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A SYSTEM FOR RADIATION MONITORING OF OCCUPATIONAL AREAS

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Introduction

The Radiation Physics Section has the general responsibility of ascertaining that NAL personnel and the general population are protected from the harmful effects of nuclear radiations.

The maximum permissible allowable doses are given in the AEC Manual, Chapter 0524.

There are many possible ways to discharge this responsibility. In particular, two very different methods to monitor and record nuclear radiation levels are described. It is then shown that they cost about the same. However, the computer based system will have less operating costs and it will give much more information.

Definition

Radiation worker: any person employed directly or indirectly by NAL, or working for NAL as experimenter using NAL's facilities, and who may receive in any one calendar quarter a dose greater than 10% of the maximum permissible dose specified in the AEC Manual, Chapter 0524.

Monitoring Schemes

We are presenting here two very different schemes for personnel exposure control. The first scheme places the whole burden of the exposure monitoring and avoidance of over-exposures on the radiation workers themselves. This is done by issuing to the personnel two types of personal dosimeters, one with long memory (such as film badges or TLD's) to be read every month by the Radiation Physics Section, and another dosimeter (such as pocket ionization chambers) to be read hourly, daily or as needed by the radiation worker himself. The Radiation Physics Section would only make spot checks of radiation levels and it would recommend the use of sufficient (maybe excessive?) shielding to take care of possible malfunctions of beam transport equipment, etc.

The second scheme places the burden of maintaining acceptable radiation levels on the accelerator and experimental area operating crews. Monitors would be placed as needed in occupational

areas and their outputs, properly interpreted, would be given to the operating crews if untolerable dose rates should appear for too long. The radiation workers would wear long memory and direct reading personal dosimeters as needed. Two ways of implementing the second scheme are given; one purely hardwired and the other one using a computer and appropriate multiplexing techniques.

Monitoring Scheme One

1. The experimenters and radiation workers are responsible to follow their exposures within each calendar month. Radiation Physics follows their exposures on a monthly basis.

2. Radiation Physics surveys all areas once and spot checks periodically as possible. All shielding is made massive enough to stand unusual as well as usual beam losses.

3. There is no information available to the operating crews on radiation safety conditions in any area.

Implementation:

1. All radiation workers will wear a long memory, indirect reading dosimeter such as a film badge, TLD, etc., to be read monthly by the Radiation Physics Section.

2. In addition, all radiation workers will wear two high quality pocket ionization chambers of the direct reading type. Thusly, the radiation workers will be able to follow their integrated doses at least on a weekly basis without the cumbersome use of written records.

3. The use of enough biological shielding to cover all possible beam losses would be too expensive and hence impractical. Therefore, a network of radiation detectors will exist in occupational areas that will give information on radiation levels and an audio alarm in case of unacceptable high dose rates.

4. Radiation Physics will survey all areas initially and recommend adequate shielding for normal and expected abnormal beam losses. Later on only spot checks will be made as frequently as possible.

Limitations, Advantages/Disadvantages:

1. The operation crews would have no on line information about the radiation levels in occupational areas.

2. Radiation safety would be minimal and based almost exclusively in the use of expensive, massive shielding.

3. Acquisition of data for comparison of effects due to operational changes would be slow and expensive.

Monitoring Scheme Two

Philosophy:

1. The radiation levels are monitored continuously with an adequate number of detectors. The average radiation level is maintained within acceptable limits.

2. The radiation workers wear long memory personal radiation dosimeters (such as film badges, TLD's, etc.).

3. Information is conveyed to the operating crews about the radiation levels in all occupational areas. Should the levels rise above acceptable levels, the operators would have to take remedial action.

4. The control of the radiation field levels permits the control of occupational exposures.

Implementation:

1. Radiation workers will wear a long memory, indirect reading dosimeter (such as a film badge, TLD, etc.) to be read monthly by the Radiation Physics Section.

