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INSTRUMENTATION AND CONTROLS DIVISION
ENGINEERING FEASIBILITY STUDY
ON AUTOMATED ATTACK-EFFECTS
INFORMATION SYSTEMS

FINAL REPORT

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OAK RIDGE NATIONAL LABORATORY

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FINAL REPORT

by

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ABSTRACT

The Automated-Effects Information Systems-1 proposed by the Stanford Research Institute in April 1970 was studied to determine the practicability of such a system from an engineering viewpoint. At the request of the Defense Civil Preparedness Agency, ORNL prepared a preliminary design of two different models that are based on the original Basic Operating Situation (BOS) concept proposed before any work had been done on this system. Both ORNL designs will operate as dial-up systems with existing telephone networks and derive power necessary for operation directly from telephone lines. However, one is a digital system and the other is an analog system. From this study, a pressure-operated switch was developed that is automatically reset electrically and requires only a few micro-coulombs of stored energy to reset it after an interrogation. A recommendation from this study is that a test model be constructed to provide a means of checking for problems that could be encountered in a dial-up system when long distance is involved.

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1. INTRODUCTION

Familiarity with the Stanford Research Institute Report, Automated Attack-Effects Information Systems-1, (AAEIS)¹ is assumed and is a requisite for understanding this report.

1.1 Objectives

The following is a statement of the objectives of this study:

1. Study the proposals set forth in the Stanford Research Institute (SRI) Report AAEIS, and determine the desirability and practicability of such a system from an engineering viewpoint.
2. Determine acceptable design standards for the AAEIS, such as amount of information transmitted, self-checking features, costs and operating economy.
3. Design preliminary circuits and special components necessary for preparation of an AAEIS proposal.

1.2 Scope

In the early stages of this study, ORNL considered only the radiation detection phase of the overall system. Later, the study was expanded to include the complete AAEIS, with emphasis on the design of a sensor station. This latter task required a comprehensive study of the telephone system network and the circuit design to ensure their compatibility.

The problem of protecting the solid-state circuits from EMP and radiation damage at a cost that would not be deemed unreasonable received major consideration.

The concepts basic to the AAEIS are described in detail in the Stanford report, and only deviations proposed by the authors of this report from the original concepts will be discussed herein.

1. Automated Attack-Effects Information Systems-1, Stanford Research Institute (April 1970). Document prepared for OCD (now Defense Civil Preparedness Agency) under Contract No. DAHC 20-67-C-0136.

2. AAEIS DESIGN

2.1 Cost Considerations

Cost considerations forced a few changes in the conceptual design of the AAEIS and even a deletion of one of its basic functions. The estimated initial cost of a revised AAEIS, as well as the estimated costs for its operation and maintenance, had to be below certain limits so as to increase the probability that the system would become a reality. Therefore, some of the design details, such as power consumption and amount and method of information transmission, were constrained by cost limitations. In view of the high cost of dedicated telephone lines, some type of dial-up telecommunications system had to be considered.

2.2 Changes in AAEIS Concepts

The conceptual design by the SRI required that precise information be obtained on the arrival time of the shockwave at the sensor station. The method suggested was that a piezoelectric pressure transducer turn the sensor station power on to start an immediate transmission of overpressure information over a dedicated line. The station could be interrogated, after a sufficient warm-up period, for gamma radiation information.

Without a dedicated line, the inclusion of timing circuitry would complicate the system and increase the cost and standby power consumption to an extent that the timing feature would become impracticable. Since other warning and surveillance devices are available, this timing feature was deleted; thus, there was no need for the automatic turn-on feature.

The ORNL study group suggests the use of two-tone telemetry rather than amplitude tone modulation for reasons of simplicity and better noise immunity. A combination of two tones should be used to transmit each of the nine basic operating situations (BOS) (Fig.1). The sensor station should give a positive response when interrogated, even when the radiation level is < 0.5 R/hr and there has been no overpressure. Reliability and confidence in the system would be sacrificed by designing the system to indicate a BOS when there is no signal because this could also be the result of an inoperative station.

	NEGLIGIBLE FIRE	CONTROLLABLE FIRE	UNCONTROLLABLE FIRE
NEGLIGIBLE FALLOUT Less than 0.5 R/hr.	1 NEGRAD NEGFIRE	4 NEGRAD LOFIRE	7 NEGRAD HIFIRE
LOW FALLOUT Between 0.5 and 50 R/hr.	2 LORAD NEGFIRE	5 LORAD LOFIRE	8 LORAD HIFIRE
SEVERE FALLOUT More than 50 R/hr.	3 HIRAD NEGFIRE	6 HIRAD LOFIRE	9 HIRAD HIFIRE

Fig. 1. Nine basic operating conditions.

