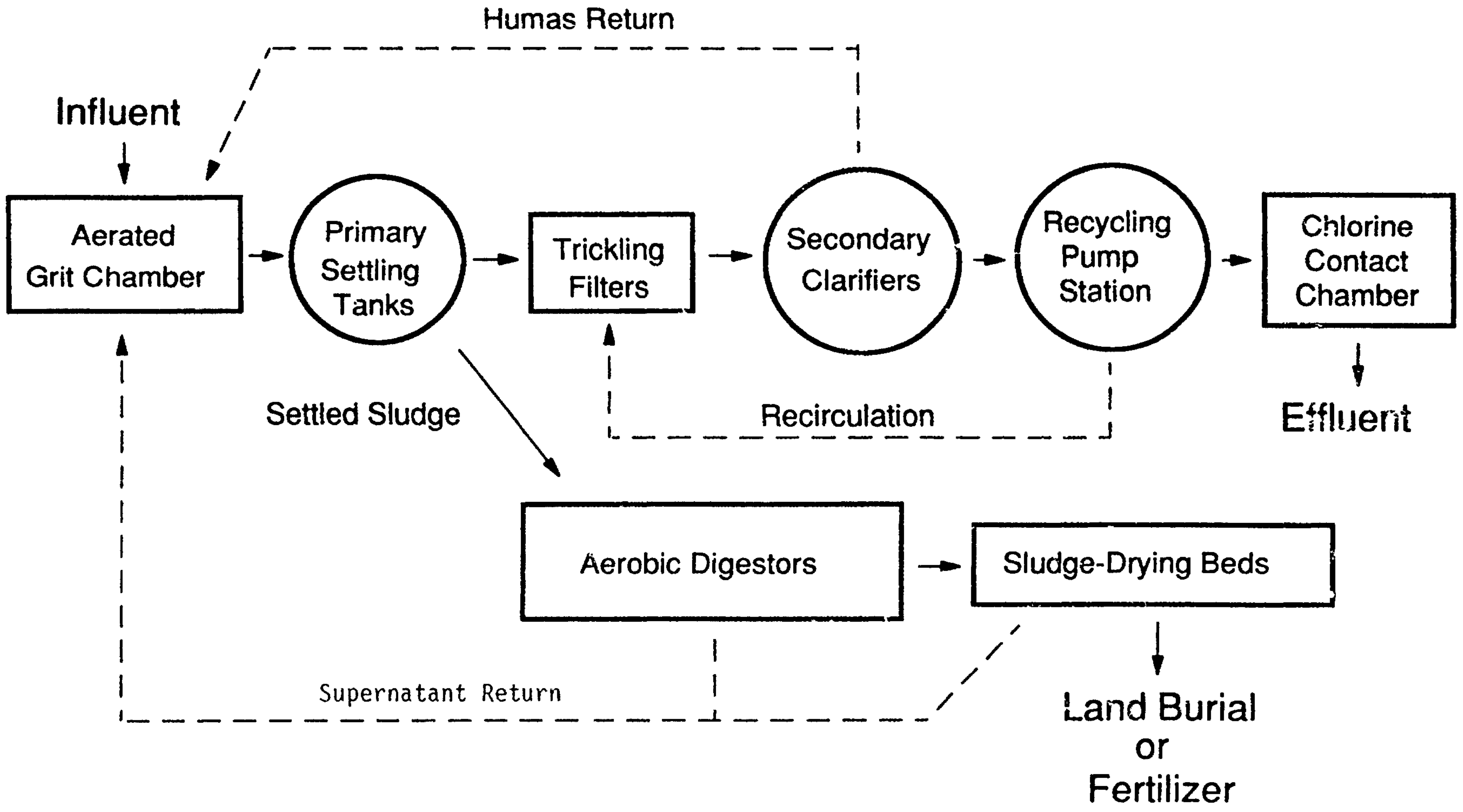

Figure 2. Schematic Diagram of the Tyndall AFB Wastewater Treatment Plant.

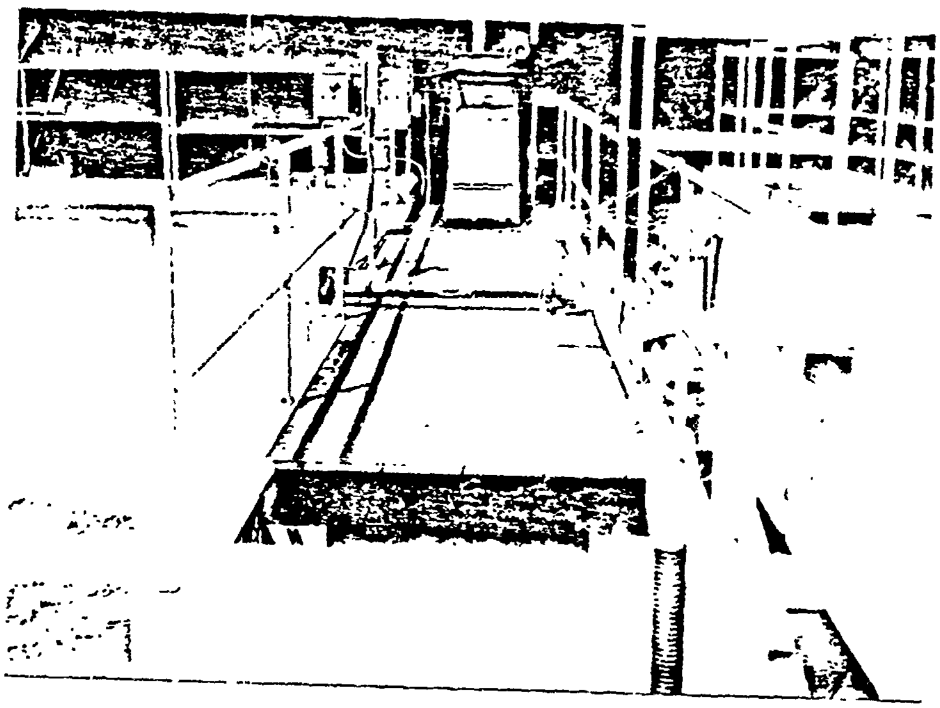

Figure 3. Channel-Type Grit Chamber (Tyndall AFB).

the bar screen is broken. The purpose of the comminutor is to chop up large solids which would otherwise be retained on the bar screen. As the wastewater flows down the grit chamber, it is aerated. Sand and other heavy particulate matter (such as coffee grounds), which settle out of the flow, are scraped out and buried.

The primary settling or sedimentation of the wastewater occurs in a set of five parallel rectangular basins (primary clarifiers) (Figure 4). The sludge which accumulates on the bottom of the basins is collected by mechanical scrapers and pushed into a sludge pit at the head of the basins. The sludge is periodically pumped to the digesters.

The effluent from the primary clarifier is split, and flows into a pair of trickling filters (Figure 5). As the wastewater flows through the voids in the synthetic filters, the microbial slime extracts most of the remaining organic matter.

The excess humas that washes through the trickling filters is settled out in the two cylindrical secondary clarifiers (Figure 6). The humas is scraped off the bottom and returned to the head of the grit chamber.

After secondary clarification the wastewater flows into the recycling pump station. During hours of normal flow (i.e., during the day), the water simply passes through the pump station to the chlorine contact chamber. During periods of low flow (e.g., at night), the water is recirculated back to the trickling filters. This is done to ensure that the flow through the filters remains nearly constant, 24 hours a day.

The chlorine contact chamber (Figure 7) is simply a holding tank for the final plant effluent. This tank allows for contact time, in which the chlorine reacts with the final effluent to kill all pathogenic bacteria and other organisms.

The sludge from the primary clarifier is pumped to the two aerobic digesters (Figure 8) for thickening and stabilization. The supernatant resulting from the thickening process flows by gravity to return pumps at the end of the drying beds, where it is then pumped back to the head of the plant.

After the sludge has been stabilized in the digesters, it is allowed to flow into the drying beds (Figure 9). The drying beds are simply dewatering tanks for the stabilized sludge. Excess supernatant is again pumped back to the head of the plant. After the sludge has dried into a cake, the drying bed is scraped off and the dried sludge is either buried or used for fertilizer.

D. OPERATIONAL STATE PARAMETERS

The sewerage system operational state parameters pertinent to an APUDAS are flow rates. Monitoring the quality of treatment in a wastewater treatment plant is outside the scope of an APUDAS.

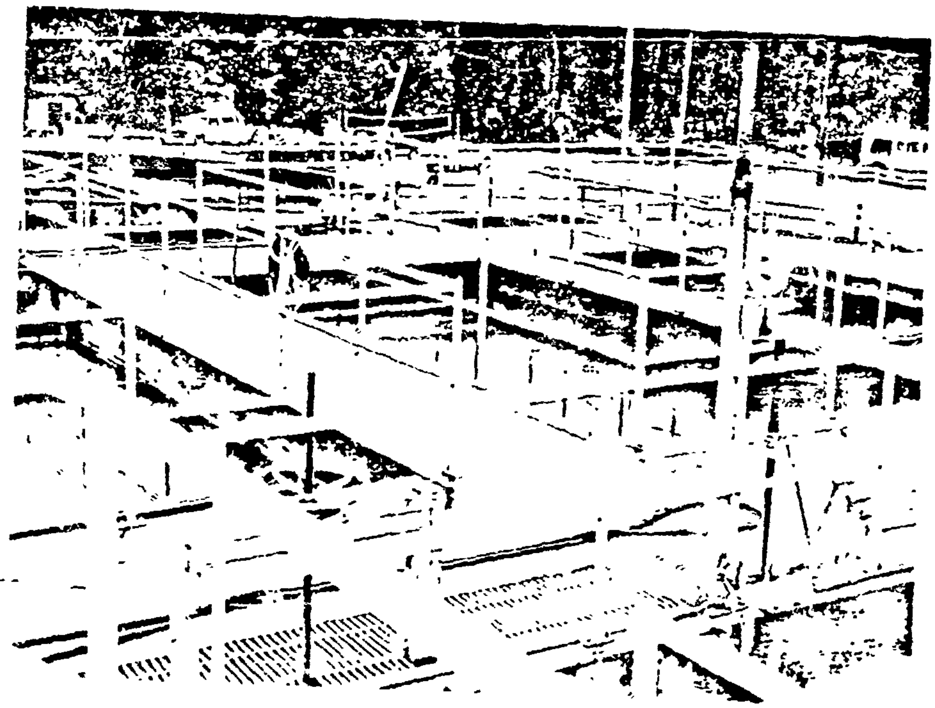

Figure 4. Primary Clarifiers (Tyndall AFB).

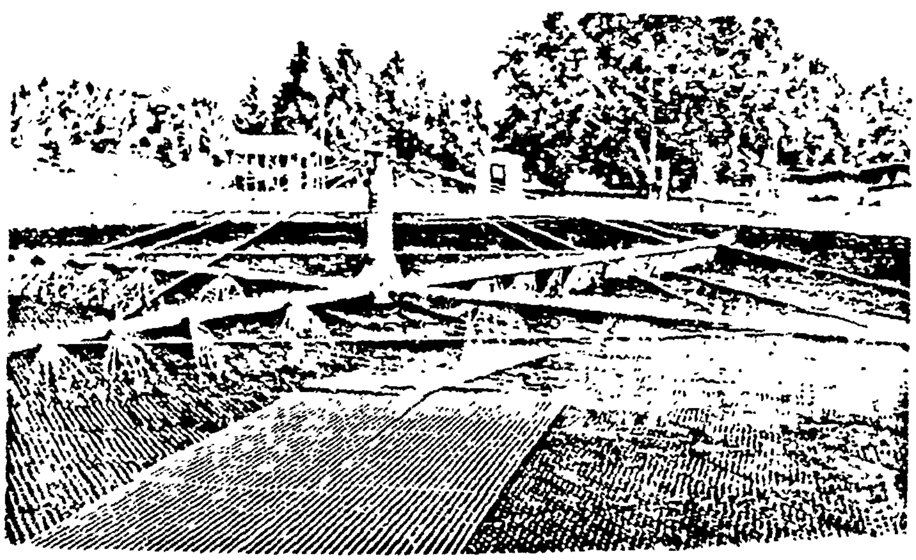

Figure 5. Trickling Filter (Tyndall AFB).

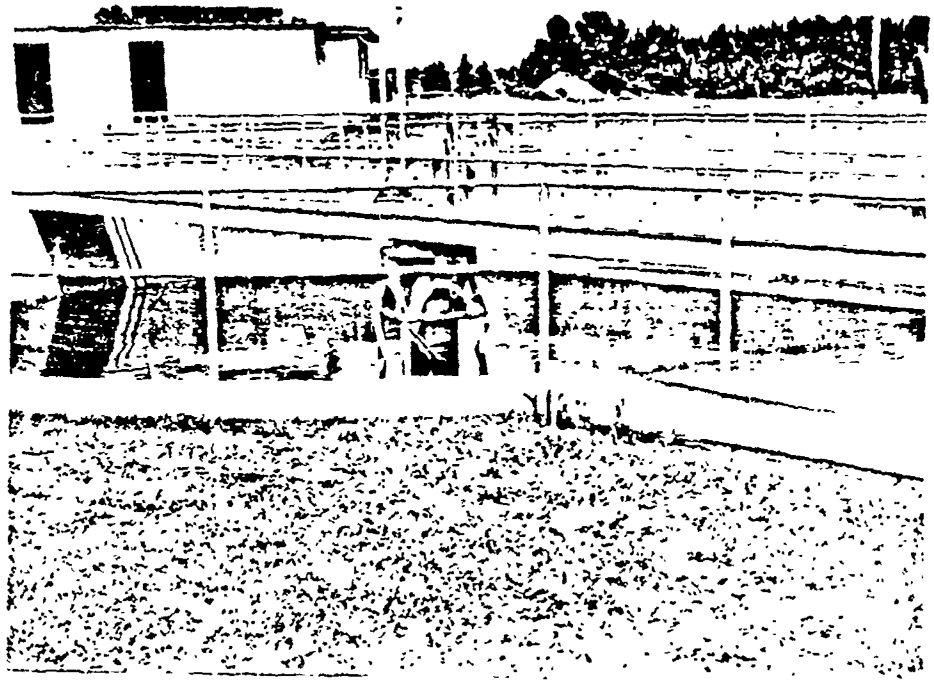

Figure 6. Secondary Clarifier (Tyndall AFB).

