

Pressurized Water Reactor Owners Group Standard Process and Methods for Calculating RCS Leak Rate for Pressurized Water Reactors



WCAP-16423-NP

Revision 0

Pressurized Water Reactor Owners Group
Standard Process and Methods for
Calculating RCS Leak Rate for
Pressurized Water Reactors

Prepared for
Pressurized Water Reactor Owners Group
Developed under PWROG Program
PA-OSC-0189
September 2006

***Joe Congdon**
Plant Operations Engineering

Approved: *John Duryea, Manager
Plant Operations Engineering

Approved: *Gordon C. Bischoff
PWR Owners Group Programs

**Electronically approved records are authenticated in the Electronic Document Management System*

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

©2006 Westinghouse Electric Company LLC
All Rights Reserved

LEGAL NOTICE

This report was prepared as an account of work performed by Westinghouse Electric Company LLC. Neither Westinghouse Electric Company LLC, nor any person acting on its behalf:

- A. Makes any warranty or representation, express or implied including the warranties of fitness for a particular purpose or merchantability, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

COPYRIGHT NOTICE

This report has been prepared by Westinghouse Electric Company LLC and bears a Westinghouse Electric Company copyright notice. As a member of the PWR Owners Group, you are permitted to copy and redistribute all or portions of the report within your organization; however all copies made by you must include the copyright notice in all instances.

DISTRIBUTION NOTICE

This report was prepared for the PWR Owners Group. This Distribution Notice is intended to establish guidance for access to this information. This report (including proprietary and non-proprietary versions) is not to be provided to any individual or organization outside of the PWR Owners Group program participants without prior written approval of the PWR Owners Group Program Management Office. However, prior written approval is not required for program participants to provide copies of Class 3 Non Proprietary reports to third parties that are supporting implementation at their plant, and for submittals to the NRC.

PWR Owners Group
Member Participation* for Project / Task PA-OSC-0189 (Reference 1)

Utility Member	Plant Site(s)	Participant	
		Yes	No
AmerenUE	Callaway (W)	✓	
American Electric Power	D.C. Cook 1&2 (W)	✓	
Arizona Public Service	Palo Verde Unit 1, 2, & 3 (CE)	✓	
Constellation Energy Group	Calvert Cliffs 1 & 2 (CE)	✓	
Constellation Energy Group	Ginna (W)	✓	
Dominion Connecticut	Millstone 2 (CE)	✓	
Dominion Connecticut	Millstone 3 (W)	✓	
Dominion Kewaunee	Kewaunee (W)	✓	
Dominion VA	North Anna 1 & 2, Surry 1 & 2 (W)	✓	
Duke Energy	Catawba 1 & 2, McGuire 1 & 2 (W), Oconee 1, 2, 3 (B&W)	✓	
Entergy Nuclear Northeast	Indian Point 2 & 3 (W)	✓	
Entergy Operations South	Arkansas 2, Waterford 3 (CE), Arkansas 1 (B&W)	✓	
Exelon Generation Co. LLC	Braidwood 1 & 2, Byron 1 & 2 (W), TMI 1 (B&W)	✓	
First Energy Nuclear Operating Co	Beaver Valley 1 & 2 (W), Davis-Besse (B&W)	✓	
Florida Power & Light Group	St. Lucie 1 & 2 (CE)	✓	
Florida Power & Light Group	Turkey Point 3 & 4, Seabrook (W)	✓	
Nuclear Management Company	Prairie Island 1&2, Pt. Beach 1&2 (W)	✓	
Nuclear Management Company	Palisades (CE)	✓	
Omaha Public Power District	Fort Calhoun (CE)	✓	
Pacific Gas & Electric	Diablo Canyon 1 & 2 (W)	✓	
Progress Energy	Robinson 2, Shearon Harris (W), Crystal River 3 (B&W)	✓	
PSEG - Nuclear	Salem 1 & 2 (W)	✓	
Southern California Edison	SONGS 2 & 3 (CE)	✓	
South Carolina Electric & Gas	V.C. Summer (W)	✓	
So. Texas Project Nuclear Operating Co.	South Texas Project 1 & 2 (W)	✓	
Southern Nuclear Operating Co.	Farley 1 & 2, Vogtle 1 & 2 (W)	✓	
Tennessee Valley Authority	Sequoyah 1 & 2, Watts Bar (W)	✓	
TXU Power	Comanche Peak 1 & 2 (W)	✓	
Wolf Creek Nuclear Operating Co.	Wolf Creek (W)	✓	
<p>* Project participants as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the PWR Owners Group Program Management Office to verify participation before sending this document to participants not listed above.</p>			

PWR Owners Group
International Member Participation* for Project / Task PA-OSC-0189 (Reference 1)

Utility Member	Plant Site(s)	Participant	
		Yes	No
British Energy	Sizewell B	✓	
Electrabel (Belgian Utilities)	Doel 1, 2 & 4, Tihange 1 & 3	✓	
Kansai Electric Co., LTD	Mihama 1, Ohi 1 & 2, Takahama 1 (W)	✓	
Korea Hydro & Nuclear Power Corp.	Kori 1, 2, 3 & 4 Yonggwang 1 & 2 (W)	✓	
Korea Hydro & Nuclear Power Corp.	Yonggwang 3, 4, 5 & 6 Ulchin 3, 4, 5 & 6(CE)	✓	
Nuklearna Electrarna KRSKO	Krsko (W)	✓	
Nordostschweizerische Kraftwerke AG (NOK)	Beznau 1 & 2 (W)	✓	
Ringhals AB	Ringhals 2, 3 & 4 (W)	✓	
Spanish Utilities	Asco 1 & 2, Vandellos 2, Almaraz 1 & 2 (W)	✓	
Taiwan Power Co.	Maanshan 1 & 2 (W)	✓	
Electricite de France	54 Units	✓	
<p>* This is a list of participants in this project as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the PWR Owners Group Program Management Office to verify participation before sending documents to participants not listed above.</p>			

EXECUTIVE SUMMARY

A survey of selected nuclear power plant Reactor Coolant System (RCS) leak rate measurement methods found a wide range of calculation methods, assumptions and leak rate reporting conditions. For example, some plants reported RCS leak rate (gallons per minute) normalized to a standard temperature of 70°F while others reported leakage at 110°F. Plant specific differences in calculation methods, assumptions and reporting conditions have the following effects:

1. Meaningful comparison across the nuclear industry is difficult.
2. Industry wide leak rate monitoring and enforcement standards cannot be applied equally without a standard leak rate calculational model.

The purpose of this document is to provide standard guidelines for RCS leak rate calculational methods, assumptions and leak rate reporting conditions.

Standard Method

This guideline recommends the use of a *two snapshot mass balance* method to calculate RCS leak rate. Where, relevant RCS and connected system conditions are taken at Time-1 and Time-2. The difference in water mass is computed between Time-1 and Time-2. The difference is expressed as a volumetric leak rate in gallons per minute.

Assumptions

The two principal assumptions in the standard RCS leak rate method are:

1. **Thermal Equilibrium:** The fundamental underlying assumption in the leak rate calculation (via mass balance) is that all control volumes are in thermal equilibrium. That is, the indicated temperature and pressure applies to the entire control volume (PZR, RCS and VCT). Therefore, it is essential to maintain plant stability throughout the duration of the leak rate test. Transients, including large boration and/or dilution rates, will introduce non-equilibrium conditions and compromise the accuracy of the leak rate test.
2. **RCS Tave:** For purposes of the standard RCS leak rate methodology, Tave is assumed to be the effective reactor coolant bulk temperature for determining mass change due to expansion/contraction in the Reactor Coolant Water Volume (*see def.*). This also assumes that reactor coolant hot legs and cold legs contain approximately equal mass in situations where Tave changes significantly from Time-1 to Time-2.

Reporting Conditions

This guideline recommends that all plants report the RCS leak rate in gallons per minute, where the reported gallon is normalized to 70°F.

Statistical Analysis – Minimum Level of Detectability

In addition to providing a standard guideline for calculating and reporting RCS leak rate, this report also includes a statistical analysis to quantitatively determine the “minimum level of detectability” (*the smallest unidentified leak rate or change in leak rate that can almost always be detected in a given period of time using a given “alarm” function*).

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Tom Veitch, current Chairman of the Pressurized Water Reactor Owners Group (PWROG) Operations Subcommittee, and former OSC Chairman, Cal Walwrath in initiating this project and in providing guidance throughout the course of the project. Members of the RCS Leak Rate Project Team are gratefully acknowledged. Paul Kramarchyk and Robert Endter for their invaluable support as the primary writers and technical contributors. Support from Rolando Perez and Warren L. Greene and the peer review comments provided by Dr. R. K. Perdue in Appendix I are also gratefully acknowledged.

The contribution of the following members of the RCS Leak Rate Working Group for their guidance, active participation and for providing review comments is greatly appreciated:

Bob Couture, Seabrook
Steve Mays, Catawba
Bruce Bauer, Palisades
Mike Hess, Millstone Point
Bill Blessie and Scott Eidem, Ft. Calhoun
Dan Hardesty, Diablo Canyon
Jim Lambert, Farley
Mark Handrick, North Anna Dominion
Jim Heinzman and Mark Kertz, Comanche Peak
Jack Patterson, Beaver Valley
Harry Vanpelt, Duke
Steve Mccord, Constellation Energy
Dennis Schreiner, Davis Besse
Jim Banke, Ginna
Don Vogt, Palo Verde
Hank Stroup, Sharron Harris
Jim Heil, Mark Coughlin, Bill Sotos and Jim Heil, South Texas Project
Greene Reeves, Wolf Creek
Hank Williams, Vogtle
Russ Warren, INPO
Gordon Cleifton, NEI

TABLE OF CONTENTS

1.	INTRODUCTION.....	1
2.	DEFINITION AND DESCRIPTION OF TERMS	2
3.	STANDARD PLANT DESIGN DEFINITION	7
3.1	Reactor Coolant Water Volume (RCWV).....	7
3.2	Pressurizer (PZR)	7
3.3	Volume Control Tank (VCT).....	7
3.4	Pressurizer Relief Tank (PRT)	7
3.5	Reactor Coolant Drain Tank (RCDT)	8
4.	STANDARD METHODOLOGY OVERVIEW	9
4.1	General Equation and LEAKAGE Relationship	9
4.2	Normalized Leak Rate.....	9
5.	PRECAUTIONS AND LIMITATIONS.....	10
6.	ASSUMPTIONS	12
7.	CALCULATION METHOD: GROSS LEAKAGE	13
7.1	Calculation Method: Pressurizer (PZR) Δ Mass	13
7.1.1	Calculation Method: Mass of PZR at Time 1	13
7.1.2	Calculation Method: Mass of PZR at Time 2	14
7.1.3	Result: PZR Δ Mass.....	15
7.2	Calculation Method: Reactor Coolant Water Volume (RCWV) Δ Mass.....	15
7.2.1	Calculation Method: Mass of RCWV at Time 1.....	15
7.2.2	Calculation Method: Mass of RCWV at Time 2.....	16
7.2.3	Result: RCWV Δ Mass	16
7.2.4	Segmented Reactor Coolant Water Volume	16
7.3	Calculation Method: Volume Control Tank (VCT) Δ Mass	17
7.3.1	Calculation Method: Mass of VCT at Time 1.....	17
7.3.2	Calculation Method: Mass of VCT at Time 2.....	18
7.3.3	Result: VCT Δ Mass	18
7.4	Calculation Method: Mass Added-Removed Change	18
7.5	Result: Gross LEAKAGE	18
8.	CALCULATION METHOD: IDENTIFIED LEAKAGE	20
8.1	Calculation Method: Reactor Coolant Drain Tank (RCDT) Δ Mass.....	20
8.1.1	Calculation Method: Mass of RCDT at Time 1	20
8.1.2	Calculation Method: Mass of RCDT at Time 2.....	21
8.1.3	Result: RCDT Δ Mass.....	21
8.2	Calculation Method: Pressurizer Relief Tank (PRT) Δ Mass.....	21
8.2.1	Calculation Method: Mass of PRT at Time 1	22
8.2.2	Calculation Method: Mass of PRT at Time 2	22
8.2.3	Result: PRT Δ Mass.....	22
8.3	Steam Generator LEAKAGE	23

8.4	Other Known RCPB LEAKAGE	23
8.5	Calculation Method: Total IDENTIFIED LEAKAGE.....	23
8.6	Result: IDENTIFIED LEAK RATE	23
9.	CALCULATION METHOD: UNIDENTIFIED LEAKAGE	25
9.1	Non-RCPB LEAKAGE.....	25
9.2	Result: UNIDENTIFIED Leak Rate	25
10.	VALIDITY CHECKS	26
10.1	Rules for Leak Rate Results and Application of Validity Checks	26
11.	STATISTICAL ANALYSIS OF THE UNIDENTIFIED LEAK RATE.....	29
11.1	Unidentified Leakage – The “Slack Variable” in the RCS Leak Rate Calculation.....	31
11.2	Comments on the (draft) NRC Guidelines	32
11.2.1	Quarterly Values of the mean (μ) and standard deviation (σ):	32
11.2.2	Definition of μ and σ :.....	33
11.2.3	Recording the “most conservative [daily] leak rate value”.....	33
11.2.4	Action Level I: 9 consecutive measurements above the [baseline] mean.....	35
11.2.5	Precursors: 5 and 7 consecutive values above the mean.....	36
11.2.6	Action Levels II and III: Measurements above Two and Three σ	37
11.3	Description of Simulation Software and Simulation Studies	39
11.3.1	Description & Use of Visual Basic Code: “RCS_EXCEED_CDF”	39
11.3.2	Description & Use of Visual Basic Code: “RCS_LEAK_SIM”	42
11.4	Minimum Level of Detection	52
11.5	Rolling Average of the Output Values	55
11.6	Linear Regression of Input Signals and/or Mass Inventories.....	55
11.7	Outlier (i.e., “Spike”) Screening and Elimination	59
11.8	Negative Leak Rate Results	61
11.9	Optimal Calculation Duration and Data Collection Frequency.....	61
11.10	Multiple Channel Averaging	62
11.11	Time Averaging.....	62
11.12	Recommendations	63
11.13	Kalman Filter.....	65
12.	REFERENCES.....	66
13.	ATTACHMENTS	68

LIST OF TABLES

11-1	Number of Action Level I, Type A (9 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 90 Days	49
11-2	Number of Action Level I, Type A (9 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 90 Days for a λ of 0.83 σ , Assuming Weekly and Monthly Rolling Average	49
11-3	Number of Action Level I, Type B (7 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 31 Days	50
11-4	Number of Action Level I, Type B (7 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 31 Days for a λ of 1.1 σ , Assuming Weekly and Monthly Rolling Average	50
11-5	Number of Action Level I, Type C (5 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 7 Days	51
11-6	Number of Action Level I, Type C (5 Consecutive Exceedences) and Action Levels II and III Occurrences Out of 1000 within 7 Days for a λ of 2 σ , Assuming Weekly and Monthly Rolling Average	51
G-1	Seabrook – Monthly Unidentified Leak Rate Data: August 2005 – March 2006	24
G-2	Comanche Peak Unit 1 – Monthly Unidentified Leak Rate Data: December 2005 – March 2006	25
G-3	Comanche Peak Unit 2 – Monthly Unidentified Leak Rate Data: December 2005 – March 2006	26
G-4	Ginna – Monthly Unidentified Leak Rate Data: December 2005 – March 2006	27
G-5	Standard Plant Participants Baseline & Related Data Summary	28
G-6	Standard Plant Participants Outlier Summary	29

LIST OF FIGURES

D-1	Typical Plant Data – RCS Volume/Mass Inventory vs. Time (15 Minute Intervals)	D-2
D-2	Typical Plant Data – Identified Leak Volume/Mass Inventory vs. Time (15 Minute Intervals)	D-3
D-3	Typical Plant Data – Unidentified Leak Volume/Mass Inventory vs. Time (15 Minute Intervals)	D-4
D-4	Cumulative Distribution Function for 9 Exceedences	D-5
D-5	Cumulative Distribution Function for 7 Exceedences	D-6
D-6	Cumulative Distribution Function for 5 Exceedences	D-7
D-7	Action Level I – “Days to Alarm” (9 Exceedences)	D-8
D-8	Precursor to Action Level I – “Days to Alarm” (7 Exceedences)	D-9
D-9	Precursor to Action Level I – “Days to Alarm” (5 Exceedences)	D-10
D-10	Simulated Leakrate Curve	D-11
D-11	Simulated Leakrate Curve (7 Days Rolling Average) (Using Daily Values Shown in Figure D-10)	D-12
D-12	Simulated Leakrate Curve (Weekly Average) (Using Daily Values Shown in Figure D-10)	D-13
D-13	Simulated Leakrate Curve (30 Days Rolling Average) (Using Daily Values Shown in Figure D-10)	D-14
D-14	Simulated Leakrate Curve (Monthly Average) (Using Daily Values Shown in Figure D-10)	D-15
D-15	Typical Plant Data – LSF of RCS Volume/Mass Inventory vs. Time Data (15 Minute Intervals)	D-16
D-16	Typical Plant Data – Spline Fit of RCS Volume/Mass Inventory	D-17
D-17	Typical Plant Data – LSF of RCS Volume/Mass Inventory vs Time Data (30 Minute Intervals)	D-18
D-18	Typical Plant Data – LSF of RCS Volume/Mass Inventory vs Time Data (1 Hour Intervals)	D-19
D-19	Typical Plant Data – LSF of RCS Volume/Mass Inventory vs Time Data (2 Hour Intervals)	D-20

D-20	Typical Plant Data – LSF of Identified Volume/Mass Inventory vs Time Data (15 Minute Interval).....	D-21
D-21	Typical Plant Data – LSF of Identified Volume/Mass Inventory vs Time Data (30 Minute Interval).....	D-22
D-22	Typical Plant Data – LSF of Identified Volume/Mass Inventory vs Time Data (1 Hour Intervals).....	D-23
D-23	Typical Plant Data – LSF of Identified Volume/Mass Inventory vs Time Data (2 Hours Intervals).....	D-24
D-24	Uncertainty in the Slopes versus Number of Data Points	D-25
D-25	Example of Inappropriate use of Least Squares Fitting.....	D-26
D-26	Cross-Plot of the 2 nd Quarter ZSCORE Values – ZSCORE uses the Leak Rate for Each Day in the 2 nd Quarter.....	D-27
D-27	Cross-Plot of the 2 nd Quarter ZSCORE Values – Includes Outliers - ZSCORE uses the Leak Rate for Each Day in the 2 nd Quarter	D-28
D-28	Cross-Plot of the 2 nd Quarter ZSCORE Values – Includes Outliers – ZSCORE for Y-Axis uses the Median (Not Mean) and “MAD” (Not Sigma)	D-29
D-29	Typical Plant Data – Unidentified Leak Rate as a Function of the Duration of Surveillance Interval	D-30
D-30	Simulated Data – Assessment of Independence	D-31
D-31	Typical Plant Data – Assessment of Independence – 15 Minute Leak Data	D-32
G-1	Illustration of the F-Test for Arbitrary Data	G-31
G-2	Illustration of the 2 Sample t-Test for Arbitrary Data	G-32
G-3	Seabrook ULR Values for Standard Plant Measurements	G-33
G-4	F and Two-Sample t-Test for Seabrook.....	G-34
G-5	Leak Rate Data for Figure G-6	G-35
G-6	R-Square as a Function of Leak Rate.....	G-36
G-7	Seabrook 7 Days Rolling Average – 6 Months of ULR Data (from 08/01/05 to 01/31/06).....	G-37
G-8	Seabrook 30 Days Rolling Average – 6 Months of ULR Data (from 08/01/05 to 01/31/06).....	G-38
G-9	Seabrook Unidentified vs. Identified Leak Rates (2 Hour Snapshot Data)	G-39
G-10	Seabrook Unidentified vs Identified Leak Rates (24 Hour Data)	G-40
G-11	Compare Seabrook 2 Hr and 24 Hr Unidentified Leak Rate Data Nov & Dec 2005	G-41
G-12	Compare Seabrook 2 Hr and 24 Hr Unidentified Leak Rate Data Jan – Mar 2006.....	G-42
G-13	Crossplot of VCT Divert (gal) vs. RCS Inventory Leakage (gpm)	G-43
G-14	Seabrook TAVE (1 Second Instantaneous and 60 Second Average Values)	G-44
G-15	Comanche Peak 1 ULR Values for Standard Plant Measurements	G-45
G-16	F and Two-Sample t-Test for Comanche Peak 1 (Variable 1 = Jan Data without Outliers, Variable 2 = Feb Data)	G-46
G-17	Comanche Peak 1 ULR (Clock Running Backward).....	G-47
G-18	Comanche Peak 2 ULR Values for Standard Plant Measurements	G-48
G-19	Ginna ULR Values for Standard Plant Measurements	G-49
G-20	Ginna Leak Rates vs Time Interval.....	G-50
G-21	Fort Calhoun Total Leak Rate Values from Procedure “Daily OP-ST-RC-3001”	G-51

APPENDICES

Appendix A:	Excerpts from (draft) NRC Documents, Documentation Supplied by the PWROG Members, and from Westinghouse Documents	A-1
Appendix B:	Derivations of Statistical Relationships	B-1
Appendix C:	Effects of Measurement Errors on the Unidentified Leak Rate	C-1
Appendix D:	Figures and Plots from Section 11	D-1
Appendix E:	Description of the Computer Codes used in Section 11	E-1
Appendix F:	NRC Final Guidelines	F-1
Appendix G:	Standard Plant Testing	G-1
Appendix H:	Comments from PWROG Members	H-1
Appendix I:	Peer Review Comments (R. K. Perdue)	I-1

LIST OF ACRONYMS

Acronym	Description
ASME	American Standard Mechanical Engineering
CDF	Cumulative probability Distribution Function
CE	Combustion Engineering
CVS	Chemical and Volume Control System (CVCS, CE design)
GL	Gross Leakage
GPD	Gallons Per Day
GPM	Gallons Per Minute
ILR	Identified leak rate (gpm)
IMSL	International Mathematics and Statistical Library
LBB	Leak Before Break
LCO	Limiting Condition for Operation
MAD	Median of all Absolute Deviations
NP	Non Proprietary
NRC	Nuclear Regulatory Commission
PI	Performance Indicator
PIV	Pressure Isolation Valve
PIG	Particulate, Iodine and Gaseous (when referring to radiation monitors)
PRT	Pressurizer Relief Tank (Quench Tank, CE design)
PWR	Pressurized Water Reactor
PWROG	Westinghouse Pressurized Water Reactor Owners Group
PZR	Pressurizer
RCDT	Reactor Coolant Drain Tank (Reactor Drain Tank, CE design)
RCP	Reactor Coolant Pump
RCPB	Reactor Coolant Pressure Boundary
RCS	Reactor Coolant System
RCWV	Reactor Coolant Water Volume
RIS	Regulatory Issue Summary
RMS	Radiation Monitoring System
RTD	Resistance Temperature Detector
SG	Steam Generator
Tave	RCS average temperature: $(T_{hot} + T_{cold})/2$
Tcold	RCS cold leg temperature
Thot	RCS hot leg temperature
TLR	Total Leak Rate (ILR + ULR) (gpm)
TS	Technical Specifications
ULR	Unidentified Leak Rate (gpm)
UTL	Upper Tolerance Limit
VCT	Volume Control Tank
WEC	Westinghouse Electric Company

1. INTRODUCTION

Plant Technical Specifications (TS) and General Design Criteria (Reference 2) limit RCS leakage and require periodic surveillance to ensure that leakage remains within the allowed limits. Standard TS limits are: 10 gpm Identified Leakage and 1 gpm Unidentified Leakage and zero pressure boundary leakage. If leakage cannot be brought within allowed limits, plant shutdown is required. Surveillance is typically done by a RCS inventory balance. The accuracy of the leak rate calculation is dependent on the stability of plant conditions. RCS temperature, inventory changes, and transient conditions should be avoided during the measurement period. Some operating plants have made improvements in determining RCS leak rates by utilizing features such as on-line monitoring and applying numerical techniques such as linear regression.

NRC Regulatory Issue Summary (RIS) 2003-13, "NRC Review of Responses to Bulletin 2002-01, Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity," indicates that the NRC believes that existing monitoring program used by utilities to ensure reactor coolant pressure boundary integrity may need to be enhanced to ensure early detection and prevention of leakage. Item 5 of RIS 2003-13 states that NUREG/CR-6582, "Assessment of Pressurized Water Reactor Primary Systems Leaks," indicates that inventory balance methods that are used to detect leakage are not sufficiently sensitive to detect small leaks. RIS 2003-13 indicates that there is no uniform industry guidance identifying actions to be taken if measured leak rates increase, and that existing procedures are weak, with actions taken on a case-by-case basis.

The "Action Plan for Addressing Davis-Besse Lessons Learned Task Force Recommendations Regarding Assessment of Barrier Integrity Requirements," includes the following item: Develop recommendations for inspection guidance pertaining to RCS unidentified leakage that includes actions levels to trigger increasing levels of NRC interaction with licensees in response to increasing levels of unidentified RCS leakage.

In June 2004, the PWROG conducted an RCS Leak Rate Workshop. The purpose of the workshop was to share information, discuss issues and concerns, and come up with a plan of action for PWROG to address the issues. Following the workshop Westinghouse Electric Company (WEC) was asked to develop any needed Project Authorizations for follow-on work. The follow-on activities fall into three areas: 1) improving RCS Leak Rate monitoring techniques, 2) compliance with TS limits and 3) improving plant response to changes in unidentified RCS leakage. The participants emphasized that any new work should augment, not replace or duplicate other RCS integrity programs already in effect. For example:

- RCS Integrity Program
- Boric Acid Corrosion Control Program
- SG Tube Integrity and Primary-to Secondary Leakage Monitoring Program

2. DEFINITION AND DESCRIPTION OF TERMS

When used in the context of this report, the terms below are defined as described.

Term	Definition				
Exceedence	<p>A valid unidentified leak rate measurement that exceeds the baseline mean.</p> <p><u>Discussion:</u> Typically exceedences are measured with respect to the median rather than the mean. However, for “near normal” distributions, the median and the mean are approximately equal.</p>				
Historical Baseline	<p>The leak rate historical baseline is the mean and standard deviation value based on one operating quarter (such as JUL-SEP). The historical baseline should be recalculated at the end of each quarter for use in the next quarter.</p>				
Kurtosis	<p>The kurtosis is a measure of the relative peakedness of the probability distribution. All normal distributions have a (relative) kurtosis of +3.0. A distribution which is flatter than the normal (i.e., the uniform distribution) has a smaller relative kurtosis and a distribution which is more peaked than the normal has a higher relative kurtosis. The relative kurtosis is always positive.</p> <p>Excel and most textbooks quote the kurtosis value as a “normalized” value (relative to the normal distribution value of +3.0). Therefore the “normalized” kurtosis of a normal distribution in Excel is quoted as +0.0.</p>				
Leak Before Break (LBB)	<p>LBB is an analysis procedure with a limited scope of applicability and requires NRC review and approval. The concept of LBB implies that any crack or defect which develops in a component will grow to a through-wall configuration, and can be detectable by plant monitoring systems before reaching a size that would significantly reduce margins to component rupture.</p> <p>A licensee may credit LBB analysis methods only in conjunction with the establishment of reliable and comprehensive means to detect primary system leaks of the relevant size. (See References 4 and 5)</p>				
Leak Rate Measurement Standard (gpm)	<p>Reactor Coolant System leakage should be reported as gallons per minute (gpm) to the nearest one-hundredth of gpm and normalized to pure water conditions at 70°F and 14.7 psia. Example: 0.10 gpm</p> <p>RCS leak rate calculations should use the following standard NIST/ASME (Reference 3) properties of water for reporting leakage:</p> <table> <tr> <td>Quality:</td><td>subcooled liquid</td></tr> <tr> <td>Temperature:</td><td>70°F</td></tr> </table>	Quality:	subcooled liquid	Temperature:	70°F
Quality:	subcooled liquid				
Temperature:	70°F				

Term	Definition
	Pressure: 14.7 psia Specific Volume: 0.0160510 ft ³ /lbm Density: 62.3013 lbm/ft ³ Gallons/Ft ³ 7.4805 gal/ft ³
LEAKAGE Type: Gross	Gross LEAKAGE is the sum of all leakage from the RCS control volume (<i>see def.</i>) during the leak rate test time interval, ΔTime.
LEAKAGE Type: IDENTIFIED	<ol style="list-style-type: none"> 1. LEAKAGE inside containment (except Reactor Coolant Pump (RCP) seal water injection or leakoff) into closed systems, such as pump seals or valve packing leaks that are captured and conducted to collection systems; sump or collecting tank, 2. LEAKAGE into the containment atmosphere from sources that are both specifically located and known either not to interfere with the operation of Technical Specification Leakage Detection Systems or not to be pressure boundary LEAKAGE, or 3. LEAKAGE through the Steam Generator (SG) to the Secondary.
LEAKAGE Type: PRESSURE BOUNDARY	LEAKAGE (except SG LEAKAGE) through a nonisolable fault in an RCS component body, pipe wall, or vessel wall.
LEAKAGE Type: Steam Generator	LEAKAGE from the RCS into the secondary side of the steam generators. Steam generator LEAKAGE includes LEAKAGE through all steam generators.
LEAKAGE Type: UNIDENTIFIED	All LEAKAGE inside containment (except RCP seal water injection or leakoff) that is not identified LEAKAGE.
LEAKAGE Type: Other Known RCS Leakage	<u>Other Known RCS LEAKAGE</u> is the sum of all leakage that is both known and documented, and <u>not</u> accounted for in RCDT LEAKAGE, PRT LEAKAGE or Steam Generator LEAKAGE. Other Known LEAKAGE may include: <ul style="list-style-type: none"> • Documented Reactor Coolant Pressure Isolation Valve (PIV) Leakage (<i>see def.</i>) • Documented fitting or gasket leaks from the RCPB that are collected and measured
LEAKAGE Type: Non-RCPB (Non-Reactor Coolant Pressure Boundary Leakage)	Non-RCPB LEAKAGE is the sum of leakage that impacts the reactor coolant system gross leakage calculation but occurs outside the RCPB and therefore should not be included in IDENTIFIED LEAKAGE or UNIDENTIFIED LEAKAGE. In order to account for Non-RCPB LEAKAGE it must be known to exist at the time of the leak rate calculation and documented. An example of Non-RCPB LEAKAGE may include: <ul style="list-style-type: none"> • Charging pump packing leakage (known and

Term	Definition
	<p>documented)</p> <ul style="list-style-type: none"> Charging pump relief valve leakage (known and documented)
Leakage Investigation Plan	An approved RCS leakage response strategy including implementing procedures and action levels.
Limit of Detectability	<p>The smallest unidentified leak rate or change in leak rate that can almost always be detected in a given period of time using a given “alarm” function.</p> <p><u>Discussion:</u></p> <p>The term “almost always” means detected at a 95% probability and 95% confidence level (i.e., “95/95”).</p> <p>The term “95/95” means that we are 95% confident that at least 95% of the time a leak of this size will be detected using a given alarm function.</p>
Mean (μ)	<p>In ordinary English, the mean is the “average,” or more correctly called the arithmetic mean.</p> <p><u>Discussion:</u></p> <p>See Section 11.2.2 of WCAP-16423-NP regarding the difference between the population mean and the sample mean.</p>
Median	<p>The median of a set of values is that “midpoint” value which is greater than $\frac{1}{2}$ of the values and less than the remaining $\frac{1}{2}$ of the values. If the number of points is even, the median is usually defined as the average of the two “innermost” values.</p> <p><u>Discussion:</u></p> <p>The median is often a more meaningful descriptor of the data than the mean when the data is “skewed”. For example, in a business with 101 employees where the CEO earns \$1,000,000 per year and the other 100 employees all earn \$25,000 per year; the median income is \$25,000 whereas the average income is \$34,653. Only one employee is above average and no employees are within 38% of the average.</p>
Outlier Screening	<p>There are two types of outlier screening used herein.</p> <p>The preferred method is “extrinsic screening” in which existing known baseline mean and standard deviation values are used to screen a “new data point” by calculating its zscore value (i.e., how many standard deviations from the mean the new data point is). The term extrinsic refers to the fact that the new data point has not been used to calculate the baseline parameters.</p> <p>A second method, “intrinsic screening” refers to outlier screening of a stand alone set of data. In this case, outliers can bias the sample mean and standard deviation so significantly that the standard zscore formula is not useful.</p>
Reactor Coolant Pressure Boundary (RCPB)	The Reactor Coolant Pressure Boundary (RCPB) consists of all those pressure-containing components which are part of the

Term	Definition
	<p>reactor coolant system or which are connected to the reactor coolant system, up to and including:</p> <ul style="list-style-type: none"> (i) The outermost containment isolation valve in system piping which penetrates primary reactor containment. (ii) The second of two valves normally closed during normal reactor operation in system piping which does not penetrate primary reactor containment, (iii) The reactor coolant system safety and relief valves.
Reactor Coolant System (RCS) Control Volume	<p>The RCS Control Volume includes:</p> <ul style="list-style-type: none"> • Reactor Coolant Water Volume (<i>see def.</i>), • Pressurizer, and • Volume Control Tank. <p>Gross leakage is calculated by measuring the change in level, temperature, and pressure conditions in each segment of the RCS Control Volume.</p>
Reactor Coolant Water Volume (RCWV)	<p>The Reactor Coolant Water Volume (RCWV) is that portion of the Reactor Coolant System where the effective bulk temperature is represented by Tave. This includes the reactor coolant liquid mass contained within:</p> <ul style="list-style-type: none"> • Hot leg piping, • Cold leg piping, • Reactor vessel, and • Steam generators.
Skewness	<p>The skewness is a measure of the lack of symmetry in a probability distribution. The normal distribution has a skewness of +0.0. Distributions with excessive left hand tails have negative skewness values and those with excessive right hand tails have positive skewness.</p>
Standard Deviation (σ)	<p>The standard deviation is a measure of the degree of dispersion of the data from the mean value. Stated another way, the standard deviation is simply the "average" or "expected" variation around an average (i.e., square all individual deviations around the average, divide by 'N', then take the square root. You then have the 'root' of the mean squared deviation in a very simple sense the "average" or expected variation around the average).</p> <p><u>Discussion:</u> See Section 11.2.2 of WCAP-16423-NP regarding the difference between the population standard deviation and the sample standard deviation.</p>
Statistical Independence	<p>Item 6 of Section 11.12 and Figures D-30 and D-31 of Appendix D of WCAP-16423-NP describe what is meant by "statistical independence". Roughly speaking, the issue was raised herein because all of the simulations and related work were based on "statistical independence" in that each simulated daily observation was based on an independent sample of a normally distributed random number. So, knowing "today's value" gives</p>

Term	Definition
	<p>no hint regarding “tomorrow’s value”. However, some members were using an “ending value” for one interval as the “starting value” for the next interval and, as a consequence, successive observations were not independent. That is, an “ending” RCS inventory value which is too high due to random errors reduces the leak rate estimate for the current sample and is expected to result in an increased leak rate estimate for the next time interval when the high “ending” inventory is used as a “starting” inventory.</p> <p>The standard 2 hour mid-shift snapshot values are statistically independent since they are recorded at disjoint two hour intervals on different days.</p>
Statistically Valid Result	<p>The term “statistically valid” refers to the results of the F and two-sample t-test for consecutive Quarters of operating ULR data. That is, the current quarter’s data and the previous quarter’s data should be screened with the (Excel) F-test to demonstrate that the standard deviations for the two quarters are not significantly different and then the t-test to demonstrate that the means for the two quarters are not significantly different.</p> <p>Failing either the F test or the t-test requires some investigation since either case implies that the process has changed.</p>
Statistically Significant Result	<p>The term “statistically significant” means some observation or set of observations is “abnormal” enough that you should be aware of it and do something.</p>
T average (Tave)	<p>RCS Tave is defined as $(T_{hot} + T_{cold})/2$.</p>
Zscore	<p>The “zscore” is a shorthand way of describing how many standard deviations a given data point is from the mean. The “zscore” is calculated by subtracting the mean from the data point and dividing the result by the standard deviation. Therefore a data point which is 3 standard deviations above the mean will have a zscore of +3.</p> <p><u>Discussion:</u></p> <p>Outliers can have a significant effect on the mean and standard deviation of a data set. As a result, there are alternative definitions of “zscore” which are less sensitive to outliers than the mean and standard deviation.</p>

3. STANDARD PLANT DESIGN DEFINITION

The Standard Plant is assumed to be a typical Pressurized Water Reactor (PWR) of Westinghouse or Combustion Engineering design consisting of the following major components and instrumentation.

3.1 Reactor Coolant Water Volume (RCWV)

The RCWV is the portion of the RCS where the effective bulk temperature of the liquid mass is represented by Tave. (*see def.*)

Instrumentation

Thot:	°F
Tcold:	°F
Tave:	°F = (Thot+Tcold)/2
Pressure:	same as PZR pressure, convert to psia
Volume:	ft ³ (plant specific)

3.2 Pressurizer (PZR)

The PZR is in constant fluid communication with the RCS and maintains RCS pressure. The PZR contains a vapor space and liquid space at saturated conditions.

Instrumentation

Level:	convert to ft ³
Temperature	°F
Pressure:	convert to psia

3.3 Volume Control Tank (VCT)

The VCT is part of the Chemical and Volume Control System. The VCT receives continuous letdown and provides suction inventory for the charging pumps. The VCT also collects reactor coolant pump controlled leak off. The VCT is included as part of the Reactor Coolant System (RCS) control volume. (*see def.*)

Instrumentation

Level:	convert to ft ³
Temperature	°F
Pressure:	convert to psia

3.4 Pressurizer Relief Tank (PRT)

The PRT is a closed tank connected to the outlet of pressurizer relief valves. The purpose of the PRT is to capture the discharge and/or leakage from the pressurizer relief valves. Combustion Engineering plants call this tank the Quench Tank.

Instrumentation

Level:	convert to ft ³
--------	----------------------------

Temperature °F
Pressure: convert to psia

3.5 Reactor Coolant Drain Tank (RCDT)

The RCDT collects “piped” leakage from specific sources within the reactor coolant system. All leakage into the RCDT is piped to ensure that only known sources contribute to RCDT inventory. Typical leakage sources to the RCDT are reactor coolant pump vapor seal leakage and selected valve stem packing. Combustion Engineering plants call this tank the Reactor Drain Tank.

Instrumentation

Level: convert to ft³
Temperature °F
Pressure: convert to psia

4. STANDARD METHODOLOGY OVERVIEW

Gross LEAKAGE is calculated by taking two sets of water inventory data separated by a time interval and calculating the inventory mass change over the specified time interval (ΔTime). The initial and final data set includes the relevant level, temperature and pressure measurements for the affected components in order to calculate the inventory mass change. (See definition of Gross LEAKAGE.)

Collected or identified leakage comes from components such as reactor coolant pump seals, valve stem packing, Steam Generator LEAKAGE, and other types of leakage that is both known and documented. (See definition of IDENTIFIED LEAKAGE.) Uncollected or unidentified leakage is, by definition, from an unknown source. (See definition of UNIDENTIFIED LEAKAGE.)

UNIDENTIFIED LEAKAGE is calculated by subtracting IDENTIFIED LEAKAGE and Non-RCPB LEAKAGE from Gross LEAKAGE.

Detailed methods for calculating each type of leakage are described below. Methods for calculating Steam Generator LEAKAGE are beyond the scope of this report. Therefore, this report assumes that a valid plant specific method is used to calculate Steam Generator LEAKAGE and/or other types of known leakage.

4.1 General Equation and LEAKAGE Relationship

4.2 Normalized Leak Rate

All leakage is first calculated in terms of mass change, and then converted to volumetric leak rate in gallons per minute in accordance with the applicable Technical Specification Limiting Condition for Operation (LCO). In order to standardize the leak rate measurement, the volumetric leak rate should be expressed in gallons per minute (gpm) at 70°F and atmospheric pressure (14.7psia).

To convert from pounds mass per minute (lbm/min) to gallons per minute (gpm), apply the following relationship:

$$\text{GPM} = (\text{lbm/min}) \times (V_{f_{70^\circ\text{F}}} \text{ ft}^3/\text{lbm}) \times (7.4805 \text{ gal/ft}^3)$$

Where:

$V_{f_{70^\circ\text{F}}} \text{ ft}^3/\text{lbm} = 0.0160510 \text{ ft}^3/\text{lbm}$, specific volume at 70°F, 14.7 psia

7.4805 gal/ft^3 = standard conversion from gallons to cubic feet

5. PRECAUTIONS AND LIMITATIONS

Plant stability is the principal factor affecting leak rate accuracy. Any measured parameters that are not in a steady-state condition will adversely affect the accuracy of leak rate results and therefore should be minimized. Consider the following items when performing the RCS leak rate test:

Pressurizer

1. Maintain pressurizer level control system in operation throughout the leak rate test.
2. Maintain pressurizer level constant. Target: +/- 0.5% of level span.
3. Minimize changes in PZR spray during RCS leak rate calculation. Pressurizer spray may affect PZR thermal equilibrium and therefore affect the calculated PZR mass.

Reactor Coolant System

1. The plant has been in steady-state conditions for at least 12 hours.
2. Maintain reactor power constant. (In this context "reactor power" refers to delta-T power. The intent is to keep the temperature profile across the core constant to prevent change in RCS mass due to change in reactor coolant density.)
Target: +/- 0.1% of rated thermal power
3. Maintain Tave constant.
Target: +/- 0.5°F
4. RCP Seals – Maintain Reactor coolant pump seal leakoff (controlled bleed-off) and vapor seal leak-off aligned to the same destination or constant during the leak rate calculation.

RCS Makeup

1. Maintain VCT divert valve positioned to return letdown to the VCT.
2. RCS makeup (boration or dilution) to the VCT may be performed as long as an accurate measurement of the water volume added is known. Makeup additions should be targeted to the middle portion of the leak rate time interval to allow time for the VCT to reach equilibrium conditions before the end point data set is taken. Also, makeup should not be in progress at the start or end of the leak rate test. Note: VCT makeup should be rounded to the nearest 1/100th of a gallon, example: 100.45 gallons.
3. If charging pump seals are known to leak whether the pump is running or not, make the appropriate adjustment to Non-RCPB LEAKAGE.

Measurement Time Interval

1. A longer leak rate time interval (Δ Time) will provide a more representative leak rate result.

Chemical Sampling

1. Notify chemistry and stop all sampling of RCS Control Volume (RCS, PZR, VCT, PRT, RCDT, etc.).

Identified Leakage

1. Do not pump identified leakage collection tanks (PRT, RCDT) during the leak rate test.

Containment Conditions

1. Maintain containment pressure and temperature stable. Change in containment pressure or temperature may affect leak rate or upset identified leakage collection tank equilibrium.

6. ASSUMPTIONS

1. **Thermal Equilibrium:** The fundamental underlying assumption in the leak rate calculation (via mass balance) is that all control volumes are in thermal equilibrium. That is, the indicated temperature and pressure applies to the entire control volume (PZR, RCS and VCT). Therefore, it is essential to maintain plant stability throughout the duration of the leak rate test. Transients, including large boration and/or dilutions, will introduce non-equilibrium conditions and compromise the accuracy of the leak rate test.
2. **RCS Tave:** For purposes of the standard RCS leak rate methodology, Tave is assumed to be the effective reactor coolant bulk temperature for determining mass change due to expansion/contraction in the Reactor Coolant Water Volume (*see def.*). This also assumes that reactor coolant hot legs and cold legs contain approximately equal mass.
3. **Mathematical Sign Convention:** In order to be consistent with the sign convention in the Technical Specifications, a positive (+) leakage is defined as a net mass loss from the RCS control volume. Therefore:

$$+ \text{LEAKAGE} = - \Delta \text{Mass}$$

Where:

$$\Delta \text{Mass} = (\text{Mass}_{\text{final}} - \text{Mass}_{\text{initial}})$$

$$\text{Mass}_{\text{final}} = \text{Mass at Time 2 (lbm)}$$

$$\text{Mass}_{\text{initial}} = \text{Mass at Time 1 (lbm)}$$

7. CALCULATION METHOD: GROSS LEAKAGE

Gross LEAKAGE is the net mass loss from the Reactor Coolant System Control Volume (*see def.*) during the leak test time interval.

General Equation:

$$\begin{aligned} \text{Gross LEAKAGE (lbm)} = & - \Delta \text{Mass}_{\text{RCWV}} \\ & - \Delta \text{Mass}_{\text{PZR}} \\ & - \Delta \text{Mass}_{\text{VCT}} \\ & + \Delta \text{Mass}_{\text{ADDED-REMOVED}} \end{aligned}$$

Calculate each input value as shown below.

7.1 Calculation Method: Pressurizer (PZR) Δ Mass

The purpose of this calculation is to determine the mass change in the pressurizer over the leak rate time interval.

General Equation:

$$\text{PZR } \Delta \text{ Mass} = M_{\text{PZR2}} - M_{\text{PZR1}}$$

Where:

M_{PZR1} = PZR Mass at Time 1 (lbm)

M_{PZR2} = PZR Mass at Time 2 (lbm)

7.1.1 Calculation Method: Mass of PZR at Time 1

Input Data Set Pressurizer Initial Conditions	Time 1 Data
PZR Level	L_{PZR1}
PZR Temperature (°F)	T_{PZR1} (Note 4)
PZR Pressure (psia)	P_{PZR1}
Liquid Specific Volume (ft ³ /lbm) at T_{PZR1} and P_{PZR1} (ASME steam tables, Ref. 3)	$V_{f\text{PZR1}}$
Vapor Specific Volume (ft ³ /lbm) at T_{PZR1} and P_{PZR1} (ASME steam tables, Ref. 3)	$V_{g\text{PZR1}}$
PZR Total Volume (ft ³)	VolumeTot _{PZR} (Note 1)
PZR Liquid Volume at L_{PZR1} (ft ³)	VolumeLiq _{PZR1} (Note 2)
PZR Vapor Volume at L_{PZR1} (ft ³)	VolumeVap _{PZR1} (Note 3)

Notes Time 1 Input Data

1. $\text{Volume Tot}_{\text{PZR}} = \text{total volume of the pressurizer (ft}^3\text{)}$
2. $\text{VolumeLiq}_{\text{PZR1}} = \text{PZR liquid volume at the measured level (ft}^3\text{)}$
This value is generally taken from a plant specific curve of indicated PZR level VS liquid volume in the pressurizer. (ft³)
3. $\text{VolumeVap}_{\text{PZR1}} = \text{volume of the vapor space at the indicated pressurizer level. Vapor space volume is the difference between the indicated liquid volume and the total PZR volume: thus,}$
 $\text{VolumeVap}_{\text{PZR1}} = \text{Volume Tot}_{\text{PZR}} - \text{VolumeLiq}_{\text{PZR1}} \text{ (ft}^3\text{)}$
4. Plants with separate temperature instruments for the vapor space and the liquid space should use the most representative temperature for each region when calculating PZR Δ Mass (lbm).

Calculate PZR Mass at Time 1

$M_{\text{PZR1}} = \text{Liquid Mass} + \text{Vapor Mass}$

Where:

$\text{Liquid Mass (lbm)} = \text{VolumeLiq}_{\text{PZR1}} \text{ (ft}^3\text{)} / V_{\text{fPZR1}} \text{ (ft}^3\text{/lbm)}$

$\text{Vapor Mass (lbm)} = \text{VolumeVap}_{\text{PZR1}} \text{ (ft}^3\text{)} / V_{\text{gPZR1}} \text{ (ft}^3\text{/lbm)}$

7.1.2 Calculation Method: Mass of PZR at Time 2

Input Data Set Pressurizer Final Conditions	Time 2 Data
PZR Level	L_{PZR2}
PZR Temperature (°F)	T_{PZR2} (Note 4)
PZR Pressure (psia)	P_{PZR2}
Liquid Specific Volume (ft ³ /lbm) at T_{PZR2} and P_{PZR2} (ASME steam tables, Ref. 3)	V_{fPZR2}
Vapor Specific Volume (ft ³ /lbm) at T_{PZR2} and P_{PZR2} (ASME steam tables, Ref. 3)	V_{gPZR2}
PZR Total Volume (ft ³)	$\text{Volume Tot}_{\text{PZR}}$ (Note 1)
PZR Liquid Volume at L_{PZR2} (ft ³)	$\text{VolumeLiq}_{\text{PZR2}}$ (Note 2)
PZR Vapor Volume at L_{PZR2} (ft ³)	$\text{VolumeVap}_{\text{PZR2}}$ (Note 3)

Notes Time 2 Input Data

1. $\text{Volume Tot}_{\text{PZR}} = \text{total volume of the pressurizer (ft}^3\text{)}$
2. $\text{VolumeLiq}_{\text{PZR2}} = \text{PZR liquid volume at the measured level (ft}^3\text{)}$
This value is generally taken from a plant specific curve of indicated PZR level VS liquid volume in the pressurizer. (ft³)
3. $\text{VolumeVap}_{\text{PZR2}} = \text{volume of the vapor space at the indicated pressurizer level. Vapor space volume is the difference between the indicated liquid volume and the total PZR volume: thus,}$
 $\text{VolumeVap}_{\text{PZR2}} = \text{Volume Tot}_{\text{PZR}} - \text{VolumeLiq}_{\text{PZR2}} \text{ (ft}^3\text{)}$

4. Plants with separate temperature instruments for the vapor space and the liquid space should use the most representative temperature for each region when calculating PZR Δ Mass (lbm).

Calculate PZR Mass at Time 2

$$M_{PZR2} = \text{Liquid Mass} + \text{Vapor Mass}$$

Where:

$$\text{Liquid Mass (lbm)} = \text{VolumeLiq}_{PZR2} \text{ (ft}^3\text{)} / V_{f_{PZR2}} \text{ (ft}^3\text{/lbm)}$$

$$\text{Vapor Mass (lbm)} = \text{VolumeVap}_{PZR2} \text{ (ft}^3\text{)} / V_{g_{PZR2}} \text{ (ft}^3\text{/lbm)}$$

7.1.3 Result: PZR Δ Mass

$$PZR \Delta \text{ Mass} = M_{PZR2} - M_{PZR1}$$

Where:

$$M_{PZR1} = \text{PZR Mass at Time 1 (lbm)}$$

$$M_{PZR2} = \text{PZR Mass at Time 2 (lbm)}$$

7.2 Calculation Method: Reactor Coolant Water Volume (RCWV) Δ Mass

The purpose of this calculation is to determine the change in liquid mass inside the Reactor Coolant Water Volume due to a change in reactor coolant temperature. The Reactor Coolant Water Volume includes: hot leg piping, cold leg piping, reactor vessel and steam generator.

General Equation:

$$RCWV \Delta \text{ Mass} = M_{RCWV2} - M_{RCWV1}$$

Where:

$$M_{RCWV1} = \text{RCWV Mass at Time 1 (lbm)}$$

$$M_{RCWV2} = \text{RCWV Mass at Time 2 (lbm)}$$

7.2.1 Calculation Method: Mass of RCWV at Time 1

Input Data Set Reactor Coolant Water Volume Initial Conditions	Time 1 Data
RCWV Tave (°F)	T_{RCWV1}
RCWV Pressure (psia)	P_{RCWV1}
Liquid Specific Volume (ft ³ /lbm) at T_{RCWV1} and P_{RCWV1} (ASME steam tables, Ref. 3)	$V_{f_{RCWV1}}$
RC Volume (ft ³) (excluding Pressurizer and VCT) (Note 1)	VolumeTot_{RCWV1}

Notes Time 1 Input Data

1. RC Volume = calculated volume of the Reactor Coolant Water Volume (ft³) (plant specific constant, *see def.*)

Calculate Reactor Coolant Water Volume Mass at Time 1

$$M_{RCWV1} \text{ (lbm)} = \text{VolumeTot}_{RCWV1} \text{ (ft}^3\text{)} / V_{fRCWV1} \text{ (ft}^3\text{/lbm)}$$

7.2.2 Calculation Method: Mass of RCWV at Time 2

Input Data Set Reactor Coolant Water Volume Final Conditions	Time 2 Data
RCWV Tave (°F)	T_{RCWV2}
RCWV Pressure (psia)	P_{RCWV2}
Liquid Specific Volume (ft ³ /lbm) at T_{RCWV2} and P_{RCWV2} (ASME steam tables, Ref. 3)	V_{fRCWV2}
RC Volume (ft ³) (excluding Pressurizer and VCT) (Note 1)	VolumeTot_{RCWV2}

Notes Time 2 Input Data

1. RC Volume = calculated volume of the Reactor Coolant Water Volume (ft³) (plant specific constant, *see def.*)

Calculate Reactor Coolant Water Volume Mass at Time 2

$$M_{RCWV2} \text{ (lbm)} = \text{VolumeTot}_{RCWV2} \text{ (ft}^3\text{)} / V_{fRCWV2} \text{ (ft}^3\text{/lbm)}$$

7.2.3 Result: RCWV Δ Mass

$$RCWV \Delta \text{ Mass} = M_{RCWV2} - M_{RCWV1}$$

Where:

M_{RCWV1} = RCWV Mass at Time 1 (lbm)

M_{RCWV2} = RCWV Mass at Time 2 (lbm)

7.2.4 Segmented Reactor Coolant Water Volume

Since the entire Reactor Coolant Water Volume (RCWV) is not at the same temperature, an alternate method for calculating RCWV ΔMass involves segmenting the RCWCV into regions with the same temperature then calculate the mass change within each region based on the local temperature change. If this method is used, the sum of the mass change within all segments is the total mass change within the RCWV.

Simplified Example of Segmented RCWV

The RCWV may be divided into two regions, Thot and Tcold. Where each region is defined as follows:

$$\begin{aligned} \text{Thot Region (ft}^3\text{)} = & \text{Volume of hot legs ft}^3 + \\ & \text{Volume of (reactor vessel ft}^3\text{)/2} + \\ & \text{Volume of steam generator primary ft}^3/2 \end{aligned}$$

$$\begin{aligned} \text{Tcold Region (ft}^3\text{)} = & \text{Volume of cold legs ft}^3 + \\ & \text{Volume of (reactor vessel ft}^3\text{)/2} + \\ & \text{Volume of steam generator primary ft}^3/2 \end{aligned}$$

The mass change within each region is calculated separately using the standard method to determine ΔMass . The total mass change of the RCWV is calculated, thus:

$$\text{RCWV } \Delta\text{Mass}_{\text{RCWV}} = \Delta\text{Mass}_{\text{Thot}} + \Delta\text{Mass}_{\text{Tcold}}$$

7.3 Calculation Method: Volume Control Tank (VCT) Δ Mass

The purpose of this calculation is to determine the mass change in the VCT over the leak rate time interval.

General Equation:

$$\text{VCT } \Delta \text{ Mass} = M_{\text{VCT2}} - M_{\text{VCT1}}$$

Where:

M_{VCT1} = VCT Mass at Time 1 (lbm)

M_{VCT2} = VCT Mass at Time 2 (lbm)

7.3.1 Calculation Method: Mass of VCT at Time 1

Input Data Set VCT Initial Conditions	Time 1 Data
VCT Level	L_{VCT1}
VCT Temperature (°F)	T_{VCT1}
VCT Pressure (psia)	P_{VCT1}
VCT Specific Volume (ft ³ /lbm) at T_{VCT1} and P_{VCT1} (ASME steam tables, Ref. 3)	Vf_{VCT1}
VCT Liquid Volume at L_{VCT1} (ft ³)	VolumeLiq $_{\text{VCT1}}$ (Note 1)

Notes Time 1 Input Data

1. VolumeLiq $_{\text{VCT1}}$ = VCT liquid volume at the measured level (ft³)
This value is generally taken from a plant specific curve of indicated VCT level versus liquid volume.
(ft³)

Calculate VCT Mass at Time 1

$$M_{\text{VCT1}} \text{ (lbm)} = \text{VolumeLiq}_{\text{VCT1}} \text{ (ft}^3\text{)} / Vf_{\text{VCT1}} \text{ (ft}^3\text{/lbm)}$$

7.3.2 Calculation Method: Mass of VCT at Time 2

Input Data Set VCT Final Conditions	Time 2 Data
VCT Level	L_{VCT2}
VCT Temperature (°F)	T_{VCT2}
VCT Pressure (psia)	P_{VCT2}
VCT Specific Volume (ft ³ /lbm) at T_{VCT2} and P_{VCT2} (ASME steam tables, Ref. 3)	V_{fVCT2}
VCT Liquid Volume at L_{VCT2} (ft ³)	VolumeLiq _{VCT2} (Note 1)

Notes Time 2 Input Data

1. VolumeLiq_{VCT2} = plant specific VCT liquid volume at the measured level (ft³)
This value is generally taken from a plant specific curve of indicated VCT level VS liquid volume. (ft³)

Calculate VCT Mass at Time 2

$$M_{VCT2} \text{ (lbm)} = \text{VolumeLiq}_{VCT2} \text{ (ft}^3\text{)} / V_{fVCT2} \text{ (ft}^3\text{/lbm)}$$

7.3.3 Result: VCT Δ Mass

$$VCT \Delta \text{ Mass} = M_{VCT2} - M_{VCT1}$$

Where:

M_{VCT1} = VCT Mass at Time 1 (lbm)

M_{VCT2} = VCT Mass at Time 2 (lbm)

7.4 Calculation Method: Mass Added-Removed Change

Gross LEAKAGE must be adjusted to account for controlled mass changes due to boration, dilution, VCT divert valve actuation, sampling and any other type of controlled addition and/or loss of reactor coolant.

Calculate the total $\Delta \text{Mass}_{\text{ADDED-REMOVED}}$ expressed in lbm.

Sign Convention:

- Positive mass change means mass added to RCS
- Negative mass change means mass loss from the RCS

$$\begin{aligned} \Delta \text{Mass}_{\text{ADDED-REMOVED}} \text{ (lbm)} = & + \text{Dilution}_{\text{ADDED}} \text{ (lbm)} \\ & + \text{Boration}_{\text{ADDED}} \text{ (lbm)} \\ & - \text{VCT Divert}_{\text{REMOVED}} \text{ (lbm)} \\ & - \text{Sampler}_{\text{REMOVED}} \text{ (lbm)} \end{aligned}$$

7.5 Result: Gross LEAKAGE

Gross LEAKAGE is the net mass loss from the Reactor Coolant System Control Volume (*see def.*) during the leak test time interval.

General Equation:

$$\begin{aligned}\text{Gross LEAKAGE (lbm)} = & - \Delta \text{Mass}_{\text{RCWV}} \\ & - \Delta \text{Mass}_{\text{PZR}} \\ & - \Delta \text{Mass}_{\text{VCT}} \\ & + \Delta \text{Mass}_{\text{ADDED-REMOVED}}\end{aligned}$$

8. CALCULATION METHOD: IDENTIFIED LEAKAGE

IDENTIFIED LEAKAGE (*see def.*) is the sum of leakage collected during the leak test time interval, plus the sum of other known and documented (quantified) leakage. Note: IDENTIFIED LEAKAGE does not include Non-RCPB LEAKAGE. Examples of IDENTIFIED LEAKAGE are:

- LEAKAGE, from pump seals or valve packing (except Reactor Coolant Pump (RCP) seal water injection or leakoff), that is captured and conducted to collection systems or a sump or collecting tank, (see method Sections 8.1 and 8.2)
- Reactor Coolant LEAKAGE through all steam generators, (see method Section 8.3)
- LEAKAGE into the containment atmosphere from sources that are both specifically located and known either not to interfere with the operation of leakage detection systems or not to be pressure boundary LEAKAGE. (see method Section 8.4)

General Method To Calculate Total IDENTIFIED LEAKAGE

$$\begin{aligned} \text{Total IDENTIFIED Leakage (lbm)} = & + \Delta \text{Mass}_{\text{RCDT}} \\ & + \Delta \text{Mass}_{\text{SPRT}} \\ & + \Delta \text{Mass}_{\text{SG}} \\ & + \Delta \text{Mass}_{\text{OTHER KNOWN}} \end{aligned}$$

Calculate each input value as shown below.

8.1 Calculation Method: Reactor Coolant Drain Tank (RCDT) Δ Mass

General Equation:

$$\Delta \text{Mass}_{\text{RCDT}} = M_{\text{RCDT2}} - M_{\text{RCDT1}}$$

Where:

M_{RCDT1} = RCDT Mass at Time 1 (lbm)

M_{RCDT2} = RCDT Mass at Time 2 (lbm)

8.1.1 Calculation Method: Mass of RCDT at Time 1

Input Data Set RCDT Initial Conditions	Time 1 Data
RCDT Level	L_{RCDT1}
RCDT Temperature (°F)	T_{RCDT1}
RCDT Pressure (psia)	P_{RCDT1}
RCDT Specific Volume (ft ³ /lbm) at T_{RCDT1} and P_{RCDT1} (ASME steam tables, Ref. 3)	$V_{f_{\text{RCDT1}}}$
RCDT Liquid Volume at L_{RCDT1} (ft ³)	VolumeLiq _{RCDT1} (Note 1)

Notes Time 1 Input Data

1. $\text{VolumeLiq}_{\text{RCDT1}}$ = RCDT liquid volume at the measured level (ft^3)
This value is generally taken from a plant specific curve of indicated RCDT level VS liquid volume. (ft^3)

Calculate RCDT Mass at Time 1:

$$M_{\text{RCDT1}} (\text{lbm}) = \text{VolumeLiq}_{\text{RCDT1}} (\text{ft}^3) / V_{\text{fRCDT1}} (\text{ft}^3/\text{lbm})$$

8.1.2 Calculation Method: Mass of RCDT at Time 2

Input Data Set RCDT Final Conditions	Time 2 Data
RCDT Level	L_{RCDT2}
RCDT Temperature ($^{\circ}\text{F}$)	T_{RCDT2}
RCDT Pressure (psia)	P_{RCDT2}
RCDT Specific Volume (ft^3/lbm) at T_{RCDT2} and P_{RCDT2} (ASME steam tables, Ref. 3)	V_{fRCDT2}
RCDT Liquid Volume at L_{RCDT2} (ft^3)	$\text{VolumeLiq}_{\text{RCDT2}}$ (Note 1)

Notes Time 2 Input Data

1. $\text{VolumeLiq}_{\text{RCDT2}}$ = RCDT liquid volume at the measured level (ft^3)
This value is generally taken from a plant specific curve of indicated RCDT level VS liquid volume. (ft^3)

Calculate RCDT Mass at Time 2:

$$M_{\text{RCDT2}} (\text{lbm}) = \text{VolumeLiq}_{\text{RCDT2}} (\text{ft}^3) / V_{\text{fRCDT2}} (\text{ft}^3/\text{lbm})$$

8.1.3 Result: RCDT Δ Mass

$$\text{RCDT } \Delta \text{ Mass} = M_{\text{RCDT2}} - M_{\text{RCDT1}}$$

Where:

M_{RCDT1} = RCDT Mass at Time 1 (lbm)

M_{RCDT2} = RCDT Mass at Time 2 (lbm)

8.2 Calculation Method: Pressurizer Relief Tank (PRT) Δ MassGeneral Equation:

$$\Delta \text{ Mass} = M_{\text{PRT2}} - M_{\text{PRT1}}$$

Where:

M_{PRT1} = PRT Mass at Time 1 (lbm)

M_{PRT2} = PRT Mass at Time 2 (lbm)

8.2.1 Calculation Method: Mass of PRT at Time 1

Input Data Set PRT Initial Conditions	Time 1 Data
PRT Level	L_{PRT1}
PRT Temperature (°F)	T_{PRT1}
PRT Pressure (psia)	P_{PRT1}
PRT Specific Volume (ft ³ /lbm) at T_{PRT1} and P_{PRT1} (ASME steam tables, Ref.3)	$V_{f_{PRT1}}$
PRT Liquid Volume at L_{PRT1} (ft ³)	VolumeLiq _{PRT1} (Note 1)

Notes Time 1 Input Data

1. VolumeLiq_{PRT1} = PRT liquid volume at the measured level (ft³)
This value is generally taken from a plant specific curve of indicated PRT level (expressed in percent or inches of water) VS liquid volume. (ft³)

Calculate PRT Mass at Time 1:

$$M_{PRT1} \text{ (lbm)} = \text{VolumeLiq}_{PRT1} \text{ (ft}^3\text{)} / V_{f_{PRT1}} \text{ (ft}^3\text{/lbm)}$$

8.2.2 Calculation Method: Mass of PRT at Time 2

Input Data Set PRT Final Conditions	Time 2 Data
PRT Level	L_{PRT2}
PRT Temperature (°F)	T_{PRT2}
PRT Pressure (psia)	P_{PRT2}
PRT Specific Volume (ft ³ /lbm) at T_{PRT2} and P_{PRT2} (ASME steam tables, Ref. 3)	$V_{f_{PRT2}}$
PRT Liquid Volume at L_{PRT2} (ft ³)	VolumeLiq _{PRT2} (Note 1)

Notes Time 2 Input Data

1. VolumeLiq_{PRT2} = plant specific PRT liquid volume at the measured level (ft³)
This value is generally taken from a plant specific curve of indicated PRT level (expressed in percent or inches of water) VS liquid volume. (ft³)

Calculate PRT Mass at Time 2:

$$M_{PRT2} \text{ (lbm)} = \text{VolumeLiq}_{PRT2} \text{ (ft}^3\text{)} / V_{f_{PRT2}} \text{ (ft}^3\text{/lbm)}$$

8.2.3 Result: PRT Δ Mass

$$\text{PRT } \Delta \text{ Mass} = M_{PRT2} - M_{PRT1}$$

Where:

M_{PRT1} = PRT Mass at Time 1 (lbm)

M_{PRT2} = PRT Mass at Time 2 (lbm)

8.3 Steam Generator LEAKAGE

Steam Generator LEAKAGE is the total leakage from all steam generators over the leak rate time interval (ΔTime). The documented Steam Generator leak rate is often expressed in gallons per day (gpd) as determined by plant specific methods. (See SG Note 1.) Therefore, in order to account for Steam Generator LEAKAGE within the IDENTIFIED LEAKAGE ΔMass , we must convert gallons per day to total SG mass loss during the leak rate time interval:

Convert SG Leak Rate (SG_{LR}) gallons per day to gallons per minute:

SG_{LR} (gallons/min) = SG_{LR} (gal/day) / 1440 (min/day)

SG_{LR} (gallons/min) = _____ gpm

Convert SG Leak Rate (SG_{LR}) gallons per minute to lbm per minute:

SG_{LR} (lbm/min) = [SG_{LR} (gal/minute) / (7.4805 gal/ft³)] / $Vf_{70°F}$ (ft³/lbm)

SG_{LR} (lbm/min) = _____ lbm/min

Find total SG ΔMass over the leak rate time interval:

SG_{LR} (lbm/min) x ΔTime (min) = _____ lbm

SG Notes

1. Calculation of primary-to-secondary leak rate is typically quantified using chemistry/isotopic methods, and as such, not within the scope of this report.

8.4 Other Known RCS LEAKAGE

Other Known RCS LEAKAGE is the sum of all leakage that is both known and documented, and not accounted for in RCDT LEAKAGE, PRT LEAKAGE or Steam Generator LEAKAGE.

Other Known LEAKAGE may include:

- Documented Reactor Coolant Pressure Isolation Valve (PIV) Leakage (*see def.*)
- Documented fitting or gasket leaks from the RCPB that are collected and measured

8.5 Calculation Method: Total IDENTIFIED LEAKAGE

Calculate the total IDENTIFIED LEAKAGE. Note: IDENTIFIED LEAKAGE does not include Non-Reactor Coolant Pressure Boundary Leakage.

Total IDENTIFIED Leakage (lbm) =

- + ΔMass_{RCDT}
- + ΔMass_{PRT}
- + ΔMass_{SG}
- + $\Delta\text{Mass}_{OTHER KNOWN}$

8.6 Result: IDENTIFIED LEAK RATE

IDENTIFIED Leak Rate (gpm) =

[IDENTIFIED Leakage (lbm) x $Vf_{70°F}$ (ft³/lbm) x 7.4805 (gal/ft³)] / ΔTime (min.)

Where:

IDENTIFIED Leakage (lbm) = calculated total IDENTIFIED Leakage

$V_{f_{70^{\circ}\text{F}}} (\text{ft}^3/\text{lbm}) = 0.0160510 \text{ ft}^3/\text{lbm}$ specific volume at 70°F, 14.7 psia

$7.4805 (\text{gal}/\text{ft}^3)$ = standard conversion gallons per cubic feet

$\Delta\text{Time (min.)} = (\text{Time 2} - \text{Time 1}) \text{ minutes}$

9. CALCULATION METHOD: UNIDENTIFIED LEAKAGE

$$\text{UNIDENTIFIED Leakage (lbm)} = \text{Gross LEAKAGE} - \text{IDENTIFIED LEAKAGE} - \text{Non-RCPB LEAKAGE}$$

9.1 Non-RCPB LEAKAGE

Non-RCPB LEAKAGE is the sum of leakage that impacts the reactor coolant system gross leakage calculation but occurs outside the RCPB and therefore should not be included in IDENTIFIED LEAKAGE or UNIDENTIFIED LEAKAGE.

In order to account for Non-RCPB LEAKAGE it must be known to exist at the time of the leak rate calculation and documented. An example of Non-RCPB LEAKAGE may include:

- Charging pump packing leakage (known and documented)
- Charging pump relief valve leakage (known and documented)

9.2 Result: UNIDENTIFIED Leak Rate

$$\text{UNIDENTIFIED Leak Rate (gpm)} = \frac{[\text{UNIDENTIFIED Leakage (lbm)} \times V_{f_{70^{\circ}\text{F}}} (\text{ft}^3/\text{lbm}) \times 7.4805 (\text{gal}/\text{ft}^3)]}{\Delta \text{Time (min.)}}$$

Where:

UNIDENTIFIED Leakage (lbm) = calculated UNIDENTIFIED Leakage

$V_{f_{70^{\circ}\text{F}}} (\text{ft}^3/\text{lbm}) = 0.0160510 \text{ ft}^3/\text{lbm}$ specific volume at 70°F, 14.7 psia

7.4805 (gal/ft³) = standard conversion gallons per cubic feet

$\Delta \text{Time (min.)} = (\text{Time 2} - \text{Time 1}) \text{ minutes}$

10. VALIDITY CHECKS

Validity checks are a set of plant conditions which must be maintained during the RCS leak rate test to ensure a known level of plant stability and thereby provide more consistent and accurate leak rate results. The conditions listed below provide limits for certain plant parameters which affect leak rate accuracy. Limits in [square brackets] are suggested values for the range of operation during a leak rate test. Each plant should determine their own plant specific limits, keeping in mind that plant stability (thermal equilibrium) is a key factor for accurate leak rate results.

1. Tave remains constant [$\pm 0.5^{\circ}\text{F}$] throughout the leak rate time interval.
2. Pressurizer Level remains constant [$\pm 0.5\%$] of level span.
3. Reactor Power remains constant [$\pm 0.1\%$] of rated thermal power.
4. VCT divert valve remains in position to return letdown to the VCT.
5. Makeup to VCT (boration or dilution) is limited to [x gallons] of total VCT volume.
6. RCP controlled bleedoff returns to VCT.
7. No sampling was done on the leak rate control volume.
8. Identified leakage collection tanks have not been pumped (PRT, RCDT).

10.1 Rules for Leak Rate Results and Application of Validity Checks

The following rules apply to scheduled and unscheduled TS Surveillance Tests for calculating RCS leak rate.

Rule 1) Valid Result -- If a leak rate is performed within the bounds of the validity checks, then the leak rate should be considered valid.

- a. Compare result to Acceptance Criteria and report (SAT or UNSAT) completion of TS surveillance requirement in accordance with [TS Surveillance Program administrative procedures]
- b. Include result in the long term statistical data set for calculating the running mean.

Rule 2) Invalid Result -- If a leak rate is performed outside the bounds of the validity checks, then the leak rate should be considered invalid.

- a. Document reason for invalid result (specify validity check not satisfied), and abort or invalidate test in accordance with [TS Surveillance Program administrative procedures].
- b. The result should not be used as input to the baseline statistical data set for the historical mean leak rate.
- c. Leak rate test should be repeated or deferred until the plant is in a more stable condition.

Rule 3) Outliers and Screening for Outliers -- Anytime a leak rate is performed within the bounds of the validity checks with the intent of recording the daily surveillance value (Rule 1), *but* the result is more than 2.5 standard deviations from the running mean, then the leak

rate result is suspect (i.e., probably is an outlier if the result is 2.5 standard deviations or more below the mean and may either be an outlier or an indication of an increase in the leak rate if the value is 2.5 standard deviations or more above the mean). In addition, an indication that is 3.0 standard deviations or more above the mean implies a potential Action Level III event and an indication that is only 2.0 standard deviations or so above the mean implies a potential Action Level II event if one more such reading is observed.

The question is: **“What should be done when such readings occur?”**

(The data in Appendix G suggests that about 4% of all “good” readings may result in such extreme zscore values (where a zscore value of +2.5 implies a reading 2 ½ standard deviations above the mean as discussed in Section G-3 and, also in Equation 11.3).

If the suspect reading is below the mean (i.e., has a negative zscore), there is no reason to suspect that the leak rate has increased. In this case, the data point can be recorded as the daily value with a notation or flag that the quality is “indeterminate”. Some investigation of the inputs should be performed to assign a probable cause and, if there is a clear reason the value is invalid, the quality of the point can be changed to “bad”. At the end of the quarter when the baseline mean is reevaluated, no “bad” or “indeterminate” points should be used. A re-measurement during the current calendar day is appropriate but not absolutely required unless the 72 hour Tech Spec or internal reporting requirement is challenged.

If the suspect reading is above the mean (i.e., has a positive zscore), there is a potential problem since the value may be either spurious or real.

If you take the equivalent of a two hour snapshot reading once per day during the mid-shift (say 1:00 AM – 3:00 AM as in the Standard Plant Activity) with the intent of using it for the daily surveillance value in the NRC Guidelines, there is a very simple process which may avoid entering any Action Level. This process is:

“By plant procedure, agree that any mid-shift reading with a zscore of +2.00 or more will be investigated by examination of the inputs and/or other reasonable means and always followed by a repeat measurement later that calendar day. If the mid-shift measurement is judged to be flawed, the later measurement will be used for the daily surveillance value. If the mid-shift measurement is “indeterminate” or “good”, the two values will be averaged and the average value will be recorded as the daily (average) surveillance value for that day. As above, at the end of the quarter when the baseline mean is reevaluated, no “indeterminate” points should be used.”

Hopefully, averaging of the two values to create the single daily average value will either clear any potential Action Level II or III events or confirm that something real is happening that needs to be investigated. Note: a critical feature of the above process is to get a daily observation during the mid-shift so that you have some clock time to investigate and re-measure before the day ends. Note: also, there is typically ample time to resolve indeterminate points before they are potentially used at the end

of a calendar quarter. Finally, a quarter has a lot of points so the final call on a few “indeterminate” values will probably not influence the resulting baseline values in a significant way.

We recognize that the above process may not work smoothly for all Members due to local variations in the way measurements are performed and recorded. In addition, any such process is only needed if the frequency of positive outliers is fairly high. Each Utility should adjust as needed to avoid entering Action Levels due to spurious measurements.

11. STATISTICAL ANALYSIS OF THE UNIDENTIFIED LEAK RATE

The principal objective of this Section is to develop and use statistical methods, including a “Monte Carlo” stochastic simulation, to quantitatively determine the “minimum level of detectability.” The results are described in Section 11.4. Roughly speaking, the “minimum level of detectability” describes the smallest unidentified leak rate or change in leak rate that can be detected in a given period of time using a given “alarm” function such as Action Level I defined in p. D-6 of draft Appendix D (NRC Inspector Guidance). (This page is excerpted from the draft NRC Appendix D on p. A-2 of Appendix A.)

When Section 11 of this Report was prepared in mid-2005, NRC Appendix D was available in the draft form shown on p. A-2 of Appendix A. Since this draft was presented without any accompanying basis, Section 11.2 of this document provided our best explanation of the critical features of the method. In addition, the statistical analyses in Sections 11.3 through 11.11 and the Recommendations in Section 11.12 were designed to keep the Utility’s procedures in step with the (draft) NRC Inspector Guidelines. In December of 2005, the final NRC Appendix D Guidelines were issued. A copy of Attachment 1 of the final NRC Appendix D Guidelines is presented in Appendix F herein along with a brief critique of several significant changes. We have made no attempt to revise our analyses to conform to the final Guidelines since we believe our approach is prudent, statistically valid, and, in total, more limiting than the final NRC Guidelines. As stated in Appendix F, we do not agree with certain elements of the revised process. Given these differences, the PWROG Members should recognize that it is possible that the NRC Site Inspector will enter into Action Levels at different points in time than the Utility.

The question: “What am I supposed to do when an “alarm” goes off?” is addressed by the follow-on Action Levels and Response Guidelines Owners Group task (PA-OSC-0218), as documented in WCAP-16465-NP, Standard RCS Leakage Action Levels and Response Guidelines for Pressurized Water Reactors,” Reference 25.

The Minutes of the May 12th, 2005 Conference Call describe three types of Action Levels. That is, there will be Action Levels in Reference 25 based on:

1. “Change” in leakage as measured by deviation from a “baseline mean”
2. Absolute Leakage (in gpm).
3. Cumulative or Integrated Leakage over a period of time (in gallons).