With available micropowered circuits, the sensor stations can be powered with dc power from the telephone lines if the sensors are located relatively close to the central office or local battery. (Limitations in distance will be discussed in Design Proposals). The minimum load current required to supervise and hold a switched telephone line (18-30 mA) is more than adequate to power the sensor station. Since a sensor station cannot be interrogated unless the line is intact and functional, this power should be used when possible to obtain the following advantages: (1) elimination of batteries results in a substantial savings in operating and maintenance costs, (2) elimination of battery holders (the weakest link in most battery-powered equipment) yields greater reliability, and (3) elimination of battery operation in extremely cold environments where battery terminal voltages can drop below rated values also yields greater reliability.

These advantages of line power in most situations will outweigh the disadvantages of having to place the sensor station relatively close to the central office or local battery. Where it is necessary to place the sensor stations at remote locations, the systems proposed by ORNL can easily be adapted to battery operations.

3. DESIGN STANDARDS

3.1 Gamma Detector

We propose the following design standards for the gamma detection:

1. The detector must have a useful range of a minimum of three decades. A linear response would be desirable.
2. The detector should transmit an adequate output signal when subjected to the most credible radiation intensity and fallout.
3. The temperature coefficient should be less than $0.1\%/^{\circ}\text{C}$ within the limits of -30 to $+68^{\circ}\text{C}$.
4. The detector performance should not be affected by high humidity.

3.2 Pressure Sensor

We propose the following design standards for the pressure sensor:

1. The frequency response of the pressure sensor should be constant within ± 3 dB over a range from 0.1 to 4.6 Hz.
2. The temperature coefficient should not exceed $0.1\%/^{\circ}\text{C}$.
3. The sensor should withstand a pressure up to 15 psi with no lessening of its performance.
4. The sensor should be operable and capable of retaining its memory even when there is no power to the sensor.

3.3 Circuits

The circuits should meet the following design standards:

1. The power requirement of a sensor station should be less than 150 μW while in standby and less than 200 mW while being interrogated. This meets the power consumption requirements of the telephone system for line powered equipment when the primary voltage requirement of the equipment is within a range from 4 to 10 V.
2. The circuits should require no warm-up time so that a sensor station can be interrogated and turned off within 1 min from the time it is turned on. This would ensure a long shelf life for low-capacity dry batteries if they had to be used as well as minimum telephone charges when long distances are involved.
3. The output from a sensor station must be within the frequency versus power limits of the telephone system and compatible with the BOS requirements.
4. The method of transmitting information must have an inherently good noise immunity.
5. The circuits must be sufficiently protected against EMP so that a properly installed circuit will survive EMP without malfunctioning.
6. The stability and selectivity of the telemetering circuits should not allow interference between adjacent channels.
7. The system should operate without maintenance for long periods of time.

4. SENSOR STATION PROPOSAL 1

4.1 Brief Description

4.1.1 Packaging

The proposed sensor station will be packaged in a corrosion resistant pipe, 3-4 in. OD and about 11 ft long. The circuit will be constructed in a hermetically sealed container about 12 in. long and placed in one end of the pipe, and the integrating pulse discharge ionization chamber (IPDIC)² and pressure transducers will be installed in the other end. The end of the pipe containing the circuitry will be set in the ground to a depth of ~ 5 ft to shield it from gamma radiation and extreme temperature. Portions of the pipe wall will be cut out at the pressure transducer location to make the housing transparent and omnidirectional to shock waves.

4.1.2 Circuits and Operating Principle

Figure 2 is a diagram of a sensor station circuit. All of the circuit except the input protective circuit and ring circuit is usually disconnected from the line. When a sensor station is dialed by either a manual or an automatic dialing circuit located in either a national or state Emergency Operating Center (EOC), the ring signal will close two latching relays (block 6), which serve the same function as hook switches on voice-type telephones. Electrical power from the nominally 48-V dc line supply then becomes available to be regulated and to power the entire sensor station.

When power is supplied to a circuit, it functions in the following manner. The dc-to-dc converter (block 4) supplies 45 V to power the 1-min timer (block 5) which generates a signal after a delay of 1 min to unlatch the relays and reset the pressure transducers. One of the pressure tone generators (blocks 17, 18, and 19) immediately starts generating a tone. The pressure decoder (block 13) makes the decision based on either the

2. C. Distenfield, W. Bishop, and J. Lamplough, "Accelerator Radiation Monitoring and Dosimetry with Integrating Pulse Discharge Ionization Chamber Detectors," Nucl. Instr. Methods 49, 309-315 (1967).

