

Evaluation of Portacount for Determining Respirator Fit Factors, Part I: Executive Summary and Portacount Manual

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This report will be followed by Part II, "Fit-Factor Measurements with the Portacount and the Aerosol Photometer," and Part III, "Suitability of the TSI Portacount for Determining Respirator Fit Factors."

Executive Summary

We investigated the use of a portable condensation nucleus counter (the model 8010 Portacount by Thermo Systems, Inc.) as a detector for quantitative fit testing of respirators. Fit test results were compared with measurements using an aerosol photometer, which is the current instrument of choice for quantitative fit testing of respirators. In the first phase of this study, simultaneous measurements were made with the two instruments using both a mannequin head and breathing machine to test the instrumentation without the added variability of human test subjects. The second phase of the study involved characterizing the aerosols in the ambient environment, calculating the effect of fine particles generated by human breathing, and comparing the fit test results obtained by the Portacount and the photometer from human test subjects. We also compiled a supplementary manual of special instructions for using the Portacount, such as the application limit of the instrument, startup procedure, data collection, and maintenance. These supplementary instructions are included immediately following the Executive Summary.

In the first phase of our experiment, we fitted a mannequin head with an MSA Ultravue full-face respirator. The mannequin and respirator were enclosed in a 1-m³ exposure chamber. A cyclic breathing rate of 23.6 breaths/min, at 40 lpm, was simulated through the respirator using a breathing machine. The two aerosol detectors were compared at several different simulated leak conditions. Two challenge aerosols were selected for these investiga-

tions: an oil mist aerosol and the ambient room aerosol. The oil mist aerosol is similar to that routinely used in fit tests using the photometer as the detector. The room aerosol was of interest because the Portacount can be used with less-concentrated aerosols due to its greater sensitivity. In addition to comparisons of measured fit factors, we were interested in the stability and sensitivity of the Portacount with regard to fit factor measurements.

Because the aerosol photometer measures the amount of light scatter from a concentration of particles within its sensitive volume, its output depends on aerosol properties such as size, shape, and index of refraction. Larger particles result in higher signal levels. The photometer's dynamic operating range is typically six orders of magnitude. In contrast to photometers, condensation nucleus counters such as the Portacount count individual particles after they have grown to a detectable size. In the fit test sample mode, the instrument automatically alternates between the chamber and mask volumes with 5-s chamber and 60-s mask sample periods, respectively. The dynamic range of the Portacount is 0.05 to 500,000 particles/cm³ in the fit test mode. Therefore, the Portacount is much more sensitive than the photometer. Unfortunately, the entire dynamic range is not applicable to fit testing. Other investigators have shown that aerosol concentrations of exhaled air from respirator wearers can be on the order of several particles per cubic centimeter. This background aerosol negates a portion of the Portacount's greater sensitivity over the photometer.

Tests using the oil mist as the challenge aerosol were conducted with **dioctylsebacate** (DOS) concentrations of 5 and 30 **mg/m³**. The oil mist aerosol was produced by a cold, bubbler-type generator using DOS. This resulted in an aerosol having a size distribution with a geometric median diameter and standard deviation of 0.32 and 1.8, respectively. Corresponding particle concentrations of the higher challenge concentration were about **1.7 x 10⁵ particles/cm³** as measured by the Portacount. Leak rates were varied, resulting in photometer fit factors ranging from 10 to 100,000. For the higher leak conditions, corresponding to fit factors less than 1000, fit factors as measured by the two instruments agree to within 25%. However, with increasing protection levels, greater discrepancies are seen, with the Portacount indicating fit factors much lower than those of the photometer. Such differences are to be expected, since the means of aerosol detection differ between the two instruments.

Stability tests were conducted to assess the variability in fit factors for experiments that were 1 hr and 8 hr in duration. The 1-hr stability test indicated standard deviations in Portacount fit factors from 1.8 to 5.5% for fit factors ranging from 350 to 11,000 (as measured by the photometer). The higher standard deviations were the direct result of decreased particle counts at the lower leak conditions. These standard deviations are comparable to—if not somewhat better than—those of the photometer used in these studies. Portacount relative standard deviations in fit factors as great as 20% were noted when using the room aerosol for challenge because of the much lower particle concentrations.