2. In especially hazardous locations, additional dosimeters may be worn.

3. A network of radiation monitors would be installed in all occupational areas in adequate numbers. This will permit monitoring of radiation field intensities in the vicinity of any working party.

4. The outputs from these monitors will be available locally and remotely. The remote users would be the operating crews and radiation physics technicians.

5. In addition to the semi-fixed radiation monitors described in part 3, spot surveys will be made by the Radiation Physics Section. These spot surveys would give information on areas between detectors and also would check the operation of the detector between calibrations.

First variant: no computer.

All signals are sent via twisted pairs to recorders. One recorder per detector is used. Integral discriminators sound an alarm if the levels of radiation are too high at any location.

Second variant: multiplexing and computer.

The signals are multiplexed and gathered by a small computer. A certain amount of flexibility is now possible.

Limitations, Advantages/Disadvantages:

1. The operating crews would have records, on request, on the radiation levels over large areas of the accelerator complex.

2. Single or a few "bad" acceleration cycles may be disregarded under certain conditions.

3. Messages would be presented to the operating crews as needed and for purposes which may vary with operating conditions.

4. The use of a multiplexing system plus a small computer would permit the future expansion of the system at no more cost than the cost of the additional detectors.

5. The use of a multiplexing system would permit, at limited additional cost, the integration of the dose to individual radiation workers working in the vicinity of a radiation monitor.

6. The use of twisted pairs between detectors and operating crews would cause ground loop problems and great expense in cable pulling, cable costs and would be inflexible with regards to relocation of detectors or future expansion in the case of the hardwired system.

Costs

I. First Scheme:

No control over radiation fields.

600 people under control, 1200 pocket ion chambers (high quality: low leakage)	k$ 120.00
100 radiation alarms	k$ 100.00
	k$ 220.00

II.A Second Scheme:

Controlled radiation fields.

Hardwired.

200 pocket ion chambers	k$ 20.00
250 radiation monitors	k$ 250.00
cabling	k$ 82.00
	k$ 352.00

II-B Computer Based:

200 pocket ion chambers	k$ 20.00
250 radiation monitors	k$ 250.00
computer	k$ 30.00
interfacing	k$ 20.00
cabling	k$ 8.00
	k$ 328.00

Note:

These prices do not include other necessary systems such as water radioactivity measurements, monitoring of radiation accidents, etc.

Conclusions

The first scheme is not acceptable since it provides for no radiation protection. There is no provision for monitoring and then controlling the intensity of the nuclear radiation fields. It allows only for a monitoring of the dose after the events have taken place.

The second scheme is better. It allows for monitoring, controlling and then avoiding unnecessary occupational exposures.

Of the two variants for the second scheme, the computer based one has many advantages:

1. Lower initial cost,
2. Lower operational costs,
3. Possibility of varying the conditions leading to an alarm,
4. Possibility of presentation of data in many useful forms,
5. Possibility of preparing resumes of radiation levels per shift, per day, etc. In particular, presenting only significant data and avoiding storage of useless data.

In view of the advantages of the computer based radiation monitoring system, an appendix follows in which some of the possibilities of this system are presented.

APPENDIX I

A SYSTEM FOR RADIATION MONITORING BASED ON A SMALL DIGITAL COMPUTER

M. Awschalom, R. Shafer & D. Theriot

Introduction

This system is designed to monitor the radiation levels in all occupational areas. Hence, it will permit limiting beam losses by the operating crew such that the average radiation levels remain within acceptable levels.

This system is designed to operate in low level radiation areas. However, some of the detectors may have large dynamic range. Still, this system will be supplemented with a number of passive radiation detectors (film badges, TLD's, activation detectors, etc.) in areas where catastrophic losses of beam could drive the radiation detectors temporarily outside their linear ranges.

In addition, this system will permit the operating crews to concentrate their attention on those areas where beam losses may be about to cause or are already causing radiation levels higher than the acceptable average.

Furthermore, the system will have in its memory available for display, the average and certain peak radiation levels in each location for a certain period. This information may be useful in trouble shooting or spotting some accelerator malfunctions.