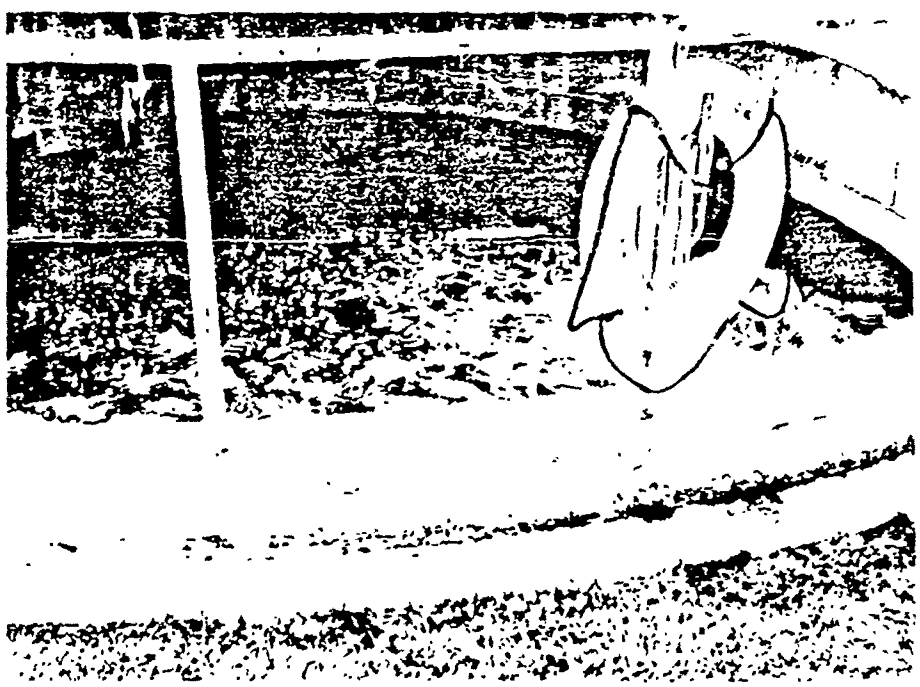

Figure 7. Chlorine Contact Chamber (Tyndall AFB).

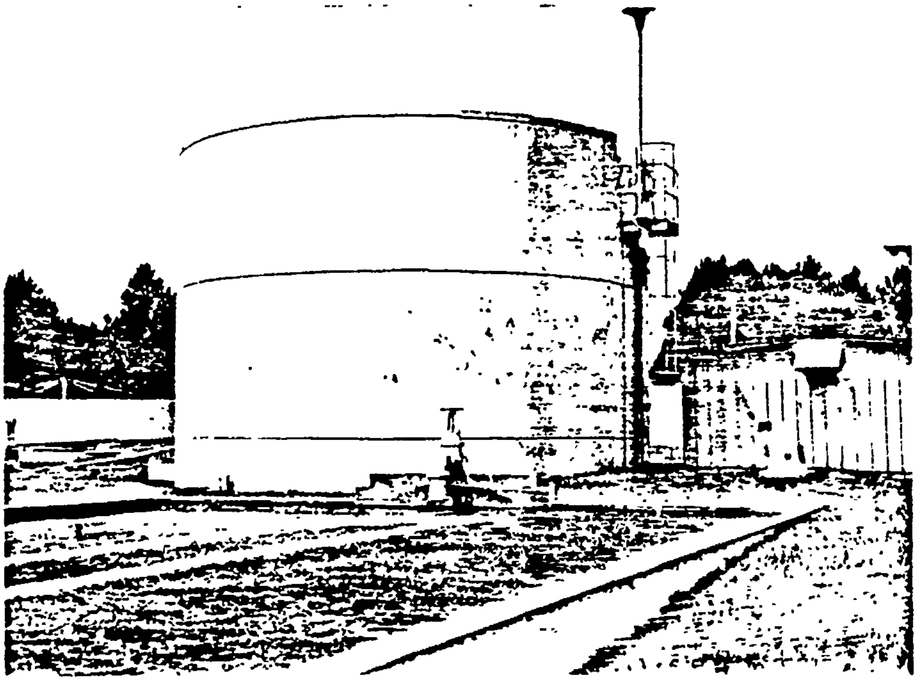

Figure 8. Aerobic Digestor (Tyndall AFB).

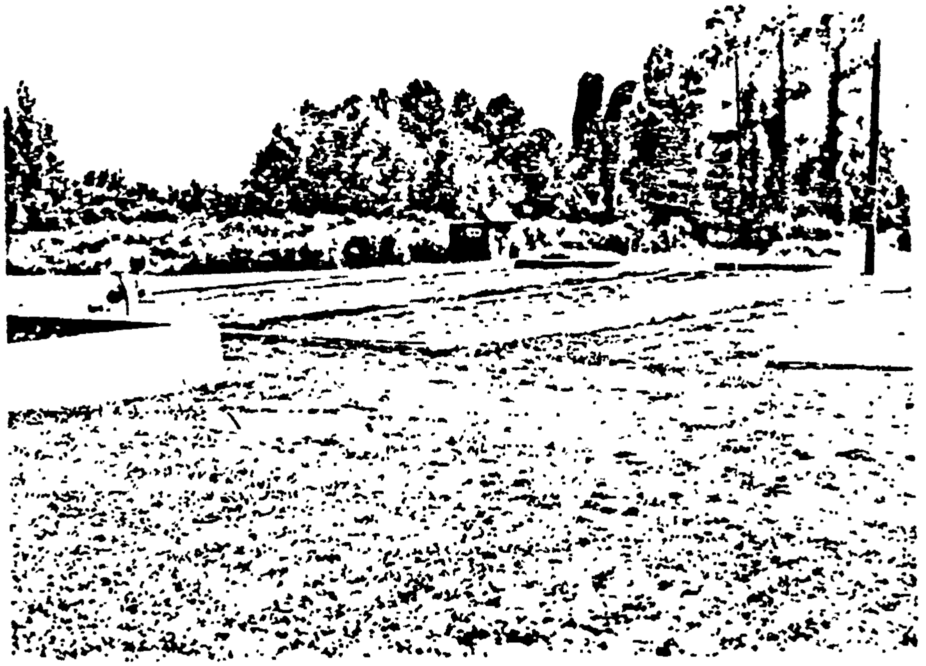

Figure 9. Sludge-Drying Bed (Tyndall AFB).

E. DAMAGE MODES

A conventional weapon detonation can cause a crater which either ruptures a sewer line, causing a massive leak, or plugs the line. In either case, the flow downstream from the damage zone is reduced to zero, or near zero. In the case of a massive leak, the flow rate above the leak increases as the flow approaches the leak. In the case of a plugged line, the flow rate above the leak decreases as the flow approaches the plug.

From the basic schematic diagram of Figure 1 (and the TAFB schematic of Figure 2), it is apparent that major facility damage in a wastewater treatment plant can be detected by simply checking the continuity of flow through the plant. Globally, the volume of treated effluent leaving the plant (V_e), must be approximately equal to the volume of raw wastewater influent (V_i), minus the volume of stabilized sludge (V_s),

$$V_e \approx V_i - V_s \tag{1}$$

The above equality is only approximate because of evaporation during the treatment process.

Equation (1) also applies to each treatment process individually. For example, Equation (1) applies directly to the process of primary clarification. The volume of water leaving the primary clarifier must be approximately equal to the volume of wastewater which entered the clarifier minus the volume of sludge extracted during clarification.

For processes which do not extract sludge, such as chlorination, the continuity equation simplifies to

$$V_e \approx V_i \tag{2}$$

(i.e., the flow out must equal the flow in.)

Equation (2) also applies to any closed piping system in which the flow is steady. The volume of water exiting a section of pipe must equal the volume of water which entered the pipe. If this is not the case, then either there is a break in the pipe, or the flow is unsteady.

Simple continuity checks such as those described above should be sufficient to detect major damage to most components of a modern sewerage system.

F. AUTOMATED DAMAGE ASSESSMENT FOR TYNDALL AFB

To illustrate how the simple flow continuity concept would be applied, consider the TAFB wastewater treatment plant. A detailed schematic of the TAFB plant is shown in Figure 10. Figure 10 is a more accurate representation of how the wastewater is actually directed through the plant, than that shown in Figure 2. Notice how the flow is separated and then rejoined as it passes through the trickling filters and the secondary clarifiers. This gives the

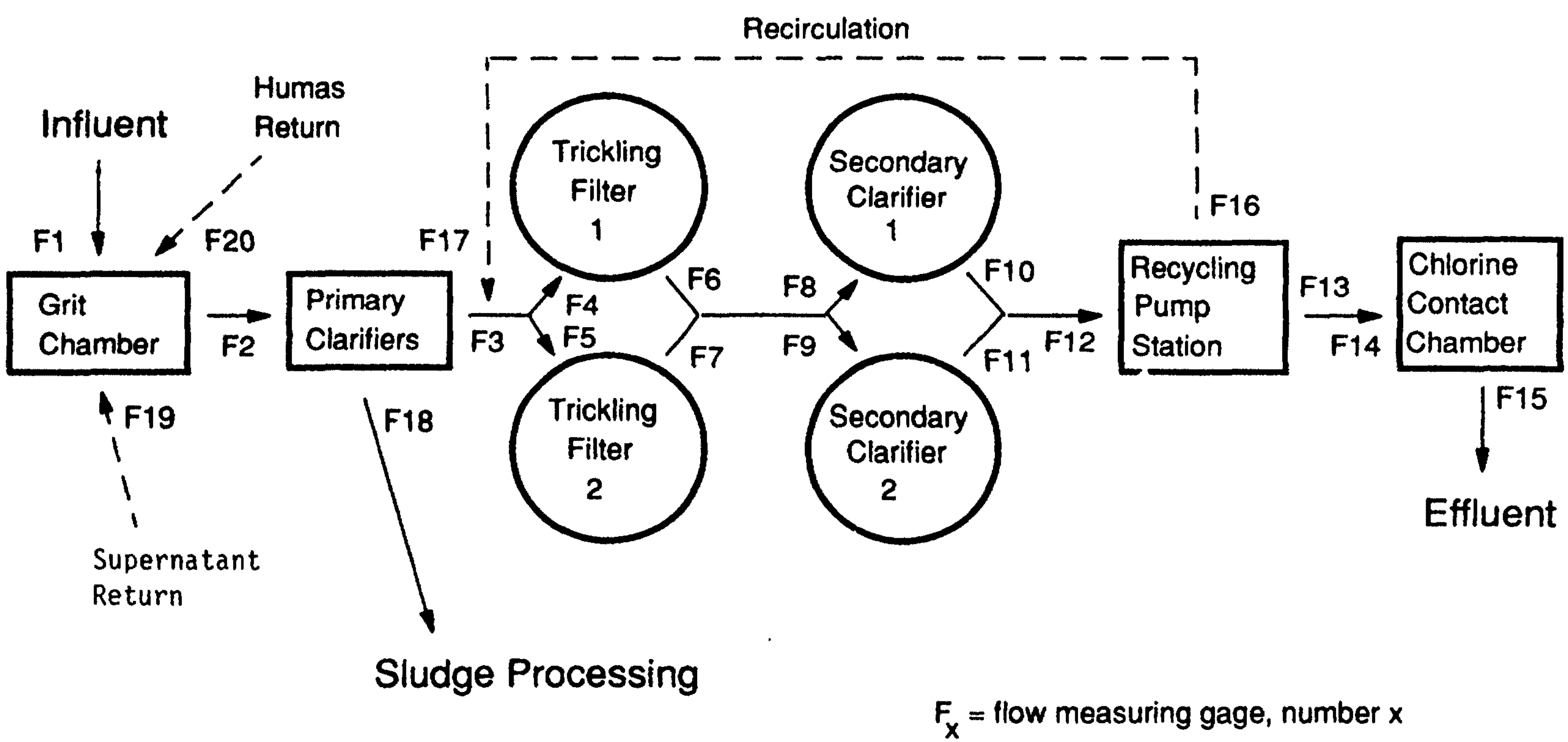

Figure 10. Representation of Wastewater Flow at the TAFB Treatment Plant.

plant a certain level of redundancy. The failure of a trickling filter or a secondary clarifier is not detrimental to the operation of the plant. The flow is simply redirected to the functioning unit. Also notice that the sludge processing portion of the plant is represented in very little detail. This is because it would be very difficult to assess damage in the sludge handling operation. The sludge collected in the primary clarifier is pumped to the digesters only as required. The process is not continuous. This sludge then remains in the digesters for several days. After the sludge is stabilized it is pumped into the drying beds. This process is also done quite infrequently. Therefore, very little knowledge would be gained by monitoring the flow around the digesters. The monitoring effort should concentrate on the more continuous process of wastewater flow through the plant.

