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ground being eliminated by subtraction. In the first measurement, the radioactive fluid is present in both chambers CH1, CH2. In the second measurement, the radioactive fluid is present in chamber CH2 and a non-radioactive fluid is present in chamber CH1. The radioactivity is monitored using a single detector DET.

(54) Radioactivity monitoring

(57) The radioactivity of a radioactive fluid, e.g. in a nuclear reactor, is monitored, in the presence of background radiation, without interruption of radioactivity detection by performing successive measurements on two different volumes of the radioactive fluid, the back-

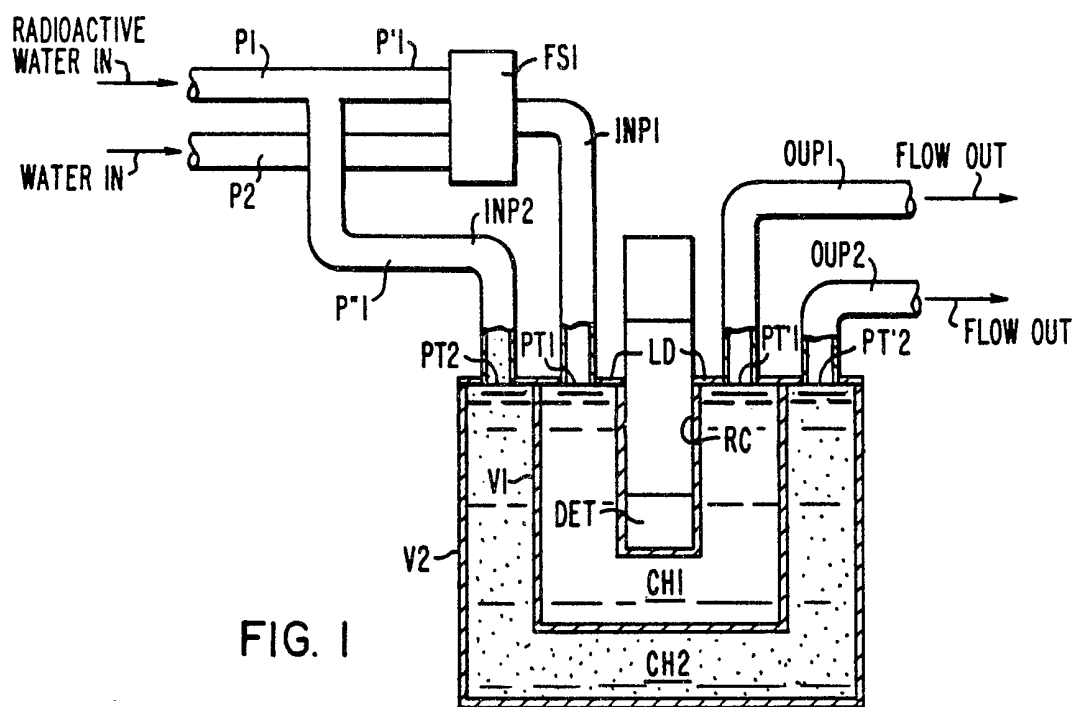
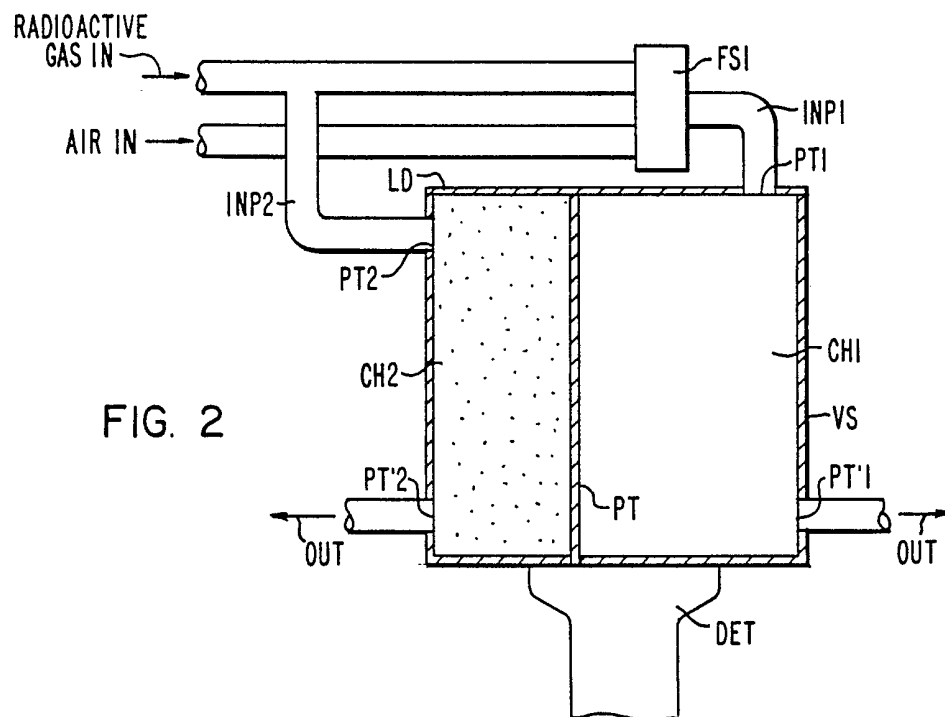
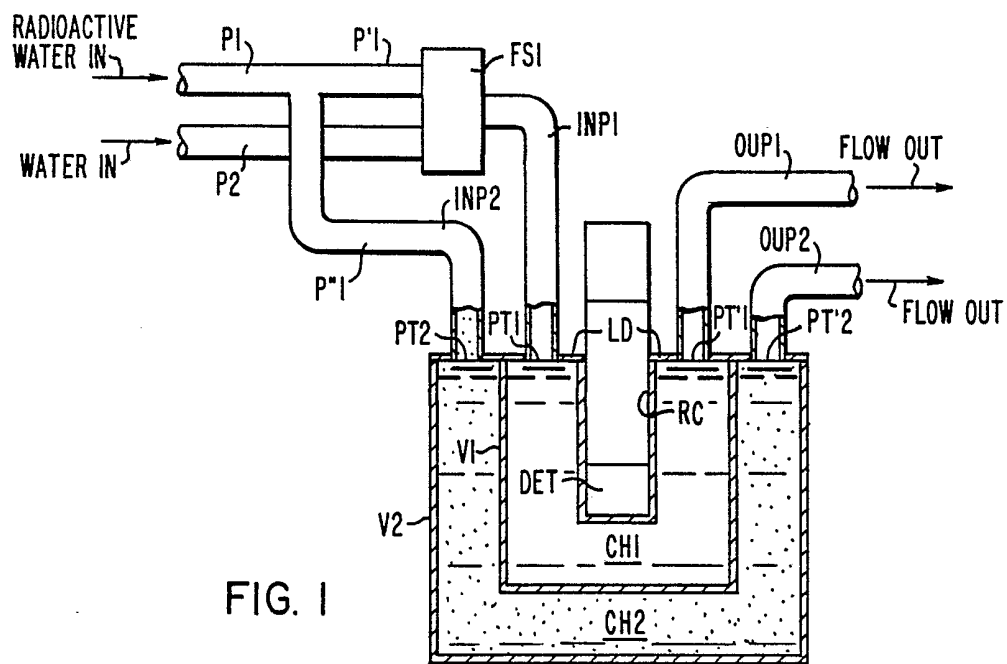