Fig. 2. Diagram of sensor station.

absence or the magnitude of an overpressure since the station was last interrogated as to which tone generator will be energized. [The pressure transducers (block 7 or 8) supplying information to the decoder may be simple pressure-operated, latching switches].

The dc-to-dc converter (block 4) also supplies regulated 550 V to the gamma detector (block 9). The counting circuits monitor the pulses from the detector and supply dc signals to the decoder (block 14). The decoder responds to the signals received from the counting rate meters and energizes the appropriate tone generator (blocks 20, 21, and 22). One of the tone generators will be energized regardless of the radiation level, because only one pulse from the detector is required to energize the < 0.5 R/hr tone generator and at least one pulse will be produced by the turn-on charging current. Although this feature tests the counting rate circuit and the radiation detection, it serves no other useful function because an absence of a tone from the other two tone generators can also be interpreted as a radiation level of less than 0.5 R/hr.

The signals from the radiation tone generator and the overpressure tone generator are mixed in a linear mixer (block 16) and transmitted to the EOC. The two tones are decoded in a 3×3 matrix at the EOC, and the information is punched on paper tape or stored on magnetic tape simply as a single BOS number, 1 to 9. The station identification number is also recorded, and both numbers can be transmitted later to an EOC at a state or national level.

The operation of the sensor station can be stated briefly as follows. When a station number is dialed, the station responds by transmitting two tones, which can be decoded as one of nine BOS. After a total on-time of 1 min, the station automatically disengages itself from the line ("hangs up").

4.1.3 Power Requirements

The power required to satisfactorily operate the sensor station is 10 V at 18 mA. Since a current of approximately 18 mA is required to hold and supervise a telephone line, the power can be drawn from the 48-V dc line supply while meeting all requirements imposed by the telephone system, as long as the sensor station is located close enough to the central station

or local battery that the additional voltage drop in the sensor station does not limit the current to less than 18 mA.

4.1.4 Cost Estimate

The following estimated cost of an installed sensor station was determined from the costs of electronic components bought in small quantities. (Some of these components might cost as much as 40% less in quantities of 1000 or more). The costs of the stainless steel housing and pressure switches (or transducers) include the development cost prorated over 1000 units.

Electronic components	\$285
Latching type pressure switches (two at \$75 each)	150
Stainless steel housing	200
Labor for assembly (quantity production)	120
Installation, including cost of a protective fence	<u>125</u>
Total cost of installed sensor station	\$930

This estimate is a simple engineering "best guess" and does not include any charges by a telephone company for installation or equipment.

4.2 Detailed Description

4.2.1 Pressure Sensors

As previously stated, the pressure sensors should register the pressure signals without any source of electrical power. Such a sensor, constructed at ORNL to determine its feasibility, is a pressure operated switch that has sufficient hysteresis to maintain closure indefinitely until it is re-set electrically.

The switch is a reed relay, with two soft-iron pole pieces attached to the relay lead wires (Fig. 3). The relay is closed when a magnet attached to the diaphragm is moved closer to the pole pieces by a shock wave. When the switch is closed, the reluctance of the magnetic circuit is reduced sufficiently to keep the switch closed after the shock wave has passed and the magnet has returned to its normal position. The coil is used in this

Fig. 3. Sensor station circuit.

application to open the switch after the station has been interrogated.

There are two pressure sensitive switches; one closes at an overpressure of 0.5 psi and the other at 5 psi.

The mass of the diaphragm and magnet and the displacement required to reliably operate the switch can create some difficulty in obtaining the fast response time required to accurately detect a peak overpressure from a low-yield burst over smooth terrain. For example, the shock wave pressure from a 200 kiloton device will decay to 80% of its peak value in 160 msec.³ However, the overpressure decay times are much longer for higher-yield devices (megaton range); therefore, sensors for high-yield devices do not require as fast a response time to accurately determine the peak overpressures as for low-yield devices. A sensor that will respond to a step increase in pressure with an error of only 10% at $T_0 + 80$ msec will have an adequate speed of response. This corresponds to 4.58 Hz in the frequency domain.

Since a sensor must adjust to changes in atmospheric pressure, its low-frequency response must also be controlled. A technique for achieving this is to allow the cavity to breathe through a short length of capillary tubing. This extends the low-frequency response far below that required for accurate peak pressure detection.

