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PRESENT AND FUTURE ASPECTS OF PROSA – A COMPUTER PROGRAM FOR NEAR REAL TIME ACCOUNTANCY

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ABSTRACT

The methods of near real time accountancy (NRTA) for safeguarding nuclear material received a lot of attention in the last years. We developed PROSA 1.0 as a computer program to evaluate a sequence of material balance data based on three statistical tests for a selected false alarm probability. A new NRTA test procedure will be included and an option for the calculation of detection probabilities of hypothetical loss patterns will be made available in future releases of PROSA. Under a non-loss assumption, PROSA may also be used for the analysis of facility measurement models.

1. INTRODUCTION

The computer program PROSA for statistical analysis of near real time accountancy (NRTA) data[1] with the intention to detect a loss of material in one or more balance periods has been applied to simulated data from model facilities, e.g., the DWK 500 t/y reprocessing facility,[2] and real data from existing facilities. The experience gained in applying PROSA 1.0 to a number of data sets suggests some new aspects and some changes for the computer program.

2. SHORT DESCRIPTION OF PROSA 1.0

The essential input of the current version PROSA 1.0 consists of

(1) the desired false alarm probability for a given number of balance periods,

(2) the measurement model of the considered facility,

(3) the given series of material balance results $(MUF_1, MUF_2, \ldots, MUF_n)$ which is assumed to be multivariate normally distributed with known dispersion matrix Σ.

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The matrix Σ is the condensed form of the measurement model of the facility under consideration. It is an essential component for the statistical analysis of the MUF sequence. Based on these data, PROSA calculates the thresholds for three statistical tests by a Monte Carlo simulation. One of these tests uses the cumulative sum of the original MUF series and is called Truncated Sequential CUMUF Test. The other two tests use the cumulative sum of the so-called stochastically independent MUF residuals, which are the linear transformed MUFs. The tests are named Page's Test and Power One Test. Statistical analyses show that the combination of these three tests is able to detect a large number of different loss patterns with a relative high detection probability compared to the detection probability of the Neyman-Pearson Test.[3,4] But this test cannot be applied because the loss pattern will not be known. The MUF-vector undergoes these three statistical tests to decide if the situation of loss or non-loss of material pertains. We assume two statistical hypotheses which describe the non-loss or loss situation.

$$H_0 \text{ (non-loss): } E(MUF_k) = 0 \text{ for all periods } k=1,2,\ldots,n \qquad (2.1)$$

and

$$H_1 \text{ (loss): } E(MUF_k) = m_k \text{ with } m_1 + m_2 + \ldots + m_n > 0 \quad . \qquad (2.2)$$

The sequential tests in PROSA 1.0 are truncated versions, i.e., they give a decision at the end of the nth balance period or earlier. PROSA 1.0 can be provided on diskettes with executable files for an IBM PC/AT. A manual on how to use PROSA is also available.[1] In Fig. 2.1 a simulated MUF sequence of 23 values based on the model reprocessing facility in Refs. 2 and 5 is shown, and in Figs. 2.2-2.4 the results obtained by PROSA are graphically displayed where a 5% false alarm probability is assumed. We see that none of the tests gives an alarm, i.e., no anomaly is detected among the data.

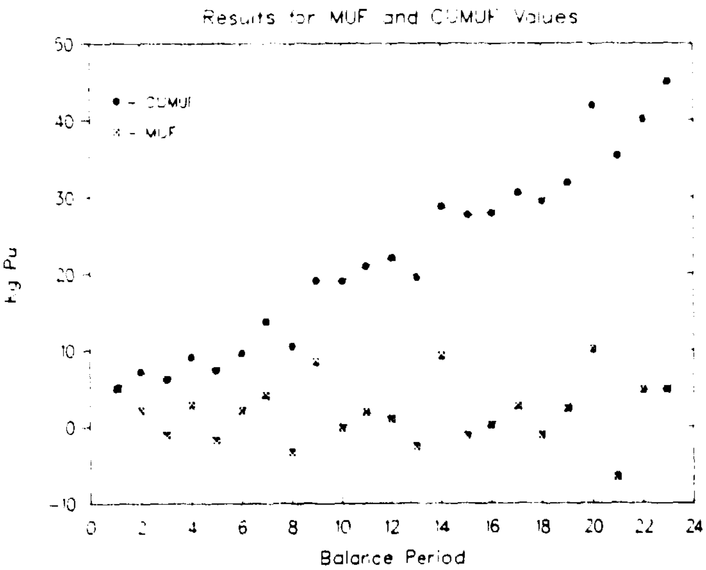

Fig. 2.1.
Simulated MUF sequence for the 500 t/y model reprocessing facility.