Most major damage sustained by the TAFB wastewater treatment plant could be detected with 20 flow-measuring gages. The locations of the 20 gages are shown in Figure 10. The gages are numbered F1 through F20. The flow is monitored as it enters and exits each water treatment chamber. For the reasons discussed above, this plan does not attempt to assess damage to the sludge handling portion of the plant. A description of the purpose of each flow-measuring gage is given in Table 1. The flow volumes measured by these gages can be used to determine if any of the major components of the plant (excluding the sludge processing components) were damaged during an attack. Damage to a particular component of the plant can be determined from an inconsistency in certain gage readings. The inconsistencies (rules) associated with each damage mode are summarized in Table 2. Certain tolerances must be applied to these rules, since the gage readings will never be exactly equal (i.e., there will never be perfect continuity in a real system).

The flows measured by gages F-18 - F-20 are infrequent and quite small compared with the other flow values being recorded. These gages could be omitted without affecting the system. They were included only for completeness.

The rules given in Table 2 were implemented in a short computer program, PDAT. A listing of PDAT is given in Appendix A. The program reads in the 20 gage readings. The readings are then compared against the rules, to locate any inconsistencies in flow. If an inconsistency is located, the program prints out the name of the damaged component.

G. FLOW RATE MEASUREMENT

The recommended sewerage system APUDAS design concept uses flow rate measurements, both in the sewer lines and in the sewage treatment plant. This is because flow rate is the principal variable of concern throughout a sewerage system. As explained above, sewage is mostly water, and most sewage flow is open-channel flow. Even in a sewage treatment plant where some flow is under pressure, the pressure is low enough that the principles of open-channel flow rate measurement still apply (Reference 13).

TABLE 1. DESCRIPTION OF FLOW GAGES.

GAGE	QUANTITY BEING MEASURED
F1	Total treatment plant influent
F2	Flow exiting grit chamber, flow entering primary clarifier
F3	Flow exiting primary clarifier
F4	Flow entering trickling Filter 1
F5	Flow entering trickling Filter 2
F6	Flow exiting trickling Filter 1
F7	Flow exiting trickling Filter 2
F8	Flow entering secondary Clarifier 1
F9	Flow entering secondary Clarifier 2
F10	Flow exiting secondary Clarifier 1
F11	Flow exiting secondary Clarifier 2
F12	Flow entering recycling pump station
F13	Flow exiting pump station for chlorination
F14	Flow entering chlorine contact chamber
F15	Final treatment plant effluent
F16	Flow exiting pump station for ecirculation
F17	Flow entering trickling filters from recycling station
F18	Flow of sludge exiting primary clarifier
F19	Flow of supernatant entering grit chamber
F20	Flow of humas entering grit chamber

TABLE 2. DAMAGE ASSESSMENT RULES.

RULE	DESCRIPTION OF DAMAGE
(F2) .NE. (F1+F19+F20)	Grit chamber is damaged.
(F3+F18) .NE. (F2)	Primary clarifiers are damaged.
(F4+F5) .NE. (F3+F17)	Pipe break between primary clarifiers and trickling filters.
(F6) .NE. (F4)	Trickling Filter 1 is damaged.
(F7) .NE. (F5)	Trickling Filter 2 is damaged.
(F8+F9) .NE. (F6+F7)	Pipe break between trickling filters and secondary clarifiers.
(F10) .NE. (F8)	Secondary Clarifier 1 is damaged.
(F11) .NE. (F9)	Secondary Clarifier 2 is damaged.
(F12) .NE. (F10+F11)	Pipe break between secondary clarifiers and recycling pump station.
(F12) .NE. (F13+F16)	Recycling pump station is damaged.
(F14) .NE. (F13)	Pipe break between recycling station and chlorine contact chamber.
(F15) .NE. (F14)	Chlorine contact chamber is damaged.
(F17) .NE. (F16)	Pipe break between recycling station and trickling filters.

Commercial, off the shelf equipment is available to measure open-channel or surcharged flow in sewers or sewage treatment plants. The preferred method for measuring open-channel flow rate uses a pressure transducer to measure flow depth, or elevation of the hydraulic grade line. If the elevation of the hydraulic grade line is known, the relation between the fluid particle velocity at a fixed velocity sensor location and the mean particle velocity, or flow rate, can be determined. Thus the flow rate can be measured. Three representative manufacturers of open-channel flowmeters suitable for a sewerage system APUDAS are: Isco, Inc. Environmental Division, Lincoln, NE; Marsh-McBirney, Inc., Gaithersburg, MD; and Montedoro-Whitney, San Luis Obispo, CA. Literature from these three manufacturers is contained in References 14, 15, and 16, respectively. Each of the three open-channel flowmeters can be linked to a remote terminal unit (RTU), which is, in turn, linked to a radio, which receives commands from and broadcasts data to the APUDAS host computer.

SECTION IV

HVAC SYSTEM APUDAS DESIGN CONCEPT

A. HVAC SYSTEM FUNCTION

The term HVAC system includes systems which heat, cool, and control the humidity in a space. The term also includes systems which ventilate a space. Ventilation may be required to remove odor, dust, carbon dioxide, etc. In a facility like the survivable collective protection system, the ventilation apparatus must bring in outside air while filtering out chemical and biological weapon (CBW) agents or even fuel-air-explosive gases.

HVAC systems come in all sizes and configurations, from spot coolers for a single room to large central units to heat and cool most of the buildings on a base. Air conditioning, heating, and ventilating systems each require a different set of sensors and logic to assess damage. The following sub-sections discuss cooling and heating systems separately, and recommend approaches to detect damage. The remaining subsection discusses the sensors needed to measure HVAC system status parameters.

B. COOLING SYSTEMS

Figure 11 is a generalized schematic of an air conditioning system. The system consists of a compressor, a condenser with a source of coolant, an expansion valve, and an evaporator which chills water or directly cools the air. Sometimes the refrigerant is piped to several evaporators. If humidity control is required, the air may require reheating by mixing with outside air or adding energy through a heater. In operation the refrigerant is compressed isentropically in the compressor; then cooled at constant pressure in the condenser; then throttled at constant enthalpy through an expansion valve with a corresponding decrease in temperature; and finally heated (removing energy from the room) at constant pressure in the evaporator. Figure 12 is a temperature - entropy diagram describing this process.

Efficient operation of an air conditioning system requires a control system with several sensors and automatic valves. For example, during normal operation, a thermostat in the cooled space senses temperature. When the temperature reaches a preset upper limit, a signal from the thermostat opens a solenoid liquid valve located between the condenser and the expansion valve. In most systems, a receiver tank to hold the liquid refrigerant is located just after the condenser. The expansion valve is thermostatically controlled by a temperature sensor, which is usually mounted on the suction intake pipe to the compressor. Refrigerant flow and evaporation in the evaporator cause the pressure to increase in the compressor suction pipe. A low-pressure sensor signal then starts the compressor. When the room has been cooled sufficiently, the room thermostat causes the solenoid liquid valve to close. The compressor then reduces the suction line pressure below a preset limit, and a pressure sensor signal shuts off the compressor. Typcially, a second

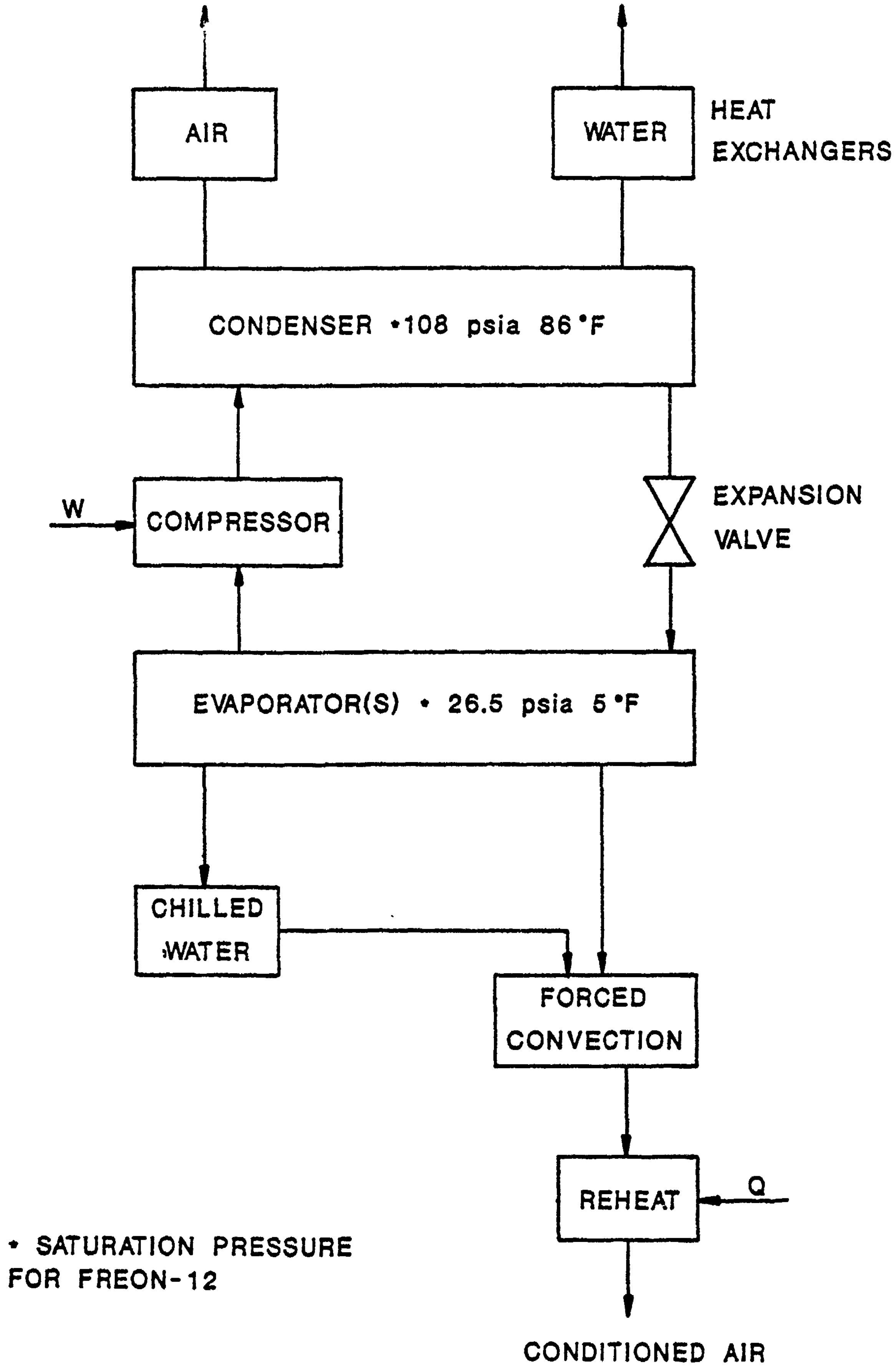

Figure 1. Air Conditioning System Schematic.

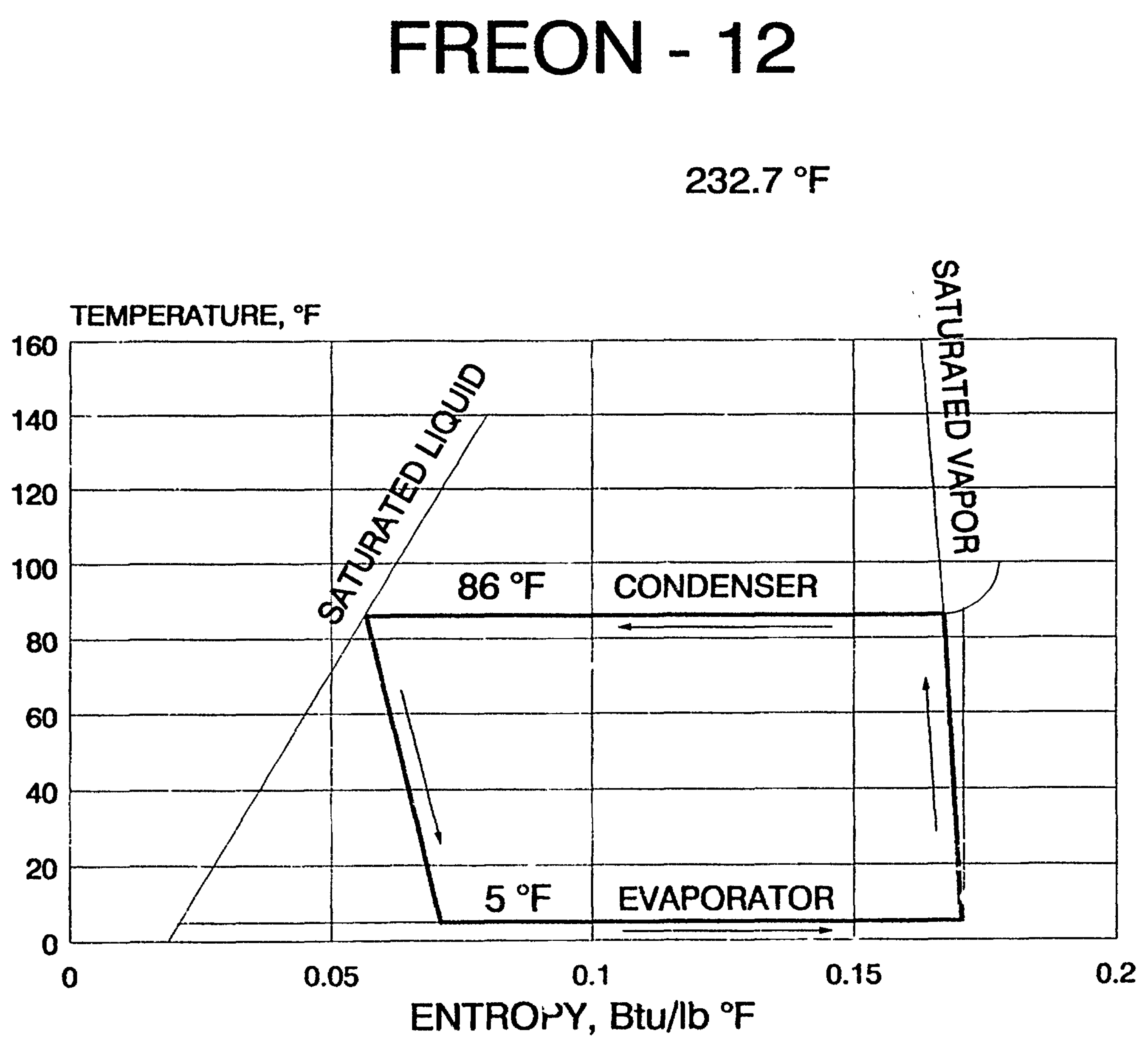

Figure 12. Refrigeration Cycle.

pressure sensor will be located at the compressor discharge. Signals from these sensors are also used to initiate cooling system shutdown. The room thermostat is often also used to switch the cool air handling system on and off.