Section 11 addresses Item 1 above since it is the focus of the NRC Inspector Guidelines. Items 2 and 3 were included in the design of the “RCS_LEAK_SIM” code as described in Section 11.3.2.1 and, also, Appendix E. However, all details regarding Items 2 and 3 are addressed in Section 5 of Reference 25. Note: the NRC Guidelines place no direct numerical limits on either the “baseline mean” (μ) or the “baseline standard deviation” (σ). Suggested limits on both of the baseline parameters are provided in Section 5 of Reference 25.

The development of the numerical and statistical techniques described in this Section is primarily based on the use of stochastic simulation models. A summary of Recommendations is in Section 11.12. In essence, the recommended Standard Process is to report exactly one high quality (i.e., well within the limits of validity) measurement over a period of approximately two hours each day. (This was the process used in the Standard Plant Testing reported in Appendix G.) If the fluctuations in these daily values are acceptable and if the probability of observing “outliers” or otherwise erroneous results is historically small, nothing more is required. However, Section 11.12 lists a number of simple data checks that can be performed to track and provide “early warning” of any changes in the unidentified leak rate.

We recognize that individual PWROG members may not adopt every recommendation in the Standard Guidelines. As a result, there may be variations in how the utilities arrive at a “daily average” RCS Leak Rate. The “exactly one high quality measurement over a period of approximately two hours each day” approach may be replaced by some other acceptable approach. However, it is important that all PWROG members report a “daily average” value which is determined in a consistent fashion day after day. If the “daily average” values are not consistent, the Action Levels in the NRC Guidelines are likely to be challenged even when no change in leakage has occurred.

To make this Section more readable, most of the complicated details have been put in Appendices as follows:

- Pertinent excerpts from (draft) NRC documents, excerpts from documentation supplied by the PWROG members, or from internal Westinghouse documents are contained in Appendix A. (Attachment 1 of the final NRC Guidelines is documented and critiqued in Appendix F.)
- Derivations of selected statistical relationships are listed in Appendix B. (Appendix B contains a list of all derivations. The handwritten derivations are available in Reference 24.) A derivation of the effects of measurement errors on the unidentified leak rate is in Appendix C. (The conclusions reached in Appendix C are summarized in Section C-4 of Appendix C.)
- Appendix D contains all Figures and Plots and related data described herein except for Tables 11-1 through 11-6 in Section 11.3.
- Appendix E contains a brief functional description of the computer codes used in the stochastic simulation studies described herein.
- Appendix F contains Attachment 1 of the final NRC Inspection Guidelines and a critique of changes with respect to the draft version in Appendix A.
- Appendix G contains a summary of the results of the Standard Plant measurements for the five Standard Plant participants (i.e., Seabrook, Comanche Peak Units 1 and 2, Ginna and Fort Calhoun).

- Appendix H contains a list of all comments from PWROG members on this document and all Westinghouse responses.
- Appendix I contains a list of comments from a Westinghouse Peer Reviewer and responses
- A number of statistical terms used herein are defined in Section 2.1.

Overall, there is a broad spectrum of methods used in the RCS unidentified leak rate calculation by the participating Utilities. Many of these methods address what we define as “continuous monitoring” (i.e., the use of computerized algorithms which provide frequent continuous estimates during plant operation, which either violates or challenges the limits of validity for the leak rate calculation). The analysis in this Section does not address such “continuous monitoring” situations. Rather, it is focused on the “snap shot” method which is typically used to comply with Technical Specification surveillance requirements.

The work in this project provides a foundation for follow-on activities (i.e., PA-OSC-0218) defining action levels and response guidelines. Therefore, particular emphasis has been given to the (draft) Resident site inspector’s activities and Action Levels (I-III) as described on p. D-6 of Appendix D (NRC Inspector Guidance, see also Appendix F for a critique of the final Guidelines). Since (draft) Appendix D states that “*the most conservative leak rate value for a given day should be used in the assessment,*” the expected daily “target” surveillance measurement should be exactly one measurement for a $[2 \pm 1]$ hour period each day at a time when potential disruptions due to plant maintenance, grid/dispatcher requirements, and diurnal changes are minimized. Typically, the most probable time for this measurement is during the “mid-shift” (i.e., during the period from 1 – 4 AM). It is expected that this measurement will not challenge the limits of validity as stated in Section 10 and will minimize the occurrence of “outliers” and spikes. The daily “target” surveillance measurement can also include the collection of the required input data at intermediate time points. These values can be used to stabilize the resulting measurement by using linear regression methods or, as an alternative, provide “backup” data during the time interval in the unlikely event that the measurement based only on the start & end times show an unexpectedly large value (as described in Section 10.1).

In September 2005, this (draft) material was made available to the NRC for an informal review by the NRC personnel associated with the (draft) NRC Appendix D Guidelines for the purpose of carrying out a “peer” review of the presentation. Unfortunately, as of this date, that informal review has not been carried out. Consequently, this material was provided to Dr. Robert Perdue, who is the resident statistical expert at the Westinghouse Science & Technology Department for his (informal) review. His comments (and our list of responses and associated modifications to this document) are provided in Appendix I herein.

11.1 Unidentified Leakage – The “Slack Variable” in the RCS Leak Rate Calculation

Reference 6 (p. 266) defines a “slack variable” as a term which is added to an equation in order to convert an inequality into an equality (which is then easier to analyze). Of course, conservation of true mass ultimately requires that the RCS leakage balance sheet shows a net

loss of zero if true values are used everywhere. However, every time a measured quantity (temperature, pressure, level) or approximate calculated quantity (RCS volume, pressurizer diameter, etc.) is used to estimate the terms in Section 7, a small error is introduced relative to truth. A detailed uncertainty analysis of each component of the mass balance equation would associate these individual errors with each individual measurement. However, in the absence of such a detailed evaluation, all these small errors accumulate in one variable – the unidentified leak rate. As a consequence, the unidentified leak rate should be viewed as the sum of two parts:

1. The actual leak rate component which is either a (small) constant value, or increases slowly over long periods of time with some probability of infrequent sudden step increases and
2. The “slack variable” component which fluctuates significantly in time in order to conserve measured mass and, in one place, accounts for the accumulated fluctuations in all the actual measured quantities.

For an example of this fluctuation, see Appendix D, Figure D-3. This figure shows the increasing unidentified mass leakage (in gallons) over a 10 hour period at 15 minute intervals for typical operating data. (Figures D-1 & D-2 show the same 10 hour trend for the RCS inventory and identified leakage. These trends show less scatter. Figure D-2 is particularly well behaved. These data sets were also used for illustration purposes in a number of other applications such as linear regression studies, cross-validation spline smoothing, and odd-even independence. **All illustrations which use this data in Appendix D are labeled “Typical Plant Data.”**)

11.2 Comments on the (draft) NRC Guidelines

When Section 11 of this Report was prepared in mid-2005, NRC Appendix D was available in the draft form shown on p. A-2 of Appendix A. Since this draft was presented without any accompanying basis, this section provided our best explanation of the critical features of the method. In addition, the statistical analyses in Sections 11.3 through 11.11 and the Recommendations in Section 11.12 were designed to keep the Utility’s procedures in step with the (draft) NRC Inspector Guidelines. In December of 2005, the final NRC Appendix D Guidelines were issued. A copy of Attachment 1 of the final Appendix D Guidelines is presented in Appendix F herein along with a brief critique of several significant changes. We have made no attempt to revise our analyses to conform to the final Guidelines since we believe our approach is prudent, statistically valid, and, in total, more limiting than the final NRC Guidelines. As stated in Appendix F, we do not agree with certain elements of the revised process. Given these differences, the PWROG Members should recognize that it is possible that the NRC Site Inspector will enter into Action Levels at different points in time than the Utility.

11.2.1 Quarterly Values of the mean (μ) and standard deviation (σ):

There exists a point of confusion regarding the definition of a “Quarter” in the draft Guidelines. The phrase “past 3 months” in the first paragraph implied to some readers that a 3-month “rolling average” of the last 90 days was used to calculate the mean and standard deviation. That is, every day, the oldest observation would be discarded as the newest was recorded and new values

of μ and σ would be developed. However, the phrase “Once a quarter” in the second paragraph implies that the mean and standard deviation will be recalculated only once every 90 days and a single set of values will be used throughout the entire following quarter. This latter definition was used to define the term “Historical Baseline” in Section 2. As discussed in various Telecons, this definition protects against a “creeping” mean which slowly increases over time. (The final NRC Guidelines in Appendix F modify this approach.)

11.2.2 Definition of μ and σ :

Typical usage for the mean (μ) and standard deviation (σ) values would consider them as samples from an infinite population so that the population mean, μ , (*see definitions*) would be denoted as \bar{x}_{BAR} and the population standard deviation, σ , (*see definitions*) would be denoted as s . The expression for \bar{x}_{BAR} would be identical to that given for μ . However, the expression for s would be altered to divide by $(n-1)$ rather than n . The usual explanation for the use of $(n-1)$ is that one degree of freedom has been removed from the data set $\{x_i\}$ in the calculation of the sample mean. It is also true that the use of $(n-1)$ instead of n forces s to be “an unbiased estimate” of σ . That is, the best possible estimate (i.e., the expected value) of σ is given by s . (Equations 4.3.1, 4.4.1, 8.5.5 and 11.1.8 of Reference 7 document these facts.)

It appears that the (draft) Guideline considered the set of 90 values for a given Quarter as the entire population (for that Quarter). Using n as opposed to $n-1$ is not significant, so the stated equations and definitions are suitable. However, if two sets of Quarterly data are compared (for example using the “two sample t-test” described in Section 15.4 of Reference 7), the comparison should be thought of as a statistical comparison – that is, the fact that the two means and the two standard deviations are different (by a small amount) does not imply that any change in the unidentified leak rate has occurred. (The two sample t-test will be discussed in Sections 11.4 and 11.12.)

11.2.3 Recording the “most conservative [daily] leak rate value”

The draft Guidelines state that the most conservative daily leak rate value should be used in the assessment. (This approach is modified in the final NRC Guidelines in Appendix F.) There are two potential difficulties with this approach:

First, suppose that multiple values with the same intrinsic accuracy are recorded each day. Also, suppose that the most limiting value is then recorded for use in calculating the mean and standard deviation per the Guidelines. Use of this approach is essentially “auctioneering” the measurements and creates a bias in the daily recorded results. (For example, measuring a given true temperature with 5 unbiased equivalent RTDs and selecting the highest indication produces a result which has a 95% probability of exceeding the true unknown temperature. A general description of the effects of “auctioneering” is in Reference 8 (Reference 8 is also included in Appendix A). The governing equations are also presented on p. 94 of Reference 7.) Of course, one can argue: “So what? The results are still conservative.” However, problems develop if limits are developed using, say, 3 measurements per day and then a decision is made to change to 5 measurements a day. The most conservative of the 5 values will be conservatively biased with respect to limits derived from 3 daily measurements and may, as a result, needlessly actuate

Action Level(s). In like manner, varying the number of measurements each day results in a confused picture for the “daily record.”

Second, it is unlikely that all multiple daily measurements will actually have the same intrinsic accuracy since measurements which challenge the limits of validity are more likely to occur as more measurements are taken. As a result, it is likely that the discerning power of the good measurements is diluted when the best results are effectively auctioneered with the worst measurements. (For example, Section 11.3 shows that small step increases of less than one standard deviation eventually have a high probability of detection if all measurements are equally accurate.)

The recommendation that “exactly one high quality measurement be reported each day” doesn’t mean that members should not perform lower quality “continuous monitoring” measurements as often as desired. In addition, the surveillance measurements used to document compliance with the Technical Specifications do not necessarily have to be based on the recommended measurement. What is intended, is that each member utility consider reporting similar “standardized” daily measurements as part of the Standardization process developed in this project. These measurements would allow a more meaningful comparison of leak rates across the membership. (Table G-5 of Appendix G compares the baseline standard deviations for the three Standard Plant members that rigorously carried out the daily “two-hour snapshot method”. All three plants show the same standard deviation (.03 gpm) which is not too surprising given similar plant instrumentation, similar tight control of the limits of validity for the two hour period, and the same method of measurement. This observation does not mean that all plants carrying out the “two-hour snapshot method will have the same standard deviation. See the discussion about “Page 48” in the peer review in Appendix I.)

WEC recognizes that individual PWROG members use a variety of techniques to carry out the required surveillance measurements. As a result, the “exactly one high quality measurement over a period of approximately two hours each day” process is unlikely to be uniformly used in the future. However, it is important that all PWROG members report a “daily average” value which is determined in a consistent fashion day after day. If the “daily average” values are not consistent, the Action Levels in the NRC Guidelines are likely to be challenged even when no change in leakage has occurred.

In all likelihood, a significant step change in the leak rate will be detected by other monitoring systems. This is especially true if leak rate measurements are performed for only one two hour period per day. However, as discussed in Section 11.3, a good two hour measurement performed once per day has a high probability of detecting a leak of 1 standard deviation or so (typically < .06 gpm) within a one month period. So, this system is good at seeing small changes over long periods of time and other systems are good at seeing larger changes over short periods of time. By analogy, this system, when used in a consistent manner, is like the “dipstick” rather than the “oil pressure gauge” in your car.

11.2.4 Action Level I: 9 consecutive measurements above the [baseline] mean

Action Level I was the principal focus of the simulations reported in Section 11.3. This focus is primarily due to the expectation that larger leaks (Action Levels II & III) would be detected by other monitoring systems and that Action Level I was most likely to be encountered for small leaks. (The simulation results show that this is correct.)

If you think of a measurement above the mean as a “head” and below as a “tail,” then the probability of getting 9 heads in a row is: $\frac{1}{2} \times \frac{1}{2} \times \dots \times \frac{1}{2}$ or $1/512$. (That is, the probability on each throw is $\frac{1}{2}$ and, since each throw is independent, the probability is $1 / (2^9)$). Of course, this is the probability if no change in the mean leak rate relative to the baseline value has occurred. If the mean shifts to a higher value relative to the baseline, it is more likely that new observations will exceed the baseline value. Therefore, 9 consecutive “*exceedences*” (*a measurement that exceeds the baseline mean, see definitions*) will be observed, and Action Level I will occur.

The question is: “Where did the value of 9 come from?” Intuitively, we would expect that the longer we toss a coin, the more likely it is that a given “odd result” will occur. For example, tossing a coin 1,000 times should probably result in at least one run of 9 heads in a row. So, the choice of 9 is likely related to the number of “tosses.” Why does the number 90 (the number of days in a Quarter) seem like a likely candidate?

Any textbook on Quality Control (such as References 9 and 10) discusses the concept of “Control Charts” to track a production process and determine when the process is out of statistical control. A run of “significant length” above or below the *median* (*see definitions*) is always taken as an indicator of an “out of control” process. (Here, the mean and median are considered as equivalent since the process is “normally distributed” and the population mean and median of a normal distribution are identical.) Chapter 13 (Statistical Control) of Reference 7 provides an excellent discussion of runs above and below the median and also provides an approximate definition of what the term “significant length” means.

Statisticians typically use a “significance level” of 5% to identify an unexpected or unusual result. That is, if an event has a probability of 1 chance in 20 or less of occurring, they, by convention, agree to call it “significant”. Page 352 of Reference 7 shows that (approximately):

$$\text{Eqn 11.1 Length of a Statistically Significant Run} = [3.3 (\{\text{LOG}_{10} \text{ NOBS}\} + 1)]$$

In the above equation, NOBS is the number of independent observations and “[...]” denotes “integer value of.” (Coin tosses are usually considered to be independent since a “head” on toss 1 doesn’t give any information on what will happen on toss 2. On the other hand, if the RCS mass inventory at 2 hours is used as the “end time” in the snapshot calculation of the leak rate from 1 to 2 hours and, also, as the “start time” in the snapshot calculation of the leak rate from 2 to 3 hours, the two results are not statistically independent (*see definitions*) since the same value (the 2 hour mass inventory) was used in both calculations. For example, if the 2 hour RCS mass inventory is significantly lower than the “true” value due to instrument fluctuations, then the leak rate from 1 to 2 hours will be excessively high and, in like manner, the leak rate from 2 to 3 hours will be excessively low. A second observation regarding the use of an

intermediate point as both the “end time” of one measurement and the “start time” of the next is that the intermediate value (the 2 hour mass inventory in the above example) “disappears” from the calculation in the sense that the average of the 1 to 2 hour leak rate value and the 2 to 3 hour leak rate value is identical to the 1 to 3 hour leak rate value. This fact is demonstrated in Appendix B, Derivation B.01.)

Evaluating this equation for $\text{NOBS} = 90$, we obtain 9.74 or an integer value of 9 for the “Length of a Statistically Significant Run.” So, a run of 9 values above the mean in one Quarter should be considered statistically significant. Note: Equation 11.1 is relatively insensitive to the value of NOBS due to the LOG function. That is, as NOBS varies from 54 to 107, the integer value of Equation 11.1 remains fixed at 9.

11.2.5 Precursors: 5 and 7 consecutive values above the mean

Based on one measurement per day, it would take a significant amount of time to record 9 exceedences. As a result, we considered applying Equation 11.1 to shorter periods of time – 1 month (30 days) and 1 week (7 days).

When NOBS is 30, the Length of a Statistically Significant Run is 8 and becomes an integer value of 7 at 26 days. Since Equation 11.1 is only approximately correct, we selected a run of 7 consecutive values above the baseline mean in a period of 30 days (1 month) as a precursor to Action Level I.

When NOBS is 7, the Length of a Statistically Significant Run is 6 and becomes an integer value of 5 at 6 days. Since Equation 11.1 is only approximately correct for such small values, we selected a run of 5 consecutive values above the baseline mean in a period of 7 days (1 week) as an additional precursor to Action Level I.

The simulation studies reported in Section 11.3 investigate each of these three situations:

- 9 consecutive values (exceedences) above the baseline mean in 90 days.
- 7 consecutive values (exceedences) above the baseline mean in 30 days.
- 5 consecutive values (exceedences) above the baseline mean in 7 days.

Note: the number of “false alarms” (observing the specified number of exceedences in the specified time when no change in the baseline mean has occurred) is expected to increase as the number decreases. For example, the probability of 5 values above the mean is $1/32$ rather than $1/512$.

Section 11.12 suggests that weekly and monthly averages be recorded along with the observed number of exceedences. This data can aid in detecting small changes in the unidentified leak rate.

11.2.6 Action Levels II and III: Measurements above Two and Three σ

Action level II is triggered when 2 of 3 consecutive measurements exceed the baseline mean by 2 standard deviations. Action Level III is triggered when one measurement exceeds the baseline mean by 3 standard deviations. Each of these Action Levels was simulated in the stochastic simulations performed in Section 11.3.

If there is no shift in the mean to a value above the baseline value, the probability of observing one or more 3 σ values in 3 consecutive measurements is approximately three times the probability that one single measurement is 3 σ or more. Normal distribution tables show that the probability of a value of 3 σ or more is .0013 so the probability of one or more 3 σ readings in three consecutive measurements is approximately .0039. A derivation of the exact value is provided in Appendix B, Derivation B.02.

Item number 145 in Appendix H (i.e., PWROG Member's comments) questioned our use of "one or more measurements greater than 3 σ in three consecutive measurements" since Action Level III is based on a single observation 3 σ above the mean. As explained in the response to item number 145, we calculated the value of "one or more 3 σ readings in three consecutive measurements" (i.e., .0039) so that we could compare it to the Action Level II value of "two or more 2 σ values in 3 consecutive measurements" (i.e., .0015) in the following paragraph.

If there is no shift in the mean to a value above the baseline value, the probability of observing two or more 2 σ values in 3 consecutive measurements is approximately three times the probability that one single measurement is 2 σ or more squared. Normal distribution tables show that the probability of a value of 2 σ or more is .0227 so the probability of two or more 2 σ readings in three consecutive measurements is approximately (3 x .0227 x .0227) or .0015. A derivation of the exact value is provided in Appendix B, Derivation B.03.

As a result of the above evaluation it might appear that the Action Levels are reversed since Action Level III has a higher probability than Action Level II. However, the picture changes when a significant step change in the leak rate occurs. For example, if there is a step change in the leak rate of size 2 σ , the new mean will be equal to the baseline mean + 2 σ . Therefore, the probability of seeing a value 2 σ above the baseline mean is the same as the probability of seeing a value above the new mean or $\frac{1}{2}$ (i.e., 50%) and the probability of encountering Action Level II is the same as the probability of getting at least 2 heads out of 3 coin tosses (i.e., 50%) whereas the probability of encountering Action Level III in three consecutive observations is approximately 40.5%. A derivation of these values is provided in Appendix B, Derivation B.04. (Note: a 3 σ observation above the baseline mean is now only 1 σ above the new mean.) In similar manner, a step change in the leak rate of size 3 σ has a 50% chance of entering Action Level III on the very first measurement whereas Action Level II, by definition, will require at least two consecutive measurements to be actuated and Action Level I will require 9 consecutive measurements to be actuated. Overall, we see that, as the step size of the leak rate increases, the first Action Level to occur migrates from Action Level I (step changes in leak rate of about 1 σ) to Action Level II (step changes in leak rate of about 2 σ), and finally to Action Level III (step changes in leak rate of about 3 σ). The simulation study documented in Section 11.3 confirms

this concept and provides quantitative details for step changes in leak rate ranging from 0 σ to 3 σ in steps of .5 σ .

Appendix C documents a “lumped” and “tuned” analysis of the relationship between the relevant measurement uncertainties and the observed scatter in the unidentified leak rate measurements (i.e., the quantity σ which defines Action Levels I – III). The term “lumped” means that all of the measurement uncertainties which affect the results are concentrated in the single most important variable – the RCS TAVE measurement. This process is expected to result in an exaggerated value for the TAVE uncertainty to offset the fact that all other uncertainties have implicitly been set to zero. The term “tuned” means that the ultimate value for the RCS TAVE uncertainty is determined by insisting that this uncertainty give rise to the observed fluctuation in the unidentified leak rate. Appendix C shows that the two values are numerically about equal for a 2 hour leak rate measurement. (That is, the fluctuation in the RCS TAVE value in units of °F is numerically equal to the fluctuation in the unidentified leak rate in units of gpm.) However, there are two other effects which may influence the value of σ and potentially cause it to vary from day to day. Of course, any significant variation in the day-to-day value of σ will cause problems in properly implementing the Action Levels – particularly Action Levels II & III. Details are:

- The fluctuations due to the instrumentation are probably reasonably consistent from day to day for a given Utility provided that the instrumentation is functioning properly and has not been replaced recently. The instrument fluctuations (called σ_{INST} .) probably set the “lower limit” on the observed scatter in the unidentified leak rate in the sense that, if you do everything else perfectly, you cannot expect the observed leak rate fluctuation to be lower than this value unless you implement methods such as linear regression.
- Measurements which challenge the limits of validity are likely to increase the observed fluctuation. Therefore day-to-day measurements which are not uniform with respect to the limits of validity are likely to cause some added fluctuation in the observed value of σ . Since this added fluctuation is due to the physical process rather than the instruments, we will call this quantity σ_{PROCESS} . This value is expected to “root-sum-square” with σ_{INST} .
- Advanced methods such as linear regression are expected to reduce the observed value of σ by a significant amount. (Linear regression is addressed in Section 11.6.) However, day-to-day variations in the linearity of the mass inventory or instrument readings which are fit to “straight lines” from the start to the end of the snapshot period are likely to cause some increased fluctuation in the (reduced) value of σ . At first glance, it would seem that reducing σ from .055 or so (in the standard snapshot value) to a small value of .01 or less on average (in the linear regression method) would be a good bargain even if the value of .01 sometimes increased to .02 or so. We agree, but the current statement of Action Levels II & III doesn’t recognize this situation. This needs to be addressed by incorporating some latitude in Action Levels II & III in the concurrent PWROG Task. An intelligent solution to this issue will require assessment of some Utility data. (Section 5.2.2 of Reference 25 addresses this issue.)

One variable that does not affect the observed fluctuation in the unidentified leak rate is the leak rate itself. That is, there is no credible reason to believe that a small step change in the unidentified leak rate will affect the scatter of the leak rate data about the new mean. All the simulations described in Section 11.3 used one value of σ both before and after a step change in the unidentified leak rate.

11.3 Description of Simulation Software and Simulation Studies

The statistical simulation reported herein was performed using Visual Basic PC software. The focus of the simulation described in Section 11.3.1 was Action Level I of both the draft and final versions of NRC Appendix D (i.e., “Nine (9) consecutive leakage measurements above the mean”). Additional items were added to the simulation described in Section 11.3.2 to include Action Levels II and III as well as “rolling average,” weekly average, monthly average results, absolute leakage (in gpm), and total integrated leakage (in gallons).

The codes described in Sections 11.3.1 and 11.3.2 are discussed in Appendix E herein.

11.3.1 Description & Use of Visual Basic Code: “RCS_EXCEED_CDF”

The investigation of “exceedences” (i.e., a sequence of N consecutive observations which exceed a given value - in this case the baseline mean) is a well known topic in extreme value theory. (This theory has its origins in the study of floods.) There are “closed form” expressions for the parameters of interest which are documented in References 11 and 12. Reference 11 is also in Appendix A). However, the closed form expressions are asymptotically correct only for large values of N (i.e., values much larger than 9). As a consequence, a simulation program was developed to characterize the desired statistical properties. This program:

- Generates uniformly distributed pseudorandom numbers starting from a selected random number seed. (These are independent random numbers which have an equal probability of taking on any value from 0.0 to 1.0. The numbers are “pseudorandom” in that they are generated by a reproducible algorithm which generates values which only “appear” to be random. You can picture the string of numbers produced as a bicycle chain where each link (i.e., execution of the algorithm) leads to the next. The random number seed used sets the starting location on the chain.)
- Uses the uniform deviates (two at a time) to generate “unitary normal deviates” based on the method of Box & Muller described in Reference 13. (Unitary normal deviates (denoted as \hat{u} herein) are normally distributed values with a mean of 0.0 and a standard deviation of 1.0. Only unitary deviates are needed in this code. However, in Section 11.3.2, unitary deviates are the “stepping stone” to generate normal deviates (denoted as \hat{y} herein) with any given mean (μ) and standard deviation (σ) using the simple transformation:

$$\text{Eqn. 11.2} \quad \hat{y} = \mu + \hat{u} \cdot \sigma$$

The quantity μ in Equation 11.2 is often called the “location value” and σ is called the “scale value.” As discussed in Section 11.7, other definitions of location and scale are sometimes used as an aid in identifying outliers because the usual values (i.e., the sample mean (\bar{x}) and sample standard deviation (s)) are easily corrupted by outliers. Equation 11.2 is often restated so that populations with different means and standard deviations look the same. The term “zscore” (see definitions) is often used for the restated value. That is, the zscore is defined as:

$$\text{Eqn. 11.3 } \text{zscore}(\hat{y}) = (\hat{y} - \mu) / \sigma$$

Or, in general,

$$\text{Eqn. 11.4 } \text{zscore}(\hat{y}) = (\hat{y} - \text{“location value”}) / \text{“scale value”}$$

Note: if \hat{y} is 3 standard deviations above the baseline mean, then \hat{y} has a zscore of 3. These are just two different ways of saying the same thing. Screening a data set for (positive) outliers is equivalent to screening the zscore of each data value to see if it exceeds a large positive value, typically 2.5 or 3.0. (The term zscore will resurface in Section 11.7.)

RCS_EXCEED_CDF was used to study the ability of the RCS leak rate algorithm to detect a “step jump” in the mean leak rate with respect to the baseline mean value. Both before and after the “step jump,” the individual observations are assumed to be normally distributed about their respective mean values with the same (unchanged) standard deviation. However, after the “step jump,” the individual observations are likely to exceed the baseline mean if the size of the “step jump” is large enough. The exact results can be derived by simply examining a string of N unitary normal random deviates and finding the smallest of the N values (called MIN { \hat{u} (1→N)}). Note: this value has only a small probability of being positive when N = 9 (i.e., $1/2^9$ - or- $1/512$). Using a given sampled value of MIN { \hat{u} (1→N)}, it is shown in Appendix B, Derivation B.05 that all N observations in the sample will exceed the baseline mean if:

$$\text{Eqn. 11.5 } \text{Shift in the Mean } (\mu) \geq - \text{MIN } \{ \hat{u} (1 \rightarrow N) \} \cdot \sigma$$

Or, restating Equation 11.5 to evaluate the shift in the mean in units of the standard deviation:

$$\text{Eqn. 11.6 } [\text{Shift in the Mean } (\mu) / \sigma] \geq - \text{MIN } \{ \hat{u} (1 \rightarrow N) \}$$

For example, Table A-37 of Reference 14 (i.e., a table of unitary normal random deviates) shows the following 9 entries in Row 1:

0.048 1.040 -0.111 -0.120 1.396 **-0.393** -0.220 0.422 0.233

Since the smallest value in the first nine values in this row is **-0.393**, then a shift in the baseline mean of $.393 \times \sigma$ would, for this sample, actuate Action Level I of Appendix D as soon as 9 observations were recorded after the shift took place. It is important to note that this code is calculating the shift in the mean (in units of σ) which force exactly the next 9 (or 5 or 7) values to exceed the baseline mean. Section 11.3.2 describes a more general simulation which

investigates the probability of observing 9 (or 5 or 7) exceedences over a fixed period of time (such as 90 days) after a step increase occurs.

The RCS_EXCEED_CDF computer code calculated the Cumulative probability Distribution Function (CDF) shown in Figure D-4 as follows:

1. Generate a set of 9 unitary normal deviates (i.e., $\{\hat{u}(1 \rightarrow 9)\}$) and store the most negative value (i.e., $\text{MIN}\{\hat{u}(1 \rightarrow 9)\}$).
2. Repeat Step (1.) 1000 times.
3. Change the sign of all 1000 values (to calculate $-\text{MIN}\{\hat{u}(1 \rightarrow 9)\}$) and order the 1000 values from smallest to largest.
4. Construct the estimated CDF by setting the CDF to 0.0 and increasing the CDF by .001 (i.e., $1/1000$) at the smallest of the 1000 values in Step (3.), increase it by another .001 at the 2nd smallest, and so on until the CDF has a value of 1.000 at the largest value.
5. Put the 1000 CDF values and 1000 values from Step (3.) into an EXCEL spreadsheet and plot them to obtain the CDF figure shown in Figure D-4 of Appendix D.

Exactly the same method was used to generate Figures D-5 and D-6 except that Step (1.) was modified to select either 5 or 7 unitary normal deviates. (The approach described in Steps (1.) through (5.) is the standard way to generate a CDF from “experimental” data. For example, if you recorded the speed of the first 1000 cars observed on a local highway, ordered the speeds from smallest to largest and followed Steps (4.) and (5.), you would generate an approximate CDF for the distribution of observed speeds. CDFs generated by this method are approximate in that changing the source of data such as the random number seed (or the time when the speeds are observed) will change the result slightly. The CDF values near 0.0 and 1.0 – the lower and upper tails of the distribution – are most volatile and the CDF values near .5 are least volatile.)

The two significant observations from Figures D-4 through D-6 are:

- It takes a pretty big shift in the mean in Figure D-4 to have a 95% probability of generating Action Level I in the first 9 observations after the step increase occurs (i.e., 2.48σ). A similar statement holds for the precursor levels of 5 and 7 exceedences (i.e., 2.28 for 5 in Figure D-6 and 2.37 for 7 in Figure D-5). With shifts this large, it would seem likely to enter into Action Level II or III as well.
- There is a low probability of a “false alarm” in one set of 5 or 7 or 9 consecutive values if no change in the baseline mean occurs. (The “false alarm” values are shown as 0.0 sigma values and correspond to the area of the curve between x co-ordinates of -1 and 0. These correspond to cases where all 5 or 7 or 9 unitary deviates were positive and all would have been above the baseline mean even if no shift occurred.

As expected, it is more likely to get 5 “heads” in a row than it is to get 9 “heads” in a row.

After seeing these results, you might conclude that “9 exceedences” aren’t very important as an Action Level because, in order to have a high probability of generating this Action Level, you need an event so large that you are more likely to get Action Level II or III. But, there is a significant result hiding in Figure D-4 which “saves the day” for Action Level I. Figure D-4 shows that 25% of the time, the first 9 values will exceed the baseline mean for a shift in the mean of only 1.1σ or less.

Suppose that we divide the 90 days following a step increase of 1.1σ into 10 separate sets of 9 days each. According to Figure D-4, we might expect about a 25% chance of seeing 9 exceedences in any one of these 10 sets. What is the chance that all of them would fail? If the probability of success is 25% and the probability of failure is 75% in each set, the probability of at least one success in 10 sets is given by $[1 - (3/4)^{10}]$ or about 94% (i.e., the probability of at least one success is 1.0 minus the probability of 10 failures). **That is, the probability of getting 9 exceedences in the 90 days following a step jump of 1.1σ is at least 94%.** The probability is actually higher than this because the 90 days are not divided into 10 separate pieces. For example, if 0 means “no exceedence” and 1 means “an observation above the baseline mean,” two adjoining sets of 9 daily measurements like those shown below would both fail to have 9 exceedences but Days 14 → 22 would result in Action Level I.

- Day 10 → 18 = [0,1,0,0,1,1,1,1,1]
- Day 19 → 27 = [1,1,1,1,0,1,1,1,1]

The above example made it clear that we needed to develop a simulation program which would initiate a step change in the mean leak rate and track events such as Action Levels I, II and III as a function of time after the step jump occurred. This program and its results are described in Section 11.3.2.

11.3.2 Description & Use of Visual Basic Code: “RCS_LEAK_SIM”

RCS_LEAK_SIM models individual (daily) surveillance measurements before and after a “step jump” increase in the mean leak rate using independent, normally distributed values based on the user input baseline mean (μ) and associated standard deviation (σ). (The values simulated are considered to be the results of one “good” daily measurement. However, there is nothing in the simulation which requires this interpretation. That is, they could be considered as measurements taken every 12 hours, etc.) Per Section 11.2.6, the standard deviation is constant throughout the simulation and is not perturbed by the step increase in the leak rate. A typical simulation is shown in Figure D-10.

11.3.2.1 Inputs & Outputs from Visual Basic Code: “RCS_LEAK_SIM”

As shown in Figure D-10, the step jump in the leak rate always occurs at time equal to “day 0.” The step jump is input in units of the standard deviation. Therefore, the mean after the jump is: “baseline mean” + $\lambda\sigma$ where λ is the non-negative multiplier set by the user (as shown in column

1 of the Tables). The size of the step jump is specified in units of σ because that is the natural unit to use and, also, it allows the data shown in Tables 11-1 through 11-6 to be applied to any individual user. (That is, Table 11-1 shows that there is approximately a 95% probability at a 95% confidence level that a step jump of size 0.83σ will generate Action Level I within 90 days. **Therefore, the 95/95 Minimum Level of Detectability (based on Action Level I) for any Member for a 90 day period is “ $0.83 \times$ site value of σ .”)**)

It is pretty obvious that none of the critical simulated results shown in the Tables depend on the “baseline mean.” That is, if the “baseline mean” of .06 in Figure D-10 was changed to .08, all the points on the strip chart recording would simply shift by .02. It is less obvious but true that the results shown in the Tables also do not depend on the value of σ . (That is why the Tables apply to all Members.) The reason the value of σ does not matter is that both the size of the step jump and the fluctuation about the new mean shown in Figure D-10 are occurring in units of σ . If we reduced σ by $\frac{1}{2}$ or doubled it, everything in the picture would be scaled by the same amount and the picture would look exactly the same. As a result, the key input in the simulation is the multiplier on σ . (These facts were verified by executing runs with the same starting seed, etc. and a μ of 0.0 and an σ of 1.0. Identical results for the critical values shown in the Tables were obtained.) All of the runs reported in the Tables used a μ of 0.06 and an σ of 0.055. These values were selected based on typical plant data discussed in the Telecons. As noted above, these specific values have no influence on the critical results in the Tables. They do make plots like Figure D-10 resemble actual plant strip chart recordings. (Such as page A.2 in Appendix A.)

The input allows modeling the “pre-jump” history (where the leak rate is set to the baseline value) for an arbitrary number of days. After the jump on “Day 0,” the simulation **always** continues for at least a user input number of days. For example, Table 11-1 is based on a user input value of 90 (days). During this 90 day period, the simulated data is examined to determine if Action Level I, II, or III is generated at each simulated time point. If an Action Level (sometimes called an “alarm”) is generated, a flag is set to “TRUE.” It is important to note that, at the end of a given simulation case, a given flag (there are three – one for each Action Level) is either TRUE or FALSE. That is, these “Boolean” (on/off) flags do not count how many times an Action Level occurs within a 90 day period. A second counter (DAY_{alarm1}) records the day which generated the first Action Level I alarm. For example, if 9 exceedences are first observed on day 21, this value would be set to 21. A given simulation case will continue past the user input number of days and keep going until the user input “number of exceedences” (9, 7, or 5 in the Tables) is observed. (Note: the 95/95 limit of 3274 days for DAY_{alarm1} in Table 11-1 when a multiplier of 0.0 on σ was used.) Note: the simulation will stop at the user input number of days if the flag for Action Level I is set to TRUE at the end of the selected number of days.

Typically, exactly 1000 case histories are executed for a given set of user input data. (There is a special option to rerun a single case from an earlier run of 1000 case histories with “debugging” type print options turned on.) The data in each row in Tables 11-1 through 11-6 is therefore based on exactly 1000 case histories using the user specified input. Case-by-case random number seeds are based on a simple algorithm which uses the case number (from 1 to 1000) in conjunction with the single user input random number seed. That is, changing the single input value will cause all 1000 cases to change. Therefore, the effects of the random number sequence (which are present in every stochastic simulation) can be observed by rerunning a simulation

with one changed input – the user selected seed. Use of the case-dependent algorithm allows rerunning a single case and preserving exactly the same random number sequence used for that case as when all 1000 cases were run. For example, Case 567 will have the same results whether it is run by itself with debugging turned on or as one of a 1000 cases.

All of the runs reported in the Tables used an arbitrary seed of -200. Slightly different results would be obtained if we reran these cases with a different input value. However, it is important to note that the 95/95 limits stated in the Tables are valid 95/95 limits even if another seed would produce different values. (This is one of the nicest features of statistical simulations – everyone can get a different answer and everyone can be right.)

The decision to run exactly 1000 case histories in each simulation greatly simplifies statistical calculations related to normality tests and the calculation of 95/95 normal and nonparametric tolerance limits. In addition, 1000 case histories is a large enough value to reduce the fluctuations that occur when different random number seeds are used. A brief description of the important statistical parameters is:

- A “normality test” is performed on the 1000 values of $\{DAY_{alarm1}\}$ obtained in each simulation. This testing follows the American National Standards Institute description in Section 7 of Reference 15. This testing determines whether the assumption of normality is justified or not. The test involves ordering a given set of 1000 values from smallest to largest, multiplying the j th value in the ordered list by $\{j - (1001)/2\}$, summing up the resulting values and dividing by a simple quantity related to the sample standard deviation. The test is completed by checking the result in Table 5 of Reference 15. The normality test typically fails if the data has a long tail (i.e., “skewness”) in either the positive or negative direction. A typical histogram of the $\{DAY_{alarm1}\}$ data from the simulation is shown in Figure D-7. As a result of the long positive tail, the data (typically) fails to pass normality. Note: the equations shown below are general in that they apply to any sample of independent data from any population. However, in this case, they are applied to the 1000 values of $\{DAY_{alarm1}\}$ obtained in the simulation.
- If the sample passes the normality test, the 95/95 tolerance limit is defined as:

$$\text{Eqn. 11.7} \quad \text{“95/95” Normal Tolerance Limit} = \bar{x}_{BAR} + k \cdot s$$

Where k is the 95/95 one-sided tolerance factor (for a sample of size 1000) documented in Table 1.4 of Reference 16 (i.e., 1.727). Note: as the sample size approaches infinity, the limit in Equation 11.7 approaches:

$$\text{Eqn. 11.8.a} \quad \text{“95/95” Normal Tolerance Limit} = \mu + 1.645 \cdot \sigma$$

- If the sample fails the normality test, a nonparametric (i.e., distribution free) 95/95 Upper Tolerance Limit (UTL) for a sample of size 1000 is obtained from the normal approximation to the binominal probability distribution (p.172 of Reference 17) as:

$$\text{Eqn. 11.8.b} \quad \text{“95/95” Nonparametric Pointer} = 950 + 1.645 \sqrt{[1000(.95)(.05)]}$$

The “pointer” in Equation 11.8.b has an integer value of 961 (for a sample of size 1000). The upper tolerance limit is obtained by ordering a sample from smallest to largest and selecting the 961st value as the nonparametric limit. Reference 11 has a similar description of the so-called “Rule of 59” which states that the largest value in a random sample of size 59 is a 95/95 one-sided tolerance limit for the population regardless of the type of population which generated the sample. Reference 11 is included in Appendix A. (This limit is shown as a broken line at 94 days in Figure D-7.) See the discussion regarding “Page 60” in the peer review in Appendix I. Note: also, non-parametric tolerances will generally be more conservative than their parametric counterparts. That is, the value supplied by Equation 11.8.b will typically be larger than the value supplied by Equation 11.8.a when the underlying distribution is normal. (Pages A-20 and A-21 of Appendix A provide a numerical comparison for a sample of size 59.)

The simulation code can model “rolling average” leak rate values by simply basing each daily recorded value on the average of the last N daily observations instead of the actual daily observation. Figures D-11 and D-13 show 7 day and 30 day “rolling average” results using the daily values from Figure D-10.

One of the typical decisions that need to be made in simulation analyses concerned how to handle exceedences about the baseline value immediately prior to the step jump at time “0 days.” The two choices were:

1. Inherit the exceedence count from times before the step jump. This could result in generating Action Level I at the very first time point after the step jump.
2. Reset the exceedence counter to 0 at the step jump. This would make it impossible to get Action Level I before Day 8.

The simulation code uses choice 1. This choice is more coincident with reality in that the exceedence count will typically be non-zero when a step jump occurs and this count will contribute to generating Action Level I even though these values occurred before the initiating event at time “0 days.”

RCS_LEAK_SIM has a number of capabilities which were not utilized in the simulation results described in Tables 11-1 through 11-6 in Section 11.3.2.2. All of the capabilities are described in Appendix E. The principal results described in the next Section utilize items: 2, 4 through 7, and 9 in the following list:

1. Absolute Leak Rate (in gpm). (This item is addressed in Section 5 of Reference 25.)
2. Probability of detection of the user input change in the mean (μ) leak rate using the user defined alarm function.

3. Total Integrated Leakage (in gallons). (This item is addressed in Section 5 of Reference 25.)
4. Statistics on the “time-to-alarm” using the user defined alarm function
5. Statistics on the “time-to-alarm” using the three Action Levels defined in Appendix D (generalized to include 2 -> 9 exceedences).
6. Probability of an alarm within a user-defined time interval T.
7. Rolling average results defined on a user selected string of the individual history output values. (Linear regression fitting of input signal values is discussed in 11.6 below.) The rolling average is targeted for use in observing small changes in the baseline mean (μ) over short (i.e., weekly) periods of time. That is, a running average of the last [7 to 9] daily surveillance results will be updated on a daily basis by including the newest measurement and discarding the oldest. Averaging should reduce the inherent fluctuation by a factor of $\sqrt{[7 \text{ to } 9]}$ and reveal short term trends.
8. Modeling of “spikes” (i.e., outliers) based on a user defined frequency and amplitude model.
9. Graphical display (i.e., “strip chart” recording) of the case history for any selected case and scenario.

11.3.2.2 Results of the Simulations Performed with “RCS_LEAK_SIM”

The principal objective of the simulations reported in Tables 11-1 through 11-6 is to determine the “minimum level of detectability.” The results in Tables 11-1 through 11-6 are used to state the results in Section 11.4. A second objective is to examine the effects of weekly and monthly “rolling averages” on the appearance of the data and on the associated Action Levels I – III if the “rolling average” value is used in place of the daily value to enter the Action Level.

As stated in Section 11.3.2.1, all of the simulations reported in the Tables used a baseline mean: $\mu = .06$ gpm and a standard deviation: $\sigma = +.055$ gpm. In addition, all runs used the same starting random number seed. Using the same seed makes the individual rows of all Tables more comparable. As discussed in Section 11.3.2.1, the baseline mean and standard deviation used have no effect on the values shown in the Tables. (They do make “strip chart” recordings such as Figures D-10 through D-14 look more like real plant data.)

The first set of simulations (reported in Tables 11-1, 11-3 and 11-5) calculated the 95/95 Upper Tolerance Limits (UTL) on $\{\text{DAY}_{\text{alarm}1}\}$ and the results for the Boolean “on/off” flags for Action Levels I – III as a function of the step jump multiplier on the value of σ . Each run used multipliers from 0.0 to 3.0 in steps of .5. Note: Table 11-1 tabulates results for 9 consecutive exceedences in 90 days, whereas Table 11-3 tabulates results for 7 consecutive exceedences in 30 days, and Table 11-5 tabulates results for 5 consecutive exceedences in 7 days. These last two cases are “precursors” to NRC Action Level I. **Note: the Tables refer to 9 exceedences as**

“Type A” and the precursor values of 7 and 5 exceedences as “Type B” and “Type C” respectively.

A second set of simulations were performed for each Table to “zero in” on the appropriate 95/95 limit on $\{\text{DAY}_{\text{alarmI}}\}$. That is, we wanted to find the σ multiplier which would result in a 95/95 limit of approximately 90 days for Table 11-1, approximately 31 days for Table 11-3, and approximately 7 days for Table 11-5. These rows are highlighted in **bold** in each Table. **The values of these multipliers essentially set the minimum level of detectability as shown in Section 11.4.** Figures D-7 through D-9 shows the histograms of the values of $\{\text{DAY}_{\text{alarmI}}\}$ for each of these cases. Note: the data shown in Figure D-7 has an exceptionally long positive tail. As shown on the Figure, the most probable number of days to generate Action Level I is only 8 days and the median value is 22 days. The worst case in the simulation took 183 days to invoke Action Level I. The long tail is occurring because anytime a unitary normal deviate less than negative .83 (i.e., $-.83$) is drawn to create the “daily sample,” the resulting value is less than the baseline mean, and the count starts all over again. The probability of drawing a value less than $-.83$ is about 20% so this happens fairly often for a step jump of this size (i.e., $.83 \sigma$). Note: the UTL of 94 days is reduced to 24 days when the step jump is doubled (i.e., 1.5σ).

Tables 11-2 and 11-4 tabulate the effects of the use of a “rolling average” calculation. The effect on both 95/95 tolerance limits and the likelihood of encountering Action Levels I – III are shown. Rolling average values based on 7 days and 30 days are included. Figures D-10 through D-14 show the effects of the use of “rolling average” and “weekly” and “monthly” averages on the daily data.

Examination of the data shows:

- The 95/95 UTL (upper tolerance limits) on the number of days required to get 9 or 7 or 5 exceedences for a “zero” step jump is a measure of the “false alarm” rate. This rate is, as expected, higher for 5 exceedences than it is for 9 exceedences. Note: an UTL of 3274 days in Table 11-1 means that 38 cases out of 1000 required more than 3274 days to get 9 exceedences in a row. (That is, the nonparametric UTL is set by the 961st case starting from the smallest or the $[1000 - 961^{\text{st}}$ or 39th] case starting from the largest. Therefore, there are 38 cases “worse” than this one. The same concept applies to all the UTL values in all the Tables.
- The number of Action Level I – III occurrences and the relative numbers of Action Level I – III occurrences trend is as expected as the step jump size increases in Tables 11-1, 11-3 and 11-5. That is, each item grows as the step size increases and, in each row, Action Level I is greater than Action Level II which, in turn, is greater than Action Level III. (Row 1 of Table 11-1 appears to show the effects described in Section 11.2.6. Note: Row 1 of Table 11-1 shows that Action Level III has a significant probability of about 10% (i.e., 100 events out of 1000 trials) of occurring at least once during a calendar quarter even if no increase in the leak rate has developed. This implies that Action Level III may occur even when no initiating event has developed. The 10% value shown in Table 11-1 is in good agreement with the theoretical value of 11% (i.e., $\{1 - .9987^{90}\}$).

- An interesting observation concerning a trend in Table 11-1 was raised by reviewer comment 120 in Appendix H. Note: doubling the size of the step increase in the leak rate (say from 1 to 2 or 1.5 to 3 in column 1 of Table 11-1) reduces the 95/95 UTL on the “Days to Action Level I” (i.e., column 2) by much more than a factor of 2. For example, when the leak rate increases from 1 to 2, the limit on the number of days decreases from 58 to 17 (a factor of 3.4). Similarly, an increase from 1.5 to 3.0 causes a decrease from 24 to 8 (a factor of 3.0). This is important because it implies that the increase in the integrated leakage from the time of initiation to the 95/95 limit on the time to detect (using Action Level I) decreases as the leak rate increases. For example, if σ is .055 and a step increase of the leak rate of 1σ occurs, there is a 95/95 chance that it will be detected in 58 days. Therefore, the “added” leakage is: .055 gpm x 60 x 24 x 58 -or- 4594 gallons. If, on the other hand, a step increase of 2σ occurs, the added leakage in 17 days is: $2 \times .055 \times 60 \times 24 \times 17$ -or- 2693 gallons. Note: the limiting case over a 90 day period coincides with the value which was used to set the minimum level of detectability in Section 11.4 (i.e., .83 in column 1 of Table 11.1). That is, the “added” leakage for this case is: $.83 \times .055 \times 60 \times 24 \times 90$ -or- 5916 gallons. (The .83 value is limiting because, as this value grows, the time to detect is reduced by a larger factor. If the .83 factor is reduced to a smaller value, the time interval remains fixed at 90 days, so the leakage is reduced.)
- The behavior shown in Tables 11-2 and 11-4 is easier to understand after examination of Figures D-11 and D-13 (which show the effects of a step jump of size 2σ rather than $.83\sigma$). As shown in the Figures, the “rolling average” reduces the fluctuation in the daily readings (i.e., $\sigma = .055$) to a value of $\{.055/\sqrt{7}\}$ for the “rolling average” of 7 values and to a value of $\{.055/\sqrt{31}\}$ for the “rolling average” of 31 values. As a consequence, the “rolling average” “homes in” on the mean after the jump so that values below the baseline mean (which occur fairly frequently for the daily values shown in Figure D-10) almost never occur. At the same time, the “homing in” prevents the occurrence of Action Level II and III for the small step jumps used (i.e., $.83\sigma$ in Table 11-2 and 1.1σ in Table 11-4.) However, Table 11-6 which is based on a step jump of 2σ shows a significant number of Action Level II occurrences because the new mean is the {baseline value + 2σ } and the rolling average is “homing in” on the new mean. Also note: there is an enormous difference between the number of Action Level II and Action Level III alarms (445 vs. 6) for the same reason.

As discussed in Section 11.3.2.1 and Appendix E, RCS_LEAK_SIM has many capabilities which have not been fully exercised herein. It would be prudent to collect some operating data based on the Recommendations in Section 11.12 before proceeding with more simulations which, for unforeseen reasons, don’t fully represent reality.

(The Standard Plant activity described in Appendix G collected and analyzed “real” operating data from several member utilities. This data was primarily based on the use of the standard two-hour snapshot method. As discussed in Appendix G, the collected data coincides with the model used in the RCS_LEAK_SIM simulations. That is, the data is approximately normally distributed with a persistent mean and standard deviation. The only shortfall in the modeling is

that the observed frequency of outliers in the “real” data was fairly high. (Table G-5 shows that there were 21 outliers in 561 data points or about 4%.) Although RCS_LEAK_SIM is capable of modeling outliers, this option was not invoked in any of the simulation runs reported here. However, a review of the Appendix G data shows that the actual outliers observed had essentially no impact. That is, two positive outliers never occurred close enough together to mistakenly invoke Action Level II nor did any outlier change the length of an exceedence run. However, an examination of all observed outliers in Table G-6 shows that 3 Ginna outliers implied potential engagement of Action Level III (i.e., 3 or more standard deviations above the mean). Section 10.1 discusses what to do when an observation leads to Action Level III.)

Table 11-1

**Number of Action Level I, Type A (9 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 90 Days**

Step Increase (σ Multiplier) λ	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
0	3274	80	98	100
0.5	283	665	510	395
0.8	105	946	845	734
0.83	94 (\cong 90)	959	864	757
0.85	86	967	870	767
1	58	996	961	887
1.5	24	1000	1000	1000
2	17	1000	1000	1000
2.5	13	1000	1000	1000
3	8	1000	1000	1000

Table 11-2

**Number of Action Level I, Type A (9 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 90 Days for
a λ of 0.83 σ , Assuming Weekly and Monthly Rolling Average**

Rolling Average Interval (Days)	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
7	13	1000	24	0
31	20	1000	0	0

Table 11-3

**Number of Action Level I, Type B (7 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 31 Days**

Step Increase (σ Multiplier) λ	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
0	803	86	43	35
0.5	121	558	234	185
1	36	937	693	601
1.1	31	964	784	676
1.5	17	1000	984	920
2	11	1000	1000	999
2.5	8	1000	1000	1000
3	6	1000	1000	1000

Table 11-4

**Number of Action Level I, Type B (7 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 31 Days for
a λ of 1.1 σ , Assuming Weekly and Monthly Rolling Average**

Rolling Average Interval (Days)	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
7	11	1000	53	0
31	15	1000	0	0

Table 11-5

**Number of Action Level I Type C (5 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 7 Days**

Step Increase (σ Multiplier) λ	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
0	192	123	14	7
0.5	44	374	67	58
1	18	705	230	226
1.5	10	906	591	454
1.9	7	962	834	715
2	7	967	882	762
2.1	6	977	920	808
2.5	4	990	990	946
3	4	1000	1000	997

Table 11-6

**Number of Action Level I, Type C (5 Consecutive Exceedences) and
Action Levels II and III Occurrences Out of 1000 within 7 Days for
a λ of 2 σ , Assuming Weekly Rolling Average**

Rolling Average Interval (Days)	95/95 UTL on Days to Action Level I (Days)	Number of Action Level I (Out of 1000)	Number of Action Level II (Out of 1000)	Number of Action Level III (Out of 1000)
7	6	999	445	6

11.4 Minimum Level of Detection

The “minimum level of detectability” describes the smallest unidentified leak rate or change in leak rate that can be detected in a given period of time using a given “alarm” function. The purpose of this Section is to more precisely quantify the meaning of the term “minimum level of detectability” and the principal factors that affect it using the results of the stochastic simulations reported in Tables 11-1 through 11-6 of Section 11.3.2.2.

Customer comment #26 in Appendix H points out that NRC (draft) Safety Evaluation for implementing Technical Specifications Task Force-449 (CLIP for SG Tube Integrity) states that “leakage of 150 gallons per day (i.e., .104 gpm) cannot be measured accurately by an RCS water inventory balance”. As a result of this statement and other similar considerations, the absolute leakage limits in Section 5 of Reference 25 were set at $1/10^{\text{th}}$ of the Tech Spec limit (i.e., .1 gpm). The question is: What does the statement “measured accurately” mean and does this statement, if true, imply that the minimum level of detectability is on the order of .1 gpm?

WEC responses to Customer comments #43 and #44 in Appendix H address the question of “measured accurately”. That is, the (mean) accuracy of the RCS water inventory balance is not generally known. However, we believe that the mean error is typically small based on the expected agreement between observed small measured values of the “snapshot” results and the associated independent results from plant walk downs and the use of other instrumentation systems during the heatup and initial power operation near Beginning of Cycle.

The problem with the snapshot method is not the mean accuracy; it is the (typical) large fluctuation. So, when a measurement of +.1 gpm shows up on a given day, is the unidentified leak rate really +.1 gpm or is it merely due to random scatter in the data? (Note: the only Action Level in Section 5 of Reference 25 that can occur due a single reading of +.1 gpm is Action Level III in Section 5.2.2. This Action Level will occur if the baseline mean and baseline standard deviation satisfy the constraint: $(\mu + 3\sigma \leq +.1 \text{ gpm})$. Even when this is the case, repeated measurements are advised to see if the value is “real” or a statistical anomaly (i.e., “outlier” per Section 10.1 and 11.7).

The method of “consecutive exceedences above the baseline mean” deals with the fluctuation in the RCS Inventory Method in that a significant number of exceedences directly imply that a step increase in the unidentified leak rate has occurred regardless of the scatter in the daily leak rate measurements. So, can you detect a .1 gpm step change of the leak rate in one day? Yes, if your standard deviation is small enough (i.e., Action Level III) and if you actually perform surveillance measurements on a daily basis (rather than following the Technical Specification limit of 72 hours). However, (based on row 4 of Table 11-3) everyone will almost always “detect” a step change of about .1 gpm in the leak rate in no more than 31 days or so if they look for a run of 7 exceedences above the baseline mean in a given 30 day period. (Note: the limit shown in Table 11-3 is a step increase of 1.1σ . Since Section 5.2.2 of Reference 25 sets a limit of +.1 on the value of σ , the step increase is limited to .11. Row 4 of Table 11-1 shows a similar result for 9 exceedences in 90 days.) “Detect” here means that there will be an indication that a step change has likely occurred. Some additional effort is needed to see if this could possibly be a false alarm. The term “almost always” is a simple way to express the term “at a

95% probability and 95% confidence level”. As noted in the peer review in Appendix I, a more precise definition of “95/95” is that we are 95% confident that at least 95% of the population will be below this value. See “Page 60” in Appendix I for additional detail.)

So, overall, the principal factors which set the actual numerical value of the minimum level of detectability are the amount of scatter in the daily measurements and the simple ticking of the clock as daily measurements accumulate and exceedences above the baseline mean are observed. Details follow.

The factors which affect the appearance & quoted values of any statement that tries to define the minimum level of detection are:

- **The “alarm algorithm”** such as “9, 7, or 5 consecutive exceedences” (i.e., Action Level I or precursors to Action Level I), or such as Action Levels II or III or some entirely different as yet undefined alarm mechanism obviously has a significant impact on the detection capability. For example, Table 11-2 shows that Action Levels II and III have a zero probability of detecting a step increase of $.83\sigma$ if a 31 day “rolling average” is used in place of the daily measurement.
- **The nature of the initiating event.** Depending on the initiating event, (i.e., leakage past valve packing/ seals, fatigue cracking of an instrument line, or caustic stress corrosion cracking), the change in leak rate may be a sudden step change or a gradual increase over time. Also, if the initiating event is related to equipment that is only periodically placed in service, the leak rate may fluctuate based on system lineup. In this case, it seems unlikely that the “9 exceedence” method would ever detect the increase. (However, the “24 hour” method discussed in Appendix G, Section G-5 and Figures G-9 to G-13 would certainly “see” such an event.) Therefore, considering all the possibilities, only step jumps were analyzed in this analyses, although the simulation code will model ramps in the leak rate as discussed in Appendix E.
- **The allowed time** (i.e., 7 – 90 days herein) to look for a persistent leak influences the ability to detect a given leak rate. Section 11.3.1 showed how a relatively low probability of detecting a small step change in the leak rate in the first nine days after it occurs translates into a very high probability of detecting it within a period of 90 days.
- **The probability and confidence criterion** used strongly influences the result. Herein we used the “gold standard” of “95/95” (i.e., almost always). If we had used a “50/50” type criterion the resulting statement would be significantly different. An inspection of Figure D-7 shows that the median number of days to get 9 exceedences is 22 days for a step increase in the leak rate of $.83\sigma$ whereas the 95/95 limit in Table 11-1 is 94 days.
- **The individual site value of σ** has a significant influence on the stated level of detection. Section 11.2.6 indicates that poor control of the “limits of validity” described in Section 10 is highly likely to increase the observed scatter in the leak rate measurements. On the other hand, use of linear regression methods applied to intermediate measurements within the surveillance interval is highly likely to reduce the scatter in the leak rate

measurements. Note: as explained in Section 11.3.2.1, the minimum level of detectability has the same statement regardless of the site value of σ . However, reducing the scatter by a factor of 2 improves the level of detection by a factor of 2 in terms of real gpm.

Typical statements of the “Minimum Level of Detectability” based on Section 11.3.2.2 are:

“THERE IS A 95% PROBABILITY AT A 95% CONFIDENCE LIMIT THAT A STEP INCREASE IN THE LEAK RATE OF $.83 \sigma$ WILL GENERATE ACTION LEVEL I WITHIN THE FIRST 90 DAYS AFTER THE STEP INCREASE OCCURS”

“THERE IS A 95% PROBABILITY AT A 95% CONFIDENCE LIMIT THAT A STEP INCREASE IN THE LEAK RATE OF 1.1σ WILL GENERATE A PRECURSOR TO ACTION LEVEL I (I.E., 7 EXCEEDENCES) WITHIN THE FIRST 30 DAYS AFTER THE STEP INCREASE OCCURS”

“THERE IS A 95% PROBABILITY AT A 95% CONFIDENCE LIMIT THAT A STEP INCREASE IN THE LEAK RATE OF 2σ WILL GENERATE A PRECURSOR TO ACTION LEVEL I (I.E., 5 EXCEEDENCES) WITHIN THE FIRST 7 DAYS AFTER THE STEP INCREASE OCCURS”

Section 11.12 recommends that the member utilities use Microsoft EXCEL or similar methods to execute the “F-test” and “two sample t-test” on data obtained from consecutive Quarterly sets of daily leak rate measurements (such as 90 values from Jan through Mar and 90 values from Apr through Jun) before using the Apr through Jun values to screen values in the upcoming Quarter (Jul through Sep). The “F-test” checks to see if the (sample) standard deviations have changed significantly from one Quarter to the next. The one-sided t-test checks to see if a significant upward shift in the (sample) mean has occurred in the last Quarter. Section 15.4 of Reference 7 gives a complete description of these two tests. (The F-test is called the ν^2 test in Reference 7.) Page 3-34 of Reference 14 also gives a simple recipe for the calculation which can be used to decipher the EXCEL output summary. Reference 14 shows that there is a significant shift in the Quarterly mean (in units of the standard deviation) if:

$$\text{Eqn 11.9 } [X_{\text{bar}}(\text{Apr-Jun}) - X_{\text{bar}}(\text{Jan-Mar})]/\sigma > 1.653 \cdot \sqrt{(2/90)} \text{ (or about .25)}$$

In the above equation, 1.653 is the appropriate t-value. The equation assumes that the data passes the F-test and that σ represents the “pooled” standard deviation (as computed in Reference 14 and also by EXCEL). This recommendation is discussed here because the discriminating power of this test is about $.25 \sigma$ units. This is a really low number and implies that these “two sample t-test” comparisons can detect very small changes over long periods of time.

Equation 11.9 was tested by using the simulator described in Section 11.3.2 to generate two 90 day (independent) samples with mean = .06 and $\sigma = .055$. The samples were then tested to ensure that they passed the F-test and t-test. Then the second sample was “shifted” to a new mean by adding +.014 to each of the 90 values (.014 is approximately

.25 x .055 or .25 σ). After this perturbation, the data failed the two sample t-test at the 5% significance level. The F-test was unaffected by this shift in the mean since it uses only sample standard deviations (which did not change). All of these tests were performed with EXCEL.

11.5 Rolling Average of the Output Values

Figures D-10 through D-14 show comparisons of 7 day and 31 day “rolling average” to the individual daily observations. As shown therein, the fluctuation in the observed values is reduced (by a factor of $\sqrt{7}$ for the weekly average and a factor of $\sqrt{31}$ for the monthly average). Tables 11-2, 11-4 and 11-6 show how initiation of Action Levels I – III would change if the rolling average is used in place of the daily measurement. (This interpretation is not recommended.) However, Section 11.12 suggests that weekly and monthly rolling average charts be maintained since they seem to give a clearer picture when changes are occurring.

11.6 Linear Regression of Input Signals and/or Mass Inventories

Linear regression of input signals such as Tave or the associated mass inventories at intermediate time points during the recommended two hour snapshot surveillance interval is expected to reduce the fluctuation in the daily surveillance values provided that the data used in the fitting process over the two hour period is “sufficiently” linear. Significant deviations from linearity can lead to erroneous results (as shown in Figure D-25). Moderate deviations from linearity from day-to-day will probably cause the associated day-to-day fluctuations to increase. That is, it will appear that σ is varying as the day-to-day data becomes more or less linear. As discussed in Section 11.2.6, this can cause problems with Action Levels II and III.

Herein, we will define “linear regression” of input signals (such as Tave) to mean:

The actual values of Tave at the start and end of the surveillance interval are not used in the calculation of the RCS inventory. Instead, the start and end values along with numerous intermediate Tave values and the associated times are used to fit a straight line of Tave versus time. The straight line is then evaluated at the start and end points and the resulting values are used in place of the (now discarded) actual measurements.

The question is: “Why are the fit values “better” than the actual values?”

Appendix C documents a “lumped and tuned” evaluation of instrument uncertainties which “lumps” all the uncertainties into the single most important value (i.e., Tave) and then determines a plausible value for the fluctuation in the Tave signal. This value is then “tuned” to cause all the observed fluctuation in the output unidentified leak rate. It is worth noting that Appendix C also shows that biases in the Tave signal (which persist throughout the surveillance interval) have essentially no relevance to the leak rate measurement process. Section C-3.3 shows that the numerical value of the leak rate fluctuation (typically .055 gpm) and the numerical value of the Tave fluctuation (in °F) are virtually identical if the leak rate fluctuation is based on a 2 hour surveillance interval. So, roughly, if the site is doing standard 2 hour measurements and seeing a fluctuation of .055 gpm, then, the lumped model used in Appendix C implies that the fluctuation in the associated measurement of Tave at the start point is about .055 ° F. That is, $\sigma_{\text{fluctuation}}$ for

Tave is .055 ° F. Note: all measurements during the two hour period follow the same rule. Every Tave measurement is “off” by an independent sample from a normal distribution with mean (μ) = 0.0 ° F and standard deviation ($\sigma_{\text{fluctuation}}$) = .055 ° F.

As an aside, Section C-3.2 of Appendix C shows that this fluctuation in Tave applied to both the starting and ending time is expected to cause a one standard deviation fluctuation in the mass inventory of (124 gal./°F) x $\sigma_{\text{fluctuation}}$ or 6.8 gallons in any surveillance interval. That is, if you have a 15 minute interval, 6.8 gallons can show up or disappear due to the fluctuation. If you have a 2 hour interval, 6.8 gallons can also show up or disappear. Note: a fluctuation of 6.8 gallons in 120 minutes is (6.8/120) gpm or .055 gpm and 6.8 gallons in 15 minutes is .45 gpm. (This is roughly the fluctuation in the 15 minute data shown in Figure D-3). Of course, the .055 gpm value shown for the two hour period is not fortuitous but a direct result of the “tuning” process described in Appendix C.

To understand why linear regression potentially improves the results, let’s suppose that:

1. The “true” value of Tave is increasing in exactly a linear trend with slope β over the surveillance interval.
2. An origin of co-ordinates is defined at the true starting temperature.
3. All temperature changes are measured relative to the true starting value.
4. The starting time is set to 0 hours and the ending time is 2 hours.
5. The true temperature change at time 0 is 0.0. (Since all temperatures are expressed in units of the change relative to time 0, the true temperature at time 0 hours is 0.0.

Given the above, the true temperature (relative to the start) at the end of two hours is $2 \cdot \beta$.

Now suppose that we randomly pick a (large) number (N) of time points between time 0 and 2 hours and write down the measured Tave and use this data to fit a straight line. How will the slope of this line differ from β ? The answer is given by Equation 18.3.31 from Reference 7:

$$\text{Eqn. 11.10} \quad \beta_{\text{measured}} = \beta + \hat{u} \cdot (\sigma_{\text{fluctuation}}) / \sqrt{[\sum (t_i - t_{\text{bar}})^2]}$$

That is, the measured slope will be equal to the true slope plus a random sample from the unitary normal distribution times the fluctuation in the Tave values divided by the square root of the sum of the squares of each individual time relative to the average time (which will be about 1 hour). A little sleight of hand in Appendix B, Derivation B.06 shows that the denominator (which looks like a standard deviation without the $1/\sqrt{N}$ term) is a simple constant times \sqrt{N} .

As a result, Equation 11.10 can be restated as:

$$\text{Eqn. 11.11} \quad \beta_{\text{measured}} = \beta + \hat{u} \cdot (\sigma_{\text{fluctuation}}) \cdot \text{constant} / \sqrt{N}$$

Noting that the intercept of the measured fit (which will typically not be exactly 0.0 as in the true fit) plays no role since it is the same at the start and end times, the change in measured temperature from the start time to the end time is obtained by multiplying Equation 11.11 by 2 (hours):

$$\text{Eqn. 11.12} \quad \text{Change in Temperature} = 2 \beta + 2 \cdot [\hat{u} \cdot (\sigma_{\text{fluctuation}}) \cdot \text{constant}] / \sqrt{N}$$

Or:

$$\text{Eqn. 11.13} \quad ([\text{Measured} - \text{True}] \text{ Change}) = + 2 \cdot [\hat{u} \cdot (\sigma_{\text{fluctuation}}) \cdot \text{constant}] / \sqrt{N}$$

Of course, this equation shows that we can reduce the 6.8 gallons error described above by simply making N large enough to make the right hand side of Equation 11.13 as small as we like. Note: N will be 7200 if 1 second measurements are made. **Equation 11.13 explains why linear regression improves the result if the underlying trend is truly linear and is simply contaminated by noisy measurements. See also the discussion of “Page 75” in the peer review documented in Appendix I.**

To show a sample calculation of these effects, the RCS and Identified leak data shown in Figures D-1 and D-2 were fit with linear regression curves which used all the data (recorded in 15 minute intervals), every other data point (30 minute intervals), then 1 and 2 hour intervals. EXCEL was used for all of these calculations. The results are shown in Figures D-15, and D-17 through D-23. Each Figure states the estimated 10 hour unidentified leak rate using the straight line fits. These values increase from .048 gpm when all data is used to .077 gpm when only the 6 data points associated with 2 hour intervals are used. Figure D-24 shows the uncertainty in the slope (obtained from the associated EXCEL outputs) versus the number of points used in the fit. The data follows the same “1/√N” trend predicted by Equation 11.13.

Examining these Figures, the questions are: “Is this data linear?”, “How do we tell if it is or not?”, and “What do we do if it isn’t linear?” The answers to these questions are:

- The best single way to judge linearity is to simply inspect the data. This is particularly true if you see the same kind of data every day, so you can make a comparative as opposed to absolute judgment. It is easy to see how the use of the linear regression equation will affect the results. For example, if the change in Mass Inventory shown in Figure D-15 is smaller in the fit than it is in the raw data (which it is), you will get a reduced leak rate relative to the raw data. (The raw data implies an unidentified leak rate of about .069 gpm.) In similar fashion, Figure D-19 implies that the change in the fit is higher than the change in the raw data (since it “hits” the 10 hour point and is higher than the starting point). As shown, the fit value is .077 gpm. Of course, knowing how the results are affected doesn’t tell you which results are correct.
- A second approach is to use the “R²” value edited by EXCEL. This value is a measure of linearity as documented on p. 14 of Reference 18. (The R² value is

essentially the fraction of the scatter of the individual " y_i " (i.e., dependent variable) values about the average " y " value (i.e., y_{BAR}) which is explained by the regression. If every $\{y_i\}$ point landed exactly on the regression line, R^2 would be unity (i.e., 1). Thus, values close to 1 are good and small values of R^2 indicate that a linear fit of the data doesn't have much value in explaining the scatter in the $\{y_i\}$ data. That is, small values of R^2 can occur when the data is really linear but the linear behavior is overwhelmed by the "noise" in the data and, also, of course, when the data is highly nonlinear or truly uncorrelated with the independent variable.

- If you believe that the data is not linear and don't want to "throw in the towel," you can try the method shown in Figure D-16. This method is essentially free of any assumptions about the true time-dependent trend of the data and often reveals trends that aid in understanding why the data isn't linear. For example, Figure D-16 shows a smooth periodic sinusoidal variation which is almost exactly 2 hours "peak-to-peak" throughout the entire ten hour period. Without further analysis we can't be sure of the cause. However, after discussion with the cognizant Utility, it is not caused by any dilution cycle (mass addition) at BOL. Figure D-16 is based on an algorithm called "generalized cross-validation spline smoothing." The method basically starts from the raw data and tries to find a smooth "corner-free" fit to the data which minimizes the error between the raw data and the fit. References 19 and 20 provide all the details. The most important fact concerning this method is that it can be invoked with a simple subroutine call to a routine (i.e., subroutine "CSSCV") in the International Mathematics and Statistics Library (IMSL) – Reference 22. Most FORTRAN compilers which run in the PC environment already include this subroutine package. (The calculations shown in Figure D-16 were performed using the IMSL package installed on the Westinghouse UNIX workstations.) Note: the spline fit shows an increased leak rate relative to Figure D-15 and also has a better fit to the data based on the standard deviation of the errors shown on the two figures. The per cent standard deviations shown on Figures D-15 and D-16 are very small values because they are normalized to the RCS volume (approximately 63000 gal.)

Two final notes on linear regression are:

- Figure D-25 shows that linear regression of the data can lead to a large error if the data actually follows a linear trend up to just before the time of the last observation and the Operator tries to return to the original starting temperature at the end point. This error could be easily be avoided by not using linear regression if this maneuver is performed. As an alternative, reassigning the end point to an earlier time will eliminate the problem.
- The Palo Verde data shown in Appendix A is contaminated with "outliers." They eliminate these values by a series of linear regression calculations which find points outside the confidence bounds of the fit, delete them, and iterate until the slope and intercept stabilize. This process typically also rejects valid data points. An alternative, one step procedure to do this is described in Section 11.7.

11.7 Outlier (i.e., “Spike”) Screening and Elimination

The use of “exceedences” is expected to minimize the effects of “spikes” since the contribution of one single spike is reversed when a subsequent reading falls below the baseline mean (μ) (and the count of exceedences resumes at a value of one when the next observation above the mean (μ) occurs). However, the effect of a single large positive spike invokes Action Level III in (draft) NRC Appendix D.

In the event that such a spike is observed during the daily surveillance measurement, the mass inventories at the start and end time of the snapshot and the mass inventories at all intermediate points should be plotted versus time and examined. Mass inventories rather than leak rates (which use two mass inventory values) should be used since a corrupt mass inventory value potentially corrupts two leak rate values if a mass inventory is used as the “end point” in one calculation and as the “start point” in the next leak rate calculation. The graphical examination of the data should reveal if what appears to be an outlier is actually a trend supported by the remaining data. If the data is visually judged to be an outlier, it can be discarded and the remaining intermediate data can be used to determine a valid daily leak rate value. An alternate, more quantitative method is the application of “zscores” to detect outliers in any data set. This approach is described below for the examination of a set of quarterly data (i.e., 90 daily leak rate measurements) before the values are used to determine the updated mean and standard deviation for the upcoming quarter.

Section 10.1 notes that outliers should not be included in the long term statistical data set (which will ultimately be used to define the baseline mean and standard deviation). Of course, a visual inspection should always be the first step. But, if the daily leak rate data looks like Figure D-10 that might not be very revealing. An alternate quantitative approach is to calculate the “zscore” for each daily leak rate measurement in the current Quarter. Equation 11.3 defines the “zscore” calculation for a given daily value. That is, the values are effectively normalized by subtracting a mean (or “location value”) from each measurement and then dividing by a standard deviation (or “scale value”). Figure D-26 shows a calculation of “zscore” values for simulated data. The “y-axis” zscore data uses mean and standard deviation values from the current quarterly data (i.e., Apr – Jun) and the “x-axis” zscore data uses the mean and standard deviation from the previous quarter (i.e., Jan through Mar). All of the data falls along the “45 degree line” showing that using the last quarter mean and standard deviation or the current quarter mean and standard deviation produce about the same result when the current quarter data is well-behaved. (Typically, values with zscores greater than 2.5 or 3.0 and less than -2.5 or -3.0 are “suspect outliers” and need to be investigated. If daily leak rate values have zscores above 2.5 to 3.0 they may indicate that the leak rate has increased or they may simply be corrupted data. If daily leak rate values have zscores below -2.5 to -3.0 they indicate that the leak rate algorithm is probably not functioning in a reliable mode but they don’t imply that the leak rate has increased. Figure D-26 has no such values.

Figure D-27 shows what happens when the current quarter’s data has outliers and the zscores are calculated with the corrupted data from the current quarter. That is, outliers typically cause a significant increase in the standard deviation and may cause a significant shift in the mean. These changes in the current statistics distort the zscore calculation and the outliers tend to go undetected. That is essentially what happened in Figure D-27. (Note: the zscores on the y-axis

are “rotated” below the “45 degree line” because the outliers caused the Apr through Jun standard deviation to increase from 0.054 (Figure D-26) to 0.075 (Figure D-27).) The outliers shown in this simulated data set were randomly assigned to individual daily leak rate values. Each daily value which was selected (10 out of 90 data points) was increased by a random value ranging from $+2.5 \sigma$ to $+3.5 \sigma$. Note: all these outliers were positive so that both the mean and standard deviation were increased. This choice on our part seemed consistent with the only available data on outliers in mid-2005 (i.e., page A-2 in Appendix A). (The Standard Plant Activity documented in Appendix G provided additional information on the frequency of outliers.) **The key conclusion from Figure D-27 is that zscore screening for outliers should not use the mean and standard deviation of the contaminated data set.** In the example, using the previous quarter’s mean and standard deviation (which are not contaminated) to calculate the zscore data correctly identified the suspect points.