FIG. 1

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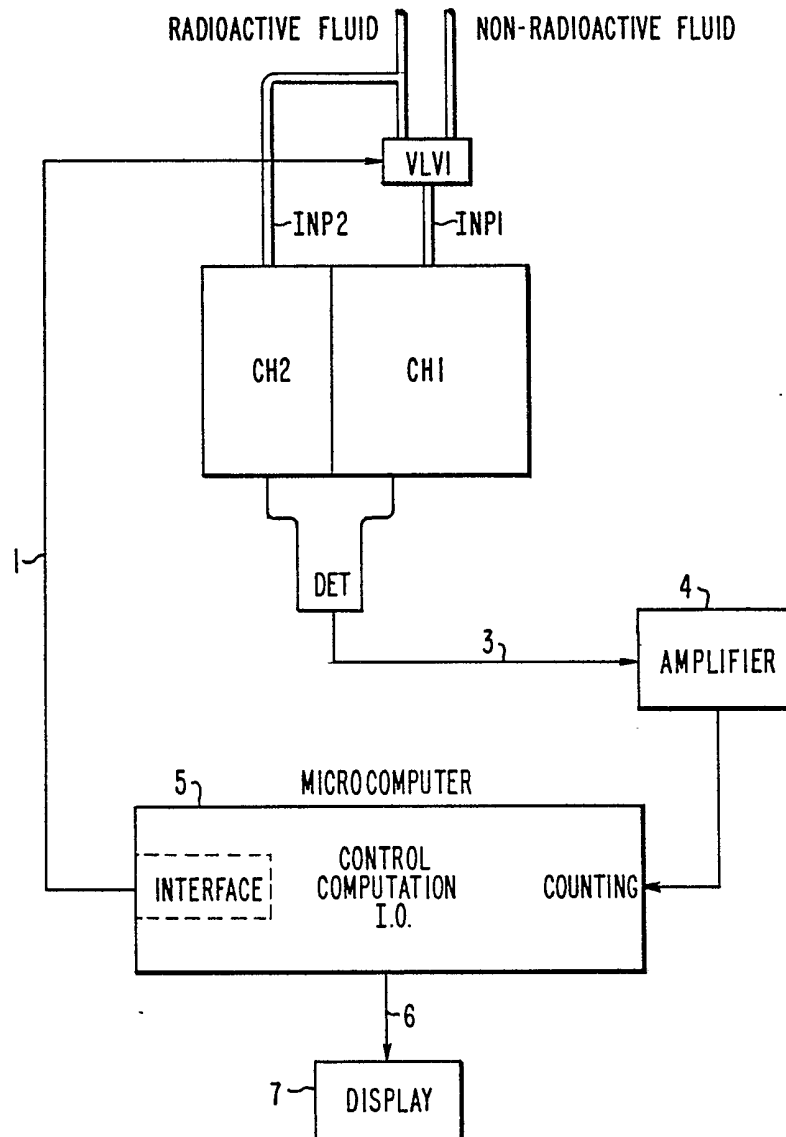


FIG. 3

SPECIFICATION

Radiation monitoring apparatus

- 5 The invention relates to radiation monitoring, e.g. to systems for ascertaining intermittently or continuously the radiation level in installations such as a nuclear reactor. Radiation monitoring involves the use of radiation detectors placed at selected locations. Of all basic types of detectors, the present invention pertains to the "on-line" and/or "off-line" type of radioactive gas and/or liquid detector. See for instance—Westinghouse Engineer, January 1972, Vol. 32, pp. 2–8, "Radiation Monitoring System for Nuclear Power Plants" by S. A. Lane, C. Griesaker and T. Hamburger. Also "Radiation Monitoring—An Instrumentation System for Control of Radiation Hazards" by R. Rastman and D. M. Gallagher, pp. 110–115.
- 10 Detection of radioactivity in a gas, or liquid, involves the combination of an on-line, or an off-line, volume of radioactive fluid and a detector of the radiation emitted by such a volume.
- 15 However, such a detection most of the time is taking place in the presence of a significant background of radiation, which moreover may vary substantially. One of the precautions taken to subtract such background from the measurement has been to make an initial calibration of the detector. The intervening variations in the background level, however, will defeat the purpose. Shielding of the equipment is not satisfactory because effective shielding would be prohibitive in cost and weight.
- 20 Therefore, the problem is to obtain a true radioactivity measurement with radioactive fluid while accepting some sort of background information in the derived reading.
- A number of approaches have been used in the past to solve this problem, but they all have failed because of serious drawbacks.
- 25 A first approach is to measure the background separately, using an auxiliary detector, e.g., a small counter disposed externally. This is not satisfactory because while the auxiliary detector is outside the normal shielding, the background radiation effect on the main monitor as seen from inside the shielding is much different from the one detected outside. This is particularly true with gamma rays, which are the radiation encountered in a nuclear reactor plant. Therefore, the outside counter will often give a false indication of the background counts seen by the monitor detector itself. Clearly under these circumstances the compensation will not be effective.
- 30 A second approach consists of purging the detection monitoring system of the radioactive gas or liquid under detection, and measuring the background level separately with the main detector or counter. The main drawback in this case is the resulting interruption of the radiation measurement. Any rapid or continual increases in radioactivity release levels which occur during these purging periods will not be detected and so the opportunity for rapid corrective action in the plant may be missed.
- 35 It is the principal object of the invention to provide a continual radioactivity monitor.
- One aspect of the invention resides broadly in a radiation monitor system comprising two adjoining chambers and a radiation detector responsive to fluid in both of said chambers; comprising circuits for comparing the response of said radiation detector in a first mode of operation when radioactive fluid is contained in both of said chambers, and in a second mode of operation when non-radioactive fluid is contained in one of said chambers, said first and second mode of operation being in successive order.
- 40 Another aspect of the invention resides broadly in a method of detecting the radioactivity of radioactive fluid in the presence of a background level of radiation, comprising the steps of: measuring the radioactivity of a first volume V_1 of said fluid to derive a first radioactive count N_1 including background; measuring the radioactivity of a second volume V_2 of said fluid to derive a second radioactive count N_2 including background; and subtracting one of said first and second counts from the other to derive an indication of fluid radioactivity which is free from background information.
- 45 The invention resides in deriving an indication of the radioactivity of a fluid in the presence of a common background of radiation by taking two independent measurements with two different volumes of said fluid to derive a first and a second count of radiation, respectively, and combining algebraically said first and second counts to derive an indication of fluid radioactivity which is substantially free from said common background information.
- 50 The invention is preferably conducted in two successive steps, which may be performed consecutively and/or cyclically. During the first step the volume of radioactive fluid is chosen so that the intrinsic response be as large as practical. During the second step the volume is chosen to be as small as possible while still allowing the detection of any change in fluid radioactivity intervening during such second step.
- 55 Typically, said intrinsic responses are in a ratio of two to one.
- Figure 1 shows a liquid monitoring according to the present invention.
- 60 Figure 2 shows a gas monitor according to the present invention.
- 65