Initially, the radiation monitoring computer will not be connected to the control computer.

Description of the System.

The system will consist of:

a - radiation detectors of various types whose outputs will be digitized by means of "local electronics" as needed,

b - the "local electronics" of the detectors may have many possible variants and options,

c - several sets of cables to multiplex the detector outputs to a centrally located computer. Each set of cables plus the associated hardware is known as a "branch",

d - each "branch" will have a number of connectors to which any of the detectors may be plugged in,

e - the output of the computer will be in the form of typed/printed displays as well as plots on charts and or oscilloscopes for such areas as one may designate. Also, there will be aural alarms to be sounded at the radiation physics operations area(s) when some detectors will signal radiation levels greater than the average acceptable radiation levels for a time longer than one arbitrarily preset period,

f - the minimum dynamic range of the radiation detectors will be 10^4:1, generally starting at about 0.1 m rem/hr. This includes all necessary correction factors for the very small duty cycles of the linac, the booster and three turn extraction from the main accelerator during bubble chamber runs,

g - initially, some 250 detectors will be connected to five or six "branches".

"Local Electronics"

The local electronics at the detectors will vary depending on the nature of the detectors, since both ionization chamber and pulse type detectors may be used simultaneously.

In some cases, the minimal local electronics will consist of power supplies, discriminator, pre-scaler and interfacing to the "branch".

In other cases, the minimal local electronics may need an integrator-digitizer circuit, but will not need a discriminator.

Among the local optional electronics there will be scalers with visual read-out, ratemeters with chart recorders and even automatic occupational time announcers with audio alarm. Our present design of the detector multiplexing system is a 3 wire time-coded dedicated channel system in which the detector identity is specified by the timing of the data pulses. The multiplexer may transmit single pulses from each detector, or contents of binary registers.

Another possible option will be to permit the integration of dose to certain personnel working in any area by the insertion of "identity-plugs" in some detectors.

One example of operation: Polyethylene moderated, Ag-activated GM neutron detector.

A counting rate of 1 c/sec ~ 1 mrem/hr for our present design fast neutron monitors. Then, for the cannonical 2.5 mrem/hr for 300 detectors, and using a prescaler of ten, we would expect,

2.5 c/sec/det x 300 det/10 = 75 c/sec, arriving at the computer. Even if 10% of the detectors should increase their counting rates by 10^4, the resulting counting rate of 75 kHz at the computer would be tolerable. Hence, there are no problems here.

Should there be objectionable losses in some "branch", some or all the prescalers in that branch may be changed.

Since we are talking here of detectors using Ag-foils, the half-lives of ^{108}Ag and ^{110}Ag (2.4 min and 24 sec, respectively) are the effective integrating time constant of these detectors. So, during normal operation there will only be small changes in the counting rates.

Computer Operation

When the memory location corresponding to a particular detector is incremented, the contents will be compared with a stored threshold number.

In some locations, a convenient threshold value could be a dose corresponding to a dose rate of 2.5 mrem/hr for a period of 7.5 minutes or 0.3 mrem.

The choice of 7.5 minutes as a unit of time was made for three reasons,

1 - it is approximately 3 half-lives of ^{108}Ag,

2 - it is 2^{-3} of one hour, and,

3 - it gives reasonable counting statistics even at 2.5 mrem/hr.

A dose of 0.3 mrem would correspond to approximately 100 counts (using a prescaler of ten), or 10 counts (using a prescaler of one hundred). In both cases the overall uncertainity is $\pm$ 3.2% plus a scaling error of $\pm$ 1 count.

If in Δt, during a unit time, the counter exceeds the threshold value, the effective dose rate would be computed thusly,

(0.3 mrem/unit time) x (number of units of time per hour) x (unit time/Δt) = (number of mrem per hr).

