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A COMPUTER-CONTROLLED SAMPLING SYSTEM
FOR AIRBORNE RADIONUCLIDES

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A COMPUTER-CONTROLLED SAMPLING SYSTEM FOR AIRBORNE RADIONUCLIDES*

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Summary

A computer-controlled air sampling system has been designed and is presently being constructed. The self-contained, mobile system will collect and record data from eight meteorological sensors. This information will be used in the study of resuspended airborne activity. Air sampler operation will be based on comparisons between the meteorological data and the sampling criteria selected by the operator at the beginning of the run. Correlations between meteorological parameters and resuspension will be used to develop a predictive model. The paper includes a description of system hardware and discussion of the software concept.

Introduction

Under certain circumstances, the resuspension, by wind, of ground-deposited radionuclides can represent a considerable health hazard. Materials present in the form of respirable-sized particles and those which are retained for long periods by the body are especially hazardous. Of particular interest in our case is the metal ^{239}Pu and its oxide $^{239}\text{PuO}_2$. Plutonium is an alpha emitter with an extremely long half-life (24,390 years).

The hazards associated with ^{239}Pu skin absorption and ingestion are less significant than those related to inhalation of respirable-sized particles. While inhaled plutonium is cleared rather rapidly from the upper respiratory areas, about 15% is retained in the pulmonary exchange areas of the lung¹. Clearance from these areas is accomplished by movement of the plutonium to the lymph nodes, liver and skeletal system where it then remains indefinitely.

^{239}Pu is used primarily as fissile material in nuclear weapons. Dispersal of radioactive debris during non-nuclear test shots and at the time of weapon accidents has occurred several times in the past. The need to understand the hazards associated with plutonium releases has led to the study of this problem in great detail.

The Lawrence Livermore Laboratory (LLL) is presently conducting an experimental program at the AEC's Nevada Test Site (NTS) aimed at developing a model which will quantify the ^{239}Pu resuspension hazard. The site chosen was one which was utilized between 1954 and 1956 for plutonium experimentation. The contaminated area covers approximately 200,000 square meters of desert surface with soil activity greater than 41,000 dpm/gm at the hottest locations.

Since early 1972, the experimental efforts have primarily involved the concurrent measurements of ^{239}Pu air concentration and the local meteorological parameters at NTS. Because of the low air concentrations, ($<10^{-12}$ picocuries/m³) it has been necessary to run high-volume air samplers for as long as 30 days to obtain a sample which can be analyzed for ^{239}Pu .

*This work was performed under the auspices of the U. S. Atomic Energy Commission.

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Constant monitoring of several meteorological parameters for a period that long is impractical in the remote desert environment. Even if the data were collected, attempting to relate measured air concentration to the variety of weather conditions experienced in 30 days would be almost impossible. In an attempt to improve this situation, we have taken two parallel steps. The first was the development of an ultra-high-volume air sampler, described elsewhere², which runs at nearly 2000 m³/hr. This sampler allows an analyzable sample to be collected in 2-4 hours. The second step involves development of a computer-controlled system which, while running unattended, can collect and record data on meteorological conditions, then use these data to control operation of a conventional air sampler. The sampler used in this system will be activated only when specified meteorological parameters fall within preselected ranges. This will allow correlations between these parameters and measured air concentrations to be studied.

System Description

The computer-controlled sampling system, as presently conceived, is shown schematically in Figure 1. A Digital Equipment Corporation¹ PDP-12 computer was chosen for reasons of availability rather than capability. While its use does place several constraints on system design, the computer does adequately satisfy many of our requirements. The PDP-12 is a parallel processor, 12-bit "minicomputer", first marketed about 1969. Our system consists of the basic 4,096-word (4K) machine with analog-to-digital (A/D) converter, two LINCtape drives, cathode ray tube display, relay register and Teletype. A real-time clock has recently been added for the sampling application. The A/D converter is a multiplexed, 16-channel device, however only 8 channels are available for external signal input. The remaining channels are connected internally to 10-turn potentiometers and are normally used for manual parameter input to various programs.