Figure 3 is a radiation monitoring system embodying the radiation monitors of Figs. 1 or 2.

The present invention rests upon an approach to background elimination in a radiation monitoring system which no longer requires interrupting the radiation measurement.

The invention resides in successively measuring two proportionate levels of radioactivity and in subtracting one radioactivity measurement from the other in order to eliminate a common background level affecting both measurements.

This is achieved by measuring with a common radioactivity detector two different volumes of a sample of radioactive fluid. Indeed, this does not need to be done off-line, it can be accomplished on-line as well.

More specifically, a sampling chamber is first filled up with radioactive fluid, then, it is partially purged, e.g., partially filled with radioactive fluid, the radioactivity detector providing a response successively for each filling condition of the sampling chamber.

In accordance with another embodiment of the invention, two sampling chambers are juxtaposed, or concentrically related, in front of the radioactivity detector so that in one mode of operation both chambers are filled with radioactive fluid, and in a second mode only one is so filled. Preferably, one chamber is larger than the other, and still more specifically, the smaller one gives about one-half the response of the larger one.

In this respect, it is observed that maximum accuracy in the radioactivity measurement is obtained when the radioactivity level is measured with a chamber completely filled with radioactive fluid and when the background level is separately measured with the chamber completely filled with non-radioactive fluid, e.g., purged.

In accordance with the present invention, the background level is always detected by the monitor in the presence of radioactive fluid in the chamber. This is achieved first with a full volume of radioactive fluid, secondly with a minimal volume of radioactive fluid. Measurement of radioactivity with such minimal volume may become a problem for the detection of radioactivity level since the detector measures too weak an indicative level against the background level. Therefore, the residual volume of radioactive fluid should not be too much reduced. A compromise is reached, in accordance with the present invention, by making the minimal volume have about one-third the response in the detector as the full volume.

The advantage of this invention involving the cycling back and forth between two such alternate modes is that it will allow the activity and background to be determined while the monitor remains functional and stays on the alert for any sudden changes in either the activity level or the background level.

This improvement stems from the observation that the ability of radiation monitors to detect radioactivity of interest is limited by the background in the monitor. Present day monitors are constructed with reduced shielding which results in a moderately high background rate. The radioactive signal and background levels are separated by careful statistical analysis. This makes it necessary to perform an accurate background subtraction to obtain a measurement of sufficient accuracy.