Only a few additional sensors are required to allow an APUDAS to monitor an HVAC system. Figure 13 is a logic diagram for pinpointing a cooling system failure. The first indication of system failure is when the room temperature exceeds a preset value. If this occurs, the next logical step is to test the line voltage. If the line voltage is satisfactory, the system checks the evaporator temperature. If this temperature is high, there is probably something wrong with the refrigeration system; otherwise, the fault probably lies with the air-handling or chilled-water system. If the evaporator temperature is high, the next logical step is to measure the pressure drop across the compressor. A low pressure drop indicates loss of refrigerant. A normal pressure drop indicates a problem in the condenser. High temperature here indicates an obstruction in the coolant system.

C. HEATING SYSTEMS

Heating systems come in an endless array of configurations. In general, heating systems consist of four parts - an energy source, machinery to convert the energy to heat, in some large systems a mechanism to transport heat to several rooms or buildings, and heat exchangers or moving air systems to distribute the heat in a room. Figure 14 depicts the four parts of this heat cycle. The most common energy sources are electricity and fossil fuels. Fossil fuels include gas, oil, coal, and wood. Other energy sources include the sun, wind, geothermal heat, and nuclear fission. This study focuses on electricity and fossil fuels.

Electrical energy is converted to heat either by resistance heating or a heat pump. Figure 15 shows typical systems for electric heating. Electric energy is converted directly to heat through a series of resistance coils. Heat can then be radiated directly into the room by small space heaters, or heated air can be circulated throughout the building. A heat pump, on the other hand, uses a reversed refrigeration cycle to "pump" heat from a reservoir, such as water from a well or river, or ambient air. This cycle was described under the above section on COOLING. However, in this case inside air is blown over the condenser coils rather than the evaporator coils.

Fossil fuels are burned in a furnace or boiler to generate heat, which produces steam, hot air, or hot water. The hot air is circulated through the building using forced convection. Hot water is usually pumped through the system to radiators. Steam heating systems rely on natural convection. Figure 16 illustrates this class of systems.

Most heating systems have thermostats, pressure and temperature sensors, flowmeters, and the like to control their operation. A rather sophisticated APUDAS can be based on these existing sensors. Some additional sensors will be required in most cases. The first indication of system failure will be when a thermometer shows that room temperature has fallen below some

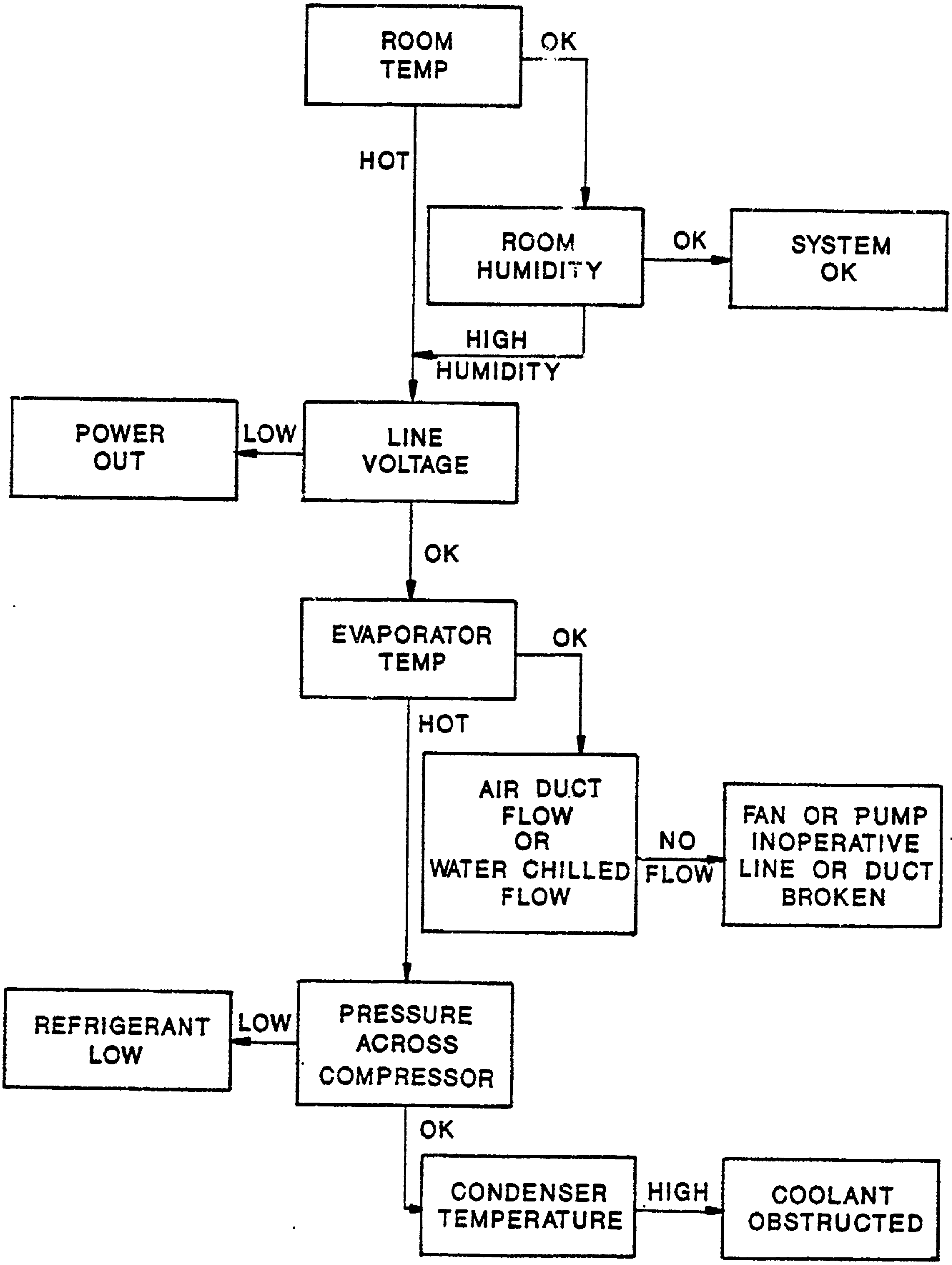

Figure 13. Cooling System Fault Tree.

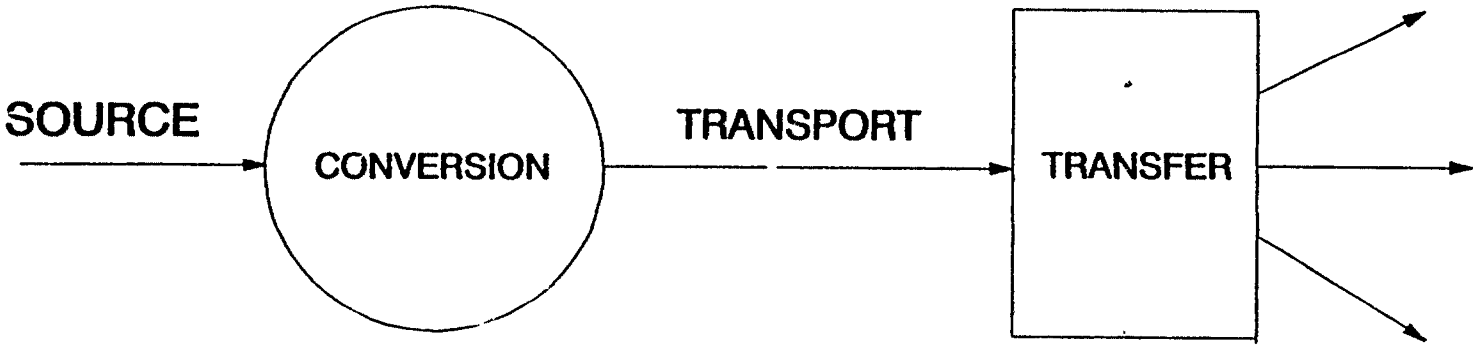

Figure 14. Heat Cycle.

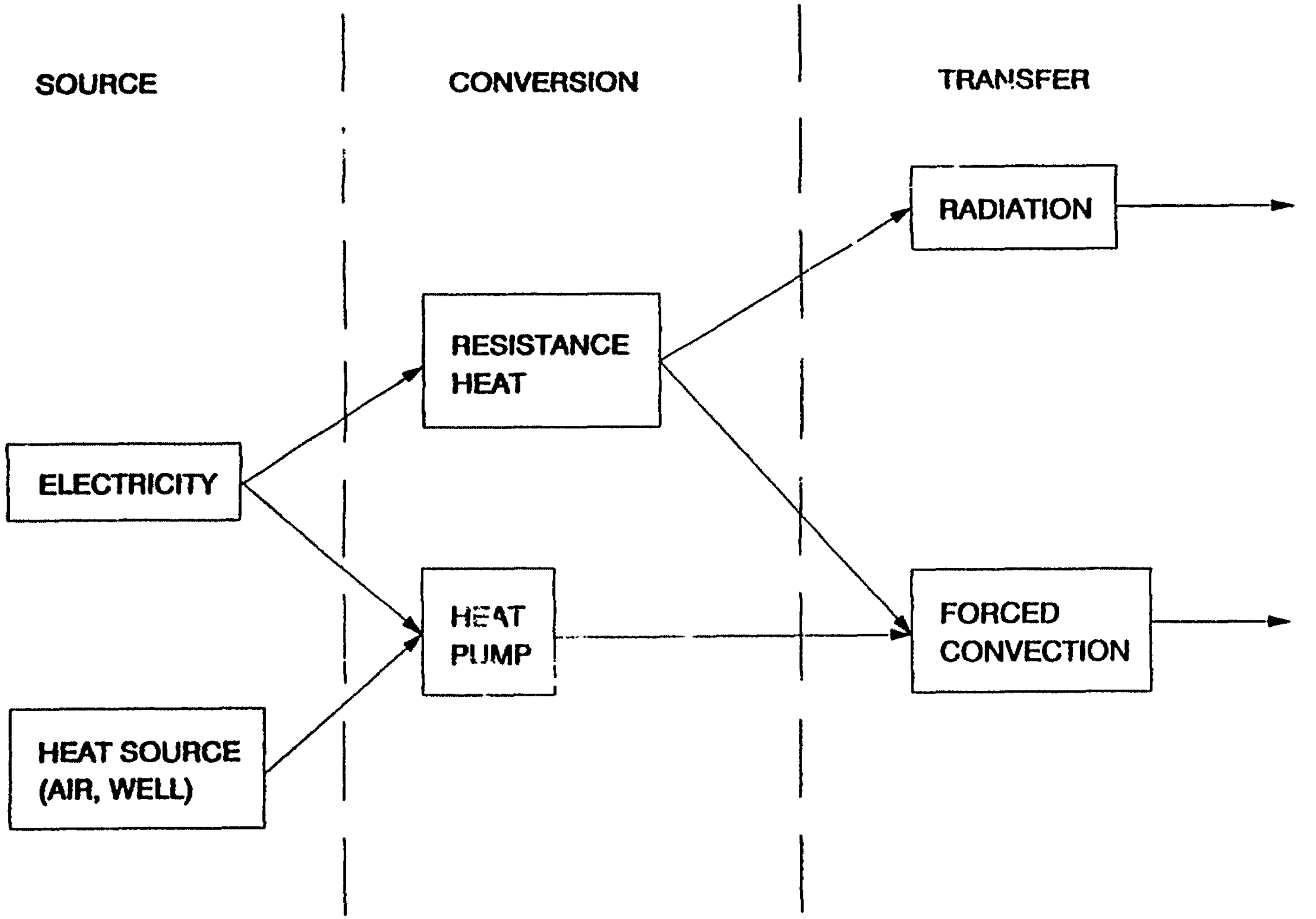

Figure 15. Electric Heating.