Sensors

The eight meteorological sensors chosen for the initial system are described below and summarized in Table 1. The sensors will be mounted on towers at the specified heights.

Climet wind speed sensors will be located 2 m and 10 m above the ground. The sensors are equipped with three lightweight cups for measurements of wind speed between 0.3 and 40 m/sec. Response characteristics of an anemometer are normally specified in terms of the distance a wind velocity step-function travels in the time it takes the anemometer to reach 63% of the new speed value. For the Climet sensor, this "distance constant" is 1.5 m. Output from the instrument is caused by a magnetic reed switch which closes one time for each revolution of the anemometer shaft. Appropriate electronics convert the switch closure frequency to an analog signal which can then be fed into the computer.

A Geotech wind speed transmitter, similar to the Climet sensor, produces a pulse output by interrupting a light beam falling on a small photodiode. Use of a lightweight 6-cup assembly on the anemometer results in a 1.0 m distance constant. This sensor will be mounted 3 m off the ground and is included for measurement of horizontal turbulence.

Wind direction at a height of 2 m will be monitored with a Climet wind vane sensor. The instrument consists of a polyurethane wind vane coupled to a 360° potentiometer. A "constant current" power supply will drive the potentiometer, resulting in an output voltage which is linearly dependent on wind direction.

Mounted at the 3 m level will be a Gill Propeller Anemometer for measurement of vertical air movement. This particular unit incorporates a small d.c. generator which provides a voltage output proportional to the propeller's speed of rotation. Design of the propeller is such that its response to wind at various angles to the vertical very closely approximates a cosine function.

Temperature is measured by a thermistor at 2 m and one at 10 m above the ground. Climet aspirated shields protect the thermistors from solar and ground radiation while allowing a representative sample of ambient air to reach them. The thermistors will be connected into an electronic bridge for generation of an analog signal.

The temperature shield at 10 m includes separate space for a dew point sensor. A thermistor, separate from those used for ambient temperature measurement, is located inside a hollow tube exposed to the air. The tube is covered with a lithium-chloride-saturated cloth which absorbs moisture from the air and thereby changes resistance. Current flow through two electrodes on the tube is dependent on the resistance of lithium chloride. Since this same flow of current tends to heat and dry the tube, an equilibrium condition is maintained. The temperature inside the tube, as sensed by the thermistor, is directly related to ambient dew point temperature. A commercial electronics card converts the thermistor resistance to an analog voltage output. Range of the instrument is -30°C to +5°C.

Data Acquisition

The relationship between meteorology and particle resuspension is a complex one, probably not quantifiable in terms of only directly-measurable parameters. In some cases, the more interesting quantities are actually combinations of several parameters. For example, particle resuspension is not expected to depend very much on ambient temperature alone. Of greater importance are temperature gradients in the vertical direction and the associated atmospheric stability. The two temperature and two Climet wind sensors at heights of 2 m and 10 m provide difference inputs for calculation of the Richardson's Number, a common stability parameter.

The vertical propeller and Geotech anemometer will be used together to quantify local wind fluctuations, both those parallel to the horizontal wind (u-direction) and those in the vertical (v) direction. Both parameters are expected to be important for resuspension modeling. Turbulence, however, is not as simply calculated as the Richardson's Number, for measurements of vertical and horizontal winds are not easily interpreted. As we gain experience with the system, we hope to develop a combination of the two parameters that can quantify the turbulence sufficiently for our needs.

Data from the wind direction transmitter and dew point sensor are processed individually by the computer and not combined with any other parameters. Wind direction is important in our experiment because the radioactive source has a relatively small areal extent. The amount of ^{239}Pu collected by the samplers is expected to be a strong function of the amount of time they are downwind from the source. For this reason, wind direction will be one of the most basic criteria for sampler control.