The question is: “What should we do if there is no comparable, uncontaminated data set?” The answer, contrary to the conventional wisdom, is that you should get MAD. Here, however, MAD means the “Median of all Absolute Deviations.” Recall that Equation 11.4 of Section 11.3.1 generalized the definition of zscore so that the value commonly used for μ could be replaced by some other “location value” and the value commonly used for σ could be replaced by some other “scale value.” Pages 16.3 and 16.4 of Reference 23 shows that using the median of the data set for the “location value” (rather than the mean) and MAD for the “scale value” (rather than the standard deviation) provides a “robust” estimator of the zscore data in that it is not typically distorted by outliers. Reference 23 defines MAD as:

$$\text{Eqn. 11.14 } \text{MAD}_\lambda(\{x_i\}) = \lambda \text{ median } |x_j - \text{median } \{x_i\}|$$

That is, the MAD of a data set is the median of the absolute difference between each member of the set and the median of the set. A multiplier of 1.0 – 1.5 (i.e., λ) is often used to force the value of MAD to agree with the conventional scale value (i.e., σ). Reference 23 shows a value of 1.483 for λ but we used a value of 1.0 in Figure D-28. Equation 11.14 is easily calculated with EXCEL.

Figure D-28 shows the result of using the median and MAD to recalculate all the y-axis zscore data plotted against the x-axis zscore data from Figure D-27. Note: σ in Figure D-27 is .075 whereas the value of MAD for the same data is .047. That explains why the data is now rotated to more than the “45 degree line.” The degree of rotation implies that a larger value of λ (> 1.0) should have been used in Figure D-28. However, if you use this approach to only detect potential outliers, it is probably acceptable to “over-identify” as long as you are careful in deleting suspect data.

A final note addresses a potential “one-iteration” method of identifying outliers in linear regression analyses. Note: outliers in linear regression calculations affect the intercept and slope of the data and force “good” data points to have larger residual errors than they would otherwise have. Figure 16.4 of Reference 23 shows an example where one outlier changes the linear regression curve so dramatically that the outlier looks like the only “good” point on the curve. (This kind of change is called a “leverage” error and could occur if all the x-axis time data were recorded in minutes and the 60 minute value was erroneously recorded as 1.0 (hour).) The

method is called “Least Median of the Squares” (LMS) fitting and involves finding slope and intercept values for the data set which minimize the median of the squares of the distance from each data point to the LMS line. The LMS line is characterized as being at the center of the narrowest strip which covers half of the data. Obviously, this method would be ideal for rejecting outliers. Reference 23 provides a source for software to perform the LMS calculation. IMSL (Reference 21) does not have a routine to perform this calculation. However, IMSL does have a number of nonlinear optimization routines which could be used to obtain the LMS solution. We did not attempt to perform these calculations.

The peer review documented in Appendix I notes that “outliers” should (in principle) not be thrown out unless some physical or conceptual reason for their generation can be identified or conjectured. See the discussion of “Page 76-78” in Appendix I.

11.8 Negative Leak Rate Results

Negative values should be included along with positive values in calculating the “baseline” values of mean and standard deviation. However, as discussed in Section 5 of Reference 25, no credit can be taken for negative daily average values when calculating the absolute leak rate (Section 5.2.1 of Reference 25) or the total integrated leakage (Section 5.2.3 of Reference 25).

A more detailed description of the rationale for retaining negative values in the calculation of the baseline mean and standard deviation is presented in Comment 6 in Appendix F. As noted in Appendix F, the NRC Guidelines do not include negative values in the calculation of the baseline values.

Table G-5 of Appendix G shows that one of the Standard Plant participants (Comanche Peak Unit 2) had a negative baseline mean (-.0005 gpm). Inspection of the associated plot of ULR versus time for this Unit (Figure G-18 of Appendix G) shows, as expected for normally distributed data with a small negative mean, that about ½ of all the data is negative and would be censored in the NRC scheme.

See also the discussion of this issue (i.e., “Comments on Appendix F”) in the peer review in Appendix I.

Customer Comment #163 of Appendix H documents that it is possible for real (i.e., non-spurious) in-leakage to occur in some plants. (It did occur at Palisades.) Obviously, censoring negative values in this situation would be inappropriate.

11.9 Optimal Calculation Duration and Data Collection Frequency

As discussed in Section 11 the “target” duration for the Standard Plant “snap shot” Process (which was used in the Standard Plant measurements described in Appendix G) is expected to be $[2 \pm 1]$ hours exactly once daily at the optimum time for stable plant conditions $[1 - 4 \text{ AM}]$. In addition, frequent intermediate sets of instrument data may be recorded (at intervals ranging from 1 to 15 minutes) if outliers are likely to occur. This data can be used to resolve “outlier” or “spiking” issues with the initial and final recorded time point data on an “as needed” basis or can be used routinely in a data smoothing algorithm such as linear regression to reduce the standard deviation of the daily surveillance results.

(We recognize that individual PWROG members use a variety of techniques to carry out the required surveillance measurements. As a result, the “exactly one high quality measurement over a period of approximately two hours each day” process is unlikely to be uniformly used in the future. However, it is important that all PWROG members report a “daily average” value which is determined in a consistent fashion day after day. If the “daily average” values are not consistent, the Action Levels in the NRC Guidelines are likely to be challenged even when no change in leakage has occurred.)

Figure D-29 shows a calculation of the unidentified leak rate based on the “typical plant data” in Figures D-1 through D-3. The calculation always used the “0 minutes” value as the starting point but varied the “ending point” from 15 minutes to 600 minutes. The Figure shows that the leak rate value reaches an asymptotic value after 2 to 3 hours and oscillates for the remainder of the 10 hour period. (These oscillations are correlated with the similar behavior observed in Figure D-16.) The conclusion from Figure D-29 is that little additional value is derived from leak rate surveillance intervals beyond 2 to 3 hours. In addition, there is an increased challenge to maintaining the conditions of validity as the length of the surveillance interval grows.

Appendix B, Derivation B.07 contains a brief derivation which documents the same conclusion shown in Figure D-29. That is, the measured leak rate over a given time interval is equal to the true leak rate plus a random component divided by the length of the surveillance interval:

$$\text{Eqn. 11.15 } \text{Leak Rate}_{\text{measured}} = \text{Leak Rate}_{\text{true}} + (\hat{u} \cdot \sigma) / \text{Length of Interval}$$

This equation shows that as the length of the interval increases, it will “damp out” the effects of the uncertainties associated with the measurement. (The symbol \hat{u} in Equation 11.15 represents a normal deviate with mean 0.0 and standard deviation of 1.0.) A similar result was observed in Section 11.6 where we showed that a measurement of any length was contaminated by a “6.8 gallon” fluctuation. Therefore short intervals (15 minutes) had large leak rates whereas long intervals (2 hours) had acceptably small leak rates. Note: both of these investigations implicitly ignore whatever is causing the oscillations in Figure D-16.

11.10 Multiple Channel Averaging

If multiple instrument channels are available for the same input parameter, and each channel has the same range and is known to be equally accurate, then, the average value of all redundant input channels should be used. Multiple channels averaging tends to null instrument noise, single channel bias, and coarse node effects (few instruments measuring conditions in large control volume). Examples where this technique may apply are: pressurizer level (channel X and Y), pressurizer pressure (multiple safety channels and control channels) and reactor coolant system temperatures (multiple hot leg and cold leg temperatures).

11.11 Time Averaging

Averaging data over short intervals tends to null the effect of instrument noise and small transient effects and provide more representative data than instantaneous snap-shot data. Time averaging should only be used when the measured parameter is assumed to be stable (not

changing) and the time over which the average value is taken is short with respect to the dynamic response of the plant. During controlled steady state operation a one minute average is typically used. Longer averaging times should be used with care to ensure that averaging is not masking real change. (Figure G-14 in Appendix G compares 1 second to 60 second average Tave values. By inspection, there is a significant difference between these values in that the 60 second average has a much smaller standard deviation. Figure G-14 is discussed in Section G-5 of Appendix G.)

11.12 Recommendations

These Recommendations are not mandatory.

The principal recommendation is to report exactly one high quality (i.e., well within the limits of validity) measurement over a period of approximately two hours each day. The preferred time for the two hour snapshot is during the mid-shift around 1:00 AM to 3:00 AM each day. If the fluctuations in these daily values are acceptable and if the probability of observing “outliers” or otherwise erroneous results is historically small, nothing more is required. However, this section lists a number of simple data checks that can be performed to track and provide “early warning” of any changes in the unidentified leak rate.

The recommendation that “exactly one high quality measurement be reported each day” doesn’t mean that members should not perform lower quality “continuous monitoring” measurements as often as desired. In addition, the surveillance measurements used to document compliance with the Technical Specifications do not necessarily have to be based on the recommended measurement. **What is intended is that each member utility report similar “standardized” daily measurements as part of the Standardization process developed in this project. These measurements allow a meaningful comparison of leak rates across the membership.**

Additional data recording and evaluations which can be used to detect and eliminate outliers, provide insight into any anomalous behavior observed in the leak rate trends and demonstrate the validity of models used to evaluate the minimum level of detectability and other similar results herein are:

1. Intermediate instrument readings or the associated mass inventory values can be recorded at intermediate time points ranging from every minute to every 15 minutes during the 2 hour daily surveillance measurement. (These values can be used to investigate any anomalies observed in the “start” and “end” time data and/or used in linear regression calculations.)
2. Any data used in linear regression evaluations to determine the leak rate during the 2 hour surveillance interval should be assessed for linearity. This should always include at least a visual check of the data by personnel familiar with the daily observations.
3. The Quarterly data for the current quarter should be screened using the “F-test” and “two sample t-test” described in Section 11.4 before the associated mean and standard deviation are used in the next Quarter. (This screening can be performed with EXCEL.) The results should be recorded for future use. An investigation and assessment should be performed if either test fails. Appendix G, Sections G-3 and G-5 provide details on how

to easily perform these tests with Excel and how to interpret the results. See also the discussion of this topic in the peer review of Appendix I. (That is, at “Page 19” of the comments on WCAP-16465-Section 5.)

4. The daily ULR data should be visually examined for outliers and screened using the extrinsic screening algorithm described in Equation 11.3 of Section 11.3.1 and Equation G.4 of Appendix G, Section G-3.4. A zscore value of +2.0 or higher should be investigated following the method described in Section 10.1, Rule 3. Results of any outlier rejection or assessment should be recorded.
5. The Quarterly data should be tested for normality using the simple procedure in Reference 15 and in the Template Excel file in Section G-11 of Appendix G. In addition, the simple statistical edits from Excel which provide the kurtosis, skewness, mean and median should be examined to ensure that the limits obey Equations G.1, G.2.b and G.3.b.
6. The “24 hour data” described in Appendix G, Section G-4 and G-5 and Figures G-9 to G-13 should be recorded if possible. Based on observations at Seabrook, this data corroborates the daily 2 hour snapshot measurement and, also, provides an “event trap” for any event that perturbs the RCS inventory throughout the entire operating cycle.
7. Observed “runs” of length 5 and 7 above the baseline mean should be carefully examined. Although Section G-4 concludes that runs of length 5 may be false alarms, they should still be used to whet your curiosity. If the run extends to 7, you have 2 more days to Action Level I. More investigation is called for at this point.

Other points to consider are:

The Quarterly “two hour” snapshot data does not need to be examined for “statistical independence.” However other types of ULR data where the ending point of one interval is used as the starting point for the next interval can be examined for statistical independence. An example of this simple process is shown in Figure D-30. In this Figure, the “odd day” measurements (i.e., 1, 3, 5, ...) are plotted on the x-axis and the following “even day” value is plotted on the y-axis. As shown on the Figure, the Quarterly mean should be used as the origin of co-ordinates. The Figure demonstrates that these paired values are independent since knowing the odd value provides no information on the associated even value. Using the specified origin of co-ordinates should result in approximately an equal number of points in each quadrant which is also demonstrated in the Figure. (Figure D-31 shows the same crossplot for the typical plant data used throughout the analysis. This data indicates that, whenever the odd data is above the mean, the following even data is likely to be below the mean (i.e., there are too many data points in the fourth quadrant). This correlation is probably occurring because a given point is used as both the end point of one leak rate calculation and the start point of the next.)

“Weekly rolling average” and “weekly average” plots and “Monthly rolling average” and “monthly average” plots similar to Figures D-11 through D-14 can be maintained since they help in identifying any trends.

11.13 Kalman Filter

In early 2006, we were asked by a Member to consider the use of Kalman Filtering to reduce the “noise” in the daily ULR values. Several discussions were held with Westinghouse engineers familiar with the method. The general conclusion was that it would be relatively complicated to carry out relative to other simple methods such as the use of “rolling average” or “linear regression”.

We also examined several web sites to find information on the use of Kalman Filters for simple problems like the one at hand (i.e., a more or less constant “true” value contaminated by a significant amount of white (i.e., normally distributed) noise. The following internet address provides a good description of the application of Kalman filtering to that simple situation:

http://www.cs.unc.edu/~welch/media/pdf/kalman_intro.pdf

See also the discussion of Kalman filtering in Customer Comment #174 of Appendix H and the peer review discussion regarding “Page 82-83” in Appendix I.

12. REFERENCES

1. Westinghouse Owners Group Project Authorization, Standardization of RCS Leak Rate Program, No. PA-OSC-0189, Revision 0, October 2004.
2. 10 CFR 50 Appendix A, General Design Criteria 30
Criterion 30 – Quality of reactor coolant pressure boundary. Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.
3. NIST/ASME Steam Properties, Standard Reference Database 10, Version 2.11.
4. NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee," U.S. Nuclear Regulatory Commission, (Vol. 1) August 1984, (Vol. 2) April 1985, (Vol. 3) November 1984, (Vol. 4) December 1984, (Vol. 5) April 1985.
5. NUREG-0800, Standard Review Plan 3.6.3, Leak-Before-Break Evaluation Procedures.
6. B. Noble, Applied Linear Algebra, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1966.
7. A. Hald, Statistical Theory with Engineering Applications, J. Wiley & Sons, N.Y., N.Y., 1952.
8. W. L. Greene, R. K. Endter, "Uncertainties for Auctioneered Instruments," GM-FE-0244, July 15, 1996. (Also included in Appendix A herein.)
9. K. Ishikawa, Guide to Quality Control, Quality Resources, White Plains, N.Y., 1991.
10. E. M. Schrock, Quality Control and Statistical Methods, Waverly Press, Inc., Baltimore, Md., 1957.
11. R. K. Endter, "Rule of 59" – Distribution-Free Tolerance Limits," RPP-79-163, September, 1979. (Also in Appendix A – see Eqn. 3-B – Eqn. 8-B).
12. M. Mazumdar, "Use of Statistical Theory of Extremes in Hot Channel Analysis of a Liquid Metal Fast Breeder Reactor," Nuclear Science & Engineering, Vol. 47, p. 187-194, 1972.
13. G. E. P. Box and M. E. Muller, "A Note on the Generation of Random Normal Deviates," The Annals of Mathematical Statistics, Vol. 29, pp.610-611, 1959.
14. M. G. Natrella, Experimental Statistics, National Bureau of Standards Handbook 91, U. S. Department of Commerce, Washington, D. C., 1966
15. American National Standards Institute "Assessment of the Assumption of Normality," ANSI N15.15-1974, 1973.
16. R. E. Odeh & D. B. Owen, Tables for Normal Tolerance Limits, Sampling Plans, and Screening, Marcel Dekker, Inc. N. Y., N. Y., 1986.
17. W. Feller, An Introduction to Probability Theory and Its Applications, John Wiley & Sons, Inc., N. Y. N. Y., (Vol. 1), 1957.

18. N. R. Draper & H. Smith, Applied Regression Analysis, J. Wiley & Sons, Inc., N.Y., N.Y., 1966.
19. P. H. Merz, "Spline Smoothing by Generalized Cross-Validation, A Technique for Data Smoothing," Chevron Research Company, Richmond, California, Revision 1, May 1982.
20. P. Craven & G. Wahba, "Smoothing Noisy Data with Spline Functions," *Numerische Mathematik*, Vol. 31, pp.377-403, 1979.
21. International Mathematics and Statistics Library (IMSL), Houston, Texas, 1989.
22. G. J. Hahn & S. S. Shapiro, Statistical Models in Engineering, J. Wiley & Sons, N.Y., N.Y., 1967.
23. P. J. Rousseeuw, "Robust Estimation & Identifying Outliers," (Chapter 16 in: The Handbook of Statistical Methods for Engineers and Scientists, McGraw-Hill, Inc., N.Y., N.Y., 1990.
24. R. Perez, "Archival of Electronic Files Associated with WCAP-16423-NP," LTR-TAS-06-65, September 26, 2006. .
25. WCAP-16465-NP, "PWROG Standard RCS Leakage Action Levels and Response Guidelines for Pressurized Water Reactors," September 2006.
26. R. A. Fisher, Contributions to Mathematical Statistics, J. Wiley & Sons, N.Y., N.Y., 1950.
27. H. A. David, Order Statistics, J. Wiley & Sons, N.Y., N.Y., 1981.
28. 00000-ICE-36156, Revision 0, "Code to Analyze One-Dimensional Statistical Data – Error," June 12, 1981.
29. Norman L. Johnson, University of North Carolina, Chapel Hill and Samuel Kotz, Temple University, Philadelphia, Continuous Univariate Distributions-1, Houghton Mifflin Company, Copyright 1970.
30. NRC Regulatory Issue Summery (RIS) 2003-13, NRC Review of Responses Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity".
31. NUREG/CR-6592, "Assessment of Pressurized Water Reactor Primary Systems Leaks".
32. "Action Plan for Addressing Davis-Besse Lessons Learned Task Force Recommendations Regarding Assessment of Barrier Integrity Requirements," 8/15/2003 update.

13. ATTACHMENTS

None

APPENDICES

Appendix A: Excerpts from (draft) NRC Documents, Documentation Supplied by the PWROG Members, and from Westinghouse Documents	A-1
Appendix B: Derivations of Statistical Relationships	B-1
Appendix C: Effects of Measurement Errors on the Unidentified Leak Rate.....	C-1
Appendix D: Figures and Plots from Section 11	D-1
Appendix E: Description of the Computer Codes used in Section 11	E-1
Appendix F: NRC Final Guidelines.....	F-1
Appendix G: Standard Plant Testing	G-1
Appendix H: Comments from PWROG Members.....	H-1
Appendix I: Peer Review Comments (K.K. Perdue)	I-1

Appendix A

**Excerpts from (draft) NRC Documents, Documentation Supplied by
the PWROG Members and from Westinghouse Documents**

(Best Available Copies)

P-A-12

Attachment -1

Assessing Reactor Coolant System (RCS) Unidentified Leakage Rate Trend

In order to track and assess the unidentified leak rate trend, the inspectors should utilize existing licensee's performance trend analysis of plant RCS leakage rate data. The inspector should obtain the mean value (μ) for the past 3 months of RCS unidentified leakage rate and the corresponding standard deviation (σ) from the licensee, on a quarterly basis. The mean value (μ) and the standard deviation (σ) are defined by the following equations:

$$\mu = (x_1 + x_2 + \dots + x_n)/n; \quad \sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{n}}$$

assuming the unidentified leakage rate, x , is a random variable which has a mean value, μ , and known standard deviation, σ .

Once a quarter, the inspectors will use the mean value (μ) and the standard deviation (σ) to calculate the three action level triggers. The action levels were determined by statistical analysis:

- | | |
|--------------------------|--|
| Action Level I: | Nine (9) consecutive leakage measurements above the mean μ |
| Action Level II: | Two (2) of three (3) consecutive measurements exceed the $\mu + 2\sigma$ |
| Action Level III: | One (1) measurement of leak rate exceeds the $\mu + 3\sigma$ |

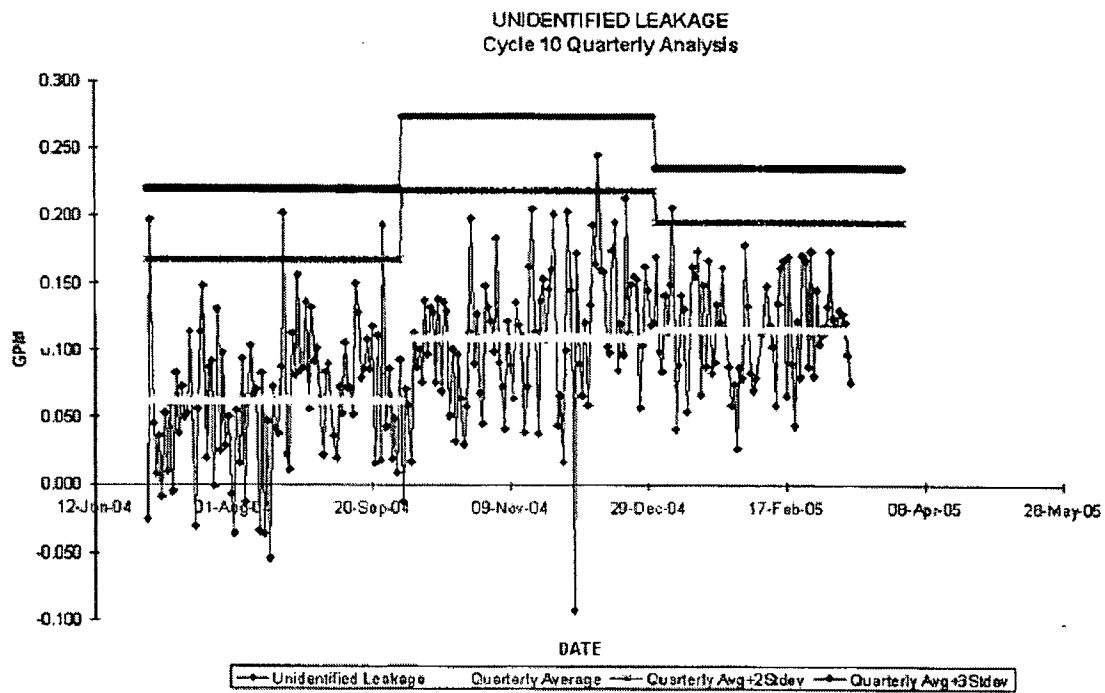
During the daily plant status review, the inspector should compare the licensee calculated RCS unidentified leakage rate data to the three action level triggers to determine if there is a potential adverse trend and take appropriate actions.

For the purpose of the daily plant status, the most conservative leak rate value for a given day should be used for this assessment. If the licensee performs the RCS leakage rate calculations hourly, the inspector should only compare one RCS leakage rate data per day to the action level triggers. If the licensee, following their Technical Specification, only performs a RCS leakage rate calculation once per 72 hours, then the inspector should perform this comparison once per 72 hours.

Upon reaching one of the action level triggers, the inspector should consider the following actions to ensure that licensees are monitoring and taking appropriate actions to bring the leakage down when statistically significant leakage trends exist and to ensure that the proper levels of NRC management are informed of potential adverse trends in RCS leakage.

PA-23

Typical Plant Data



D-A-34 Linear Regression Description

7.3.1 Introduction

7.3.1.1 Purpose

The RCSLEAK calculation has been developed to provide an automated calculation of the Total RCS leak rate and the Unidentified leak rate.

7.3.1.2 Description

ERFDADS performs a linear regression on the input points to RCSLEAK to calculate a slope (rate of change) over the time period input by the user.

The basic equation is: Leak Rate = (final volume- initial volume) / delta time

Inputs

<u>SPDS0260</u>	RCS LIQUID VOLUME
<u>SPDS0261</u>	PRESSURIZER LIQUID VOLUME
<u>SPDS0262</u>	VCT LIQUID VOLUME
<u>SPDS0263</u>	SIT'S LIQUID VOLUME
<u>SPDS0265</u>	RDT LIQUID VOLUME
<u>SPDS1750</u>	TOTAL RCS LIQUID VOLUME
<u>SPDS1751</u>	SUM OF RDT AND SIT

RCSLEAK Regression output data sheet

Algorithms

See Linear Square Fit Analysis for a description of the Regression Analysis for RCS Leak. (Sect. 7.4)

RCSLEAK Regression output data sheet

Total Leak Rate = linear regression calculated slope of SPDS1750 * -(60)

Where the calculated slope is in gallons/second.

60 is a conversion factor to convert from seconds to minutes to obtain a gallons/minute leak rate.

Standard convention is to have leakage out of the system shown as a positive leak rate. From the basic equation described above, leakage out of the system will result in a smaller final volume. This produces a negative leak rate (regression function will calculate a negative slope). In order to obtain the desired standard convention (positive value), the regression calculated slope is multiplied by a negative value.

Identified Leak Rate = linear regression calculated slope of SPDS1751 * 60

Where the calculated slope is in gallons/second.

60 is a conversion factor to convert from seconds to minutes to obtain a gallons/minute leak rate.

If the slope of SPDS1751 is negative, then the value of Identified Leak Rate = 0.

7.4 Regression Analysis for RCS Leak

This Section documents the Linear Regression (Least Squares Fit) performed in ERFDADS

p-A-X 5

7.4.1 Introduction

Previous versions of ERFDADS had a statistical package designed to perform linear regressions of any selected number of variables. One of the main uses of the regression algorithm was to perform a linear regression of the total RCS volume to infer the leak from the system. The program was designed to recognize a number of specific variables, like the RCS volume, to perform a couple of additional computations in order to aid the operators with the RCS Leak Surveillance Test.

The routines had some minor problems and limitations, like the fact that all the data was used even when some abnormal data spikes were present. These spikes could erroneously bias the data in one direction and miscalculate the actual system leak. The routines presented here fix those problems. These routines have been made common between the ERFDADS and the RMS system. The RCS leak test is the only ERFDADS specific coding section that only executes when a set of three ERFDADS specific variables is requested. Since these particular variables are not part of the RMS system, it is not possible for this section of the code to execute while running on the RMS system.

7.4.2 Formula Derivation

Assume that there is a linear relationship between the two variables x and y . The relationship between these variables can be defined by the straight-line equation:

$y = ax + b$. The parameters of this equation are calculated by minimizing the sum of the square of the errors.

For every x_i , there is an observation y_i . For the same x_i , the predicted value from the linear relationship is $ax_i + b$, and the error between the prediction and the observation is defined by:

$$E = y_i - (ax_i + b)$$

The least square fit is calculated by minimizing the sum of the square of the errors, that is minimizing the function SSE, defined as:

$$SSE = f(a, b) = \sum [y_i - (ax_i + b)]^2$$

The values of a and b that minimize this function are calculated by equating to zero the partial derivatives of this function with respect to each one of the variables a and b .

$$\begin{cases} \frac{\partial f(a, b)}{\partial a} = 0 \\ \frac{\partial f(a, b)}{\partial b} = 0 \end{cases}$$

Expanding the function SSE, we obtain:

$$SSE = f(a, b) = \sum [y_i^2 + (ax_i + b)^2 - 2y_i(ax_i + b)] = \sum [y_i^2 + a^2x_i^2 + b^2 + 2abx_i - 2ax_iy_i - 2by_i]$$

Taking the partial derivatives, produces,

p-A-8 6

The 99% prediction interval is the area in which you expect 99% of all data points to fall. This is different than the 99% confidence interval, which is the area that has a 99% chance of containing the true regression line.

From the book "Applied Regression Analysis" by N. R. Draper and H. Smith (page 30), the predicted value of an individual observation is given by:

$$\hat{y}_0 \pm t(\nu, 0.99) \left\{ 1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{\sum (x_i - \bar{x})^2} \right\}^2 s$$

Where ν is the number of degrees of freedom on which s is based, and $t(\nu, 0.99)$ is the two-sided probability for 99% confidence. For a large number of points, $t(\nu, 0.99) = 2.576$.

7.4.4 Building Blocks for Computations

To avoid round off errors, some formulas can be substituted when performing calculations. The following terms are all equivalent.

$$\begin{aligned} S_{xy} &= \sum (x_i - \bar{x})(y_i - \bar{y}) \\ &= \sum (x_i - \bar{x})y_i \\ &= \sum x_i(y_i - \bar{y}) \\ &= \sum x_i y_i - (\sum x_i)(\sum y_i) / n \\ &= \sum x_i y_i - n\bar{x}\bar{y} \end{aligned}$$

Similarly we can write

$$\begin{aligned} S_{xx} &= \sum (x_i - \bar{x})^2 \\ &= \sum (x_i - \bar{x})x_i \\ &= \sum x_i^2 - (\sum x_i)^2 / n \\ &= \sum x_i^2 - n\bar{x}^2 \end{aligned}$$

And

$$\begin{aligned} S_{yy} &= \sum (y_i - \bar{y})^2 \\ &= \sum (y_i - \bar{y})y_i \\ &= \sum y_i^2 - (\sum y_i)^2 / n \\ &= \sum y_i^2 - n\bar{y}^2 \end{aligned}$$

The easily remembered formula for σ is then

p. A-67

$$a = S_{xy} / S_{xx}$$

The solution for b , the intercept at $x = 0$ of the fitted straight line, is

$$b = \bar{Y} - a\bar{X}$$

7.4.5 Testing

The Least Square Fit algorithm and the algorithm for spike elimination were tested by comparing them against the results from an EXCEL spreadsheet. The strategy of data elimination was performed by means of a macro that simply copied data from one region to another and repeated the least square fit in an iterative fashion. The statistical routines used in EXCEL are built-in functions and therefore the verification can be considered as an independent calculation.

The following sections contain three different test cases that were analyzed to show that the statistics routines were programmed correctly into ERFDADS. These test cases also show that the strategy for elimination of spike data works as expected.

For each one of the test cases, a summary of the calculations performed by ERFDADS is shown first continued by a series of graphs and numeric results from EXCEL.

7.4.5.1 TEST CASE 1

This test case presents data with two spikes. One of the spikes is located close to the center of the time series while the second spike is positioned on the right half. Intuitively, this second spike in particular would make the LSF line to be flatter than if it were calculated without the spike data. This is proved correct later when removing the spikes, since the slope becomes more positive.

The correctness of the algorithms coded into ERFDADS is verified by comparing the value of the slope at each one of the various iterations performed. The printout from ERFDADS shows the statistics for a number of variables; however, the EXCEL spreadsheet only calculates the statistics for the variable SPDS1751, which is the one used in the comparison.

The data table just under each one of the graphs shows the slope and intercept results for the original raw data (iteration 1) and the results after the points outside the 99% confidence have been eliminated (iteration 2). The data eliminated consists of all the points outside the two lines marked as "Upper 99%" and "Lower 99%".

This process is iterative. This means that the next graph, the one labeled as iteration 2, contains as raw data the data that was labeled as 99% confidence data in the graph for iteration 1. This process is repeated 4 times and it can be seen that the results from EXCEL and ERFDADS are identical in all cases.

An additional iteration, iteration 5, is performed only in the EXCEL spreadsheet to show that even though a few more "good points" are rejected, the final result is basically unchanged.

7.4.5.1.1 Test Case 1 - ERFDADS Results

Tue Jan 11 10:47:59 2000 1

ARCHIVE RETRIEVAL STATISTICS (raw data)

START TIME: 01/11/00 07:11:57
END TIME: 01/11/00 09:11:57
DURATION: 0002:00:00
RESOLUTION: 00.00:01.0

DATASETS RETURNED: 7201

POINTNAME	UNITS	DESCRIPTION	SPDS0260	SPDS0261	SPDS0262	SPDS0263	SPDS0265	SPDS1750	SPDS1751
SPDS0260	GAL	RES LIQUID VOLUME (EXCL PER)	7201	7201	7201	7201	7201	7201	7201
SPDS0261	GAL	PRESSURIZED LIQUID VOLUME	0	0	0	0	0	0	0
SPDS0262	GAL	NET LIQUID VOLUME	4.609E+04	3.246E+03	3.780E+03	6.693E+04	1.404E+03	7.312E+04	6.063E+04
SPDS0263	GAL	LIQUID VOLUME IN SI TANKS	1.309E+01	8.360E+00	1.543E+01	6.010E+01	5.710E+00	2.671E+01	6.024E+01
SPDS1750	GAL	NET LIQUID VOLUME	-2.481E+03	1.321E+03	8.893E+03	-5.425E+04	2.736E+03	5.012E+03	5.194E+03
SPDS1751	GAL	RES TOTAL VOLUME EDT & SIT VOLUME	4.609E+04	3.241E+03	2.740E+03	5.994E+04	1.404E+03	7.202E+04	6.063E+04
MEAN			4.609E+04	3.246E+03	3.780E+03	6.693E+04	1.404E+03	7.312E+04	6.063E+04
STD DEVIATION			1.309E+01	8.360E+00	1.543E+01	6.010E+01	5.710E+00	2.671E+01	6.024E+01
SLOPE			-2.481E+03	1.321E+03	8.893E+03	-5.425E+04	2.736E+03	5.012E+03	5.194E+03
INTERCEPT			4.609E+04	3.241E+03	2.740E+03	5.994E+04	1.404E+03	7.202E+04	6.063E+04
REGRESS STD DEV			1.309E+01	7.739E+00	1.731E+01	6.009E+01	4.914E+01	3.088E+01	4.007E+01
SLOPE STD DEV			6.832E+03	4.387E+03	9.555E+05	3.407E+04	2.788E+04	1.184E+04	3.458E+04
SLOPE 95 PCT CONF			1.309E+04	8.393E+03	1.938E+04	6.077E+04	3.453E+06	1.350E+04	6.674E+04
CONF. COEFF.			-0.390668	0.378182	0.731663	-0.016767	0.396221	0.633576	0.675708
MODEL			weak	weak	moderate	weak	strong	moderate	weak

ARCHIVE RETRIEVAL STATISTICS AFTER REMOVAL OF SPIERS (3 iterations)

START TIME: 01/11/00 07:11:57
END TIME: 01/11/00 09:11:57
DURATION: 0002:00:00
RESOLUTION: 00.00:01.0

DATASETS RETURNED: 7201

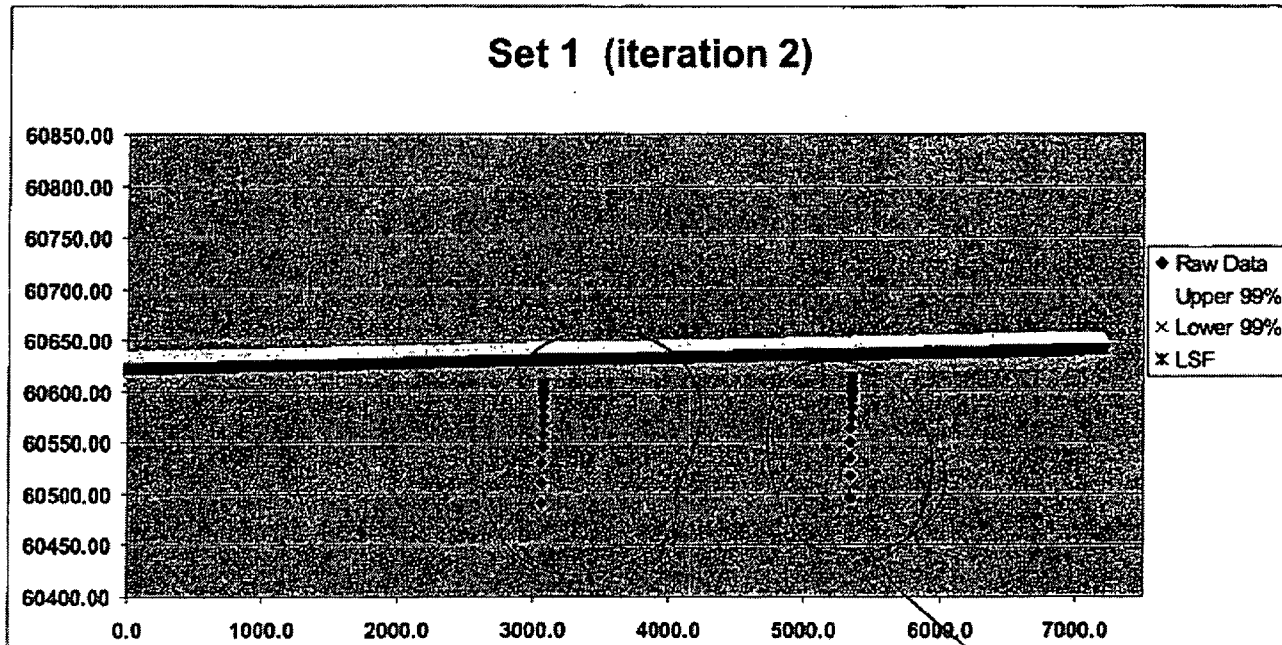
POINTNAME	UNITS	DESCRIPTION	SPDS0260	SPDS0261	SPDS0262	SPDS0263	SPDS0265	SPDS1750	SPDS1751
SPDS0260	GAL	RES LIQUID VOLUME (EXCL PER)	7166	7145	7067	7169	7162	7083	7169
SPDS0261	GAL	PRESSURIZED LIQUID VOLUME	36	54	134	32	39	118	32
SPDS0262	GAL	NET LIQUID VOLUME	4.609E+04	3.246E+03	3.778E+03	6.694E+04	1.404E+03	7.312E+04	6.063E+04
SPDS0263	GAL	LIQUID VOLUME IN SI TANKS	1.309E+01	8.134E+00	1.276E+01	6.009E+01	5.709E+00	2.674E+01	6.024E+01
SPDS1750	GAL	NET LIQUID VOLUME	-2.483E+03	1.494E+03	8.828E+03	-1.001E+04	2.736E+03	5.012E+03	5.194E+03
SPDS1751	GAL	RES TOTAL VOLUME EDT & SIT VOLUME	4.609E+04	3.241E+03	2.740E+03	5.994E+04	1.404E+03	7.202E+04	6.063E+04
MEAN			4.609E+04	3.246E+03	3.778E+03	6.694E+04	1.404E+03	7.312E+04	6.063E+04
STD DEVIATION			1.309E+01	8.134E+00	1.276E+01	6.009E+01	5.709E+00	2.674E+01	6.024E+01
SLOPE			-2.483E+03	1.494E+03	8.828E+03	-1.001E+04	2.736E+03	5.012E+03	5.194E+03
INTERCEPT			4.609E+04	3.241E+03	2.740E+03	5.994E+04	1.404E+03	7.202E+04	6.063E+04
REGRESS STD DEV			1.076E+01	7.520E+00	1.323E+01	4.594E+00	4.769E+01	1.706E+01	4.577E+01
SLOPE STD DEV			6.129E+03	4.371E+03	7.800E+05	3.109E+04	2.710E+04	9.673E+03	3.397E+04
SLOPE 95 PCT CONF			1.198E+04	8.370E+03	1.470E+04	5.098E+03	3.312E+04	1.894E+04	5.060E+04
CONF. COEFF.			-0.433171	0.582534	0.813611	-0.046416	0.096506	0.595681	0.787977
MODEL			weak	weak	strong	weak	strong	moderate	moderate

P-A-78

P-A-9

Outliers

7.4.5.1.3 Test Case 1 (Iteration 2) – Excel Results

**original data**

points 7169
 Slope 2.636E-03
 Intercept 6.062E+04
 Leak 0.158

spike eliminated**(99% confidence data)**

points 7138
 Slope 2.669E-03
 Intercept 6.062E+04
 Leak 0.160

NEASS334

ABB

Combustion Engineering, Inc. Nuclear Power Systems	
QUALITY RECORD	
Date 8/8/96	Article HVC

Inter-Office Correspondence

To: M. Golbabai

p-A-10

R. K. Endter
W. L. Greene
 cc: M. A. Book
 D. Bojjacasa
 M. R. Kutwich
 E. P. Hunger
 K. M. Randall
 J. C. Arpin
 H. F. Shamro
 QR(2)

 July 15, 1998
 GM-FE-0244
 Revision 00

Subject: Uncertainties for Auctioneered Instruments

This memo will define the relationship between the uncertainty on a single instrument channel and the uncertainty on the result of auctioneering several similar instrument channels.

Auctioneering is defined as taking the lowest reading of a set of similar instruments when a low reading is conservative or the highest reading of a set of instruments when a high reading is conservative.

Take n instruments with identical uncertainties given by probability distribution $p(x)$. From Reference 1, page 91, equation 5.2.3 gives the cumulative probability distribution $P(x)$:

$$P(x) = \int_{-\infty}^x p(x) dx \quad \text{Equation 1}$$

Making the following definitions:

$I_n(x)$ = distribution function for lowest of n instruments
 $L_n(x)$ = cumulative distribution for lowest of n instruments
 $u_n(x)$ = distribution function for highest of n instruments
 $U_n(x)$ = cumulative distribution for highest of n instruments

Applying equation 5.2.17 from Reference 1, page 94, with $m=1$ gives:

$$I_n(x) = n(1 - P(x))^{n-1} p(x) \quad \text{Equation 2}$$

$$u_n(x) = nP(x)^{n-1} p(x) \quad \text{Equation 3}$$

where P, p are the cumulative and frequency distributions of a single instrument.

P-A-11

GM-FE-0244
Page 2

Integrating equations 2 and 3 gives:

$$L_n(x) = -(1 - P(x))^n + C_L \quad \text{Equation 4}$$

$$U_n(x) = P(x)^n + C_U \quad \text{Equation 5}$$

where C_L and C_U are constants of integration.

Applying boundary conditions $L_1(x) = U_1(x) = P$, we obtain: $C_L = 1$, $C_U = 0$. Therefore equations 4 and 5 give:

$$L_n(x) = 1 - (1 - P(x))^n \quad \text{Equation 6}$$

$$U_n(x) = P(x)^n \quad \text{Equation 7}$$

These equations are not based on any conditions on P , p except that they are the same for all instruments and that the uncertainties in similar instruments are uncorrelated (i.e., independent).

For a typical application of equations 6 and 7, assume that the frequency distribution for the n instruments is normal with zero mean ($\mu = 0.0$) and standard deviation σ . Assume that the n sensors are auctioneered high and that we want to determine the error E which sets the lower bound at a 95% probability on the auctioneered-high indication. That is, 95% of the time, the auctioneered high error will exceed E . For one sensor, this value is -1.645σ . As more sensors are included this value increases and, as shown below, becomes positive for 5 or more sensors.

Define a new variable (unitary, normalized):

$$x = (Error - \mu)/\sigma$$

$$Mean(x) = 0$$

$$\sigma(x) = 1$$

Since 95% of E is above the desired value, equation 7 gives:

$$U_n(x) = P(x)^n = .05 \quad \text{Equation 8}$$

or

$$P(x) = (.05)^{1/n} \quad \text{Equation 9}$$

Using equation 9 and Table III of Reference 2, the fractiles of the normal distribution can be determined for various values of n :

p-A-12

GM-FE-0244
Page 3

Fractiles of the Normal Distribution		
<i>n</i>	<i>P</i>	<i>x</i>
1	.05	-1.645
2	.2238	-0.76
3	.3684	-0.336
4	.4729	-0.068
5	.5493	0.124

Since these fractiles are based on a normalized standard deviation, they can be used as multipliers on the standard deviation of an instrument to determine the value by which the auctioneered high value of a set of *n* instruments reads low.

Similarly, to find the error *E* such that for the auctioneered minimum of *n* instruments there is a 95% probability that the auctioneered low error will be below *E*:

Since 95% of *E* is below the desired value, equation 6 gives:

$$I_n(x) = 1 - (1 - P(x))^n = .95$$

Equation 10

or

$$P(x) = 1 - (.05)^{1/n}$$

Equation 11

Using equation 11 and Table III of Reference 2, the fractiles of the normal distribution can be determined for various values of *n*:

Fractiles of the Normal Distribution		
<i>n</i>	<i>P</i>	<i>x</i>
1	.95	1.645
2	.7764	0.76
3	.6316	0.336
4	.5271	0.068
5	.4507	-0.124

Since these fractiles are based on a normalized standard deviation, they can be used as multipliers on the standard deviation of an instrument to determine the value by which the auctioneered low value of a set of *n* instruments reads high.

Example:

For 3 pressurizer pressure instruments, each with an uncertainty of 35.6 psi (2σ , 0 mean), the auctioneered minimum of the 3 readings would have a 95% probability of reading high by less than:

$$(35.6 / 2) \times .336 \text{ psi}$$

or:

$$5.98 \text{ psi}$$

P-A-13

GM-FE-0244
Page 4

This result was also confirmed by a direct simulation of the auctioneered sensor uncertainties. Details of the simulation are available from the authors.

References

1. A. Hald, "Statistical Theory with Engineering Applications," John Wiley & Sons, Inc., New York, 1952.
2. A. Hald, "Statistical Tables and Formulas," John Wiley & Sons, Inc., New York, 1952.

Interoffice Correspondence



P-A-14

To: J. P. Pasquenza B

R. K. Endter

cc: J. F. Church B
W. R. Concoran C
R. G. Foster C
R. Goldstein B
J. J. Herbst C
R. W. Knapp C

September 19, 1979

RPP-79-163

"Rule of 59"Distribution-Free Tolerance Limits

770749-T

INTRODUCTION

The purpose of this memo is to inform you of the "Rule of 59" and to describe several work areas where the "Rule" might be applied in order to: achieve savings in manpower/computer expenditures, improve the technical accuracy of design procedures, and improve response capability to operational problems.

Briefly, the "Rule of 59" states that there is a 95% probability that the smallest of 59 random samples from any continuous* population is less than 95% of the population. Thus it is possible to obtain a "95/95" one-sided (lower) tolerance limit for any continuous population by drawing 59 random samples and setting the limit to be the smallest value observed. Similarly, the largest of the 59 values is a "95/95" one-sided (upper) tolerance limit.**

The "Rule" is a special case resulting from the application of the binominal distribution to random sampling from arbitrary distributions. Details are available in Ref. 1-5.

* Recent publications in the literature generalize the statement to cover discrete populations. These publications are currently on order.

** A brief derivation of the "Rule of 59" is presented in Appendix A.

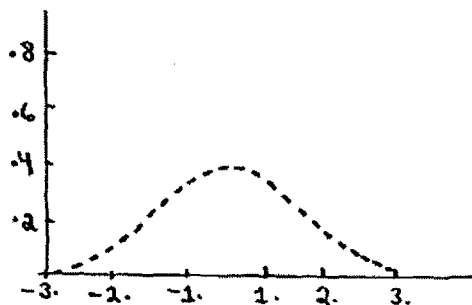
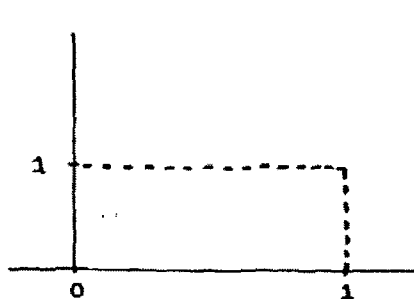
p-A-15

CONCLUSIONS

1. The "Rule" was tested for the upper and lower tails of each of the following four continuous distributions:

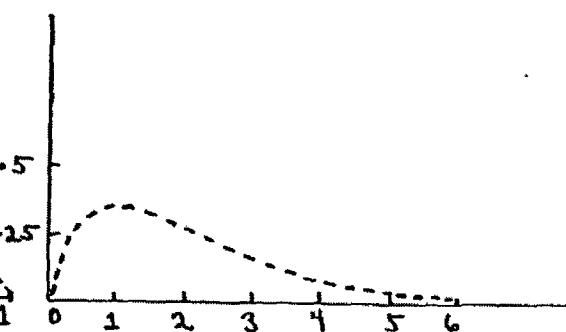
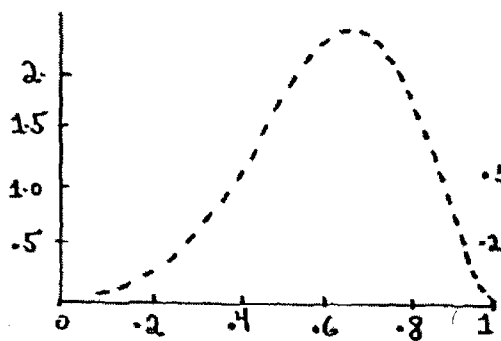
A.) Uniform

B.) Normal (0,1)



C.) BETA (4,2)

D.) GAMMA (2,1)



The tests consisted of drawing 100 samples of size 59 from each population, picking the minimum and maximum from each sample, and comparing the histogram of the 100 minimum (and maximum) sampled values to the 5% (and 95%) points of the parent population. All tests indicated that the "Rule" was valid. In addition, tests were run for the discrete COLSS-FLAIR error distributions documented in Ref. 6. These tests also verified the validity of the "Rule." Complete details and microfiche of the computer runs are available from the author.

p-A-16

Page 3
RPP-79-163

2. The "Rule" is less accurate* than the one-sided tolerance limit "k-factor" methodology (see Ref. 7) if it is known that the parent distribution is normal. Roughly speaking, the "k-factor" approach provides a more accurate estimate for a normal distribution because the detailed shape of the distribution is used to determine the k-factor. A detailed numerical comparison of the relative accuracy of the "Rule" and the k-factor methods is presented in Appendix B.

A similar conclusion applies to any population distribution in that tolerance limits obtained expressly for the distribution under consideration will be more accurate than the one obtained using the estimates provided by the "Rule of 59." The benefit offsetting this loss of accuracy is that the validity of any assumptions concerning the distribution of the population do not need to be addressed. It appears that use of the "Rule" is most appropriate in situations where the loss (of "margin," money, etc.) due to the relative inaccuracy of the "Rule" is more than offset by the cost of performing an investigation to characterize the parent population which governs the observed samples.

3. The "Rule" is expected to provide a more accurate tolerance limit than that provided by the "k-factor" methodology if the distribution is significantly non-normal. In particular, if the distribution looks like Fig. 1 (d), the "k-factor" lower tolerance limit will be overly conservative and if it looks like Fig. 1 (c), the "k-factor" approach will underpredict the required tolerance limit and thus be non-conservative.

RECOMMENDATIONS

Distribution-free tolerance limits should be investigated further so that, if valid, the resulting techniques can be incorporated into our design procedures when required. Possible savings and improvements include:

1. Currently our analyses require running ~ 7200 COLSS/CPC/FLAIR cases to generate the COLSS/CPC penalty factors. The total run of these cases requires 30-60 minutes of computer time. The amount of manpower and computer time required to perform the final analysis is currently acceptable. However, during the course of the analysis, many revisions are made and scoping studies are performed to optimize constants, investigate coding changes, and determine the impact of assumed error distributions for "noise", CEA position uncertainty, and failed detectors.

* Less accurate means that there is more dispersion in the parameter for successive samples from the population.

P-A-17

Page 4
RPP-79- 163

The "Rule of 59" could be used for these investigations if a random set of 59 cases was selected and the same set was used throughout the scoping study.* This reduction in problem size would allow us to run these analyses during normal working hours** and thus reduce the calendar time and manpower required to complete the study.

2. The COLSS and CPC analyses for ANO-2 Cycle 1 each resulted in non-normal distributions for certain parameters. The "Rule" appears to be a satisfactory tool for determining tolerance limits for such distributions. The approximate methods used to deal with non-normality in the past are not generic in nature and potentially expose us to future licensing questions. This issue is particularly important because the NRC is beginning to require assessments of population normality whenever analytic methods relying on normality are used (see Ref. 8).
3. Other analyses (outside MSP) which require large amounts of computer time per sample or where only a fixed small number of samples are available and where normality is not assured can use the "Rule" to obtain tolerance limits. Examples of such analyses are:
 - TORC Uncertainty Assessments
 - CETOP Uncertainty Assessments
 - Statistical Uncertainty Analyses applied to BG&E and FPL 18-month Cycles
 - ANO-2 Statistical Uncertainty Analyses proposed for 2nd cycle
 - Work on EPRI Statistical Contract
 - Core Uplift Calculation
 - Error Analysis of Design Codes used for LOCA

* Conceptually, this set of 59 random cases represents a "response surface" for the results obtained with the full set of cases.

** Due to reduced priority for for long running computer jobs

p.A-18

APPENDIX A

Derivation of the "Rule of 59"

Suppose that a lower "95/95" tolerance limit for a given population is required. That is, a value x_{tol} must be found with the property that there is a 95% probability that at least 95% of the population is greater than x_{tol} .

To determine x_{tol} , define $x_{.05}$ as the solution to:

$$\text{Eqn. 1A} \quad \int_{-\infty}^{x_{.05}} F(x) dx = .05$$

where $F(x)$ is the population density distribution (i.e., $1/\sqrt{2\pi} e^{-.5x^2}$ for the normal distribution).

Note that $x_{.05}$ is the point such that 5% of the population is less than $x_{.05}$ and 95% is greater than $x_{.05}$.

If N independent random samples are drawn from the population, the probability that at least one (i.e., the smallest) will be less than $x_{.05}$ is given by:

$$\begin{aligned} \text{Eqn. 2A} \quad \text{Prob} \left\{ \begin{array}{l} \text{at least one point from a sample} \\ \text{of size } N \text{ will be less than } x_{.05} \end{array} \right\} = \\ 1 - \text{Prob} \left\{ \text{all } N \text{ points exceed } x_{.05} \right\} \end{aligned}$$

But,

$$\begin{aligned} \text{Eqn. 3A} \quad \text{Prob} \left\{ \text{all } N \text{ points exceed } x_{.05} \right\} = \\ \text{Prob} \left\{ \text{1st point exceeds } x_{.05} \right\} \times \\ \text{Prob} \left\{ \text{2nd point exceeds } x_{.05} \right\} \times \\ \dots \times \\ \text{Prob} \left\{ \text{Nth point exceeds } x_{.05} \right\} \end{aligned}$$

p-A-19

Appendix
Page 2

Since the probability that a single point will exceed $x_{.05}$ is 95%, we have:

$$\text{Eqn. 4A Prob } \left\{ \begin{array}{l} \text{at least one point from a sample} \\ \text{of size } N \text{ will be less than } x_{.05} \end{array} \right\} = 1 - (.95)^N$$

Therefore, if a value of N is found such that $\{1 - (.95)^N\}$ is greater than or equal to 95%, then the smallest value from a sample of that size has a 95% probability of being less than $x_{.05}$. Thus, this smallest value is a "95/95" tolerance limit.

$$\text{Since: } 1 - (.95)^{58} = .94895$$

$$1 - (.95)^{59} = .95151$$

we see that the required sample size is 59.

P-A-20

APPENDIX BComparison of the "Rule of 59" and the "k-factor" Methodology
Applied to a Normal Distribution

In the following, we assume that the normal distribution under consideration is unitary (mean=0, variance=1).

If a sample of size 59 is drawn at random from a unitary normal population, it can be shown that the expected value of the 95/95 tolerance limit based on the one-sided 95/95 k-factor is:

$$\text{Eqn. 1-B Expected Value}_k = k_{95/95}$$

where $k_{95/95}$ for 59 data points and 58 degrees of freedom is 2.026

(See Ref. 7).

and that the standard deviation of the observed tolerance limit about the expected value is approximately:

$$\text{Eqn. 2-B Std. Dev}_k = \frac{\sqrt{1/59 + \frac{k^2_{95/95}}{2(59-1)}}}{2(59-1)} = .229$$

(See Ref. 9)

Under the same conditions, it can be shown that the expected value of the largest data point drawn in 59 successive random draws is approximately:

$$\text{Eqn. 3-B Expected Value Rule 59} = x_{59} + \frac{v}{f(x_{59})}$$

where: v = Euler's Constant (.5772 . . .)

x_{59} is the solution to the following equation:

p.A-21

Appendix B
Page 2

$$\text{Eqn. 4-B} \quad \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x_{59}} e^{-5t^2} dt = \frac{59-1}{59}$$

and $f(x_{59})$ is specified by the following equation:

$$\text{Eqn. 5-B} \quad f(x_{59}) = \frac{59}{\sqrt{2\pi}} e^{-5x_{59}^2}$$

These equations are described in Reference 10.

Evaluating Eqn. 3-B, we obtain*:

$$\text{Eqn. 6-B} \quad \text{Expected Value}_{\text{Rule 59}} = 2.3539$$

The standard deviation of the observed maximum value about the expected value specified in Eqn. 6-B is (approximately):

$$\text{Eqn. 7-B} \quad \text{Std. Dev.}_{\text{Rule 59}} = \frac{\pi}{\sqrt{6}} * f(x_{59})$$

Evaluating Eqn. 7-B results* in:

$$\text{Eqn. 8-B} \quad \text{Std. Dev.}_{\text{Rule 59}} = .517$$

By comparing Eqn. 1-B, 6-B and Eqn. 2-B, 8-B, we obtain a measure of the relative efficiency of the two methods for a normal distribution. Clearly the k-factor approach is more efficient in that the standard deviation is a factor of 2 smaller. Of course, the major advantage of the "Rule of 59" is that questions of normality do not need to be addressed.

* The sampling described in Conclusions for the normal distribution (1(b)) resulted in estimates for Eqn. 6-B, Eqn. 8-B of 2.358 and .455.

p-A-22

REFERENCES

1. J. V. Bradley, Distribution-Free Statistical Tests, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1968.
2. D. B. Owen, "Distribution-Free Tolerance Limits," SCTM 66A-57(51), June 24, 1957.
3. R. L. Kirkpatrick, "Sample Size to Set Specification Limits," BDX-613-1223, January, 1975.
4. D. L. Hanson and D. B. Owen, "Distribution-Free Tolerance Limits Elimination of the Requirement that Cumulative Distribution Functions be Continuous," Technometrics, Vol. 5, No. 4, November, 1963, pp. 518-522.
5. R. B. Murphy, "Non-parametric Tolerance Limits," Ann. Math. Statist. Vol. 19, pp. 581-589.
6. R. K. Endter, "COLSS Uncertainty Analysis Documentation," RPP-79-143, September 7, 1979.
7. D. B. Owen, "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans," SC-R-607, March 1963.
8. R. J. Krisst, "Error Analysis of Shape Annealing Factors," PDP-79-208, August 22, 1979.
9. A. Hald, Statistical Theory with Engineering Application, J. Wiley & Sons, N.Y., N.Y., 1952 (see Eqn. 11.9.9).
10. M. Mazumdar, "Use of Statistical Theory of Extremes in Hot Channel Analysis of a Liquid Metal Fast Breeder Reactor," Nuclear Science & Engineering, Vol. 47, p. 187-194, 1972.

APR 10 1981

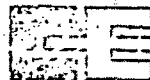
P-A-23

WAPD-TM-1292
DOE RESEARCH AND
DEVELOPMENT REPORT

STATISTICS FOR NUCLEAR ENGINEERS
AND SCIENTISTS
PART 1: BASIC STATISTICAL INFERENCE

FEBRUARY 1981

PSG LIBRARY SERVICES



R+D REPORTS SECTION

CONTRACT DE-AC11-76PN00014

BETTIS ATOMIC POWER LABORATORY
WEST MIFFLIN, PENNSYLVANIA
Operated for the U. S. Department of Energy by
WESTINGHOUSE ELECTRIC CORPORATION



P-A-24

WAPD-TM-1292

STATISTICS FOR NUCLEAR ENGINEERS AND SCIENTISTS

PART 1: BASIC STATISTICAL INFERENCE

William J. Beggs

February, 1981

Contract No. DE-AC11-76PN00014

Printed in the United States of America
Available from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

BETTIS ATOMIC POWER LABORATORY
West Mifflin, Pennsylvania

Operated for the U.S. Department of Energy by
WESTINGHOUSE ELECTRIC CORPORATION

79-778/0152L

P-A-25

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States, nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ii

P-A-26

CHAPTER 6 COMPARISONS OF POPULATIONS

Thus far we have discussed the analysis of data coming from a single population. In many circumstances we want to compare two or more populations. We may compare the mean value of two production processes or compare their variance to see if one process is more consistent or precise than another. We may compare a new process against a standard or compare many processes to see if any differences exist. In this chapter we shall first examine the problem of comparing two populations and then present a general procedure for comparing any number of populations by an Analysis of Variance (ANOVA) table.

6.1 Comparison of Two Means, Variance Known

Suppose we are interested in comparing the means of two processes, observations from which are considered to have come from the same population. Let x_{ij} be the i th observation from the j th population, μ_j be the mean of that population and ϵ_{ij} be the random error occurring on the i th observation on the j th population. Thus, we may write a model for the problem as

$$x_{ij} = \mu_j + \epsilon_{ij}$$

where we usually assume that the errors are independently and normally distributed with mean 0 and variance σ_j^2 . The processes under consideration

may differ in their means because they represent different treatments, such as two chemical additives, two analytical measuring devices, or two plans of operation. With variances known we can with the use of the Central Limit Theorem compare the means of the treatments by a standard normal variable; let

$$z = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \quad (6.1.1)$$

where \bar{x}_j is the average of the n_j observations from the j th treatment and σ_j^2 is the known variance. These observations are obtained in a random order to ensure their independence. Thus, the variance of the statistic $\bar{x}_1 - \bar{x}_2$ is $\sigma_1^2/n_1 + \sigma_2^2/n_2$. To test the null hypothesis that $H_0: \mu_1 - \mu_2 = 0$ (or any other value), or to compute a confidence interval for $\mu_1 - \mu_2$, we need only to refer to the table of standard normal deviates.

Example 6.1

Suppose it is thought that by changing the rate of cooling liquid flowing across the cutting edges of a high speed drill the tool life

P-A-27

could be increased. To test this hypothesis, seven observations were obtained using the standard flow rate (process 1) and six observations were obtained using the new (process 2) flow rate, all thirteen trials performed in random order. The results were $\bar{x}_1 = 12.4$ hours $n_1 = 7$, $\bar{x}_2 = 13.6$ hrs., $n_2 = 6$, where

it is also assumed that $\sigma_1^2 = 1.0$ (hrs.)², and $\sigma_2^2 = 2.0$ (hrs.)².

$H_0: \mu_1 = \mu_2$ (equivalently $\mu_1 - \mu_2 = 0$)

$H_A: \mu_1 < \mu_2$ ($\mu_1 - \mu_2 < 0$)

$$z = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} = \frac{12.4 - 13.6 - (0)}{\sqrt{\frac{1}{7} + \frac{2}{6}}}$$

$$= \frac{-1.2}{\sqrt{0.48}} = -1.74$$

Since -1.74 is much less than -1.645 ($\Pr(z < -1.645) = 0.05$), we reject the hypothesis that the flow rates have no effect on tool life. This inference is based on a one-sided hypothesis test with a 5% significance level (i.e., Type I error probability).

6.2 Comparison of Two Variances

We may also desire to test whether or not two variances are the same. Suppose observations from two sources are normally distributed. Is one process or treatment more variable than another? More precise or reproducible? To answer the question, we need first estimate the variance from each process as follows:

$$s_1^2 = \frac{\sum_{i=1}^{n_1} (x_{i1} - \bar{x}_1)^2}{n_1 - 1}, \quad s_2^2 = \frac{\sum_{i=1}^{n_2} (x_{i2} - \bar{x}_2)^2}{n_2 - 1}$$

Each s^2 follows a χ^2 distribution. More specifically $\frac{(n_1 - 1) s_1^2}{\sigma_1^2}$ distributed as $\chi^2_{n_1-1}$ and $\frac{(n_2 - 1) s_2^2}{\sigma_2^2}$ is distributed as $\chi^2_{n_2-1}$. To test

the null hypothesis $H_0: \sigma_1^2 = \sigma_2^2 = \sigma^2$, we need to develop a test

$$\frac{VS_u}{\sigma^2} = \chi^2_v$$

normal dist.

$$128 \quad \frac{s_1^2 / \sigma_1^2}{s_2^2 / \sigma_2^2} = \frac{\chi^2_{v_1} / v_1}{\chi^2_{v_2} / v_2} = F_{v_1, v_2}$$

die square variable

$$\frac{s_1^2}{s_2^2} = \frac{\sigma_1^2}{\sigma_2^2} F_{v_1, v_2}$$

P-A-28

statistic. In testing a hypothesis about a single variance we used the χ^2 distribution. To test two variances for equality we use the test statistic s_1^2/s_2^2 , which follows the F-distribution.

Definition

$$F_{\nu_1, \nu_2} = \frac{\sigma_1^2 X_{\nu_1}^2 / \nu_1}{\sigma_2^2 X_{\nu_2}^2 / \nu_2}$$

Where F_{ν_1, ν_2} is a F-distribution with 2 parameters, ν_1, ν_2

which are the degrees of freedom of the two χ^2 distributions

involved in the ratio, ν_1 associated with the numerator and ν_2 with the denominator.

It follows that

$$\frac{s_1^2}{s_2^2} = \frac{\sigma_1^2 X_{n_1-1}^2 / (n_1-1)}{\sigma_2^2 X_{n_2-1}^2 / (n_2-1)} = \frac{\sigma_1^2}{\sigma_2^2} F_{n_1-1, n_2-1}$$

That is, s_1^2/s_2^2 follows a F_{n_1-1, n_2-1} distribution, if $\sigma_1^2 = \sigma_2^2$. Thus,

under $H_0: \sigma_1^2 = \sigma_2^2 = \sigma^2$ (i.e., $\sigma_1^2 / \sigma_2^2 = 1$), the test statistic

s_1^2/s_2^2 follows a F-distribution with $n_1 - 1$ and $n_2 - 1$ degrees of freedom.

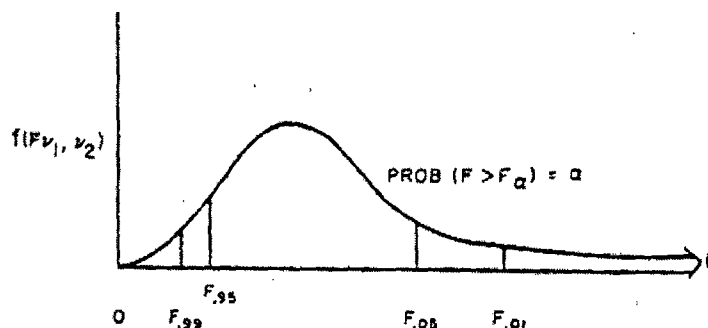


Figure 6.1. F-Distribution

P-A-29

The test of $\sigma_1^2 = \sigma_2^2$ becomes then (for $H_A: \sigma_1^2 \neq \sigma_2^2$)

$$\Pr \left\{ F_{\nu_1, \nu_2, 1-\alpha/2} < F_{\nu_1, \nu_2} < F_{\nu_1, \nu_2, \alpha/2} \right\} = 1 - \alpha$$

What are the reasonable values to expect from the distribution? A useful relationship when dealing with the left hand tail of a F-distribution is

$$F_{\nu_1, \nu_2, 1-\alpha} = \frac{1}{F_{\nu_2, \nu_1, \alpha}}$$

Example 6.2.

Returning to the tool life problem in Example 6.1, construct a 90% confidence interval for the ratio of variances. Suppose the estimates of variances are

$$s_1^2 = 0.74, n_1 = 7, \nu_1 = 6$$

$$s_2^2 = 2.239, n_2 = 6, \nu_2 = 5$$

$$\text{Hypothesis: } H_0: \frac{\sigma_1^2}{\sigma_2^2} = 1 \quad \frac{s_1^2}{s_2^2} = \frac{0.74}{2.239} = 0.3305$$

$$H_A: \frac{\sigma_1^2}{\sigma_2^2} \neq 1$$

$$F_{6,5} = \frac{s_1^2 / \sigma_1^2}{s_2^2 / \sigma_2^2}$$

$$\Pr \left\{ \frac{1}{F_{5,6,0.05}} < F_{6,5} = \frac{s_1^2}{s_2^2} / \frac{\sigma_1^2}{\sigma_2^2} < F_{6,5,0.05} \right\} = 0.90$$

Then inverting and reversing the signs of the inequalities,

$$\frac{s_1^2}{s_2^2} F_{6,5,0.05} < \frac{\sigma_1^2}{\sigma_2^2} < \frac{s_1^2}{s_2^2} F_{5,6,0.05}$$

P-A-30

from the table of the F-distribution, $F_{5,6,0.05} = 4.39$, $F_{6,5,0.05} = 4.95$.

$$\frac{0.3305}{4.95} < \frac{\sigma_1^2}{\sigma_2^2} < 0.3305 \times 4.39$$

$$0.067 < \frac{\sigma_1^2}{\sigma_2^2} < 1.45$$

Thus, we can believe with 90% confidence the $\frac{\sigma_1^2}{\sigma_2^2}$ lies between

0.067 and 1.45. Therefore, accept H_0 that σ_1^2 and σ_2^2 could be equal.

A standard approach to comparing two variances is to put the larger estimate in the numerator and test only against $\sigma_A^2 > \sigma_B^2$ (where $s_A^2 > s_B^2$).

By this approach, we would test $H_0: \sigma_2^2 / \sigma_1^2 = 1$ against $H_A: \sigma_2^2 > \sigma_1^2$

by comparing $\frac{s_2^2}{s_1^2} = \frac{2.239}{0.74} = 3.03$ against $F_{5,6,.05} = 4.39$.

Then we would accept H_0 . (This is a one-sided 5% test, or equivalently, a two-sided 10% test).

The assumption of normality of the observations was made in constructing this test. In comparing variances, departures from a normal distribution can cause significant errors in the probability of accepting unequal variances as equal, and vice versa. Thus, care should be taken in comparing variances, particularly in recognizing the distributions involved.

6.3 Comparing Two Means, Variance Unknown

In comparing two processes for differences in their means when the variances were known, it made no difference whether or not these variances were equal. We simply calculated the appropriate standardized normal value and compared it to the critical value. When the variances are unknown, we proceed just as we did when we dealt with a single population; i.e., we replace σ^2 by its estimate s^2 and z by t . As we shall see, however, the inequality of variances causes certain extra difficulties. We shall begin with the assumption that the variances are equivalent. This is often a reasonable assumption since the variance of the data is the variance of the errors involved, $\text{Var}(x_{ij}) = \text{Var}(\mu_j + \epsilon_{ij}) = \text{Var}(\epsilon_{ij})$. We often use the same equipment and procedure to obtain data even though the process may have changed, and these errors are sometimes larger than differences in process variability.

p-A-31

6.3.1 t-Test, Variance Equal

In comparing means of two populations where $\sigma_1^2 = \sigma_2^2$, we use the following:

$$t_{n_1+n_2-2} = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{s_p \sqrt{1/n_1 + 1/n_2}} \quad (6.1.2)$$

where $t_{n_1+n_2-2}$ is a t-distribution with n_1+n_2-2 degrees of freedom since these are the degrees of freedom in the pooled estimate of variance s_p^2 .

$$s_p^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1-1 + n_2-1} = \frac{\sum_{i=1}^{n_1} (x_i - \bar{x})^2 + \sum_{i=1}^{n_2} (x_i - \bar{x})^2}{n_1+n_2-2}$$

variance but equal variances (σ^2)

If it is true that $\sigma_1^2 = \sigma_2^2$, then the observations about \bar{x}_1 can be expected to vary about as much as the observations about \bar{x}_2 vary. Thus, two independent estimates of the same parameter σ^2 are available and can be combined. Since there are $n_1 - 1$ and $n_2 - 1$ degrees of freedom (i.e., the means μ_1 and μ_2 were estimated by \bar{x}_1 and \bar{x}_2) in the individual estimates, there are $n_1 - 1 + n_2 - 1$ degrees of freedom in the pooled or combined estimate of σ^2 . If $\bar{x}_1 - \bar{x}_2 > t_{n_1+n_2-2, 0.025} s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$ then the hypothesis $\mu_1 - \mu_2 = 0$ has been rejected at the 5% level (2-sided test). This statistic, however, is completely general for testing any hypothesis

$H_0: \mu_1 - \mu_2 = A$. Note that if

$$\sigma_1^2 = \sigma_2^2, \text{ then } \text{Var}(\bar{x}_1 - \bar{x}_2) = \left(\frac{1}{n_1} + \frac{1}{n_2}\right) \sigma^2$$

is minimized when $n_1 = n_2$ [try $n_1 + n_2 = 8$: $n_1 = n_2 = 4$ yields

$$\frac{1}{4} + \frac{1}{4} = \frac{1}{2}; n_1 = 3, n_2 = 5 \text{ yields } \frac{1}{3} + \frac{1}{5} = 0.533; \frac{1}{2} + \frac{1}{6} \text{ yields } 0.667, \text{ etc}]$$

This also holds when we estimate σ^2 by s_p^2 . Thus, if we assume

$$\sigma_1^2 = \sigma_2^2 = \sigma^2 \quad (\text{known or unknown}), \text{ choose equal sample sizes}$$

p-A-32

$n_1 = n_2$ in order to minimize $\text{Var}(\bar{x}_1 - \bar{x}_2)$ and hence shorten the corresponding confidence interval.

If $n_1 = n_2$, then the test statistic reduces to

$$t_{2(n-1)} = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{2s_p^2 / n}} \quad (6.1.3)$$

where $n_1 = n_2 = n$, $\sigma_1^2 = \sigma_2^2 = \sigma^2$ and

$$s_p^2 = \frac{s_1^2 + s_2^2}{2} = \frac{\sum_{j=1}^2 \sum_{i=1}^n (x_{ij} - \bar{x}_j)^2}{2(n-1)}$$

Example 6.3. Consider again the tool life problem.

Given the following results, test $\mu_1 - \mu_2 = 0$.

$$\bar{x}_1 = 12.4, s_1^2 = 0.74, n_1 = 7, \nu_1 = 6$$

$$\bar{x}_2 = 13.6, s_2^2 = 2.239, n_2 = 6, \nu_2 = 5$$

$$H_0: \mu_1 - \mu_2 = 0$$

$$H_A: \mu_1 - \mu_2 \neq 0$$

A 95% confidence interval is

$$\bar{x}_1 - \bar{x}_2 \pm t_{11, 0.025} s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

$$t_{11, 0.025} = 2.20, s_p^2 = \frac{6(0.74) + 5(2.239)}{11} = \frac{15.635}{11} = 1.42$$

$$s_p \sqrt{\frac{1}{7} + \frac{1}{6}} = 0.66.$$

The 95% confidence interval, then, is

$$12.4 - 13.6 \pm 2.20 (0.66)$$

$$-1.2 \pm 1.45$$

$$(-2.65 < \mu_1 - \mu_2 < 0.25).$$

*Two populations
variances are
the same.*

P-A-33

Since the interval contains the value of zero, we do not reject the hypothesis H_0 , that the means are equal.

6.3.2 t-test, Variances Unequal

If $\sigma_1^2 \neq \sigma_2^2$, what happens? Replacing σ_1^2 by s_1^2 and σ_2^2 by s_2^2 ,

the test statistic becomes

not student's

$$t^* = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

but the exact distribution is not clear. The problem of comparing two means when the variances are unknown but unequal is known as the Behrens-Fisher problem and there have been several solutions proposed. Two are suggested here. The basic problem is to correctly specify the critical t-value.

A weighted critical value suggestion is found in Cochran and Cox [5].

Wald's approximation

$$t^* = \frac{\frac{s_1^2}{n_1} t_{\nu_1, \alpha/2} + \frac{s_2^2}{n_2} t_{\nu_2, \alpha/2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (6.1.5)$$

which reduces to $t_{n-1, \alpha/2}$ if $n_1 = n_2$. It can be shown [26] that the Type I error probability remains reasonably constant over the whole range of possible

ratios for σ_1^2 / σ_2^2 if the sample sizes are equal. Thus, when the

variances are unknown, choosing equal sample sizes protects against erroneous conclusions.

A second solution makes use of the fact that the sum of two independent χ^2 variables is a weighted χ^2 variable.

That is,

$$\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \sim a \chi_b^2$$

Wald's approximation

P-A-34

where a is a multiplying constant, $a > 0$, and b is the degree of freedom of the resulting χ^2 distribution. By equating the first two moments of the two sides and solving for b , we can obtain the appropriate critical values for the test of means.

$$E \left[\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \right] = E \left[\frac{\sigma_1^2}{n_1 \nu_1} \chi_{\nu_1}^2 + \frac{\sigma_2^2}{n_2 \nu_2} \chi_{\nu_2}^2 \right]$$

$$= \frac{\sigma_1^2}{n_1 \nu_1} \nu_1 + \frac{\sigma_2^2}{n_2 \nu_2} \nu_2$$

$$= \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

$$\text{Var} \frac{\sigma_1^2}{n_1 \nu_1} \chi_{\nu_1}^2 + \frac{\sigma_2^2}{n_2 \nu_2} \chi_{\nu_2}^2 = \frac{\sigma_1^4}{n_1^2} \frac{2\nu_1}{\nu_1^2} + \frac{\sigma_2^4}{n_2^2} \frac{2\nu_2}{\nu_2^2}$$

$$E(a\chi_b^2) = ab, \text{Var}(a\chi_b^2) = 2a^2b.$$

$$\text{Thus, } ab = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

$$a^2b = \frac{\sigma_1^4}{n_1^2 \nu_1} + \frac{\sigma_2^4}{n_2^2 \nu_2}$$

Solving gives

$$b = \frac{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right)^2}{\left(\frac{\sigma_1^2}{n_1} \right)^2 \frac{1}{\nu_1} + \left(\frac{\sigma_2^2}{n_2} \right)^2 \frac{1}{\nu_2}}$$

$$a = \left(\frac{\sigma_1^4}{n_1^2 \nu_1} + \frac{\sigma_2^4}{n_2^2 \nu_2} \right) / \left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right)$$

P-A-35

Thus, t^* follows a t_b distribution since $\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \sim a^2 \chi_b^2$

where b is estimated by replacing σ_1^2 and σ_2^2 by s_1^2 and s_2^2 ,

$$b = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \right)^2}{\frac{(s_1^2/n_1)^2}{n_1-1} + \frac{(s_2^2/n_2)^2}{n_2-1}} \quad (6.1.6)$$

Note that $\min(n_1-1, n_2-1) < b \leq n_1 + n_2 - 2$.