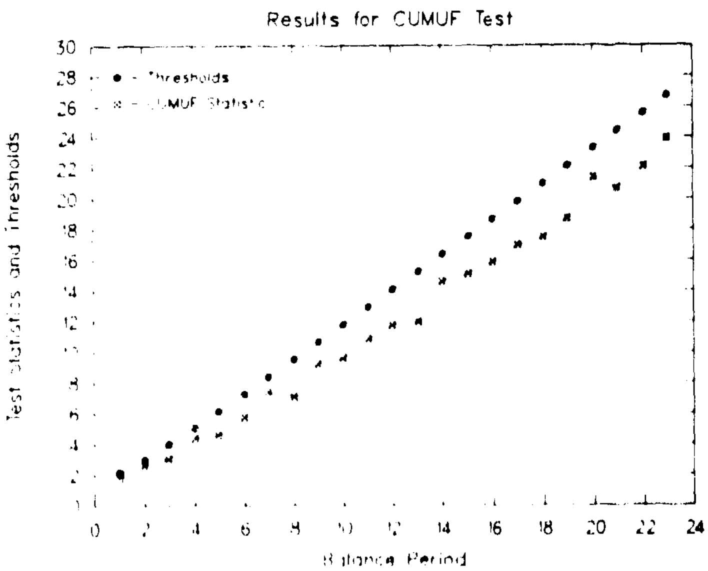

Fig. 2.2.
Graphical display of the test thresholds for the CUMUF Test under $\alpha = 0.05$ and measurement model of model facility and standardized CUMUF statistic of the data in Fig. 2.1.

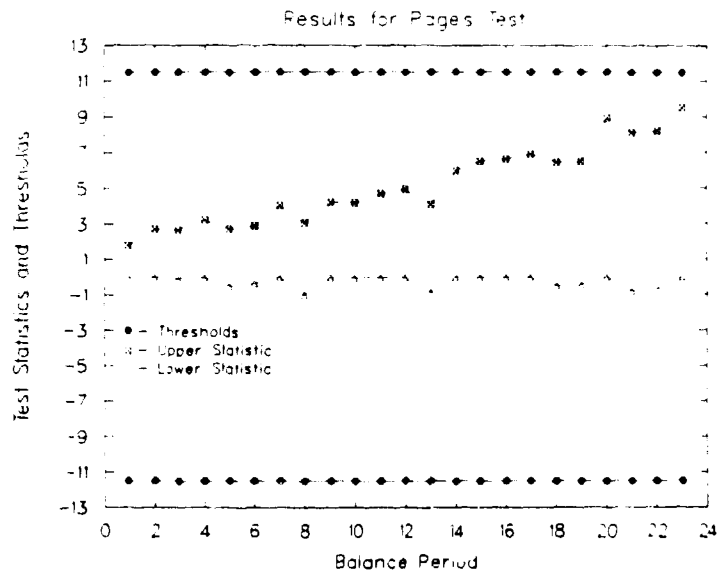

Fig. 2.3.
Graphical display of the test thresholds for Page's Test under $\alpha = 0.05$ and measurement model of model facility and standardized Page statistic of the data in Fig. 2.1.