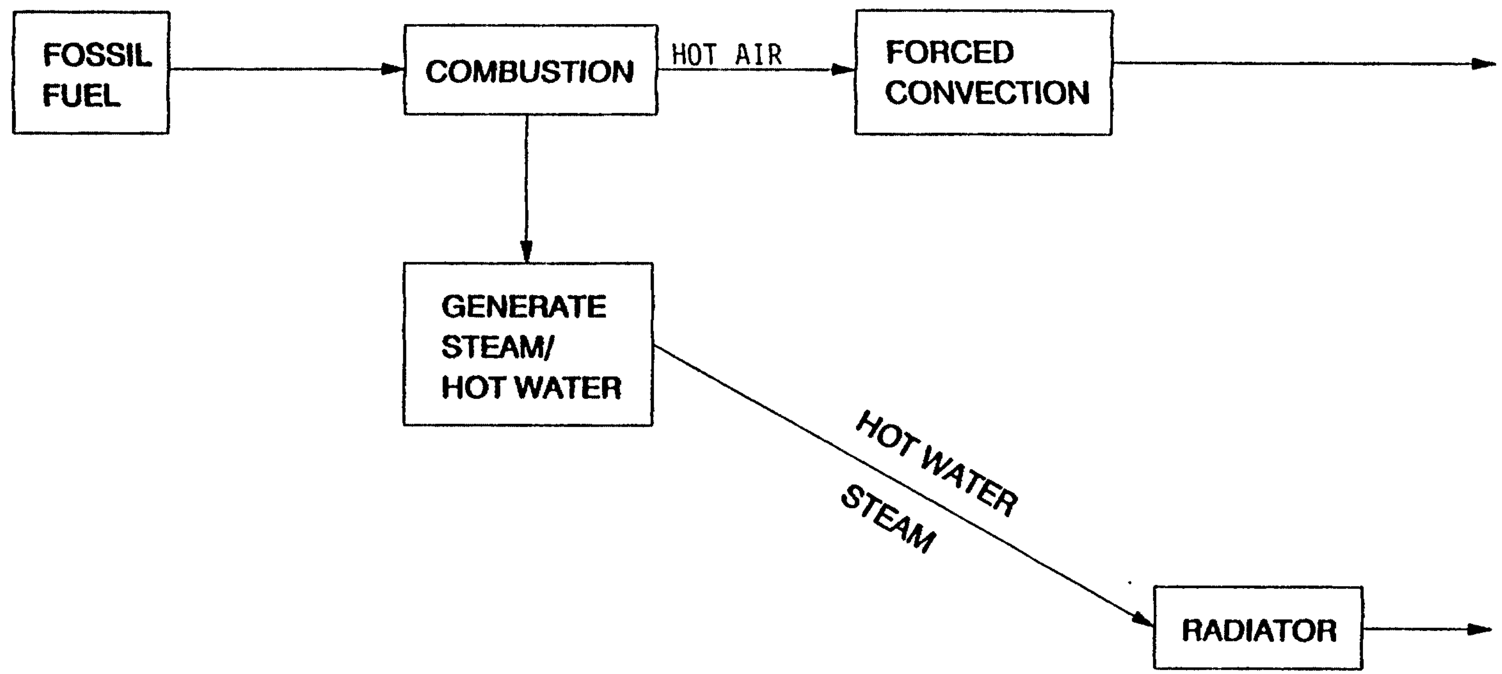

Figure 16. Fossil Fuel Heating.

threshold. Since nearly all heating systems use electric power, and since power is very vulnerable to attack, the next logical step is to measure input voltage. The remaining steps to determine damage will depend on the configuration of the heating system.

Figure 17 is a simple logic tree for assessing damage to a forced air resistance heating system. As stated above, the first step after discovering that the room is cold is to measure the line voltage. If power is available, the next step is to measure the furnace or heating element temperature. A cold temperature indicates a broken heating element or an inoperative thermostat. If the furnace temperature is satisfactory, the next step is to measure the duct air flow near the furnace. No flow indicates a broken fan. Normal flow indicates a break in the air ducts. An extensive air duct system for a large building is similar to the water distribution system described in Reference 1. Pressure sensors and flowmeters are required to pinpoint a break.

Figure 18 presents a simple logic tree to assess damage to a fossil fuel heating system. After the power check, the combustion or furnace temperature should be measured. If the furnace is cold, the pilot temperature should be measured. If the pilot light is on or if the electronic ignition is working properly, the safety interlocks should be checked. Larger furnaces will have purge, low air flow, low fuel supply, loss of flame, fan, low water, and high combustible content interlocks. If all the interlocks are satisfied, there must be an interrupt in the fuel system. Water flow should be measured if the furnace temperature is satisfactory. Normal flow indicates a leak in the boiler or a break in the hot water lines. No flow implies water pump failure.

The dashed lines in Figure 18 show the logic for a forced air system. Normal duct air flow near the furnace implies a break in the duct. No flow indicates a broken fan.

D. SENSORS

A sophisticated APUDAS system to assess HVAC system damage requires only a relatively small suite of sensors. Many of the sensors will be in place as part of the HVAC operating system. Additional sensors may be required to measure temperature, humidity, flow, pressure, and voltage. Table 3 lists the required measurements and ranges for each sensor.

The first indication of trouble in an HVAC system will be that the room is either too hot or too cold. APUDAS could use either thermocouples, thermistors, or platinum resistance temperature devices (RTDs) to measure temperature. Omega Engineering, Inc. manufactures an RTD which will cover the entire temperature range of interest in HVAC systems. Reference 17 includes literature on the OMEGA Type 100W30 RTD. References 17 through 20 do not contain an exhaustive list of equipment; only a single representative example is included for each type of HVAC sensor.

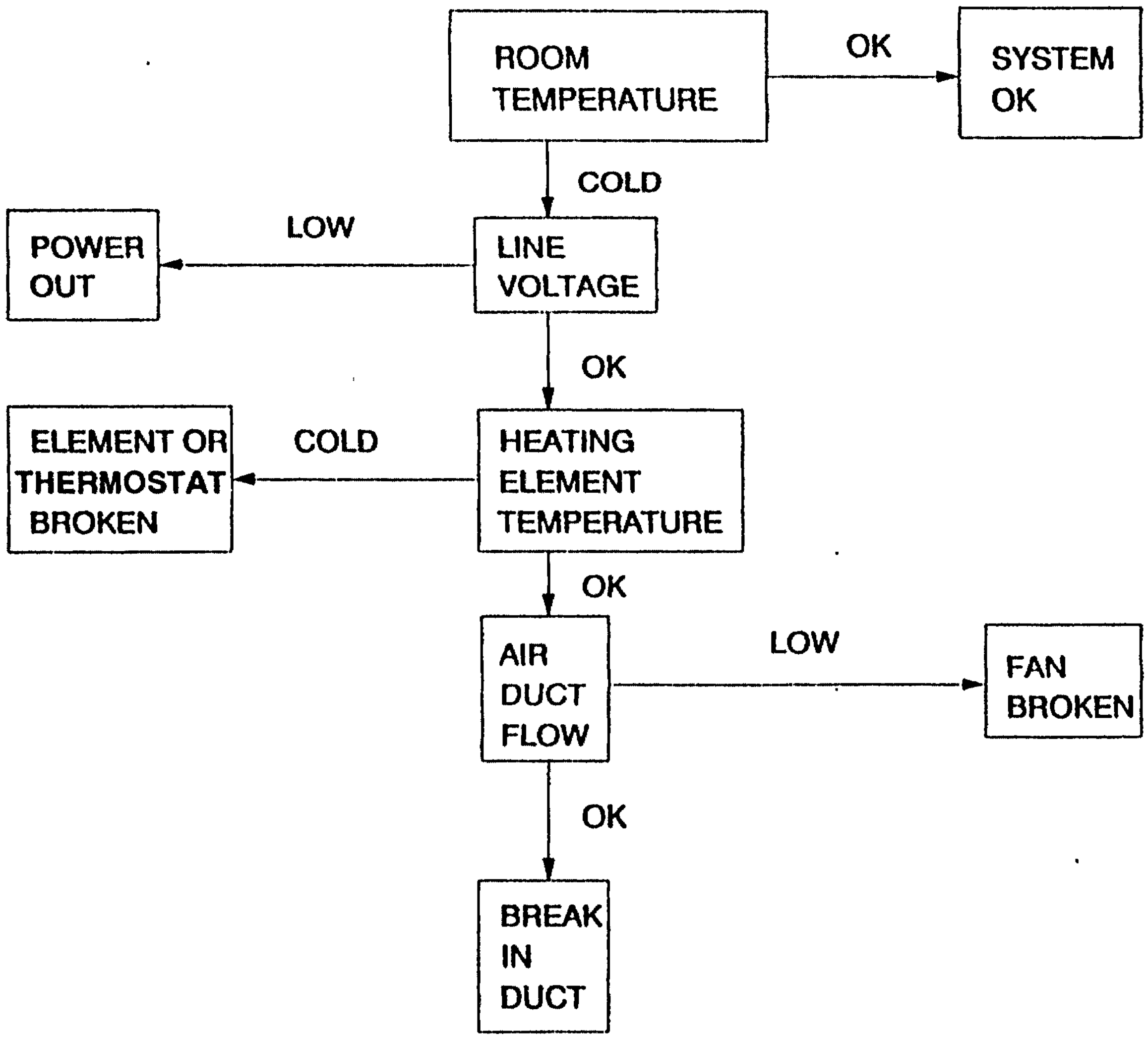

Figure 17. Electric Resistance Heat.

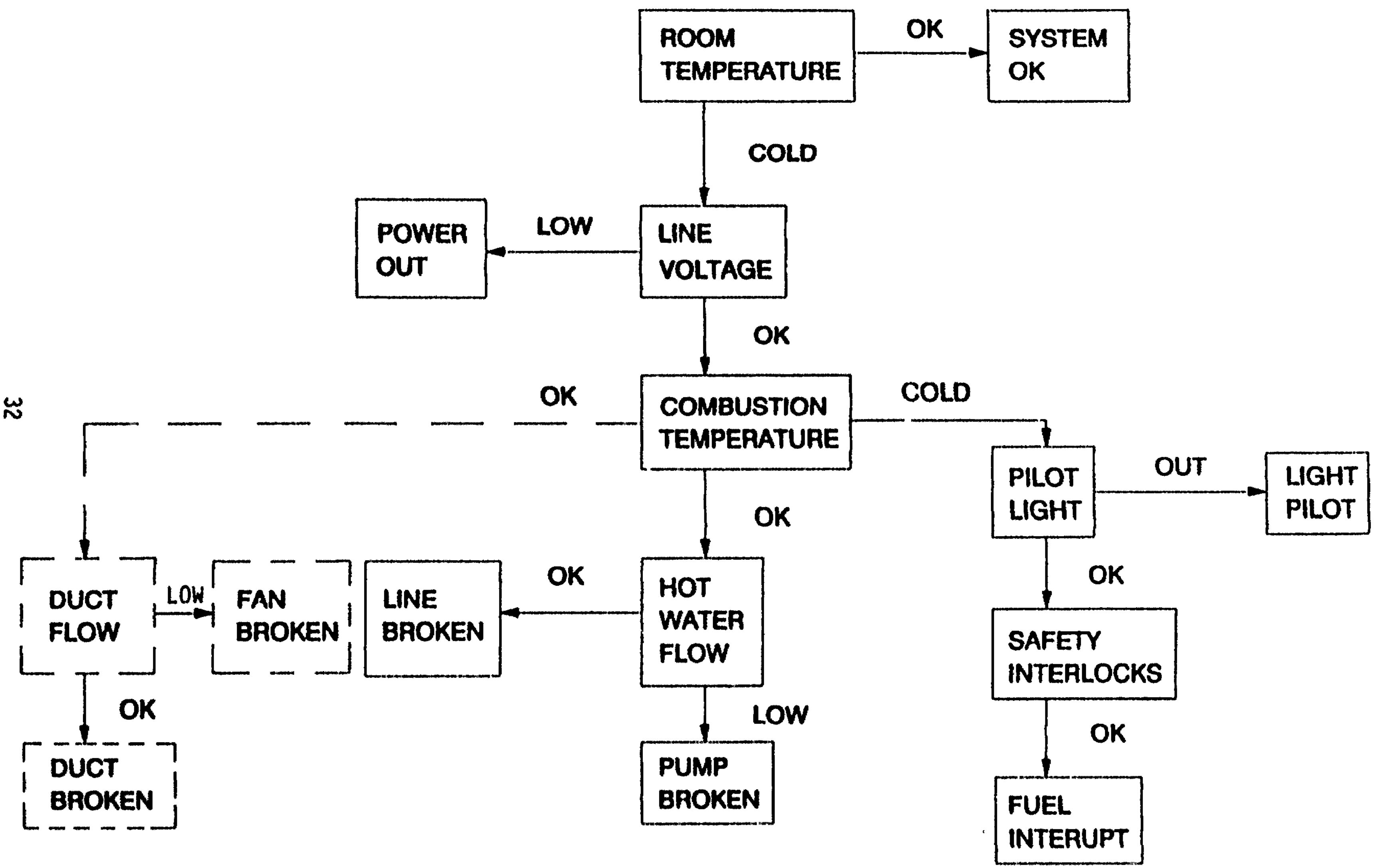

Figure 18. Fossil Fuel Heat.

TABLE 3. HVAC APUDAS SENSORS.

QUANTITY	RANGE
Temperature	
Room	-4 to 140°F
Evaporator	0°F
Condenser	100°F
Heating Element	> 500°F
Combustion	> 500°F
Humidity	
Room	5% to 95%
Flow	
Air Duct	5 - 50 fps
Chilled Water	5 - 35 fps, 40°F
Hot Water	5 - 35 fps, 300°F
Pressure Differential	
Compressor	100 psi
Voltage	
Line	100 - 600 volts

Air conditioning systems are frequently used to control humidity. High humidity can destroy electronic equipment and materials. In such an installation, temperature and humidity can be used to indicate an HVAC malfunction. The OMEGA Model HX91 sensor described in Reference 18 combines both measurements. If this sensor were combined with a voltage-sensing relay, the APUDAS operator could tell whether the air conditioning system was inoperative, and if so, whether the failure was due to a power interrupt.

Chilled water and hot water flow can be detected by a paddle switch. Reference 19 contains literature describing the OMEGA Engineering Models FSW-21 and FSW-23 paddle switches.