In experiments using the room aerosol as the challenge, we were interested in determining the maximum fit factor that the Portacount could measure, as well as how these measurements compared with those using the DOS aerosol as the challenge. Using identical leak conditions, the Portacount fit factors were usually 2 to 7 times higher for the ambient aerosol challenge as for the DOS. Such discrepancies can be explained by the fact that the ambient aerosol was considerably smaller in size than the oil mist. Although measured in only a few tests, our laboratory room aerosol distributions had a median diameter of 0.092 μm and a corresponding standard deviation of 2.1. The room aerosol posed a further constraint on fit factor measurements. Challenge particle concentrations are much lower—on the order of 10,000 **particles/cm³**. This value along with the exhalation background mentioned previ-

ously limits the measurement of protection levels to fit factors of 1000 or less. **Naturally**, in environments with higher particle concentrations, higher fit factors could be measured. Correspondingly, in cleaner areas, even a fit factor of 1000 would not be attainable. The ambient aerosol concentration in buildings was measured at 31 locations around the Lawrence Livermore National Laboratory. The concentrations ranged from 1.6×10^3 to 2.8×10^5 **particles/cm³** with a median of 8.1×10^3 **articles/cm³**.

The fit factor measured by the Portacount is based on the number **concentrations** of particles penetrating into the respirator. In contrast, the fit factor determined by the photometer is more closely related to the particle mass penetration. The Portacount compares favorably with the aerosol photometer in this study for fit factors below 1000 using the oil mist aerosol **used** as the challenge. The Portacount has the added advantages of portability and increased sensitivity. From these **mannequin/breathing-machine** experiments using an ambient aerosol, we found that the Portacount appears to be a satisfactory instrument to use when measuring fit test results on respirators for fit factors less than 1000. Care must be used to make sure an acceptable particle-size distribution and concentration are available in the area used to carry out the respirator fit test. To assure comparable fit test results for the Portacount and the photometer, tests should be performed on human subjects in both the laboratory and typical workplace environments.

The second phase of our study, which used human subjects, found results that were in agreement with the **mannequin/breathing-machine** results. The fit testing involved 10 human subjects using the eight exercises from the Occupational Safety and Health Administration (OSHA) asbestos standard. Masks that gave a broad range of fits to the subjects were used. Once the subject comfortably donned the mask, he or she did not readjust it until completing two series of the exercises. The first series used the ambient room aerosol as the challenge agent and the Portacount as the detector. The second series used on oil mist aerosol as the challenge. One sampling line was attached to the respirator, but the line was divided such that both the Portacount and the photometer received proper samples. We found good general agreement between the three sets of fit tests results. However, when we examined the results critically, some differences were noted. There is a bias for the Portacount fit factors to be a factor of 1.7 less than the photometer fit factors. A nonparametric statistical analysis on the simultaneous measurements showed that at a fit factor of 100, the Portacount

meets the ANSI **Z88.10** criteria for validation of a new qualitative fit test method; however, it does not meet these criteria at a fit factor of 1000. The **effect of fine particles in the exhaled breath** was **significant—though conservative—at** a fit factor of 1000 and low ambient aerosol concentrations. We concluded that

the **Portacount** can be used with ambient aerosols to confidently measure fit factors of 100. When used to measure fit factors of 1000 with ambient aerosols, several complications can occur that cause the measured fit factor to be low. Although this is undesirable, it errs on the side of safety and can be tolerated.

Portacount Supplementary Manual

Although the Portacount is a relatively simple instrument to **operate**, we and others have experienced some difficulty with a few of its features. Filling the unit with alcohol, changing the battery pack, and interpreting its error messages **have** been particular problem areas. The **following** manual discusses solutions to these **difficulties** as well as certain restrictions in the ambient aerosol concentration.

Safety

Unpack the Portacount unit and attach the twin tubing to the hose barbs on the left side. One tube will be marked with an "**A**," which goes to the "A" hose barb. The tube marked with an "S" goes to the "S" hose barb. The third exhaust port needs no connection. (See pp. 8–10 of the Portacount Operation and Service Manual for illustrations.)

Battery

To install the battery pack, flip the latch on the right side of the Portacount **toward the back** and pull the latch away from the back cover. Plug the connector into the battery pack; it will go only one **way**. (The batteries may need to be charged before use.) Slip the battery into the compartment with the plug downward. Keep the wires under the battery **and** by the connector; do not **allow** them to go beside the battery because they will wedge the battery, making removal difficult later. Replace the cover (it will fit in only one orientation) and fasten the clip.