The calculation of degrees of freedom in this manner is known as Satterthwaite's Approximation and the method can be applied in general for combining several independent estimates of variance into a single estimate of total variance. However, in some complex cases, care must be taken to assure that one is adding estimates of variances, not subtracting them. In such complex cases, it is recommended that you consult your local statistician!

Example 6.4. Tool life data from Example 6.2.

$$n_1 = 7, s_1^2 = 0.74, \nu_1 = 6$$

$$n_2 = 6, s_2^2 = 2.239, \nu_2 = 5$$

$$t = \frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \text{ is to be compared to the critical value of}$$

Cochran-Cox,

$$t_{0.025}^* = \frac{\frac{s_1^2}{n_1} t_{6,0.025} + \frac{s_2^2}{n_2} t_{5,0.025}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} = 2.546$$

p. A-36

UNITED STATES DEPARTMENT OF COMMERCE • Luther H. Hodges, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

Experimental Statistics

Mary Gibbons Natrella
National Bureau of Standards

Reprint of the Experimental Statistics Portion
of the AMC Handbook

By permission of the
Army Materiel Command



National Bureau of Standards Handbook 91

Issued August 1, 1963

Reprinted October 1966 With Corrections

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price \$11
Stock Number 003-003-00135-0
Catalog Number C13.11:91

Appendix B

Derivations of Statistical Relationships

B-1 List of Derivations of Statistical Quantities Documented in Reference 24

The following derivations (in handwritten form) are included in Reference 24. (Reference 24 also archives all computer codes, code inputs, code results, all Standard Plant inputs (from the cognizant Utilities) and all Standard Plant calculations performed by Westinghouse.) A copy of Reference 24 is available upon request.

- B.01 **Derivation:** Using an intermediate RCS mass inventory value as both the “end time” of one RCS leak rate measurement and the “start time” of the next results in the intermediate value “disappearing” from the calculation. For example, the average of the 1 to 2 hour leak rate value and the 2 to 3 hour leak rate value is identical to the 1 to 3 hour leak rate value. (See Section 11.2.4.)
- B.02 **Derivation:** Evaluates the exact value of the probability of one or more 3σ readings in three consecutive measurements. (The approximate value shown in Section 11.2.6 is .0039.)
- B.03 **Derivation:** Evaluates the exact value of the probability of a value of 2σ or more in three consecutive measurements. (The approximate value shown in Section 11.2.6 is .0015.)
- B.04 **Derivation:** Shows that the probability of getting at least 2 heads out of 3 coin tosses (i.e., 50%) whereas the probability of encountering Action Level III in three consecutive observations when a step increase of the leak rate equal to 2σ has occurred is approximately 40.5%. (See Section 11.2.6.)
- B.05 **Derivation:** Verifies Equations 11.5 and 11.6 in Section 11.3.1.
- B.06 **Derivation:** Shows that Equation 11.10 can be restated in the form shown in Equation 11.11 in Section 11.6.
- B.07 **Derivation:** Verifies Equation 11.15 in Section 11.9.

Appendix C

Effects of Measurement Errors on the Unidentified Leak Rate

C-1 METHODOLOGY

C-1.1 Method Summary

- Lump all Gross Leakage measurement uncertainties into the single most important input parameter, Reactor Coolant System (RCS) average temperature. (Justified on page C-4)
- Evaluate the uncertainty in the Gross Leakage as a function of the uncertainty in RCS average temperature.
- Given a value for the observed fluctuation in the leak rate, i.e., the output, determine the magnitude of the fluctuation in RCS average temperature.
- Demonstrate that constant bias values in the RCS average temperature readings have a minimal effect on the observed values of the output of the leak rate calculation.

C-1.2 Gross Leakage

Gross Leakage (GL) is defined as:

$$GL = \Delta Mass_{PZR} + \Delta Mass_{RCWV} + \Delta Mass_{VCT} \quad (\text{Eq. C.1.2-1})$$

where: $\Delta Mass_{PZR}$ = change in mass in the pressurizer (lbm)
 $\Delta Mass_{RCWV}$ = change in mass in the reactor coolant water volume (lbm)
 $\Delta Mass_{VCT}$ = change in mass in the volume control tank (lbm)

Each mass calculation (MC_i in lbm) at a given time point, i , is defined as:

$$MC_i = Mass_{PZRi} + Mass_{RCWVi} + Mass_{VCTi} \quad (\text{Eq. C.1.2-2})$$

Substituting the mass calculation terms from Section 7 gives:

$$MC_i = [\text{VolumeLiq}_{PZRi} / Vf_{PZRi} - (\text{VolumeTot}_{PZR} - \text{VolumeLiq}_{PZRi}) / Vg_{PZRi}] \\ + \text{VolumeTot}_{RCWVi} / Vf_{RCWVi} \\ + \text{VolumeLiq}_{VCTi} / Vf_{VCTi} \quad (\text{Eq. C.1.2-3})$$

where: VolumeLiq = volume of liquid (PZR or VCT) in ft^3
 VolumeTot_{PZR} = total volume of pressurizer (constant) in ft^3
 VolumeTot_{RCWV} = total volume of reactor coolant (constant) in ft^3
 Vf = specific volume of fluid in ft^3/lbm
 Vg = specific volume of gas in ft^3/lbm

The variance in each mass calculation (from equation 7-7. page 231 of Reference 22) is:

$$\delta MC_i = [\sum_n (\partial MC_i / \partial p_n)^2 \delta p_n^2]^{1/2}$$

where: δMC_i = uncertainty in mass MC_i (lbm)
 p_n = independent parameter, n , used to calculate MC_i at time point i
 δp_n = uncertainty on parameter p_n at time point i

Since MC_i is a function of the volumes and specific volumes, the variance in each mass calculation can be written as:

$$\begin{aligned}\delta MC_i^2 = & (\partial MC_i / \partial \text{VolumeLiq}_{PZ Ri})^2 (\delta \text{VolumeLiq}_{PZ Ri})^2 + (\partial MC_i / \partial V_{f_{PZ Ri}})^2 (\delta V_{f_{PZ Ri}})^2 \quad (\text{Eq. C.1.2-4}) \\ & + (\partial MC_i / \partial V_{g_{PZ Ri}})^2 (\delta V_{g_{PZ Ri}})^2 + (\partial MC_i / \partial V_{f_{RCW Vi}})^2 (\delta V_{f_{RCW Vi}})^2 \\ & + (\partial MC_i / \partial \text{VolumeLiq}_{VCT i})^2 (\delta \text{VolumeLiq}_{VCT i})^2 + (\partial MC_i / \partial V_{f_{VCT i}})^2 (\delta V_{f_{VCT i}})^2\end{aligned}$$

Since the volumes and specific volumes are functions of levels, temperatures and pressures, the variance in each mass calculation can be expanded as:

$$\begin{aligned}\delta MC_i^2 = & (\partial MC_i / \partial \text{VolumeLiq}_{PZ Ri})^2 (\partial \text{VolumeLiq}_{PZ Ri} / \partial \text{Level}_{PZ Ri})^2 (\delta \text{Level}_{PZ Ri})^2 \quad (\text{Eq. C.1.2-5}) \\ & + (\partial MC_i / \partial V_{f_{PZ Ri}})^2 [(\partial V_{f_{PZ Ri}} / \partial T_{PZ Ri})^2 (\delta T_{PZ Ri})^2 + (\partial V_{f_{PZ Ri}} / \partial P_{PZ Ri})^2 (\delta P_{PZ Ri})^2] \\ & + (\partial MC_i / \partial V_{g_{PZ Ri}})^2 [(\partial V_{g_{PZ Ri}} / \partial T_{PZ Ri})^2 (\delta T_{PZ Ri})^2 + (\partial V_{g_{PZ Ri}} / \partial P_{PZ Ri})^2 (\delta P_{PZ Ri})^2] \\ & + (\partial MC_i / \partial V_{f_{RCW Vi}})^2 [(\partial V_{f_{RCW Vi}} / \partial T_{RCW Vi})^2 (\delta T_{RCW Vi})^2 + (\partial V_{f_{RCW Vi}} / \partial P_{RCW Vi})^2 (\delta P_{RCW Vi})^2] \\ & + (\partial MC_i / \partial \text{VolumeLiq}_{VCT i})^2 (\partial \text{VolumeLiq}_{VCT i} / \partial \text{Level}_{VCT i})^2 (\delta \text{Level}_{VCT i})^2 \\ & + (\partial MC_i / \partial V_{f_{VCT i}})^2 [(\partial V_{f_{VCT i}} / \partial T_{VCT i})^2 (\delta T_{VCT i})^2 + (\partial V_{f_{VCT i}} / \partial P_{VCT i})^2 (\delta P_{VCT i})^2]\end{aligned}$$

Equation C.1.2-5 is based on all the terms being independent. The pressurizer temperature is common to two terms. The pressurizer pressure is the same instrument signal as reactor coolant pressure, and thus is common to three terms. These non-independent terms must be combined by addition:

$$\begin{aligned}\delta MC_i^2 = & (\partial MC_i / \partial \text{VolumeLiq}_{PZ Ri})^2 (\partial \text{VolumeLiq}_{PZ Ri} / \partial \text{Level}_{PZ Ri})^2 (\delta \text{Level}_{PZ Ri})^2 \quad (\text{Eq. C.1.2-6}) \\ & + [(\partial MC_i / \partial V_{f_{PZ Ri}})^2 (\partial V_{f_{PZ Ri}} / \partial T_{PZ Ri})^2 + (\partial MC_i / \partial V_{g_{PZ Ri}})^2 (\partial V_{g_{PZ Ri}} / \partial T_{PZ Ri})^2] (\delta T_{PZ Ri})^2 \\ & + [(\partial MC_i / \partial V_{f_{PZ Ri}})^2 (\partial V_{f_{PZ Ri}} / \partial P_{PZ Ri})^2 + (\partial MC_i / \partial V_{g_{PZ Ri}})^2 (\partial V_{g_{PZ Ri}} / \partial P_{PZ Ri})^2] (\delta P_{PZ Ri})^2 \\ & + (\partial MC_i / \partial V_{f_{RCW Vi}})^2 (\partial V_{f_{RCW Vi}} / \partial P_{PZ Ri})^2 (\delta P_{PZ Ri})^2 \\ & + (\partial MC_i / \partial V_{f_{RCW Vi}})^2 (\partial V_{f_{RCW Vi}} / \partial T_{RCW Vi})^2 (\delta T_{RCW Vi})^2 \\ & + (\partial MC_i / \partial \text{VolumeLiq}_{VCT i})^2 (\partial \text{VolumeLiq}_{VCT i} / \partial \text{Level}_{VCT i})^2 (\delta \text{Level}_{VCT i})^2 \\ & + (\partial MC_i / \partial V_{f_{VCT i}})^2 [(\partial V_{f_{VCT i}} / \partial T_{VCT i})^2 (\delta T_{VCT i})^2 + (\partial V_{f_{VCT i}} / \partial P_{VCT i})^2 (\delta P_{VCT i})^2]\end{aligned}$$

The partial derivatives of MC_i in Equation C.1.2-6 are obtained by differentiating Equation C.1.2-3 with respect to each parameter:

$$\partial MC_i / \partial \text{VolumeLiq}_{PZ Ri} = 1 / V_{f_{PZ Ri}} - 1 / V_{g_{PZ Ri}} \quad (\text{Eq. C.1.2-7})$$

$$\partial MC_i / \partial V_{f_{PZ Ri}} = - \text{VolumeLiq}_{PZ Ri} / V_{f_{PZ Ri}}^2 \quad (\text{Eq. C.1.2-8})$$

$$\partial MC_i / \partial V_{g_{PZ Ri}} = \text{VolumeLiq}_{PZ Ri} / V_{g_{PZ Ri}}^2 \quad (\text{Eq. C.1.2-9})$$

$$\partial MC_i / \partial V_{f_{VCT i}} = - \text{VolumeLiq}_{VCT i} / V_{f_{VCT i}}^2 \quad (\text{Eq. C.1.2-10})$$

$$\partial MC_i / \partial V_{f_{RCW Vi}} = - \text{VolumeLiq}_{RCW Vi} / V_{f_{RCW Vi}}^2 \quad (\text{Eq. C.1.2-11})$$

$$\partial MC_i / \partial \text{VolumeLiq}_{VCT i} = 1 / V_{f_{VCT i}} \quad (\text{Eq. C.1.2-12})$$

The partial derivatives of the volumes and specific volumes in Equation C.1.2-6 are obtained from the slopes of the functions used to determine these parameters, evaluated at selected points of interest:

$$\partial \text{VolumeLiq}_{\text{PZRI}} / \partial \text{Level}_{\text{PZRI}} = \Delta \text{VolumeLiq}_{\text{PZRI}} / \Delta \text{Level}_{\text{PZRI}} \quad (\text{Eq. C.1.2-13})$$

$$\partial \text{Vf}_{\text{PZRI}} / \partial \text{T}_{\text{PZRI}} = \Delta \text{Vf}_{\text{PZRI}} / \Delta \text{T}_{\text{PZRI}} \quad (\text{Eq. C.1.2-14})$$

$$\partial \text{Vg}_{\text{PZRI}} / \partial \text{T}_{\text{PZRI}} = \Delta \text{Vg}_{\text{PZRI}} / \Delta \text{T}_{\text{PZRI}} \quad (\text{Eq. C.1.2-15})$$

$$\partial \text{Vf}_{\text{PZRI}} / \partial \text{P}_{\text{PZRI}} = \Delta \text{Vf}_{\text{PZRI}} / \Delta \text{P}_{\text{PZRI}} \quad (\text{Eq. C.1.2-16})$$

$$\partial \text{Vg}_{\text{PZRI}} / \partial \text{P}_{\text{PZRI}} = \Delta \text{Vg}_{\text{PZRI}} / \Delta \text{P}_{\text{PZRI}} \quad (\text{Eq. C.1.2-17})$$

$$\partial \text{Vf}_{\text{RCWVi}} / \partial \text{P}_{\text{PZRI}} = \Delta \text{Vf}_{\text{RCWVi}} / \Delta \text{P}_{\text{PZRI}} \quad (\text{Eq. C.1.2-18})$$

$$\partial \text{Vf}_{\text{RCWVi}} / \partial \text{T}_{\text{RCWVi}} = \Delta \text{Vf}_{\text{RCWVi}} / \Delta \text{T}_{\text{RCWVi}} \quad (\text{Eq. C.1.2-19})$$

$$\partial \text{VolumeLiq}_{\text{VCTi}} / \partial \text{Level}_{\text{VCTi}} = \Delta \text{VolumeLiq}_{\text{VCTi}} / \Delta \text{Level}_{\text{VCTi}} \quad (\text{Eq. C.1.2-20})$$

$$\partial \text{Vf}_{\text{VCTi}} / \partial \text{T}_{\text{VCTi}} = \Delta \text{Vf}_{\text{VCTi}} / \Delta \text{T}_{\text{VCTi}} \quad (\text{Eq. C.1.2-21})$$

$$\partial \text{Vf}_{\text{VCTi}} / \partial \text{P}_{\text{VCTi}} = \Delta \text{Vf}_{\text{VCTi}} / \Delta \text{P}_{\text{VCTi}} \quad (\text{Eq. C.1.2-22})$$

Since the RCWV is significantly larger than the other volumes (PZR, VCT), and since the effect of temperature changes on RCWV specific volume are much greater than that of pressure changes, Equation C.1.2-6 can be reduced to:

$$\delta \text{MC}_i^2 = (\delta \text{MC}_i / \partial \text{Vf}_{\text{RCWVi}})^2 (\partial \text{Vf}_{\text{RCWVi}} / \partial \text{T}_{\text{RCWVi}})^2 (\delta \text{T}_{\text{RCWVi}})^2 \quad (\text{Eq. C.1.2-23})$$

That is, the effect of all other less significant contributors is 'lumped' into the single most important variable. As a consequence, the 'tuning' process described in Section C-3.3 will tend to overestimate the magnitude of $\delta \text{T}_{\text{RCWVi}}$ in Equation C.1.2-23.

Substituting equations C.1.2-11 and C.1.2-19 into equation C.1.2-23 gives:

$$\delta \text{MC}_i^2 = (- \text{VolumeLiq}_{\text{RCWVi}} / \text{Vf}_{\text{RCWVi}}^2)^2 (\Delta \text{Vf}_{\text{RCWVi}} / \Delta \text{T}_{\text{RCWVi}})^2 (\delta \text{T}_{\text{RCWVi}})^2 \quad (\text{Eq. C.1.2-24})$$

The mass calculation uncertainty at time point i is then the square root of the variance:

$$\delta \text{MC}_i = (- \text{VolumeLiq}_{\text{RCWVi}} / \text{Vf}_{\text{RCWVi}}^2) (\Delta \text{Vf}_{\text{RCWVi}} / \Delta \text{T}_{\text{RCWVi}}) (\delta \text{T}_{\text{RCWVi}}) \quad (\text{Eq. C.1.2-25})$$

And at time point j:

$$\delta \text{MC}_j = (- \text{VolumeLiq}_{\text{RCWVj}} / \text{Vf}_{\text{RCWVj}}^2) (\Delta \text{Vf}_{\text{RCWVj}} / \Delta \text{T}_{\text{RCWVj}}) (\delta \text{T}_{\text{RCWVj}}) \quad (\text{Eq. C.1.2-26})$$

Since the reactor coolant system leak rate is determined from the difference of two mass calculations separated by an interval of time (time points i and j), the uncertainty in the mass calculation is applied twice.

The total uncertainty in $\delta \text{T}_{\text{RCWV}}$ is composed of a bias component which is unchanged in time and a small fluctuation component which varies with time.

That is:

$$\delta \text{T}_{\text{RCWVi}} = \hat{u}_{\text{bias}} \sigma_{\text{bias}} + \hat{u}_i \sigma_{\text{fluctuation}} \quad (\text{Eq. C.1.2-27})$$

and

$$\delta T_{RCWVj} = \hat{u}_{bias} \sigma_{bias} + \hat{u}_j \sigma_{fluctuation} \quad (\text{Eq. C.1.2-28})$$

where \hat{u}_{bias} , \hat{u}_i and \hat{u}_j are independent samples from the unitary normal distribution with mean =0 and standard deviation =1, and σ_{bias} and $\sigma_{fluctuation}$ are the standard deviations of the bias and fluctuation uncertainties. Typically $\sigma_{bias} \gg \sigma_{fluctuation}$.

Since reactor coolant temperature and pressure are essentially constants during the leak rate measurement,

$$(- \text{VolumeLiq}_{RCWVi} / V_{f_{RCWVi}}^2)(\Delta V_{f_{RCWVi}} / \Delta T_{RCWVi}) \approx \quad (\text{Eq. C.1.2-29})$$

$$(- \text{VolumeLiq}_{RCWVj} / V_{f_{RCWVj}}^2)(\Delta V_{f_{RCWVj}} / \Delta T_{RCWVj})$$

so that

$$\Delta \text{Mass}_{RCWV} = \text{Mass}_{RCWVj} - \text{Mass}_{RCWVi} \quad (\text{Eq. C.1.2-30})$$

$$\Delta \text{Mass}_{RCWV} = (- \text{VolumeLiq}_{RCWV} / V_{f_{RCWV}}^2)(\Delta V_{f_{RCWV}} / \Delta T_{RCWV}) \sigma_{fluctuation} (\hat{u}_j - \hat{u}_i) \quad (\text{Eq. C.1.2-31})$$

But the standard deviation of $(\hat{u}_j - \hat{u}_i)$ is $\sqrt{2}$ since \hat{u}_j and \hat{u}_i are independent and σ for each is 1. Therefore, the standard deviation of Gross Leakage (δGL) is:

$$\delta \text{GL} = \sqrt{2} (- \text{VolumeLiq}_{RCWV} / V_{f_{RCWV}}^2)(\Delta V_{f_{RCWV}} / \Delta T_{RCWV}) \sigma_{fluctuation} \quad (\text{Eq. C.1.2-32})$$

The leak rate is the Gross Leakage over the time interval between the samples. The standard deviation of the leak rate (δLR) is:

$$\delta \text{LR} = \delta \text{GL} / \text{time interval} \quad (\text{Eq. C.1.2-33})$$

C-2 INPUT DATA

C-2.1 Reactor Coolant Water Volume

A typical reactor coolant volume for CE fleet plants is:

$$10 \times 10^3 \text{ ft}^3$$

C-2.2 Nominal Conditions

The nominal operating cold leg temperature and pressurizer pressure for CE fleet plants are:

$$550 \text{ }^\circ\text{F}$$

$$2250 \text{ psia}$$

The nominal hot leg temperature is assumed to be 50 °F above the cold leg temperature:

$$600 \text{ }^\circ\text{F}$$

This gives an average coolant temperature of:

$$575 \text{ }^\circ\text{F}$$

C-2.2 Average Coolant Temperature Uncertainty

Since the uncertainty in Gross Leakage will be determined as a function of RCS average temperature, the temperature uncertainty used in Equation C.1.2-25 is arbitrary. Variation in average coolant temperature for the purpose of determining sensitivity:

$$1 \text{ }^\circ\text{F}$$

This is the variation in the temperature value used in the mass calculation, and is a function of the variations of the hot and cold leg temperature signals used to determine that average temperature. This is the quantity $\sigma_{\text{fluctuation}}$ in Equation C.1.2-32.

C-2.3 Measurement Time Interval

Arbitrary time interval between mass calculations:

$$120 \text{ min. (2 hours)}$$

C-3 ANALYSIS

C-3.1 Mass Uncertainty Calculations

C-3.1.1 Specific Volume Calculations

Using the NIST/ASME Steam program, specific volume values are interpolated for nominal pressure and two small temperature bands above the average coolant temperature:

	2250 psia
575 °F	0.0221533 ft ³ /lbm
576.5 °F	0.0221712 ft ³ /lbm
576 °F	0.0221892 ft ³ /lbm

The associated partial derivatives of specific volume with respect to temperature at nominal pressure are calculated using Equation C.1.2-19:

$$\begin{aligned}\Delta v_{f_{RCWVI}} / \Delta T_{RCWVI} &= (0.0221712 - 0.0221533) / (575.5 - 575) \\ &= 3.58 \times 10^{-5} \text{ ft}^3/\text{lbm}/^\circ\text{F} \\ &= (0.0221892 - 0.0221712) / (576 - 575.5) \\ &= 3.60 \times 10^{-5} \text{ ft}^3/\text{lbm}/^\circ\text{F}\end{aligned}$$

C-3.1.2 Partial Derivative Calculations

The partial derivatives of total reactor coolant volume with respect to specific volume are calculated using Equation C.1.2-11 and inputs from Sections C-2.1 and C-3.1.1.

$$\begin{aligned}- \text{VolumeLiq}_{RCWVI} / v_{f_{RCWVI}}^2 &= - 10 \times 10^3 \text{ ft}^3 / (0.0221533 \text{ ft}^3/\text{lbm})^2 \\ &= - 2.038 \times 10^7 \text{ lbm}^2/\text{ft}^3 \\ &= - 10 \times 10^3 \text{ ft}^3 / (0.0221712 \text{ ft}^3/\text{lbm})^2 \\ &= - 2.034 \times 10^7 \text{ lbm}^2/\text{ft}^3\end{aligned}$$

C-3.1.3 Mass Uncertainty Calculation

Inserting the derivative values from Sections C-3.1.1 and C-3.1.2, and the instrument error from Section C-2.2 into Equation C.1.2-25:

$$\delta MC_i = (- \text{VolumeLiq}_{RCWVi} / V_{fRCWVi}^2)(\Delta V_{fRCWVi} / \Delta T_{RCWVi})(\delta T_{RCWVi})$$

$$\delta MC_{i575} = (- 2.038 \times 10^7 \text{ lbm}^2/\text{ft}^3)(3.58 \times 10^{-5} \text{ ft}^3/\text{lbm}/^\circ\text{F})(1^\circ\text{F})$$

$$\delta MC_{i575} = - 729.5 \text{ lbm}$$

$$\delta MC_{i575.5} = (- 2.034 \times 10^7 \text{ lbm}^2/\text{ft}^3)(3.60 \times 10^{-5} \text{ ft}^3/\text{lbm}/^\circ\text{F})(1^\circ\text{F})$$

$$\delta MC_{i575.5} = - 732.4 \text{ lbm}$$

At 70 °F and 14.7 psia:

$$\delta MC_{i575} = - 11.71 \text{ ft}^3$$

$$\delta MC_{i575} = - 87.6 \text{ gal.}$$

$$\delta MC_{i575.5} = - 11.76 \text{ ft}^3$$

$$\delta MC_{i575.5} = - 87.9 \text{ gal.}$$

or approximately:

$$\delta MC_i = - 88 \text{ gal.}$$

for an instrument uncertainty of 1 °F. In general:

$$\delta MC_i = - 88 \text{ gal.} / ^\circ\text{F}$$

C-3.2 Gross RCS Leak Rate Uncertainty Calculation

Inserting the mass uncertainty from Section C-3.1.3 into Equation C.1.2-32:

$$\delta GL = \pm \sqrt{2} * |\delta MC_i| = \pm (124 \text{ gal.} / ^\circ\text{F})(\sigma_{\text{fluctuation}} ^\circ\text{F})$$

The leak rate uncertainty is given by applying Equation C.1.2-33:

$$\delta LR = \pm (124 \text{ gal.} / ^\circ\text{F})(\sigma_{\text{fluctuation}} ^\circ\text{F}) / 120 \text{ min.} \approx \pm (1 \text{ gpm} / ^\circ\text{F})(\sigma_{\text{fluctuation}} ^\circ\text{F})$$

C-3.3 Sample Tuning Calculation of the Temperature Fluctuation

If two hour snapshot readings of the leak rate show a fluctuation of $\pm 0.055 \text{ gpm}$ (1 standard deviation), then the estimated value of $\sigma_{\text{fluctuation}}$ is:

$$\pm 0.055 \text{ gpm} / (1 \text{ gpm} / ^\circ\text{F})$$

$$\text{or: } \pm 0.055 ^\circ\text{F}$$

C-4 CONCLUSIONS

The lumped parameter model where all the less important measurement errors are effectively eliminated from consideration and represented by a (slightly increased) RCS average temperature fluctuation shows that the 1σ fluctuation observed in the standard 2 hour leak rate measurement in gpm is approximately numerically equal to the 1σ fluctuation in the RCS average temperature measurement in °F.

Any bias component in the RCS average temperature measurement has minimal effect on the snapshot leak rate calculation per Equation C.1.2-32 because it has an equal effect on the start and end point average temperature measurements and effectively disappears from the calculation.

Appendix D

Figures and Plots from Section 11

Figure D-1
Typical Plant Data
RCS Volume/Mass Inventory Vs. Time
(15 Minute Intervals)

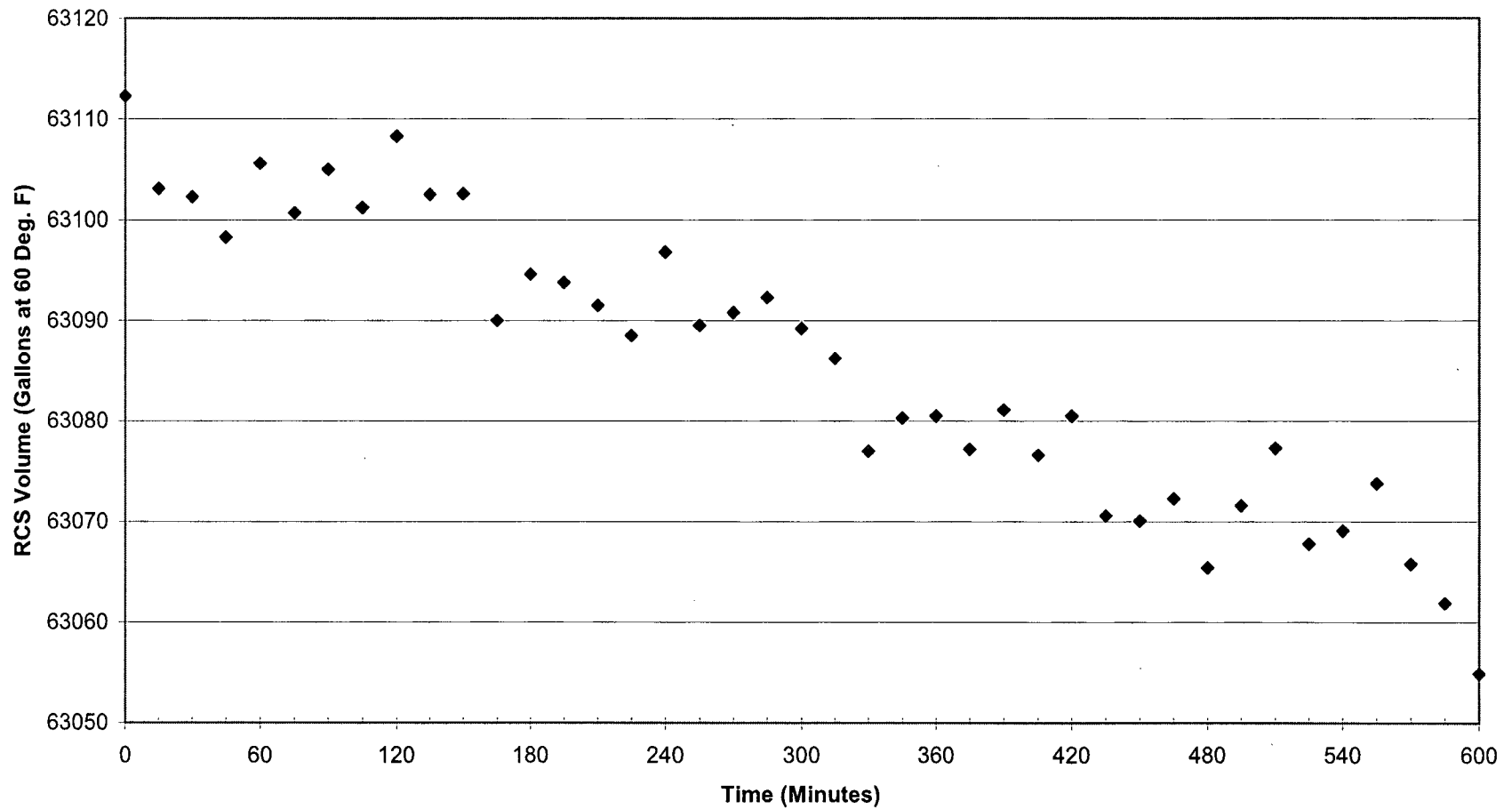


Figure D-2
Typical Plant Data
Identified Leak Volume/Mass Inventory Vs. Time
(15 Minute Intervals)

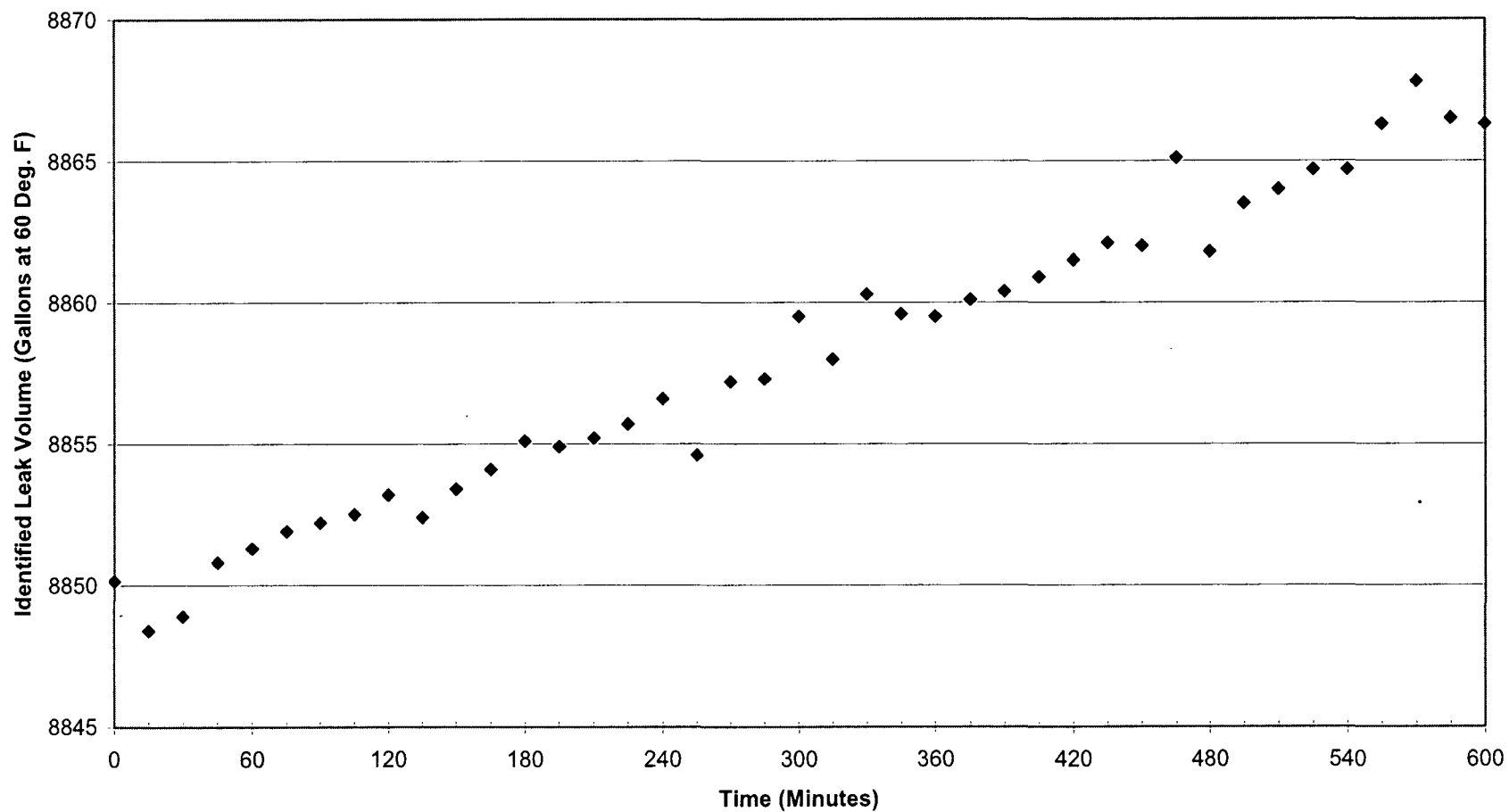


Figure D-3
Typical Plant Data
Unidentified Leak Volume/Mass Inventory Vs. Time
(15 Minute Intervals)

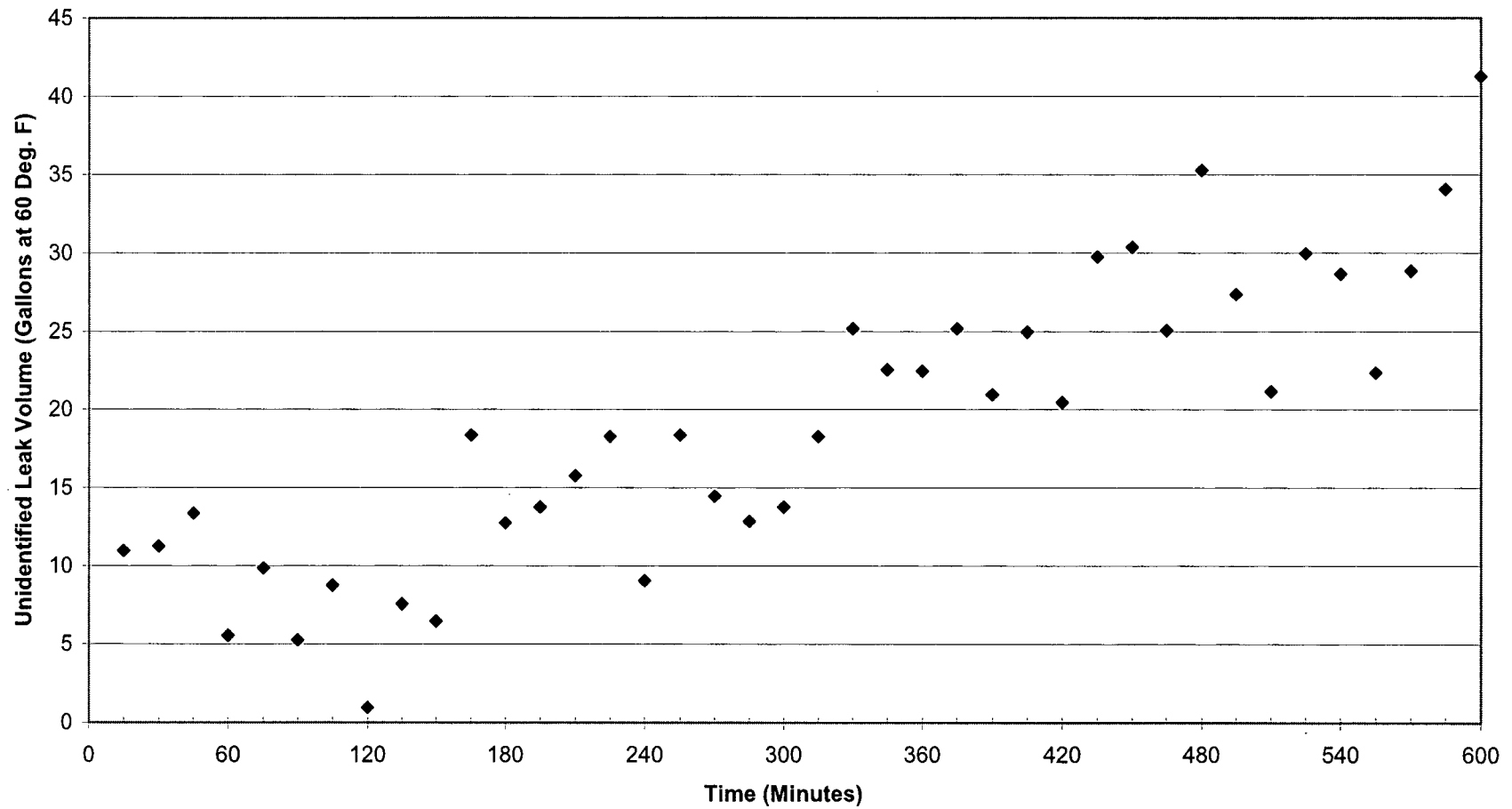


Figure D-4
Cumulative Distribution Function for 9 Exceedences

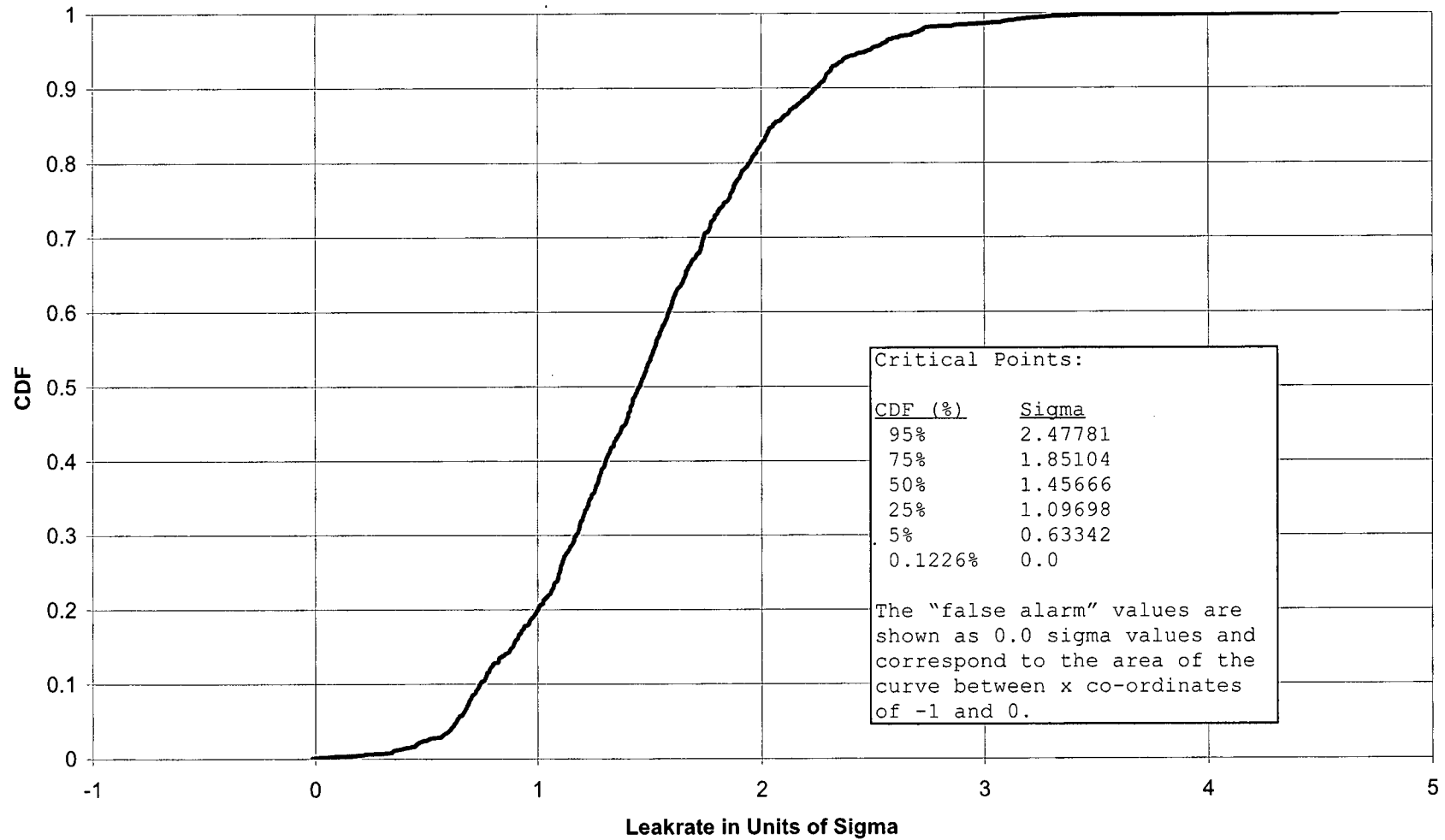


Figure D-5
Cumulative Distribution Function for 7 Exceedences

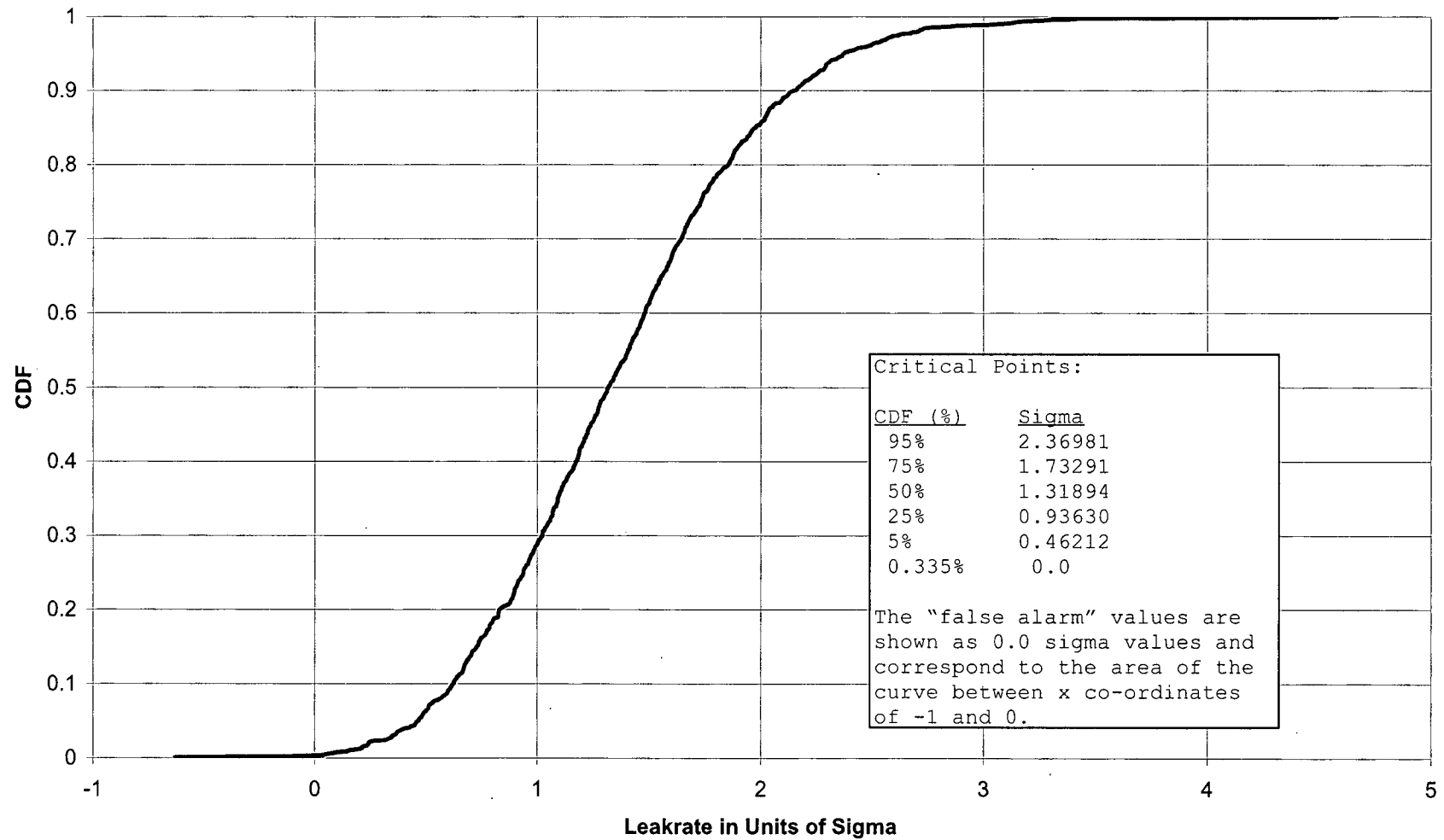


Figure D-6
Cumulative Distribution Function for 5 Exceedences

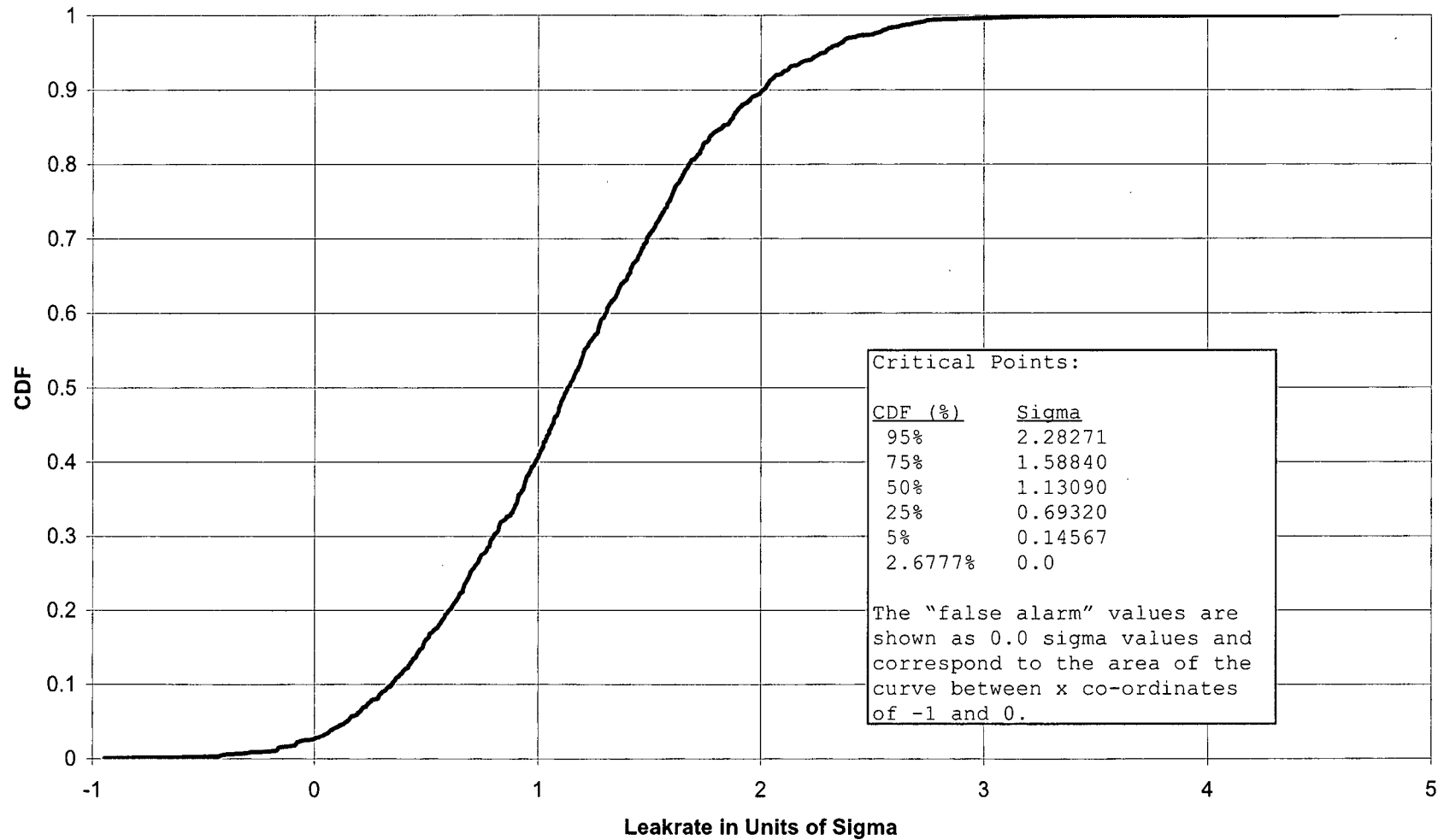


Figure D-7
Action Level I - "Days to Alarm"
(9 Exceedences)

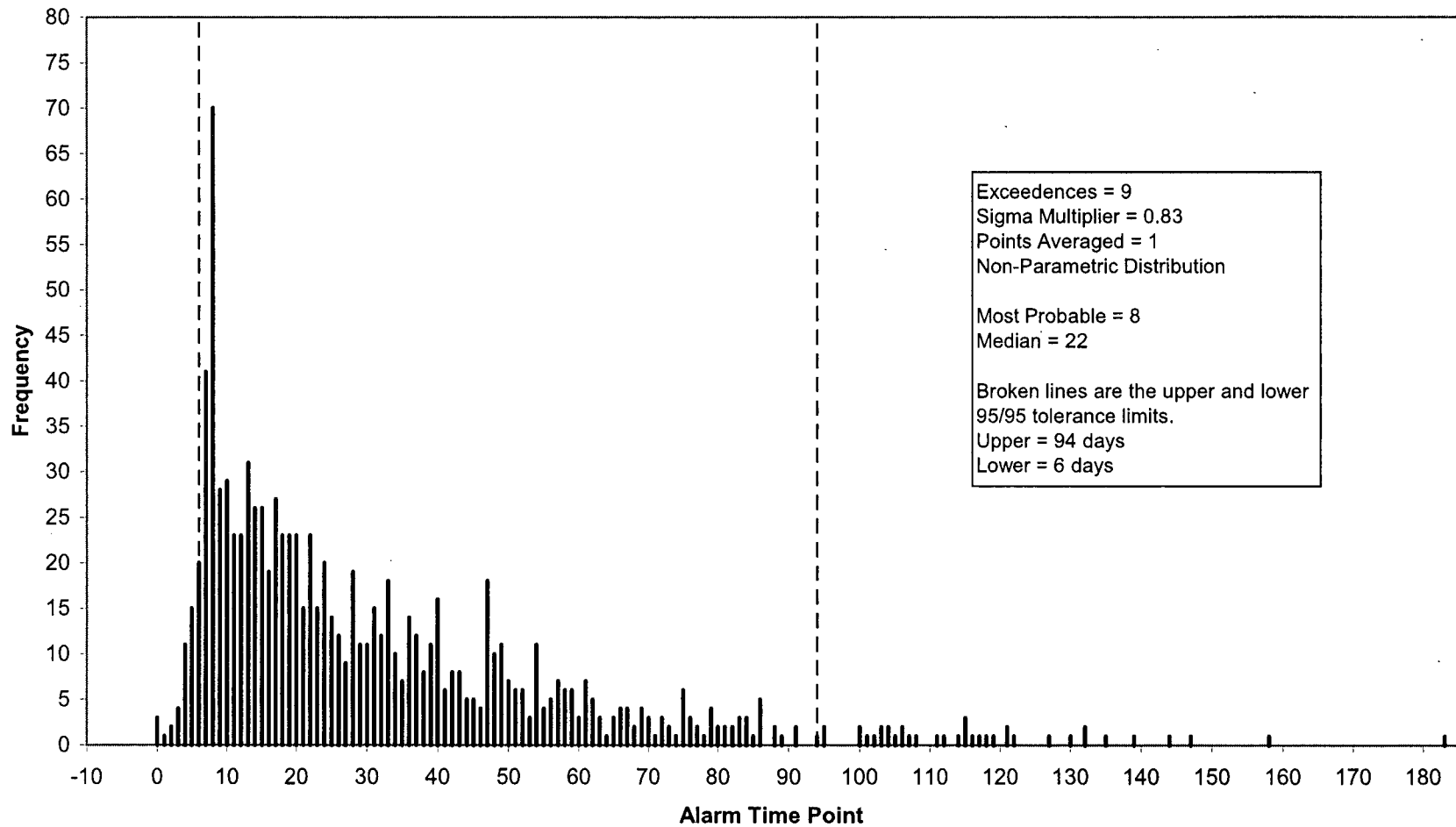


Figure D-8
Precursor to Action Level I - "Days to Alarm"
(7 Exceedences)

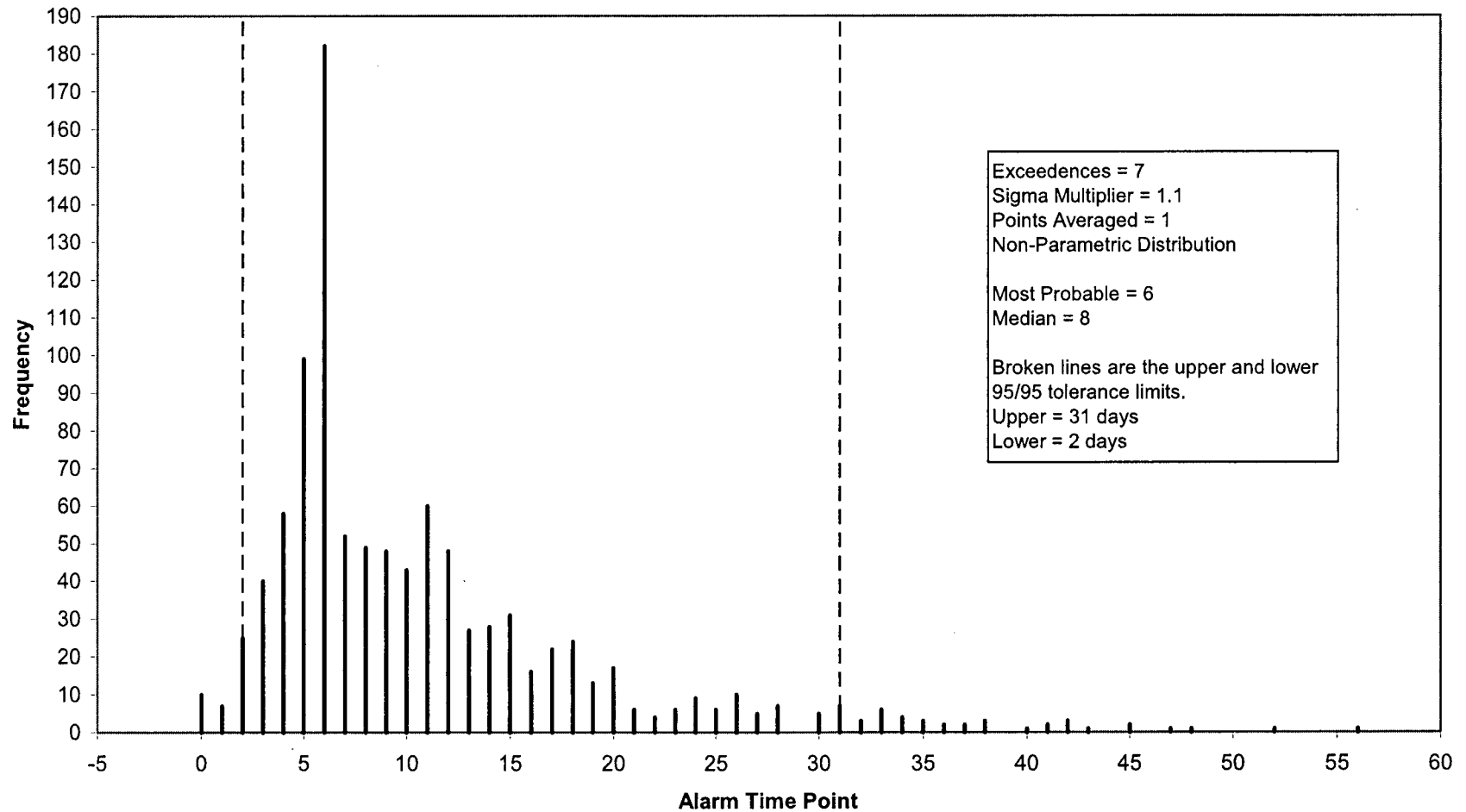


Figure D-9
Precursor to Action Level I - "Days to Alarm"
(5 Exceedences)

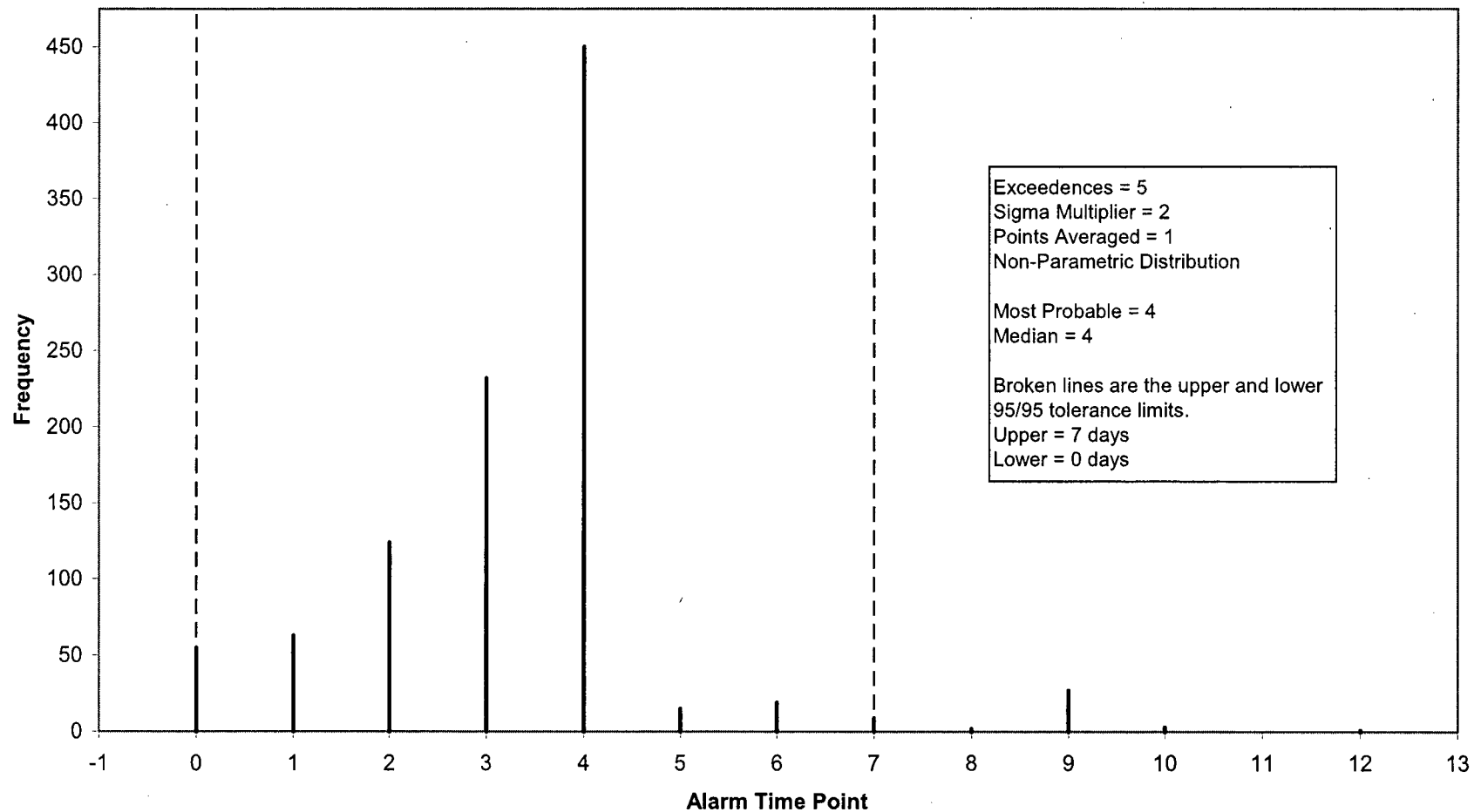


Figure D-10
Simulated Leakrate Curve

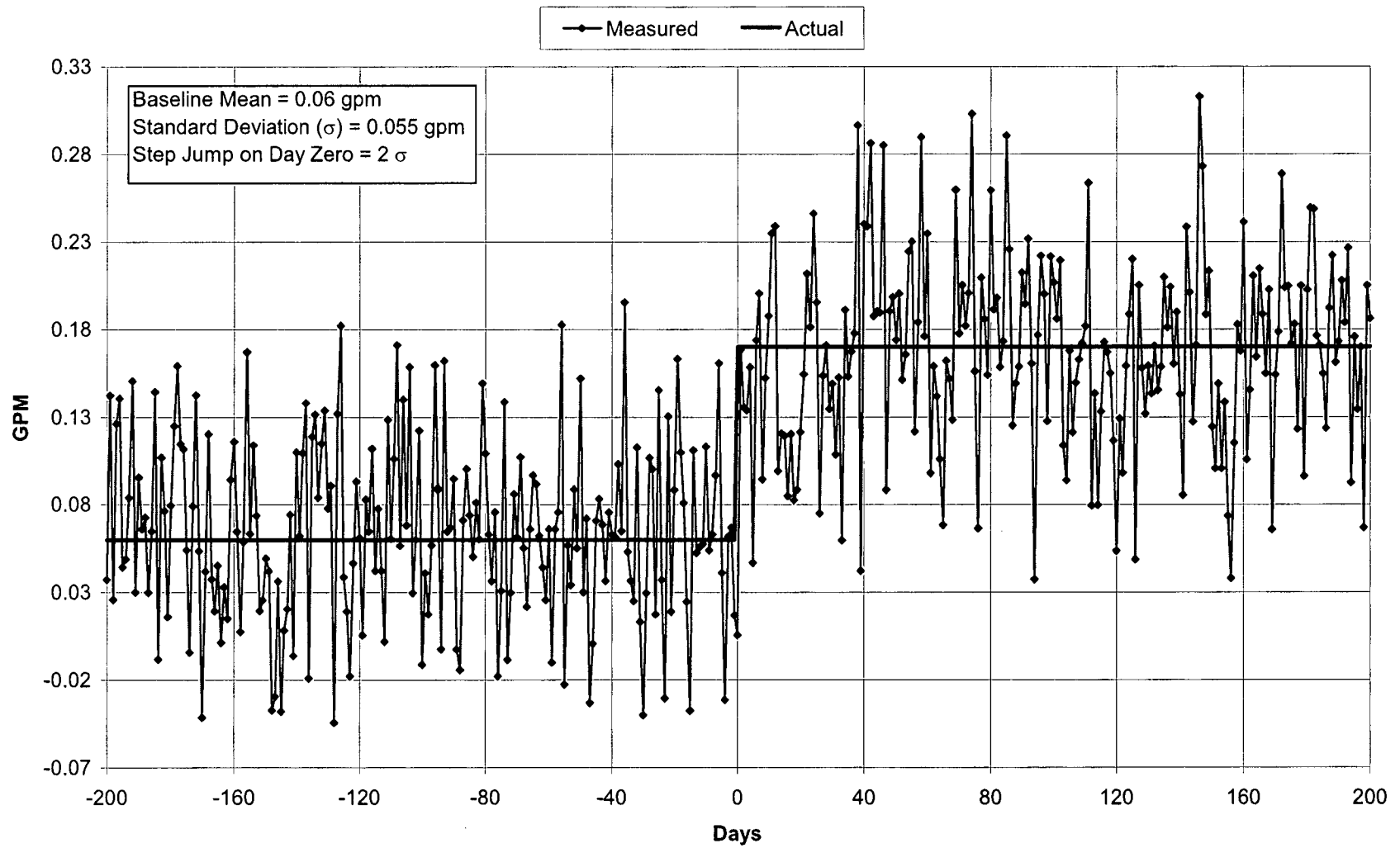


Figure D-11
Simulated Leakrate Curve (7 Days Rolling Average)
(Using Daily Values Shown in Figure D-10)

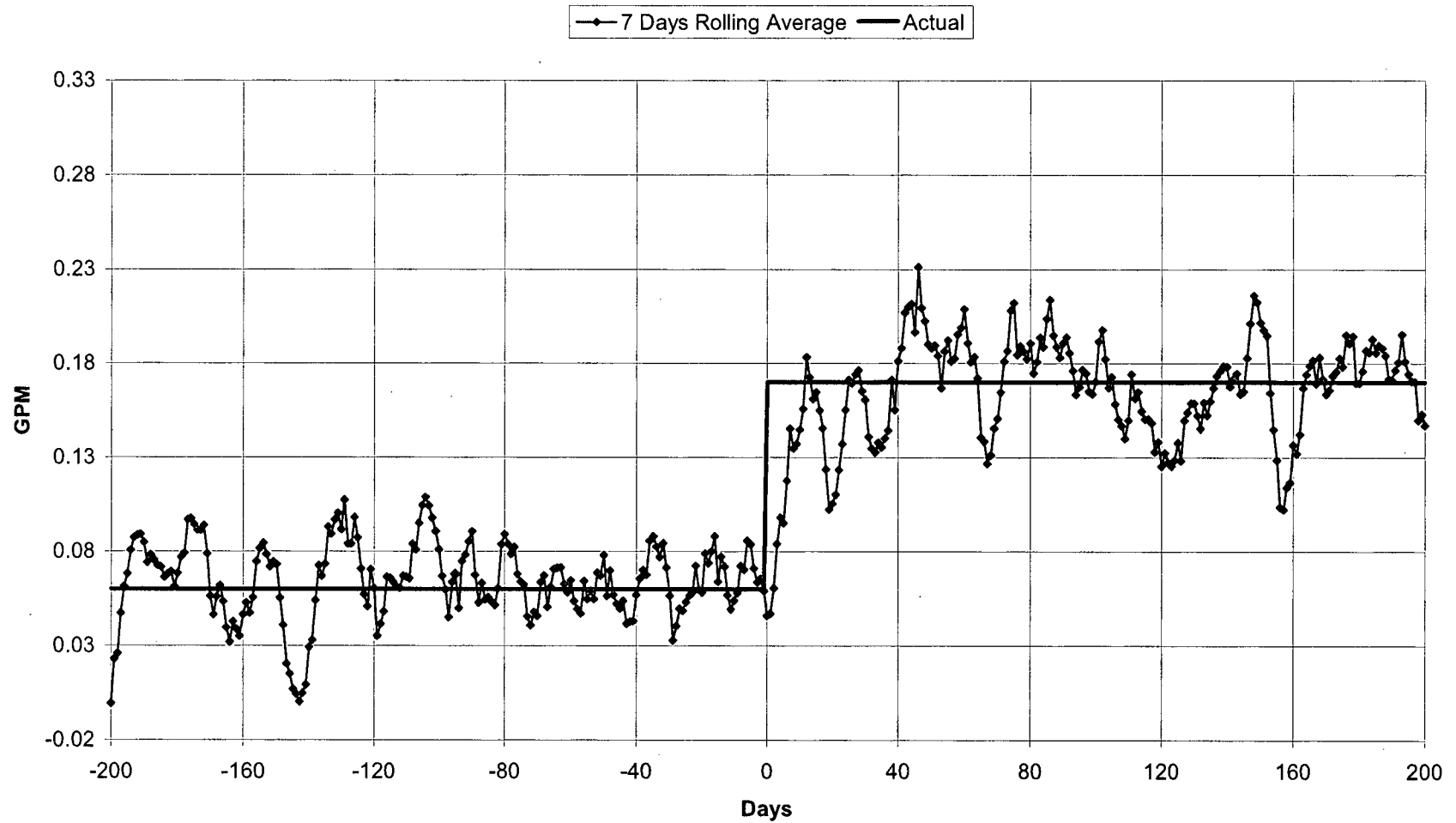


Figure D-12
Simulated Leakrate Curve (Weekly Average)
(Using Daily Values Shown in Figure D-10)

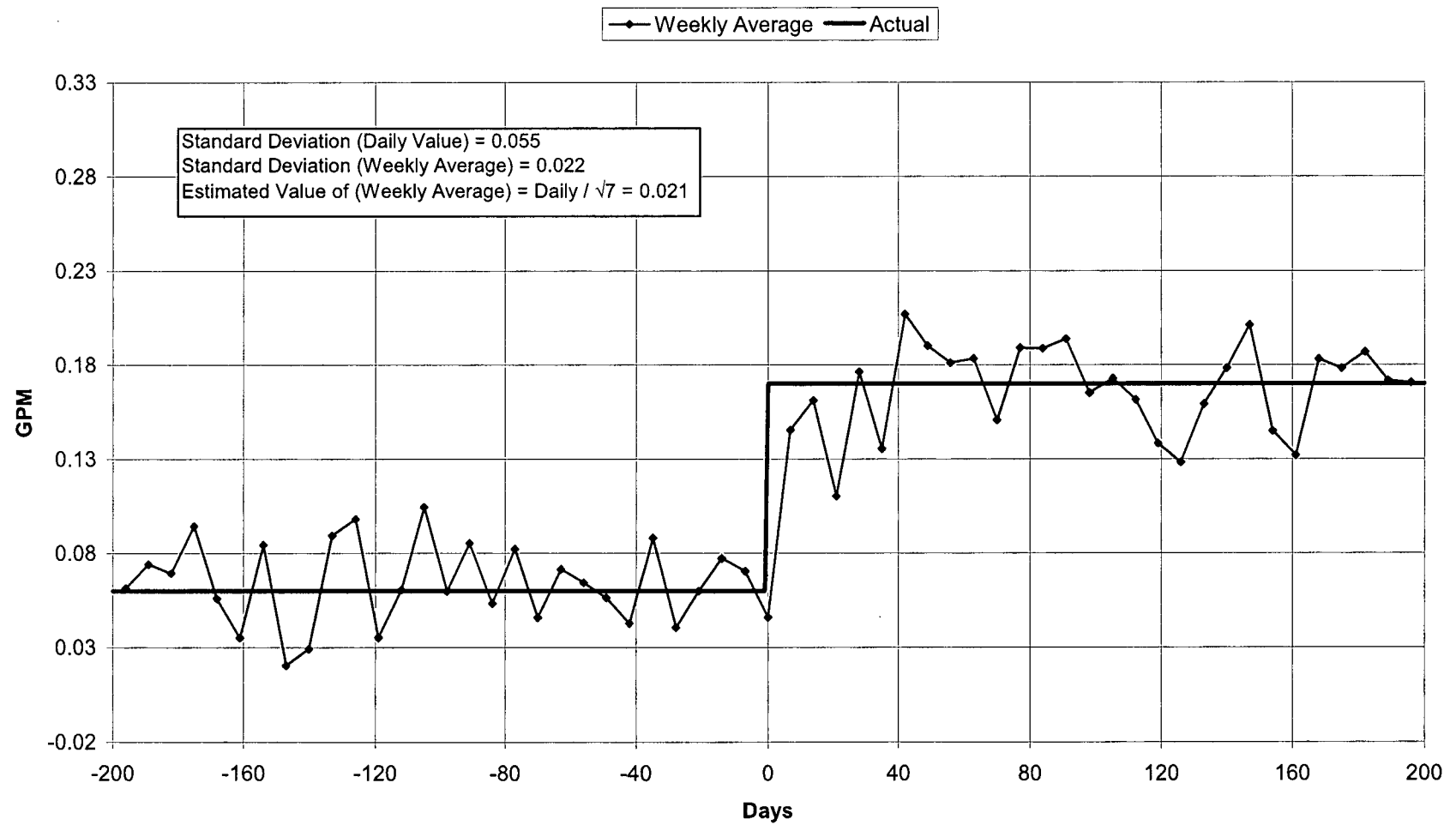


Figure D-13
Simulated Leakrate Curve (30 Days Rolling Average)
(Using Daily Values Shown in Figure D-10)

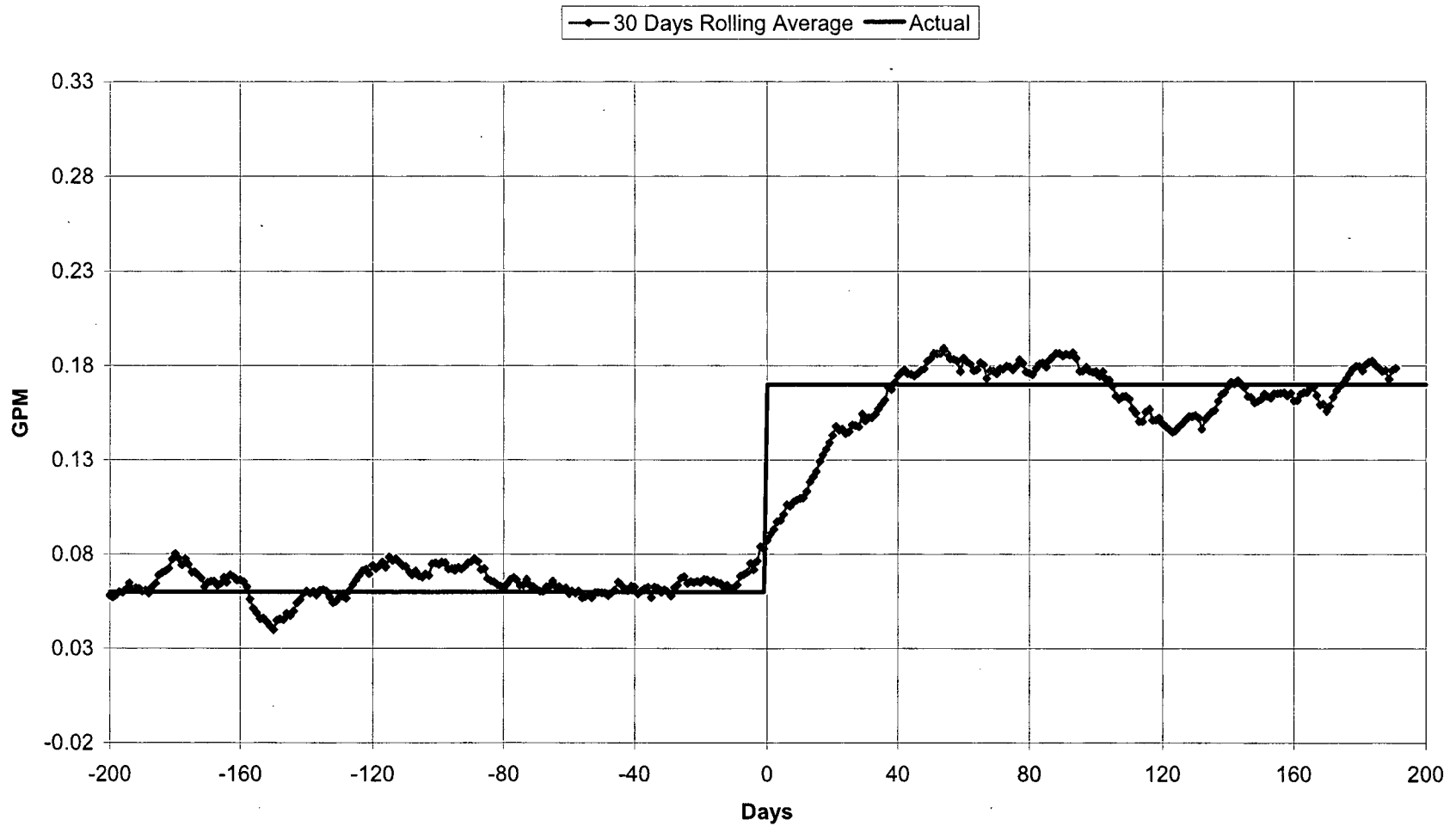


Figure D-14
Simulated Leakrate Curve (Monthly Average)
(Using Daily Values Shown in Figure D-10)