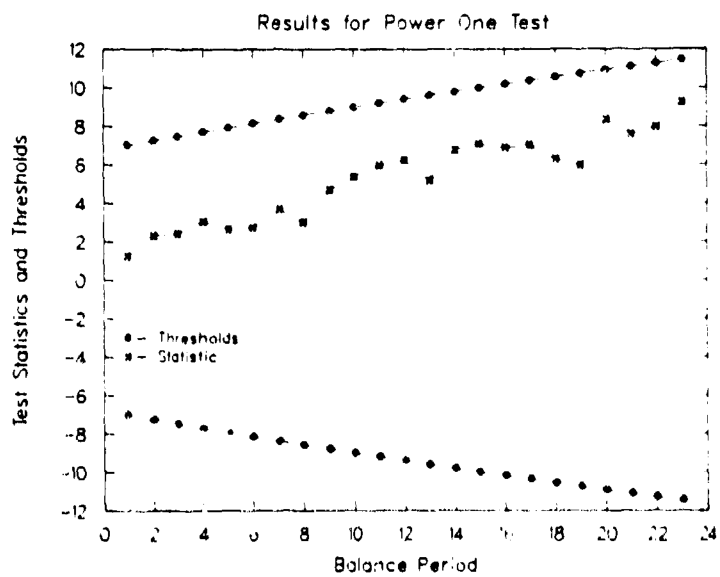

Fig. 2.4.
Graphical display of the test thresholds for Power One Test under $\alpha = 0.05$ and measurement model of model facility and standardized Power One statistic of the data in Fig. 2.1.

3. THE GeMUF TEST

The application of PROSA 1.0 to various data sets revealed that the application of the Power One Test does not provide a substantial increase in detection capability of anomalies among the data compared to the Page's Test. This is not very surprising because the statistics of both tests are very similar. But there are cases where CUMUF Test as well as Page's Test do not perform very well.[4] So at KfK we are looking for a test that is based on the idea of the Neyman-Pearson Test that should close the gap. The idea is to replace the Power One Test by this newly developed test. We know that there exists exactly one best test to test H_0 against H_1 when in case of loss the loss pattern will be known exactly. This is the Neyman-Pearson Test[4] which may be formulated as

$$Z \begin{cases} > k \text{ , reject } H_0 \\ < k \text{ , reject } H_1 \end{cases} \qquad (3.1)$$

where

$$Z = (m_1, m_2, \ldots, m_n) \Sigma^{-1} (MUF_1, MUF_2, \ldots, MUF_n)^t \quad .$$

Because in the case of loss the exact pattern will normally not be known, this test cannot be applied. The idea of the new test, which is called GeMUF Test, is to estimate the loss m_i of period i, $i=1,2,\ldots,n$, by MUF , which is an unbiased estimate.[6] The statistics of this test may now be written as

$$GeMUF_i = (MUF_1, MUF_2, \ldots, MUF_i) \Sigma_i^{-1} (MUF_1, MUF_2, \ldots, MUF_i)^t \quad ,$$

where Σ_i^{-1} is the inverse of the dispersion matrix for the random vector $(MUF_1, MUF_2, \ldots, MUF_i)$. The test may now be formulated as

for $i=1,2,\ldots,n-1$:

$$GeMUF_i \begin{cases} < t_i, \text{ no decision and go to the next period} \\ > t_i, \text{ reject } H_0, \end{cases} \qquad (3.2a)$$

for $i=n$:

$$GeMUF_n \begin{cases} < t_n, \text{ reject } H_1 \\ > t_n, \text{ reject } H_0 \quad . \end{cases} \qquad (3.2b)$$

The thresholds t_i have to be calculated by a Monte Carlo simulation to allow a total overall false alarm probability α. Statistical properties of the test will not be addressed here because this will be done by Seifert, but promising results in applying this test can be reported. It has to be reminded that in PROSA all the statistics that are used are standardized to variance one. The test will be illustrated by the following example shown in Fig. 3.1, where the same data as in Fig. 2.1 have been used with 5% false alarm probability. It is obvious that we do not get an alarm.

4. CALCULATION OF DETECTION PROBABILITIES WITH PROSA

The current version PROSA 1.0 is designed to test a given sequence of MUF values on the basis of the assumed measurement model and gives a yes-no decision; i.e., it tells if the non-loss assumption has to be rejected or not. In many situations, e.g., for model facilities in a design-state, one would like to have more information about the NRTA test procedures. Such information might be the detection probabilities for several kinds of loss patterns for a number of balance