Since dew point data is considered of secondary importance, provision will be made for replacing the dew point sensor with a dust-loading instrument to measure dust loading at times when this device is available. Two instruments are contemplated for this purpose, both utilizing light scattering principles. One, a Climet Particle Analyzer, uses a finely-focused light beam to size and count individual particles. Its output is fed into a pulse height analyzer which stores the particle counts in 200 channels. The second unit, an MRI nephelometer, records the scattering from many particles at once, in a fairly large cavity. Both instruments can provide information on the concentration of soil particles in the air; however, the analog output of the nephelometer results in simpler interfacing with the computer.

Data Processing

As stated earlier, the computer-controlled-sampling system has a two-fold task: collection and recording of meteorological data; and operation of selected air samplers based on a comparison of these data with preselected criteria. The following paragraphs describe the concepts upon which the system software will be designed.

For the initial program, a minimum sampling interval of 15 minutes was chosen. No decisions regarding operation of the samplers will be made by the computer on a time scale less than 15 minutes. This prevents samplers from being constantly turned on and off with the attendant extra motor wear and uncertainty regarding exact volume of air sampled. This admittedly arbitrary figure will be reviewed after the system has been in use for some time to determine if it is compatible with the time scale of meteorological variations.

The 15 minute decision period will be broken into five 3-minute intervals. At the end of each interval, the computer will compare the appropriate meteorological parameters (sampled and averaged during the previous three minutes) with the sampling criteria preselected by the operator at the beginning of the run. The computer will register YES or NO "votes" each three minutes for each selected parameter, reflecting whether or not the three-minute mean falls within the required range. At the end of 15 minutes the "votes" will be tallied to determine whether the sampler should be on or off for the next 15 minutes. Four out of five YES or NO votes will constitute a sufficient majority for that parameter. The sampler will not, however, be turned on or off unless ALL parameters show at least 4 out of 5 YES votes. The 4-out-of-5 scheme allows for an anomalous parameter variation to occur during a minimum sampling period without disturbing the decision process.

Values for the three-minute means will be arrived at differently for the various sensors. Because of the computer's limited memory capacity, only a minimum amount of calculations will be performed. The initial system concept was set up as follows.

The two temperature sensors will be sampled every 15 seconds and a mean temperature calculated for each at the end of 3 minutes. The means will be subtracted to obtain a 3-minute ΔT . A similar process will be used for the Climet wind speed sensors. The Δu and ΔT values will be combined in an equation to obtain the Richardson's Number every 3 minutes.

Horizontal turbulence will be sensed by sampling the Geotech anemometer once per second. To obtain a representation of the fluctuations in wind speed, the one-second values will be subtracted from a running mean calculated from previous readings. These differences will be combined into an rms horizontal fluctuation every 3 minutes.

The Gill vertical propeller will be sampled ten times per second. RMS values for the vertical velocity will be calculated and recorded every 3 minutes.

Wind direction and dew point temperature will be sensed every 15 seconds and appropriate means calculated and recorded.

It has not been determined at this time how much computer storage will be available for calculations in addition to Richardson's Number. As our study progresses, and other parameters are identified as being important in the resuspension process, we will attempt to implement their computation and recording.

One of the design criteria for the computer-controlled sampling system is that it must operate "unattended" for long periods of time. An important concern, then, is how rapidly the tapes become filled with data. Taking an absolute minimum "unattended" time of 24 hours, plus 8 hours safety factor, one tape spool could hold the equivalent of approximately 200 words written every 3 minutes. If the second tape drive were similarly utilized either the time interval or total number of words could be doubled. However, it is not certain at this time that all the software required by the system will fit in the 4K core and still leave enough space for the computer's "scratch pad" calculations of means, "vote" storage, etc. Part or all of the second tape may be required as a memory extension.

The 200 word figure quoted above may not be adequate for the recorded data. Although there are not a great deal of numbers to be stored every 3 minutes, there may not be sufficient core capability to insure the data is stored in an efficient format, for example, floating-point notation. Also, in addition to the meteorological data, it is necessary to record date and time, data identifiers, and sampler status information. Also, with turbulence data being collected on a very fine time scale, it is desirable to save more than a 3-minute rms value on tape. Further study is required to arrive at an effective plan for data recording.