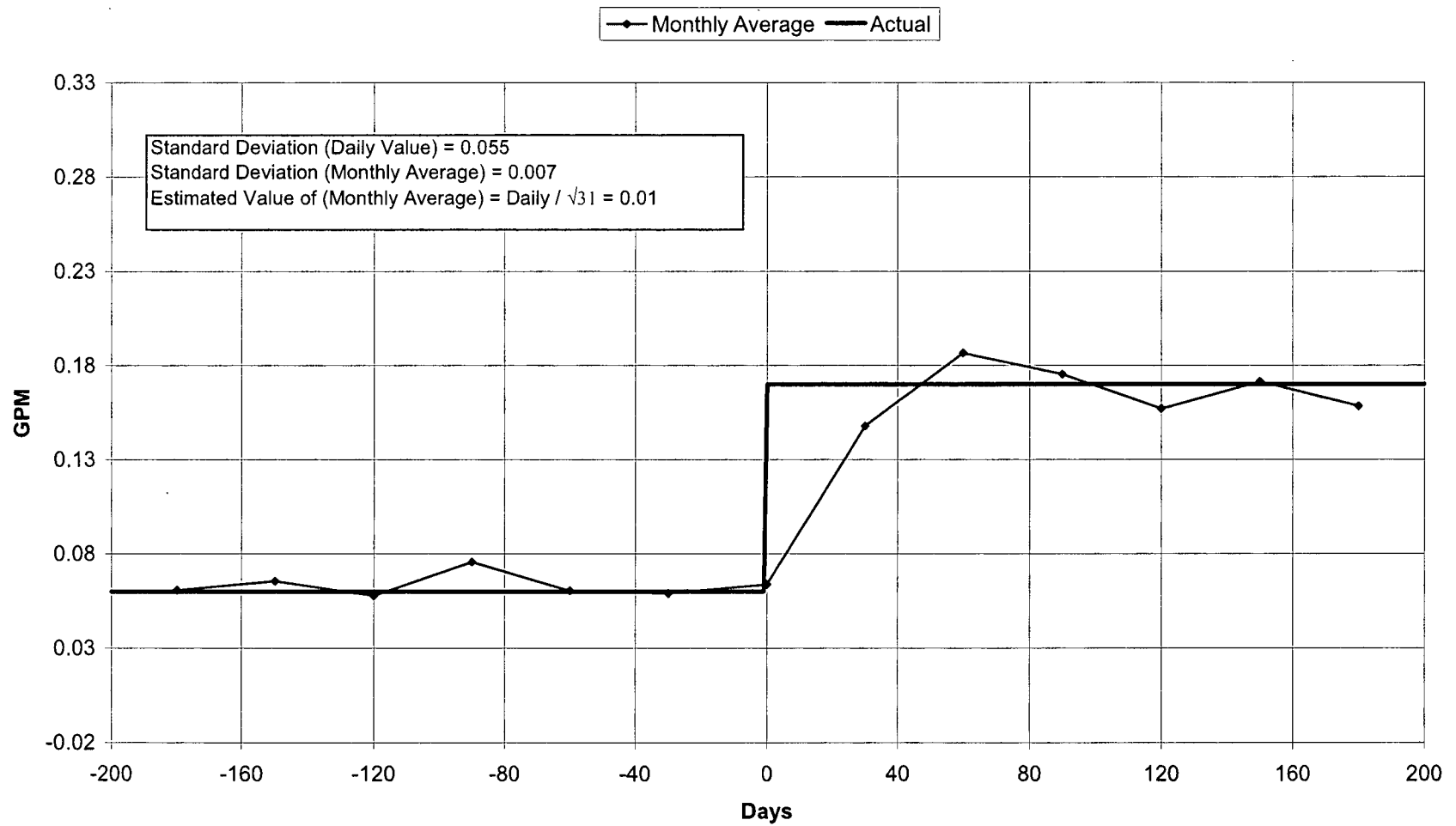


Figure D-15
Typical Plant Data
LSF of RCS Volume/Mass Inventory Vs. Time Data
(15 Minute Intervals)

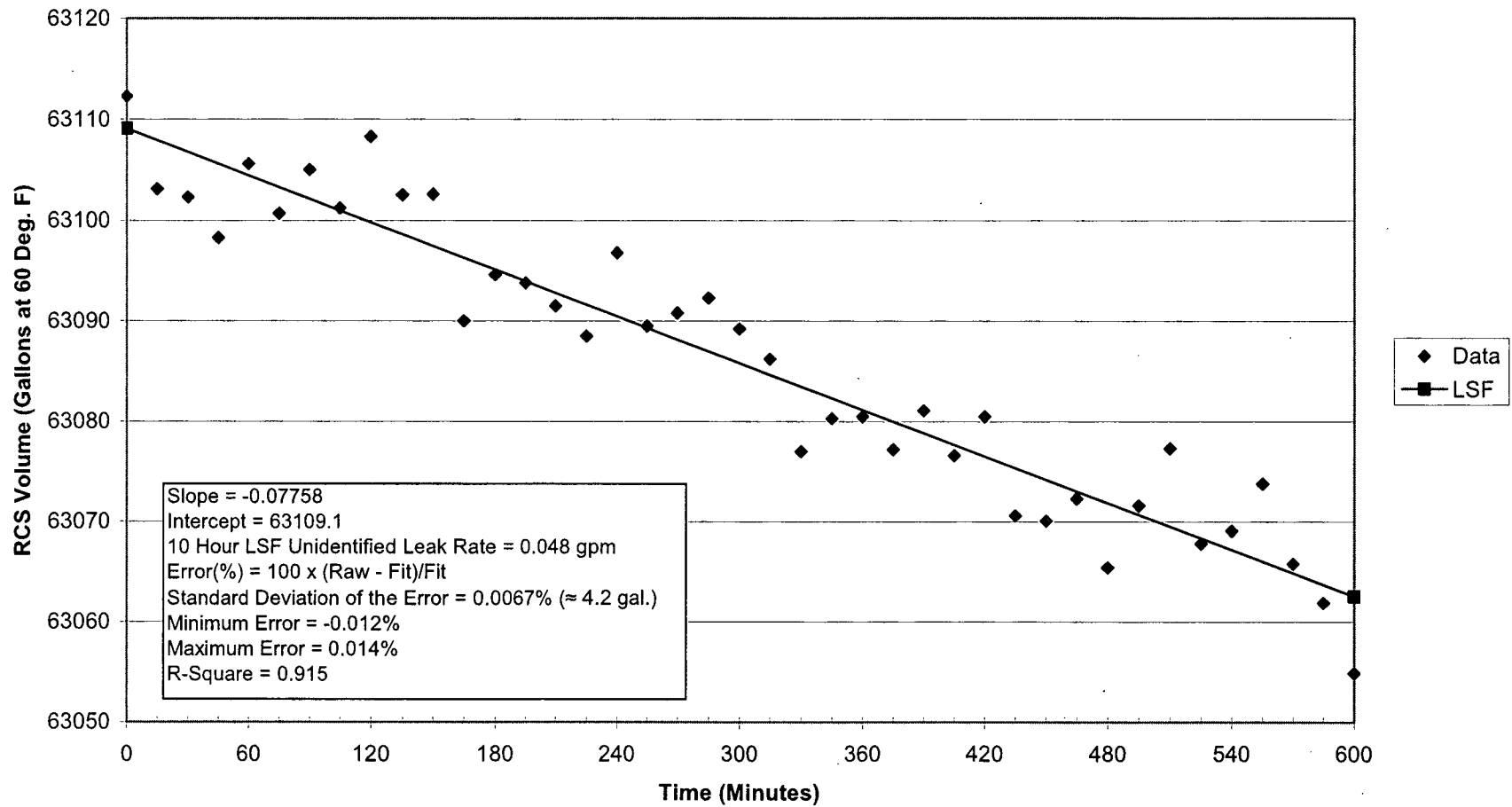


Figure D-16
Typical Plant Data
Spline Fit of RCS Volume/Mass Inventory

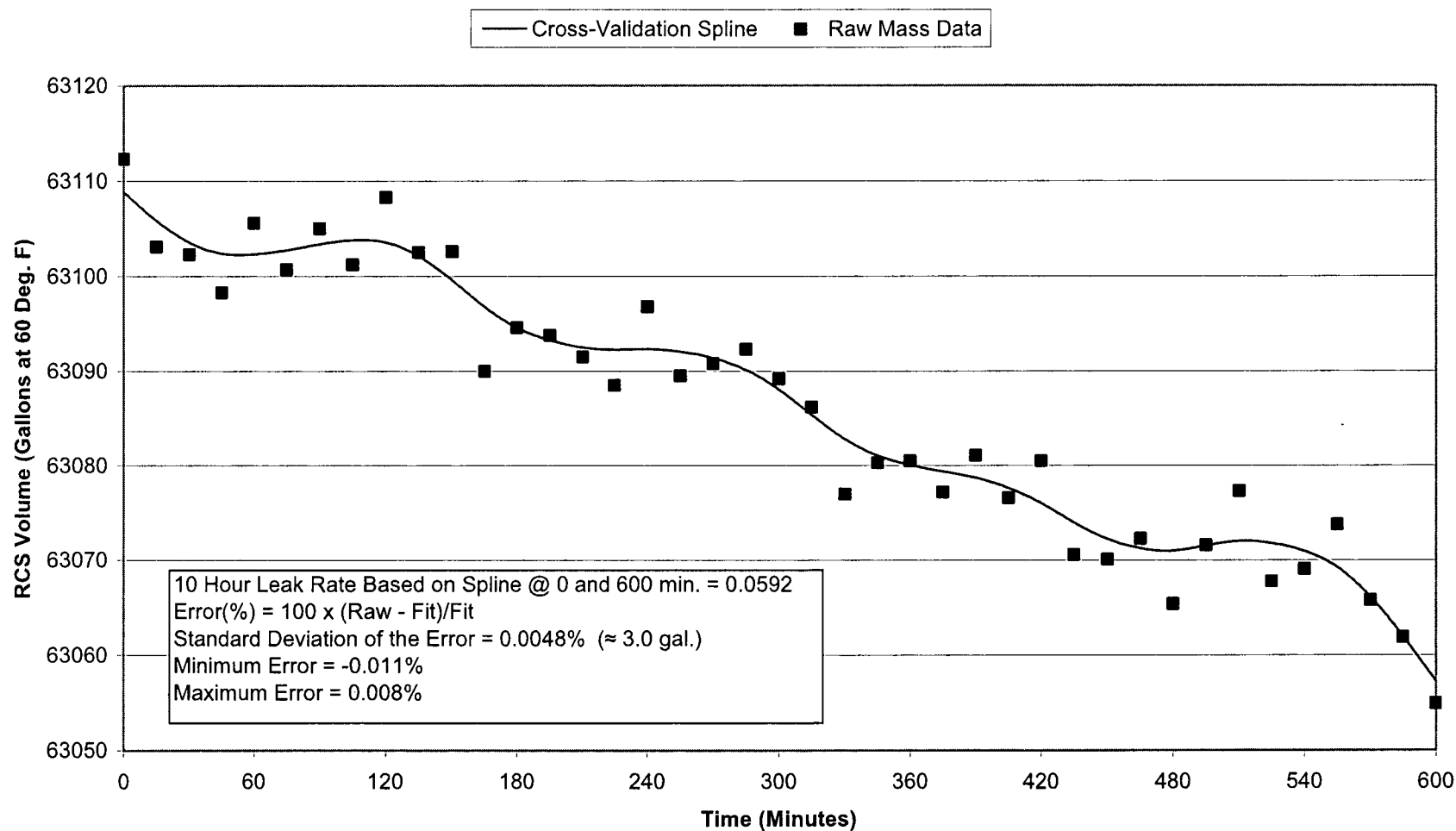


Figure D-17
Typical Plant Data
LSF of RCS Volume/Mass Inventory Vs. Time Data
(30 Minute Intervals)

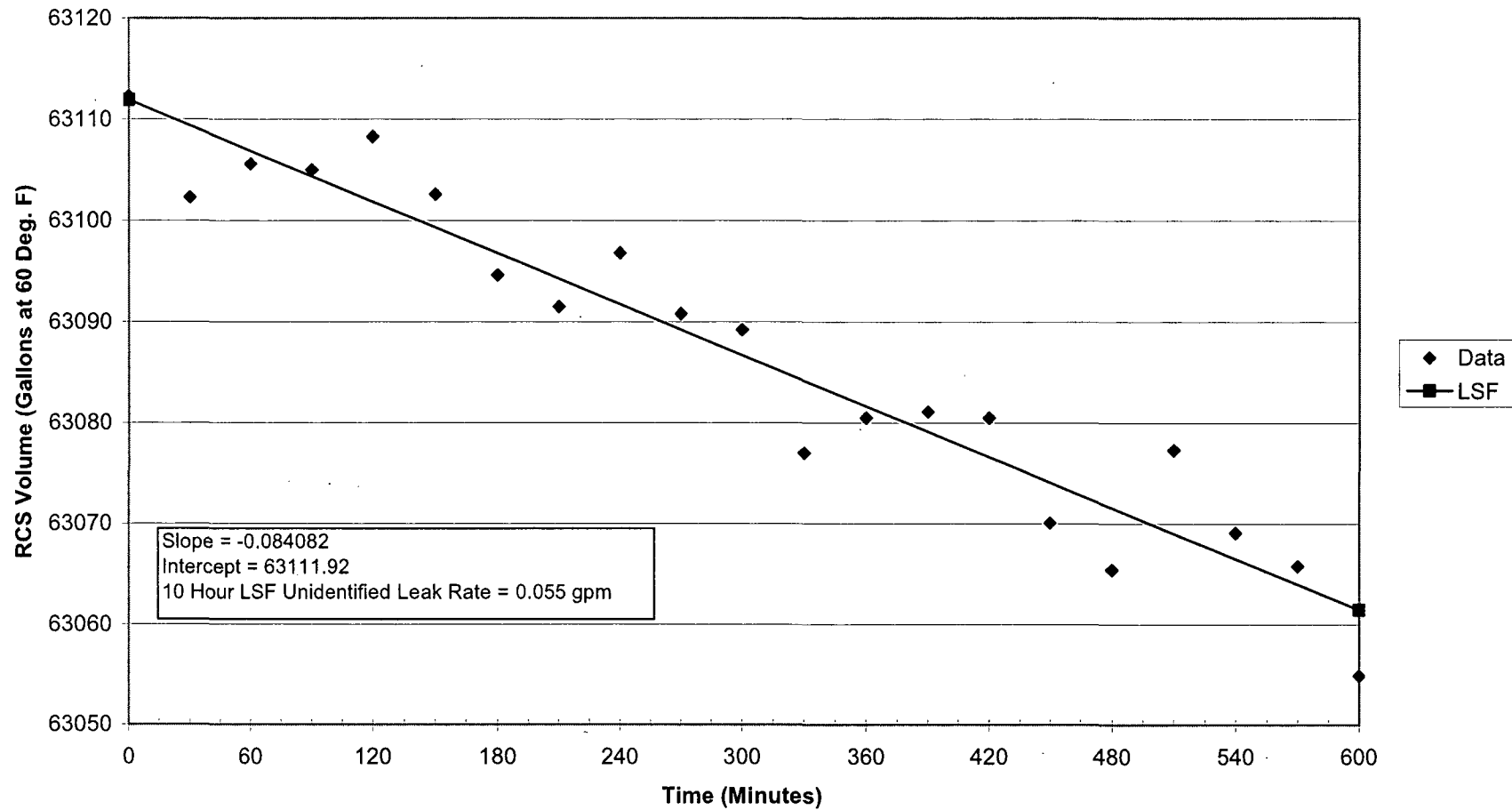


Figure D-18
Typical Plant Data
LSF of RCS Volume/Mass Inventory Vs. Time Data
(1 Hour Intervals)

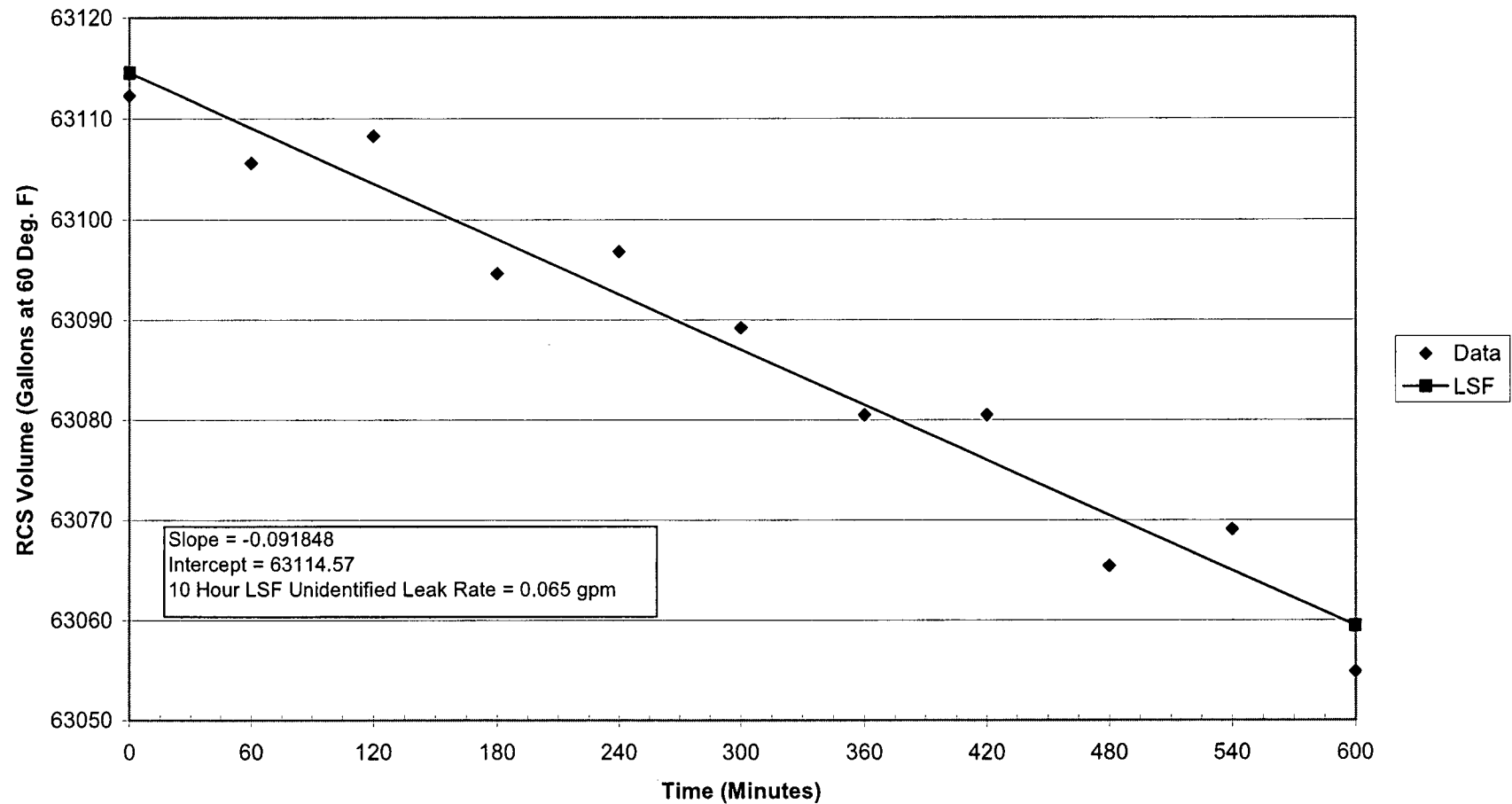


Figure D-19
Typical Plant Data
LSF of RCS Volume/Mass Inventory Vs. Time
(2 Hour Intervals)

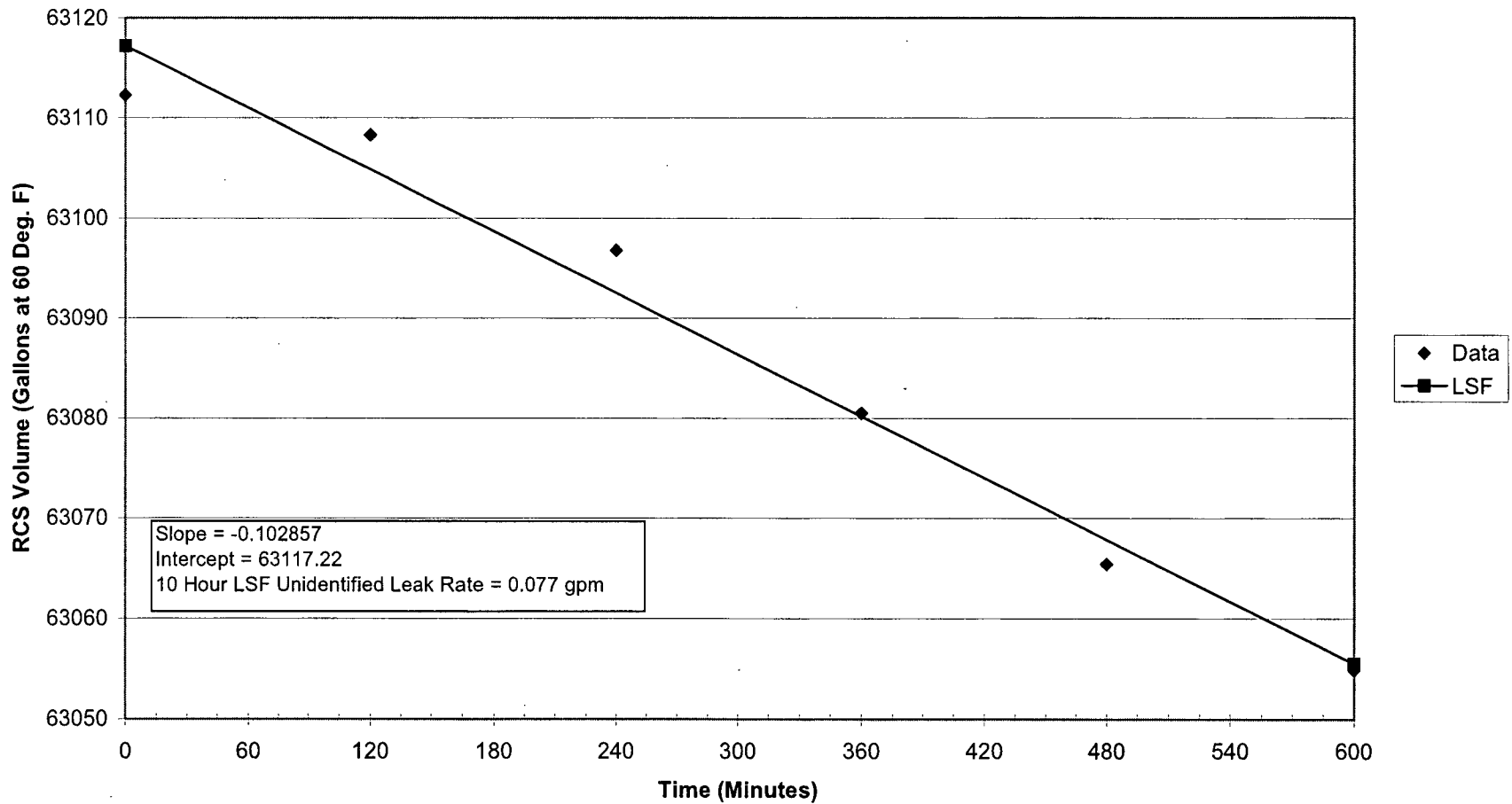


Figure D-20
Typical Plant Data
LSF of Identified Volume/Mass Inventory Vs. Time Data
(15 Minute Intervals)

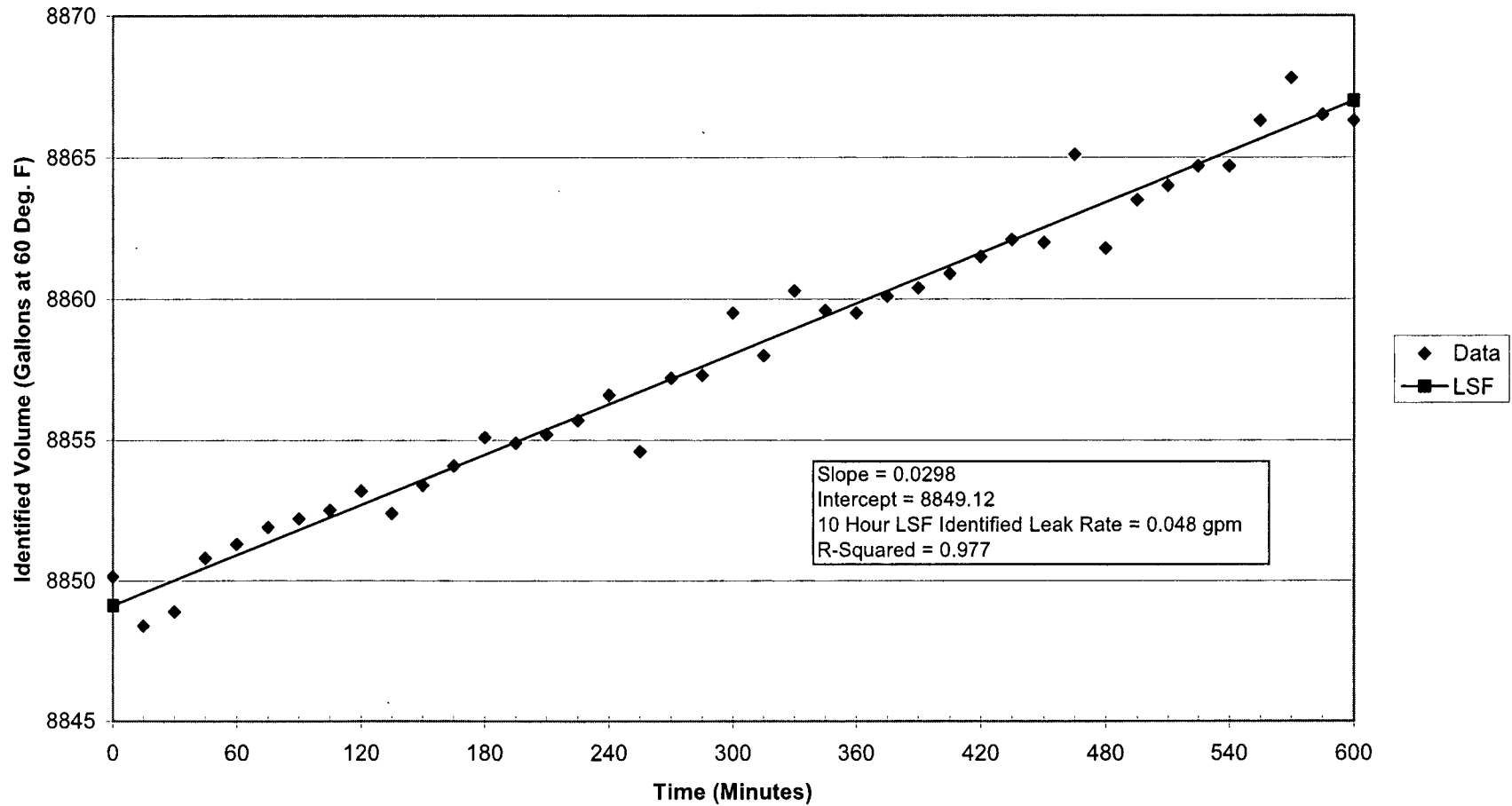


Figure D-21
Typical Plant Data
LSF of Identified Volume/Mass Inventory Vs. Time Data
(30 Minute Intervals)

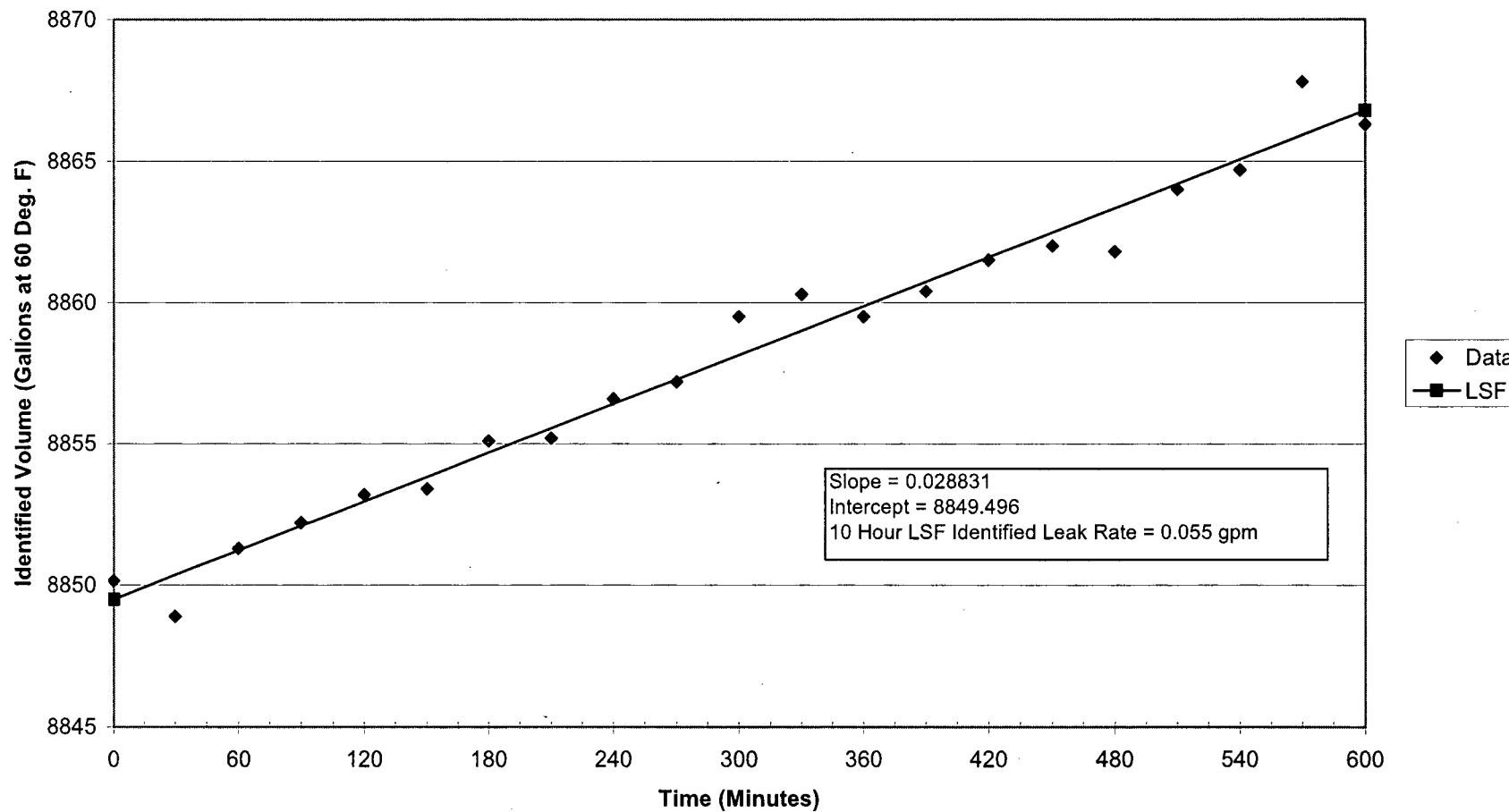


Figure D-22
Typical Plant Data
LSF of Identified Volume/Mass Inventory Vs. Time Data
(1 Hour Intervals)

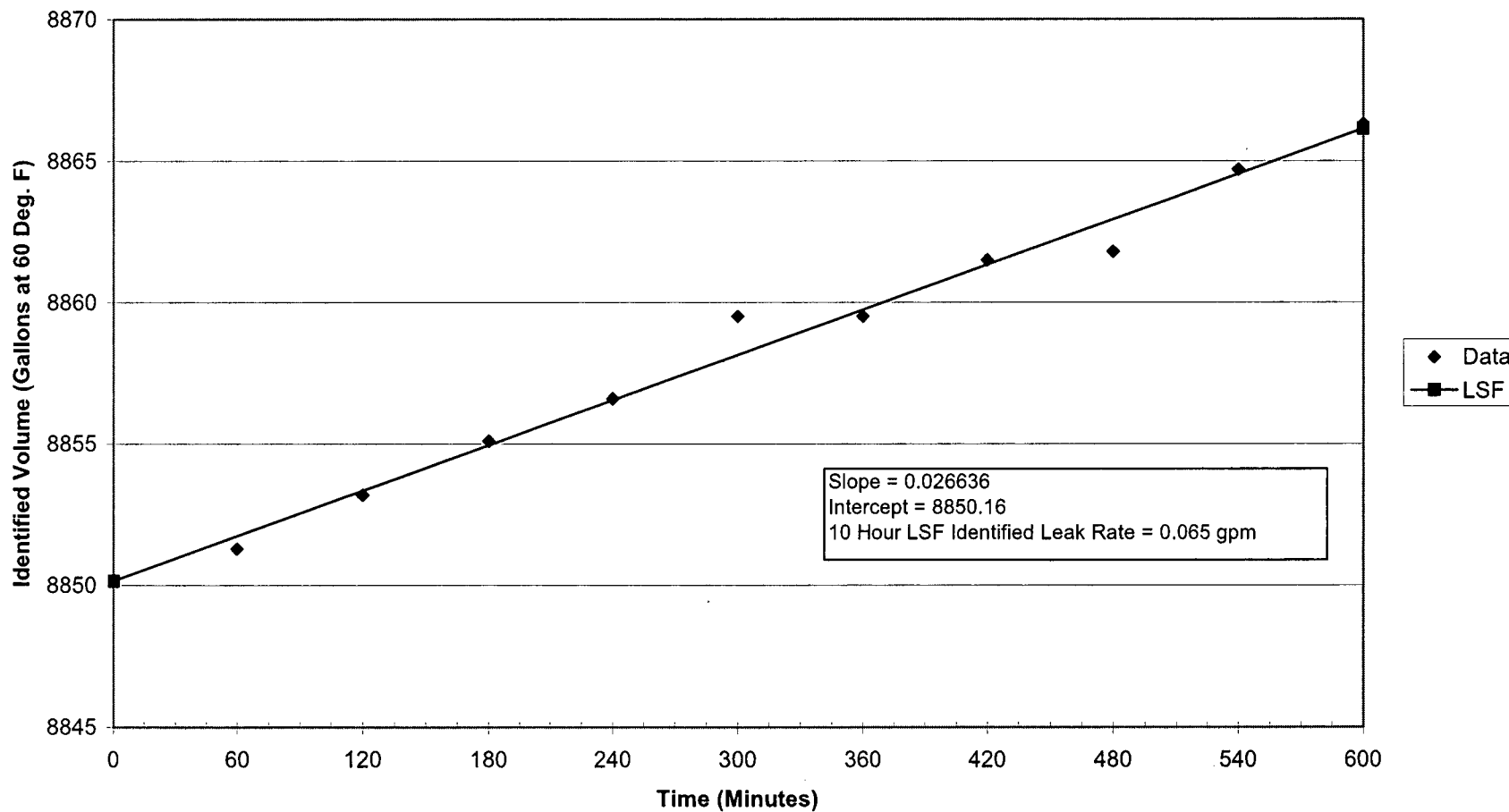


Figure D-23
Typical Plant Data
LSF of Identified Volume/Mass Inventory Vs. Time Data
(2 Hours Intervals)

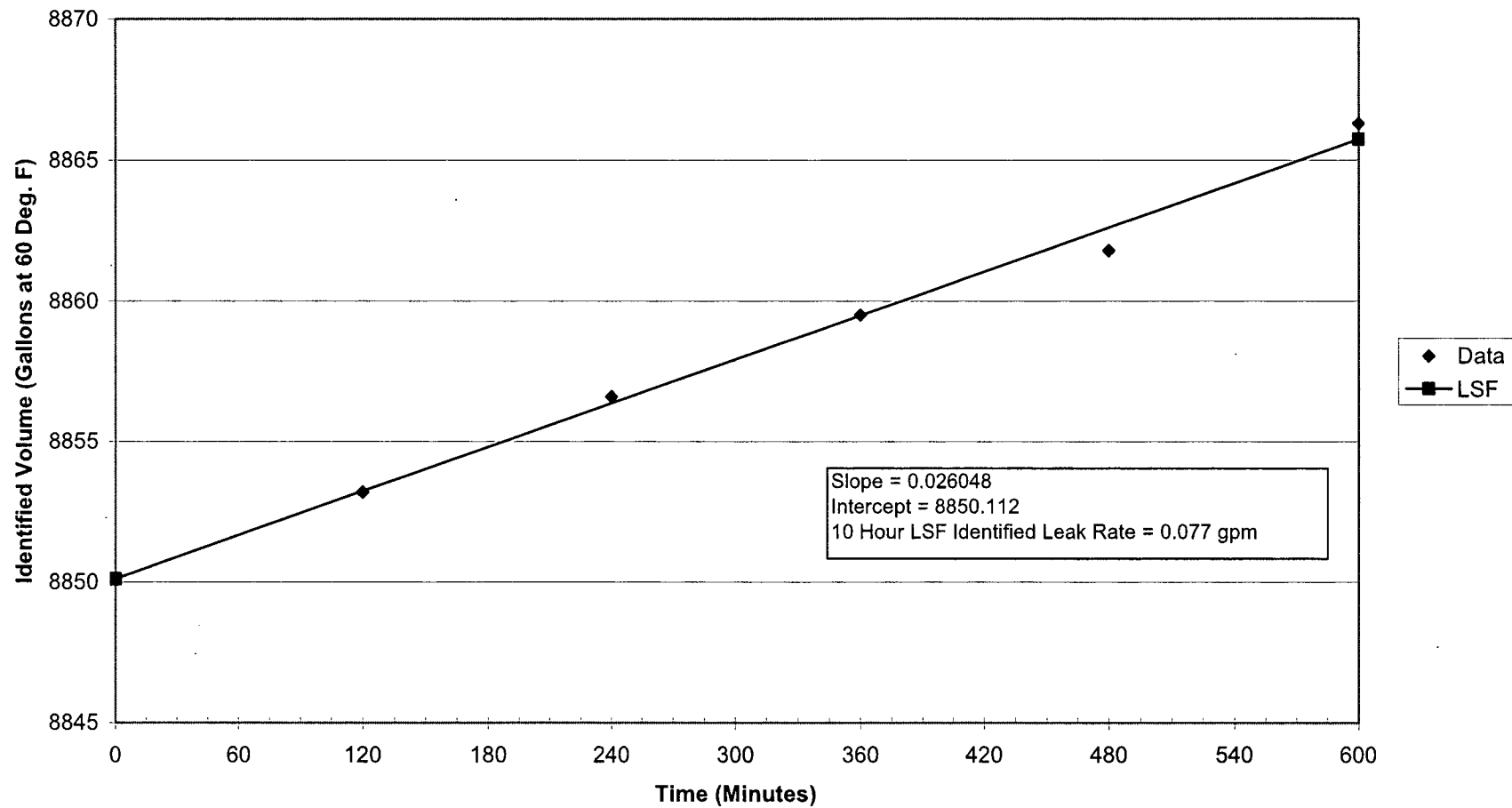


Figure D-24
Uncertainty in the Slopes Versus Number of Data Points

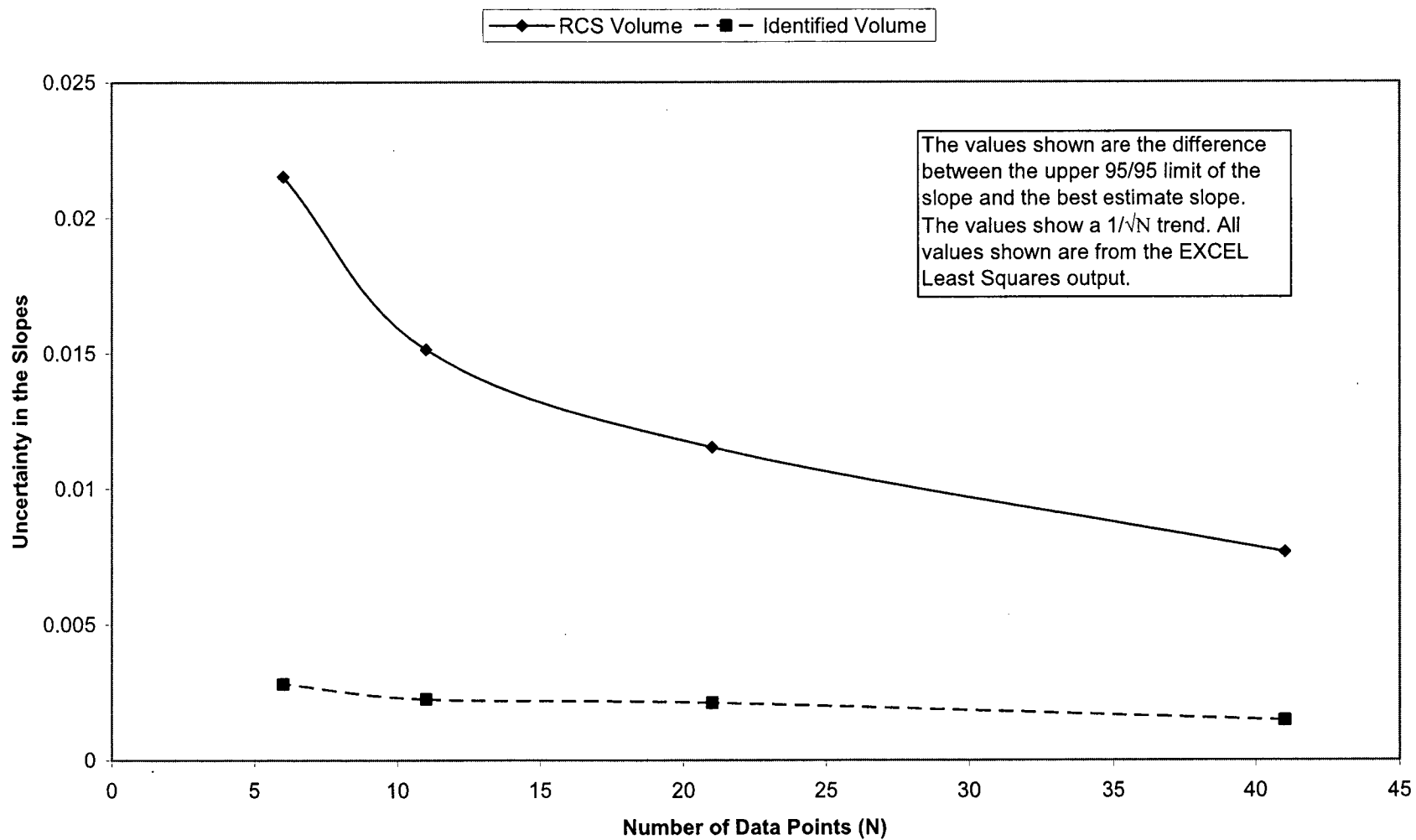


Figure D-25
Example of Inappropriate Use of Least Squares Fitting

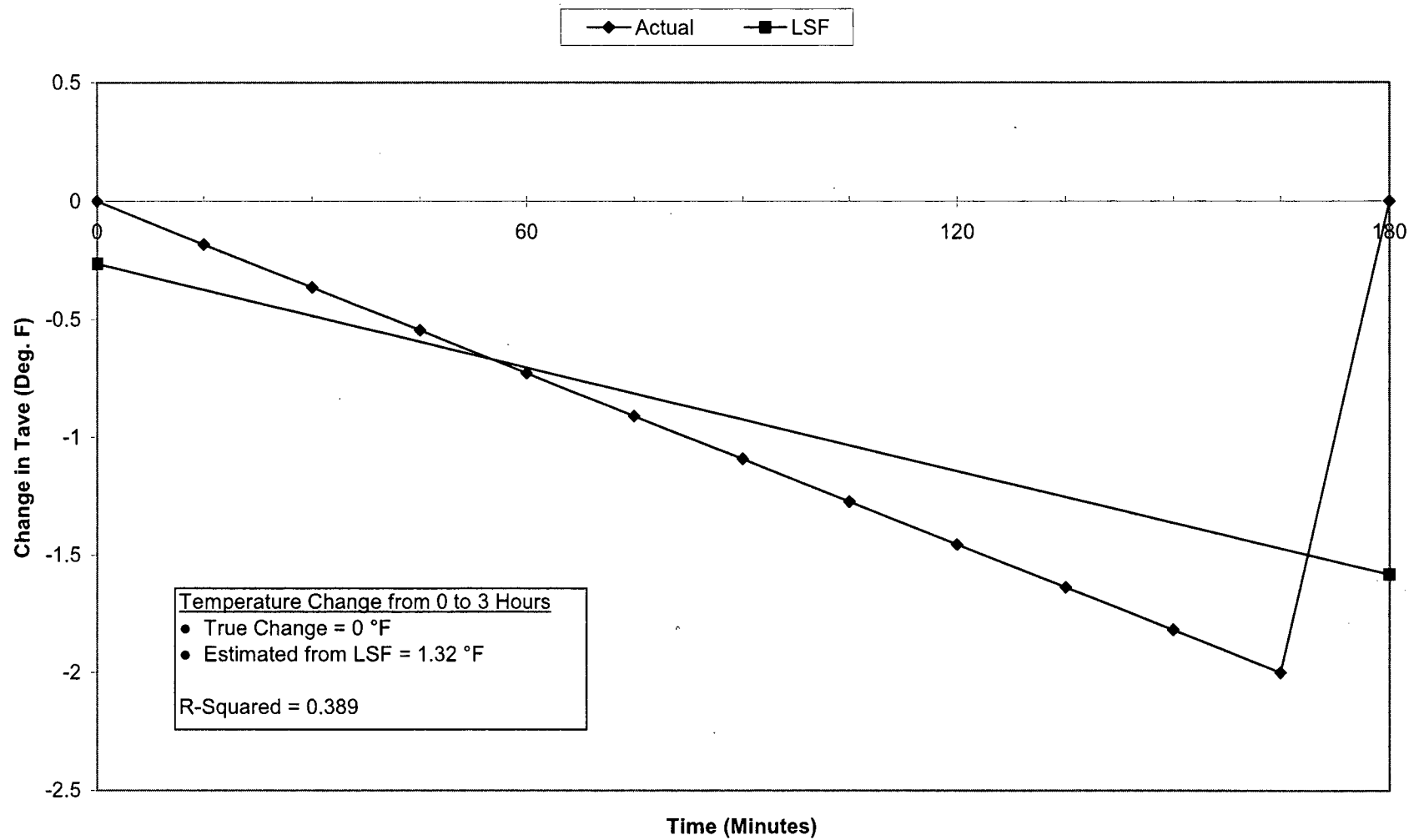


Figure D-26
Cross-Plot of the 2nd Quarter ZSCORE Values
ZSCORE Uses the Leak Rate for Each Day in the 2nd Quarter

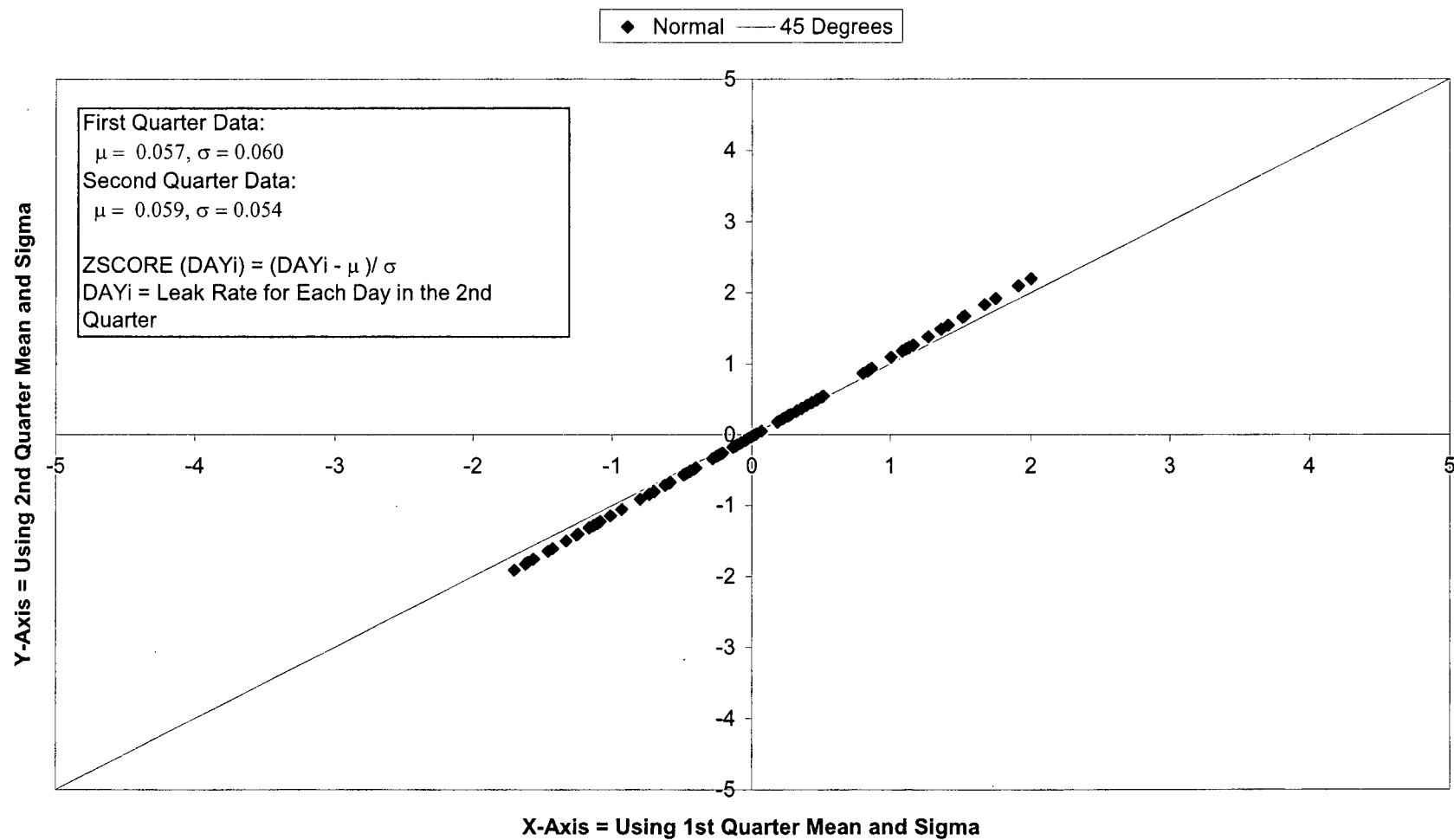


Figure D-27
Cross-Plot of the 2nd Quarter ZSCORE Values - Includes Outliers
ZSCORE Uses the Leak Rate for Each Day in the 2nd Quarter

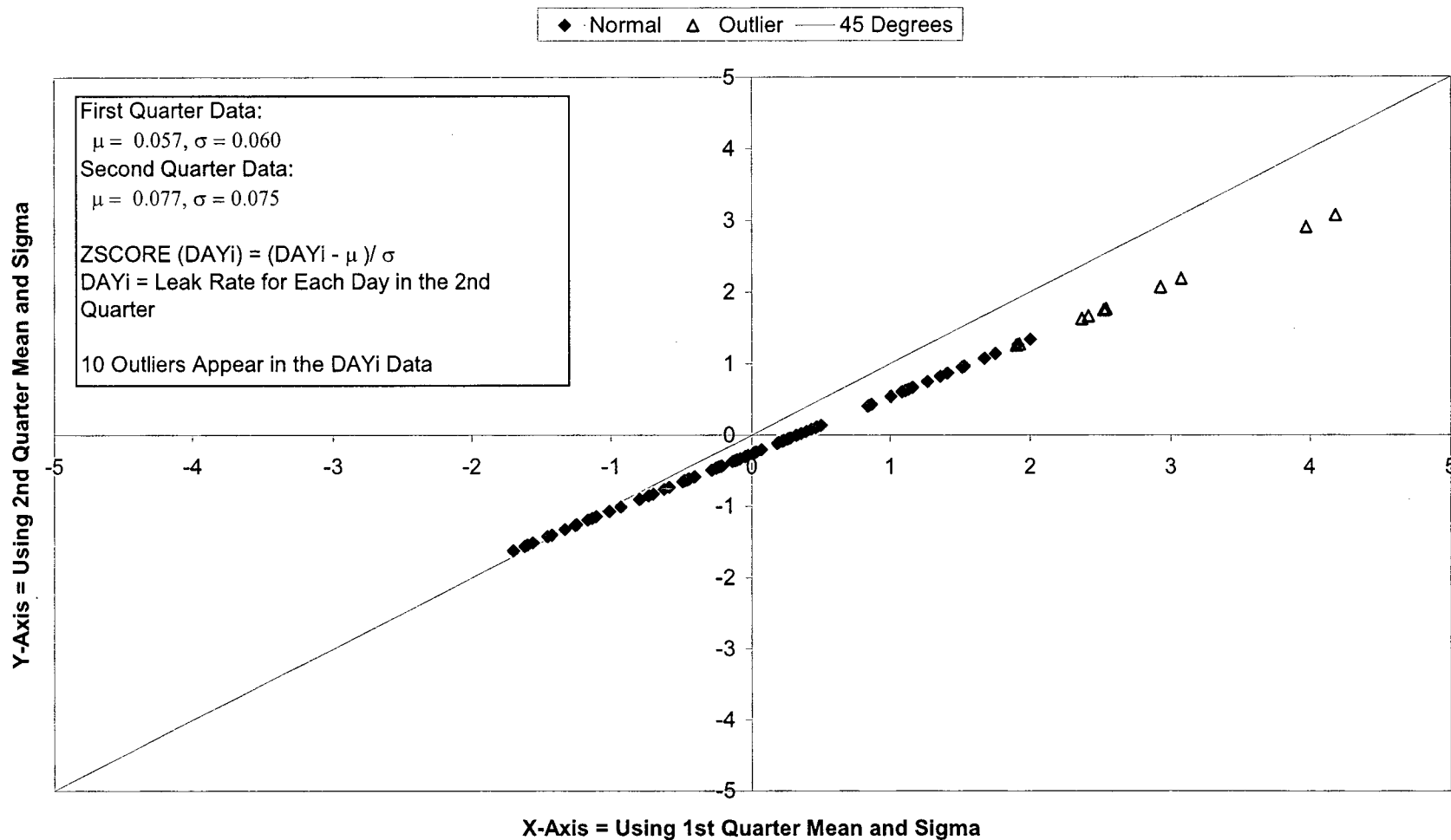


Figure D-28
Cross-Plot of the 2nd Quarter ZSCORE Values - Includes Outliers
ZSCORE for Y-Axis Uses the Median (Not Mean) and "MAD" (Not Sigma)

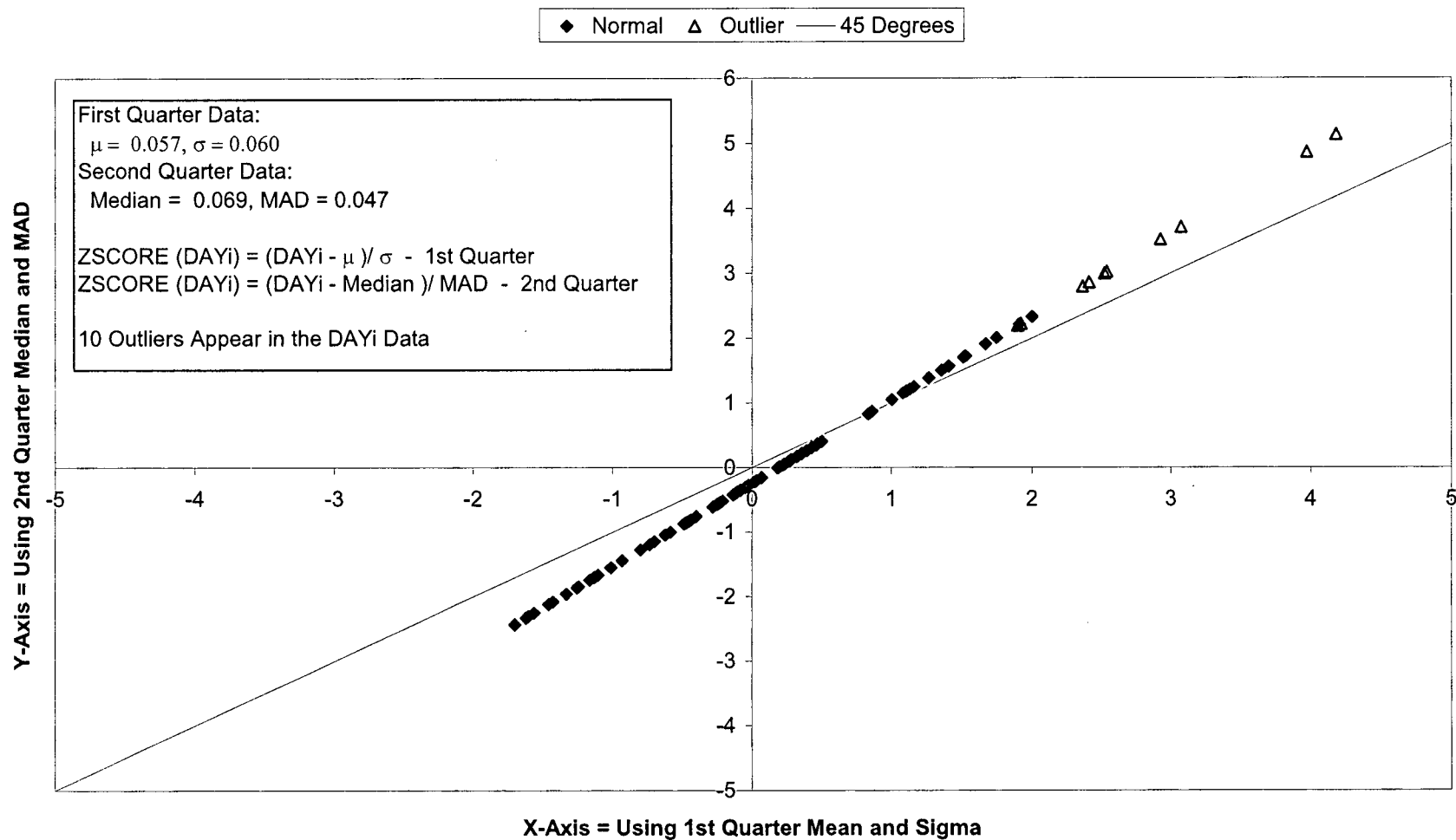


Figure D-29
Typical Plant Data
Unidentified Leak Rate as a Function of the Duration of Surveillance Interval

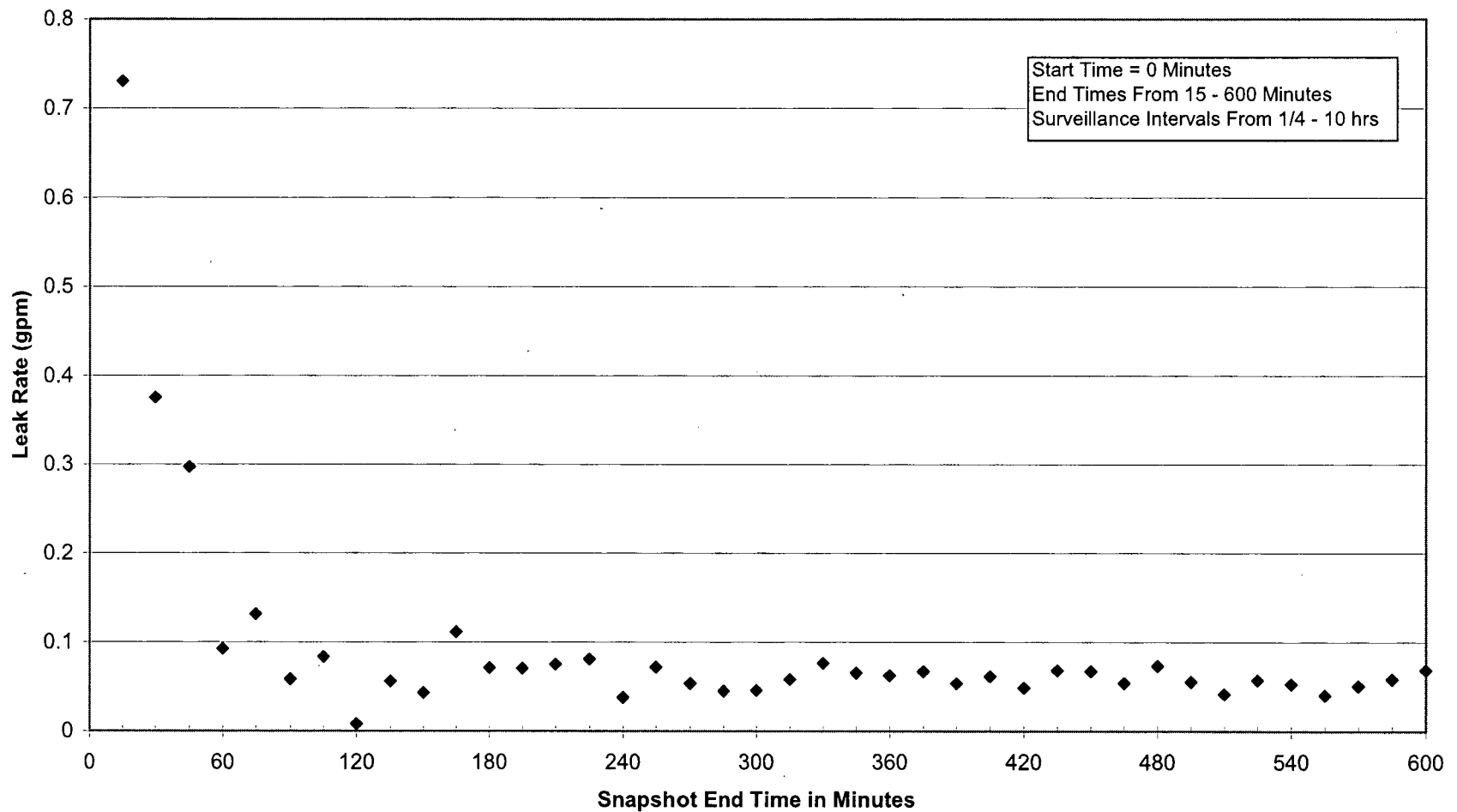


Figure D-30
Simulated Data - Assessment of Independence

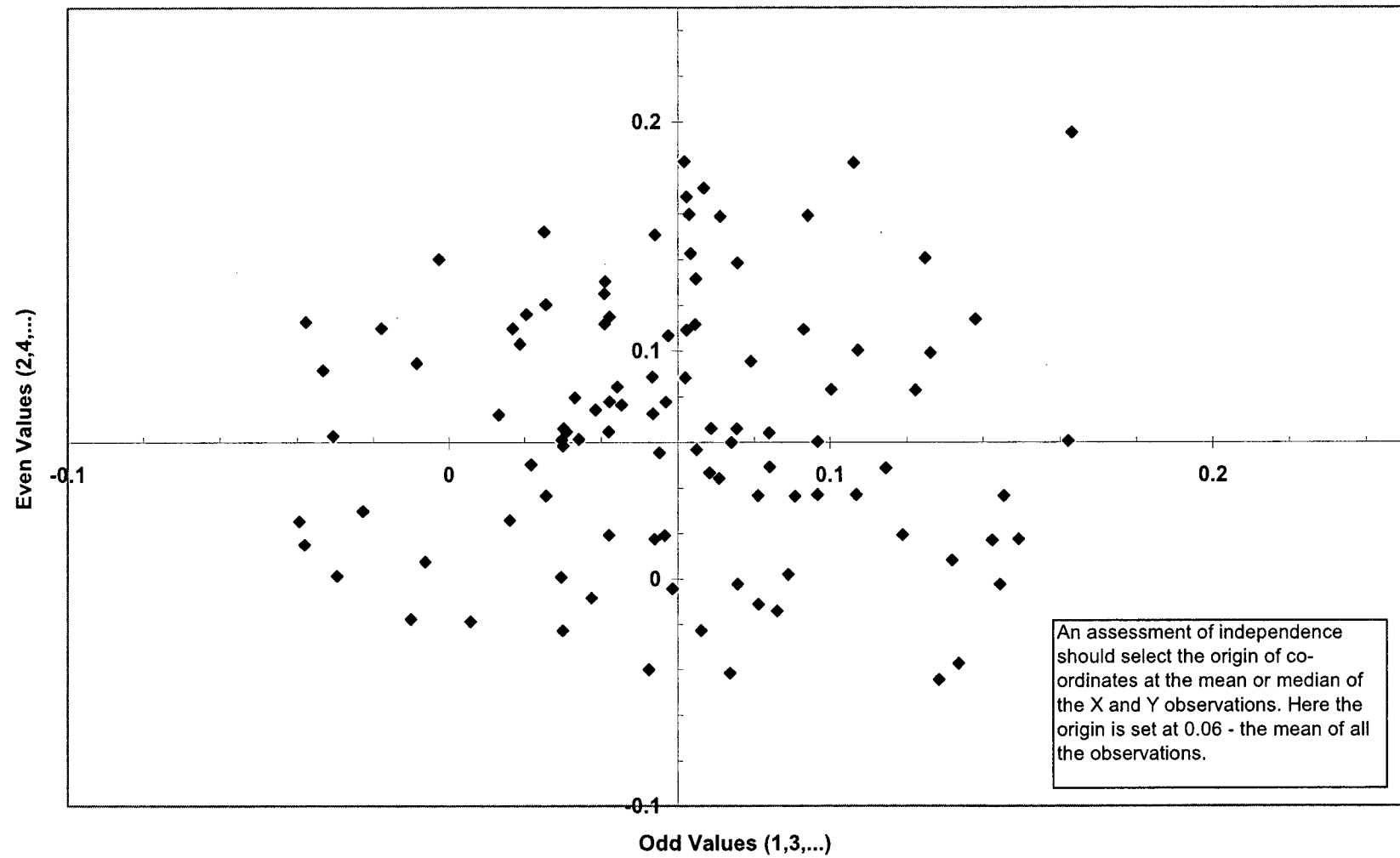
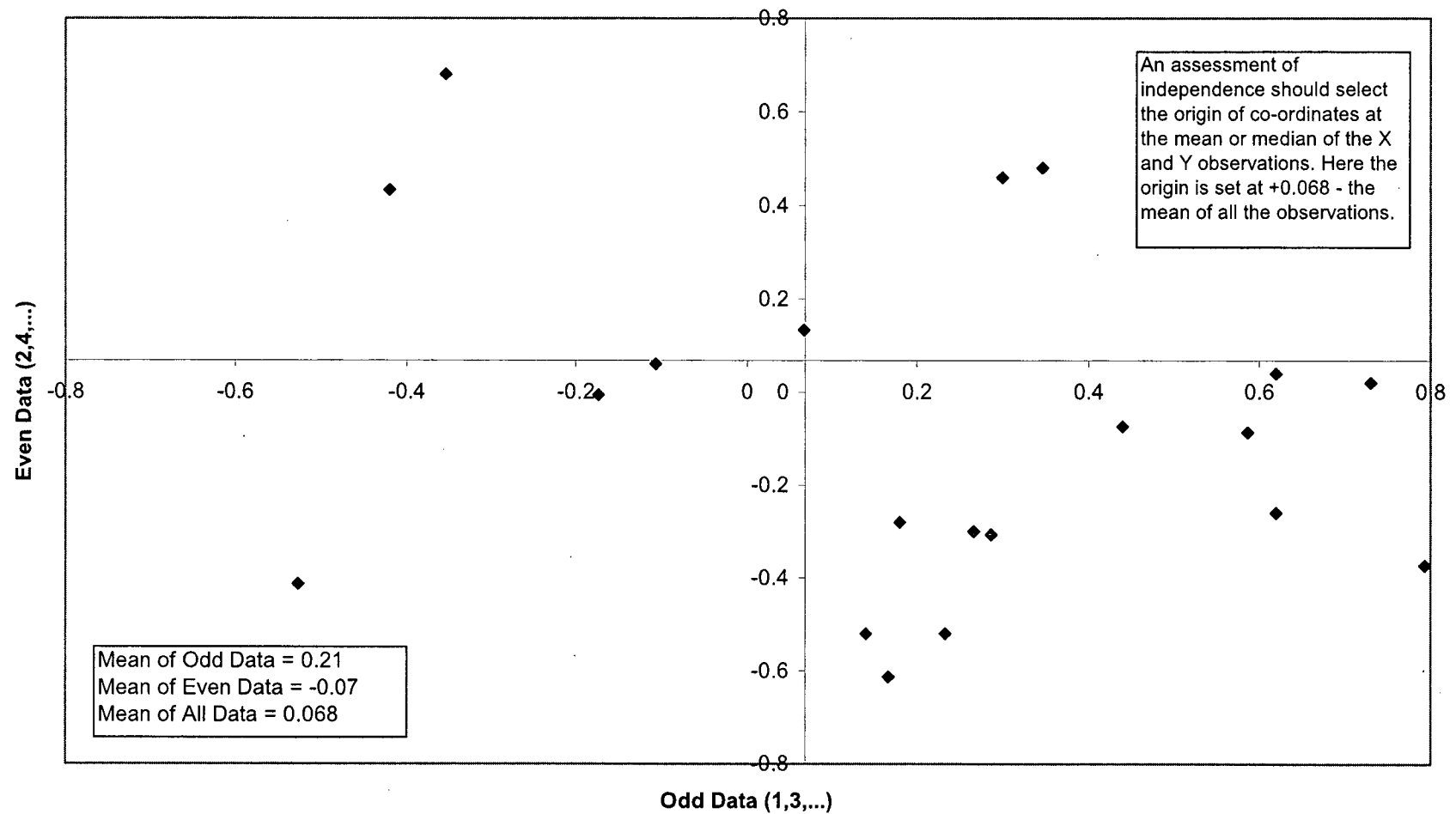


Figure D-31
Typical Plant Data - Assessment of Independence
15 Minute Leak Data



Appendix E

Description of the Computer Codes used in Section 11

E-1 Introduction

The investigation of Action Levels I, II and III discussed in Section 11 was performed using two Microsoft Visual Basic PC computer programs named RCS_EXCEED_CDF and RCS_LEAK_SIM. These computer programs utilize a statistical technique called Stochastic Simulation (A.K.A. Monte Carlo Simulation) to simulate the fluctuations (noise) observed in the surveillance measurements of the unidentified leak rate (illustrated in Appendix D, Figure D-3). These simulations assume that these fluctuations are characterized by a normal (Gaussian) distribution and that all surveillance measurements are statistically independent.

E-2 Description of RCS_EXCEED_CDF, Version 1.0

Program RCS_EXCEED_CDF was written to investigate the statistical characteristics of the “exceedences” detection method (i.e., a sequence of N consecutive leak rate measurements exceeding the baseline mean value). The draft NRC Inspector Guidance (see Appendix A) presently defines Action Level I based on 9 exceedences. Program RCS_EXCEED_CDF can be used to investigate exceedences of any N value, but it was used in Section 11 to investigate exceedences of 5, 7 and 9.

The user input to RCS_EXCEED_CDF is the selected N value. The code generates 1000 sets of N “unitary random normal deviates” (i.e., 1000 x N random numbers sampled from a normal distribution having a mean of zero and a standard deviation of one). By generating a large number of samples like the one described above, we can “build” the cumulative probability distribution which describes the probability of detecting a given step jump as a function of the number of exceedences used and the standard deviation (σ) observed in the surveillance procedure. In addition, the “false alarm” rate can be determined. (The “false alarm” rate is the probability of getting N exceedences when no change in the baseline mean (μ) has occurred.)

RCS_EXCEED_CDF calculates and stores the minimum random normal deviate for each of the 1000 sets of N sampled values representing the noise in the first N consecutive leak rate measurements after a step jump occurs. The mean and the standard deviation of the 1000 minimum values are determined. The D’ normality test (Reference 15) is then applied to this data to determine if it agrees with a normal distribution or not. If the data passes the D’ normality test, the 95/95 upper and lower tolerance limits are determined using the 95/95 k factor (1.727) published in Reference 16 for a set of 1000 values. If the data fails the D’ normality test, non-parametric statistics (Reference 17) are used to calculate the 95/95 upper and lower tolerance limits.

The code calculates the fraction of the cases that have positive minimum normal deviate values. These cases correspond to the “false alarm” probability. The 1000 minimum normal deviates are input to a Microsoft Excel spread sheet that calculates and plots the Cumulative Distribution Function (see Appendix D, Figures D-4 to D-6).

These calculations can be performed using different values for the “seed” of the Visual Basic pseudo-random number generator.

E-3 Description of RCS_LEAK_SIM, Version 1.0

Program RCS_LEAK_SIM was written to study the ability to detect a “step jump” in the mean leak rate with respect to the baseline mean value when using the following types of detection methods:

- The “exceedences” method, for any N value. This is the same as Action Level I of Appendix A when N = 9. This method is referred to as “Alarm 1” in the discussion that follows.
- Two out of three consecutive measurements exceeding the baseline mean by a value that is greater than or equal to twice the baseline standard deviation. This is the same as Action Level II of Appendix D and is referred to as “Alarm 2” in the discussion that follows.
- Any measurement exceeding the baseline mean by a value that is greater than or equal to three times the baseline standard deviation. This is the same as Action Level III of Appendix D and is referred to as “Alarm 3” in the discussion that follows.

(Program RCS_LEAK_SIM was also configured to carry out calculations which modeled absolute leak rates and total integrated leakage in potential support of limits on these quantities set in Reference 25.)

Program RCS_LEAK_SIM generates 1000 “strip chart” recordings analogous to the one illustrated in Appendix D, Figure D-10. The fluctuations in the measured leak rate values around the mean leak rate value are simulated using random normal deviates. The user inputs the mean (μ) and standard deviation (σ) values to be used in the simulation. In each “strip chart” simulation case, a step increase in the mean leak rate value is assumed to occur at a time point that for convenience is labeled as time zero. Prior to time point zero, the leak rate is assumed equal to the baseline mean value. The magnitude of the step increase in the mean leak rate value is specified through input as a multiplier (M) of the baseline standard deviation ($M \times \sigma$). The user also inputs a time limit for reaching any of the alarms identified above (T). The construction of the strip chart ends when Alarm 1 is reached or when the specified time limit is reached, whichever is greater. The program stores for each “strip chart” case the time point when Alarm 1 is reached and the total integrated leakage, calculated from time point zero to the time point when Alarm 1 is reached. The mean, standard deviation, and the 95/95 upper and lower tolerance limits of the distribution of the times when Alarm 1 is reached are determined. The code has the capability of producing a histogram of this data (see Appendix D, Figures D-7 to D-9). If that distribution is not normal, based on the D’ normality test (Reference 15), the 95/95 upper and lower tolerance limits are calculated based on the non-parametric method (Reference 17). The program calculates the fraction of the cases that produced Alarms 1, 2 and 3 within the specified time period. For Alarms 2 and 3, the times when these alarms are first achieved are not recorded.

Program RCS_LEAK_SIM includes the following capabilities and options:

- The code can also simulate a ramp increase in the unidentified leak rate over a selected time period.
- The code can perform a rolling average calculation of the simulated leak rate measurements for any time period (for example, a 7 day rolling average). This option can be used to study the advantages and disadvantages of using the rolling average technique on the measurements.
- The code has a model for producing random “spikes” (i.e., outliers) in the simulations of the unidentified leak rate measurements. The user inputs the probability of having a spike and a range for the magnitude of the spike (specified as a multiplier of the baseline standard deviation).
- The code has a model for producing sinusoidal variations in the simulations of the unidentified leak rate measurements. The user inputs the amplitude (specified as a multiplier of the baseline standard deviation) and the period (the number of time points) for the sinusoidal variations.
- The code includes options to facilitate the plotting of specific “strip chart” cases. The user inputs the selected case (for example, case 75 of the 1000 cases simulated) and the number of simulated measurements to produce prior to the step jump. The code produces an output file containing the simulated unidentified leak rate values and the rolling average value for each time point. This file can be easily imported into a Microsoft Excel spreadsheet to generate a plot of the strip chart as illustrated in Appendix D, Figure D-10. The user can also specify the printing interval for the data (for example, every 7 time points relative to time point zero). Combined with the rolling average feature, this printing option can be used to generate weekly averages of the simulated measurements.

These computer codes, and all associated input and output files are stored in CDROM and archived in Reference 24.

Appendix F

NRC Final Guideline

Attachment 1

Assessing Reactor Coolant System (RCS) Unidentified Leakage Rate Trend

In order to track and assess the unidentified leak rate trend, the inspector should utilize licensee's RCS leakage rate data. Once each month, the inspector should obtain the mean value (μ) and the standard deviation (σ) of RCS unidentified leakage rate for the past three months, representing a 3-month rolling data set, using the Quattro Pro spreadsheet (see ROP Digital City Web link <http://nrr10.nrc.gov/rop-digital-city/pwrleakage07.qpw> (PWR) and <http://nrr10.nrc.gov/rop-digital-city/bwrleakage07.qpw> (BWR). During the ensuing month, the inspector should use the resulting μ and σ to establish action thresholds as described below.