There are numerous ways to measure flow in an air duct, including using a pitot tube, measuring the pressure drop along a section, and using a wind turbine or paddle switch. The exact magnitude of the flow velocity is not required for APUDAS; therefore, water paddle switches described earlier were investigated for use in air ducts. Figure 19 shows the computed response of an OMEGA paddle switch outfitted with a larger paddle.

Most air conditioning systems contain sensors that measure compressor inlet and exhaust pressures. This information is needed to control the system. In most cases APUDAS will be able to use these sensors.

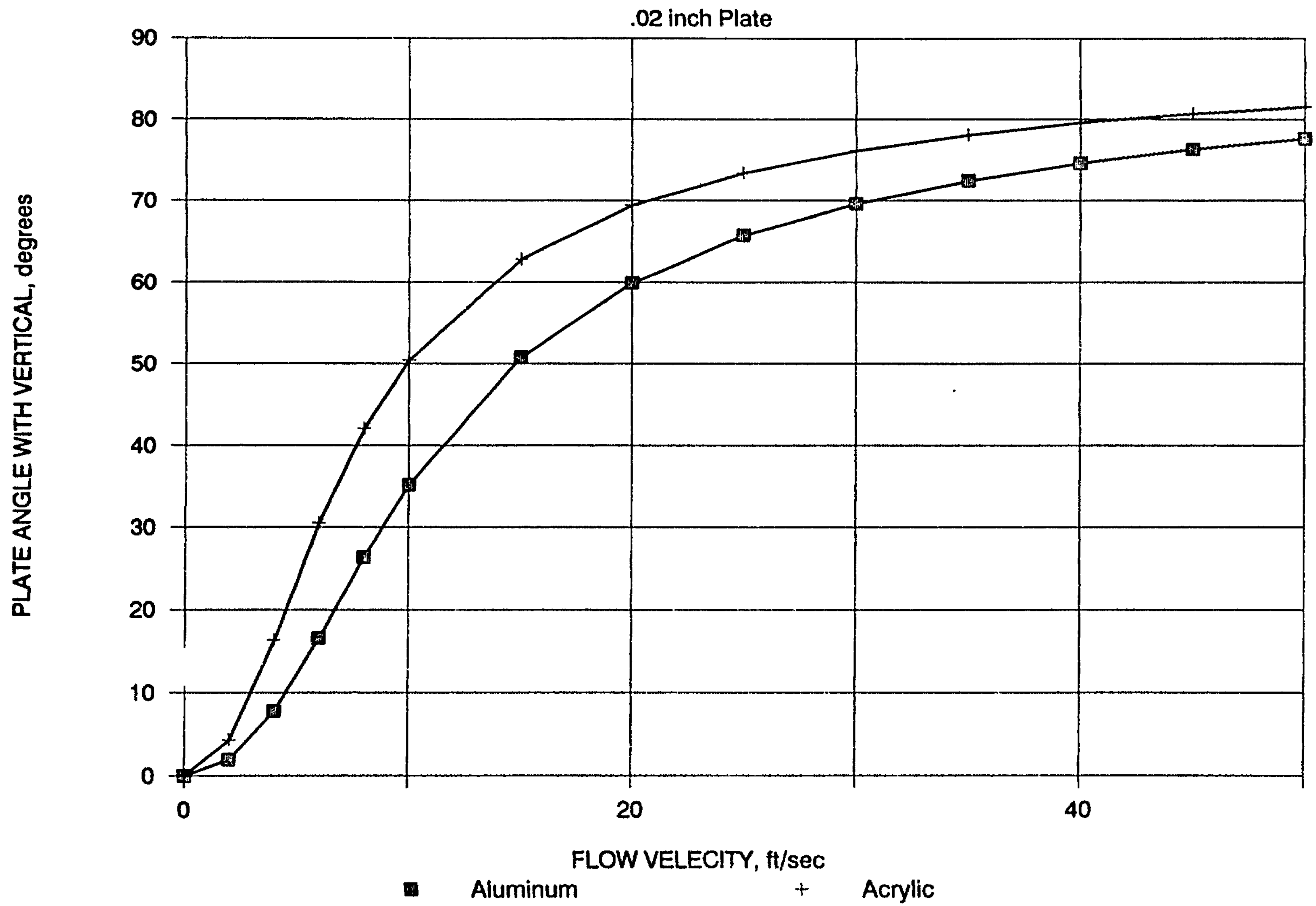

Figure 19. Flat Plate Flow Sensor.

Line voltages can be sensed using a relay such as the CSJ and CSL series shown in Reference 20. A transformer may be required to measure high voltages.

SECTION V

APUDAS DATA SYSTEM DESIGN CONCEPT

A. DATA SYSTEM FUNCTIONS

An entire APUDAS is an automated data system, used to acquire and display utility system status information faster, more completely, and more reliably than can be done manually. The nine detailed data-handling functions of an APUDAS data system are:

1. Acquisit on from sensors
2. Remote storage
3. Remote control
4. Remote transmission
5. Central reception
6. Central control
7. Central storage
8. Central processing
9. Central display

Acquisition is recording a sensor signal, e.g., the flow rate in a sewer pipe. Remote storage is preserving the recorded sensor signal in computer memory, so it can be used later. Remote control is knowing when to record a sensor signal, and when to transmit recorded information to a central receiver. Remote transmission is sending remotely acquired information to a central location. Central reception is receiving transmitted information from many remote sites at a single (or a few) central sites. Central control is telling the remote sites when to record their respective sensor signals, and when to transmit recorded information to a central receiver. Central storage is preserving the transmitted information in a central computer memory for later processing and display. Central processing is interpreting the centrally stored information, and putting it in a form which can be displayed for quick use by decision makers in the SRC/ASRC and the DCC. Central display is presenting the processed information visually. Figure 20 shows the recommended APUDAS functional structure, identical to that shown in Figure 13 of Reference 1 except for addition of functional blocks for sewerage and HVAC systems.

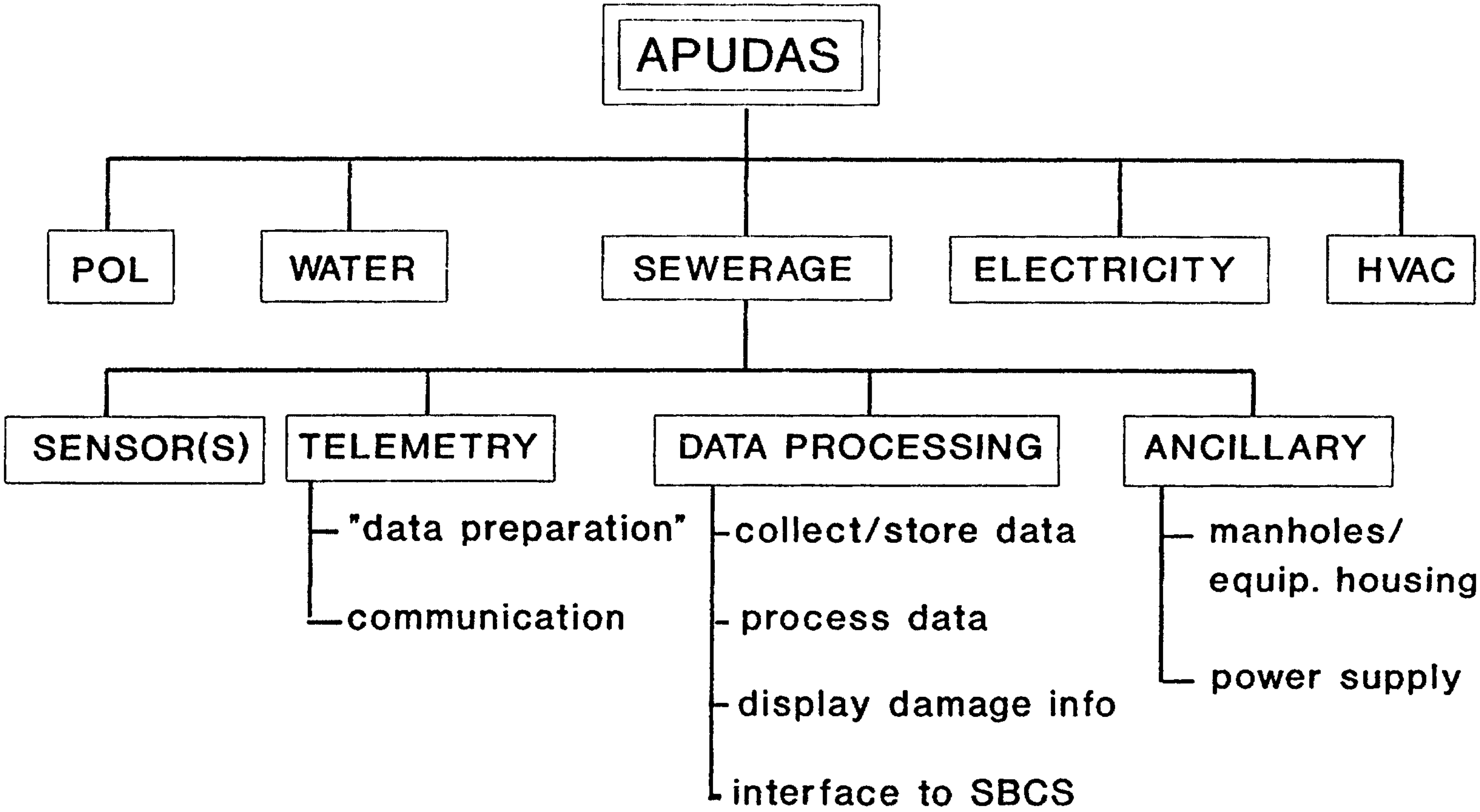

Figure 20. APUDAS Functional Structure.

B. CONFIGURATION CONCEPT

The recommended APUDAS data system design concept is the same as that shown in Figure 14 of Reference 1, and shown here in Figure 21. The only problem with this concept is that the DCC is not part of the SBCS. This is a serious error, and should be corrected by the SBCS SPO.

The recommended APUDAS remote terminal unit (RTU) configuration is the same as that shown here in Figure 22. Squelch detection reduces the noise level. PTT means "press to talk". FSK means "frequency shift keying", a technique employed in analog to digital conversion. The RTU is basically a small computer, and performs the first three APUDAS data system functions: acquisition, remote storage, and remote control.

The recommended APUDAS central hardware configuration is the same as that shown in Figure 16 of Reference 1, and shown here in Figure 23. One possible problem with this architecture (see also Figure 21) is that the SRC, ASRC, and DCC may not all have survivable backup power. Without power to the central hardware, APUDAS is nonexistent.

Reference 1 recommends that water and POL system APUDAS sensors, RTUs, and remote radios and their antennae be housed in protective manholes. The same concept is convenient for the sewerage system APUDAS, which already uses manholes for the basic system. Additional manholes would still be needed for the sewerage system APUDAS, however, to protect the RTUs, radios, and antennae, and to place sensors where there currently is no manhole.

C. HARDWARE

The <u>Thomas Register</u> lists a large number of firms who manufacture and/or sell data communication equipment. Among them are:

Amocams, Inc.
Automation Engineering, Inc.
Ayden Vector Division
Digitize, Inc.
Femco
General Electric Company
Husky Computers, Inc.
Martin Marietta Data Systems
Motorola, Inc.
PEER, Inc.
Remtron, Inc.
Sutton Designs, Inc.
VC Controls
Vectran Corporation
Westernan Controls

Reference 1 recommended an Amocams AI-1000 RTU, coupled with a General Electric DL100 remote radio to transmit sensor signals to the APUDAS central computer. Subsequent discussions between ARA and the Amocams Marketing

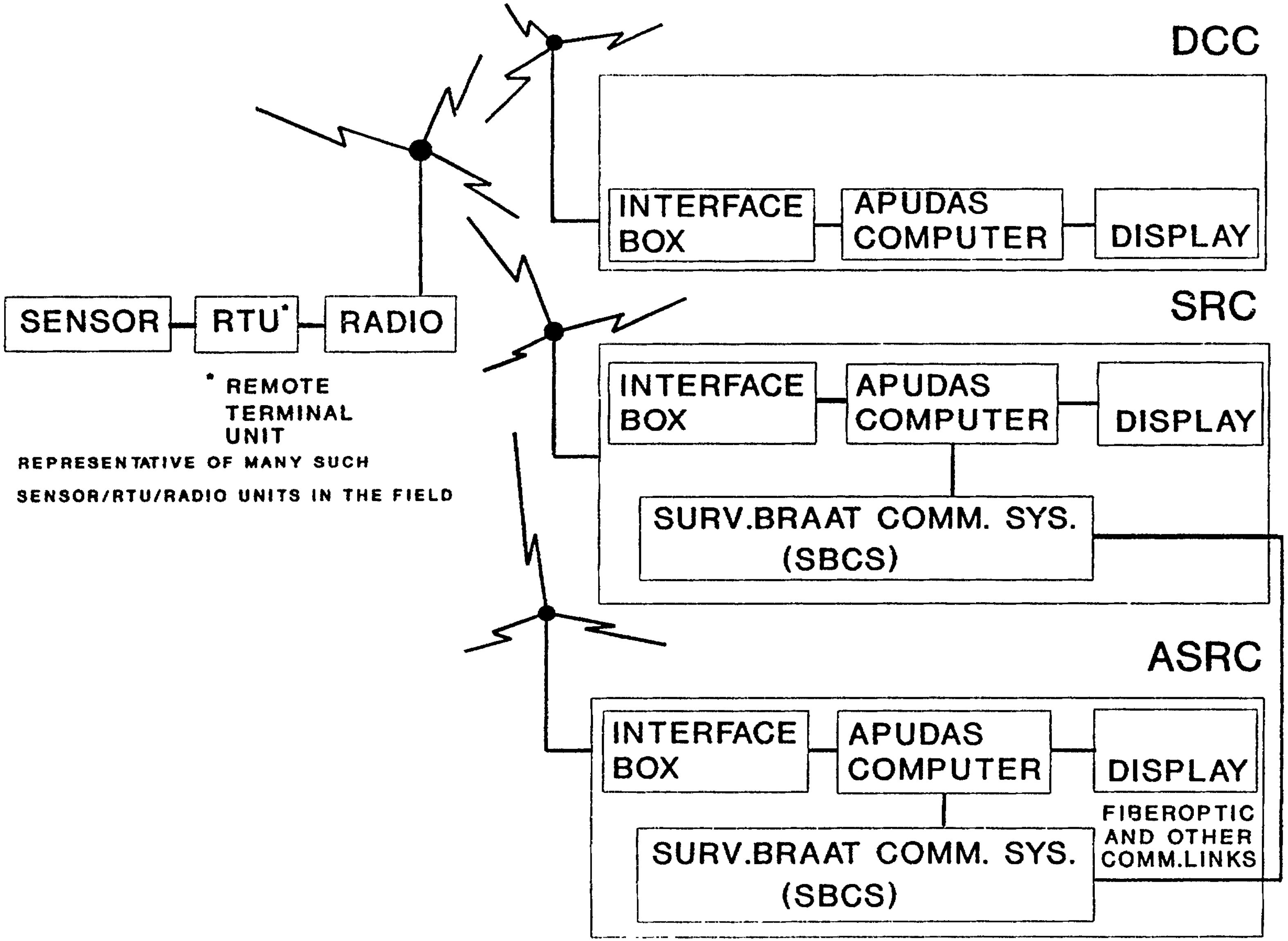

Figure 21. APUDAS Architecture.