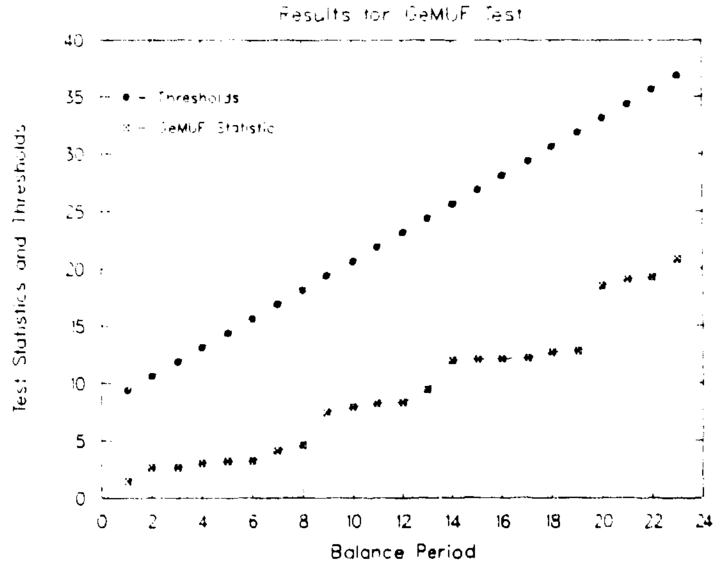

Fig. 3.1.
Graphical display of the test thresholds for GeMUF Test under α = 0.05 and measurement model of model facility and standardized GeMUF statistic of the data in Fig. 2.1.

periods. If, for a certain NRTA test procedure, this loss pattern, which is most difficult to detect, is known, then it is possible to calculate guaranteed detection probabilities for a certain amount of loss no matter how this loss is distributed among the considered balance periods. The foregoing considerations will be illustrated with the help of the Truncated Sequential CUMUF Test. Let us assume that $1-\beta\,(m_1, m_2, \ldots, m_n)$ is the detection probability for false alarm probability α of the Truncated Sequential CUMUF Test for a facility with n balance periods and dispersion matrix Σ, where the total loss is $M = m_1 + m_2 + \ldots + m_n$. We are now interested in the minimization problem

$$\min \{1 - \beta\,(m_1, m_2, \ldots, m_n) : m_1 + m_2 + \ldots + m_n = M\} \quad .$$

It can be shown that this minimization problem can be solved[7] and that the vector $(0,0,\ldots,M)$ leads to the minimal detection probability. That means that the case of total loss in the last balance period is for this test most hard to detect. This is now the situation where another test has to be used that has, for this kind of loss pattern, a better detection capability. Let us, for example, assume a loss of 30 kg of plutonium in the 23rd balance period. It is very unlikely that the CUMUF Test would detect such a loss; i.e., the detection probability is about 11%. But in this case the GeMUF Test will detect it. For illustrative purposes a MUF sequence with a loss of 30 kg in the last balance period is evaluated. The results are shown in Figs. 4.1-4.3.

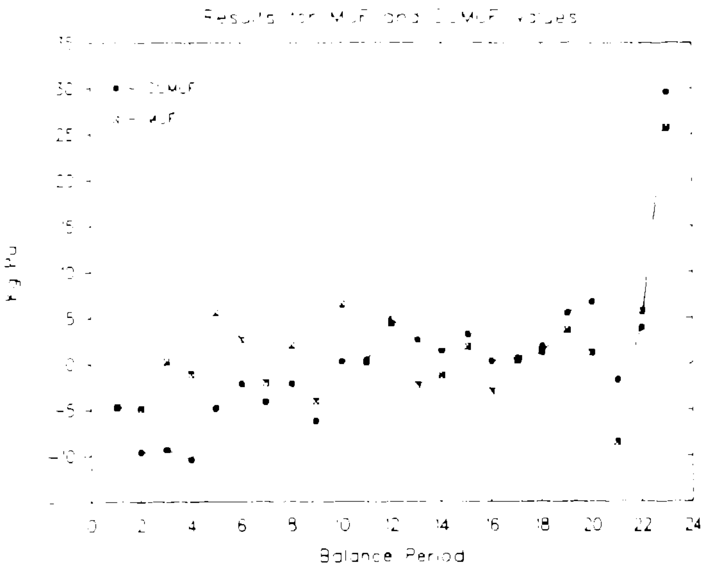

Fig. 4.1.
Simulated MUF sequence for the 500 t/y model reprocessing facility where a loss of 30 kg in balance period 23 is introduced.