Comment # 1

Comment # 2

Note: For licensees who calculate the leak rate more than once per day, ensure that the leak rate value for calculating the mean value is the average for that day. When starting a new operating cycle after refueling, the mean, standard deviation and action levels should be calculated based upon the first three months of steady state leakage data following an outage. The expectation is that the steady state leak rate at the beginning of the new operating cycle should be lower than the average leak rate during the period just prior to the plant shutdown for the refueling, maintenance or forced outage. This is based on the assumption that the licensee has identified and corrected all potential leakage source(s).

The mean value (μ) and the standard deviation (σ) are defined by the following equations:

$$\mu = (\underline{x_1} + \underline{x_2} + \dots + \underline{x_n})/n; \quad \sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{n}}$$

Comment # 3

assuming the unidentified leakage rate, x , is a random variable which has a mean value, μ , and a known standard deviation, σ .

Comment # 4

Once a month, the inspector should use the mean value (μ) and the standard deviation (σ) from the previous three months to calculate the three action level triggers (μ , $\mu + 2\sigma$, $\mu + 3\sigma$). The action levels were determined by statistical analysis:

- | | | |
|-------------------|--|---|
| Action Level I: | Nine (9) consecutive leakage measurements above the mean μ | } |
| Action Level II: | Two (2) of three (3) consecutive measurements exceed the $\mu + 2\sigma$ | |
| Action Level III: | One (1) measurement of leak rate exceeds the $\mu + 3\sigma$ | |

Comment # 5

During the daily plant status review, the inspector should compare the licensee calculated RCS unidentified leakage rate data to the three action level triggers to determine if there is a potential adverse trend and take appropriate actions, if necessary.

If the licensee performs the RCS leakage rate calculations several times a day, the inspector should only compare the average positive value per day to the action level triggers. If the licensee, following their TS, only performs a RCS leakage rate calculation once per 72 hours, then the inspector should perform this comparison once per 72 hours. For BWRs, if the drywell floor sump is pumped less frequently than daily, then average positive value should only be entered for those days that the sump is actually pumped. Note: Zero or negative values should not be entered into the spreadsheet.

Comment # 6

Upon exceeding one of the action level triggers, the inspector should take the following actions to ensure that licensees are monitoring and taking appropriate actions to reduce the leakage when statistically significant leakage trends exist and to ensure that the proper levels of NRC management are informed of potential adverse trends in RCS unidentified leakage.

Action Level I - Nine (9) consecutive leakage measurements above the mean μ

Actions:

1. Continue to monitor licensee's actions.
2. Determine if the licensee is increasing awareness of other containment parameters.

Action Level II - Two (2) of three (3) consecutive measurements exceed the $\mu + 2\sigma$

Actions:

1. Take the steps in Action Level I, if not already done.
2. Determine if other data such as sump chemistry samples, containment atmosphere radioactivity, and humidity levels indicate no RCS leakage.
3. If there are indications of RCS leakage activity from other data such as sump chemistry samples, containment atmosphere radioactivity, containment temperature, pressure and humidity levels, review licensee's plans for identifying source of unidentified leakage and proposed corrective actions.
3. Discuss licensee's actions with regional branch chief and engage licensee if necessary.

Action Level III - One (1) measurement of leak rate exceeds the $\mu + 3\sigma$

- Actions:**
1. Take the steps in Action Level II, if not already done.
 2. If leakage trend continues upward for the next 24 hours with positive identification of RCS leakage from other data, discuss these indications with licensee's operations management and monitor licensee's proposed corrective actions.
 3. Ensure regional management at the Director level is informed via the branch chief of the status of licensee's actions.
 4. The Region should notify the appropriate NRR technical branches via the NRR project manager if the trend continues to increase from Action Level III over the next 72 hours with confirmation of RCS leakage activity from other data and the licensee has not taken prompt corrective actions. The region should expect additional dialogues with the licensee.

END

No.	Comment
1	Unable to access these documents. Therefore, Westinghouse has not reviewed them.
2	<p>The 02/05 draft of 2515 Appendix D, (Appendix A, p. A-2) specifies that “the most conservative leak rate value for a given day” should be used rather than the “average value” specified in the 12/02/05 version of 2515 Appendix D, Section 11.2.3 discusses some of the difficulties associated with the use of the “most conservative” value. (Westinghouse recommendation that “exactly one high quality measurement” be performed each day was, in part, an attempt to eliminate this issue by having only one measurement recorded. Therefore, this value was, by default, the most conservative value.) The use of the “daily average” value is an improvement relative to “the most conservative value”. Nonetheless, some of the same concerns described in Section 11.2.3 still apply. For example, if a significantly different number of measurements are “averaged” from day to day, the daily results are not directly comparable. In a similar manner, if the conditions of validity vary throughout the day, the average is somewhat contaminated by the worst measurements.</p> <p>The Guidance for what to use for a baseline value for the first three months after a refueling is not clear. A strict interpretation implies that the Action Levels are undefined since no baseline values are available for the first three months after startup. The issue of what to use for a baseline after startup is addressed by the PWROG in the standard Action Levels and Response guidelines, (Ref. 25).</p>
3	Strictly speaking, the symbols μ and σ are typically used to represent population values whereas the symbols \bar{x} and s are used to represent sample values from the population. It appears that the Appendix D Guidelines consider the values recorded in a given month as “the population” for that month rather than a sample of 31 values drawn from a larger population. If the values are considered as a sample, the standard deviation should use a divisor of (n-1) rather than n. This is not a significant difference for samples of size 90. See also the discussion in Section 11.2.2.
4	<p>The draft Appendix D directed the inspector to calculate a new μ and σ “Once a Quarter” rather than “Once a month”. Westinghouse recommends updating the baseline mean and baseline standard deviation on a Quarterly basis. There are several reasons for this:</p> <ul style="list-style-type: none"> • Less burden for the Utility Staff • The discriminating power of the “two-sample t-test” is roughly a factor of 2 better for comparison of two 90 day samples as opposed to two 30 day samples. (See details in Customer Comment #75, Appendix H.) As a result, the Utility is better able to detect a small creeping leak rate in successive Quarters. • Westinghouse does not recommend that the utility blindly throw out the oldest Quarter’s data and simply plug in the newest Quarters data without first performing an F-test to look for any significant shifts in the baseline standard deviation and a two-sample t-test to detect any small shifts in the baseline means. Since there is some effort involved in inspecting the results and understanding any trends, it is prudent to carry out the effort less frequently. <p>However, if there is a small creeping leak rate which grows on a month by month basis, it may be appropriate to use the NRC “30 day” approach since it is possible that Action Level I will occur frequently near the end of a calendar quarter. This point is discussed in Customer Comment #11 in Appendix Attachment 11.1 of Reference 25.</p>

No.	Comment
5	The NRC does not provide numerical limits on the allowed values of μ and σ , the PWROG guidelines do (refer to Section 5 of Reference 25).
6	<p>Westinghouse does not agree that negative (or zero) values should be excluded in the determination of the baseline mean and baseline standard deviation. We do agree that negative observations should not be included when determining absolute leak rate limits and total integrated leakage limits as described in Sections 5.2.1 and 5.2.3 of Reference 25. Section 11.8 and Customer Comment #16 of Attachment 11.1 of Reference 25 discuss the issue in detail.</p> <p>In addition, it is worth noting that a Utility that performs a leak rate once every 72 hours with a mean near 0.0 gpm is expected to see roughly $\frac{1}{2}$ of all values less than 0.0 gpm. As a result, a "month's observations" might consist of just 5 values (i.e., $\frac{1}{2} \times 30 \text{ days} \times 1/3 \text{ samples/day}$). This situation could be even worse if the Utility is operating with a small negative mean and a small standard deviation. In this case, it is possible that all the measurements are excluded resulting in no monthly observations.</p> <p>For readability, Customer Comment #16 is included below:</p> <p><i>Unlike NRC App. D, we continue to recommend that the calculation of the Baseline mean and standard deviation include both positive and negative "daily average" data values. Retaining these values rather than ignoring them "forces" the distribution to approach normality which then coincides with the models and conclusions documented in the Section 11, Ref. 2 simulations. (Note that all the Standard Plant measurements passed the normality tests to date.)</i></p> <p><i>In addition, the F-test, the two-sample t-test, and the substitution of the mean in place of the median start to fall apart when the distribution of observations is not normal. (We recognize that the mean of the data will increase if negative values are deleted (which increases the Action Level "triggers" in Section 5.2.2). At the same time, the standard deviation will decrease if negative values are discarded.)</i></p> <p><i>Finally, I think we all agree that the negative values are not "real" in the sense that water is not appearing from nowhere. That is, negative values are appearing due to the accumulation of errors of measurement and so on (i.e., the so called "slack variable" effect discussed in Sec. 11.1 of Ref. 2). As a consequence, the negative values provide "real information" about the accuracy of the system. In particular, we would expect that spurious positive readings of the same magnitude as the spurious negative readings must be occurring (provided that there are no significant spurious biases).</i></p>

Appendix G

Standard Plant Testing

G-1 Standard Plant Task Description

Introduction

Appendix G documents the results of the Standard Plant Activity. The contents of each Section are:

- Section G-1 documents the scope and purpose of the Standard Plant Activity
- Section G-2 documents the Participants and the data collected.
- Section G-3 is quite analytical and describes the Westinghouse methods used to analyze and examine the data. This Section is “required reading” only for downstream users who may need to perform similar analyses in the future.
- Section G-4 summarizes the most important conclusions obtained from the activity. Since these conclusions are used to make recommendations in Section 11.12 of the main body, this section is recommended reading for all.
- Sections G-5 to G-9 describe individual results for each of the 5 Standard Plant participants. Each of these sections excerpts significant results from the Excel spreadsheet used to perform analyses for each participant. These results support the conclusions but may be of limited interest to the typical reader.
- Section G-10 presents a brief cross-comparison of selected results for all Standard Plant participants. A list of all identified outliers by participant is included. These results may be of interest to a typical reader to evaluate where his plant stands relative to the participants.
- Section G-11 documents an Excel template file which can be used to step through the analysis process Westinghouse used for Sections G-5 to G-9.

The single most important conclusion from Section G-4 is that the snapshot method and associated equations documented herein in Sections 4 to 10 is accurate and unambiguous. That is, we did not receive one question from any Participant asking for any clarification nor any comment suggesting that the method, as described, lacked sufficient detail or was erroneous. As shown in Section G-10, the cross-comparison of results for the three participants who used the “two hour, midshift snapshot method” were in good agreement – particularly with respect to the observed scatter in the results (i.e., the standard deviation of the daily ULR values for those three participants was virtually identical at .03 gpm).

The two biggest surprises were the relatively high frequency of “outliers” (i.e., roughly 4% of all observations) and the ease of taking associated “24 hour” measurements which have approximately 1/12 the scatter of the 2 hour measurements and which effectively trap any event which effects the RCS inventory around the clock. (The 24 hour measurements are discussed in Section G-5.)

Overview of the Activity

The following text is excerpted from the description of the Standard Plant Task that was distributed to the Standard Plant Task Members when the work on the Task was initiated (November 15th, 2005):

“Task 6 of PA-OSC-0189 (Reference 1) requires that Westinghouse exercise and evaluate the draft Standard Guidelines at a typical plant. Westinghouse, with utility assistance, will exercise the standard principles and recommendations on data provided from up to four Standard Plants. The principal activity for each Standard Plant member is to record ... one high quality (i.e., well within the limits of validity) measurement over a period of approximately two hours each day. The standard plant participants do not have to change their current methodology for performing the leak rate calculation to the standard methodology to participate. However, in order to evaluate the usefulness of the guidelines as a tool to improve the accuracy and consistency of leak rate results, all significant deviations or other plant specific differences (such as validity checks, plant instrumentation, treatment of inputs, etc.) which may impact the Standard Plant activity should be recorded along with a comment describing the expected impact. Details on any deviations and/or other changes will be included in the final report describing the results of the “Standard Plant” activity.

The “Standard Plant” activity is expected to continue for roughly two “90 day” quarters in order to record sufficient data to determine the suitability of as many of the recommendations included in Section 11 of the current draft RCS Leak Rate Standard Guidelines as possible.”

Conclusions from this Activity are presented in Section G-4.

Overview of the Data Collection Process

Template Excel Spreadsheets were distributed to the Standard Plant Members to record and transmit the required data. These spreadsheets were based on those supplied by Seabrook for the August - October 2005 data but were expanded to address issues discussed in the November 15th Telecon and to bring the nomenclature into conformance with the current Guidelines. **These Spreadsheets along with the Seabrook spreadsheet have been archived in Reference 24 and are available to all Members upon request.**

The template consists of the 7 individual spreadsheets described below:

Sheet 1:

Sheet 1 tabulates the parameter of greatest interest (i.e., the Unidentified Leak Rate (ULR) data. The Identified Leak Rate (ILR) data is also included. All remaining data in Sheet 1 can be used to investigate the cause of any anomalies observed in the ULR and ILR data. Participating members were allowed to exclude or alter the 5 headings in Sheet 1 and provide outputs that were convenient for them to use.

Sheet 2:

Sheet 2 provides simple descriptive statistics that can be easily obtained from the URL and IRL data shown in Sheet 1. (Details on the process are described in a comment on Sheet 2.) For now, the parameters of greatest interest are the mean, standard deviation, and minimum and maximum values. Parameters such as the median, kurtosis and skewness can be used to infer if the data is normally distributed. Details are provided in Section G-3. Note: downstream users must install an Excel "add in" if their Excel Toolbox does not have the "Data Analysis" option.

Sheets 3 through 6:

Sheets 3 through 6 provide a way to record selected instrumentation data for each of the 5 items shown in Sheet 1 (i.e., PZR, RCWV, VCT, RCDT, PRT). This data is not required. In addition, if selected data such as TAVE is entered, the other data was not required (i.e., the participants were told to pick & choose whatever was convenient for them).

Sheet 7:

Sheet 7 was used to record any intermediate instrumentation readings. This data could then be used to examine "linearity" issues and can also be used to investigate any anomalies in the leak rate data based on only the start & end time observations. Again, recording this data was optional.

Summary of Responsibilities for the Standard Plant Activity:**Member Utilities:**

The Member Utilities were responsible for using the supplied Excel spreadsheets to record daily leak rate values and then transmitting the resulting data to Westinghouse on a monthly basis for the duration of the Standard Plant activity.

Westinghouse:

Westinghouse examined the supplied monthly data for normality, outliers, exceedences and performed the "F test" and the "two sample t-test" on selected data. Baseline mean and standard deviations were obtained from the data. Finally, anomalies in the data were examined, specific questions from the Members were addressed, and various crossplots and plots versus time of selected data were created.

G-2 Standard Plant Members & Data Collected

Five member Utilities supplied data as part of the Standard Plant activity. Details are:

- Seabrook supplied daily “2 hour” data from August 1st of 2005 to March 31st of 2006. Seabrook also supplied several other sets of data per our request. All Seabrook data is described in Section G-5.
- Comanche Peak Unit 1 and Comanche Peak Unit 2 supplied daily “2 hour” data from December 1st of 2005 to March 31st of 2006. Comanche Peak Unit 1 experienced a relatively significant leak (about .1 gpm) during the first half of December 2005. All Comanche Peak Unit 1 data is described in Section G-6. All Comanche Peak Unit 2 data is described in Section G-7.
- Ginna supplied daily data from December 2005 through March 2006. The daily data was recorded for varying time intervals throughout the period. The time intervals varied from less than 1 hour to approximately 13 hours (see Figure G-20). All Ginna data is described in Section G-8.
- Fort Calhoun supplied daily data for the Total Leak Rate (TLR) which is essentially a “24 hour” average value from October 1st, 2005 to March 31st, 2006. The Fort Calhoun data is discussed in Section G-9. (TLR is the sum of the ULR and ILR values at each recorded time point.)

Data collection was terminated on March 31st of 2006.

All input Excel spreadsheet data obtained from the Standard Plant Members has been archived in Reference 24.

G-3 Westinghouse Methods Used to Examine the Data

Overview

A plant and unit-specific “Master” Excel spreadsheet was created for each participant. As monthly data arrived for a given Member, it was added to the “Master” spreadsheet for that Member and various analyses of the monthly data were performed depending on the characteristics of the data. Although similar methods were generally applied to all data (such as normality testing), the methods also tended to evolve with time. As a result, the newest data was typically examined in ways that were not applied to the earliest data received. As an example, the August - November data for Seabrook was only visually examined for outliers because that data passed the normality test. Later, data from other plants failed to pass normality and, also, failed a visual examination for outliers. As a consequence, more recent data was examined with the “median/MAD” method described in Section 11.7 and Equation 11.14. In retrospect, application of this method to the earliest Seabrook data would have resulted in some outlier rejection. In this sense, the methods used were slightly inconsistent because they evolved with time. (Table G-5 which summarizes results for the Standard Plant members resolved these

inconsistencies in approach.) The final “Master” Excel Spreadsheets have been distributed to the individual participants and are also archived in Reference 24.

Details

Each of the principal parameters analyzed is described below. Results of the analysis are presented in Sections G-5 through G-10. Section G-11 provides a template Excel file which illustrates the process.

- Mean and Median
- Kurtosis & Skewness
- Normality
- Outlier Screening
- Baseline Mean & Baseline Standard Deviation
- Maximum & Minimum Observations
- Consecutive Exceedences above the Baseline Mean
- F test & the two sample t-test

G-3.1 Mean and Median

The NRC Guidelines use exceedences above the baseline mean to detect changes in the leak rate. In principle, the median is most suitable to use for tracking exceedences since, by definition, the probability that the “next sample” will lie above the median is equal to the probability that it will lie below the median if no changes in the process have occurred. However, since the unidentified leak rate values are expected to be approximately normally distributed, and, since the population median and population mean of a normal distribution are equal, **using the mean (i.e., an efficient statistic as described below) to track exceedences is appropriate.**

Of course, in the real world, the mean and median of a sample will not agree even if the sample is approximately normal. However, significant differences between these two parameters will occur if there are “outliers” since the mean is directly effected by extreme observations whereas the median is essentially immune to extreme values. (For example, if you simply take the highest observed value and arbitrarily increase it, the median remains constant.) If there are no “outliers”, differences can still occur if the underlying distribution is significantly non-normal. **The Standard Plant data is essentially normal so the most likely cause of any significant difference between the mean and median are “outliers”.**

Provided that any outliers have been removed, the mean is called an “efficient” statistic because the variance of the mean (i.e., square of the standard deviation) is $\{\sigma^2/N\}$ (where σ is standard deviation of the population that the sample is drawn from and N is the sample size). No other statistical parameter has a smaller variance or scatter than the mean which explains the label “efficient”. However, the median is not an “efficient” statistic because the variance of the median is $\{(\pi/2) \sigma^2/N\}$ which is 1.57 times greater than the variance of the mean. This factor of 1.57 implies that the median uses only 64% of the information in a sample (i.e., $(2/\pi) \times 100\%$) whereas the mean uses 100% of the information in the sample. An interesting sidelight to the relative efficiency (i.e. .64) is that the theoretical correlation between the median and the mean of

a given sample is approximately equal to the square root of the relative efficiency (i.e., $\sqrt{(.64)}$ - or- .80). (This relationship holds for all other inefficient statistics as well – the correlation is the square root of the relative efficiency.) The simulation described below verified this correlation. Pages 11.703 to 11.707 of Reference 26 explain and derive the above relationships. **Provided that care is taken to identify outliers, it is appropriate to use a baseline (sample) mean rather than a baseline (sample) median to check for exceedences because the mean is an efficient statistic and uses 100% of the information available in a given sample.**

A simulation was performed to calculate “95/95” nonparametric bounds (see description in Section 11.3.2.1) on the absolute value of the difference between the median and mean of a given normal sample as a function of the sample size. (Note: this difference tends to zero as the sample size increases since both the sample mean and the sample median converge to the population mean.) The simulation was performed on the Westinghouse workstations using the IMSL library routines documented in Reference 21. Copies of all Fortran files and associated output files are documented in Reference 24.

The simulation shows that the “95/95” limit of the absolute difference between the sample mean and the sample median depends on the standard deviation of the population the sample is drawn from (i.e., σ) and the sample size (i.e., N). There is no dependence on the population mean (i.e., μ). (Independence of the absolute difference with respect to the mean is expected based on theoretical results governing “order statistics” – see p.21 of Reference 27.)

A reasonably accurate simple formula which bounds the difference at a “95/95” level (i.e., almost always) is:

$$\text{Eqn. G.1} \quad |\text{sample mean} - \text{sample median}| < 1.6 \sigma / \sqrt{N}$$

In the above formula, σ is the population mean which can be interpreted either as the “baseline standard deviation” (preferred) or the sample standard deviation (s) of the sample which generated the sample mean and median and N is the sample size.

Values which significantly exceed the limits of Equation G.1 indicate that there may be outliers present in the data set or that the data may not be normally distributed. Therefore, when this limit is exceeded, the data should be screened for outliers and a normality test should be performed.

G-3.2 Kurtosis and Skewness

The sample kurtosis and skewness can also be used to provide an indication of the presence of outliers and/or other deviations from normality.

Roughly speaking, the relative kurtosis is a measure of how “peaked” the distribution is. That is, if the normal bell-shaped curve was made of rubber and you pulled the highest point (i.e., the mean μ) to a higher value, the relative kurtosis would increase from the value which all normal distributions have (i.e., 3.00) to a higher value. Likewise, if you pushed the peak down to flatten the curve, the relative kurtosis would decrease. (A uniform distribution has a relative

kurtosis of 1.8.) The exact mathematical definition of relative kurtosis is provided in Section 2-9 of Reference 22. (It is important to note that most definitions of kurtosis (including Excel) normalize the value by subtracting the normal distribution value of +3.00 so the “relative kurtosis” of a bell-shaped curve is 3.00 but the “normalized kurtosis” or just the “kurtosis” is 0.0. **Therefore an Excel kurtosis value of 0.0 implies that the sample has the same value as the bell-shaped curve.**

The skewness is a measure of the asymmetry between the left and right tails of the distribution. For example, pulling on the right hand tail of the rubber bell-shaped curve causes the skewness to increase from the 0.0 value of the normal distribution to a positive value. Similarly, pulling on the left hand tail causes the skewness to decrease from 0.0 to a negative value. Again, Section 2-9 of Reference 22 provides examples and an exact mathematical definition.

The simulation described in Section G-3.1 was used to provide 95/95 nonparametric limits on the upper and lower limits for the kurtosis. (These limits are not symmetric because a relative kurtosis less than 1.0 is impossible but distributions such as the log normal distribution can have very high relative kurtosis values of 9 or more.) The simulation also provided 95/95 upper limits on the absolute value of the skewness (negative and positive values of the skewness are equally likely). For a normal distribution both of these limits are a function of sample size and are expected to converge to a kurtosis of +0.0 and a skewness of 0.0 for very large sample size. Limits were simulated for samples of size 31 (1 month) and 92 (1 Quarter).

Eqn. G.2.a $-1.1 < \text{“normalized kurtosis” for a sample of size 31} < +1.4$

Eqn. G.2.b $-0.75 < \text{“normalized kurtosis” for a sample of size 92} < +0.95$

Eqn. G.3.a $|\text{skewness for a sample of size 31}| < +0.75$

Eqn. G.3.b $|\text{skewness for a sample of size 92}| < +0.50$

Values which significantly exceed the limits of Equations G.2 or G.3 indicate that there may be outliers present in the data set or that the data may not be normally distributed. Therefore, when either of these limits is exceeded, the data should be screened for outliers and a normality test should be performed. The “normalized kurtosis” is calculated by Excel and is exactly 0.0 for a normal distribution.

Note: this simulation and the above Equations treat these two parameters as if they were independent. Figure 6-1 of Reference 22 shows that these parameters are related for typical non-normal distributions. However, since these limits are most likely to be violated due to the presence of outliers, Figure 6-1 of Reference 22 doesn't directly apply.

G-3.3 Normality

Normality tests were performed using the “W Test” (i.e., M. B. Wilk) from Reference 15 for monthly samples of size 31 and the “D’ Test” (i.e., R. B. D’ Agostino) from Reference 15 for quarterly samples of size 92. These tests were performed by entering the raw data into an Excel spreadsheet and performing the simple manipulations required to carry out the test(s).

Section 11.3.2.1 provides an overview of the method. We altered the algebraic formula for the W Test shown in Reference 15 by expanding terms such as “ $a_n(x_n - x_1)$ ” as shown in Section 4.2.3 of Reference 15 to: “ $a_n(x_n) \dots -a_n(x_1)$ ”. This change did not alter the result but made the computation more straightforward since the raw data was simply sorted and then multiplied term by term by the vector $\{a_n, a_{n-1}, \dots, a_1, -a_1, \dots, -a_{n-1}, -a_n\}$. In addition, since the “a” coefficients depend on the sample size, we ensured that each “month” had 31 days by borrowing adjacent values from the previous month until 31 values were present. (The alternative requires templates with 28,29,30,31 “a” values with additional templates required if outliers are rejected from the raw data.)

The D’ test applied to the quarterly data uses simple constants which were easily calculated in the spread sheet. However, the D’ Test Statistic which is tabulated in Table 5 of Reference 15 depends on the sample size. So, even in this case, we typically borrowed adjacent data to get the quarterly data to exactly 92 points.

Section G-11 documents an Excel template file which provides a template for the normality calculation for 31 and 92 data points.

G-3.4 Outlier Screening

There are two approaches which can be used to screen for outliers. We will use the terms “extrinsic screening” and “intrinsic screening” to describe them. (These terms were created by us and are not standard statistical jargon.)

Extrinsic screening uses the standard baseline mean and baseline standard deviation (i.e., μ and σ) to calculate the zscore of each new data point using Equation 11.3 of Section 11.3.1. This equation is repeated below for ease of reference:

$$\text{Eqn. G.4 } \text{zscore}(\text{“new data point”}) = (\text{“new data point”} - \mu) / \sigma$$

The term “extrinsic” is used to denote the fact that the baseline values were determined before the “new data point” was measured. Therefore, the new data point had no influence on the value of μ and σ . **This is the preferred method of screening new data points and can always be used after valid baseline values are obtained for the current operating cycle.**

Typically, zscore values are “suspicious” when the absolute value of the zscore is 2.5 or greater (i.e., 2.5 standard deviations above the mean). Of course, positive zscore values greater than +2.0 need to be examined very carefully since they may imply that NRC Action Level II or III

have been or are about to be exceeded. Negative values are of less concern since they don't actuate Action Levels. Details on what to do when these suspicious values occur are discussed in "Rule 3" of Section 10.1.

Intrinsic Screening refers to the examination of a "stand-alone" sample of data when no other information is available. In this case, the mean and standard deviation are of questionable value since outliers can significantly affect these parameters. Therefore, conclusions reached using Equation G.4 may be erroneous. Equation 11.14 of Section 11.7 shows that using the **sample median** in place of μ for the so-called "location value" in Equation G.4 and using the "**sample MAD**" in place of σ for the so-called "scale value" in Equation G.4 allows the calculation of meaningful (and equivalent) zscore values for a stand-alone sample:

$$\text{Eqn. G.5} \quad \text{zscore ("data point")} = (\text{"data point"} - \text{sample median}) / \text{sample MAD}$$

The guidance regarding "suspicious" values is the same as discussed above. However, strictly speaking, the NRC Action Levels can not be actuated by intrinsic screening since only baseline values are used to set Action Levels.

G-3.5 Baseline Mean and Baseline Standard Deviation

The baseline mean and standard deviation values are defined by the average and standard deviation of a given Quarter's daily ULR values after outliers have been addressed. Extrinsic screening of the current Quarter's daily ULR values is straightforward using the previous Quarter's baseline values and so on and so on.

The only fly in the ointment is what to do for the initial baseline values and how to screen the initial values for outliers. This issue is addressed in Reference 25. This problem occurred in the Standard Plant analysis since we typically had only 4 months of data to work with. As described in the Overview for Section G-3, for the most part, we simply analyzed each set of monthly data on a "stand-alone" basis as it arrived and deferred issues related to the baseline values to the end of the data collection process.

At the end of the process, we wanted to define baseline values which would allow us to examine all the data collected as opposed, for example, to using the first three months of measurements to define baseline values and then applying them only to the remaining month's data. The most straightforward way to do this was to simply "pool" all the data collected (for each individual participant), remove obvious outliers based on our monthly examinations, and analyze the remaining values to determine the "baseline" means and standard deviations.

This was the process used to create Figures G-3, G-15, G-18 and G-19. Examination of the data used in these Figures indicated that some data values which we would consider outliers when all the data was in hand were still included in the data set. (See for example Figure G-3.) This typically occurred because the data didn't seem too extreme based on only the monthly data. In

particular, if the data passed the (monthly) normality test, we typically did not consider removing any of the recorded data values.

Table G-5 (which contrasts baseline values and other statistics for all participants) was constructed by revisiting the outlier issue. That is, the statistics in Table G-5 deleted all values with (absolute) zscores of 2.5 or more. We judged that use of a large pooled data set (i.e., all the data recorded for each plant minus outliers) allowed us to use Equation G.4 (extrinsic screening) as opposed to Equation G.5 with minimal error. Note: our approach is essentially intrinsic screening since the pooled data is used to set μ and σ . (We used an absolute value of zscore of 2.0 to screen “suspicious” values in order to flag situations where two “+2.0” zscore values occurred in 3 consecutive observations (i.e., Action Level II in the NRC Guidelines). However, absolute zscore values less than 2.5 were not considered outliers.)

G-3.6 Maximum and Minimum Observations

Tables G-1 through G-4 document the maximum and minimum values recorded each month (including outliers). Table G-5 documents the maximum and minimum overall values recorded after all outliers were removed.

G-3.7 Consecutive Exceedences above the Baseline Mean

A simple Excel equation was used to flag any observed value above the baseline mean. Consecutive “runs” of these flags were used to document the exceedence data in Tables G-1 through G-4. If a run started near the end of one month and ended in the next month it was listed only once in the month it ended. (For example, if the last 5 days of October exceeded the mean and the first two days of November exceeded the mean, a run of length 7 was recorded for November but the run of 5 was not included for October – this approach avoided double accounting of runs.)

G-3.8 F test & the Two Sample t-test

Selected data from consecutive months, from two successive Quarters (Seabrook), and from a Quarter and the following month were analyzed using the Excel F test and the Excel two sample t-test.

The purpose of these tests is to see if it is reasonable to assume that the two consecutive sets of data came from the same underlying population (i.e., the same μ and σ). The F test **only** checks to see if the individual standard deviations of the two sets of data are similar enough to conclude that they could have come from the same population. In particular, the F test doesn’t use the means of the two sets of data. **Failing the F test by a significant amount implies that the process for recording the ULR values has changed (i.e., the process may be out of control).**

If the data passes the F test, a pooled estimate of the variance is generated (basically a weighted average of the squares of the two standard deviations) and the two sample t-test is performed. This test uses the pooled variance, the two mean values, and the sample sizes to see if it is reasonable to conclude that the two samples could have come from a single population.

Intuitively, it is harder to pass this test (i.e., the means have to be close together) when the sample size is large and the pooled variance is small – i.e., there is no “wobble room”. Small samples with a large pooled variance can be quite different and still pass. Failing the t-test implies either that the process is out of control or, more important, that the mean has shifted to a larger value in the last sample recorded because the leak rate has increased. **Therefore, failing the t-test by a significant amount is a real concern when the most recent set of data has a higher mean than the oldest data.**

Details on performing these tests (and understanding the Excel output) are described in Section G-5. Pages A-24 through A-35 of Appendix A provides a derivation and explanation regarding these two tests. Pages A-36 through A-37 of Appendix A provide a simple procedure which shows how to do this test by hand (i.e., without Excel). If the Excel output is confusing (we think it is), referring to this simple excerpt the first time Excel is invoked will walk you through the process. (Page A-37 is used to explain the Excel output in Section G-5.)

G-4 Principal Conclusions of the Standard Plant Activity

These conclusions are used to set the overall Recommendations documented in Section 11.12 of the main body.

The single most important conclusion is that the snapshot method and associated equations documented herein in Sections 4 to 10 is accurate and unambiguous. That is, we did not receive one question from any Participant asking for any clarification nor any comment suggesting that the method, as described, lacked sufficient detail or was erroneous. As shown in Section G-10, the cross-comparison of results for the three participants who used the “two hour, midshift snapshot method” were in good agreement – particularly with respect to the observed scatter in the results (i.e., the standard deviation of the daily ULR values for those three participants was virtually identical at .03 gpm).

Except for the outlier frequency, the observed data is essentially coincident with the simulation model documented in Section 11. That is each set of observed two-hour snapshot data is approximately normally distributed with a reasonably constant mean and standard deviation. As a consequence, there is no reason to believe that the results of the simulation studies are erroneous or misleading.

Outliers occur with a relatively high frequency (i.e., roughly 4% of all observations). “Extrinsic screening” which is described in Section G-3.4 is an effective way to identify potential outliers. However, as explained in Section G-3.5, we didn’t have access to that method since insufficient data was collected to generate a reliable baseline mean and standard deviation – these two parameters are the essential parameters needed for screening. The approach we used to generate baseline values is documented in Section G-3.5. If a member utility observes a significant number of outliers there are long-term and short-term decisions which must be made.

The long-term decision requires a final judgment whether a given value should or should not be included in the database before the database is used to refresh the quarterly baseline values.

The short-term decision only applies when the ULR value is a potential positive outlier. Here a decision must be made whether the value is spurious or real in which case an Action Level may be entered. "Rule 3" of Section 10.1 details a process which can be used to make the required decision.

Overall, the normality test applied to the monthly data did not seem very good at detecting outliers. In retrospect, Tables G-1 through G-4 indicate that anomalous values of the kurtosis and skewness give a better indication of the presence of outlier data. (Equations G.2.a to G.3.b of Section G-3.2 document acceptable limits on the monthly and quarterly kurtosis and skewness values.) (The limits on the difference between the median and mean shown in Equation G.1 of Section G-3.1 also did not reveal any non-normal situations. However, we did observe one case where initially the mean was dragged down so much by negative outliers that virtually every observation became an exceedence which, if unrecognized, would actuate Action Level I.)

The monthly data seems to exhibit a lot of bouncing around in Tables G-1 to G-4. This is not an issue as long as the monthly data is not used to update the baseline values (as in the NRC Guidelines). We continue to believe that use of a quarterly update is more appropriate (as described in Appendix F).

The "24 hour" data shown in Figures G-9 through G-13 is discussed in Section G-5. The discussion concludes that the 24 hour measurements are:

- Relatively easy to take as an added part of the 2 hour measurements.
- Unlike the 2 hour snapshots, they cover the entire operating cycle of the NSSS more or less continuously.
- They accurately "trap events" which have an influence on the net RCS inventory from day to day. That is, if some event is initiated by Operator action or is truly an intermittent leak, it will show up as a leak in the 24 data so it can be investigated. This is not the case with 2 hour data.

As a result a recommendation will be made in Section 11.12 to consider carrying out 24 hour measurements if possible. However, these measurements augment but do not replace the current recommendations concerning 2 hour measurements.

Using the baseline values stated in Table G-5 (with outliers removed), there was 1 "NRC Action Level I" (as shown in Table G-2), and **no Action Level II or III events** recorded for the Participating utilities. (This does not include the data associated with the leak rate event shown in Figure G-15 and G-17. The details of this event will be examined in Reference 25.)

In a total of 20 months of data there were 7 runs of length 5; 2 runs of length 7; and 1 run of length 9. The number of runs is roughly coincident with expectations. For example, there are a total of 561 valid data points in Table G-5. Therefore there are (561/31) or 18.1 sets of length 31 days. Row 1 of Table 11-3 shows that Action Level I will occur 86 times out of 1000

when there is no change in the baseline leak rate (as is the case here). Therefore, $(86/1000) \times (561/31)$ or **1.56** is roughly the expected number of runs of length 7 expected in the 561 days (which is close to the 2 actually observed). The same type calculation for runs of length 9 results in a value of **.5** (compared to 1 actually observed) and **9.85** for runs of length 5 (compared to 7 actually observed).

However, the frequency of runs of length 5 is sufficiently high that no specific action should be triggered by an event which typically may be a false alarm. Recommendations, Section 11.12 will suggest that a run of length 5 should only cause one to pay a little closer attention to the measurements in the event that the run continues to grow to 7 or 9.

G-5 Summary of the Seabrook Data Analysis

The Seabrook data is summarized in Tables G-1, G-5 and G-6 and Figures G-1 through G-14. (Figures G-1 and G-2 illustrate arbitrary data we created to illustrate the F and t-tests. They are included in this Section because they are included in the Seabrook "Master" spreadsheet file.) The Master spreadsheet file also contains numerous analyses which are not shown in this report. Results have been condensed and excerpted in order to focus on the details of greatest interest and value. For the most part, significant "insights" obtained from this data and the other Standard Plant data are discussed in Section G-4.

Table G-1 presents the results of the month-by-month analysis of the Seabrook data. Except for the rows marked "Outliers" and "Exceedences", these monthly columns are essentially independent in that only the stated month's data was used to obtain the values.

The "Outliers" are classified as Note 1 or Note 2. **Note 1** outliers were typically not identified or removed when the monthly data was analyzed. As stated in Section G-3, we typically performed a simple visual examination of the data to identify outliers and relied on the normality test to identify any suspicious data. If the monthly data passed, no further examination was performed. (In retrospect, the abnormal kurtosis value in August (and to a lesser extent in January) should have indicated a problem but the limits in Equations G.2 and G.3 were not available at that time.)

Note 2 outliers were identified during the monthly assessment and were removed in order to pass normality.

The final assessment which defined the baseline mean and standard deviation values (see Section G-3.5) was used to screen all the data and, also, deleted values with absolute zscores of 2.5 or more. Therefore, the outliers described as **Note 1** in Table G-1 were identified and deleted from the data set at the very end of the project.

In similar manner, the "exceedences" shown were determined with the final baseline mean values obtained from the pooled Seabrook data.

Table G-5 summarizes the pooled data after outliers have been removed. **Table G-6** lists the 7 Note 1 & Note 2 outliers identified for Seabrook.

The above text (with appropriate modifications) also appears at the start of Sections G-6 – G-8.

Figure G-1 illustrates the output of the Excel F-test for the “arbitrary” data we created. (These were random samples from unitary normal distributions (i.e., mean = 0.0, standard deviation = 1.0)). The only difference between Case 1 and Case 2 is which set of data is selected as “Variable 1” and “Variable 2”. (The two outputs interchange the data sets.) The outcome of this test depends only on the ratio of the variances for Variable 1 and Variable 2 and the degrees of freedom (df) for each variable (taken to be the number of data points minus 1). The value shown for “F” for Case 1 is just the ratio of the variance of Variable 1 divided by the same quantity for Variable 2 (i.e., 1.1508...). Case 2 has a value of .8689... for F which is the reciprocal of 1.1508.... The quantity F Critical one-tail in Case 1 (1.716...) is the limit on how big F can be and still pass the test. (This value is essentially a Table lookup value which uses the df inputs. It has nothing to do with the input data.) You pass the test (at the 5% significance level) if $P(F \leq f)$ one-tail is .05 or larger. Here this value is 0.3424..., so the data passes the test. (Of course, we would expect to pass since the two data sets were generated from the same probability distribution.) Note: Case 2 has the same value for $P(F \leq f)$. If you simply multiplied each value in Variable 1 by the same constant (with a value greater than 1.0) and reran the test, the F value would increase and when it approached 1.716..., the $P(F \leq f)$ value would approach .05 and you would then judge that the two sets of data probably didn’t come from the same population. (Figure G-16 shows an example of real operating data which failed the F-test. This is discussed in Section G-6.)

Figure G-2 uses the positive results of Figure G-1 (i.e., the data can be assumed to come from a normal population with the same standard deviation) to examine whether or not the mean values of the two data sets are close enough together to judge that the samples also came from the same normal population. (Note: a normal population is completely defined when μ and σ are specified. Therefore, if the F test concludes that the value of σ is common to the two samples and the t-test concludes that the value of μ is common to the two samples, the two samples came from the same population.) We will discuss the details of the Excel output when we examine Figure G-4. For the moment, examine Case 1 and Case 2 (which use the same data used in Figure G-1), to see the effects of interchanging the order of the inputs.

Figure G-3 shows all the Seabrook data plotted versus time using (approximate) values of the baseline mean and standard deviation. These values are slightly different than those shown in Table G-5 because, after this plot was developed, it was clear that we hadn’t used a “level playing field” for the outliers when we addressed them on a month-by-month basis. For example, the -.11 value shown in mid-August should clearly be considered an outlier based on the conclusions shown for the March data. The follow-on analysis described in Table G-5 addressed this issue and resulted in small changes in the baseline values.

Figure G-4 shows the F-test and the two sample t-test for the first 2 quarters of Seabrook data. (Note: Seabrook is the only plant which recorded two quarters of data.) Based on the discussion of Figure G-1, the data passes the F-test so there was not a significant change in the population standard deviation during this time period. If you did your homework assignment for Figure G-2, you know that the only effect of interchanging the order in the t-test is the sign of the “t stat”

output. If the mean of variable 1 is greater than the mean of variable 2, the sign is positive, otherwise it is negative. Since the outcome of the test centers on the value of “ $P(T \leq t)$ ” and that value is independent of input order, we will only discuss Case 1.

The homework for this Figure is page A-37 of Appendix A. Page A-37 shows 6 simple steps (labeled (1), ..., (6)) which explain the Excel output shown in Figure G-4. **Skip Step (1)** – Excel sets the default significance level to 5% (the same “1 chance in 20” that we have used throughout the text). **Skip step (2)** – Excel does this for us – we’ll discuss later. **Skip Step (3)** – Excel does all of this – results are shown in the first three lines of output. **Skip Step (4)** – Excel does this and prints the pooled variance (s_p) in line 4. (Note: the pooled variance is simply the average of the two variances if the sample sizes are equal.)

Things get a little more complicated in Steps 5 and 6. Page A-37 calculates Step (5) using the t-statistic from Step (2) and then checks to see how the difference in the means compares to the Step (5) value. (Note: the Step (6) is effectively the absolute value of the difference – so we are not really checking if A exceeds B but, rather, if the larger of A and B exceeds the lesser of A and B by a significant amount.) The Excel-calculated value of “t Stat” is simply a restatement of Steps (5) and (6) and is the only output in lines 7 through 11 which directly uses the input data. Using the nomenclature of page A-37, “t stat” is computed as:

$$\text{Eqn. G.5} \quad \text{“t stat”} = (\text{Mean (V1)} - \text{Mean (V2)}) / [(s_p) \sqrt{(n_A + n_B) / n_{ANB}}]$$

Simple rearrangement of Step (6) shows that if “t stat” exceeds the “lookup” value of $t_{(1-\alpha)}$ in Step (5), then $(\text{Mean (V1)} - \text{Mean (V2)})$ will also exceed “u” in Step (6) and we will fail the test. In the Excel output, the critical value of $t_{(1-\alpha)}$ in Step (5) is effectively a “table-lookup”, is labeled as “t Critical one-tail” and has a value of 1.6532.... (Note: this value is almost the one-sided 95% value of the normal distribution (1.645) – this is because the t-distribution and the unitary normal distribution are almost identical as the sample size increases. Roughly speaking, the t-distribution accounts for the sampling error between the sample standard deviation (s) and the population standard deviation (σ) – for example, see p. 388 of Reference 7. So, as sample size increases, the two converge.)

The “Bottom Line” is: You pass the test if the absolute value of “t stat” is less than “t Critical one-tail”. If this is the case, “ $P(T \leq t)$ one-tail” will be larger than .05 (5%). If, on the other hand, “t stat” exceeds “t Critical one-tail”, you fail the test and, “ $P(T \leq t)$ one-tail” will be smaller than .05.

Figures G-5 and G-6 investigate a question Seabrook asked regarding the R^2 value produced by Excel for linear regression data. During a two hour surveillance period, intermediate values of the RCS Inventory were recorded versus time and then analyzed with Excel. The resulting R^2 values (which measure the proportion of the total variation in the RCS Inventory data explained by the regression line) were really small – approaching 0.0. The question was: **“Why is that happening?”**

The answer is shown in the data in Figure G-5 and the plot in Figure G-6. The “True Values” shown in Figure G-5 illustrate how the initial RCS volume (63200 gal) decreases as a function of

time for a spectrum of leak rates from 1 gpm to .01 gpm. Fitting any of this data versus time would result in an R^2 value of 1.0 (i.e., perfect). However, when each measurement is contaminated by a normally distributed random measurement error with a standard deviation of either 5.4 gal or 2.7 gal, an entirely different story emerges.

(Note: Appendix C-3.2 shows that the mass uncertainty in gal is 124 gal times the standard deviation of the temperature indication in DegF. In turn, Appendix C-3.3 shows that the standard deviation of the temperature indication is numerically equal to the baseline standard deviation (i.e., .034 gpm in Table G-5). Therefore, an estimate for the Seabrook mass uncertainty is $124 \times .034$ gal -or- 4.2 gal. The 2 values chosen for the simulation bound 4.2 gal.)

For a large leak rate of 1 gpm, the “noise” can’t overwhelm the real trend of 15 gal lost every 15 minutes and we see the RCS inventory values decrease even with the noise. However, when the leak rate is .05 gpm or .01 gpm, the “noise” can overwhelm the real loss and the inventory sometimes appears to increase as a function of time.

Each of the columns in the data sets with “noise” were fit as a function of time with Excel and the R^2 values were determined. Figure G-6 plots the R^2 values as a function of the leak rate. Since a typical operating point is around .03 gpm (see Table G-5), it is expected that really small R^2 values will be observed.

As an aside, it is worth noting that all of the R^2 values shown at the bottom of Figure G-5 are less than 1.0. This is the result of the fact that *“the correlation coefficient [and the R^2 value] of the properties plus errors of measurement is always less than the correlation coefficient [and the R^2 value] of the properties themselves”* (see Reference 7, pp.615). (R^2 is the square of the correlation coefficient.)

Figures G-7 and G-8 illustrate the smoothing effect which is achieved when a rolling average of 7 days (weekly) or 30 days (monthly) is used to portray the data. The template file in Section G-11 contains the Excel spreadsheet which can easily be used to create these running averages.

Figures G-9 and G-10 illustrate a crossplot of data Seabrook supplied to us in 2005. Figure G-9 shows a crossplot of 2 hour snapshot ULR data versus ILR data. Figure G-10 shows a crossplot for the same period of time of 24 hour ULR data versus the equivalent 24 hour ILR data.

The first observation is that there is essentially no correlation between the ULR and ILR data in either set. This is the expected behavior because Appendix C indicates that the fluctuation in the Tave signal is likely responsible for most of the fluctuation in the ULR value simply because of the large volume of the RCS. (However, when extreme ULR observations occur, it is prudent to check the associated ILR value to see that it does not exhibit any anomalous behavior in the opposite direction. Seabrook informed us that this check is typically part of their investigation of any extreme ULR values.)

The second, more important observation, is that the “spread” in our, ahem, recommended duration measurements (i.e., 2 hours) is significantly greater than the “spread” in the equivalent 24 hour measurements. (The scale of the plots is slightly different because we wanted to portray

the outlier in Figure G-10 which was ultimately attributed to a maintenance operation.) This significantly reduced spread essentially follows Equation 11.15 of Section 11.9 (as we will see) but it seems to show more improvement than the data shown in Figure D-29 (which is also discussed in Section 11.9). Prior to examining this data, we believed that significantly extending the surveillance interval beyond two hours would increasingly challenge the limits of validity so that the benefit of the increased duration per Equation 11.15 would be more than offset by the oscillations within the limits of validity. As a result of this data, Seabrook gathered additional 2 and 24 hour data under carefully controlled conditions. This data is analyzed in Figures G-11 through G-13.

Figures G-11 and G-12 show plots of the 2 hour snapshot data recorded around 1:00 – 3:00 AM each day and the associated 24 hour data points. The only significant difference between the two Figures is the “VCT Divert” 24 hour data points shown in Figure G-12. (As Seabrook approaches EOC, boron dilution requires that the VCT be periodically pumped down. Since this loss of water is not explicitly in the inventory equation, the VCT Divert events appear as “leaks” in the 24 hour data.) Note: the mean value of the 2 hour and 24 hour data is about the same but the 24 hour standard deviation is smaller by a factor of about 8. Equation 11.15 suggests that this value should be inversely proportional to the relative lengths of the measurements –or- $(24/2)$ – or- a factor of 12. Certainly close enough to support the validity of Equation 11.15. The 24 hour data was recorded by simply taking exactly two inventory values, just as in the 2 hour case. The only requirement was that the start and end time of the 24 hour data be comfortably “embedded” in the 2 hour snapshot window whenever possible. The idea behind this constraint was that we know that all kinds of plant transients can be going on during the 24 period (which violate the limits of validity). However, “embedding” the 24 hour measurement within the 2 hour window ensures that the single start and end time of the 24 data set are embedded in a period of plant operation where essentially no challenges to validity are occurring. This ensures that the 24 hour measurements are not contaminated by any near-term transient effects. Of course, this also makes recording the 24 hour data pretty simple because, in principle, the 24 hour data could be determined from the same inventory data used for the two hour measurements (from adjacent days).

Figure G-13 shows that the apparent large ULR associated with the 24 hour VCT Divert events can, in fact, be resolved (and will essentially bring the VCT Divert points shown in Figure G-12 into line with the rest of the 24 hour data) if the change in VCT level is recorded whenever a VCT Divert is performed.

The three important features of the 24 hour measurements are:

- They are relatively easy to take as an added part of the 2 hour measurements.
- Unlike the 2 hour snapshots, they cover the entire operating cycle of the NSSS more or less continuously.
- They accurately “trap events” which have an influence on the net RCS inventory from day to day. That is, if some event is initiated by Operator action or is truly an intermittent

leak, it will show up as a leak in the 24 data so it can be investigated. This is not the case with 2 hour data.

As a result of the above description, a recommendation will be made in Section G-4 and Section 11.12 to consider carrying out 24 hour measurements if possible. However, these measurements augment but do not replace the current recommendations concerning 2 hour measurements.

Figure G-14 portrays 1 second and 60 second average Tave values supplied by Seabrook. Currently, the leak rate calculations use instantaneous 1 second values to determine RCS volume. It is their intent to investigate the use of 60 second average values in order to stabilize the snapshot calculation. This seems like an excellent idea and coincides with the discussion in Section 11.11. This change should significantly improve the observed scatter in the Seabrook ULR data (i.e., the current standard deviation of .034 gpm (Table G-5) should be reduced by approximately a factor of 8 –or– $\sqrt{(60)}$).

G-6 Summary of the Comanche Peak Unit 1 Data Analysis

The Comanche Peak Unit 1 (CP1) data is summarized in Tables G-2, G-5, and G-6 and Figures G-15 through G-17. The Master spreadsheet file also contains numerous analyses which are not shown in this report. Results have been condensed and excerpted in order to focus on the details of greatest interest and value. For the most part, significant “insights” obtained from this data and the other Standard Plant data are discussed in Section G-4.

Table G-2 presents the results of the month-by-month analysis of the CP1 data. Except for the rows marked “Outliers” and “Exceedences,” these monthly columns are essentially independent in that only the stated month’s data was used to obtain the values.

The “Outliers” are classified as Note 1 or Note 2. **Note 1** outliers were typically not identified or removed when the monthly data was analyzed. As stated in Section G-3, we typically performed a simple visual examination of the data to identify outliers and relied on the normality test to identify any suspicious data. If the monthly data passed, no further examination was performed.

Note 2 outliers were identified during the monthly assessment and were removed in order to get the data to pass normality.

The final assessment which defined the baseline mean and standard deviation values (see Section G-3.5) was used to screen all the data and, also, deleted values with absolute zscores of 2.5 or more. Therefore, the outliers described as **Note 1** in Table G-2 were identified and deleted from the data set at the very end of the project.

In similar manner, the “exceedences” shown were determined with the final baseline mean values obtained from the pooled CP1 data.

Table G-5 summarizes the pooled data after outliers have been removed. **Table G-6** lists the 6 Note 1 and Note 2 outliers identified for CP1.

Figure G-15 shows all the CP1 data plotted versus time using (approximate) values of the baseline mean and standard deviation. These values are slightly different than those shown in Table G-5 because, after this plot was developed, it was clear that we hadn't used a "level playing field" for the outliers when we addressed them on a month-by-month basis. The follow-on analysis described in Table G-5 addressed this issue and resulted in small changes in the baseline values. Note: there was a known leak at CP1 during the first part of December 2005. This data is identified in Figure G-15 and was not included in the calculation of the baseline values. (Reference 25 will perform a more detailed examination of this data to investigate how the various Section 5 Action Levels are entered as a result of the fairly significant leak rate magnitude.)

Figure G-16 shows the only example we encountered of two sets of data which did not pass the F test. As shown, the probability of this happening at random is on the order of 1.1%. Note: the data does pass the two sample t-test (i.e., 43.2%). If two sets of data fail the F test, a special, approximate two sample t-test is required to continue the analysis of the means. This approximate method is invoked when the Excel option "two sample t-test with unequal variances" is selected. The details of the approximation are too complicated to present here but are described in detail in Appendix A, pp. A-33 to A-35.

The most likely explanation for the F test failure is some change in the way the measurements were performed or some change in the approach to the limits of validity in the respective months. However, it is important to point out at least one alternative (which doesn't seem to apply here). That is, if roughly halfway through the month, there is a step change in the leak rate we would expect the "leaky" data to have the same standard deviation around the new, increased mean as the earlier data had around the original mean (see Section 11.2.6). However, since the reported mean for the month will now land roughly halfway between the old mean and the new "leaky" mean, the apparent scatter of the monthly data will increase. (This is obvious upon inspection of Figure G-15 if you consider what would happen to the December mean and standard deviation if the early December "leaky" data had been included.) Note: this effect is minimized if the increase in leak rate occurs either early or late in the month. In any event, if you encounter data which fails the F test, you should consider this effect as one possible reason. (Since the CP1 data easily passes the t-test this effect seems unlikely here.)

Figure G-17 shows the February 2006 to December 2005 data as if it was recorded in reverse order (i.e., "clock running backward"). We did this to see how an established 7 day rolling average would look as the leak was "initiated" in mid-December. As mentioned above, this data will be examined in more detail in Reference 25.

G-7 Summary of the Comanche Peak Unit 2 Data Analysis

The Comanche Peak Unit 2 (CP2) data is summarized in Tables G-3, G-5 and G-6 and Figure G-18. The Master spreadsheet file also contains numerous analyses which are not shown in this report. Results have been condensed and excerpted in order to focus on the details of greatest interest and value. For the most part, significant "insights" obtained from this data and the other Standard Plant data are discussed in Section G-4.

Table G-3 presents the results of the month-by-month analysis of the CP2 data. Except for the rows marked “Outliers” and “Exceedences,” these monthly columns are essentially independent in that only the stated month’s data was used to obtain the values.

The “Outliers” are classified as Note 1 or Note 2. **Note 1** outliers were typically not identified or removed when the monthly data was analyzed. As stated in Section G-3, we typically performed a simple visual examination of the data to identify outliers and relied on the normality test to identify any suspicious data. If the monthly data passed, no further examination was performed.

Note 2 outliers were identified during the monthly assessment and were removed in order to get the data to pass normality. **However CP2 had no Note 2 outliers.**

The final assessment which defined the baseline mean and standard deviation values (see Section G-3.5) was used to screen all the data and, also, deleted values with absolute zscores of 2.5 or more. Therefore, the 2 outliers described as **Note 1** in Table G-3 were identified and deleted from the data set at the very end of the project.

In similar manner, the “exceedences” shown were determined with the final baseline mean values obtained from the pooled CP2 data.

Table G-5 summarizes the pooled data after outliers have been removed. **Table G-6** lists the 2 Note 1 outliers identified for CP2.

Figure G-18 shows all the CP2 data plotted versus time using (approximate) values of the baseline mean and standard deviation. These values are slightly different than those shown in Table G-5 because, after this plot was developed, it was clear that we hadn’t used a “level playing field” for the outliers when we addressed them on a month-by-month basis. The follow-on analysis described in Table G-5 addressed this issue and resulted in small changes in the baseline values.

G-8 Summary of the Ginna Data Analysis

The Ginna data is summarized in Tables G-4, G-5 and G-6 and Figures G-19 and G-20. The Master spreadsheet file also contains numerous analyses which are not shown in this report. Results have been condensed and excerpted in order to focus on the details of greatest interest and value. For the most part, significant “insights” obtained from this data and the other Standard Plant data are discussed in Section G-4.

Table G-4 presents the results of the month-by-month analysis of the Ginna data. Except for the rows marked “Outliers” and “Exceedences,” these monthly columns are essentially independent in that only the stated month’s data was used to obtain the values.

The “Outliers” are classified as Note 1 or Note 2. **Note 1** outliers were typically not identified or removed when the monthly data was analyzed. As stated in Section G-3, we typically performed

a simple visual examination of the data to identify outliers and relied on the normality test to identify any suspicious data. If the monthly data passed, no further examination was performed.

Note 2 outliers were identified during the monthly assessment and were removed in order to get the data to pass normality. **This strategy did not work for Ginna.** December 2005 and March 2006 did not pass the normality test at the 5% significance level.

The final assessment which defined the baseline mean and standard deviation values (see Section G-3.5) was used to screen all the data and, also, deleted values with absolute zscores of approximately 2.5 or more. Therefore, the 6 outliers described as **Note 1** and **Note 2** in Table G-4 were identified and deleted from the data set at the very end of the project.

In similar manner, the “exceedences” shown were determined with the final baseline mean values obtained from the pooled Ginna data.

Table G-5 summarizes the pooled data after outliers have been removed. **Table G-6** lists the 6 Note 1 and Note 2 outliers identified for Ginna.

Figure G-19 shows all the Ginna data plotted versus time using (approximate) values of the baseline mean and standard deviation. These values are slightly different than those shown in Table G-5 because, after this plot was developed, it was clear that we hadn’t used a “level playing field” for the outliers when we addressed them on a month-by-month basis. The follow-on analysis described in Table G-5 addressed this issue and resulted in small changes in the baseline values.

Figure G-20 shows the crossplot between the observed ULR data recorded for Ginna versus the time interval used to perform the snapshot measurement. (This interval ranges from approximately 1 hour to 13 hours.) The data shows some decreasing trend versus increased time as predicted by Equation 11.15 of Section 11.9. The fact that this data appears to have a decreased standard deviation as the surveillance interval increases may explain some of the difficulties with the normality test. (That is, the data has different subpopulations with different statistical characteristics.) The variation in the length of the surveillance interval only occurred for Ginna. Note: the ILR data shows a minimal effect versus time interval.

G-9 Summary of the Fort Calhoun Data Analysis

The Fort Calhoun TLR data (Total Leak Rate) is shown in **Figure G-21**. No analysis beyond that shown was performed for Fort Calhoun because the TLR data didn’t separately report ULR and ILR values and, also, because the data was essentially an average 24 hour data measurement and, thus, was not directly comparable to the data for the other plants.

G-10 Summary of All Standard Plant Participants Baseline & Outlier Data

Table G-5 summarizes the measurements for Seabrook, CP1, CP2 and Ginna. Conclusions are addressed in Section G-4.

Table G-6 summarizes all outlier data observed for the four plants.

G-11 Template & Sample Excel Spreadsheet Files Available to All Members

A template Excel file which provides sheets for all the significant calculations performed as part of the Standard Plant Analysis are documented in Reference 24 and available upon request.

Table G-1: Seabrook Monthly Unidentified Leak Rate Data: August 2005 – March 2006								
Item	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mean	.036	.025	.017	.018	.028	.030	.030	.024/.016
Standard Deviation	.044	.040	.034	.042	.039	.036	.031	.022/.041
Median	.043	.026	.018	.028	.032	.025	.032	.023/.023
Kurtosis	2.54	-0.56	1.10	-0.64	-0.74	1.67	-0.91	-0.06/8.19
Skewness (Note5)	-0.96	0.06	-0.62	-0.18	-0.13	0.31	-0.09	-.19/-2.47
Maximum Note6	<u>.12</u>	.11	.09	.09	.09	Note4 <u>.14</u>	.08	.06/.06
Minimum Note6	<u>-0.11</u>	-0.06	<u>-0.07</u>	<u>-0.07</u>	-0.05	-0.05	-0.03	-.03/-0.15
Outliers Type & (Number)	Note1 (2)	0	Note1 (1)	Note1 (1)	0	Note1 (1)	0	Note2 (2)
Passed Normality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes/No
Exceedences Note 3	1 run: 5		1 run: 5	1 run: 5	1 run: 7			
Note 1	No formal “outlier” tests were performed. Outlier detection was based on a visual inspection and the (positive) results of the normality test. The outlier count shown in parentheses is based on the final screening performed at the end of the project using the overall best estimate mean and standard deviation. Details are in Section G-3.							
Note 2	Two outliers were observed visually and by excessive kurtosis and/or skewness values and by the failure to pass the normality test. The second value shown in each row is the value <u>before</u> outliers were removed. The value with outliers removed is shown in bold							
Note 3	Exceedences describe a “run” of consecutive, valid values above the baseline mean in Figure G-3.							
Note 4	This is the single largest observation. As shown in Figure G-3, it is 2.97 standard deviations above the baseline mean and was judged to be an outlier based on the overall best estimate mean and standard deviation.							
Note 5	Gray denotes values outside the limits specified in Section G-3.2.							
Note 6	<u>Underline Italics</u> denote max & min values later declared as outliers							

Table G-2: Comanche Peak Unit 1
Monthly Unidentified Leak Rate Data: December 2005 – March 2006

Item	Dec.	Jan.	Feb.	Mar.
Mean	.036	.023/.012	.027	.011
Standard Deviation	.029	.025/.045	.034	.032
Median	.042	.022/.020	.025	.012
Kurtosis	-0.71	1.07/7.93	-0.32	0.11
Skewness (Note 5)	.049	-0.66/2.53	-0.21	-0.40
Maximum Note 6	.09	.06/.06	.09 Note 4	.07
Minimum Note 6	-.01	-.04/-.18	-.04	-.06
Outliers Type & (Number)	Note 1 (1)	Note 2 (3)	0	Note 1 (2)
Passed Normality	Yes	Yes/No	Yes	Yes
Exceedences Note 3	1 run: 6	1 run: 5	1 run: 9	
Note 1	No formal "outlier" tests were performed. Outlier detection was based on a visual inspection and the (positive) results of the normality test. The outlier count shown in parentheses is based on the final screening performed at the end of the project using the overall best estimate mean and standard deviation. Details are in Section G-3.			
Note 2	Three outliers were observed visually and by excessive kurtosis and skewness values and by failure to pass the normality test. The second value shown in each row is the value <u>before</u> outliers were removed. The value with outliers removed is shown in bold			
Note 3	Exceedences describe a "run" of consecutive, valid values above the baseline mean in Figure G-15.			
Note 4	This is the single largest observation (i.e., .088 on 2/24/06). As shown in Figure G-15, it is 2.13 standard deviations above the baseline mean and is not considered an outlier.			
Note 5	<u>Gray</u> denotes values outside the limits specified in Section G-3.2.			
Note 6	Underlined Italics denote max or min later declared to be an outlier			

Table G-3: Comanche Peak Unit 2 Monthly Unidentified Leak Rate Data: December 2005 – March 2006				
Item	Dec.	Jan.	Feb.	Mar.
Mean	.004	.000	-.011	-.001
Standard Deviation	.028	.028	.031	.027
Median	.005	.005	-.010	.004
Kurtosis	<u>1.32</u>	<u>-1.19</u>	.022	-.038
Skewness Note 5	<u>-0.97</u>	-0.30	-0.11	-0.42
Maximum Note 6	.05	.04	.05 Note 4	.05
Minimum Note 6	<u>-0.08</u>	-0.05	<u>-0.08</u>	-0.06
Outliers	Note 1 (1)	0	Note 1 (1)	0
Passed Normality	Yes	Yes	Yes	Yes
Exceedences Note 3	1 run: 5			1 run:5
Note 1	No formal "outlier" tests were performed. Outlier detection was based on a visual inspection and the (positive) results of the normality test. The outlier count shown in parentheses is based on the final screening performed at the end of the project using the overall best estimate mean and standard deviation. Details are in Section G-3.			
Note 3	Exceedences describe a "run" of consecutive, valid values above the baseline mean in Figure G-18.			
Note 4	This is the single largest observation (i.e., .0517 on 2/14/06). As shown on Figure G-18, it is 1.88 standard deviations above the baseline mean and is not an outlier.			
Note 5	<u>Gray</u> denotes values outside the limits specified in Section G-3.2.			
Note 6	<u>Underlined Italics</u> denote max or min values later declared outliers			

Table G-4: Ginna Monthly Unidentified Leak Rate Data: December 2005 – March 2006				
Item	Dec.	Jan.	Feb.	Mar.
Mean	.018/.019	.014	.017	.013/.015
Standard Deviation	.007/.009	.006	.007	.004/.008
Median	.016/.016	.014	.017	.014/.014
Kurtosis	-0.72/5.24	0.63	1.01	0.68/6.5
Skewness	0.57/1.88	0.41	0.76	0.26/2.1
Note 7				
Maximum	.03/.05	.03	.03	.022/.05
Minimum	.01/.01	0.0	.01	.01/0.0
Outliers	Notes 1 & 2 (1-Note 2, 2-Note 1)	0	Note 1 (2)	Note 2 (1)
Passed Normality	No (Note 5)	Yes	Yes	No (Note 6)
Exceedences Note 3			1 run: 8	
Note 1	No formal “outlier” tests were performed. Outlier detection was based on a visual inspection and the negative normality results. The total outlier count (3) shown in parentheses is based on the final screening performed at the end of the project using the overall best estimate mean and standard deviation. Details are in Section G-3.			
Note 2	One outlier in December was observed visually and by excessive kurtosis and skewness values and by failure to pass the normality test. The outlier is: December 15 th (0.054 gpm). Five March outliers were detected using the “median/MAD” method documented in Section G-3.4. Only one of the March values would be judged to be an outlier based on the final screening performed with the final baseline mean and standard deviation values. The second value shown in each row is the value before outliers were removed. The value with outliers removed is shown in bold			
Note 3	Exceedences describe a “run” of consecutive, valid values above the baseline mean in Figure G-19.			
Note 5	We replaced the 12/15 value (.054) with the 01/01 value (.021). Normality testing results improved dramatically but still failed the test at the 5% significance level. The test passed at about the 3% significance level.			
Note 6	The data did not pass normality even with the 5 outliers removed and replaced with February data. This is somewhat surprising since the final kurtosis and skewness values seem nominal.			
Note 7	Gray denotes values outside the limits specified in Section G-3.2.			

Table G-5: Standard Plant Participants Baseline & Related Data Summary

Plant	Seabrook	Comanche Peak Unit 1	Comanche Peak Unit 2	Ginna
# of Valid Daily Values	236	101	118	106
Baseline Mean	+.0265	+.0247	-.0005	+.0153
Baseline Standard Deviation	.0336	.0284	.0267	.0055
Median (Pass/Fail) Note 1	+.0283 (PASS)	+.0224 (PASS)	+.0023 (PASS)	+.0140 (PASS)*
Kurtosis	-.34	-.12	-.73	-.02
Skewness	-.14	-.05	-.23	+.38
Maximum (zscore)	+.105 (+2.34)	+.088 (+2.23)	+.052 (+1.97)	+.030 (+2.5)*
Minimum	-.063	-.042	-.062	+.003
Outliers (Positive)	2	0	0	6
Outliers (Negative)	5	6	2	0
Outliers(Total)	7	6	2	6
Outliers (%) Note 3	2.9%	5.6%	1.7%	5.4%
Passed Normality	Note 2	Note 2	Note 2	Note 2
Exceedences See Data in Table (Note 4)	G-1	G-2	G-3	G-4
Comments Note 5				Note 6
Note 1	Pass means the values obey Equation G.1 of Section G-3.1			
Note 2	Formal test was not performed based on kurtosis & skewness			
Note 3	100% x (Total Outliers)/(Total Outliers + # of Valid Values)			
Note 4	In a total of 20 months of data there were 7 runs of length 5; 2 runs of length 7; and 1 run of length 9			
Note 5	Using the stated baseline values with outliers removed, there was 1 "NRC Action Level I" (Table G-2), and no Action Level II or III events recorded			
Note 6	The Median and Mean fail Equation G.1 by an insignificant amount. The zscore used the baseline mean & std. dev. shown on Figure G-19			

Table G-6: Standard Plant Participants Outlier Summary

Plant & Outliers	Seabrook	Comanche Peak Unit 1	Comanche Peak Unit 2	Ginna
#1-Date	8/12/2005	12/29/2005	12/11/2005	12/2/2005
Value	+1.1233	-.0681	-.0793	+0.0320
Zscore	(2.66)	(-3.04)	(-2.72)	(2.63)
Type	Note 1	Note 1	Note 1	Note 1
#2-Date	8/17/2005	1/17/2006	2/17/2006	12/15/2005
Value	-.1058	-.0762	-.0829	+0.0540
Zscore	(-3.60)	(-3.31)	(-2.85)	(7.04)
Type	Note 1	Note 2	Note 1	Note 2
#3-Date	10/9/2005	1/18/2006	N/A	12/29/2005
Value	-.0742	-.0823		+0.0320
Zscore	(-2.73)	(-3.51)		(2.63)
Type	Note 1	Note 2		Note 1
#4-Date	11/23/2005	1/29/2006	N/A	2/7/2006
Value	-.0692	-.1822		+0.0340
Zscore	(-2.60)	(-6.84)		(2.95)
Type	Note 1	Note 2		Note 1
#5-Date	1/19/2006	3/8/2006	N/A	2/10/2006
Value	+1.1350	-.0600		+0.0350
Zscore	(2.97)	(-2.73)		(3.58)
Type	Note 1	Note 1		Note 1
#6-Date	3/12/2006	3/9/2006	N/A	3/1/2006
Value	-.1458	-.0582		.0450
Zscore	(-4.64)	(-2.67)		(5.40)
Type	Note 2	Note 1		Note 2
#7-Date	3/17/2006	N/A	N/A	N/A
Value	-.0742			
Zscore	(-2.71)			
Type	Note 2			
Note 1	These Outliers were not removed when the monthly data was analyzed. They were identified and removed when all data for each plant was "baselined".			
Note 2	These outliers were identified when the monthly data was analyzed. Typically they were removed because the original sample failed the normality test.			

Appendix G “Figures”

Standard Plant Testing

Figure G-1**Illustration of the F-Test for Arbitrary Data****Case 1: Variance of Variable 1 > Variance of Variable 2****F-Test Two-Sample for Variances**

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	-0.032259703	-0.181159106
Variance	0.951405782	0.826705365
Observations	92	30
df	91	29
F	1.150840217	
P(F<=f) one-tail	0.342418969	
F Critical one-tail	1.716291109	

Case 2: Variance of Variable 1 < Variance of Variable 2**F-Test Two-Sample for Variances**

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	-0.181159106	-0.032259703
Variance	0.826705365	0.951405782
Observations	30	92
df	29	91
F	0.868930356	
P(F<=f) one-tail	0.342418969	
F Critical one-tail	0.582651261	

← Reciprocal of value above

Note: Figure G-16 shows a data set which fails the F test.