For example, if unit time = 7.5 minutes, and the threshold was exceeded in 2.5 minutes, the dose rate would be,

$$(0.3 \text{ mrem}/7.5 \text{ min}) \times (8) \times (7.5 \text{ min}/2.5 \text{ min}) = \frac{7.2 \text{ mrem}}{\text{hr}}.$$

Should the dose rate exceed the threshold level, a warning would be typed out, such as ,

Time tttt date ddmmm yy

Counter #x reads 7.2 mrem/hr.

Should the threshold be exceeded in two consecutive units of time, a record will be started automatically in a Rustrak recorder. The recording of the radiation field intensity would continue until stopped by the operator. The updating of the recorded data will occur at either the end of each unit of time, or each time the threshold is exceeded, whichever occurs first.

At the end of each shift a summary of all counters will be printed out, such as,

Time tttt Date dd mmm yy

Counter #	Dose for Prev. Eight Hours (mrem)
1	18.9
2	7.2
3	12.1
4	8.3
5	12.7
.	
.	
.	
300	0.6

And for all those detectors which exceeded their threshold at any time during those eight hours, an hour by hour summary will be printed such as,

Counter/Hour	1st	2nd	3rd	4th	5th	6th	7th	8th
#1	1.5	1.0	1.3	4.5	7.1	2.2	.8	.5
#5	0.5	0.7	0.8	1.0	4.2	3.8	1.0	.7

To guard against loss of too much data in the event of computer failure, the hourly totals will be dumped on paper tape every hour.

At all times the computer will have for each detector a record of the previous three shifts, shift by shift, the previous seven hours, hour by hour, the previous seven units of time, unit by unit (7.5 min), as well as the accumulating hourly and unit time active counters.

Access to the data will be possible from the control room as well as the operational room(s) of the radiation physics section.

Counter Testing

The testing and calibration of detectors could be carried out in the framework of this scheme by having a technician place a test source which would give a known exposure rate greater than threshold for the 7.5 minute period when placed in contact with the detector. The computer would type out the warning message with the calculated exposure rate. The computer operator would know that the detector was being tested and would instruct the computer not to record this dose rate.

Computer Section

Although almost any small computer with a 16 bit word, 8 to 12 K memory could do this job, a MAC-16 with a high speed paper tape reader and punch and a KSR-35 teletype unit would be advantageous because of its use at NAL for many other functions. As we will be interfacing many device controllers to the computer as well as interfacing the computer to others at NAL, the MAC-16 would be most compatible to our system.

Operation Under Computer Failure Conditions

The price of the detectors includes local readout via Rustrak recorder, blind scalers which may be read with a portable device and an audio alarm in case the radiation field intensity becomes greater than an arbitrarily preset level. Hence, in case of computer malfunction, the scalers will be reset and the Rustrak recorders will give information on dose rates.

During the malfunction, many marginal areas may have to be fenced off and extra personnel from the operations divisions will have to be pressed into radiation safety duty.

Cost Estimates

The cost of the individual detectors with any of the "local electronics" may be calculated with the aid of the tables in Appendix II.

The computer itself, with the needed peripherals and options will cost approximately k$ 30.00.

Appendix II

DETECTOR SYSTEM - COMPONENT COST

R. Shafer

I. Detector Subsystem (Note 1).

a. GM-silver + moderator + stand + cable	(note 2)	$220
b. GM-rhodium + moderator + stand + cable	(note 2)	250
c. LiI phototube + moderator + stand + cable	(note 2)	470
d. Ion chamber + stand + cable		125
e. BF_3 + moderator + stand + cable	(note 2)	220

II. Digitizing Electronics.

a. Discriminator & gate (for items I.a, b,c)	40
b. Amplifier, discriminator & gate (for I.e only)	60
c. Operational amplifier integrator-digitizer and gate (for item I.d only).	150

III. Output Devices.

a. Local Readout Systems.