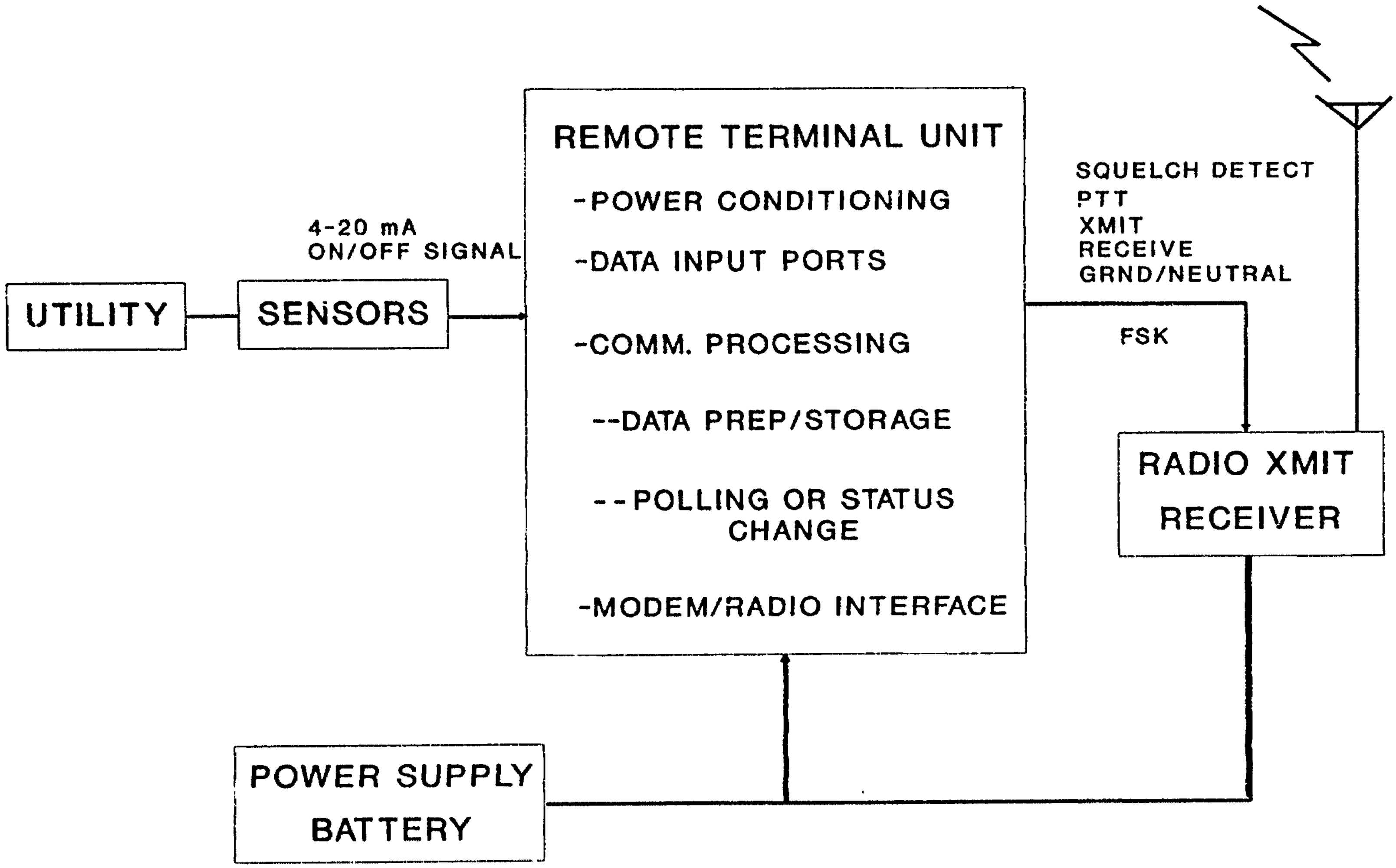

Figure 22. APUDAS Remote Terminal Unit Configuration.

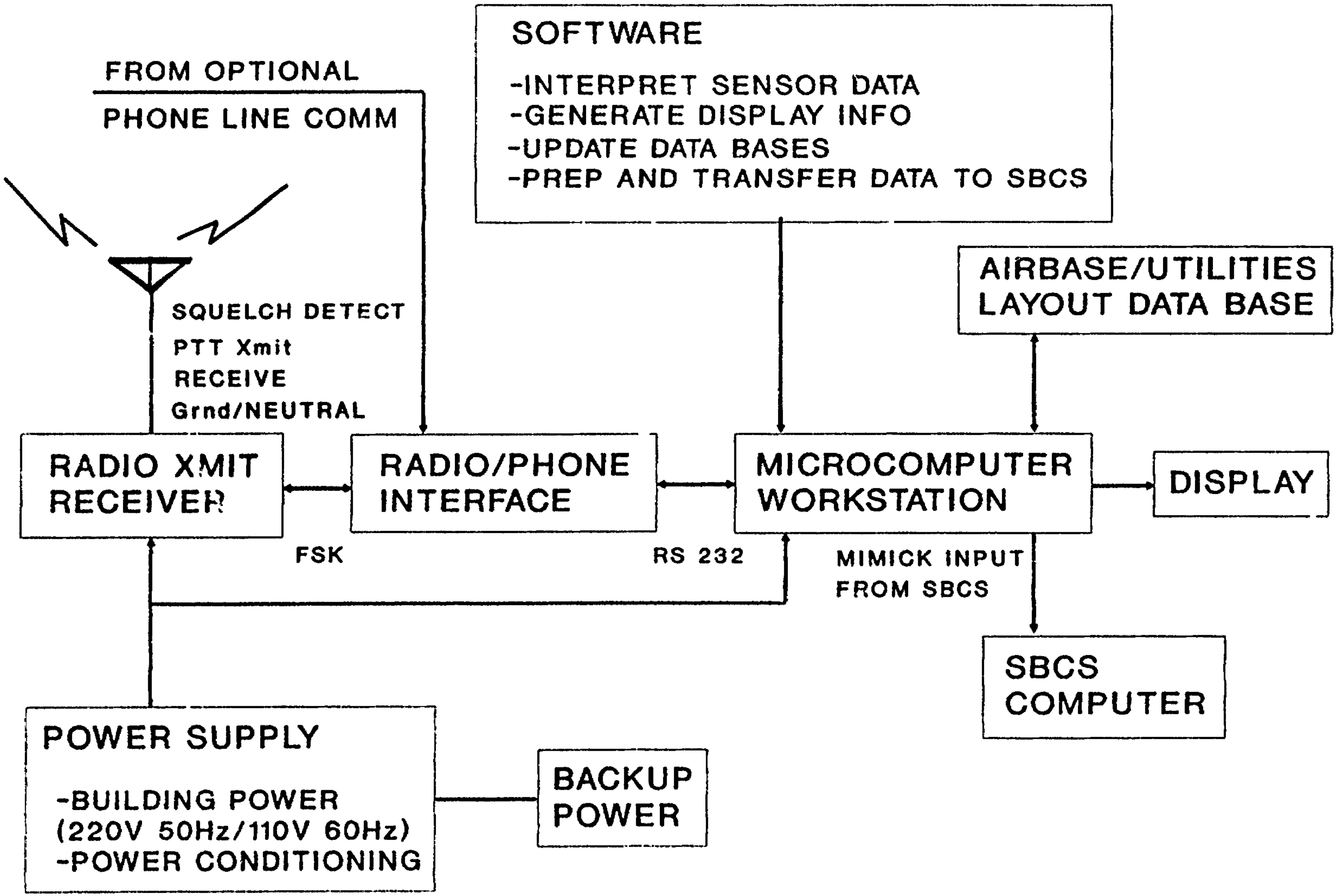

Figure 23. APUDAS Central Hardware Architecture.

Services Department have shifted attention from the AI-1000 to the AI-700 RTU, but still using the GE DL100 remote radio. Reference 1 (p. 40) recommends operating in a status change, rather than a polling mode. However, since several sensor readings may be needed to display enough information to pinpoint one damage location, a coded or random polling mode seems most practical.

The recommended central radio unit which communicates with all the remote radio units, and receives all the remote data is a GE Mastr II. As shown in Figure 23, the central Mastr II radio is linked to the APUDAS central computer, which is an IBM PS/2, Model 60 microcomputer with a color display.

Other data communication systems are available, as shown in the list of firms compiled from the Thomas Register. Detailed equipment information from Amocams, Motorola, and Remtron is contained in References 21, 22, and 23 respectively.

Both the Amocams AI-700 remote terminal unit and the General Electric DL100 Datalink radio transceiver are industrial grade, not military grade equipment. Neither the original nor the current APUDAS statements of work mentioned the need to satisfy military hardware specifications, but if and when an APUDAS is actually procured, the military specification issue will certainly arise. Other logistic requirements, not yet defined but of concern to AFESC/YE, are also likely to arise, and should be defined during full scale development.

Time is of the essence for APUDAS. The second operational requirement listed in Section II is a maximum utility damage assessment time of 20 minutes, including both data handling by APUDAS, and damage assessment by the BCE and Base Commander. Allowing 10 minutes for data handling and 10 minutes for damage assessment, and assuming a typical RTU response time to be 3 seconds (Reference 1, p. 40), the maximum number of sensors handled by one central computer is

$$N = \frac{(10)(60)}{3} = 200 \text{ sensors}$$

Since Tyndall AFB has about 312,000 feet of sewer line, and allowing 20 sensors for the sewage treatment plant, the sewerage system APUDAS sensor spacing for Tyndall AFB is

$$S = \frac{L}{N} = \frac{312{,}000}{180} = 1733 \text{ feet/sensor}$$

$$= 578 \text{ yards/sensor}$$

$$= 1/3 \text{ mile/sensor}$$

where

S = sensor spacing
L = total length of sewer lines
N = number of sensors in sewer lines

which seems reasonable.

SECTION VI

LIFE CYCLE COST

A. GROWTH RATE

The 20-year life cycle cost (LCC) of a sewerage or an HVAC system APUDAS can be calculated as the present worth of all system expenditures over the 20-year life. The present worth, P, of an expenditure, F, at the end of year n is

$$P = \frac{F}{(1+g)^n} \qquad (3)$$

where g is the growth rate, given by the formula (Reference 24)

$$g = \frac{i - r}{1 + r} \qquad (4)$$

where i is the prevailing interest rate, and r is the inflation rate. At the present time i is about 10 percent and r is about 5 percent, so that the growth rate is

$$g = \frac{10 - 5}{1.05} = 4.76 \text{ percent, say 5 percent}$$

B. MAINTENANCE, REPAIR, AND REPLACEMENT

In addition to interest and inflation, the three major factors affecting life cycle cost are initial cost, infant mortality, and age. Assuming the annual cost of maintenance, repair, and replacement (MR^2) reaches a minimum in Year 5, equal to 5 percent of initial hardware cost, and that such costs increase at the rate of 0.25 percent per year in both directions from Year 5, Equation (3) yields a total 20-year life cycle hardware cost of 1.79 times the initial hardware cost, as shown in Table 4.

C. SEWERAGE SYSTEM APUDAS LIFE CYCLE COST

The Tyndall AFB sewerage system APUDAS 20 year life cycle cost estimate is given in Table 5.

D. HVAC SYSTEM APUDAS LIFE CYCLE COST

A life cycle cost estimate is given below for selected Tyndall AFB mission-critical facilities. Annex C - Appendix 1 to Tyndall AFB BCE OPLAN 93-2, dated 12 January 1987 lists facilities in recovery priority order. Seventeen of the twenty highest priority facilities have HVAC systems, and the following life cycle cost estimate applies to those seventeen facilities. Information on sensors selected to monitor the performance of HVAC units is shown in Table 6. Table 7 shows the cost of sensors for each of the seventeen facilities. Table 8 contains the life cycle cost estimate.