Some development work and thorough testing will be required before these pressure sensors can be mass produced.

A lead zirconate-lead titanate type piezoelectric transducer and micro-power memory were also constructed and tested. The high-frequency response of this transducer is about three orders of magnitude faster than required. The low-frequency response and the calibration can be controlled easily by the external circuit. The electrical output is sufficiently high to work directly into the memory. The memory comprises a flip-flop circuit around a COS/MOS dual complementary pair. The power requirement for the memory in its quiescent state is 4-5 V at less than 0.1 μ A. When energized the power required to maintain the memory is 50 μ W. We have been informed that the telephone system will permit a constant power drain of 24 mW from its lines.

3. Samuel Glasstone (ed.), The Effects of Nuclear Weapons, U. S. Department of Defense, U.S. Atomic Energy Commission, 1967.

The advantages of piezoelectric transducers compared to pressure operated switches are a much lower cost, better frequency response, and greater ease of calibration with an external shunt capacitance. A disadvantage is that the transducer will lose its memory when the power is interrupted unless three small dry cells supply power to the memory.

Final development of such a transducer should be by a manufacturer of piezoelectric transducers. It might be difficult to obtain an acceptable temperature coefficient.

4.2.2 Radiation Detector and Rate Meter

The gamma detector, in addition to meeting the standards described in Sect. 3.1, should have a high electrical output at a fairly low impedance so that a sensitive amplifier will not be needed since sensitive amplifiers increase the complexity of construction required to achieve a desired noise immunity. Integrating pulse discharge chambers (IPDIC) seem to meet this requirement better than any other gamma detector.

An IPDIC is an ionization chamber in which the ionization current produced by gamma radiation is directly converted to electrical pulses by a cold cathode gas diode (such as a neon glow lamp) that is sealed within the chamber.^{4,5} Not only does such a chamber retain the desirable dosimetric characteristics of conventional ionization chambers, it also supplies a low-impedance pulse output that is necessary for multidecade, remote monitoring in harsh environments.

Voltage biasing and pulse detection circuits required for the IPDIC are similar to the simple circuits used with G-M counters.⁶ The high voltage bias level is not critical.

4. Serge A. Scherbatskoy, "Radiation Detection System with the Ionization Chamber and Other Sensitive Parts of the System Enclosed in an Atmosphere of Inert Dry Gas," U.S. Patent 3,177,363 (April 6, 1955).

5. J. T. De Lorenzo et al., Radiological Instrument Design Investigation for OCD, January 1970 to October 1970, Annual Report, ORNL-TM-3370 (March 1971).

6. Unlike G-M counters, the IPDIC pulses are periodic and not random.

Other documented IPDIC characteristics include good linearity over several decades and exceptional stability as a function of time and dose history. A unit manufactured by Nuclear Associates, Inc., Westbury, New York, was tested by NBS in 1968, and it was accurate within $\pm 5\%$ when checked with a ^{60}Co source over a range from 0.67 to 839.8 R/hr.⁷ Two smaller units tested at ORNL in 1970 were accurate to within $\pm 6\%$ when checked with a ^{137}Cs source over a range from 0.4 to 400 R/hr.⁵ In each case, the lack of beam uniformity at all exposure rates probably contributed to the measurement inaccuracy.

In monitoring applications at Brookhaven National Laboratory, a calibration shift of 2 to 5% per year was reported, with stabilization after 2 to 3 years.⁸ The same report indicated that there was no degradation of performance after the units had received a dose of 5×10^6 rad from ^{60}Co .

Data on temperature stability has not been reported because of the practical problem of locating a suitable gamma source inside an environmental test chamber.

The IPDIC is a relatively new detector design, and the evaluation of several theoretical aspects and practical problems remains incomplete. To date, however, no problem or anomaly has been reported that should preclude prime consideration of the IPDIC for use in an AAEIS.

The IPDIC manufactured by Nuclear Associates yields a calibrated output of 0.0005 R/pulse. When used to test the radiation detector circuit (Fig. 4), pulses from the IPDIC have sufficient amplitude to drive amplifier Q4 from its quiescent saturated state to cut off. Transistors Q5 and Q6 are the active elements of a trigger pair that forms rectangular pulses having fixed widths of 10 msec. The pulse shaper drives the normally biased-off current switch Q7 into conduction, and a current I_E flows in the emitter circuit for the duration of the pulse T. The magnitude of this current

7. National Bureau of Standards, Test Report 504.02 (June 24, 1968).

8. The AGS Magnet Enclosure Beam Spill and Personnel Safety Monitor, Health Physics Division, Brookhaven National Laboratory.