1. Blind integrating scaler	(per decade)	10
Option i portable plug in nixie readout	(per decade)	+40
Option ii permanent nixie readout	(per decade)	+30
2. Recycling scaler with nixie readout	(per decade)	50
Option i buffer memory	(per decade)	+10
3. Analog averaging circuit, blind single scale		50
Option i meter readout		+25
Option ii recorder output		+100
Option iii audible alarm		+15

	Option iv	latched audible alarm	+20
	Option v	voltage comparator with light board readout (per unit)	20
	Option vi	item v including latches (per unit)	25
	Option vii	occupation time sign	200
b.	Remote Readout System Interfacing to Only:		
1.	Hardwire readout, interfacing to only:		
	Option i	binary	10
	Option ii	binary latched	15
	Option iii	analog	30
2.	Time coded serial data transmission system including: divide by N(fixed) address comparator (8 bit), set reset flip flop circuit, and interface to 3 line system		100
	Option i	serial transmission of 8 bit scaler	+50
	Option ii	serial transmission of 8 bit personnel I.D. (per 8 bit I.D.)	+50

IV. Power Supplies

a.	Low voltage	100
b.	High voltage	150

V. Remote Readout Systems - Cabling Only

a.	Hardwire, 4500' long twisted pair including installation	(per detector)	225
b.	3 wire serial data transmission cabling including installation	(per detector)	90

VI. Remote Data Handling Subsystems - Direct Non-Computer Readout

a.	Binary signals, lamps only	(per detector)	10
b.	Analog signals, meters	(per detector)	25
c.	Alarms	(per detector)	10
d.	Recorders	(per detector)	100

e. Isolator and 3 decade blind scaler	(per detector)	80
Option i nixie readout for above	(per detector)	120
Option ii multiplexed nixie readout	(per detector)	40

VII. Remote Data Handling Subsystem - Interface to Computer

a. Clock reset signal generators	(per detector)	5
b. Interface to computer input device		
Option i 1 bit	(per detector)	20
Option ii 8 bits	(per detector)	23
Option iii 32 bits	(per detector)	25

Note 1. Includes entire detector subsystem ready to be connected to electronics.

Note 2. Present estimate of moderator cost: material $85
labor $40.

Appendix III

A POSSIBLE MULTIPLEXING SYSTEM FOR RADIATION PHYSICS

R. Shafer

The multiplexing system being described here is being considered for transmitting data from a large number of widely dispersed radiation detectors to a centralized computer.

The basic requirements of the multiplexing system are:

1. The multiplexing system shall be able to handle data from a large number of widely separated detectors at minimal cost.

2. The multiplexing system must be so designed that a failure of any kind at any detector causes minimal interference with data acquisition from any other detector.

3. The multiplexing system must be designed so that excessive counting rates from any one detector cannot inhibit data acquisition from any other detector.

4. The multiplexing system should be capable of very high instantaneous data rates under worst case conditions.

5. The computer should not spend excessive time processing data from quiet detectors. The data collection rate should be highest from the areas where the most severe radiation levels exist.

6. The multiplexing system should be flexible in the sense that the detector stations may be relocated or expanded without undue effort in rerouting cables, etc; and future features may be added without rendering the system obsolete.

Requirement #1 implies that we should consider a large number of simple multiplexing stations rather than a few centralized stations for data acquisition.

Requirement #2 implies that the data link from any detector to the computer must be a passive system (i.e., there can be no active devices such as repeater stations which are subject to failure).

Requirement #3 implies that the data be transmitted in "dedicated" channels which cannot be used by any detector other than the detector to which the channel is assigned.

There are 3 common methods of assigning dedicated channels.

1. Dedicated cables (e.g., 1 twisted pair per detector).

2. Dedicated time slots (e.g., the timing of data pulses relative to control pulses identifies the time slot and hence the detector).

3. Dedicated frequency slots.

Various types of modulation may be used within these dedicated channels: pulse height, pulse width, and frequency modulation for example.

Requirement #4 implies that:

1. Due to band-width limitations of the multiplexing system, the data transmissions from each detector should contain only the necessary and sufficient information. The detectors should not transmit more often than necessary.