Note: Holding the unit with the display facing up throughout this operation (as will be the case when the instrument contains alcohol) can be quite awkward. You may want to practice your technique.

Slip the Portacount onto its stand. (The stand resembles a bent book rack.)

Filling

To fill the unit with alcohol, first check that the instrument is turned **off**. Turn the thumbscrew at the bottom of the unit and open the cover. Slowly tip the Portacount **20–25 degrees** back so that it pivots on its stand (see Fig. 1). Do not rotate it beyond the horizontal. Open the plastic vial containing the alcohol and insert it into the rightmost hole exposed under the cover. Though not recommended, if you run out of alcohol vials, you can refill the vial **1/3** full with reagent-grade isopropyl alcohol.

Fill Slowly

Gently squeeze the bottle; allow two minutes to empty the contents. Continuously watch for any alcohol draining from the bottom-most port, which indicates that the unit has been overfilled.

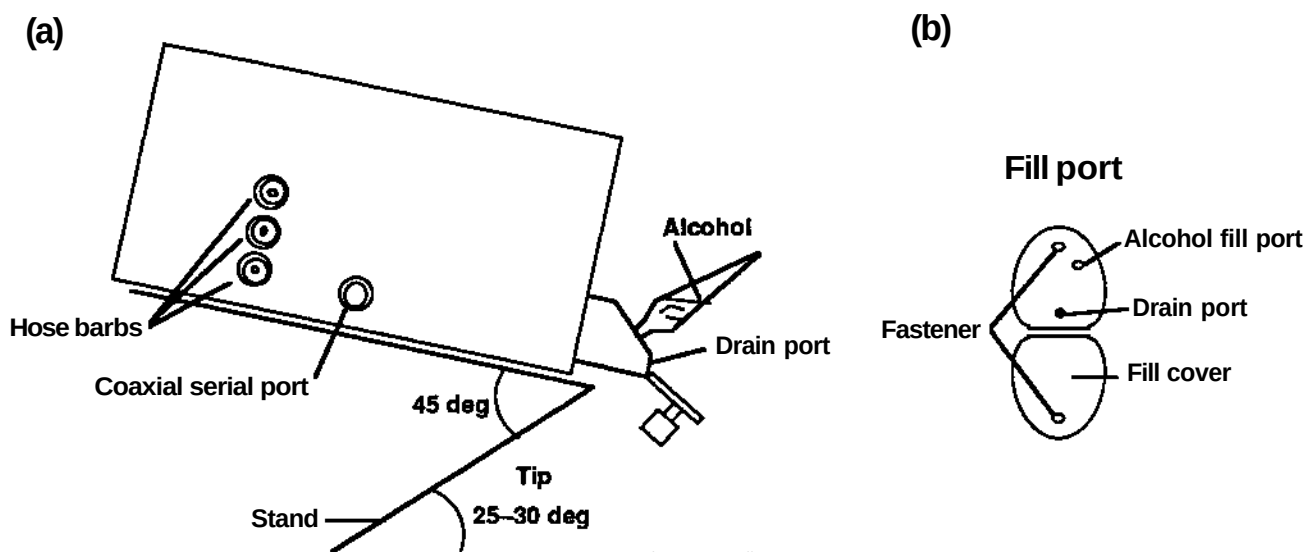


Figure 1. Left side view of the Portacount.

Add Only One Bottle of Alcohol

Never add more than one bottle of alcohol. After filling, leave the cover open for several minutes, then close and fasten the cover. Allow the instrument to sit normally on its stand.

If you are connecting a computer or printer to the unit, unscrew the cap located below the hose barbs, from the left side of the Portacount. Screw the coaxial serial end of the cable provided onto this connection. The other end of the cable will plug into the RS232c serial port on the printer or computer. The printer is not battery-operated and must be connected to a power supply.

Important Notes

The ENABLE button must be pressed in conjunction with the ON, OFF, TEST, or MODE buttons on the Portacount for the unit to operate.

The Blinking "E"

Note that the Portacount is only taking data if the "E" on the display is flashing; otherwise, it is only waiting in the mode designated by the lit yellow indicator lights.

Keep sampling lines short. Long lines can result in aerosol loss and erroneous results.

The Portacount automatically shuts off after 10 min of being idle. Keep the unit turned off and upright whenever you are moving it. Handle the unit with care.