Figure G-2

Illustration of the 2 Sample t-Test for Arbitrary Data

Case 1: Mean of Variable 1 > Mean of Variable 2

t-Test: Two-Sample Assuming Equal Variances

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	-0.032259703	-0.181159106
Variance	0.951405782	0.826705365
Observations	92	30
Pooled Variance	0.921269848	
Hypothesized Mean Difference	0	
df	120	
t Stat	0.737860315	
P(T<=t) one-tail	0.231019901	
t Critical one-tail	1.657649591	
P(T<=t) two-tail	0.462039802	
t Critical two-tail	1.979929038	

Case 2: Mean of Variable 1 < Mean of Variable 2

t-Test: Two-Sample Assuming Equal Variances

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	-0.181159106	-0.032259703
Variance	0.826705365	0.951405782
Observations	30	92
Pooled Variance	0.921269848	
Hypothesized Mean Difference	0	
df	120	
t Stat	-0.737860315	
P(T<=t) one-tail	0.231019901	
t Critical one-tail	1.657649591	
P(T<=t) two-tail	0.462039802	
t Critical two-tail	1.979929038	

Figure G-3
Seabrook ULR Values for Standard Plant Measurements

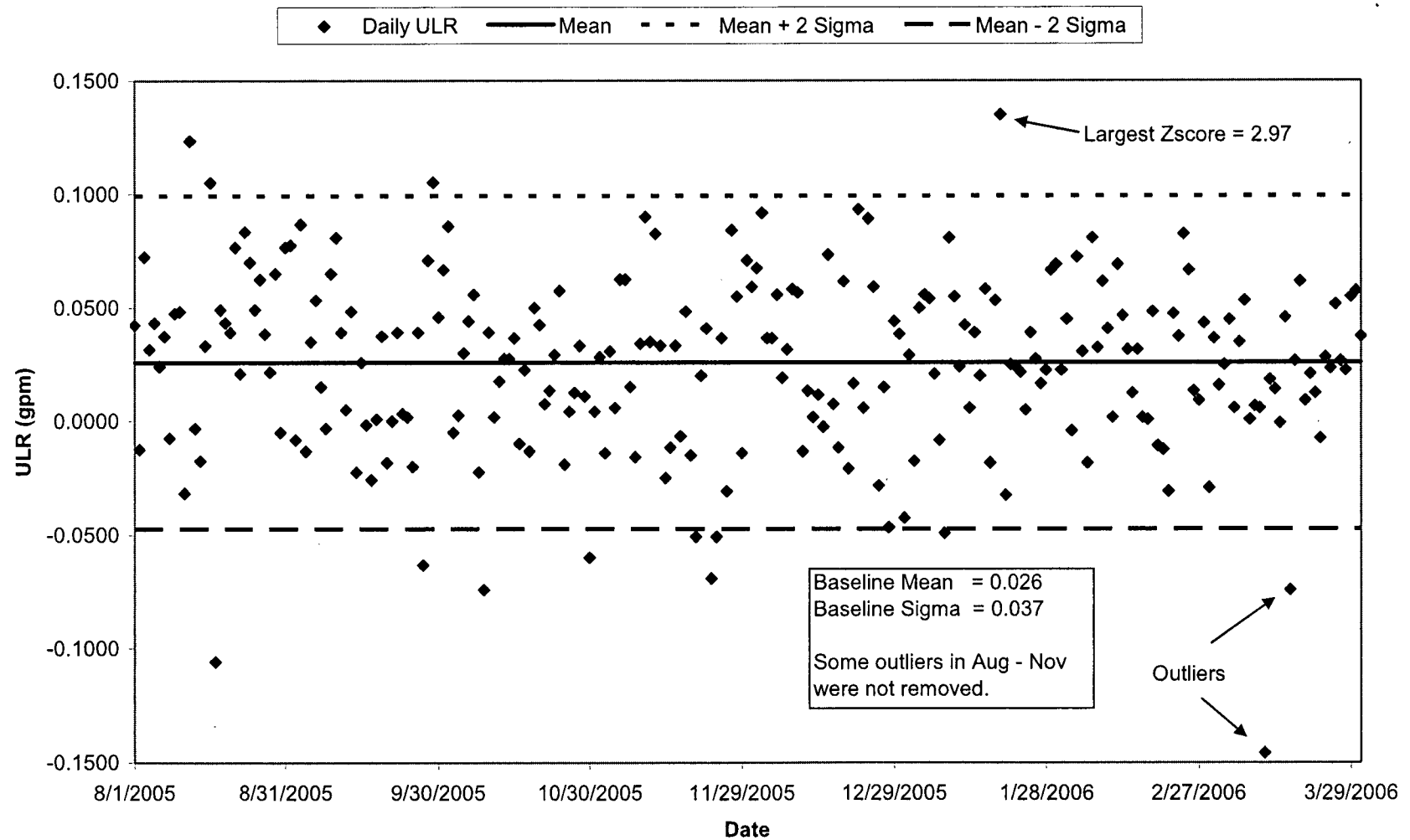


Figure G-4

F and Two-Sample t-Test for Seabrook

Variable 1 = Aug - Oct

Variable 2 = Nov - Jan

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	0.025416667	0.025887681
Variance	0.001592117	0.001511398
Observations	92	92
df	91	91
F	1.053406708	
P(F<=f) one-tail	0.40227238	
F Critical one-tail	1.414340645	

Variable 1 = Aug - Oct

Variable 2 = Nov - Jan

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	0.025416667	0.025887681
Variance	0.001592117	0.001511398
Observations	92	92
Pooled Variance	0.001551758	
Hypothesized Mean Difference	0	
df	182	
t Stat	-0.08109634	
P(T<=t) one-tail	0.467727223	
t Critical one-tail	1.653270374	
P(T<=t) two-tail	0.935454446	
t Critical two-tail	1.973085091	

Variable 1 = Nov - Jan

Variable 2 = Aug - Oct

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	0.025887681	0.025416667
Variance	0.001511398	0.001592117
Observations	92	92
Pooled Variance	0.001551758	
Hypothesized Mean Difference	0	
df	182	
t Stat	0.081096341	
P(T<=t) one-tail	0.467727223	
t Critical one-tail	1.653270374	
P(T<=t) two-tail	0.935454446	
t Critical two-tail	1.973085091	

Figure G-5**Leak Rate Data for Figure G-6****True Values:**

Time (Minutes)	Leak Rates (gpm) →					
	1	0.5	0.25	0.1	0.05	0.01
0	63200.0	63200.0	63200.0	63200.0	63200.0	63200.0
15	63185.0	63192.5	63196.3	63198.5	63199.3	63199.9
30	63170.0	63185.0	63192.5	63197.0	63198.5	63199.7
45	63155.0	63177.5	63188.8	63195.5	63197.8	63199.6
60	63140.0	63170.0	63185.0	63194.0	63197.0	63199.4
75	63125.0	63162.5	63181.3	63192.5	63196.3	63199.3
90	63110.0	63155.0	63177.5	63191.0	63195.5	63199.1
105	63095.0	63147.5	63173.8	63189.5	63194.8	63199.0
120	63080.0	63140.0	63170.0	63188.0	63194.0	63198.8

Measured Values for Sigma of 5.4 Gallons:

Time (Minutes)	Leak Rates (gpm) →					
	1	0.5	0.25	0.1	0.05	0.01
0	63197.0	63197.0	63197.0	63197.0	63197.0	63197.0
15	63188.7	63196.2	63199.9	63202.2	63202.9	63203.5
30	63172.0	63187.0	63194.5	63199.0	63200.5	63201.7
45	63157.8	63180.3	63191.6	63198.3	63200.6	63202.4
60	63136.7	63166.7	63181.7	63190.7	63193.7	63196.1
75	63127.1	63164.6	63183.4	63194.6	63198.4	63201.4
90	63103.4	63148.4	63170.9	63184.4	63188.9	63192.5
105	63097.0	63149.5	63175.8	63191.5	63196.8	63201.0
120	63081.8	63141.8	63171.8	63189.8	63195.8	63200.6

Measured Values for Sigma of 2.7 Gallons

Time (Minutes)	Leak Rates (gpm) →					
	1	0.5	0.25	0.1	0.05	0.01
0	63198.5	63198.5	63198.5	63198.5	63198.5	63198.5
15	63186.8	63194.3	63198.1	63200.3	63201.1	63201.7
30	63171.0	63186.0	63193.5	63198.0	63199.5	63200.7
45	63156.4	63178.9	63190.2	63196.9	63199.2	63201.0
60	63138.4	63168.4	63183.4	63192.4	63195.4	63197.8
75	63126.1	63163.6	63182.3	63193.6	63197.3	63200.3
90	63106.7	63151.7	63174.2	63187.7	63192.2	63195.8
105	63096.0	63148.5	63174.8	63190.5	63195.8	63200.0
120	63080.9	63140.9	63170.9	63188.9	63194.9	63199.7

R-Square Values:

Sigma	Leak Rates (gpm) →					
	1	0.5	0.25	0.1	0.05	0.01
5.4	0.992698	0.971651	0.896493	0.594216	0.280680	0.025265
2.7	0.998173	0.992760	0.971559	0.849646	0.592597	0.071893

Figure G-6
R-Square as a Function of Leak Rate

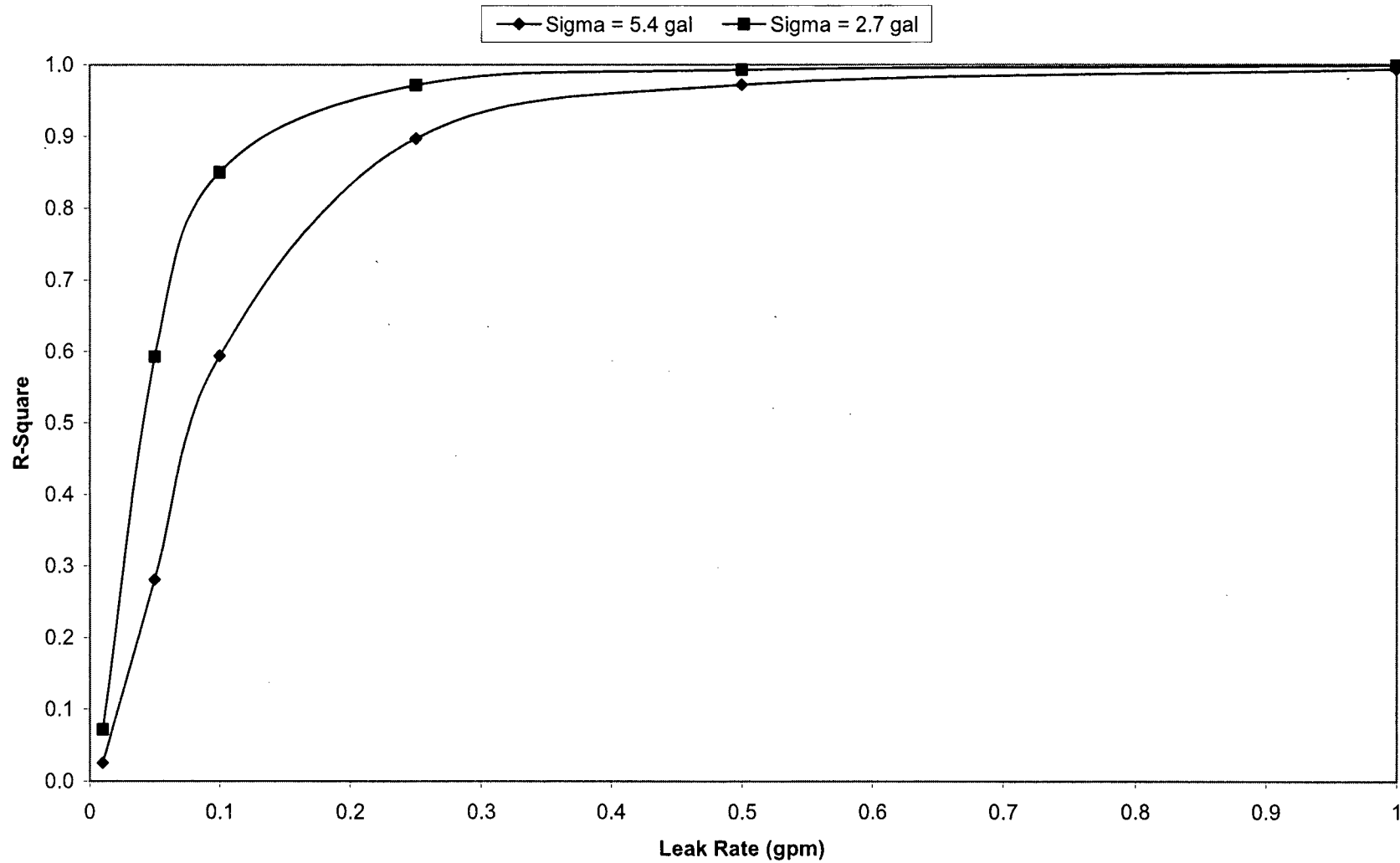


Figure G-7
Seabrook 7 Days Rolling Average
6 Months of ULR Data (from 08/01/05 to 01/31/06)

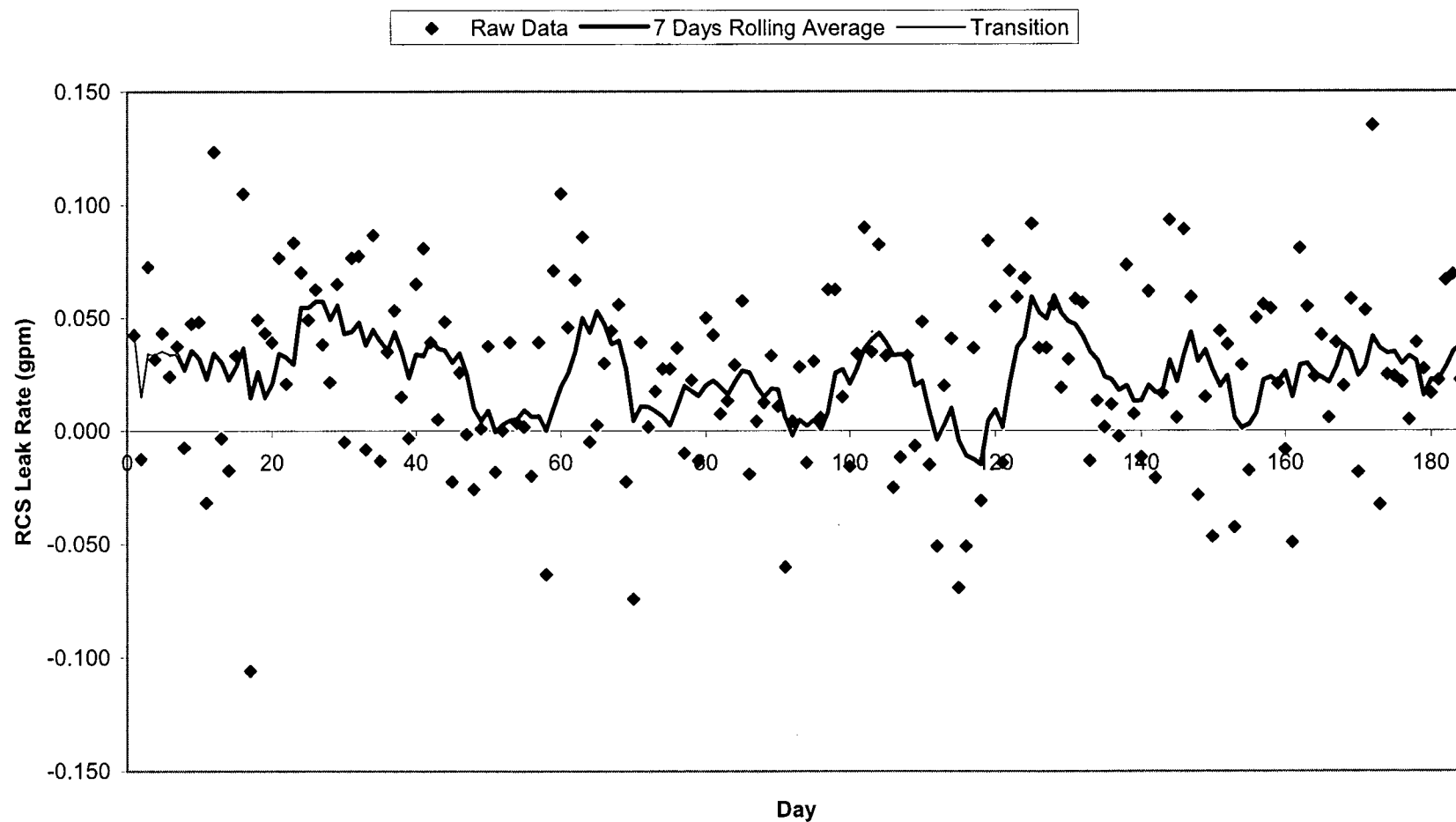


Figure G-8
Seabrook 30 Days Rolling Average
6 Months of ULR Data (from 08/01/05 to 01/31/06)

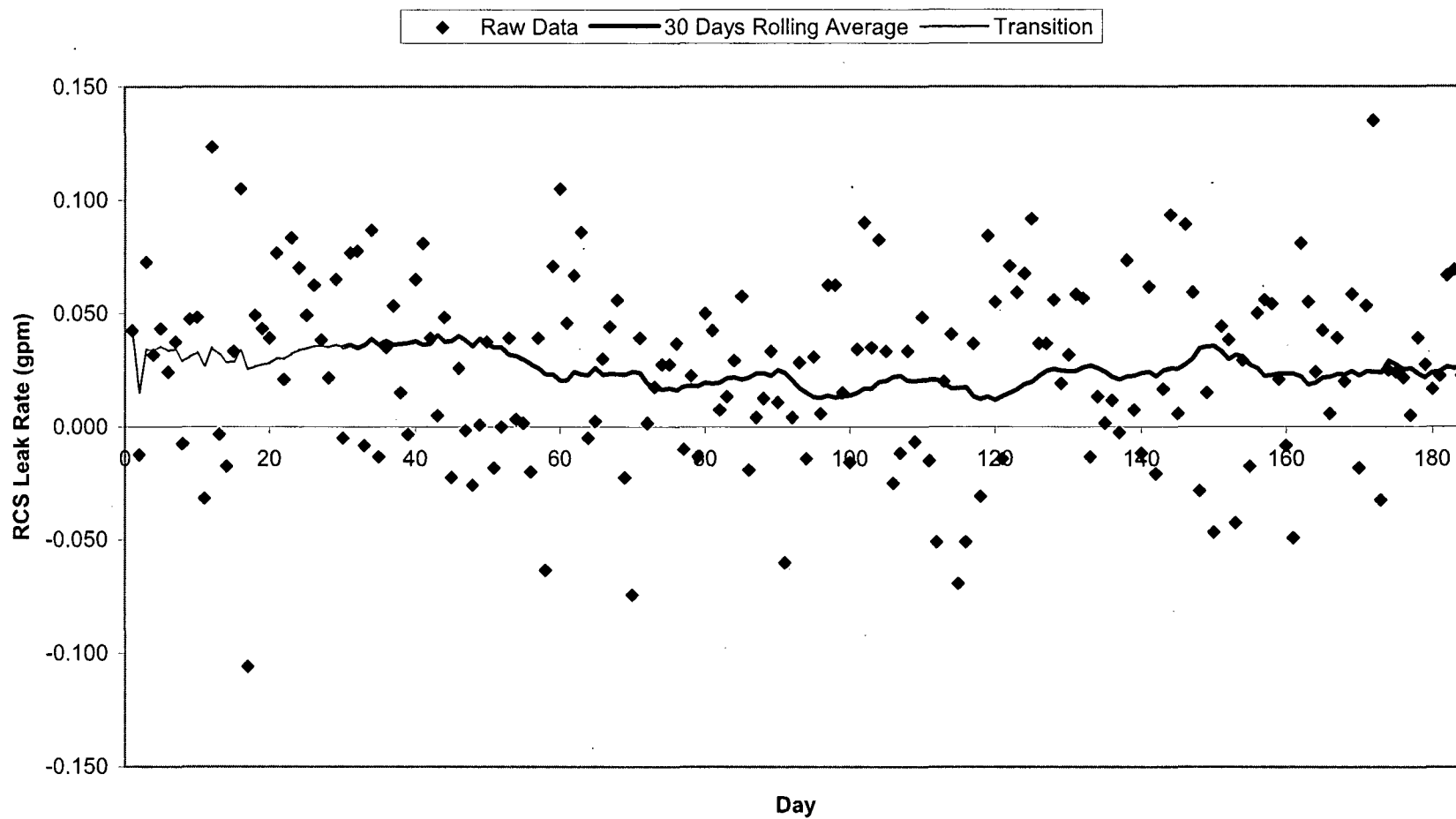


Figure G-9
Seabrook Unidentified Vs. Identified Leak Rates
(2 Hour Snapshot Data)

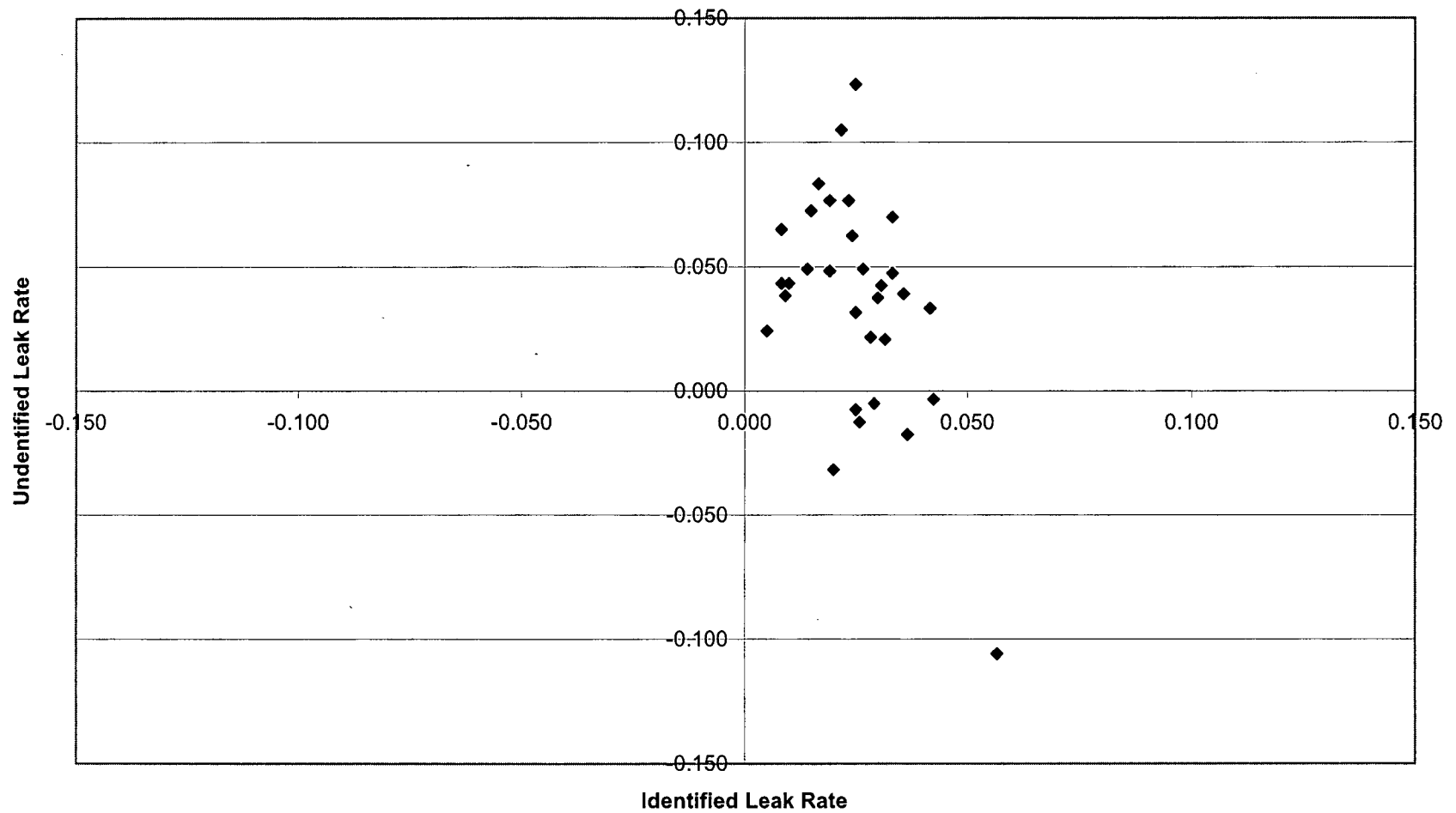


Figure G-10
Seabrook Unidentified Vs. Identified Leak Rates
(24 Hour Data)

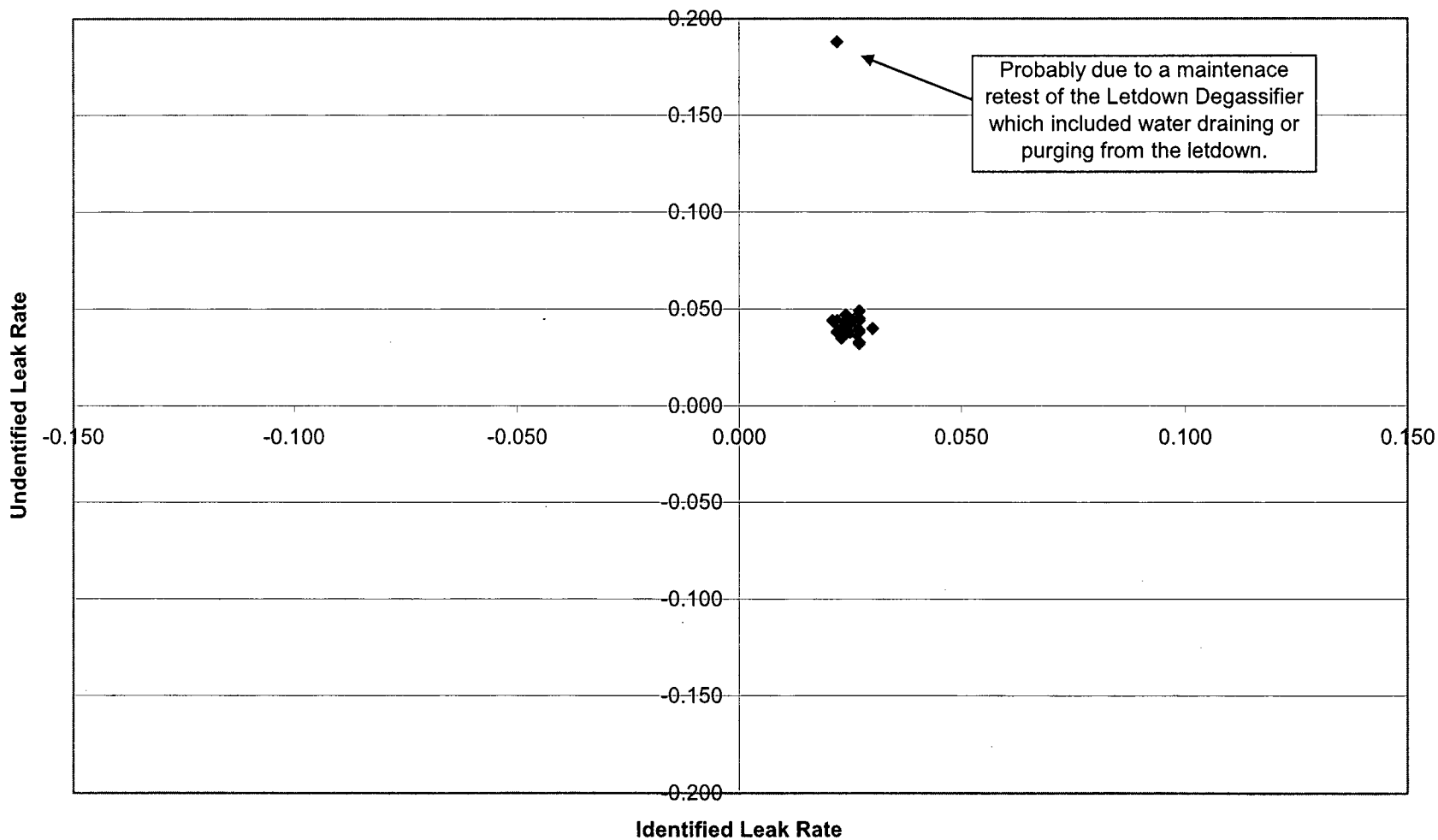


Figure G-11
Compare Seabrook 2 Hr and 24 Hr Unidentified Leak Rate Data Nov & Dec 2005

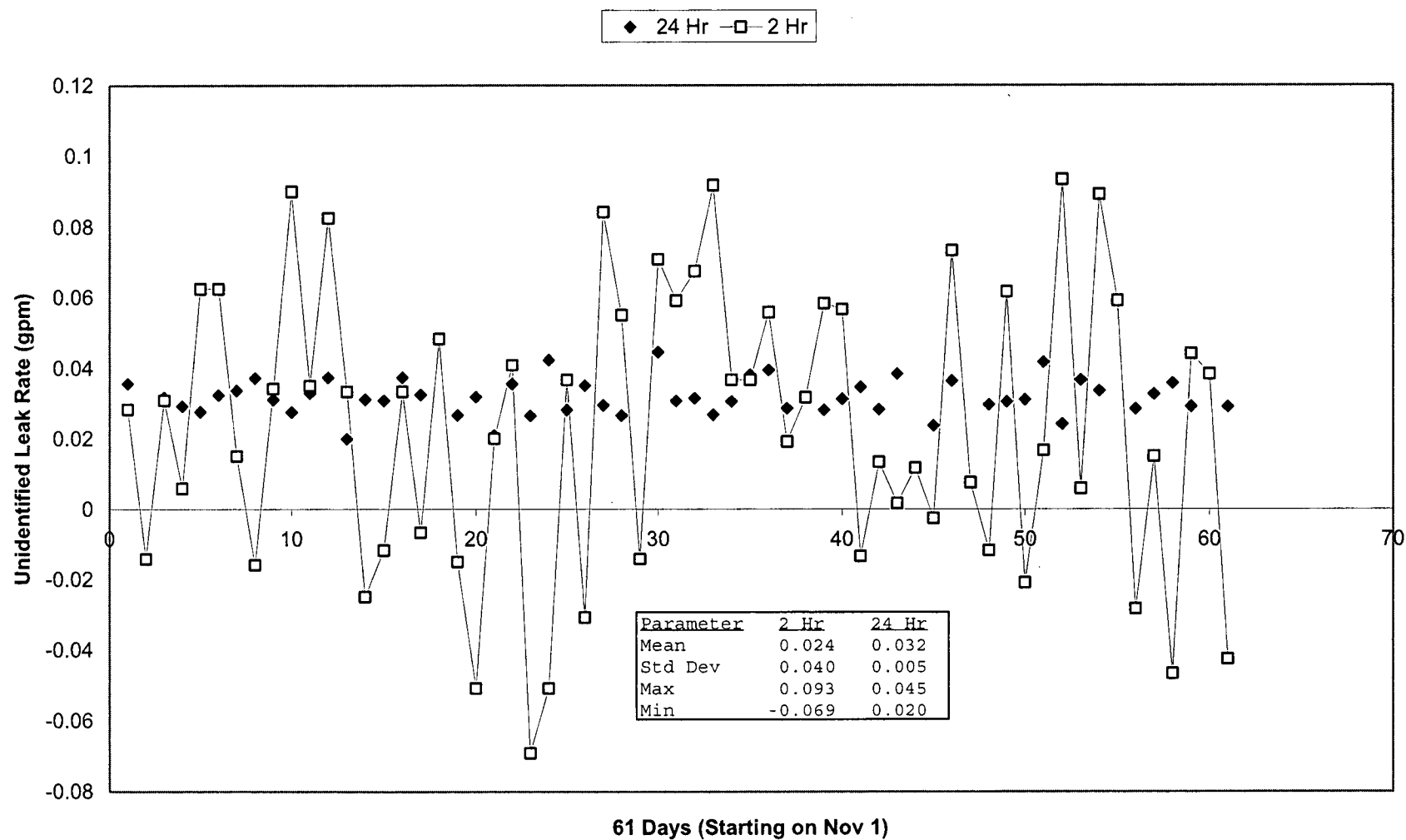


Figure G-12
Compare Seabrook 2 Hr and 24 Hr Unidentified Leak Rate Data Jan - Mar 2006

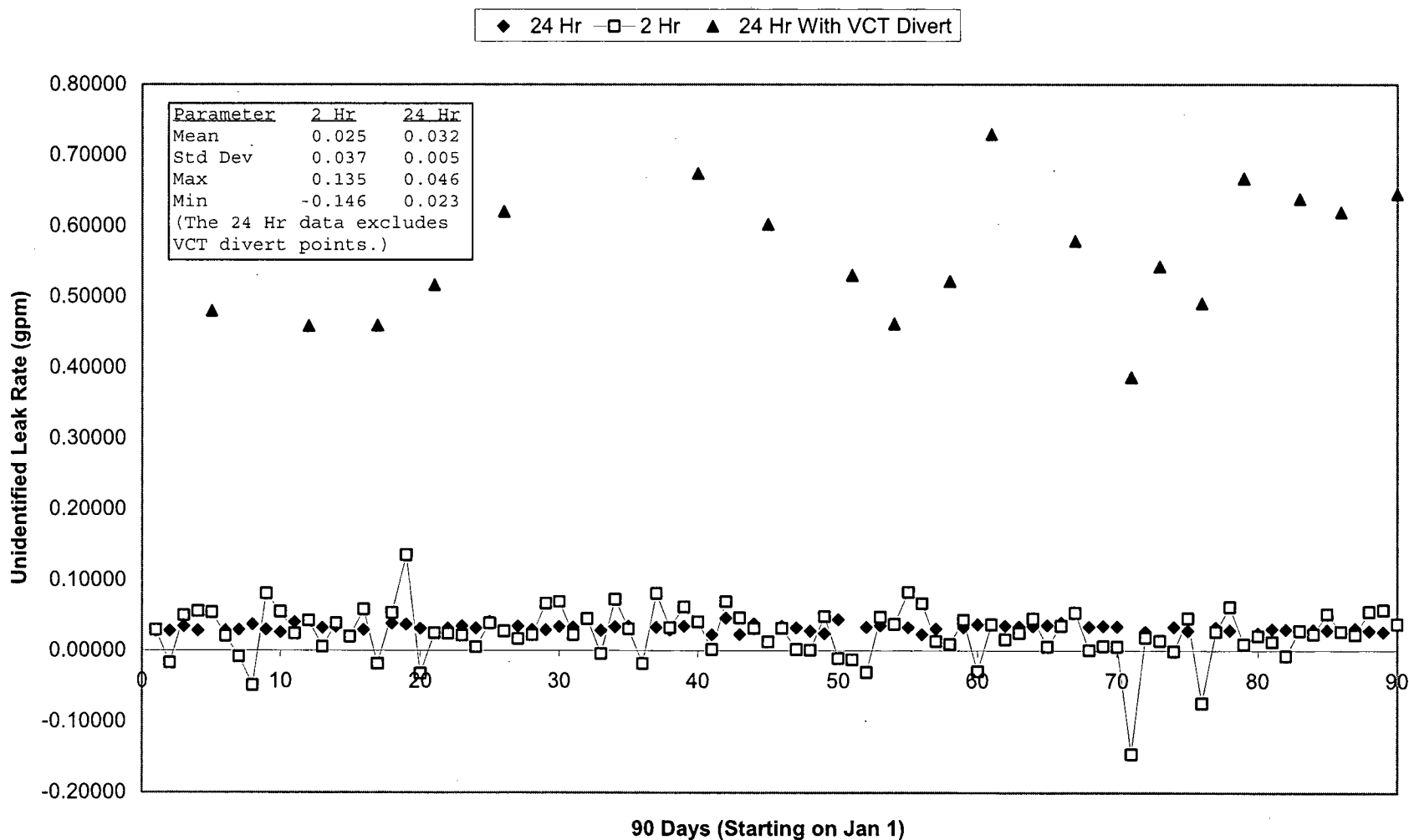


Figure G-13
Crossplot of VCT Divert (gal) vs. RCS Inventory Leakage (gpm)

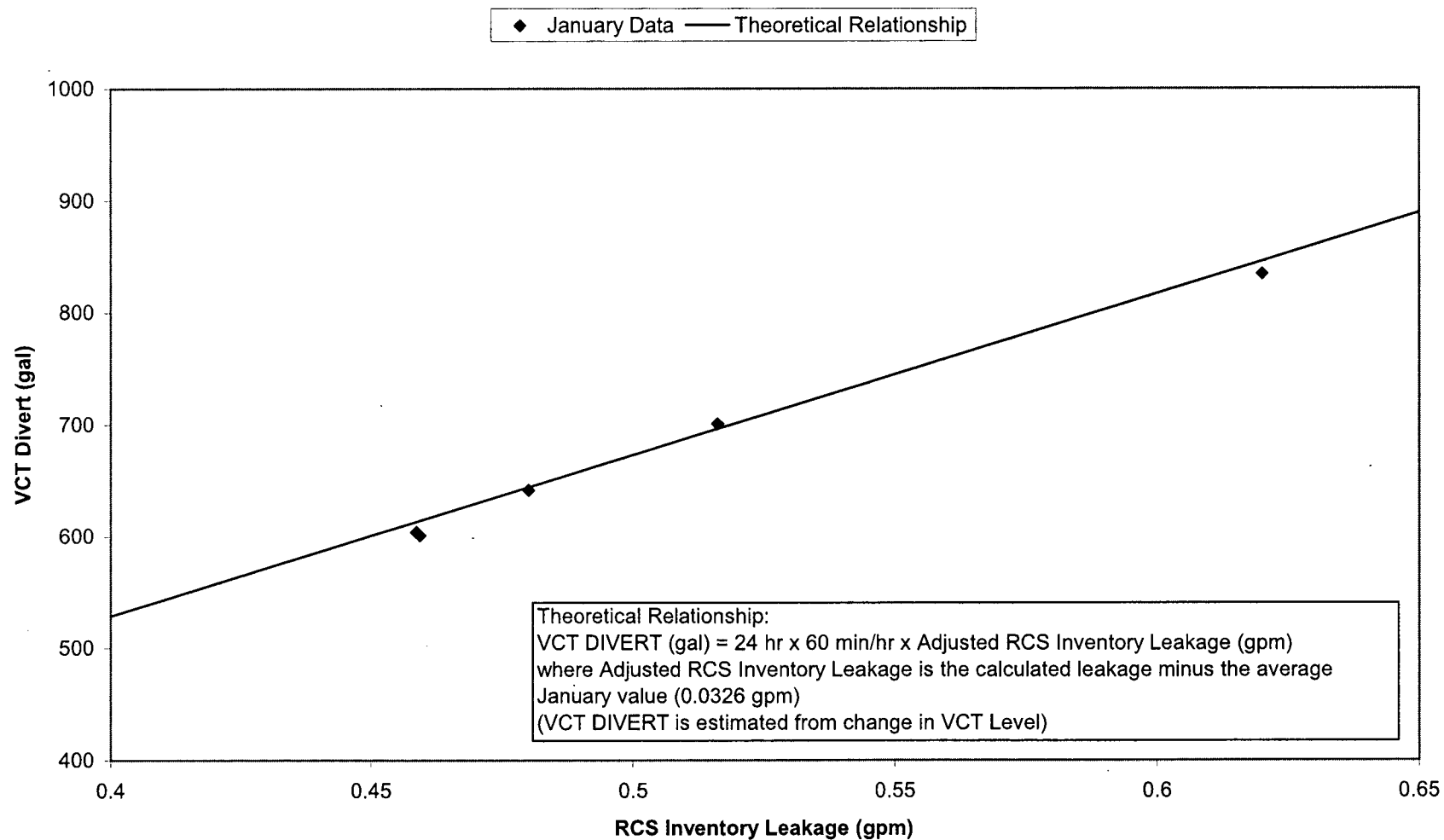


Figure G-14
Seabrook TAVE
(1 Second Instantaneous and 60 Second Average Values)

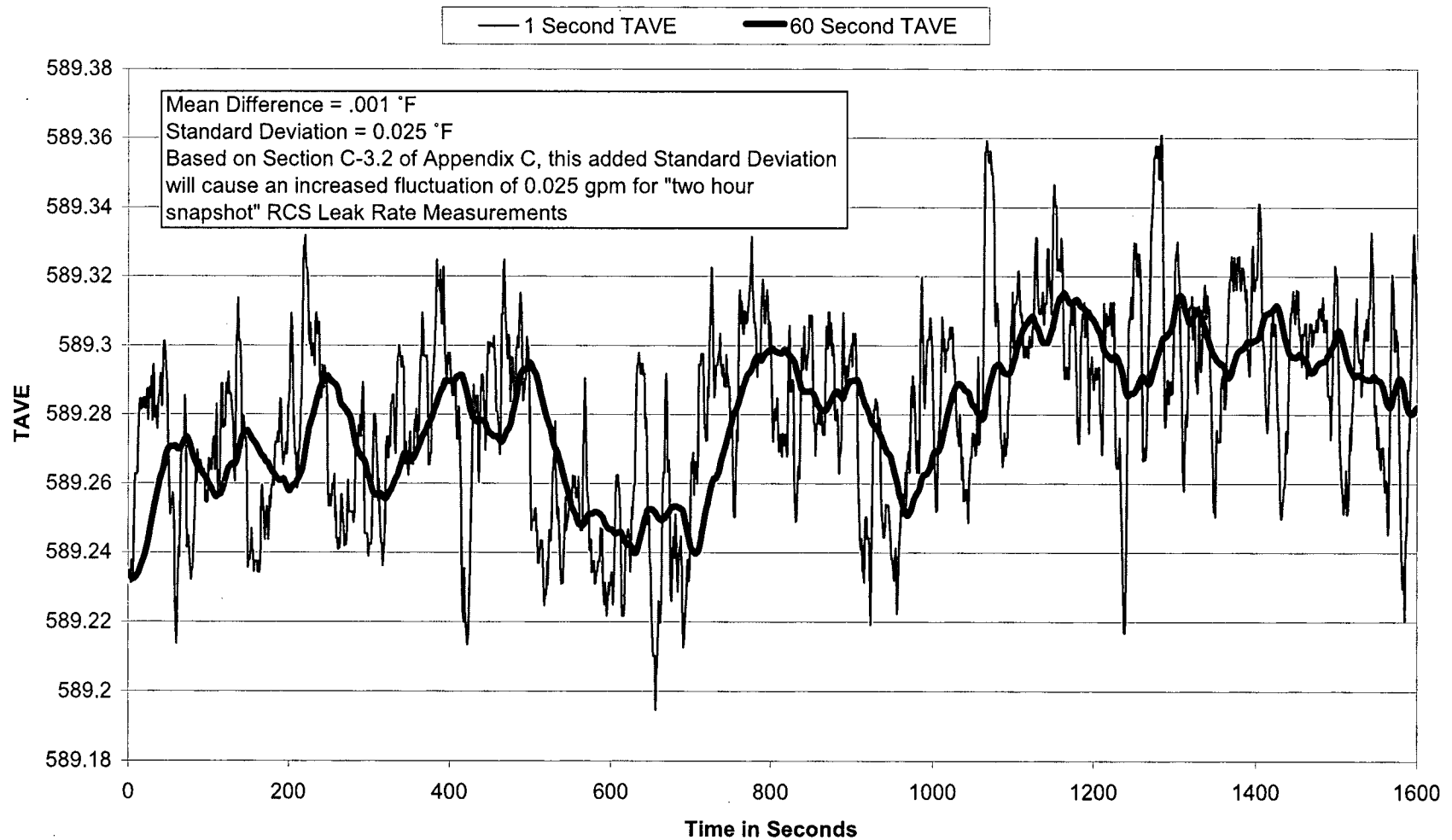


Figure G-15
Comanche Peak 1 ULR Values for Standard Plant Measurements

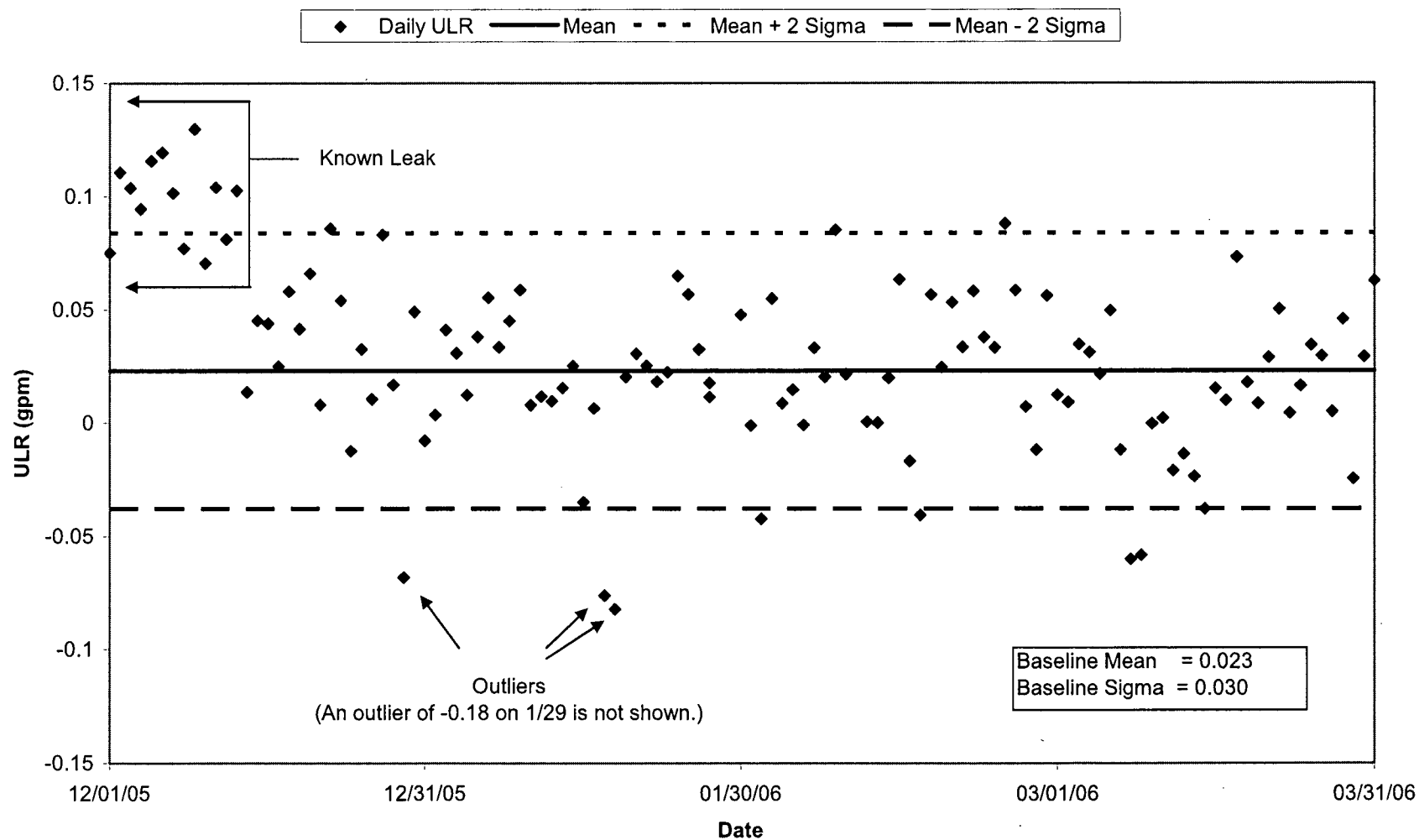


Figure G-16

F and Two-Sample t-Test for Comanche Peak 1

(Variable 1 = Jan Data Without Outliers, Variable 2 = Feb Data)

F-Test Two-Sample for Variances

	Variable 1	Variable 2	
Mean	0.025234266	0.026555888	
Variance	0.000465013	0.001147203	
Observations	28	27	
df	27	26	
F	0.405345097		← Fails F Test
P(F<=f) one-tail	0.011494911		
F Critical one-tail	0.522842214		

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2	
Mean	0.025234266	0.026555888	
Variance	0.000465013	0.001147203	
Observations	28	27	
Hypothesized Mean Difference	0		
df	44		
t Stat	-0.1719198		
P(T<=t) one-tail	0.432144439		← Passes t Test
t Critical one-tail	1.680230071		
P(T<=t) two-tail	0.864288878		
t Critical two-tail	2.0153675		

Figure G-17
Comanche Peak 1 ULR (Clock Running Backward)

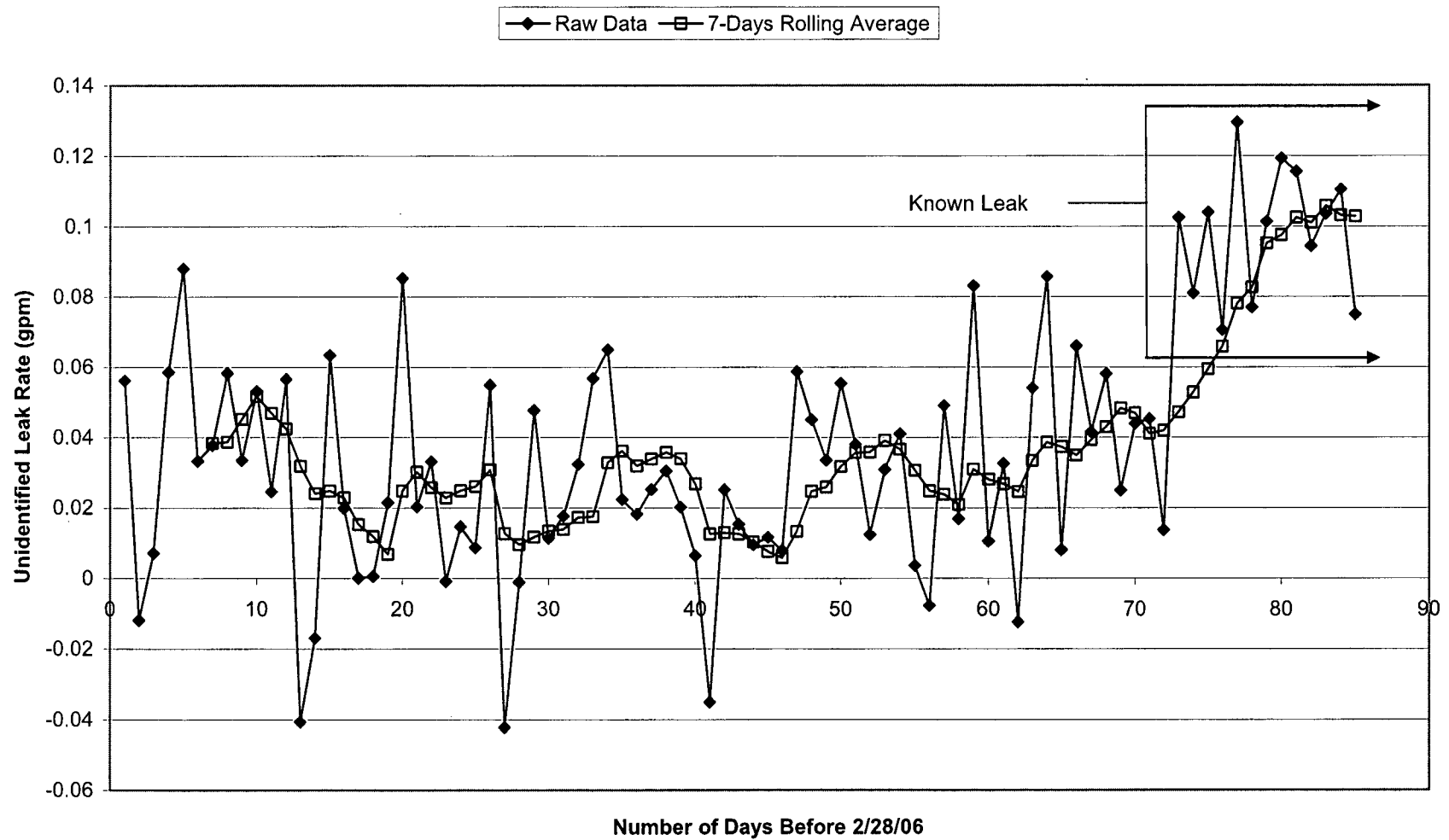


Figure G-18
Comanche Peak 2 ULR Values for Standard Plant Measurements

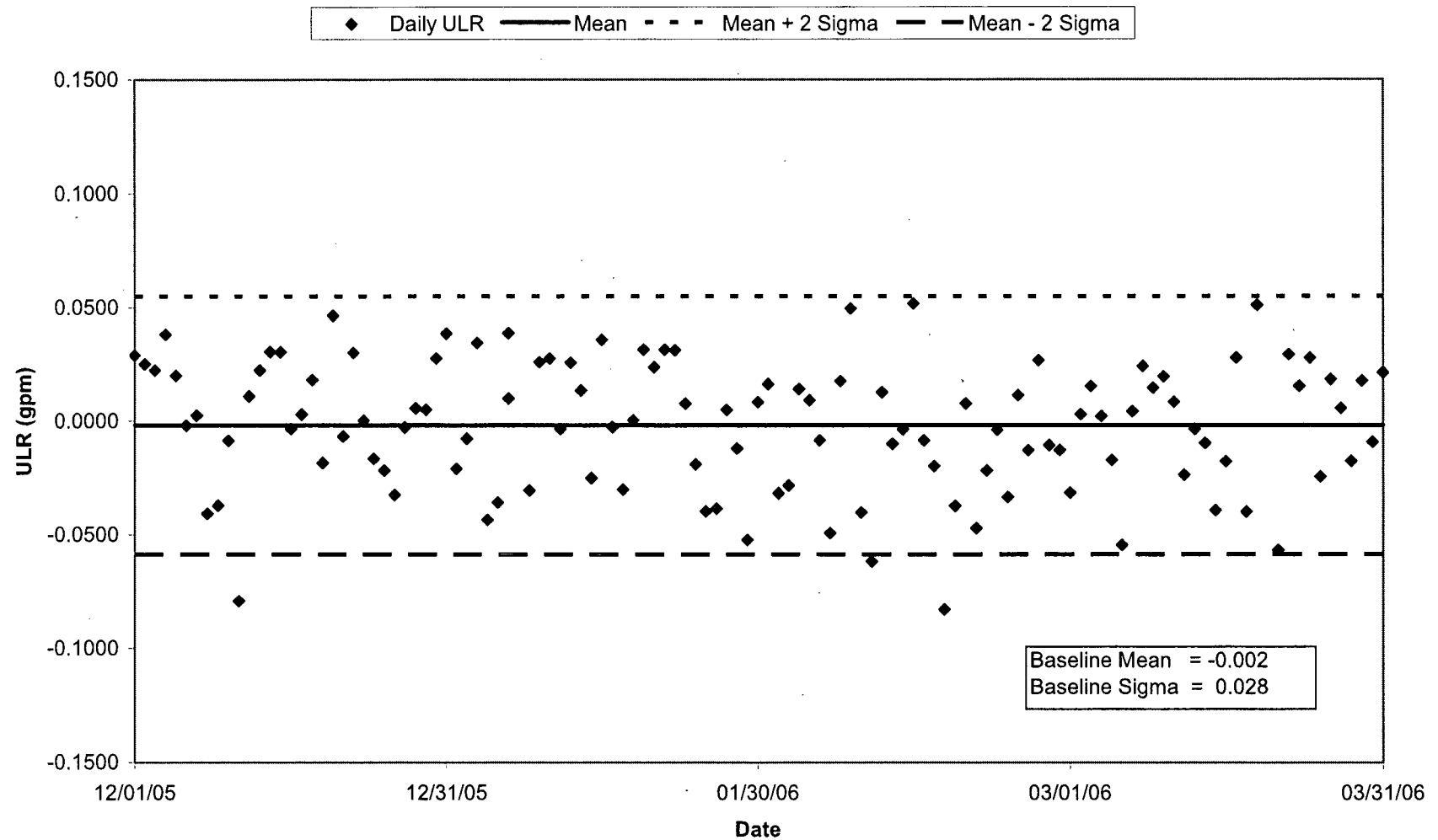


Figure G-19
Ginna ULR Values for Standard Plant Measurements

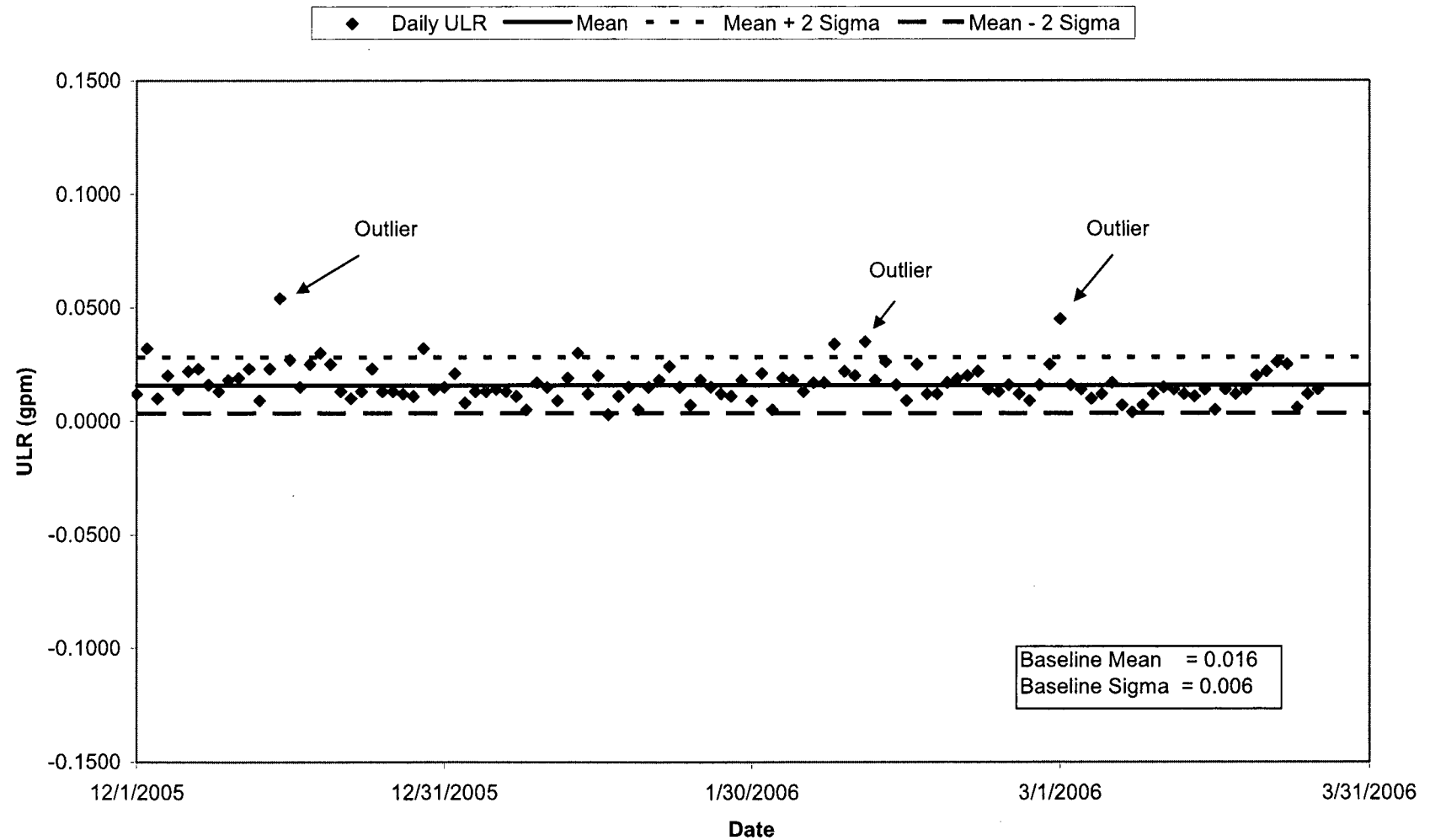


Figure G-20
Ginna Leak Rates Vs Time Interval

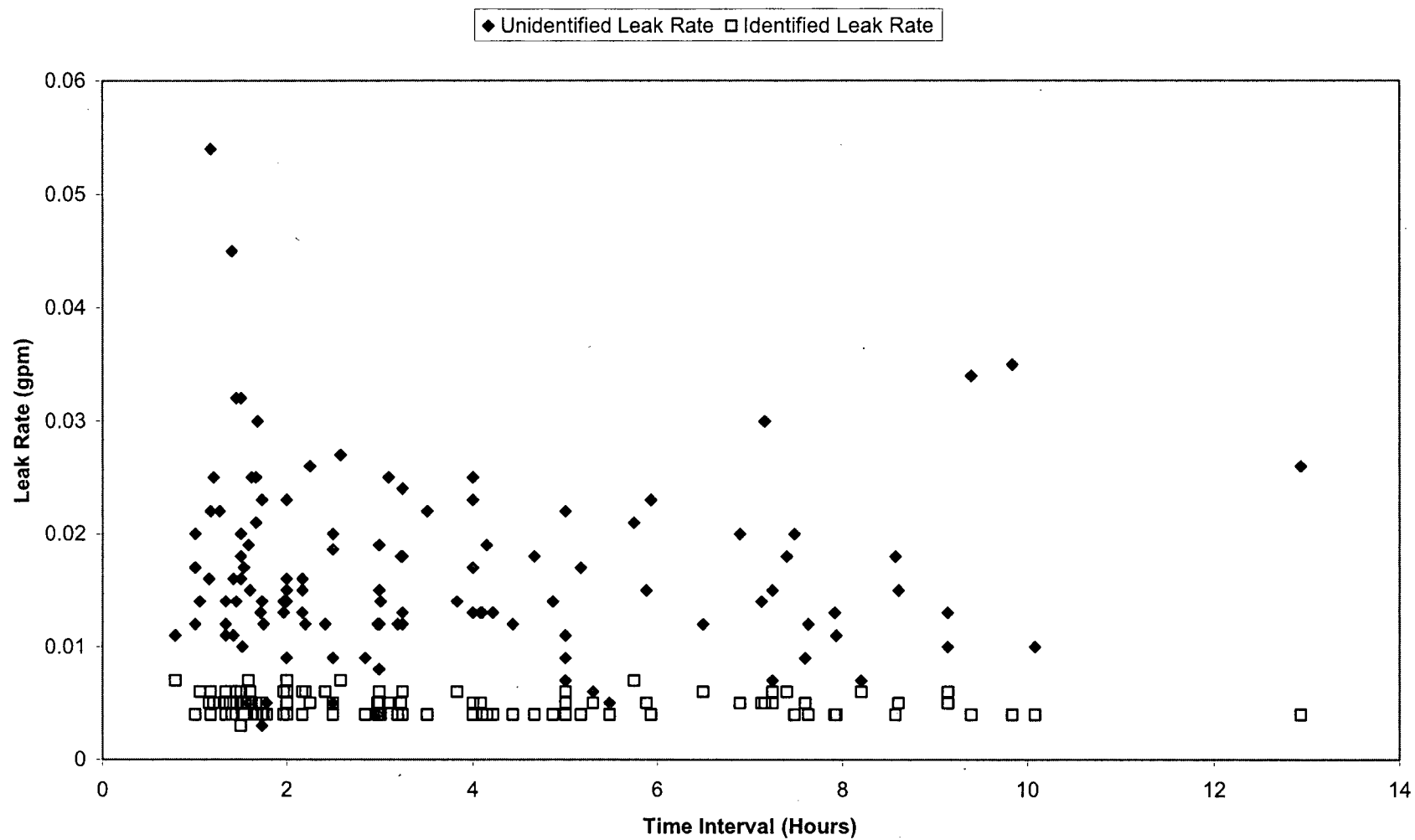
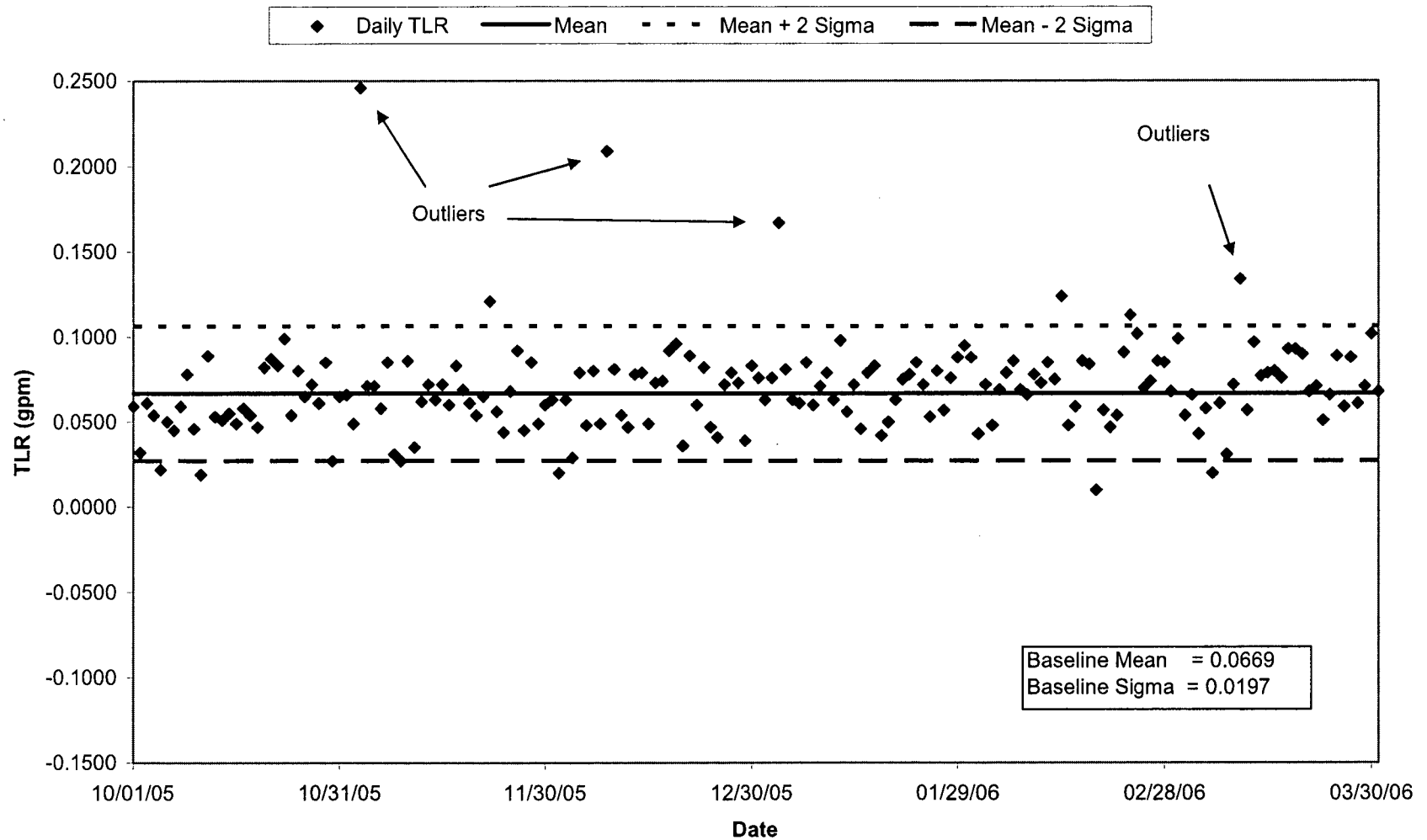


Figure G-21
Fort Calhoun Total Leak Rate Values from Procedure "Daily OP-ST-RC-3001"



Appendix H

Comments from PWROG Members

File Name: Appendix H

Summary of Utility comments on WCAP-16423-NP, through Revision 0

Item	Name/Utility	Section	Comment	Westinghouse Response
1.	Mark Handrich North Anna (4/11/05)	2.0	Minimum Level of Detectability. This definition should apply to the <u>Minimum</u> Limit of Detectability. If you propose to use statistical methods, then the mean + 3*sigma limit seems to be high. Also, how is the plant supposed to acquire the baseline normal distribution, "based on known zero leakage," when such a plant condition is practically unattainable? It seems that a minimum level of detectability should be based on (or augmented by) the instrumentation used to perform the mass inventory balance, as determined by a psuedo loop uncertainty calculation.	<p>I agree that 3 sigma is probably too large. The "3 sigma, zero leakage limit of detectability" is offered as a draft target to invite comments and alternate definitions.</p> <p>I agree that a known zero leakage mean is theoretically impossible. However, when considering leakage less than 1 gpm the standard deviation should not be significantly different whether there is leakage or not. Since the standard deviation is more a function of plant stability (small transient effects), coarse node effects, and instrument noise. Therefore, the standard deviation of the current running mean may be used.</p> <p>Also, since issuing draft v01 there have been several alternate ideas for the limit of detectability, or a more practical term "minimum threshold for action."</p> <p>A few ideas for consideration based on current NRC thinking:</p> <ol style="list-style-type: none"> 1) 5 consecutive leak rate results above the running mean. 2) 9 consecutive leak rate results above the running mean. <p>Where the running mean is the leak rate data set that has passed a predefined validity check.</p> <p>*This issue will be discussed on group conference calls. See agenda for 4/28 call.</p>
2.	Mark Handrich NorthAnna (4/11/05)	4.2	$\text{GPM} = [(\text{lbm}/\text{min}) / \text{Vf}_{100^{\circ}\text{F}} \text{ft}^3/\text{lbm}] / (7.4805 \text{ gal}/\text{ft}^3)$ <p>Please note errors in the above equation:</p> $\text{GPM} = [(\text{lbm}/\text{min}) * \text{Vf}_{100^{\circ}\text{F}} \text{ft}^3/\text{lbm}] * (7.4805 \text{ gal}/\text{ft}^3)$	corrected per comment, thank you
3.	Mark Handrich NorthAnna (4/11/05)	5.0	Editorial: Data Smoothing vs. Date Smoothing	corrected per comment, thank you

Item	Name/Utility	Section	Comment	Westinghouse Response
4.	Mark Handrich NorthAnna (4/11/05)	9.1.1	Why is PZR temperature needed if the PZR is assumed to be at saturated conditions? The PZR pressure will uniquely define the saturation temperature, and the corresponding liquid/vapor specific values.	Use both P and T to determine specific volume. Or, assume saturated conditions and use more accurate (least sensitive to error) of pressure and temperature. This issue needs group discussion for "standard guidance" resolution.
5.	Mark Handrich NorthAnna (4/11/05)	9.2.4	Segmented RCS Volume. Recommend that this be pursued as optional, rather than included as part of the standard method.	Comment noted. This issue needs group discussion for "standard guidance" resolution.
6.	Mark Handrich NorthAnna (4/11/05)	10.2.3	Equation should be $M_{PRT2} - M_{PRT1}$ (i.e. final – initial values), See Section 10.2	corrected per comment, thank you
7.	Mike Hess Millstone 3 (4/11/05)	2.0	I'd like to make it clear that leakage outside containment (Non-RCPB Leakage) is neither identified nor unidentified leakage. This fact was reinforced at the 2004 conference at Foxwoods. To do this I think we need to add the 10CFR50.2 definition for Reactor Coolant Pressure Boundary (RCPB).	Agreed — Added definition for <i>Reactor Coolant Pressure Isolation Valve (PIV) Leakage</i> : In general, PIV Leakage is limited to ≤ 0.5 gpm per nominal inch of valve size up to a maximum of 5 gpm at an RCS pressure $\geq [2215]$ psig and $\leq [2255]$ psig. See plant specific Technical Specifications. The RCS Leak Rate calculation must be adjusted such that PIV Leakage is not counted as IDENTIFIED LEAKAGE nor UNIDENTIFIED LEAKAGE.
8.	Mike Hess Millstone 3 (4/14/05)	2.0	I also recommend that we do not use the term "Reactor Coolant System" in any definitions or equations. The term is not defined and, other than the title, should not be used. I believe my recommendations are consistent with 10CFR50.2 which addresses leakage detection systems (sumps and radmonitors).	Agree — The term "RCS" is not clear in context of leak rate calc. Added definition for Reactor Coolant Water Volume (RCWV) : <i>The Reactor Coolant Water Volume (RCWV) is that portion of the Reactor Coolant System where the effective bulk temperature is represented by Tave. This includes the reactor coolant liquid mass contained within:</i> <ul style="list-style-type: none"> • Hot leg piping, • Cold leg piping, • Reactor vessel, and • Steam generators.

Item	Name/Utility	Section	Comment	Westinghouse Response
				<p>Also added definition for RCS Control Volume: <i>The RCS Control Volume includes:</i></p> <ul style="list-style-type: none"> • Reactor Coolant Water Volume (see def.), • Pressurizer, and • Volume Control Tank. <p><i>Gross leakage is calculated by measuring the change in level, temperature, and pressure conditions in each segment of the RCS Control Volume.</i></p> <p>Open to suggestions from working group.</p>
9.	Mike Hess Millstone 3 (4/14/05)	2.0	<p>Add definition for RCPB for a PWR: The Reactor Coolant Pressure Boundary (RCPB) consist of all those pressure-containing components which are part of the reactor coolant system or which are connected to the reactor coolant system, up to and including:</p> <ul style="list-style-type: none"> (i) The outermost containment isolation valve in system piping which penetrates primary reactor containment. (ii) The second of two valves normally closed during normal reactor operation in system piping which does not penetrate primary reactor containment, (iii) The reactor coolant system safety and relief valves. 	Agree — Added definition for Reactor Coolant Pressure Boundary as provided in your comment.
10.	Mike Hess Millstone 3 (4/14/05)	2.0	<p>2) Add a definition for Other Known Leakage to Other Unidentified Leakage and change Section 10.4 to match (the definition below is from Section 10.4 with changes in BOLD): LEAKAGE (Other Identified) is the sum of leakage from the RCPB that is both known and documented, and <u>not</u> accounted for in RCDT LEAKAGE, PRT LEAKAGE, or Steam Generator LEAKAGE. Other Known LEAKAGE may include: interconnected system leakage (documented valve</p>	<p>Added definition: Other Known LEAKAGE is the sum of leakage that is both known and documented, and <u>not</u> accounted for in RCDT LEAKAGE, PRT LEAKAGE, or Steam Generator LEAKAGE. Other Known LEAKAGE may include:</p> <ul style="list-style-type: none"> • Documented Reactor Coolant Pressure Isolation Valve (PIV) Leakage (see def.) • Charging pump packing leakage (known and documented) • Documented fitting or gasket leaks from the RCPB

Item	Name/Utility	Section	Comment	Westinghouse Response
			leakage from RCPB to connecting systems). fitting or gasket leaks from the RCPB that are collected and measured.	<i>(see def.) that are collected and measured</i> Revised calc. method section to reflect same.
11.	Mike Hess Millstone 3 (4/14/05)	2.0	3) Add a definition for Non-RCPB Leakage: LEAKAGE (Non RCPB) is the sum of leakage from the RCS Volume where the leak occurs outside containment (not from the RCPB) and is both quantified and documented. Other Known LEAKAGE may include such leaks as charging pump packing leakage.	I believe this leakage is included in "Other Known Leakage" definition. See above.
12.	Mike Hess Millstone 3 (4/14/05)	2.0	4) Leakage (Pressure Boundary) should be defined as: LEAKAGE (except SG LEAKAGE) through a nonisolable fault in an RCPB component body, pipe wall, or vessel wall.	Agree — Added definition per comment.
13.	Mike Hess Millstone 3 (4/14/05)	2.0	5) Leakage (Unidentified) should be: All LEAKAGE inside containment (except RCP seal water injection or leakoff) that is not identified LEAKAGE.	Agree — Revised "LEAKAGE (UNIDENTIFIED)" definition per comment.
14.	Mike Hess Millstone 3 (4/14/05)	2.0	6) Leakage (Identified) should be: 1. LEAKAGE inside containment (except Reactor Coolant Pump (RCP) seal water injection or leakoff) into closed systems , such as pump seals or valve packing leaks that are captured and conducted to collection systems; sump or collecting tank, 2. LEAKAGE into the containment atmosphere from sources that are both specifically located and known either not to interfere with the operation of Technical Specification 3.4.6.1 Leakage Detection Systems or not to be pressure boundary LEAKAGE, or 3 RCPB LEAKAGE through a steam generator (SG) to the Secondary.	Agree — Revised "LEAKAGE (IDENTIFIED)" definition per comment.

Item	Name/Utility	Section	Comment	Westinghouse Response
15.	Mike Hess Millstone 3 (4/14/05)	4.1	<p>8) Change Section 4.1 General Equation and LEAKAGE Relationship: UNIDENTIFIED LEAKAGE is the difference between Gross LEAKAGE and the total of IDENTIFIED LEAKAGE and Non-RCPB LEAKAGE, thus:</p> $\text{UNIDENTIFIED LEAKAGE} = \text{Gross LEAKAGE} - (\text{IDENTIFIED LEAKAGE} + \text{Non-RCPB LEAKAGE})$ <p>For this PA Non-RCPB LEAKAGE should always be calculated by the specific plants. For the sake of the PA, always consider Other Leakage to be zero.</p> <p>Examples of how "Other Leakage" would be used: A charging pump relief valve is leaking 0.1 gpm into a collection tank outside of containment. Because this is not from the RCPB, it is neither identified nor unidentified leakage.</p>	<p>Added Definition for Non-RCPB Leakage: Non-RCPB LEAKAGE is the sum of leakage that impacts the reactor coolant system gross leakage calculation but occurs outside the RCPB and therefore should not be included in IDENTIFIED LEAKAGE or UNIDENTIFIED LEAKAGE.</p> <p>In order to account for Non-RCPB LEAKAGE it must be known to exist at the time of the leak rate calculation and documented. An example of Non-RCPB LEAKAGE may include:</p> <ul style="list-style-type: none"> Charging pump packing leakage (known and documented) <p>Revised to reflect leakage relationship per comment.</p> <p>Group review and approval needed.</p>
16.	Jim Banke Ginna (4/26/05)	3.2	Should be specific and define Pressurizer temperature as the liquid temperature (we have both pressurizer liquid and steam temperature).	<p>Will revise per comment.</p> <p>I will add a note to use the most representative temperature for each state phase in the PZR (vapor and/or liquid).</p>
17.	Jim Banke Ginna 4/26/05)	3.4	The PRT pressure sensor at Ginna Station uses containment atmosphere as the reference pressure. Therefore when containment pressure changes the indicated PRT pressure changes.	Must use absolute pressure, psia, regardless how it is derived at any specific plant.
18.	Jim Banke Ginna 4/26/05)	4.2	<p>If the operators perform a manual calculation is the intent to have operator re-calculate</p> <p>The leakage to a normalized value? Or is this for only computer calcs?</p>	At the moment, the "Standard Methodology" is same for manual or computer. This issue needs group discussion during joint telcon.
19.	Jim Banke Ginna 4/26/05)	9.1.1	We would use liquid temperature for liquid specific volume, and steam space temperature for steam or vapor specific volume.	Noted. See comment response #16.

Item	Name/Utility	Section	Comment	Westinghouse Response
20.	Jim Banke Ginna 4/26/05)	9.1.2	May want to include CNMT pressure compensation for indicated PRT pressure.	Must use absolute pressure, psia, regardless how it is derived at any specific plant. By necessity, the "Standard Method" must be generic with wide applicability. If we address all plant specific exceptions and unique instrumentation arrangements the method will be cluttered with exceptions. Need group discussion on this issue via joint telcon.
21.	Jim Banke Ginna 4/26/05)	10.2.1	Same comment	see 20 above
22.	Jim Banke Ginna 4/26/05)	General	<p>We need the ability to prevent operator manual actions and system controls from influencing the computer leak calculations.</p> <p>For example:</p> <p>VCT divert on high level - happens near EOL when there are large dilutions. This is seen as a leak from the system</p> <p>Makeup to RCS. - Any makeup as seen as a large negative leak rate.</p> <p>RCDT - not all water sources are from the RCS - must be able to manually override or ignore when leakage confirmed from non-RCS source.</p> <p>PRT - same as RCDT, not all leakage from RCS, in Westinghouse design Safety Injection return line relief (RWST water) also relieves to the PRT.</p>	To be addressed by individual plants in their validity checks.
23.	Jim Banke Ginna 4/26/05)	General	<p>A longer linear regression may improve accuracy and remove noise, but it can also create a loss of Sensitivity and delay accurate indications of a leak.</p> <p>If any linear regression is used we can't have it last too long otherwise any errors or problems created by manual actions will influence the calculated leak rate the time</p>	<p>I agree.</p> <p>Need group discussion and input via joint telcon.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
			period of the linear regression at Ginna this is for almost 2 hours.	
24.	Bill Blessie Ft. Calhoun (4/26/05)	3.1	Include 'Volume': ft ³ (Plant specific data), as one of the parameters used to define RCCV.	Agree – revised per comment. thank you
25.	Bill Blessie Ft. Calhoun (4/26/05)	10.5	I have just a couple of minor changes, nothing really big. The calculation looks almost exactly like what Fort Calhoun uses now, except for primary-to-secondary leakage as an identified source. Which brings me to a point I'd like to make regarding identified leakage - One of the things about the use of the RCDT and PQT as identified leakage is that other systems besides the RCS also go to these tanks (i.e. SI and CCW for FCS). This makes it almost impossible to truly call in leakage to these tanks identified unless you do other analysis of the contents. This might be a topic to discuss in a conference call later on.	Agree – this issue will be discussed and resolved via joint telcon.
26.	Mark Handrich NorthAnna (5/3/05)	2.0	<p>Limit of Detectability:</p> <p>One of the goals of the RCS Leak Rate Standardization PA is to augment other industry efforts, such as SG Integrity. The NRC has published a draft Safety Evaluation for implementing Technical Specifications Task Force-449 (the CLIIP for SG Tube Integrity) in the Federal Register. This CLIIP offers revised definitions of RCS leakage, as well as a lower primary-to-secondary TS leakage surveillance requirement. One very interesting nugget of information contained in the draft SE is the following:</p> <p>"The licensee would revise the accompanying BASES justifying this change, namely, LEAKAGE of 150 gpd cannot be measured accurately by an RCS water inventory balance." (See attached pdf file, page 10309, third column, and page 10310, second column).</p>	This information will be considered as input to the bases for selecting an absolute value for the action level threshold of 0.1gpm.

Item	Name/Utility	Section	Comment	Westinghouse Response
			150 gpd equates to a 0.104 gpm RCS leak rate. Perhaps this value, accepted by the NRC, can be used as a surrogate for the Limit of Detectability parameter that we are currently struggling with. It might eliminate a lot of statistical manipulations.	
27.	Mark Handrich NorthAnna (5/3/05)	12..2.1	Leak Before Break: Item 12.2.1 only reflects Reg. Guide 1.45 requirements for leak detection of 1 gpm in 1 hour. Please expand this section to also include the guidance provided in NRC Generic Letter 84-04, which allows a more relaxed criteria of 1 gpm in 4 hours, provided a plant meets all the other requirements for implementation of Leak-before-Break. Surry has an NRC SER for approval of LBB, and Surry's basis for leak rate detection is 1 gpm in 4 hours.	Incorporated. Included in the regulatory bases review, Section 7.5.1 of WCAP-16465-NP, PA-OSC-0218, Action Levels and response guidance.