2. The computer should be able to dedicate itself to the multiplexing system when necessary. When the data rates are high this should be done even to the exclusion of other peripheral devices (except to send appropriate alarms as needed).

Requirement #5 implies that the data processing rates be proportional to radiation levels. Under normal conditions then, the computer should have sufficient time to service all other I/o devices. The rate at which the detectors are sampled may, however, remain at the maximum data collection rate as long as the rate of computer interrupts varies with radiation levels.

The multiplexing system which seems to best suit our requirements is the dedicated time slot system. This can be done with 3 cables per multiplexing system ("branch") as shown in Figure 1.

The three cables (twisted pairs) are respectively the clock pulse line, the reset pulse line, and the data pulse line. This trio of cables may be several miles long and is limited only by their band-width. At one end of the clock cable a signal generator transmits clock pulse down the clock cable. A reset signal is transmitted down the reset cable once per 2^n clock pulses ($2^n \simeq 128$ is a good number). We now have 2^n time slots which are defined as the time intervals between clock pulses, the first time slot being the slot immediately following the transmission of a reset pulse and a subsequent clock pulse. As these pulses are traveling down the cables at the same velocity, the arrival of these signals at any point along the cable remains

synchronous. Furthermore, if a pulse is transmitted in the same direction along the data cable, it also will remain synchronous with the clock pulses.

At each detector station there will be a passive isolated pickoff device on the clock and reset cables (probably a transformer-coupled zero-cross detector). These will provide timing signals to a n-bit scaler (count capacity 2^n) at each detector. Each detector will be uniquely identified by an n-bit I.D. number wired into an n-bit binary comparator. When the scaler count reaches the I.D. number of the detector the comparator identifies the assigned time slot and the detector may transmit a single binary pulse on the data line synchronous with its time slot on the clock line. The detector will ordinarily transmit no data pulse, but will transmit a data pulse only if it has counted the required number of events since last transmitting a pulse. This pulse will be put onto the data cable via transformer coupling to eliminate any common mode voltage problems. As this pulse will propagate in both directions along the data cable, both ends must be properly terminated. Due to possible interference of backwards traveling data pulses with transmission of other forward traveling data pulses (the backward traveling pulse is out of synchronization with the time slots), detectors close to the clock end of the cables should generally be assigned lower numbered time slots.