There is also the complication arising from the fact that in a nuclear plant the background level tends to vary from day to day so that it is not sufficient to measure the background level once when the monitor is installed and to apply such result for all subsequent background levels in the subtractions. The variation in background level would require a purge of the monitor at least 2-3 times a day for the purpose of measuring the background response separately. The problem with this is that it may be as long as 1-2 hours per day. If any radiation problem in the plant operations occurred during the period, the monitor would not be able to detect the problem.

In order to overcome this drawback, it has been proposed to use a small auxiliary counter outside of the monitor shield to measure the strength of the background field, thereby to permit a more accurate background subtraction. This technique requires an initial calibration relating the signal in the external counter with the background in the monitor itself. It is then assumed that such strict proportionality between the two signals remains after calibration.

There are a number of difficulties associated with this approach which detract from its reliability. First such an external counter has a different response as a function of gamma-ray energy than the counter used inside the monitor because the latter is shielded while the former is not. Consequently any change in the shape of the gamma ray spectrum will alter the relationship between the internal and external counters. For example, if the initial background field consists of ^{137}Cs (.662 MeV) and ^{60}Co (1.17, 1.33 MeV) gammas, then, a certain relationship will initially be found between the reading of the external detector and the background rate of the detector in the monitor itself. If the background field doubles but retains the same spectral shape, then, the rate in both the external and internal counters will double and correct background subtraction can be achieved by applying the initial calibration factor to the rate from the external counter. Should, however, some waste material emitting low energy radiation, say ^{57}Co (.122 MeV) be brought into the plant, low energy gamma rays will be readily detected by the external counter but will not reach the main monitor counter, because of the

monitor shield. This will result in extra counts in the external counter indicating that the background has increased and a greater background subtraction is required from the system. In actual fact, the main monitor background will not have changed and a substantial error would result in the system.

5 A second problem is associated with the use of an external counter which results from the buildup of "crud" inside the monitor. This can occur in a number of different ways in different monitors. For example, some of the radioactive material in water can deposit in dead areas of the liquid monitor, or a small fraction of the noble gases in this type of monitor can be absorbed into the material of the scintillation detector used in this type of monitor. This buildup gives rise to a background rate whose contribution is independent of the instantaneous activity concentration in the monitor at that time. In the case of the liquid monitor, the internal background will build up monotonically with time and eventually can overwhelm the background from external gamma rays. For the radiogas monitor the absorption effect will reach an equilibrium value in the presence of a steady-state noble gas activity and will change slowly if the gas activity changes. It is clear from this that the external counter will not be able to detect this type of background and the monitor system will not be able to correct for this type of effect.

Accordingly, the present invention provides a method of determining the background rate in any monitor without removing the monitor from operation and without the need for an external counter, thus, being free from spectrum shift and internal background problems associated with the external counter approach. Referring to Figs. 1 and 2, typically the radiation monitoring system combines a radiation detector and two sections of fluid liquid, or gas, which divide the detection volume. Typically, the detection volume is divided into two sections, one representing about two-thirds of the total response and the other about one-third.

Referring to Fig. 1, a liquid monitor according to the present invention includes two chambers CH1, CH2, one contained in the other. A vessel V1 defining chamber CH1 is contained in a vessel V2 defining between V1 and V2 the chamber CH2. A lid LD closes the two vessels at the upper path, which is provided with input ports PT2 for chamber CH2, PT1 for chamber CH1, on one side of the lid LD, and output ports PT'1 for chamber CH1 and PT'2 for chamber CH2 on the opposite side of the lid LD. Moreover, lid LD is provided centrally thus, at the center of chamber CH1, with a recess RC. Recess RC is defined so as to accommodate a detector DET. Thus, detector DET is exposed to radiation from radioactive liquid when chambers CH1 and/or CH2 contain such a liquid.

Radioactive water from a nuclear reactor power plant is admitted through a pipe P1 which has two branches P'1, P''1. A flow switch FS1 is provided to allow on command the radioactive water from pipe P'1 to an input pipe INP1 leading to port PT1 of chamber CH1, whereas radioactive water from pipe P''1 flows through input pipe INP2 leading to port PT2 of chamber CH2. Alternately, non-radioactive water is admitted through a pipe P2 to flow switch FS1. Chamber CH1 is connected via port PT'1 with an output pipe OUP1, while chamber CH2 is connected via a port PT'2 with an output pipe OUP2.