pulse is

$$I_E = \frac{E_S - E_R + V_D - V_{BE(on)}}{R}, \quad (1)$$

where E_S is the supply voltage (+10 V), E_R is the reference voltage (+5 V), V_D is the forward drop across D6, $V_{BE(on)}$ is for Q6, and R is the sum of resistances R20 and R21. Further, I_E is adjustable over a range from 0.6×10^{-3} to 1.6×10^{-3} A. Since transistor Q7 has a minimum current gain of 250, the collector current that flows through R22 is essentially the same as I_E . Therefore, the average current I through R22 is

$$I = I_E NT, \quad (2)$$

where N is the frequency of the pulses in Hz and T is the width of the pulse in hundredths of seconds. Since the calibrated output of the IPDIC is 0.0005 R/pulse, N is equal to 0.2777 and 27.77 Hz for gamma dose rates of 0.5 and 50 R/hr, respectively. Therefore, the average current through R22 in a 0.5 R/hr field is adjustable from 1.736×10^{-6} to 4.628×10^{-6} A. Thus, the IR drop across R22 is adjustable from 1.67 to 4.628 V, which brackets the typical switching voltage (3 V) of the NAND gates in IC1.

Since the counting rate is 27.77 counts/sec at 50 R/hr, the resistance in the emitter circuit of Q8 (R25 and R26) is a factor of 10 higher than the resistance of R20 and R21, and the resistance in the collector circuit (R27) is 0.1 the value of R22. Therefore, the voltage output from the 50 R/hr rate circuit is the same as from the 0.5 R/hr rate circuit at a counting rate that is two orders of magnitude higher than at the 0.5 R/hr range.

4.2.3 Logic

As previously stated, 3 V is a typical switching voltage for the CD4023A NAND gate. In the following discussion, any potential above 3 V will be referred to as a "1," and any potential below 3 V will be referred to as "0". The shaded portion of Table 1 shows that all three outputs may be in the 1 state if the gamma level is sufficiently high (>50 R/hr). Only the NAND gate monitoring the highest decade rate meter having an output of 3 V or more will have a 0 at its output. As shown in Fig. 3, all other

Table 1. Typical output voltages of count rate circuits and check circuit

Radiation Level (R/hr)	Count Rate (counts/sec)	Circuit Outputs (V)		
		Check	CRC1	CRC2
< 0.5	0.04	5	<< 3	0
0.5	0.2777	5	3	0.3
50.0	27.77	5	5	3.0

gates have at least one of their inputs at a 0 level. Since a 0 is required at the gate outputs to bias switches Q4, Q5, and Q6 into conduction, only one of the radiation tone generators will be energized at any given time.

The logic that determines which overpressure tone generator will be energized functions in the same manner as the decoder for the rate meter outputs. When neither of the pressure switches is closed, all three inputs of IC2A are at the 1 level (essentially +5 V). Therefore, the output of IC2A is a 0, and the 810.2 Hz tone generator is energized. If, however, the 0.5 psi switch is closed, IC2B will have a 0 at its output, and the outputs of IC2A and IC2C will be 1's. A 0 at the output of IC2C will result in a 1 at the outputs of IC2A and IC2B.

The sensor station will always transmit two tones simultaneously when interrogated. One tone will indicate one of the three radiation levels, and the other tone will denote one of the three pressures. These tones will be decoded at the EOC by bandpass filters and a 3 x 3 matrix.

4.2.4 Tone Generators

There are two separate tone generators with subminiature piezoelectric tuning forks as the frequency determining component, rather than two, frequency-shift oscillators. Figure 5 shows the tone generators and the receivers at the EOC. Their compactness, frequency stability, low cost, and low power consumption (20 mW) make them ideal for this application. The major components in the receiver and generator are identical, reducing the number of components to be purchased and stocked.

Fig. 5. Tone generator, receiver, and test circuit.

Three tuning forks having resonant frequencies corresponding to the frequencies shown in Fig. 3 were purchased and tested in the test circuit in Fig. 5. The bandpass receivers were excellent; their attenuation to adjacent channel signals was 30 dB or greater. All the forks were well within the manufacturer's specified limits for frequency and temperature coefficient.

4.2.5 Mixer and Line Driver

Q1 and Q2 and resistors R2-12 (Fig. 3) comprise the mixer and line driver. The driver has good linearity and produces negligible harmonic and inner modulation distortion. Current limiting and capacitance coupling to the line protect against short-circuits. No serious effort was made to provide a precise driving impedance, because the size of the coupling capacitors required to achieve an impedance that is essentially independent of ΔF (change in frequency) would be too large. Therefore, the system will depend on proper termination at the EOC, or the receiving end, of the transmission line.

