cation of the type of error, which in turn provides a hint about the source of error.

Note: The terminology used here (i.e., control rules, violation of control rules) is convenient for discussion purposes, both in written text and in oral presentations. However, as reviewer A.H. points out, this may cause analysts to have the feeling of doing something wrong when an out-of-control situation arises. In that sense, the choice of terminology is unfortunate. It would be more objective to use the term "decision criterion," but it is not easy to find a convenient term to use for indicating when the criterion is not met. Furthermore, the single vs plural (criterion, criteria) is difficult in oral presentations. These rules or criteria are, of course, statistical tests, but to talk of tests would be even more confusing.

Control rules should be chosen to provide a low probability for false rejection and a high probability for error detection. "False rejection" refers to the situation where the analytical process or analytical method remains stable, but a rejection signal still occurs, owing to background random error or the inherent imprecision of the analytical method. All control procedures provide some false rejections, but appropriate choice of control rules can keep the proportion low (<5%). "Error detection" refers to the situation where the analytical method has been disturbed. There are analytical errors in addition to the inherent imprecision of the analytical method. A shift or drift may have occurred, causing a systematic analytic error. The standard deviation may have increased, causing an increase in the random analytical error of the method. When such additional errors are present, the control procedure is supposed to detect them and provide a rejection signal.

In selecting control rules, it is important to first consider the probability for false rejection and to eliminate those rules where the level exceeds a probability figure of 0.05 or a percentage of 5% (*3, 5*). Then, from the remaining rules, at least one is selected that is responsive to systematic error and at least one that is responsive to increases in random error. The number of control observations per run (N) should be chosen to provide the desired probability for error detection.

In the control procedure recommended here, several control rules are used, hence the name "multi-rule" Shewhart procedure. In the daily operation of the control procedure, samples of control materials are included in each analytical run. When any one of the control rules is violated, a decision is made to reject that analytical run. A decision to accept the analytical run requires that there be no violations of any of the control rules.

Materials and Methods

Control Materials

It is not our purpose to describe the characteristics of control materials in detail. Bowers et al. (*6*) have discussed control materials in a previous volume of *Selected Methods.*

Suitable materials are generally available and in use in most laboratories, although each material may have some limitations for certain analytes. It may therefore be necessary to select control materials appropriate for different analytes, rather than use the same control materials for all methods.

In general, the most important properties are that the control materials behave like the real samples, are available in sufficient quantity for a year or so of use, are stable over the time period of use, are appropriately apportioned for convenient use, and vary little in concentration from aliquot to aliquot or vial to vial. For the control system here, two control materials having different concentrations are recommended, with one measurement being made at each concentration during each analytical run. The concentrations may be chosen to represent normal values, appropriate medical decision concentrations, or critical instrument performance limits (such as upper or lower limits of linearity).

Control Rules (Decision Criteria)

For brevity and convenience, symbols are used to represent the different control rules. The symbol has the form A_L, where A is an abbreviation for a statistic or is the number of control observations per run, and L is the control limit.

1_{2s} represents the control rule where one control observation exceeds control limits set as $\bar{x} \pm 2s$. This is the "warning" rule for a Shewhart chart and is interpreted in this discussion as a requirement for additional inspection of the control data, testing the data with the rules below to judge whether the analytical run should be accepted or rejected.

1_{3s} symbolizes the control rule where a run is rejected when one control observation exceeds control limits set as $\bar{x} \pm 3s$. These are the usual "action" or rejection limits on a Shewhart control chart.

2_{2s} is the control rule where the run is rejected when two consecutive control observations exceed the same limit, which is either $\bar{x} + 2s$ or $\bar{x} - 2s$. The rule is initially applied to the two observations within a run, one on each of two different control materials. The run is rejected when the control observations on both materials exceed their respective $+2s$ control limits or their respective $-2s$ control limits. The rule can also be applied to two consecutive observations on the same control material, one from each of two consecutive runs. When applied to consecutive observations on different materials, this will be referred to as "across" materials, to differentiate this from consecutive observations on the same material, or "within" materials.

R_{4s} is the control rule according to which the run is rejected when the range or difference between the two control observations within the run exceeds $4s$. The rule is invoked when the observation in one control material exceeds a $+2s$ limit and the observation on the other exceeds a $-2s$ limit, i.e., each observation is out by $2s$, but in opposite directions, making a total of $4s$ difference between them.

Note: Reviewer R.B. points out that this range rule could be applied when one control observation exceeds, say, $+2.5s$ and the other, say, $-1.5s$. This would be perfectly correct, though it would not be very convenient or practical without computerized data handling. There is no difficulty once an observation exceeds a $3s$ limit, because then it is out-of-control anyway. So the ambiguity in interpretation occurs when an observation is between $2s$ and $3s$. The analyst should decide how to handle this, based on what is practical in his laboratory.

4_{1s} is the control rule where the run is rejected when four consecutive control observations exceed the same limit, which is either $\bar{x} + 1s$ or $\bar{x} - 1s$. These consecutive observations can occur within one control material, which would require inspecting the observations for four consecutive runs, or across control materials, which would require inspecting only the present run and the one before it.

$10_{\bar{x}}$ is the control rule which says the run is rejected when 10 consecutive control observations fall on the same side of the mean ($\bar{x}$). These consecutive observations can occur within one control material or across control materials. This would require inspection of 10 or five consecutive runs, respectively.

A practical way of using this combination of control rules in a manual application is shown in Figure 1. The 1_{2s} rule is used as a warning rule and prompts a more detailed inspection of the data using the other control rules. If neither control observation exceeds a $2s$ limit, the analytical run is in-control and patients' data may be reported. If either observation exceeds a $2s$ limit, the control data are tested by applying the 1_{3s}, 2_{2s}, R_{4s}, 4_{1s}, and $10_{\bar{x}}$ rules. If none of these rules is violated, the run is in-control. If any one of them is violated, the