Errors and Problems

The battery may run down in the middle of a test (see the "Maintenance" section of this manual). Also, the Portacount may not be operating properly 20–30 min prior to the low-battery warning being displayed.

For other problems, the *Portacount Operation and Service Manual* contains a troubleshooting guide on pp. 17 and 51.

Common Error Messages

"E-E" Display

When "E-E" is displayed in the **FIT TEST MODE**, or unexpectedly low counts are obtained in the other modes, the instrument has one of the following problems (from p. 17 of *Portacount Operation and Service Manual*):

- Low alcohol.
- Ambient particle counts are too low to conduct a test (<1500 particles/cm³).
- Tubing is clogged.
- Instrument is flooded with alcohol.

"LO" Display

A "LO" indication is displayed when the battery is low. Because this instrument is designed to operate using batteries only, a test **will** be lost occasionally when the unit loses power while conducting a test. The batteries take six hours to recharge. For continuous use, we suggest a supply of batteries.

Ramifications of Ambient Aerosols

The differences in aerosol environments and means of detection can cause variations in determining fit factors. The operator should be aware of this when determining the confidence to place in the results. See the References for further information.

The Portacount is similar to the TSI's condensation nuclei counter (TSI model 1020) in its operation, except that the Portacount has internal valves for more convenient operation in a fit test application. Like the laboratory condensation nucleus counter (CNC), the Portacount is sensitive, though neither determines aerosol size. The Portacount is portable, which allows tests to be conducted on a subject in the actual aerosol-exposure environment.

Because the Portacount is a sensitive instrument, it is **often** used with ambient aerosols as the challenge agents. Ambient aerosols, however, vary in particle characteristics and are uncontrolled in their concentrations. Thus, tests performed with an ambient aerosol as the challenge agent may not be reproducible. A **shift** in the aerosol size distribution can cause a change in the measured fit factors. Again for further **information**, see the References.

Procedures and Cautions

If the Portacount determines that the ambient aerosol is below 1500 particles/cm³, it will abort a fit test. Typically, our laboratory has ambient aerosol concentrations between 1000 and 10,000 particles/cm³.

Ambient Particle Concentrations

Because the Portacount cannot differentiate particles expired by the subject from those that have leaked into the mask, subjects who expire particles at a higher rate will receive a lower number resulting from their fit factor test. In a situation where the mask is fitting well on the subject and the ambient aerosol concentration is low, the few particles in the mask take on greater significance in calculating a fit factor. Generally, the Portacount gives a more conservative fit factor than a photometer.

Operations

The Portacount has three modes of testing: **FIT TEST**, **SEQUENTIAL**, and **COUNT MODES**. The **FIT TEST MODE** will be used the majority of the time, but we look at in the **COUNT MODE** first.

- Press **ENABLE** and **ON**. Wait 60 seconds.

CheckZero

Check zero in COUNT MODE. In this mode, the sample is taken only from the sample port, and the unit functions like a laboratory CNC.

- Connect the **high-efficiency** air filter to the sample line, which is marked with an "S."
- Press ENABLE plus MODE twice to enter the COUNT MODE and start the test. (If the enable test is pressed, the data displayed are averaged over a 15-s period instead of a 1-s period.)
- The "counts per cubic centimeter" display should go to zero quickly.
- If a zero is not obtained, check the lines and replace the filter. (Some filters provided with the instrument were found to be defective.) A low alcohol level may also cause nonzero counts.

Check Ambient Concentration

While still in the count mode, check the ambient aerosol concentration.

CheckGraph

Remove the filter and continue in the COUNT MODE as above. Counts greater than 1500 particles/cm³ should be found before conducting the test. See Fig. 2 for determining the possible fit factors for a given ambient concentration. Low particle counts may indicate a low alcohol level. Ambient concentrations are often found between 1000 and 10,000 particles/cm³.

Concentrations above 500,000 particles/cm³ will not be counted correctly. TSI discourages the use of the instrument with certain generated aerosols (see p. 23 of *Portacount Operation and Service Manual*).