4.2.6 Power Supply Circuits

Bridge rectifier BR1 is always across the line (Fig. 3). However, C1 furnishes dc isolation, and CH1 presents high impedance to audio frequencies within the range employed in this system. The low-frequency ring signal, however, is rectified and charges C2 to a voltage sufficiently high to break down diode D6 and close latching relays S1 and S2.

Closing S1 and S2 supplies dc power to the remainder of the circuit. CH2 has low resistance to the dc power and a high impedance to the audio frequencies. Bridge rectifier BR2 ensures correct polarity in the power circuit, regardless of the line polarity. D12 is a 10 V reference diode that serves as a 10 V shunt regulator. The total power supplied by these two regulators is 180 mW.

Approximately 25 mW of this power is consumed by the dc-to-dc converter (Fig. 4) which supplies regulated +550 V for the IPDIC and regulated +45 V for the timer (R1, C3, and D13). Q1 is the switch in the blocking oscillator. Current feedback through the voltage reference tube V1 and current

amplifiers Q3 and Q2 to the base of Q1 ensures good voltage regulation and excellent efficiency.

4.2.7 Timer

After a sensor station is interrogated, it is disengaged from the telephone line by a self timer that begins its timing cycle as soon as the ring signal closes S1 and S2 to unlatch these relays. This timer comprises R1, C3, and D13 (Fig. 3). C3 is charged exponentially to the breakdown voltage of the multilayer diode. If there were no leakage current through C3 or D13 before breakdown occurs, the timing cycle would be $\sim 1.5 RC$, or 49 sec. Since there is some leakage in both components, the average timing cycle is 60 sec. When breakdown occurs, the current surge from C3 resets latching relays S1 and S2 and the pressure switches.

4.2.8 Self-Checking Features

The response of a sensor station to routine interrogations, if properly interpreted, can provide useful information concerning possible circuit malfunctions. One self-checking feature is the absence of an audio tone from the radiation detector if any one of the following components fails: dc-to-dc converter, IPDIC or its coaxial cable, amplifier, trigger-pair current switch, Q9, gate, IC1A, inverter, IC3C, or the 953.7-Hz tone generator. If all these circuits are functioning, the pulse formed in the IPDIC by the current required to charge the center electrode of the chamber will trigger flip-flop CD4013AE, which will energize the 953.7-Hz generator ($< 0.5 R/hr$). Since this automatic check includes the components that are most vulnerable to damage by lightning and EMP, one can conclude with a high degree of confidence that a satisfactory check indicates that the entire sensor station is functional.

4.2.9 Limitations

The distance over which a sensor station can transmit BOS information is not limited, but the distance between a sensor station and the nearest central exchange office or local battery is limited by the dc voltage drop of the line due to the minimum current required for station power, or if

it is greater, the minimum hold and supervise current. The maximum length $L_{\max}$ of a line in miles is

$$L_{\max} = \frac{V_1 - V_R - V_{BR} - I_{\min} R_C}{I_{\min} 2R_L}, \quad (3)$$

where V_1 is the line voltage at the terminals of the local battery (about 48 V), V_R is the voltage drop across the zener diode D12, V_{BR} is the voltage drop across the bridge rectifier BR2 (1.4 V). $I_{\min}$ is the minimum hold current (20 mA), R_C is the circuit resistance consisting primarily of the series dc resistance of the relay coil at the central exchange office and the inductance CH2 (usually 345 Ω), and R_L is the resistance of 1 mile of 26 AWG wire (typical wire gage in telephone cables). A typical value for R_L is 215 Ω . V_1 in most local systems is 48 V.

In some rural systems, state utility boards require telephone companies to install 96-V dc supplies to obtain better long-wire service. The maximum line distance for a 48-V supply is 3.6 miles and for a 96-V supply is 8.5 miles. The safety margin on power would be adequate if sensor stations were located at distances no greater than 3 and 7 miles from the 48- and 96-V supplies, respectively. Ideally there should be a minimum of 1 and 3 miles of line between the sensor stations and the 48- and 96-V supplies, respectively, to avoid saturation of inductor CH2 when additional series resistance is not used.

Longer lines can be used by supplying additional battery power at the sensor stations (Fig. 3, note 5 and terminals). We do not recommend this practice, because the line polarity would have to be determined at the time of installation and sealed compartments would have to be opened routinely to replace batteries.