Control of switch FS1 under fluid pressure from pipes P1 and P2 will either allow radioactive water to flow into chamber CH1, or non-radioactive water thereinto during purging of this chamber. Usually radioactive water will flow through CH2 during both parts of the cycle, although occasionally it will also have to be purged in order to lower "crud" buildup.

Fig. 2 shows a gas monitor which differs from the liquid monitor of Fig. 1 only in that the two chambers CH1, CH2 are juxtaposed; being contained in a common vessel VS with a common partition PT. Ports PT1, PT'1 of chamber CH1 are on one side of the vessel, namely the side of chamber CH1, whereas, ports PT2, PT'2 of chamber CH2 are on the opposite side of the vessel. Illustratively, port PT1 is in the lid LD of vessel VS near the outside wall of CH1, and port PT2 is in the upper side of the opposite wall of vessel VS, e.g. the wall of chamber CH2. Output ports PT'1 and PT'2 are at the lower part of the vessel.

A scintillation detector DET is placed at the bottom of vessel VS facing both chambers CH1, CH2 and the fluid therein.

The vessels in Figs. 1 and 2 may be cylindrical or rectangular as a matter of choice.

As shown illustratively, the volume of chamber CH1 is larger than the volume of chamber CH2. The closeness of chamber CH1 to detector DET in Fig. 1 and the area of exposure of the detector to chamber CH1 in Fig. 2 indicate a major contribution of chamber CH1 and a minor contribution of chamber CH2. Illustratively, the detection volume is divided in two sections CH1, CH2, such that CH1 represents about two-thirds of the total response and CH2 about one-third.

The plumbing is such that one of these chambers can be purged while the other retains the normal flow.

The operating procedure is then as follows. The flow of radioactive fluid travels through both chambers and is counted for a time T_1 . Then the larger chamber CH1 is purged (with air for a radiogas monitor or water for the liquid monitor) while the normal flow is retained in the smaller chamber CH2. With the latter mode of operation, the activity is counted for a time T_2 . If one knows the counting efficiency of the two chambers, then, the two measurements provide two

equations in two unknowns from which the activity concentration in the monitor can be determined.

To analyze the monitor performance, E_1 is defined as the counting efficiency of the larger chamber and E_2 the counting efficiency for the smaller chamber. Both are measured in CPM/ μ Ci/cc and the background rate is b in CPM. Then, for the first measurement, the number of counts collected (N_1) in time T_1 will be

$$N_1 = E_1 C T_1 + E_2 C T_1 + b T_1 \text{ cts} \quad (1)$$

and for the second measurement, e.g., during the partial purge, the collected counts (N_2) in time T_2 will be

$$N_2 = E_2 C T_2 + b T_2 \text{ cts} \quad (2)$$

By solving the two equations, the background term b can be eliminated, giving the following expression for the measured activity.

$$C = \frac{\frac{N_1}{T_1} - \frac{N_2}{T_2}}{E_1} \quad (3)$$

For a given value of the ratio of the background to total signal, i.e., $b/(E_1 C + E_2 C)$ and the response ratio, relative to the primary and secondary chambers, E_2/E_1 , there is an optimum way to split the time between the total response, (i.e., Equation (1)) and the partial response (given by Equation (2)). It follows that:

$$\frac{T_1}{T_2} = \frac{1 + \frac{b}{(E_1 + E_2) C}}{\frac{E_2}{E_1 + E_2} + \frac{b}{(E_1 + E_2) C}} \quad (4)$$

It is also proposed to operate radiation measurement cyclically and alternately in the first and second mode as long as the background level is sufficiently large, for instance, above 10% of the measured radiation level. However, should the background level become so low as to allow full sensitivity measurement, then, radiation measurement will be conducted primarily in the first mode. Such low level of background admitting of a single mode of operation, typically would be below 5% of the measured radiation level. Typical time ratios T_1/T_2 in the two-mode operative system according to the invention will be between 1 and 2.

Analysis of the system shows that one can always obtain a more accurate statistical determination of C if in the secondary count the measurement bears upon the background only, i.e., $E_2 = 0$. However, not making $E_2 = 0$ is a loss in accuracy which has to be paid in order to allow the monitor to be always on the alert for any sudden changes in the fluid ratio activity to be measured. Therefore, the selection is made of an optimum value for E_2/E_1 representing a compromise between the desired maximum accuracy in determining C and the need to have a monitor active during period of reduced response E_2 . The best compromise, with the dimensional example given, requires that $E_2/E_1 = .5$, since for $E_2/E_1 < .5$ a better accuracy is obtained with a poorer detection capability for the period of reduced response E_2 , while for $E_2/E_1 > .5$ the consequences are the opposite.