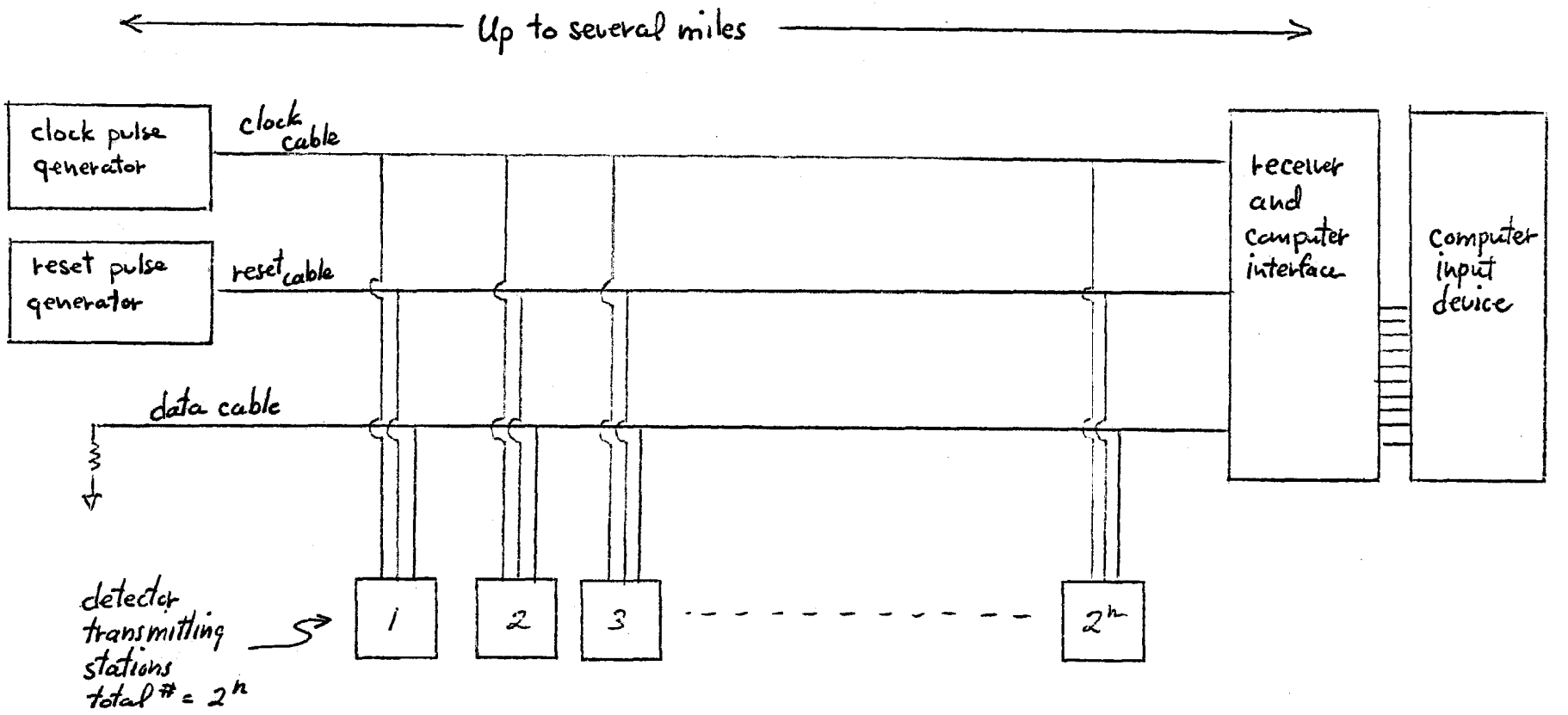
The computer interface is basically an isolated receiver on each of the three lines coupled with an n-bit scaler. The scaler is identical to the ones in each detector. Whenever a data pulse is received the contents of the scaler is instantly and non-destructively read into an n-bit buffer memory. This binary number then is read into the computer as the address of the detector which transmitted the data pulse.

Let us assume here for purposes of discussion that the clock rate in this system is limited to 64 kHz by the band-width of the cable or the computer. Let us also assume that there are 128 time slots and hence the reset pulse rate (and the strobe rate for any individual detector) is 500 Hz. Let us also assume that there are 128 detectors and only 1 time slot per reset is assinged to any one detector. The maximum rate at which each detector can transmit data (1 binary bit) is 500 Hz.

Consider now slowing the reset pulse down a factor of 8 to 62.5 Hz (and keeping the clock rate at 64 kHz). We can now assign 8 consecutive time slots to each detector, and the detector can transmit the contents of an 8 bit scaler in these time slots. As the capacity of an 8 bit scaler is 2^8, the data rate per detector is increased from the maximum rate of 500 Hz by the ratio $\frac{2^8}{8} = 32$.

It is possible also (and in addition) to assign consecutive time slots to binary numbers other than the contents of a scaler. If each employee for example were to plug an I.D. card or equivalent into the detector, the detector could transmit the employee I.D. number along with other information and the computer could keep a record of doses to individuals in the vicinity of the detector.

One must always consider the possibility that a computer shutdown would prevent acquisition of data. To insure that the data is preserved until the computer or personnel are able to read it out either locally or remotely, it is possible to halt data transmission of data by putting some signal on the control lines from the computer end - (e.g., a D.C. offset) which would disable the clock and/or reset pulse generator and allow the detectors to accumulate data internally (e.g., in a "blind" integrated circuit scaler). Such an option could be made automatic and/or manual.



Basic Block Diagram of time-coded dedicated-channel multiplex system
Detectors may be placed anywhere along the cables linking the signal generators and the computer interface