5. SENSOR STATION PROPOSAL 2

5.1 Description

This proposed sensor station is identical to proposal 1 with one major exception. In proposal 1 the radiation monitor is equipped with rate meters so that accurate timing is not required. In this proposal the radiation monitor is digital and one master timer at the EOC times the length of the count when each sensor station is interrogated. With a common clock

for all stations, the costs of the digital counter and the rate meter system are comparable.

As mentioned in Sect. 4.2.8, "Self-Checking Features," for Sensor Station Proposal 1, the current that flows during the initial charging of the center electrode in the ionization chamber provides a single pulse from the IPDIC. Since this pulse is not radiation induced, it is not counted. However, the detection and recognition of this pulse by the radiation monitor is a useful check to indicate that a large percentage of the circuit is functional.

In the digital circuit (Fig. 6), when the ring signal closes the "hook" switches at the sensor station, the regulated primary voltage rises almost exponentially, with a 4×10^{-3} sec time constant under worst case conditions, i.e., the maximum length of line. C9 couples this voltage transient into the reset circuit, resetting all counters to zero and the flip-flop so that the Q and $\bar{Q}$ outputs are low and high, respectively.

The first pulse from the discriminator (the test pulse) will trigger flip-flop IC4A, but the pulse will not be counted by IC1 because IC1 has not been enabled. $\bar{Q}$ is high before the first pulse triggers IC4A. Since the first pulse triggers IC4A and enables the counters, all subsequent pulses will be counted. Both inputs to IC6A will be positive after the first pulse triggers IC4A and the 953.7-Hz tone generator is energized. If six more pulses follow the test pulse during interrogation, IC4B will be triggered by counter IC1. After IC4B is triggered, one of the inputs to IC6A will be low and both inputs to IC6B will be high. Therefore, the 953.7-Hz generator will be energized no longer and the 1006.9-Hz generator will be energized. If 600 pulses or more, excluding the test pulse, are counted during an interrogation, the 1084.0-Hz tone generator will be energized.

The logic will allow only one of the three generators to be energized at any given time.

5.2 Advantages and Disadvantages of the Digital Counter

We believe the advantages of the digital counter to be the following:

1. The long-term stability of the digital counter is superior to the count rate circuit.

2. The digital counter can operate at the same power supply voltage as required for the logic and tone generator, thus eliminating one voltage regulator.

3. With the common supply voltage, PNP switches can be used to energize the tone generators, thereby eliminating the six inverters in IC3.

The disadvantages, in our opinion, are as follows:

1. Since the digital counter has no calibration adjustment, the IPDIC calibration must be more precise than necessary with the rate meter.

2. The accuracy of the digital counter cannot exceed the accuracy of the timer at the EOC. By comparison, the accuracy of the timer has only negligible effect on the accuracy of the count rate circuit if the timing cycle is $3 RC$ or greater, where RC is the longer of the two integrating time constants in the two counting rate circuits.

6. AAEIS TEST MODEL PROPOSAL

The sensor station would be identical to the one described in AAEIS Proposal 1 (Sect. 4) with two exceptions: (1) the packaging would be designed to withstand only a controlled environment, and (2) the pressure sensors would be replaced with simulators that could be programmed from the EOC or the data collector station.

The data collector station would have manual dialing and a 3×3 lighted matrix BOS display. Since commercial automatic dialing and answering systems are available from many sources, there would be no reason to include one in the test model. Both the sensor station and the data collector station would be built as lightweight, portable units so that either could be easily transported across town, county, or country, if desired, and plugged in to any four-wire telephone receptacle.

The estimated engineering and fabrication cost for a test model with one sensor station is \$20,000. Additional sensor stations in quantities of less than 10 would cost about \$1,500.

7. CONCLUSIONS

All circuits in the proposed AAEIS test model, excluding EMP protection with which we have no experience, have been constructed and bench tested. This model would not only yield reliability data for evaluation of the system electronic circuits, it would also allow checking problems that might be experienced with a dial system and transmission of information over a long distance.

By discharging high-voltage capacitors directly into the input of the EMP protector (see block 1, Fig. 2) and extrapolating the measured pulse voltages at various vulnerable parts of the circuit, we could possibly determine if the design has adequate protection against the 100 kV/meter intensity EMP that can be expected from a high altitude detonation.⁹

With the preceding proposals, a dial-up system is a practical compromise between cost and transmitted data without sacrificing reliability. Since we lack experience with large-scale commercial production, our estimate of the cost of sensor stations may be high by as much as 50%. Any cost estimate that we might give at this time for the data collection and computer storage parts of the system, without further investigation, would be pure conjecture.