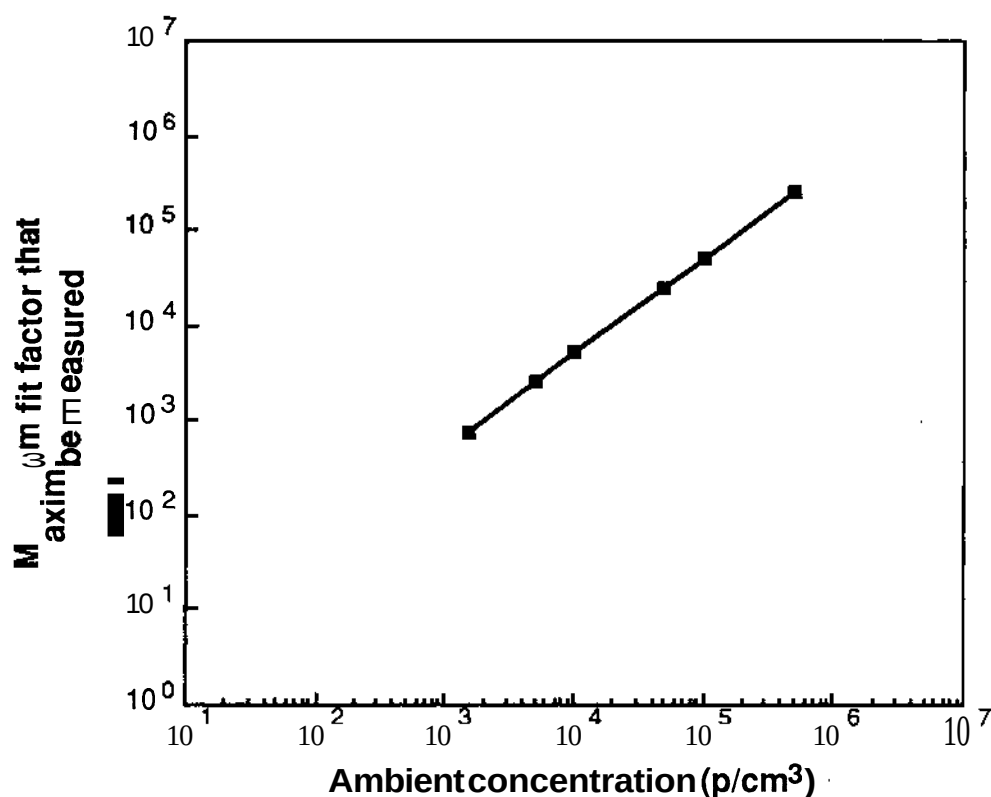


Figure 2. Ambient aerosol concentration vs maximum valid fit factor achievable. Assuming background of 1 expired particle/cm³ and a desired mask (downstream) concentration three times that of the background level, the relationship can be expressed as Concentration = 2 x FF.

Things to Check

Note: This is not a complete testing procedure. Consult the appropriate complete procedure for fit testing of a *subject*.

Preparation

Check the subject and mask. Connect the subject sample (“S”) line to the facepiece.

Verify that the subject has not smoked for at least 30 min prior to the test.

Note: The mask should be equipped with high-efficiency filters to determine the actual face *fit* factor (see p. 23 of *Portacount Operation and Service Manual*). If the actual *protection* factor is required, use the filters that would normally be fitted and conduct the tests in the actual work environment. (Remember that the Portacount detects only particles and *cannot determine gaseous protection factors*.)

Help the subject put on the mask for this test.

Commence Test

The subject should **read**, talk, do prescribed exercises, or work during the **following** testing. If the TSI software is being used on a personal computer, the operator and subject will follow the prompts. (It is possible to input an alternate set of exercises for use in place of the set that comes with the TSI software.)

To return to the FIT TEST MODE, press ENABLE and MODE (the yellow light beside this mode will be lit). Unlike the COUNT MODE, you must press the **ENABLE** and TEST buttons simultaneously to start the actual test in the FIT TEST MODE. The “E” should be flashing.

About 90 s will pass before the screen displays the fit factor, and either the pass or fail light will come on. The Portacount continues with additional tests that may validate the fit factor. These take an additional 80 s each.

Portacount Software

Six tests are included with the PC software. (See the following section of this manual for more information on the software operations and Table 1 for the exact Portacount timing sequence.)

Table 1. Internal operations and timing. ^a		
Purge	4 sec	— — for first fit factor only
Ambient sample	5 sec	
Purge	11 sec	— — for each fit factor
Respirator sample	60 sec	
Purge	4 sec	
Ambient sample	5 sec	

^a For details on the COUNT or SEQUENTIAL MODES, see pp. 31-33 of *Portacount Operations and Service Manual*

Final Number

The software will provide an average fit factor at the conclusion of the testing. If the Portacount is manually operated, press the ENABLE and TEST buttons, and the average fit factor value will be displayed.