The characteristics of a system with $E_2/E_1 = .5$ are as follows. If the background rate approximately equals the total signal rate, then, the statistical accuracy of the measured activity will be about 1.4 times poorer than if background alone were measured during the lower sensitivity period. In other words, if the monitor operating with a complete purge cycle possessed a standard deviation in the detected activity of 20%, then when using the partial purge approach just discussed, the resulting standard deviation would be 28%. This moderate loss of accuracy, however, is worth the gain in capability since errors much larger than this can occur, should the background be incorrectly determined. Moreover, the monitor is still able to detect significant changes in activity level even during the period of reduced response.

The monitor operation would involve cycling back and forth between the full and partial sensitivity modes while computing the activity and background associated with each pair. The

counting rates in either mode can be monitored continuously to check for sudden large changes and if such a change occurs, a determination of whether the background, the activity or both is responsible can be made by comparing the changes in the counts from the two modes.

The general monitor concept described herein provides a means of coping with changing external, or internal (i.e., crud buildup), backgrounds while retaining the ability to check for large changes in either activity or backgrounds. These extra capabilities are achieved at the cost of a moderate loss in statistical accuracy or moderate increase in the time required to achieve a given accuracy.

Referring to Fig. 3, a radioactivity monitoring system embodying the monitor of Fig. 1 or of Fig. 2 is shown to include two chambers CH1, CH2 of unequal volume, CH1 being the major chamber, CH2 the minor chamber. A valve VLV1 allows radioactive fluid through input pipe INP1 to fill upon chamber CH1 during one counting stage and allow the chamber to be purged during the second counting stage. The second chamber CH2 as shown is allowed to receive only radioactive fluid, and it remains in such configuration through both counting stages. A detector DET is exposed to radiation from chamber CH1 and/or chamber CH2. Exposure is during a time interval T_1 when chamber CH1 and chamber CH2 have both radioactive fluid, and during a time interval T_2 when chamber CH2 is the only one having radioactive fluid. The counting rate in the detector from radioactivity in CH2 is typically about one-half that from CH1. Detector DET is exposed to radioactive fluid during time intervals T_1 and T_2 which are in a proportion related to the relative responses of the two chambers and the ratio of the background to radioactivity counts.

Typically, assuming $E_2/E_1 \approx .5$ and the background counts equal to the counts from the radioactive fluid, T_1/T_2 would be about 1.3.

The number of counts during the time of exposure T_1 , e.g., when both chambers have radioactive fluid, is denoted N_1 . The number of counts is N_2 during the time interval T_2 , e.g., when only chamber CH2 has radioactive fluid.

Counts from the detector DET are inputted by line 3 into an amplifier 4 and then into a counting circuit in the microcomputer 5 which controls the operation of the monitor. Under control of the computer the monitor operates in the first mode for a time T_1 with VLV1 allowing the flow of radioactive fluid into both CH1 and CH2. During this time interval N_1 counts are collected from the detector. The computer then switches to the second mode in which the state of VLV1 is changed to allow the flow of non-radioactive fluid through CH1 while radioactive fluid still continues to flow through CH2. The second mode is maintained for a time T_2 during which N_2 counts are collected. These counts N_1 and N_2 can be described by equations (1) and (2) stated earlier:

$$N_1 = E_1CT_1 + E_2CT_1 + bT_1 \quad (1) \text{ mode \#1}$$

$$N_2 = E_2CT_2 + bT_2 \quad (2) \text{ mode \#2}$$

The computer calculates C from the two equations (1) and (2) and such radioactivity count C is provided as an output on line 6 and displayed by the display unit 7. Within the computer the calculated radioactivity C is used to actuate an alarm if a critical level or a critical rate of increase is exceeded.

CLAIMS

1. A radiation monitor system comprising two adjoining chambers and a radiation detector responsive to fluid in both of said chambers; comprising circuits for comparing the response of said radiation detector in a first mode of operation when radioactive fluid is contained in both of said chambers, and in a second mode of operation when non-radioactive fluid is contained in one of said chambers, said first and second mode of operation being in successive order.