9. DNA EMP Awareness Course Notes, DNA 2772T (August 1971).

8. APPENDIX: ADAPTABILITY TO RADIO COMMUNICATION

In principle, a wireless telecommunication network could be employed in both AAEIS proposals. The sensor station illustrated in Fig. 3 could be modified for wireless transmission by deleting reed relays S1 and S2, the ring circuitry that energizes these relays, the holding coil CH2, and the bridge rectifier in the 10-V power supply. A 100- Ω , 0.5-W resistor to decrease the battery voltage to 10 V would also be added. The audio output of line driver Q1 would modulate the transmitter.

Figure 7 illustrates a complete sensor station, including the radio communication equipment. In "stand-by" the receiver will be energized by normally closed contacts in the power relay. Nothing else in the station will be drawing power from the 12-V battery, which will be on trickle charge. The sensor stations can be interrogated by transmitting command signals consisting of two audio tones. The receivers in all stations will be tuned to the same radiofrequency, but each will respond to different combinations of audio tones. When a receiver detects its appropriate tone combination, the power relay and the antenna change-over relay will be energized. This will switch power from the receiver and supply power to all other circuits, including the transmitter. The transmitter will transmit a two-tone modulated signal for approximately 1 min. The transmission will be terminated by the 1-min timer, deenergizing the two relays.

Since the periods of transmission will be short and the receiver power consumption can be kept low, it should be possible to maintain operation for up to 6 weeks with a 60-A-hr, 12-V battery after loss of power. This assumes that the fully charged battery has at least 80% of its original capacity. Fairly sophisticated battery chargers will be required to assure a long battery life and to maintain the battery fully charged at all times.

The most difficult aspect of wireless transmission is to protect the solid-state radio equipment from EMP. The radio equipment will be inherently vulnerable to EMP damage since the antenna must be exposed to EMP. Signals might be generated that exceed the capability of the receivers by ten to eleven orders of magnitude. The transmitter will be vulnerable as well, but to a slightly lesser degree. To attempt to design an AAEIS

Fig. 7. Sensor station adopted for use with radio link.

employing a radio communications network without first proving that the radio equipment could withstand EMP, might be fruitless. At the time of this writing, we, the authors, are not aware of radio protection techniques that could be considered reliable.

Another area that would require considerable attention is the choice of the radiofrequency or frequencies to be used. After one determines from technical considerations the best frequency for an AAEIS, the final decision will be based on an FCC allocation for use in a time of national emergency. The technical considerations are such that the frequency should be:

1. sufficiently high that sky-wave propagation cannot take place under normal ionospheric conditions,
2. sufficiently low that satisfactory ground-wave coverage can be achieved with moderate power and antenna gain,
3. so high that the EMP amplitude is decreased by at least 50 dB,
4. high to reduce the size of the antenna,
5. sufficiently high to discriminate against the intense natural atmospheric electrical disturbances in the lower part of the radiofrequency spectrum.

Since the second requirement conflicts with the other four, a satisfactory compromise frequency seems to be the logical answer. A frequency of 150 to 200 MHz might be a good compromise. The EMP amplitude is reduced ~ 60 dB at 150 MHz and falls 40 dB/decade. An EOC with a favorable location could consistently and reliably communicate with sensor stations up to distances of 50 to 60 miles with only moderate power (this assumes narrow-band FM for good noise immunity). There is a narrow FM band assigned to the U.S. Government (157.037 to 157.1875 MHz) that technically appears to be a good choice.

Technically, the circuits in both sensor station proposals are compatible with radio communications. However, substitution of radio for telephone lines will require construction of a housing for the additional equipment and an antenna tower that can stand overpressures in excess of 5 psi.

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13. ABSTRACT The Automated-Effects Information Systems-1 proposed by the Stanford Research Institute in April 1970 was studied to determine the practicability of such a system from an engineering viewpoint. At the request of the Defense Civil Preparedness Agency, ORNL prepared a preliminary design of two different models that are based on the original Basic Operating Situation (BOS) concept proposed before any work had been done on this system. Both ORNL designs will operate as dial-up systems with existing telephone networks and derive power necessary for operation directly from telephone lines. However, one is a digital system and the other is an analog system. From this study, a pressure-operated switch was developed that is automatically reset electrically and requires only a few microcoulombs of stored energy to reset it after an interrogation. A recommendation from this study is that a test model be constructed to provide a means of checking for problems that could be encountered in a dial-up system when long distance is involved.		

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