Field Operations

During sampling operations, the computer-controlled sampling system will be located in a moderate-sized (fifteen-foot), air conditioned truck. Although diesel generators are available at the WTS experimental site, the truck will include provisions for towing a small generator to allow sampling at other sites and to make the system self-supporting.

Rather than utilize an expensive trailer-mounted tower when only two sensors need to be elevated to 10 meters, we plan to mount a light-weight, extendable tower to the side of the truck. With the exception of

the one temperature and wind speed sensor mounted on this tower, the other sensors will be attached to a small, portable tripod tower which can be placed up to 30 m from the truck to avoid wake effects. Figure 2 shows the planned arrangement.

To initiate a sampling run, the towers will be erected and the air samplers emplaced. The operator will input the system software, stored on tape, into the computer and place one or two fresh spools of tape on the drives. Then, using the Teletype, he will initiate the run by specifying date, time, sampling criteria and any pertinent comments.

Once the program is running, the data will be recorded on tape and the sampler automatically turned off and on. In addition, upon operator request, the Teletype can provide real time data on computer calculations and parameter comparisons. A simulated page of this type of TTY output is shown in Figure 3. Should the operator wish to restart a fresh sampler using revised criteria, that too will be possible using Teletype commands.

Future Improvements

As pointed out above, there are several aspects of the system concept which we hope to refine after gaining some operational experience. The 15-minute minimum sampling period, the four-out-of-five scheme and the sensor sampling intervals are all somewhat arbitrary. It is our opinion that modifications to the original plans in these areas are best arrived at empirically. For example, once the software is written to process the data tapes, it will be possible to review the meteorological measurements made during the sampler on-time. One can then evaluate how often parameters moved out of range, after the decision was made to leave the sampler running, but before the next decision could be made to turn it off.

Once operation of the initial computer program is verified and the amount of computer memory still available is determined, there are several "second generation" improvements which might be made to the software. The following are only a few of the possibilities.

- 1) Operation of multiple samplers. This may be one of the easiest improvements to implement after the initial single-sampler program is proven, assuming sufficient memory is available. In this configuration, the computer would control two or three samplers, each with its own set of sampling criteria.

- 2) More control over meteorological sensors. Although this is certainly feasible, it is not yet clear whether it would truly be useful or desirable. In this scheme, sampling intervals for each sensor would not be fixed, but would be adjusted to be compatible with the rate that sensor's parameter was changing. This would provide more data points during rapid transitions and might conserve tape space when parameters were changing very slowly.

- 3) Limited "predictive" capability. By far the most complex of the three ideas, it is also the most valuable. When the system is set up using the original concept explained earlier, its decisions for sampler control are based on measurements made during the previous 15 minutes. No consideration is given to the trend of the measurements recorded during that time, however. The value of a given parameter may have steadily approached the edge of the sampling window, or even fallen outside for the fifth 3-minute interval, but the sampler would still have been left running.

Through more sophisticated software, the system could be made sensitive to not only whether or not a measurement fell within the preselected range, but to how that value compares with previous measurements. Upon recognizing a definite trend, the program might allow for another decision to be made before the full 15 minutes elapse, should the parameter continue to approach the edge of the range. In this way the 15-minute period could truly become a minimum sampling interval. Samplers could not be on for less than 15 minutes, but neither would they have to remain on for multiples of 15 minutes, after the first interval has passed.

Many hardware improvements are unfeasible because of cost. Purchase of an additional 4K of core for the PDP-12 falls into this category. One hardware revision which may prove to be a virtual necessity, however, is the addition of an IBM-compatible tape drive. A 10 1/2-inch reel of magnetic tape offers at least two orders-of-magnitude more storage than a LINCTape spool on the PDP-12. Much more data could be recorded for later processing and the system could run unattended for longer periods. In addition, such a tape could be processed directly by the large computers at LLL. Data stored on LINCTape must first be converted to IBM-format by another computer.