2. A system of claim 1 with said adjoining chambers being laterally disposed to one another relative to said radiation detector means.

3. A system of claim 1 with a first of said adjoining chambers being superposed upon the second of said adjoining chambers as seen from said radiation detector means, said non-radioactive fluid being admitted in said second chamber in said second mode, and said radioactive fluid being admitted in both of said chambers in said first mode.

4. A system of claim 2 with said adjoining chambers exposing a different cross-section to said radiation detector, said one chamber offering a smaller cross-section than said other chamber to said radiation detector means.

5. The system of claim 1 with said two chambers surrounding said radiation detector in a concentric arrangement, said radioactive fluid being admitted into both said chambers in the first mode, with said radioactive fluid being admitted into said outer chamber and non-radioactive fluid into said inner chamber in the second mode; the system being alternately operated in the first and in the second modes.

6. The system of claim 5 with said outer chamber being such as to produce about half the response in said radiation detector as the response obtained with said inner chamber.

7. The system of claim 1 with said comparing means effecting a subtraction in the responses of said radiation detector under said successive first and second modes, thereby to

5 eliminate background level.

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8. The system of claim 1 with said radiation detector being a gamma radiation counter, and with the volume of said one and other chambers being in a ratio smaller than unity.

9. The system of claim 1 with said one and other chamber being of different size and having both radioactive fluid in said first mode; with said smaller chamber only having radioactive fluid

10 in said second mode; and with said radiation detector means being operative during a first time interval in said first mode, during a second time interval in said second mode, said first and second time intervals being in a ratio in the range of about 1.5/1 (actually 1.3-2) to 2.

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10. The system of claims 1 to 5 with said fluid being a radioactive liquid.

11. The system of claims 1 to 5 with said fluid being a radioactive gas.

15 12. The system of claims 1 to 5 with said detector means being one of a beta ray detector and a gamma ray detector.

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13. A method of detecting the radioactivity of radioactive fluid in the presence of a background level of radiation, comprising the steps of:

measuring the radioactivity of a first volume V_1 of said fluid to derive a first radioactive count N_1 including background;

20 N_1 including background;

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measuring the radioactivity of a second volume V_2 of said fluid to derive a second radioactive count N_2 including background; and

subtracting one of said first and second counts from the other to derive an indication of fluid radioactivity which is free from background information.

25 14. The method of claim 13 with said first volume and said second volume measuring steps being effected cyclically and consecutively.

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15. The method of claim 14 with said first volume V_1 being such as to maximize the first intrinsic response (E_1) to fluid radioactivity.

16. The method of claim 15 with said second volume V_2 being such as to provide a minimal second intrinsic response (E_2).

30 second intrinsic response (E_2).

30

17. The method of claim 16 with said first intrinsic response E_1 being about twice said second intrinsic response E_2 .

18. The method of claim 16 with said first count N_1 being derived during a time of exposure T_1 and said second count N_2 being derived during a time of exposure T_2 , where

35 $N_1 = E_1CT_1 + E_2CT_1 + bT_1$ and

35

$$N_2 = E_2CT_2 + bT_2$$

40 with b being the intrinsic response to background radiation;

40

said subtracting step including the computation of C , as the radioactivity to be measured, according to the formula:

$$C = \frac{\frac{N_1}{T_1} - \frac{N_2}{T_2}}{E_1}$$

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50 19. The method of claim 18 with T_1 and T_2 being selected according to the formula:

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$$\frac{T_1}{T_2} = \sqrt{\frac{1 + \frac{b}{(E_1 + E_2)C}}{\frac{E_2}{E_1 + E_2} + \frac{b}{(E_1 + E_2)C}}} \quad (4)$$

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20. The system of claim 7 with means responsive to a background level exceeding a first predetermined level for cyclically operating said radiation detector means in said first and second modes, and with means responsive to a background level reaching below a second predetermined level for operating said radiation detector means primarily in said first mode.

65 21. The method of claim 14 with said first and second volume measuring steps being

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cyclically and alternately performed when said background level is above a first predetermined level, and said first volume measuring step is performed primarily when said background level falls below a second predetermined level.

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