Operator Awareness

If the fit factor seems unusual, determine if the subject is a smoker. Check that the lines are correct and that the mask has been fitted with the proper filters. Also check the ambient aerosol concentration for the test.

Low fit factors may occur shortly before the battery goes dead. A dramatic drop in mask *and* ambient counts could be due to a low alcohol level in the unit.

Operation with TSI Software

The Portacount can be used in conjunction with an IBM-compatible PC. The software may facilitate the standardization and documentation of tests.

Match Versions

Portacount units upgraded with the new ROM chip on or after August 1987 must be operated with version 2.0 of the Portacount fit test software.

Back up the fit test software disk. Connect the serial cable provided between the Portacount and the serial port of your computer. For details, see p. 6 of *Portacount Fit Test Software Operations Manual*.

Bootting Software

Place a copy of the software into the computer default disk, type "FIT," then press RETURN. The program will come up on the computer screen.

Configure

After the test exercise screen comes up, you can press function key 3 (F3) to configure the program for your computer.

Entering Changes

You *must* hit the ENTER key after each new entry; hitting the down arrow will select the next item, but will not save the current new entry. Use the down arrow only to skip the next item. Press the ESC key to save changes and exit back to the main menu.

Test Criteria

Pressing the F1 key allows you to reset the test criteria, including the test exercises. The ESC key saves and exits to the main menu.

Documentation

Hitting the letter "T" from the main menu will bring you into the Test ID screen, where you can document the other parameters of the test. These data are included in the fit test report that can be printed or saved at the end of the test.

Enter any notes about the subject (e.g., smoker) on the comment lines.

Same Procedures

Before any test, go through the same process as for the **nonsoftware-assisted** test (see "Operations" above). Insure that the **Portacount** is connected via the serial ports to the computer.

Start the Portacount

Press the ENABLE and TEST keys on the Portacount to start the FIT TEST MODE operating (the "E" should be flashing).

Test in Progress

On the **computer**, at the main menu, press the "S" key (or place the highlighted bar using the arrow keys on "Start") and press the ENTER key.

The test has begun, but it may take the software over a minute to get in sync with the Portacount.

The computer will prescribe exercises for the subject. Each exercise takes about 80 s to complete. The **default** group of exercises contains six sets, taking **8–10 min** to complete.

Test Report

Follow the instructions and menu prompts throughout the test. At the conclusion of the test, you will be given an opportunity to print or save the test report, unless this has been set in the parameters menu to occur automatically. Any test can printed using the F2 menu.

Exit by pressing "E" at the main menu.

Maintenance

Schedule

Batteries for the Portacount last approximately six hours. Alcohol should be added at every battery change. Printer paper and ribbon should be changed as needed. (For details, see the *Portacount Operation and Service Manual*.)

Batteries

Batteries are replaced as described in the first section of this manual or on pp. 49–50 of the *Portacount Operation and Service Manual*.

Recharging the Batteries: The Portacount uses nickel-cadmium batteries. It is best to charge them only when they have been completely discharged. To charge them, plug the charging unit into the wall and press the connector into the **battery**. Like the Portacount **itself**, this plug will go in only one way. Charge the batteries for at least six hours.

Alcohol

Alcohol can be added to the Portacount, as described in the first section of this manual (see also Fig. 1) or on pp. 47–48 of the *Portacount Operation and Service Manual*. Be **careful** of the angle of the instrument during filling and do not overfill the **Portacount**—it may not require the whole vial.

Signs of **overfilling** are the presence of alcohol at the drain port (when the bottom cap is open) and the exhaust port. Also, suspect readings can be caused by alcohol interference with the optics.

Not filling the **Portacount** at the required times can result later in the **"E-E" error**, aborting the test. (The **"E-E"** error is given only in the **FIT TEST MODE**; in other modes, **lower-than-expected** counts **will** be displayed.)

Handling

Care should be taken, as with any instrument, to insure that the Portacount is not subjected to undue shock and vibration. The Portacount should be transported in a foam-lined briefcase. It should be kept upright at all times. If the unit is going any distance or will be inoperative for more than two weeks, dry out the Portacount by letting it run for six hours without refilling it with alcohol.

During operation, the Portacount should be left stationary and not vibrated.

References

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