Conclusion

This paper has presented an approach for a more exact sampling of atmospheric pollutants, particularly those resuspended from contamination sources on the ground. The system utilizes a computer-controlled

sampling system which makes decisions based on the continuous measurement of meteorological parameters. In this manner it will be possible to determine which specific atmospheric conditions enhance aerosol resuspension from a given location. This knowledge will be applied to a predictive resuspension model. This model, together with an understanding of local meteorological conditions and soil surface characteristics will allow an assessment of potential resuspension hazards.

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References

1. Langham, W. H. (Becker, J. F., ed.) "Biological Considerations of Nonnuclear Incidents Involving Nuclear Warheads." Lawrence Radiation Laboratory Report UCRL-50639 (1970).
2. (UHV sampler paper to be published)

TABLE 1

<u>Sensor</u>	<u>Height</u>	<u>Measurement</u>	<u>Range</u>	<u>Sampling Interval</u>	
Climet Anemometer	2m, 10m	Wind Speed for Richardson's #	0.3-40 m/sec	Once each 15 sec	Contact closure. Freq proportional to wind speed.
Climet Thermometer	2m, 10m	Temperature for Richardson's #	-30°C to 50°C	Once each 15 sec	Variable resistance. Function of air temperature.
Geotech Anemometer	3m	Horizontal Wind Fluctuations	0.2-40 m/sec	Once per sec	Pulse output proportional to speed.
Gill Propeller	3m	Vertical Wind	0.3-11 m/sec	10 times per sec	DC voltage proportional to speed.
Climet Wind Vane	2m	Wind Direction	0-360°	Once each minute	Variable resistance. Function of wind direction.
Climet Dew Point	10m	Dew Point Temperature	-30°C to +45°C	Once each minute	Variable resistance. Function of dew point temperature.

Figure Captions

- Fig. 1. Block diagram of the computer-controlled sampling system. The system is designed around a Digital Equipment Corporation PDP-12 computer.
- Fig. 2. Artists' conception of the computer-controlled sampling system in the field. The tower in the foreground supports five meteorological sensors 2 and 3 m above the ground. The remaining three sensors are located atop the truck-mounted tower. A commercial high-volume cascade impactor is shown in the background.
- Fig. 3. A page of simulated Teletype output from the computer-controlled sampling system. The top part of the page represents the operator's choice of sampling criteria. The lower part is a sample of the operator-requested meteorological parameter printout. The latter includes sampler status and running time information.

Fig. 1
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Fig. 2
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CCSS OPERATING PROGRAM IS INITIALIZED.....

BE SURE CLEAN TAPE IS ON UNIT ONE, THEN PROCEED

DATE? 740615
TIME? 1000
OPERATOR? C. FRY
COMMENTS?

SAMPLING CRITERIA SELECTION

WIND SPEED (2M): BETWEEN M/SEC 5
AND M/SEC 10

WIND DIREC (2M): BETWEEN DEGREES 170
AND DEGREES 180

RICHARDSON NUM: BETWEEN -999
AND -0.02

VERTICAL WIND: BETWEEN M/SEC -999
AND M/SEC 999

HORIZ WIND VAR: BETWEEN M/SEC 0.5
AND M/SEC 999

DEW POINT TEMP: BETWEEN DEGREES -999
AND DEGREES 999

DATE	TIME	U2M	U10M	T2M	T10M	VERT	HORZ	DIR	RICH#	DEW	VOTE	HOURS
740615	1309	05.3*	07.1	26.5	25.9	0.2*	0.9*	185	-0.05*	-8.1*		1.40
740615	1312	05.5*	07.5	26.4	25.8	0.1*	0.6*	177*	-0.04*	-8.1*		1.45
740615	1315	04.7	06.4	26.3	25.8	0.1*	0.7*	177*	-0.05*	-8.0*		1.50
		4/5*				5/5*	5/5*	3/5	4/5*	5/5*	OFF	1.50
740615	1318	05.9*	08.0	26.1	25.8	0.2*	0.9*	182	-0.02	-8.0*		1.50
740615	1321	05.5*	07.7	26.2	25.7	0.1*	0.7*	187	-0.03*	-8.1*		1.50