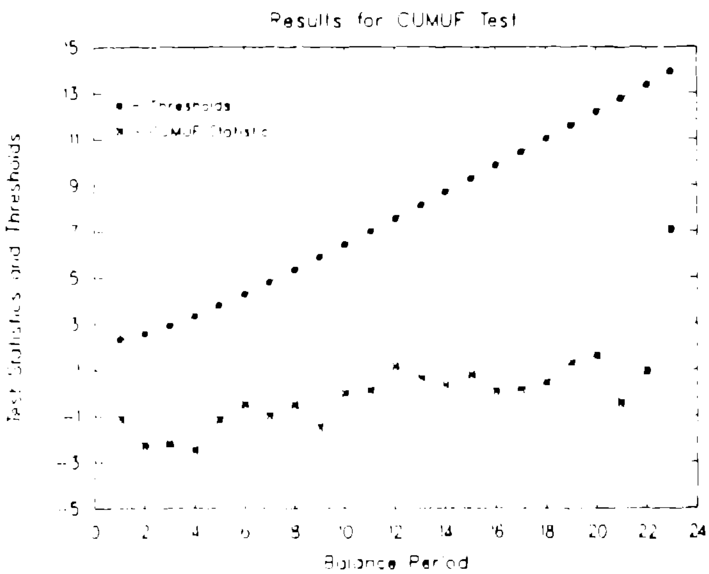

Fig. 4.2.
Graphical display of the CUMUF Test for $\alpha = 0.05$ applied to the data in 4.1; loss of material is not detected.

5. ANALYSIS OF MEASUREMENT MODELS WITH PROSA

PROSA was primarily designed to detect a possible loss in a sequence of balance periods. But the application of PROSA to real facility data revealed an interesting feature of PROSA that might be of interest, especially for plant operators. It was mentioned before that the statistical model for measuring a certain material is an essential input for PROSA. For the following, let us assume that we have the situation of

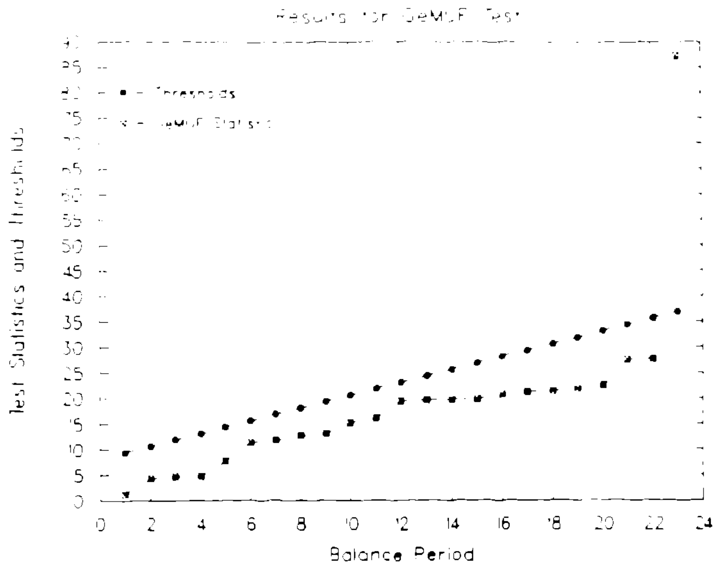

Fig. 4.3.
Graphical display of the GeMUF Test for $\alpha = 0.05$ applied to the data in Fig. 4.1; alarm in balance period 23 is clearly indicated.

non-loss. If now, for a special sequence of balance periods, a certain error model for measuring the material of interest is assumed, then the results of PROSA applied to the material balance results may show whether the measurement model may be confirmed or not. That means anomalies detected by PROSA may be caused by an error model, where the measurement uncertainties are assumed to be smaller than they really are. By looking closer at the data, it may even be possible to see where in the measurement model the wrong assumptions might be. These considerations can be illustrated by the following example, where we assume for the model facility measurement model a 0.3% random and systematic error for the input. Now we apply PROSA 1.0 to data of a reprocessing facility where the random and systematic error for the input is 1%. These data are displayed in Fig. 5.1. In Figs. 5.2 and 5.3 the results for Page's Test and CUMUF Test are shown. It is obvious that the statistics are way out of bounds even though no loss of material has taken place. If we adjust our model assumptions from 0.3% to 1% error for the input, we see in Figs. 5.4-5.5 that the data in Fig. 5.1 do not lead to an alarm because now model and data have the same measurement uncertainties.