TABLE 4. APUDAS 20-YEAR LCC CALCULATION.

YEAR	EXPENSE FACTOR	PRESENT WORTH FACTOR
0	1.0000	1.0000
1	0.0600	0.0571
2	0.0575	0.0522
3	0.0550	0.0475
4	0.0525	0.0432
5	0.0500	0.0392
6	0.0525	0.0392
7	0.0550	0.0391
8	0.0575	0.0389
9	0.0600	0.0387
10	0.0625	0.0384
11	0.0650	0.0380
12	0.0675	0.0376
13	0.0700	0.0371
14	0.0725	0.0366
15	0.0750	0.0361
16	0.0775	0.0355
17	0.0800	0.0349
18	0.0825	0.0343
19	0.0850	0.0336
20	0.0875	0.0330
Total	2.3250	1.7902

TABLE 5. TYNDALL AFB SEWERAGE SYSTEM APUDAS 20 YEAR LIFE CYCLE COST ESTIMATE.

CATEGORY	ITEM	NUMBER	UNIT COST	COST
hardware	flow rate sensor	200	4,525	905,000
	RTU/radio	181	2,500	452,500
	battery	181	90	16,290
	misc remote hardware	200	200	40,000
	base radio	1	6,075	6,075
	microcomputer	1	8,000	8,000
	UPS	1	2,000	2,000
	software	1	15,000	15,000
	misc central hardware	1	1,000	1,000
	TOTAL INITIAL HARDWARE COST			1,445,865

TABLE 5. TYNDALL AFB SEWERAGE SYSTEM APUDAS 20 YEAR LIFE CYCLE COST ESTIMATE. (CONCLUDED)

CATEGORY	ITEM	NUMBER	UNIT COST	COST
installation	site survey	1	20,000	20,000
	RTU/radio manhole	181	1,000	181,000
	frame and cover	181	300	54,300
	sensor inst & cal	200	400	80,000
	misc remote hardware	200	50	10,000
	central system inst & check	1	15,000	15,000
	TOTAL INSTALLATION COST			360,300
MR^2	(1,445,865) (0.7902)			1,142,523
TOTAL				$2,948,688

TABLE 6. APUDAS HVAC SENSORS.

QUANTITY	DEVICE	BRAND	MODEL	COST	TYPE
	AIR CONDITIONING/HEAT PUMP SYSTEM				
Temperatures					
Room	Thermostat	Honeywell	2E096	$33	A
Evaporator	RTD	Omega	100W30	$22	B
Condenser	RTD	Omega	100W30	$22	C
	AIR CONDITIONING/HEAT PUMP SYSTEM				
Humidity - Room	Transmitter	Omega	HX91	$156	D
Pressure - Comp	Press. Control	Ranco	012-1549	$118	E
Flow					
Chilled Water	Flow Meter	Omega	FSW-23	$41	F
Air Duct	Modified Flow Meter	Omega	FSW-23	$60	G
Voltage	Relay	Potter & Brumfield	CSJ 38-70010	$70	H

TABLE 5. TYNDALL AFB SEWERAGE SYSTEM APUDAS 20 YEAR LIFE CYCLE COST ESTIMATE. (CONCLUDED)

CATEGORY	ITEM	NUMBER	UNIT COST	COST
installation	site survey	1	20,000	20,000
	RTU/radio manhole	181	1,000	181,000
	frame and cover	181	300	54,300
	sensor inst & cal	200	400	80,000
	misc remote hardware	200	50	10,000
	central system inst & check	1	15,000	15,000
	TOTAL INSTALLATION COST			360,300
MR^2	(1,445,865) (0.7902)			1,142,523
TOTAL				$2,948,688

TABLE 6. APUDAS HVAC SENSORS.

QUANTITY	DEVICE	BRAND	MODEL	COST	TYPE
	AIR CONDITIONING/HEAT PUMP SYSTEM				
Temperatures					
Room	Inermostat	Honeywell	2E096	$33	A
Evaporator	RTD	Omega	100W30	$22	B
Condenser	RTD	Omega	100W30	$22	C
	AIR CONDITIONING/HEAT PUMP SYSTEM				
Humidity - Room	Transmitter	Omega	HX91	$156	D
Pressure - Comp	Press. Control	Ranco	012-1549	$118	E
Flow					
Chilled Water	Flow Meter	Omega	FSW-23	$41	F
Air Duct	Modified Flow Meter	Omega	FSW-23	$60	G
Voltage	Relay	Potter & Brumfield	CSJ 38-70010	$70	H

TABLE 7. APUDAS HVAC SENSOR COSTS (CONTINUED).

PRIORITY	# ZONES	TYPE	SENSORS #	UNIT COST	TOTAL COST	COST PER FACILITY
4	4	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		K	5	105	525	
		A	4	33	132	
		D	1	156	156	
		F	5	41	205	
		G	4	60	240	1,560
5	5	M	4	70	280	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		K	6	105	630	
		A	4	33	132	
		D	2	156	312	
		F	6	41	246	
		G	4	60	240	2,164
7	3	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		K	4	105	420	
		A	3	33	99	
		D	1	156	156	
		F	4	41	164	
			3	60	180	1,321
9	2	M	4	70	280	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		K	3	105	315	
		A	2	33	66	
		D	1	156	156	
		F	3	41	123	
		G	2	60	120	1,384
10	1	M	1	70	70	70

TABLE 7. APUDAS HVAC SENSOR COSTS (CONTINUED).

PRIORITY	# ZONES	TYPE	SENSORS #	UNIT COST	TOTAL COST	COST PER FACILITY
11	2	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		A	2	33	66	
		D	1	156	156	
		G	2	60	120	
						644
12	6	M	8	70	560	
		B	3	22	66	
		C	3	22	66	
		E	3	118	354	
		J	1	22	22	
		K	7	105	735	
		A	6	33	198	
		D	1	156	156	
		F	7	41	287	
		G	6	60	360	
						2,804
13	8	M	6	70	420	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		K	9	105	945	
		A	8	33	264	
		D	8	156	1248	
		F	12	41	492	
		G	8	60	480	
						4,173
14	3	M	4	70	280	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		K	4	105	420	
		A	3	33	99	
		D	1	156	156	
		F	4	41	164	
		G	3	60	180	
						1,623

TABLE 7. APUDAS HVAC SENSOR COSTS (CONTINUED).

PRIORITY	# ZONES	TYPE	SENSORS #	UNIT COST	TOTAL COST	COST PER FACILITY
15	1	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		A	1	33	33	
		D	1	156	156	
		G	1	60	60	
						551
16	1	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		J	1	22	22	
		K	1	105	105	
		A	1	33	33	
		D	1	156	156	
		G	1	60	60	
						678
17	1	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		J	1	22	22	
		K	1	105	105	
		A	1	33	33	
		D	1	156	156	
		G	1	60	60	
						678
18	3	M	2	70	140	
		B	1	22	22	
		C	1	22	22	
		E	1	118	118	
		K	4	105	420	
		A	3	33	99	
		D	3	156	468	
		F	3	41	123	
		G	3	60	180	
						1,592

TABLE 7. APUDAS HVAC SENSOR COSTS (CONCLUDED).

PRIORITY	# ZONES	TYPE	SENSORS #	UNIT COST	TOTAL COST	COST PER FACILITY
19	2	M	4	70	280	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		J	2	22	44	
		K	2	105	210	
		A	2	33	66	
		D	1	156	156	
		G	2	60	120	
						1,200
20	2	M	4	70	280	
		B	2	22	44	
		C	2	22	44	
		E	2	118	236	
		J	2	22	44	
		K	2	105	210	
		F	4	41	164	
		A	2	33	66	
		D	1	156	156	
		G	2	60	120	
						1,364

GRAND TOTAL $25,993

TABLE 8. TYNDALL AFB MISSION-CRITICAL HVAC SYSTEM

APUDAS 20-YEAR LIFE CYCLE COST ESTIMATE

CATEGORY	ITEM	NUMBER	UNIT COST	COST
Hardware	sensors	394	See Table 6	$25,993
	RTU/radio	17	2,500	42,500
	battery	17	90	1,530
	misc remote hardware	17	200	3,400
	base radio	1	6,075	6,075
	microcomputer	1	8,000	8,000
	UPS	1	2,000	2,000
	software	1	15,000	15,000
	misc central hardware	1	1,000	1,000
	TOTAL INITIAL COST			$105,498
Installation	sensor inst & cal	394	300	118,200
	misc remote hardware	394	30	11,820
	central system inst & ck	1	15,000	15,000
	TOTAL INSTALLATION COST			$145,020
MR^2	(105,498)(0.7902)			83,364
TOTAL				$333,882

SECTION VII

SUMMARY

APUDAS stands for Automated Postattack Utilities Damage Assessment System. Currently, there is no automated, real-time, consolidated monitoring system to accomplish a timely, comprehensive, postattack status assessment of overseas air base utilities. These utilities include the electrical distribution, potable water, POL, sewerage, and mission-critical HVAC systems. Neither is there a formal Air Force requirement for an APUDAS, although the need for it was clearly demonstrated in the Airbase Operability exercise, SALTY DEMO, at Spangdahlem AF, FRG in 1985.

An APUDAS consists of sensors distributed throughout a utility network, plus a data communication and processing system. The sensors measure whatever quantities are necessary to determine the utility's operational status. Each sensor signal is fed into a nearby remote terminal unit (RTU), which acts as a controller, transferring the sensor signal at an appropriate time to a nearby small radio transceiver, which in turn transmits the sensor signal to a central base radio. The base radio feeds all the sensor signals into a central computer, which processes the information for display in such a fashion that it permits a trained observer to quickly determine the utility's operational status, plus locate and assess damage.

Design concepts for a sewerage system APUDAS, and for an HVAC system APUDAS are described in this report. Both are quite feasible, but neither is cheap. The 20-year life cycle cost for a Tyndall AFB sewerage system APUDAS is approximately 3 million dollars. It will permit an operational status assessment within 20 minutes, allowing 10 minutes for data handling and 10 minutes for human assessment.

Current APUDAS design concepts do not include system control, so an APUDAS is not a full fledged Supervisory Control and Data Acquisition (SCADA) system. However, the potential for making an APUDAS be a SCADA system certainly exists. The barriers are cost, survivability, and reliability.

SECTION VIII

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APPENDIX A

LISTING OF PROGRAM PDAT

THIS
PAGE
IS
MISSING
IN
ORIGINAL
DOCUMENT

```
      VAR = ABS(F11-F9)
      IF (VAR.GT.TOL) CALL DAMAGE(8)
C
      VAR = ABS(F12-(F10+F11))
      IF (VAR.GT.TOL) CALL DAMAGE(9)
C
      VAR = ABS(F12-(F13+F16))
      IF (VAR.GT.TOL) CALL DAMAGE(10)
C
      VAR = ABS(F14-F13)
      IF (VAR.GT.TOL) CALL DAMAGE(11)
C
      VAR = ABS(F15-F14)
      IF (VAR.GT.TOL) CALL DAMAGE(12)
C
      VAR = ABS(F17-F16)
      IF (VAR.GT.TOL) CALL DAMAGE(13)
C
  100 CONTINUE
  200 STOP
      END
C
      SUBROUTINE DAMAGE(N)
C
C  Print the damage description
C
      IF (N.EQ.1) WRITE(*,10)
  10  FORMAT(
     &'   W A R N I N G !',//,
     &'        Grit chamber is damaged.',//)
C
      IF (N.EQ.2) WRITE(*,20)
  20  FORMAT(
     &'   W A R N I N G !',//,
     &'        Primary clarifiers are damaged.',//)
C
      IF (N.EQ.3) WRITE(*,30)
  30  FORMAT(
     &'   W A R N I N G !',//,
     &'        Pipe break between primary clarifiers and trickling',
     &' filters.',//)
C
      IF (N.EQ.4) WRITE(*,40)
  40  FORMAT(
     &'   W A R N I N G !',//,
     &'        Trickling filter 1 is damaged.',//)
C
      IF (N.EQ.5) WRITE(*,50)
  50  FORMAT(
     &'   W A R N I N G !',//,
     &'        Trickling filter 2 is damaged.',//)
C
      IF (N.EQ.6) WRITE(*,60)
  60  FORMAT(
     &'   W A R N I N G !',//,
```

```
     &'       Pipe break between trickling filters and secondary',
     &' clarifiers.',//)
C
      IF (N.EQ.7) WRITE(*,70)
 70   FORMAT(
     &'   W A R N I N G !',//,
     &'       Secondary clarifier 1 is damaged.',//)
C
      IF (N.EQ.8) WRITE(*,80)
 80   FORMAT(
     &'   W A R N I N G !',//,
     &'       Secondary clarifier 2 is damaged.',//)
C
      IF (N.EQ.9) WRITE(*,90)
 90   FORMAT(
     &'   W A R N I N G !',//,
     &'       Pipe break between secondary clarifiers and recycling',
     &' pump station.',//)
C
      IF (N.EQ.10) WRITE(*,100)
 100  FORMAT(
     &'   W A R N I N G !',//,
     &'       Recycling pump station is damaged.',//)
C
      IF (N.EQ.11) WRITE(*,110)
 110  FORMAT(
     &'   W A R N I N G !',//,
     &'       Pipe break between recycling station and chlorine',
     &' contact chamber.',//)
C
      IF (N.EQ.12) WRITE(*,120)
 120  FORMAT(
     &'   W A R N I N G !',//,
     &'       Chlorine contact chamber is damaged.',//)
C
      IF (N.EQ.13) WRITE(*,130)
 130  FORMAT(
     &'   W A R N I N G !',//,
     &'       Pipe break between recycling station and trickling',
     &' filters.',//)
C
      END
```