6. CONCLUSION

PROSA 1.0 is a helpful tool for the evaluation of NRTA data. It is intended to replace the Power One Test by a test called the GeMUF Test to improve the detection capability for a loss of material. The inclusion of detection probabilities will allow use of PROSA as a tool to estimate the capabilities of NRTA test procedures. In a non-loss case PROSA might also be used to analyze facility measurement models.

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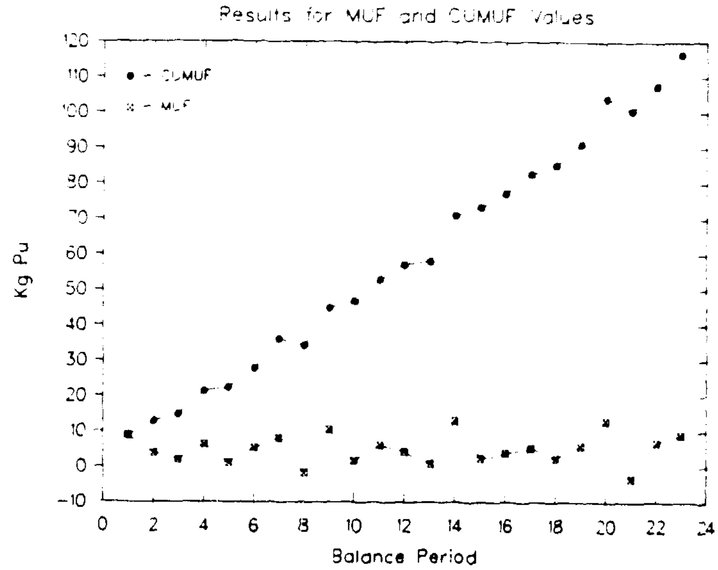

Fig. 5.1.
Simulated MUF sequence for the 500 t/y model reprocessing facility where 1% random and systematic measurement error for the input is assumed.

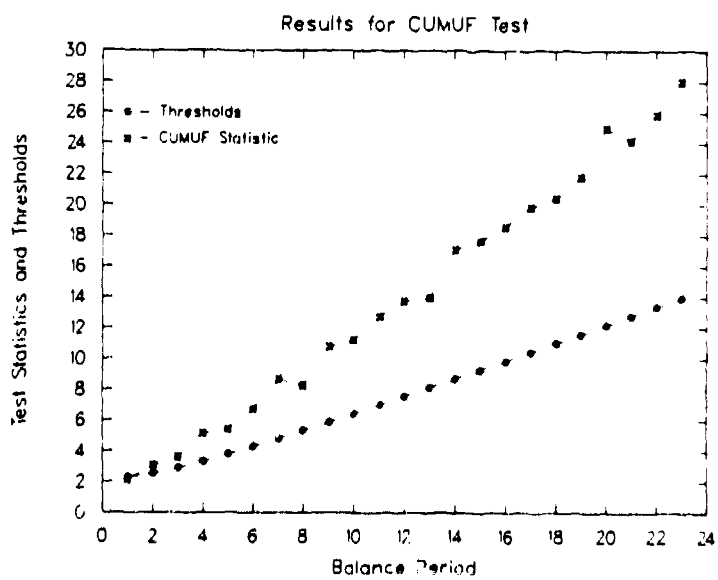

Fig. 5.2.
Graphical display of CUMUF Test for MUF sequence in Fig. 5.1 and thresholds in Fig. 2.2.

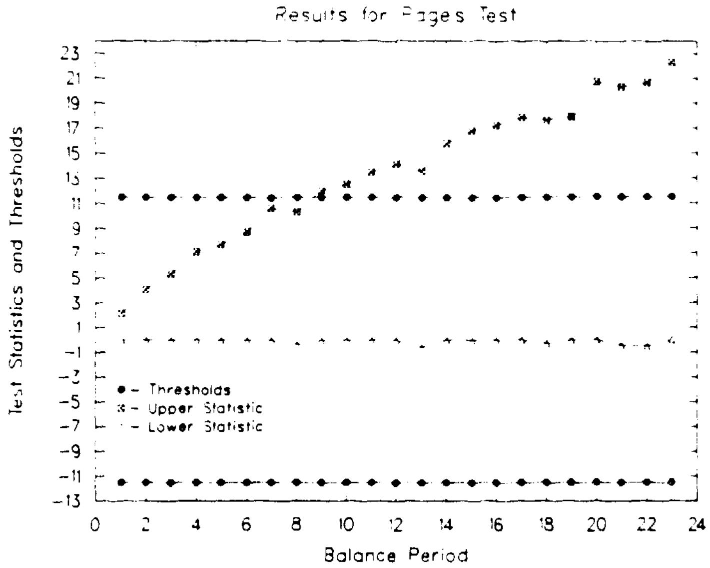

Fig. 5.3.
Graphical display of Page's Test for MUF sequence in Fig. 5.1 and thresholds in Fig. 2.3.

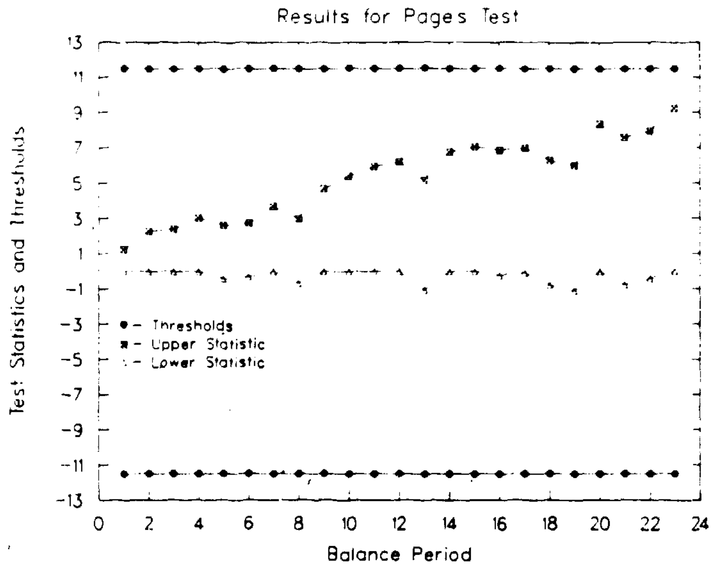

Fig. 5.5.
Graphical display of Page's Test for MUF sequence in Fig. 5.1 and thresholds based on 1% random and systematic input measurement error.

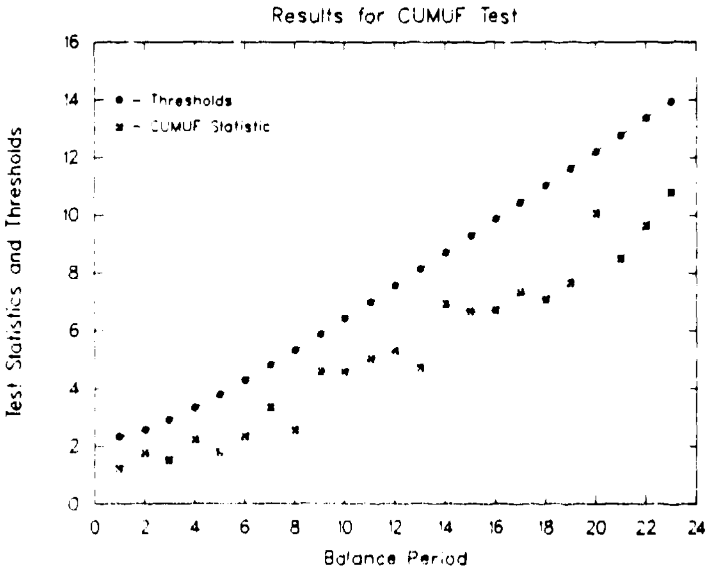

Fig. 5.4.
Graphical display of CUMUF Test for MUF sequence in Fig. 5.1 and thresholds based on 1% random and systematic input measurement error.