Item	Name/Utility	Section	Comment	Westinghouse Response
28.	Mike Hess Millstone 3 (5/11/05)	Defs	<p>In DEFINITIONS under LEAKAGE Type: "Reactor Coolant Pressure Boundary" should be "PRESSURE BOUNDARY".</p> <p>This agrees with Technical Specification which identifies UNIDENTIFIED LEAKAGE, IDENTIFIED LEAKAGE, and PRESSURE BOUNDARY LEAKAGE. This also eliminates the confusion between leakage from the Reactor Coolant Pressure Boundary (RCPB), which can include mechanical joint leakage, and T.S. PRESSURE BOUNDARY LEAKAGE, which does not include mechanical joint leakage.</p> <p>Section 4.1. General Equation and LEAKAGE Relationships should be:</p> <p>4.1.1 Gross LEAKAGE is the is the change in mass of the Reactor Coolant System Control Volume during the test.</p> <p>4.1.2 Gross LEAKAGE = IDENTIFIED LEAKAGE + UNIDENTIFIED LEAKAGE + Non-RCPB LEAKAGE (if quantified).</p> <p>4.1.3 IDENTIFIED LEAKAGE = RCDT LEAKAGE + PRT LEAKAGE + SG LEAKAGE (if quantified) + Other Known Leakage (if quantified).</p> <p>4.1.4. UNIDENTIFIED LEAKAGE = Gross Leakage - (UNIDENTIFIED LEAKAGE + Non-RCPB LEAKAGE (if quantified)).</p> <p>These changes use only defined terms. Also, I believe that IDENTIFIED LEAKAGE includes Other Known Leakage but not Non-RCPB LEAKAGE.</p> <p>Section 5. Precautions and Limitations under Chemical Sampling change "leak rate control volumes" to "RCS Control Volume".</p> <p>This change use defined term.</p> <p>Section 7.2.1 and 7.2.2 Tables have column headings of "Input Data Set</p>	Agree -- Revised per comment.
WCAP-16423-NP			<p>Reactor Coolant Control Volume Initial Conditions". This should be "Input Data Set Reactor Coolant Water Volume Initial Conditions".</p>	September 2006 Revision 0

Item	Name/Utility	Section	Comment	Westinghouse Response
29.	Mike Hess Millstone 3 (5/11/05)	4.1.1 4.1.2 4.1.3 4.1.4	<p>Section 4.1. General Equation and LEAKAGE Relationships should be:</p> <p>4.1.1 Gross LEAKAGE is the is the change in mass of the Reactor Coolant System Control Volume during the test.</p> <p>4.1.2 Gross LEAKAGE = IDENTIFIED LEAKAGE + UNIDENTIFIED LEAKAGE + Non-RCPB LEAKAGE (if quantified).</p> <p>4.1.3 IDENTIFIED LEAKAGE = RCDT LEAKAGE + PRT LEAKAGE + SG LEAKAGE (if quantified) + Other Known Leakage (if quantified).</p> <p>4.1.4. UNIDENTIFIED LEAKAGE = Gross Leakage - (UNIDENTIFIED LEAKAGE + Non-RCPB LEAKAGE (if quantified)).</p> <p>These changes use only defined terms. Also, I believe that IDENTIFIED LEAKAGE includes Other Known Leakage but not Non-RCPB LEAKAGE.</p>	Agree -- Revised per comment.
30.	Mike Hess Millstone 3 (5/11/05)	5.0	<p>Section 5. Precautions and Limitations under Chemical Sampling change "leak rate control volumes" to "RCS Control Volume".</p> <p>This change use defined term.</p>	Agree -- Revised per comment.
31.	Mike Hess Millstone 3 (5/11/05)	7.2.1 7.2.2	<p>Section 7.2.1 and 7.2.2 Tables have column headings of "Input Data Set Reactor Coolant Control Volume Initial Conditions".</p> <p>This should be "Input Data Set Reactor Coolant Water Volume Initial Conditions" .</p>	Agree -- Revised per comment.
32.	Jim Heil STP 05/24/05	4.2	<p>What is the basis for the 100°F? We should add the basis to this section.</p>	<p>100 °F is an arbitrary number, agreed to by participants in previous call. The actual standard number is not important. What is important is that all plants use a standard reference number, so that when comparing leakage from plant to plant, a gallon is the same mass every where.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
33.	Jim Heil STP 05/24/05	7.0 8.0	Changes in density are not significant enough to warrant such rigorous calculations in the event the plant computer system is not functional. An alternate calculation method simplified by assuming constant density should be provided for hand calculations.	Westinghouse believes that the standard methodology is pretty straight forward and cookbook. It should be easy for a utility to adapt/modify to a hand calc method if desired. Westinghouse re-emphasized that density changes are important and should not be ignored. The group was asked if they wanted to put the STP hand calc method into the standard guidelines. The proposal was not agreed to. No change.
34.	Jim Heil Mark Coughlin STP 05/24/05	5.0	Reactor Coolant System #2: $\pm 1\%$ may be too tight. Recommend $\leq 0.5\%$ since power changes are compensated for in the calculation of hot/cold leg temperatures.	No change. Use of nominal values with brackets around them in the Standard Guidelines is sufficient. Utilities have the prerogative to select their own Validity Checks.
35.	Jim Heil Mark Coughlin STP 05/24/05	5.0	Reactor Coolant System #2: What is being used to determine Reactor Power? How is it measured? [i.e., power range nuclear instruments or thermal power by calorimetric.	Within the context of the RCS Leak Rate calculation, the purpose of keeping reactor power constant is to keep delta-power constant, i.e. keep the temperature profile in the RCS constant. The guideline will be changed to include a little discussion in the guidelines to clearly state the intent and why it is important. Do not specify a recommended power indication (NI, Delta-t or calimetric). Plant specific.
36.	Jim Heil Mark Coughlin STP 05/24/05	5.0	Reactor Coolant System #4: This is too Plant Specific. Consider writing #4 and #5 as follows: Maintain Reactor coolant pump controlled bleed/leak-off alignment constant (Do not change).	Reactor Coolant System, item 5. Change to read: "Maintain Reactor coolant pump vapor seal leak-off (bleed-off) to the same destination or constant during the leak rate calculation."
37.	Jim Heil Mark Coughlin STP 05/24/05	5.0	Reactor Coolant System #4: Given comment above consider deleting #5.	Combine Section 5 (Precautions and Limitations), Reactor Coolant System, items 4 and 5 into one.

Item	Name/Utility	Section	Comment	Westinghouse Response
38.	Jim Heil Mark Coughlin STP 05/24/05	5.0	Add to this section: Maintain pressurizer pressure constant targeting ± 10 psig.	No change. Pressurizer Pressure was not included in the list of possible Validity Checks because density is not very pressure sensitive. Pressure is not expected to vary much during the test.
39.	Jim Heil Mark Coughlin STP 05/24/05	7.0	Section 7.0 is not operator friendly, when hand calculation methods are employed.	This document is a guideline, not a procedure. Each plant should adapt the information to their procedures as appropriate for them. No change.
40.	Mark Coughlin STP 05/24/05	7.0	Per Section 5.0 under RCS Makeup #2: Additions for RCS Makeup addition should be added to Section 7.0, Gross Leakage calculation equation.	No change. Already addressed.
41.	Jim Heil STP 05/24/05	8.0	<u>IDENTIFIED LEAKAGE</u> should include leakage from relief valves, i.e. LEAKAGE, from pump seals, <u>relief valves</u> or valve packing.	No change. Already addressed.
42.	Mark Coughlin Kim Reynolds STP 05/24/05	8.3	Section 8.3 should be a plant specific input from their respective Primary to Secondary Leakrate Program based on the NRC approved guidance NEI-97-06.	Section 8.3 states that this determination is plant specific.

Item	Name/Utility	Section	Comment	Westinghouse Response
43.	Bill Sotos STP 05/24/05	General	A precise calculation of instrument uncertainties applied when measuring RCS leak rates should be unnecessary. For example, RG 1.45 requires detecting 1 GPM in 1 hour. The 1 GPM limit is a nominal value (no precise limit is being protected) and therefore does not require precise measurement. In other words, it does not really matter (in a safety sense) if the <u>actual</u> leakrate is 1.05 GPM while the <u>indicated</u> value is 0.95 GPM. With no specific safety limit to protect, use of well maintained normal plant instrumentation and reliance in the indicated value should provide sufficient accuracy for this application. Applying uncertainties adds no value.	<p>We agree that the precise calculation of instrument uncertainties is not required (and is no longer scheduled to be performed). Representative values would be useful in carrying out the simulation described in Section 11.1 (Linear regression of input signals). Since a detailed analysis will not be performed, a "tuned, lumped parameter" model which assumes that only the instrument uncertainties for the Reactor Coolant Water Volume are significant will be developed and used in Sec.11.1.</p> <p>Is it true that the potential error in the "snapshot" measured RCS leakage calculation has never been brought into question?</p> <p>In any event, I believe that the error is small based on the (implicit) correlation between small measured values of the "snapshot" results and the independent results from plant walkdowns and the use of other instrumentation systems during heatup, etc. near BOC.</p> <p>Use of the BGE simulator was proposed as one way to investigate the error in the snapshot method. (This activity is no longer scheduled.) A second method was to actually introduce a known leak using the "sample sink". This activity was considered but ultimately not required. Analyses of actual plant data during the standard plant activity provided an opportunity to perform a similar analyses.</p> <p>Finally, as discussed in an earlier Telecon, persistent biases in the instrumentation are expected to have a minimal effect on the accuracy of the snapshot method.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
44.	Bill Sotos STP 05/24/05	General	<p>What is truly of interest is the minimum detectability limit of the equipment used to measure the leak rate and the ability to reliably trend any observed leakage and take the appropriate actions. While the minimum detectability limit is related to instrument accuracy (uncertainties), it is not the same.</p> <p>While precision is more important for this parameter, it does not have to be excruciatingly accurate for the same reasons stated in the previous comment. Detectability limits can be determined with good results by performing a relatively simple sensitivity study. Recommend that this simple method be used (or something similar), add some additional margin and come up with some generic numbers that all could use (the value would likely be in the 0.1-0.2 GPM range). Since this value will vary depending on available instrumentation and operational conditions, it may be preferable to simply provide the methodology so that the minimum detectability limit could be established in a consistent manner for each individual application.</p>	<p>We believe that the primary “driver” for the minimum level of detectability is the scatter (σ) of the leak rate output about the baseline mean. In principle, if you are willing to accept the current scatter (and it doesn’t change much), you don’t need to know anything at all about what instruments are used or what their errors are. That is, the output is the output.</p> <p>If the scatter is suppressed (by any of a variety of schemes), the minimum level of detectability improves. The scatter based only on the simple “snapshot” method is a function of both process fluctuation and appropriate instrument uncertainty (i.e., fluctuations excluding biases).</p> <p>Finally, note that smoothing data to reduce the scatter may also reduce the time response. An attempt to factor this potential tradeoff into the second definition of the limit of detectability was made by including time [T] in the definition.</p>
45.	Jim Heil STP 05/24/05	General	Add Proposed Calculation Of RCS Leakage When The Plant Computer System Is Not Functional (See attached file).	Discussed previously. No change.
46.	Jim Banke /Steve McCord Ginna 05/23/05	2.0	<p>Reactor Coolant Pressure Boundary - RCPB - Sub Section ii:</p> <p>With regard to the two normally closed valves, can these be check valves? Or do they have to be valves that can be closed from the main control board? I would think that if the check valves are in your IST program, such that they are leak rated etc... you should be able to credit them.</p>	Yes. Interpretation is correct.

Item	Name/Utility	Section	Comment	Westinghouse Response
47.	Jim Banke /Steve McCord Ginna 05/23/05	8.0	The examples given are outside containment, I believe that known leakage to the Regenerative Heat Removal and Safety Injection Systems would also qualify, if they do we should also give them as examples since these are probably the hardest situations to determine.	Yes. Agreed
48.	Jim Banke Ginna 06/02/05	10.1	<p>Question and ideas to consider relative to calculating the Standard Deviation: Is this a "rolling period calculation" (i.e. last 30 or 60 days) Or is this a from the beginning of cycle calculation? This would then reset at the refueling outage (RFP). Then what will be the rules for startup, last 30 days prior to the RFO?</p> <p>In addition the data during startup and going up in power is always transient data and not accurate. Shouldn't the data start approx 72 hours after full power is reached? It would make the data more meaningful.</p> <p>Just some ideas</p>	<p>Appendix D implies this is a value which is based on one operating quarter (such as JUL-SEP) and refreshed at the end of each quarter for use in the next quarter. In this picture, the value would have a (small) step jump up or down about 4 times per year. We expect that the scatter should be reasonably stable since it is a function of your algorithm, instrumentation, and limits of validity. During the first quarter after startup you could probably use a slightly biased past value.</p> <p>Defining a baseline or historical mean. Based on the NRC guidance in Appendix D, we would suggest that you take an operating quarter for the year, average them and use it as your baseline. For example, if calendar quarters are used, data from J, F and M would be used to define the number (the baseline) used in A, M and J. On July first you would switch to the number defined by A, M and J. The danger of using a rolling average (not recommended) is that you may have a 'creeping mean'. The intent is to define a number based on a large number of measurements (90 or 100). Then you have a good bases for doing a '2 sample t' test to see if there has been any statistical shift in the data between the quarters.</p> <p>We do not recommend using a rolling average to define the historical baseline (historical) mean because of the negatives associated with a 'creeping mean'. We are setting limits based on a departure from mean, so a creeping mean would make it more difficult to reach our limit.</p> <p>Coming out of the outage, we would recommend using the last good quarter data prior to the outage as the baseline until you operate long enough to collect sufficient data to calculate a new baseline.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
49.	Hank Stoup 5/23 conference call	2.0	Define the 'historical baseline' {Standard Deviation}: Similar to previous question.	<p>One suggestion is to use the plant's current inservice inspection program to establish "historical baseline."</p> <p>Also, we need to adopt rules for re-base lining if necessary during the course of a refueling cycle due to plant configuration changes.</p> <p>Have Utilities observed large shifts in sigma between EOC(N) -> BOC(N+1) ?</p> <p>10/04 Call discussion summary: Guidelines should address how to calculate the baseline. When to re-baseline is subjective. Plant will be polled and the best practices included in the guidelines.</p>
50.	Bruce Bauer Palisades 05/26/05	2.0	Make the definition on mean simple. Throw away the first sentence.	Done. Previously changed.

Item	Name/Utility	Section	Comment	Westinghouse Response
51.	Bruce Bauer Palisades 05/26/05	2.0	How many sigma is 95%. It is easier to talk in terms of sigma. How long a time frame are you assuming for determining the mean and sigma. In reality you should be looking at the number of leak rate results that should be included.	<p>We used the "95/95" terminology because it is used in everything we do in the analysis of protection & monitoring systems. The quantity [$\mu + 1.645\sigma$] bounds 95% of the normal distribution. That is, 95% of the area is below that point and 5% is above. There is only 1 chance in 20 that a single sample picked at random from the population will fall above this value. The "1 in 20" chance is almost always used as the significance level in most statistical investigations and that is why we initially selected it. WE SHOULD DISCUSS THIS IN THE NEXT TELECON. (Note also that the idea of "1 in 20" applies to any distribution whereas the relationship between μ, σ, and the 95th percentile of the distribution varies. Probably not important here since we are assuming all the data is normally distributed.)</p> <p>The Appendix D writeup implies that the values are based on approximately 90 days of past measurements (1 per day for the past quarter.</p> <p>Discussed on 7/19/05 conference call. Bob Endter pointed out a potential problem with the NRC Appendix D Action Levels that are based solely on a deviation from mean (one sigma, two sigma and three sigma). If your sigma is very small you may easily hit these action levels. Sigma is probably not constant. It will vary with time of cycle and things such as how diligent you are maintaining the validity checks. Therefore, action levels should be based on some real numbers as well as departure from mean or standard deviation. The idea would be to observe a leakrate of [X] gpm (to be defined) before taking any action, regardless of the number of standard deviations from the mean.</p>
52.	Bruce Bauer Palisades 05/26/05	3.5	We call ours the Primary System Drain tank not Reactor drain tank.	No need for the standard guidelines to mention all plant specific variations in design terminology.

Item	Name/Utility	Section	Comment	Westinghouse Response
53.	Bruce Bauer Palisades 05/26/05	4.0	You need to address the know additions and removals from the RCS that occur during the specified time interval (i.e. dilutions, samples and diversions). Depending on the length of the calculation it may be necessary to track these changes. It is especially important to address this issue if the calculation is performed on a continuous basis by a computer. We account for both in our continuously running computer based calculations. We do not have a way of tracking chemical samples thought so it looks like a leak has occurred.	Discuss during 7/19/05 conference call. The basic methodology is a 'snap shot' approach. It is suggested that the calculation be performed at least once a day at a 2+1 hour time interval. Beyond this there are a multitude of options available to the plants with regard to test frequency (plant specific choices).
54.	Bruce Bauer Palisades 05/26/05	4.1 section	Again you need to account for PCS additions and removals of inventory during the time interval of the calculation.	Done. See section 7.4 controlled mass changes.
55.	Bruce Bauer Palisades 05/26/05	5.	Change the wording to minimize changes in pressurizer spray. We operate our system with all heaters on all of the time. This results in our spray valves being open all of the time providing a relatively constant spray flow. This again will result in a equilibrium state.	Revised per comment, thus: "Minimize changes in PZR spray during RCS leak rate calculation. Pressurize spray may affect PZR thermal equilibrium and therefore affect the calculated PZR mass."
56.	Bruce Bauer Palisades 05/26/05	5.	Reactor Coolant System section Item 5 has typo 'indentifid' should be 'identified'.	Done. Previously changed.
57.	Bruce Bauer Palisades 05/26/05	5.	This section appears to only address conditions for doing a snap shot leak rate. It does not address the conditions for performing a continuous leak rate. This maybe should be covered under a different section or include some wording in the general paragraph. Note that the conditions specified will not be maintained in such a stable condition. Again the continuous leak rate calculations are used mainly for trending purposes except for the periodic times when it is used to measure leak rate for technical specification surveillance intervals.	Discussed during 7/19/05 conference call. From a statistical point of view, every thing is based on one good measurement, once a day with a 2+ 1 hour test interval. In the report, continuous leak rate calculations will be discuss only in general terms based on a review of plant documentation at utilities where it is being performed.
58.	Bruce Bauer Palisades 05/26/05	5.	RCS Makeup section Item 3 – charging pump seal leakage is not part of identified leakage as defined in the definition section. This leakage is removed before identified and unidentified leakage is calculated. Any other leakage in the CVCS system needs to also be identified and accounted for.	Revised per comment, thus: "If charging pump seals are known to leak whether the pump is running or not, make the appropriate adjustment to Non-RCPB LEAKAGE."

Item	Name/Utility	Section	Comment	Westinghouse Response
59.	Bruce Bauer Palisades 05/26/05	7.	Are the volumes used, the volumes of the equipment when at full system temperature and pressure or the values of cold? Do they account for thermal and static pressure expansion of the vessels and piping? Do the volumes discount all of the internal structures?	Use plant specific data (curves) for system volume and other factors that affect leak rate via mass balance method.
60.	Bruce Bauer Palisades 05/26/05	7.	Do plants actually calculate out the mass each time or have the generated a factor that takes into account the change in mass and directly convert it to gallons. As an example, we use a factor of 66.16 gallons per percent change in the pressurizer. We use a correction factor that accounts for Tave changes, pressurizer level changes and VCT level changes. These numbers are based on mass calculations I believe. I have never been able to find the basis for the numbers in our records dating back to 1969.	Some/most plants do two snap shot total mass balance. Relative to RCS volume at point one vs. point two, we know it is probable not exactly the same but we believe the delta is not significant. based on the fact that we recommend using fairly tight validity checks on temperature and pressure. Therefore, using the same volume value at point 1 and point 2 can be justified.
61.	Bruce Bauer Palisades 05/26/05	8.	Typo – ‘General Method to Calculate Total IDENTIFIED LEAKAGE’ should be ‘IDENTIFIED’.	Done. Previously changed.
62.	Bruce Bauer Palisades 05/26/05	8.3	Why don't we do the calculation for the changes in the RCS first convert it to gallons and then do the final balance. Change the Δ Mass of the pressurizer, RCS and VCT to gallons then add in the changes do to dilutions, borations, diversions. Then divide by the time interval. This will yield the total gross leakage in gpm. Now remove the Non-RCPB leakage to get total RCS leakage. Since the conditions do not change much as far as temperature and pressure for the RDCT and PRT direct conversion to gallons would be easy. You make an assumption that the change in temperature will result in minor changes in leakage. Do plants have temperature indication for their RDCT and PRT?	See Comments 60.
63.	Bruce Bauer Palisades 05/26/05	10.1	Rule 2 – send line ‘in valid’ should be ‘invalid’. Add to the rule that the leak rate could be used for trending with the understanding that it is not as accurate and can not be used for meeting technical specification surveillance requirements.	Re:“invalid”.. revised per comment Joe Congdon revised wording for validity check Rules. See latest ver of report text.
64.	Bruce Bauer Palisades 05/26/05	10.1	Rule 3.a – this is contrary to the NRC guidance that I have seen. They require the use of the highest value if multiple leak rates are performed on the same day. I like your rule better.	NRC guidance is to follow approved procedures. If you proceduralize validity checks, there should not be a problem.

Item	Name/Utility	Section	Comment	Westinghouse Response
65.	Hank Stroup Sharon Harris 6/14/05		Section 10.1 should clarified that all leakrate results, regardless of whether they are statically "valid", "invalid" or and "outlier", satisfy the periodicity for Tech Spec surveillance. Re-performance of the leakrate as described in the section are to obtain "valid" results and or to determine if a truly measurable change in the leak rate has occurred. Compliance with Tech Spec Actions statements is required regardless on the statistical validity of the results. Actions to comply with plant administrative limits may also be applicable.	Incorporated
66.	Hank Stroup Sharon Harris 6/14/05		How can plant deal with small amounts of leakage that can be measured only over a long time frame and that may differ dependent on plant configuration. For example, at HNP we have approximately a 0.07 gpm leakby past what we call the "B" CSIP alternate miniflow valve. The alternate miniflow valves provide a recirculation path back to the RWST for our charging/SI pumps following a safety injection signal. They are closed during normal operations, and one of our two charging/SI pumps is always in service as a "charging" pump. We know that when the "B" train CSIP is in service, RCS total leakage is ~ 0.07 gpm higher than when "A" train is in service. RWST level trends confirm the leakage past the valve, but the 1 week of level data is required to quantify the inleakage. It would be hard with the present definitions to classify this leakage as "known" RCPB leakage. Also, for this case should the plant carry two statistical averages, one for each train?	10/04 conference call discussion. Base action levels associated with a deviation from mean on the unidentified leakage, not total leakage value. Plant configuration changes such as charging pumps and recirculation paths back to the RWT are outside the RCPB should not affect unidentified leakage results if properly accounted for in the leak rate calculation.

Item	Name/Utility	Section	Comment	Westinghouse Response
67.	Jim Neil STP 7/18/05	10.0	<p>Clarification on Section 10 validity check statement, "Limits in [square brackets] are suggested values for the range of operation during a leak rate test."</p> <p>I believe that intent of the Group is to validate that the difference between start and stop values doesn't deviate by the value of the validity check, not that 'the range of operation' doesn't deviate, which would have the operating staff verifying data from the whole period [not just start-stop]. I recommend the wording be revised to: "Limits in [square brackets] are the suggested maximum difference between each parameter's start and stop values."</p>	<p>Westinghouse disagrees. The intent is to start the leakrate calculation with as stable a plant as possible and to maintain it as stable as possible throughout the leakrate time interval. Accepting data taken when the system may be in a dynamic condition defeats the purpose of the validity checks and is not recommended. A couple of other reasons to support our position; first we may recommend that data be collected at a few intermediate points in the leak rate time interval to be used if needed in the event that something goes wrong with the end point data. These data could be used to possibly save the calculation so it don't have to be repeated. So these potential data points need to satisfy the validity checks. Secondly, if you desire to use linear regression to smooth the input data, the data being regressed should satisfy the same validity checks to produce a representative result.</p>
68.	Mike Hess Millstone 3 (08/02/05)	11.2	<p>Concerning BASELINE.</p> <p>Since BASELINE is established using valid numbers, BASELINEs only need to use 30 data points.</p> <p>BASELINE should be adjusted whenever:</p> <ol style="list-style-type: none"> 1) Leakage is reduced by maintenance or operations. 2) A leakage increase is verified to not be T.S. PRESSURE BOUNDARY LEAKAGE. <p>During refuel outages leaks are fixed and the containment is walked down to verify that there is no PRESSURE BOUNDARY LEAKAGE. Therefore, adjust the BASELINE after a refuel.</p> <p>The Actions proscribed for exceeding certain limits should be sufficient to establish a new BASELINE. Those actions could be as simple as verifying that containment sump rate-of-fill and containment atmospheric radiation have not Increased leakage inside containment may require Containment Entry to prove that the leakage is from a mechanical joint. BASELINE adjustments should not require quantifying</p>	<p>Relates to comment #49.</p> <p>The scope of the current leak rate project is confined to leak rate methodology and limit of detection. The current definition for "Baseline" is only a target draft to invite comment. This definition is still being developed by Bob Endter, et al. The definition will have important impact on the follow-on project where threshold for action and recommended actions are determined.</p> <p>The main reason why <u>we</u> selected the 90 day period is that it conforms to (draft) Appendix D. The real question is: Why did the NRC select it ? We expect to recommend that Participants keep a weekly average & monthly average of the daily surveillance results as well as the 90 day record set by App. D. The purpose of the shorter averages is to (visually) detect any small increasing trends or step changes embedded in one of the weekly records. We plan on including some typical results in the WOG writeup. One reason for using a longer period is that it improves the "resolving power" of the comparison. That is, if a small change occurs in the 1st month (Apr) of the 2nd Quarter (Apr -> Jun), comparing the 90 2nd Quarter measurements to the 90 1st Quarter measurements would be expected to detect ("resolve") a smaller change than a comparison of the</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
			leaks. It must be remembered that BASELINE adjustments reset the action limits but do not affect the T.S. limits.	<p>30 March & 30 April measurements alone. There are probably some good arguments related to protecting against a "sliding mean" (i.e., ramping leak) which increases below the resolving power of 30 day measurements and results in a new (slightly increased) mean every 30 days for the App. D-type Action Levels. Finally, it seems easier to use one number for a quarter than replacing it every 30 days.</p> <p>I agree that the source of the Baseline values used near BOC(N) are somewhat in question. I like the idea of using EOC(N-1) values for awhile & substituting 7 day values and then 30 day values until the 1st quarter is completed. I agree that setting the Baseline value sets the Action Levels (to be agreed upon in the next Task). It seems to me that if there is significant variability in how the Baseline is set amongst the Participants then there will be significant variability in the implementation of the Action Levels as well - even if the stated Action Levels are identical amongst the Participants. For example, if one Participant always takes one surveillance measurement a day and uses it to determine the Baseline mean and to implement the Action Levels and a second Participant takes 1 - 5 measurements a day and always records the worst one (per App. D) to determine the mean and Action Levels, the Action Levels look the same but may not behave the same for the two Participants. (Auctioneering 5 equivalent measurements typically produces an output which is inherently conservative with respect to unbiased measurement errors - cfr GM-FE-0244.)</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
69.	Mike Hess Millstone 3 (08/02/05)	10.0	<p>Concerning Validity Checks.</p> <p>Validity checks are recommendations and not requirements. If a utility adjust for temperature changes, there is no need to keep a tight temperature limit. All that is required is that the utility be able to explain where and why they differ from the recommendations. Of course, a utility that has a large standard deviation may want to reconsider their deviation from the WCAP recommendations.</p> <p>Also, validity checks should only be applied to the beginning and endpoint data. Specifying that we want steady state power should be sufficient to avoid upset conditions during the data collection time frame. Expecting the Operators to monitor the conditions, during data collection, places an additional burden on Operators. For those using the computer, the expectation is that the Operators will adjust to meet the end-point conditions for a valid calculation, and then call for the calculation.</p>	<p>1) Validity checks are a recommendation not requirement . They ought to be developed on a plant specific basis. Validity checks should be both reasonable and doable without major change to the plant's operating model.</p> <p>2) The purpose of validity checks is to impose more discipline on steady state plant control and thereby provide a conditional norm for RCS leak rate reporting and statistical record keeping. It's clear that plant stability and "assumed equilibrium conditions" are major contributors to leak rate variability. If validity checks are only imposed on the endpoint conditions, the "assumed equilibrium condition," inherent in the leak rate methodology, is seriously in question. Especially if a large dilution makeup to VCT is done during leak rate count interval.</p> <p>I've reviewed Paul's writeup & agree. An added concern (expressed earlier) is the use of intermediate valid measurements in place of the usual "end-time" values if other circumstances prevent getting a valid "end-time" measurement or if the "start" or "end time" data proves to be unacceptable after the surveillance is performed. (The intent is to address this visually by checking the mass inventory at selected intermediate times during the measurement period - sudden changes would indicate potential "outliers" in the data set.) Also, if the intermediate data is used for least squares or rolling average calculations, the fit/average will be compromised if the conditions of validity are not maintained.</p> <p>Also see response to comment #67</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
70.	Mike Hess Millstone 3 (08/02/05)	11.9	Concerning data collection time frame: 2+1 hours is not sufficient for MP3. At Millstone 3 we find that instrument noise and unmonitored changes (degassifier level oscillations) cause changes in the RCS leak rate calculation. We have settled on four hours as a good data collection time. Why did Westinghouse pick one to three hours?	A review of some of the Client-supplied data indicates a typical 2 hour time frame shortened to 1 hour if necessary. A review of some Seabrook data as a function of collection time indicated that 2 hours is probably OK. In all cases, increasing the surveillance interval should improve the results (with diminishing returns in improvement) PROVIDED THAT THE PLANT CAN BE MAINTAINED IN A STABLE CONDITION THROUGHOUT THE SURVEILLANCE INTERVAL - WE ESTIMATED THAT THE RCS TAVE COULD DRIFT DOWN BY APPROXIMATELY .2 DEGF NEAR EOC DUE TO FUEL DEPLETION IF NO OTHER REACTIVITY CHANGES OCCUR - GUESSED THAT THE OPERATORS HAVE AN INCREASING BURDEN TO MAINTAIN "GOOD" CONDITIONS AS TIME PASSES AND THAT THIS TENDS TO OFFSET ANY IMPROVEMENTS DUE TO THE INCREASED INTERVAL. Can Mike supply some typical data which shows how things improve from 1 hr -> 4hrs ? We will add it to our document if that is OK.
71.	Mike Hess Millstone 3 (08/04/05)	2.0	Follow-up comment on #49. "Have Utilities observed large shifts in sigma between EOC(N) ->BOC(N+1) ?" At Millstone one STDEV is usually around 0.5. The only changes are when there is a trend in the leakrate.	I don't know - we have no database that would answer this question. We would expect the <u>mean</u> to show some improvement due to outage maintenance (which sort of implies using the EOC(N) mean should bound the expected value of the new mean in cycle N+1). We don't have any good data on this either. We estimated the NEU stdev as .055 from Cycle 10 data. The .5 is clearly a typo.
72.	Mike Hess Millstone 3 (08/04/05)	2.0	Follow-up comment on #51. Statistically, 95.5% of a normally distributed population lies within two standard deviations of the mean.	We are using one-sided limits to bound values <u>above</u> the mean. Per the W response to 51, 95% of the area is below [mean + 1.645 sigma] and 5% is above. In our experience, most of the statistical problems we deal with are concerned with "one-sided" limits. Per App. D, the NRC is not too concerned about measurements that are 3 sigma <u>below</u> the mean. (However, such measurements would indicate a measurement process that is out of control but would not indicate a significant RCS leak.)
73.	Mike Hess Millstone 3 (08/04/05)	4.0	Follow-up comment on #53. Doesn't the response to 54 answer 53?	Yes

Item	Name/Utility	Section	Comment	Westinghouse Response
74.	Mike Hess Millstone 3 (08/04/05)	8.3	Follow-up comment on #62. Whether we translate directly to gallons at 100 (70)F or whether we translate to mass and then back to gallons at 100 (70)F should be left to the plant.	Not clear what the comment is. The current report suggests all plants report leak rate in accordance with the Technical Specification as gallons/minute. In addition, the WOG report also suggests that the reported leak rate should be adjusted to gallons at 70°F. That way, a reported 1 gpm leak rate at Millstone II is the same mass leakage as 1 gpm at Millstone III.
75.	Mike Hess Millstone 3 (08/23/05)	11.2	<p>Follow-up on #68 I still feel that: BASELINE should be adjusted whenever: 1) Leakage is reduced by maintenance or operations. 2) A leakage increase is verified to not be T.S. PRESSURE BOUNDARY LEAKAGE.</p> <p>The idea of changing Baseline, just because the quarter changes, would allow a slow leak to develop unaddressed.</p> <p>I am still uncomfortable with the quarterly average. From my statistics class I remember that 20 points is sufficient to eliminate most of the risk. Using 30 points seems like we'd have a much better chance of capturing a period of steady leak rate. Choosing 90 because the NRC took it on a first cut, does not seem like a good reason to pick 90.</p>	<p>BASELINE – The purpose of a baseline leak rate is to establish a benchmark for comparison that can be used to evaluate the current leak rate for a statistically significant change. Where, the level of statistical significance can be adjusted to balance both the need for sensitivity and minimize false positives. Any “baseline” definition that satisfies this criteria is okay by me.</p> <p>MH..... #1 Leakage is reduced by maintenance or operations. pk..... The current definition accounts for this “as long as” the reduction happened in the last quarter. But I see your point. The question is “when” to re-baseline? Consider: The follow on project will determine leak rate change setpoints for action and the actions. This task should also address when to re-baseline due to a lowering leak rate change.</p> <p>MH..... #2 A leakage increase is verified to not be T.S. PRESSURE BOUNDARY LEAKAGE. pk..... If leakage is UNIDENTIFIED, no amount of inspection or analysis can determine that it is not pressure boundary leakage. By definition it is “unidentified.”</p> <p>RKE... Not sure I agree with the "unaddressed" piece. As report will discuss & as mentioned in an earlier email, the "two sample t-test" which compares last quarter & this quarter will detect very small shifts in the mean and also (using the F-Test) detect significant shifts in the standard deviation. So, I think it is fair to say that a little checking (with EXCEL for example) will show changes when they are significant. At the same time, making a (small) upward</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
				<p>quarterly adjustment in the mean as small, "acceptable" leaks develop during the cycle resets Action Level I to a meaningful level - that is, if you never reset the mean (to a higher level) when a small acceptable leak was observed, you would get Action Level I continuously and it would lose its meaning.</p> <p>Think about how this works in your personal life as your (Ford P/U) ages from 50,000 miles to 150,000 miles. At some point you realize that you are using a pint of oil every 1,000 miles rather than no oil at all between changes. Mentally, you "reset" your alarm point to a leak rate of 1 pint/1000 miles rather than 0 pint/1000miles and look for changes with respect to the new mean. I think the NRC setup is designed in a similar way to detect changes with respect to the current (degraded) condition.</p> <p>RKE....Second part: The work underway on Section 11 of the Guidelines will recommend maintaining both weekly & monthly average values including checking for "precursors" to Action Level I which will be 5 "exceedences" (values above the baseline mean) in 1 week or 7 "exceedences" in 1 month. As will be shown, the # of exceedences goes hand-in-hand with the observation period - 7 in a month is about as unusual as 9 in a quarter. So, we think the use of 9 exceedences is about right for a 90 day period.</p> <p>It is true, as mentioned in an earlier email, that the discriminating power of 90 days is significantly better than 30 days for the "2 sample t-test" discussed above. For example, a significant shift in the mean (in units of the standard deviation) is detected in a 30 OR 90 day period if the shift exceeds:</p> <p>Shift > $1.672 \times \text{SQRT}(2/30) = .43$ (30 DAYS) Shift > $1.653 \times \text{SQRT}(2/90) = .25$ (90 DAYS)</p> <p>As you say, choosing 90 is somewhat arbitrary although there is a significant benefit in having everyone use the same</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
				<p>rules. I'm sure that these guidelines will evolve with time if it becomes apparent that a revision is in order.</p> <p>(As an aside, the draft report currently under preparation documents that the "magic number" of points to determine a nonparametric "95/95" limit is 59. That is, the largest observation in a simple random sample of size 59 is a "95/95" limit for the parent population. I think your statement about 20 points is probably related to confidence limits on the population mean (for a normal population) as opposed to confidence limits on the 95th percentile of an arbitrary population as in the "Rule of 59."</p>
76.	Bob Couture Seabrook (09/08/05)	2.0	<p>Definition for Leak Before Break, bottom of page 11 of 94.</p> <p>The last line of this definition refers to references 5 and 6. Reference 6 "applied Linear Algebra" is not correct.</p>	<p>revised to read: "See Ref. 4 and 5"</p>
77.	Bob Couture Seabrook (09/08/05)	3.5	<p>Reactor Coolant Drain Tank (RCDT), page 17 of 94.</p> <p>I'm not sure if many plants have RCDT pressure available either on the plant computer or as a gauge reading on a control panel somewhere in the plant. Recommend that you determine from WOG leak rate review participants the general availability of RCDT pressure. If this parameter is not generally available, then need to modify the document to remove reference to using RCDT pressure and make appropriate changes to the calculational method. The calculational changes could involve items such as assigning a constant RCDT pressure (based on the limited allowed range of pressures for the tank) or assuming the specific volume for a saturated liquid at RCDT pressure thereby not requiring any RCDT pressure value to be assumed/used.</p>	<p>the report method is by definition a "generic, idealized method"</p> <p>Some plants have RCDT pressure indication available in the control room, some do not. Those that do not will have to assume a value to be used in the calculation.</p> <p>No change in the guidelines.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
78.	Bob Couture Seabrook (09/08/05)	5.0	<p>Item 2 for <u>Reactor Coolant System</u>, page 20 of 94.</p> <p>The target value to maintain reactor power constant to within +/- 0.1% of rated thermal power during the RCS leak rate measurement will be a challenge for the operators to maintain/verify. At Seabrook, that would equal an allowed power level "band" of +/- 3.6 MWt. I'm not disputing the fact that it is very desirable to maintain power as constant as possible but we need to provide recommended bands that are reasonable for operators to monitor/maintain during normal steady state operation. Consider a statement such as reactor power needs to be maintained as stable as practical and in all cases power level changes should be less than 0.5%.</p>	<p>The numbers in the guideline generic validity checks are typical. The brackets mean that you are to insert a plant specific number that is reasonable and practical at your plant.</p> <p>No change to the guideline</p>
79.	Bob Couture Seabrook (09/08/05)	7.5	<p>Calculation Method: Gross LEAKAGE, discussion at top of page 23 of 94.</p> <p>For the Gross LEAKAGE calculation, the relationship between mass change in the system and leak rate is as follows:</p> $\text{Leak rate (gpm)} = \text{Negative of the Gross Leakage (lbm)} \times \text{change in time}$ <p>Reviewing the write-up in sections 7, 8, and 9, it would seem that the easiest way to make the required change is in the Gross Leakage General Equation at the top of page 23 which should be modified as shown below:</p> <p><u>General Equation:</u></p> $\text{Gross LEAKAGE (lbm)} = \Delta \text{Mass}_{\text{CONTROLLED}} - \Delta \text{Mass}_{\text{PZR}} - \Delta \text{Mass}_{\text{RCWV}} - \Delta \text{Mass}_{\text{VCT}}$	<p>Refer to comment, 88 and 126 suggestions</p> <p>Added assumption #3 to Section 6. stating that leakage is defined as the net mass loss from the RCS control volume</p> <p>Changed the definition of Gross Leakage prior to the general equation in sections 7.0 and 7.5 to clarify the leakage is the net mass loss for the RCS control volume.</p> <p>Changed definition of terms in Section 9.1 as follows:</p> <p>UNIDENTIFIED Leakage (lbm) = negative of the calculated UNIDENTIFIED Leakage</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
80.	Bob Couture Seabrook (09/08/05)	7.1.1	<p>Calculational Method: Mass of PZR at Time 1, Notes on page 24 of 94 after the table. The Title line "<u>Notes Time 2 Input Data</u>" should read "<u>Notes Time 1 Input Data</u>"</p> <p>Note 2 first line Liq_{PZR2} should read Liq_{PZR1}</p> <p>Note 3, two locations, first and last lines Vap_{PZR2} should read Vap_{PZR1}</p>	<p>Incorporated</p> <p>Incorporated</p> <p>Incorporated</p>
81.	Bob Couture Seabrook (09/08/05)	7.2	<p>Calculational Method: Reactor Coolant Water Volume (RCWV) Δ Mass, page 26 of 94, last two lines</p> <p>M_{RC1} should be M_{RCWV1} M_{RC2} should be M_{RCWV2}</p>	Incorporate change as noted.

Item	Name/Utility	Section	Comment	Westinghouse Response
82.	Bob Couture Seabrook (09/08/05)	7.2.1	<p>Calculational Method: Mass of RCWV at Time 1, last item in table on page 26 of 94</p> <p>This comment also applies to the table in Section 7.2.2. The text in the left hand column for RC Volume indicates that it should be for the RCS at temperature T_{RCWV1}. I do not believe that it is feasible for utilities to accurately calculate true RCS volume as a function of temperature. While RC Volume does change in response to changing temperatures (specifically the SG U-tubes), this calculation should be based on a constant value for the calculated RC volume. This would make the RCWV mass calculation consistent with the Section 7.1 pressurizer mass calculation in the treatment of total volume.</p> <p>This is a judgment call but I believe that since a calculated RCS leak rate is based on incremental changes that occur during steady state operation and the expectation is to accurately detect very low levels of leakage, it is more accurate to use a constant volume to calculate the total contained mass.</p> <p>Also in Appendix C, section C.1.2, the total volume of the reactor coolant is stated to be a constant and the derivation in this section treats this item as a constant.</p>	<p>In the table under section 7.2.1 and 7.2.2,</p> <ul style="list-style-type: none"> delete "at $T_{RCWV1(2)}$," Move Note 1 from right column to left column, Change Note 1 to read; "RC Volume = Calculated volume of the Reactor Coolant Water Volume (ft^3) (plant specific constant)"
83.	Bob Couture Seabrook (09/08/05)	7.2.1	<p>Calculational Method: Mass of RCWV at Time 1, last two lines on page 26 of 94</p> <p>"Calculate Reactor Coolant Mass at Time 1" should read "Calculate Reactor Coolant Water Volume Mass at Time 1"</p> <p>Last line, M_{RC1} should read M_{RCWV1}</p>	incorporate change as noted.

Item	Name/Utility	Section	Comment	Westinghouse Response
84.	Bob Couture Seabrook (09/08/05)	7.2.2	<p>Calculational Method: Mass of RCWV at Time 2, left column table heading on top of page 27 of 94</p> <p>The column heading of Input Data Set Reactor Coolant Water Volume Initial Conditions should read Input Data Set Reactor Coolant Water Volume Final Conditions</p>	incorporate change as noted.
85.	Bob Couture Seabrook (09/08/05)	7.2.2	<p>Calculational Method: Mass of RCWV at Time 2, last item in table on page 27 of 94</p> <p>This comment is the same as comment number 7 above. The text in the left hand column for RC Volume indicates that it should be for the RCS at temperature T_{RCWV2}. I do not believe that it is feasible for utilities to accurately calculate true RCS volume as a function of temperature. While RC Volume does change in response to changing temperatures (specifically the SG U-tubes), this calculation should be based on a constant value for the calculated RC volume. This would make the RCWV mass calculation consistent with the Section 7.1 pressurizer mass calculation in the treatment of total volume.</p> <p>This is a judgment call but I believe that since a calculated RCS leak rate is based on incremental changes that occur during steady state operation and the expectation is to accurately detect very low levels of leakage, it is more accurate to use a constant volume to calculate the total contained mass.</p> <p>Also in Appendix C, section C.1.2, the total volume of the reactor coolant is stated to be a constant and the derivation in this section treats this item as a constant.</p>	<p>In the table under section 7.2.1 and 7.2.2,</p> <ul style="list-style-type: none"> • delete "at $T_{RCWV1(2)}$," • Move Note 1 from right column to left column, • Change Note 1 to read; "RC Volume = Calculated volume of the Reactor Coolant Water Volume (ft^3) (plant specific constant)"

Item	Name/Utility	Section	Comment	Westinghouse Response
86.	Bob Couture Seabrook (09/08/05)	7.2.2	<p>Calculational Method: Mass of RCWV at Time 2, second to last line on page 27 of 94</p> <p>“Calculate Reactor Coolant Mass at Time 2” should read “Calculate Reactor Coolant Water Volume Mass at Time 2”</p>	incorporate change as noted.
87.	Bob Couture Seabrook (09/08/05)	7.3.3	<p>Result: VCT ΔMass, page 29 of 94</p> <p>In the first line change delete the “+ Makeup” at the end of the line and change the second M_{VCT2} to and M_{VCT1}. The modified first line should then read “VCT Δ Mass (lbm) = $M_{VCT2} - M_{VCT1}$”</p> <p>Delete the last line of this section that reads “Makeup = Makeup (lbm)”</p> <p>Makeup is discussed/contained in Section 7.4 of the document.</p>	<p>incorporate change as noted.</p> <p>incorporated.</p>
88.	Bob Couture Seabrook (09/08/05)	7.5	<p>This comment is the same as comment number 4 above. For the Gross LEAKAGE calculation, the relationship between mass change in the system and leak rate is as follows:</p> <p>Leak rate (gpm) = Negative of the Gross Leakage (lbm) X change in time</p> <p>Reviewing the write-up in sections 7, 8, and 9, it would seem that the easiest way to make the required change is in the Gross Leakage General Equation on page 30 which should be modified as shown below:</p> <p><u>General Equation:</u> Gross LEAKAGE (lbm) = $\Delta Mass_{CONTROLLED} * - \Delta Mass_{PZR} - \Delta Mass_{RCWV} - \Delta Mass_{VCT}$</p>	<p>Refer to comment, 79 and 126 suggestions</p> <p>Added assumption #3 to Section 6. stating that leakage is defined as the net mass loss form the RCS control volume</p> <p>Changed the definition of Gross Leakage prior to the general equation in sections 7.0 and 7.5 to clarify the leakage is the net mass loss for the RCS control volume.</p> <p>Changed definition of terms in Section 9.1 as follows:</p> <p>UNIDENTIFIED Leakage (lbm) = negative of the calculated UNIDENTIFIED Leakage</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
89.	Bob Couture Seabrook (09/08/05)	7.5	<p>Result: Gross LEAKAGE, last two lines on page 30 of 94</p> <p>Text at the end of the note on the last two lines should be deleted. The modified text should read “ Keep sign (+/-) of $\Delta M_{\text{SSCONTROLLED}}$ consistent with section 7.4 above.”</p>	incorporated.
90.	Bob Couture Seabrook (09/08/05)	8.0	<p>Calculational Method: IDENTIFIED LEAKAGE, page 31 of 94</p> <p>First bullet, Reference to sections 10.1 and 10.2 should be to sections 8.1 and 8.2.</p> <p>Second bullet, Reference to section 10.3 should be to section 8.3.</p> <p>Third bullet, Reference to section 10.4 should be to section 8.4.</p> <p>Middle of page, typo in underlined header text. “IDENDIFIED” should be “IDENTIFIED”</p>	incorporate changes as noted.
91.	Bob Couture Seabrook (09/08/05)	8.1	Header line, page 31 of 94, Typo. (RCDC) should be (RCDT)	Incorporated
92.	Bob Couture Seabrook (09/08/05)	8.1 and 8.2	<p>Table entries for RCDT pressure, page 32 of 94</p> <p>This comment is the same as comment number 2 above. Tables in both of these sections as well as the calculation require the use of RCDT pressure. This parameter may not be generally available.</p>	No change. See comment # 77
93.	Bob Couture Seabrook (09/08/05)	9.1	<p>Result: UNIDENTIFIED Leak Rate, page 37 of 94</p> <p>In the fist line after the word “Where:”, IDENTIFIED needs to be changed to UNIDENTIFIED in two places.</p>	revised per comment

Item	Name/Utility	Section	Comment	Westinghouse Response
94.	Bob Couture Seabrook (09/08/05)	10.0	Validity Checks , item 3 on page 38 of 94 This comment is the same as comment number 3 above. A power level band of +/- 0.1% of rated thermal power may be too restrictive for the operators.	The numbers in the guideline generic validity checks are typical. The brackets mean that you are to insert a plant specific number that is reasonable and practical at your plant. No change to the guideline
95.	Bob Couture Seabrook (09/08/05)	10.0	Validity Checks , item 5 on page 38 of 94 This item is different from the text in section 5 that discusses makeup. In Section 10, a limit of "x gallons" is proposed for makeup without any discussion of the need to accurately determine the amount added. Should the discussions in sections 5 and 10 concerning markup be consistent?	Added 1/100 th gallon precision qualification to makeup section. Incorporate. Replace section 10.0, Item 5 with test currently in section 5.0, RCS Makeup, Item 2 OR ?. Not sure what the resolution was on the call. (tape stopped)
96.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.1.2	Gross Leakage , sentence prior to equation C.1.2-23 on page C-4 This sentence simply states an important assumption "Recognizing that the change in reactor coolant temperature is the most significant contributor to the mass calculation variance...". Recommend you add some amount of justification for this statement. I believe it would be as simple as discussing how the small changes in specific volume are applied to the volume of the reactor coolant system which is significant when compared to other volumes (i.e. pressurizer or VCT) being analyzed.	Text was modified by Author (WLG). RKE – The assertion is "self-justifying" in that lumping all uncertainties into the Tave variable resulted in a "1σ" fluctuation of .055 DegF in Section C-3.3. This small value results from the enormous derivative of 88 gal/DegF shown in Section C-3.1.2. The .055 value is small with respect to a typical RTD uncertainty of 1.0 DegF. If some other source of uncertainty was (wrongly) selected as "most important", the resulting Appendix C "lumped" uncertainty would likely be a value which significantly exceeded the known uncertainty of that sensor. For example, the pressurizer level uncertainty might turn out to be 4 feet.
97.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.1.2	Gross Leakage , paragraph after equation C.1.2-23 on page C-4 The second sentence has a typo and references a non-existent Section 4.3 (i.e. "Secion 4.3"). Should this read "Section C-3.3"?	Corrected

Item	Name/Utility	Section	Comment	Westinghouse Response
98.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.1.2	Gross Leakage , equation at the top of page C-5 (no equation number) Typo. In the left hand side of the equation, " δT_{RCWVij} " should read " δT_{RCWVj} "	Corrected
99.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.3.1.2	Partial Derivative Calculation , second line, page C-7 Should the reference to "Equation C.1.2-4" be changed to "Equation C.1.2-11"?	Corrected
100.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.3.1.3	Mass Uncertainty Calculation , top line on page C-8 The section number is incorrect. It reads " C-3.1.2, Mass Uncertainty Calculation " but should read " C-3.1.3, Mass Uncertainty Calculation "	Corrected
101.	Bob Couture Seabrook (09/08/05)	Appendix C, Section C.3.1.3	Mass Uncertainty Calculation , second line on page C-8 The reference to the instrument error from "Section C-2.3" should be changed to "Section C-2.2".	Corrected Bob, thanks for reviewing Appendix C so carefully. These errors occurred when WLG's document was converted into an Appendix and a "brute force" method was used to perform corrections.
102.	Scott Eidem Ft. Calhoun (09/21/05)	2.0	Page 12 LEAKAGE Type: IDENTIFIED – What if a specific plant (i.e. Fort Calhoun) does not have a method to measure remotely the types of leakage discussed in item 1 or has historic local measurements showing changes in these parameters?	No change. Plant specific design requires deviation for standard guidelines.
103.	Scott Eidem Ft. Calhoun (09/21/05)	2.0	Page 13 LEAKAGE Type: UNIDENTIFIED – "RCPB" has transposed letters in it.	revised per comment
104.	Scott Eidem Ft. Calhoun (09/21/05)	5.0	Page 20 Section 5, Pressurizer – Note 3 – "Pressurizer" missing an "r"	revised per comment

Item	Name/Utility	Section	Comment	Westinghouse Response
105.	Scott Eidem Ft. Calhoun (09/21/05)	6.1	Page 22, Section 6.1 -“underlying” is misspelled	revised per comment
106.	Scott Eidem Ft. Calhoun (09/21/05)	10.0	<p>Page 38;</p> <p>a) Is there any additional specific guidance that can be provided for setting the tolerance band/limits (i.e. instrument accuracy, etc.)?</p> <p>b) What is the basis for the eight listed tolerances?</p> <p>c) Why has Pressurizer Pressure not been included as a controlled input parameter with applicable tolerances? FCS experience shows that this parameter can affect the RCS leak rate calculation.</p> <p>d) The current Fort Calhoun procedure does not allow makeup to the VCT – can this point (and any others) be specifically tailored to each plant’s preference?</p>	Validity checks provided in the report are generic guidance only (as stated). Each plant should establish their own validity bounds consistent with their ability to maintain stable plant conditions and their operational model.
107.	Scott Eidem Ft. Calhoun (09/21/05)	11.0	<p>Page 40 Second Paragraph – What is the basis for the two hour measurement period?</p> <p>What is the effect on accuracy if tank in-leakage values are averaged over a longer time period?</p>	<p>The 2 hour period is the typical “historical” value used in surveillance measurements. The optimal value is a “balancing act” between the attempt to extend the period as long as possible per Eqn. 11.15 while maintaining tight control of the plant parameters (limits of validity). As discussed on p.48, the σ in Eqn 11.15 is likely to increase due to process effects as the period is extended and offset the increased time interval. Fig. D-29 (& p. 72) defend the use of the 2 hour period.</p> <p>Figs. D-20 – D-23 indicate that the identified leakage is quite linear, at least for the “typical plant data”. As a consequence, using a good linear fit over a longer time period to infer values over a shorter time frame might be OK. Of course, this needs to be evaluated on a case-by-case basis along with some way of determining when (i.e., which plant process changes) might invalidate such usage.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
108.	Scott Eidem Ft. Calhoun (09/21/05)	11.0	Page 73 Section 11.11 – If the plant is considered relatively stable, and tank in-leakage rate trends are analyzed, adverse trends identified, and tank level changes are averaged up to a 24 hour time period, daily average RCS leakage may be compared to tank in-leakage. Does this methodology go against the proposed standardized method mentioned in Section 11.12?	Strictly speaking, yes. It does violate the proposed standardized method. However, as discussed in 107, it is possible to “build an argument” that the violation has a minimal effect on the results.
109.	Scott Eidem Ft. Calhoun (09/21/05)	11.0	Page 73 Section 11.12 – The Fort Calhoun Total RCS Leak Rate is identified once per day, normally on the night shift, per a surveillance procedure. The normal method is to extract a representative leak rate from the plant computer, which computes the running total, unknown, and known leak rates every 30 seconds. If the plant computer is not functioning, the procedure allows manual computation similar to the equations developed earlier in this document. If the daily total RCS leak rate is a snapshot value taken at the same time, does this invalidate the standardization recommendation?	The intent of our recommendation that every plant do exactly one high quality 2 hour leak rate each day was to bring some standardization to the results such that they could be compared plant to plant. We thought that all plant could do this irregardless of the method (snap shot or continuous monitoring) they are currently using. No change required.

Item	Name/Utility	Section	Comment	Westinghouse Response
110.	Mark Handrick Dominion (09/23/05)	11.2.5	<p>For leak rate measurements taken once per day, the condition of 5 consecutive values above the baseline mean will always be met before a run of 7 consecutive exceedences. Therefore, this situation appears redundant to the evaluated condition of 7 consecutive exceedences in a 30 day period, at least from a statistically meaningful viewpoint.</p> <p>Is there really any value added by trending rolling monthly average values, in terms of flagging precursors to Action Level 1?</p>	<p>It's true that if you get 7, you also hit 5 2 days ago and hit 6 yesterday. It is also true that, if you did not get a "hit" yesterday (on day 6), the counter for 7 exceedences will reset.</p> <p>The question is: "What did you do 2 days ago when the count hit 5 and what did you do yesterday when it hit 6 (or failed)? Were the 5 hits a "false alarm"? Will you be at 9 two days from now and be in Action Level I of Appendix D?"</p> <p>As stated on p. 40, the questions regarding what you should do when a (precursor) alarm goes off will be answered in the follow-on Task. However, in general terms, the 5 & 7 precursors should probably be used to check other indicators to see if there is some confirmation of the trend.</p> <p>The flagging of exceedences is based on the daily values as in Figure D-10 and has nothing to do with the rolling averages as shown in Figure D-13. However, we think that Figure D-13 might be helpful in seeing a small change in leak rate that would be more difficult to observe in D-10. So, when the exceedence "alarm" goes off based on D-10, you might look at D-13 to see if (and when) a change might have occurred and use what you see there to investigate changes in other independent indicators.</p>
111.	Mark Handrick Dominion (09/23/05)	11.3.2.2	<p>The last paragraph of this section states that the some of the RCS-LEAK_SIM results "don't fully represent reality." This statement needs to be augmented to explain the limitations of RCS-LEAK_SIM.</p> <p>Are the statistical results supporting Action Levels and Minimum Level of Detectability valid as currently reported?</p>	<p>We will expand the paragraph on p. 59. By design, the simulation used statistically independent, normally distributed fluctuations with a constant mean and standard deviation. The Recommendations in Section 11.12, items 3 – 6 are intended to see if "reality" (i.e., your measurements) is well described by the model. If not, something needs to be done to make the two (simulation & reality) coincide.</p> <p>Yes ! The results are valid for the simulation & are also valid for "reality" provided that the site data validates Section 11.12, items 3 -6. Of course, if the simulator is adjusted to match "reality", the simulation-based statements in Section 11.4 may change.</p>

Item	Name/Utility	Section	Comment	Westinghouse Response
112.	Jim Lambert Farley (09/23/05)	General	I have reviewed the changes and have no additional suggestions at this time. I appreciate the work that is going into this project.	Thanks.
113.	Jack Patterson Beaver Valley (09/23/05)	General	<p>I have reviewed the draft report for Beaver Valley Power Station. I thought the report was excellent. I had some difficulty understanding section 11.</p> <p>To better understand this material, I think a meeting with all the utilities would be very helpful.</p>	<p>Thanks. We hope that no one is under the impression that the material in Section 11 is just the same old statistical stuff for us either. Although the two authors of Section 11 have worked in the area of stochastic simulation for many years, this is the first time we have encountered the somewhat peculiar approach described in NRC (draft) App. D. This approach is driven by the need to detect small real changes in the face of significant fluctuations as shown in Fig. D-10 and it all seems to hang together pretty well provided that items 3 -6 in Section 11.12 are validated.</p> <p>Implementing Section 11.0. Implementation guidance for section 11.0 will be developed as part of the standard plant activity.</p>
114.	Jack Patterson Beaver Valley (09/23/05)	7.2.4	I also think that Section 7.2.4 should be eliminated, this is too much detail for the test.	Segmented RCS (7.2.4). No change. Some plants are using this approach.

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
115.	Gleene Reeves Wolf Creek (09/21/05)	12		Typo	In the definition for: LEAKAGE Type: Gross, "leak <i>rate</i> time interval" should be "leak <i>test</i> time interval". (See Step 7, pg. 23)	done -- revised per comment
116.	Gleene Reeves Wolf Creek (09/21/05)	13		Typo	In the definition for: LEAKAGE Type: Other Known RCPB Leakage, RCPB should be RCPB.	done -- revised per comment
117.	Gleene Reeves Wolf Creek (09/21/05)	13		major	In the definition for: LEAKAGE Type: Other Known RCPB Leakage, the first bullet includes PIV leakage. Because this leakage is not "real", if it is added here, when IDENTIFIED LEAKAGE is subtracted from GROSS LEAKAGE to yield UNIDENTIFIED LEAKAGE, the result will often be a negative number.	Comment accepted. Reference to PIV leakage on page 12, section 2.0 and on page 35, section 8.4 will be deleted. ECCS or RHR system PIV leakage, measured when the plant is shutdown, does not belong in this calculation. If certain PIVs, such as SIT outlet check valves, leak by during normal operations, then this leakage will be accounted for in the mass change in specific tanks.
118.	Gleene Reeves Wolf Creek (09/21/05)	31	8.4	major	Step 8.4, Calculation Method: IDENTIFIED LEAKAGE, includes: "Reactor Coolant Pressure Isolation Valve (PIV) Leakage (see <i>def.</i>)". The referenced definition for: LEAKAGE Type: IDENTIFIED, on page 12, exactly matches the Technical Specification definition of IDENTIFIED LEAKAGE and does not include PIV leakage. Technical Specification LCO 3.4.14 addresses PIV leakage. It should not be included in LCO 3.4.13 calculations.	See resolution to comment #117.
119.	Gleene Reeves Wolf Creek (09/21/05)	13		question	Has the NRC bought in to the concept of "Non-RCPB LEAKAGE"?	Don't know. But we believe it is correct and is a defensible position. No change.

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
120.	Gleene Reeves Wolf Creek (09/21/05)	13		typo?	<p>In the definition for: Limit of Detectability {definition version 2.0} Should "<i>less</i> than or equal to" be "<i>greater</i> than or equal to"?</p> <p>"That is, the total measured increase in leakage over [T] hours is less than or equal to [X] x [T] x 60 Gallons at [standard conditions]."</p>	<p>This definition will ultimately be reworded to coincide with the text in Section 11.4. However, this is still an interesting question.</p> <p>In general terms, "less" is always the preferred word because we want to set an "upper bound" on how much water could possibly leak in a given number of hours. If we take "95/95" to mean that we will essentially always see (i.e., "get an alarm") an increase in the leak rate of X gpm within T hours, then, if the leak rate increase is exactly X gpm, the amount of increased leakage when we get the alarm cannot be more than X.T because we will always get an alarm by time T (or earlier). If the increase in the leak rate is 0 gpm or X/2 gpm or any number less than X, we may not get an alarm by time T but the increased leakage is still less than X.T gal. at time T. The interesting question is: "What if the step change is 2.X or 3.X ?" That is, if we double the leak rate, does it take only half as much time to see it (i.e., get an alarm). Column 2 of Table 11-1 answers this question. That is, a 1σ step increase in the leak rate takes 58 days to detect (at a 95/95 level), a 2σ step increase takes 17 days and a 3σ increase takes 8 days. As a result, doubling the leak rate reduces the required time to see it by more than a factor of 2. This is an interesting aspect of Tables 11-1, etc. that I hadn't thought about. We will probably modify the text to discuss this point.</p>

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
121.	Gleene Reeves Wolf Creek (09/21/05)	15		suggestion	Suggest providing a definition for: LEAKAGE Type: Controlled	There is no "controlled leakage" per se. See 7.4 -- Gross LEAKAGE must be adjusted to account for <i>controlled mass changes</i> due to boration, dilution, VCT divert valve actuation, sampling, and any other type of controlled addition and/or loss of reactor coolant. Calculate the total $\Delta \text{Mass}_{\text{CONTROLLED}}$ expressed in lbm. Sign Convention: <ul style="list-style-type: none"> • Positive mass change means mass added to RCS. • Negative mass change means mass loss from the RCS.
122.	Gleene Reeves Wolf Creek (09/21/05)	19		suggestion	Suggest providing the exact equation that should be used to convert pounds mass per minute (lbm/min) to gallons per minute (gpm). Suggest: $\text{GPM} = \text{lbm/min} \times 0.1200695 \text{ gal/lbm}$	no change -- Grand mixed unit conversion factors are left to the plant to employ, or not. All the necessary info to do such a thing is there. If group wants this, I will add it.
123.	Gleene Reeves Wolf Creek (09/21/05)	20	RCS Makeup, Step 2	moderate	Considering the fact that page 12 requires reporting of leakage test result values to the nearest one-hundredth of gpm, the minimum required accuracy of the RCS makeup meter should be specified.	Added note: Note: VCT makeup should be rounded to the nearest 1/100 th of a gallon, example: 100.45 gallons.
124.	Gleene Reeves Wolf Creek (09/21/05)	20	RCS Makeup, Step 3	minor	Step 3 deals with Non-RCPS LEAKAGE. It has nothing to do with RCS Makeup. It should be deleted or moved to the "Identified Leakage" section.	No change. Charging pump seal leakage is classified as non-RCPB leakage. It was mention under section 5, RCS Makeup because the charging pumps are part of the CVCS and this may be a new term to some utilities. Related to comment # 119.

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
125.	Gleene Reeves Wolf Creek (09/21/05)	20	Measurement Time Interval, Step 1	suggestion	To ensure accuracy and consistency, a 'standard' time interval should be specified. In fact, a short time interval (i.e. one hour) might not yield the required accuracy.	<p>Section 11.12 says: "The principal recommendation is to report <u>exactly</u> one high quality (i.e., well within the limits of validity) measurement over a period of approximately two hours each day."</p> <p>See also the discussion for 107. We agree with the notion that the accuracy might be reduced. However, it may be necessary to reduce the surveillance interval on occasion due to unforeseen events or to deal with sporadic outliers near the start or end of the usual interval. In addition, good instrumentation and stable plant conditions may give good results for some utilities using a reduced surveillance interval.</p>
126.	Gleene Reeves Wolf Creek (09/21/05)	23	7	moderate	<p>Gross LEAKAGE is defined on page 20 as "the sum of all leakage from the RCS control volume during the leak test time interval, ΔTime."</p> <p>However, the equations on pages 23 and 30 mathematically define Gross LEAKAGE as the sum of <u>mass changes</u> (i.e. $\Delta\text{Mass}_{\text{PZR}} + \Delta\text{Mass}_{\text{RCWV}} + \Delta\text{Mass}_{\text{VCT}} + \Delta\text{Mass}_{\text{CONTROLLED}}$). This creates signage confusion. Leakage should be defined, mathematically, as either the sum of mass losses or the negative of mass changes.</p> <p>Suggest mathematically defining Gross LEAKAGE = $-\Delta\text{Mass}_{\text{PZR}} - \Delta\text{Mass}_{\text{RCWV}} - \Delta\text{Mass}_{\text{VCT}} - \Delta\text{Mass}_{\text{ADD-REMOVE}}$</p> <p>In lieu of $\Delta\text{Mass}_{\text{CONTROLLED}}$, if $\Delta\text{Mass}_{\text{ADD-REMOVE}}$ is used, then the required signage of the term is obvious.</p>	<p>Refer to comment, 79 and 88 suggestions</p> <p>Added assumption #3 to Section 6. stating that leakage is defined as the net mass loss from the RCS control volume</p> <p>Changed the definition of Gross Leakage prior to the general equation in sections 7.0 and 7.5 to clarify the leakage is the net mass loss for the RCS control volume.</p> <p>Changed definition of terms in Section 9.1 as follows:</p> <p>UNIDENTIFIED Leakage (lbm) = negative of the calculated UNIDENTIFIED Leakage</p>

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
127.	Gleene Reeves Wolf Creek (09/21/05)	23 thru 37			<p>The unit designator for pounds mass (lbm) is overused and used inconsistently in the equations in Sections 7, 8 and 9.</p> <p>Suggest making ALL general equations similar to the following:</p> $PZR \Delta Mass = M_{PZR2} - M_{PZR1}$ <p>Where: $PZR \Delta Mass = M_{PZR2} - M_{PZR1}$ M_{PZR1} = PZR Mass at Time 1 (lbm) M_{PZR2} = PZR Mass at Time 2 (lbm)</p>	done - Revised per comment.
128.	Gleene Reeves Wolf Creek (09/21/05)	24	7.1.1	typo	In Note 1, 2 and 3, all references to "Time 2" should be to "Time 1". For example, Note 2 should begin with: "VolumeLiq _{PZR1} " in lieu of "VolumeLiq _{PZR2} ".	done - Revised per comment.
129.	Gleene Reeves Wolf Creek (09/21/05)	26	7.2	minor	The General Equation should read "RCWV $\Delta Mass =$ " versus " $\Delta Mass =$ "	done - Revised per comment.
130.	Gleene Reeves Wolf Creek (09/21/05)	27	7.2.4	minor	If the desire is to standardize leakage rate methodology, then Section 7.2.4 should either be specified as the desired method or it should be deleted.	Refer to resolution of Comment #1114.
131.	Gleene Reeves Wolf Creek (09/21/05)	28	7.3	minor	The General Equation should read "VCT $\square Mass =$ " versus " $\Delta Mass =$ "	done - Revised per comment.
132.	Gleene Reeves Wolf Creek (09/21/05)	28	7.3	minor	Delete unnecessary parenthesis in the VCT $\Delta Mass$ equation.	done - Revised per comment. Deleted unnecessary parenthesis.
133.	Gleene Reeves Wolf Creek (09/21/05)	29	7.3.3	moderate	<p>The VCT $\Delta Mass$ equation is incorrect:</p> <p>Current: $VCT \Delta Mass (lbm) = M_{VCT2} - M_{VCT2} + Makeup$ Correct: $VCT \Delta Mass (lbm) = M_{VCT2} - M_{VCT1}$</p> <p>Delete the equation that defines "Makeup".</p>	done - Revised per comment. Deleted equation that defines makeup.

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
134.	Gleene Reeves Wolf Creek (09/21/05)	30	7.4	moderate	In lieu of $\Delta \text{Mass}_{\text{CONTROLLED}}$, if $\Delta \text{Mass}_{\text{ADD-REMOVE}}$ is used, then the required signage of the term is obvious.	Incorporated
135.	Gleene Reeves Wolf Creek (09/21/05)	30	7.5	moderate	To be consistent with page 23, suggest mathematically defining Gross LEAKAGE: $\text{Gross LEAKAGE} = - \Delta \text{Mass}_{\text{PZR}}$ $- \Delta \text{Mass}_{\text{RCWV}}$ $- \Delta \text{Mass}_{\text{VCT}}$ $- \Delta \text{Mass}_{\text{ADD-REMOVE}}$ In lieu of $\Delta \text{Mass}_{\text{CONTROLLED}}$, if $\Delta \text{Mass}_{\text{ADD-REMOVE}}$ is used, then the required signage of the term is obvious. Delete the asterisked note associated with the signage of the last term.	Incorporated
136.	Gleene Reeves Wolf Creek (09/21/05)	31	8	typo	Correct "IDENDIFIED" to read "IDENTIFIED".	done - Revised per comment.
137.	Gleene Reeves Wolf Creek (09/21/05)	31	8	minor	Reformat the General Equation identifying Total IDENTIFIED LEAKAGE to be the same as the other General Equations.	done - Revised per comment.
138.	Gleene Reeves Wolf Creek (09/21/05)	31	8.1	typo	Change "RCDC" to "RCDT".	done - revised per comment. (good catch)

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
139.	Gleene Reeves Wolf Creek (09/21/05)	35	8.4	major	Reactor Coolant Pressure Isolation Valve (PIV) Leakage is being added into IDENTIFIED LEAKAGE before it is used to determine UNIDENTIFIED LEAKAGE. The problem with this is that the value being used for PIV leakage is often higher than actual; this often causes UNIDENTIFIED LEAKAGE values to be lower than actual and/or negative. Recommend this methodology be changed and, if needed, Tech. Spec. bases be changed to remove PIV leakage from the IDENTIFIED LEAKAGE term.	Good comment. Need group discussion on this topic. Tech. Specs. may vary. See resolution of Comment # 117
140.	Gleene Reeves Wolf Creek (09/21/05)	36	8.6	minor	Reformat the General Equation identifying Total IDENTIFIED LEAKAGE to be the same as the other General Equations.	Revised format per comment, sect. 8.0 and 8.6
141.	Gleene Reeves Wolf Creek (09/21/05)	37	9.1	suggestion	Suggest providing the exact equation that should be used to convert pounds mass per minute (lbm/min) to gallons per minute (gpm). Suggest: $GPM = lbm/min \times 0.1200695 \text{ gal/lbm}$	no change -- Grand mixed unit conversion factors are left to the plant to employ, or not. All the necessary info to do such a thing is there. If group wants this, I will add it.
142.	Gleene Reeves Wolf Creek (09/21/05)	38	10	moderate	The leak test should be considered valid even if performed during a time when a leak exists that exceeds the Tech. Spec. limits. Placing too stringent of tolerances on PZR level and VCT makeup could make it impossible to perform a 'valid' test to quantify an actual leak. Suggest making the validity checks for PZR level and VCT makeup applicable only when plant conditions are normal.	See sect. 10.1, Rule 2: Valid vs. Invalid only apply to whether the leak rate result is put into the historical baseline data set. Whether the plant logs the leak rate result is left to the plant's leak rate procedure. The validity checks are merely examples. Per sect. 10, "Each plant should determine their own plant specific limits, keeping in mind that plant stability (thermal equilibrium) is a key factor for accurate leak rate results."

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
143.	Bob Couture Seabrook (09/15/05)		All		<p><u>General Comment:</u></p> <p>There is no specific discussion on how a plant might determine the smallest leak rate that is statistically valid. All of the information provided (specifically Section 11.4) is useful but the following basic question does not seem to be addressed:</p> <ul style="list-style-type: none"> For a specific plant, how is the minimum level of detection determined? <p>All plants do not have the same capabilities for instrumentation or methods of calculating RCS leak rates. Therefore, I believe that it is important to address this issue as part of the leak rate document. If a plant has a "high" minimum level of detection and is told to take action on pre-determined leak rate changes that are smaller than can be statistically determined (for example, a management directive to initiate actions to identify increased leakage when an increase of 0.05 gpm in the unidentified leak rate is observed), the plant staff will forever be chasing "phantom" leaks.</p>	<p>The second paragraph in Section 11.3.2.1 discusses the notion that the conclusions of the simulation described in Section 11.3.2.2 and 11.4 apply to all members provided that they use their respective site value of σ in the statements in Section 11.4 (and that the conditions described in Section 11.12 are valid). So, roughly, if you know your σ, you can use Section 11.4. Based on internal discussions, our definitions in Section 11.4 describe what the leak rate detection algorithm is <u>capable</u> of doing. A separate, quantitative definition is needed to define the <u>required</u> minimum level of detectability. If your plant's capability falls short of what is required, something needs to change. It is expected that the required (numerical) values will be developed in the next Task (currently underway).</p>

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
144.	Bob Couture Seabrook (09/08/05)	top of p. 11	2		<p><u>Specific comment:</u> Definitions and Description of Terms, Historical Baseline definition</p> <p>With very “tight” systems and relatively small leak rates present, it is possible that plants will come out of a refueling outage with a higher (but still acceptable) RCS unidentified leak rates. This circumstance does not lend itself to comparing the initial post outage leak rate data to the last quarterly average prior to the outage. This needs to be specifically discussed with recommendations on actions to take until enough data is available post outage to revert back to comparison to the previous quarter.</p>	<p>See discussion for #68. We agree that some clarification is required for BOC application and, also, after leak rate or instrumentation maintenance operations. I’m a bit puzzled re. how to handle this. If you use “low” starting values, you can immediately get into Action Levels. On the other hand, if you use “high” values, you cannot ever get exceedences (and, therefore, be able to see small step increases near BOC).</p> <p>This is a topic will continued to be discussed in the Action Level project.</p>
145.	Bob Couture Seabrook (09/08/05)	bottom of p. 46 of 94	11.2.6		<p><u>Specific comment:</u> Action Level II and III: Measurements above Two and Three σ</p> <p>This section seems to be a continuation of previous sections that evaluate the NRC proposed guideline “triggers” for action levels as presented on page 1 of Appendix A. However, why in the discussion for action level III do you evaluate and discuss one or more measurements greater than 3 sigma in three consecutive measurements? I believe that the intent of the NRC draft guidance is that any valid, calculated leak rate greater than 3 sigma would invoke the stated action. Does the discussion and examples in this section concerning values greater than 3 sigma need to be modified?</p>	<p>The use of three successive measurements for both “at least one 3σ” or “two or more 2σ” allowed us to compare the relative probabilities of the two events. The text then goes on to discuss the notion that the corresponding Action Levels are “backward” because it is more likely to get “at least one 3σ” than “two or more 2σ”. (The text points out that this doesn’t apply when a step change in the leak rate occurs.)</p>

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
146.	Bob Couture Seabrook (09/08/05)	59	11.3.2.2		<p><u>Specific comment:</u> Results of the Simulation Performed with "RCS_LEAK_SIM"</p> <p>The last sentence ends with the phrase "...simulation which, for unforeseen reasons, don't fully represent reality." In studying the three bullets prior to this text, it is not obvious to me what item(s) are the concern for the departure from reality. Could more text be added to specifically clarify the concern?</p>	See the discussion and resolution for #111. We will modify the text to address this point.
147.	Bob Couture Seabrook (09/08/05)	74, item 6	11.12		<p><u>Specific comment:</u> Recommendations</p> <p>Item 8 discusses checking the data for statistical independence. It offers the view that if data is skewed, as shown in Figure D-31, then one possible reason is that a given point is used as both the end and start point for data evaluations. However, this document only evaluates daily high quality measurements and, for this case, it would be impossible for the same data to be used as both the end and start values. Are there other more probable reasons for the Figure D-31 behavior that are more consistent with the concept of a daily high quality measurement?</p>	We would expect the daily high quality measurements to be independent and can't envision any plausible reason why they would be dependent. We included Figure D-31 to make the point that "continuous monitoring" data could show these effects and potentially lead to erroneous conclusions and, also, provide a simple mechanism to investigate the phenomena.

Item	Name/Utility	Page	Section	Type	Comment	Westinghouse Response
148.	Bob Couture Seabrook (09/08/05)	C-6 of App.C	C-2.2 of App.C		<p><u>Specific comment:</u> Average Coolant Temperature Uncertainty</p> <p>I'm not sure how to interpret the first sentence ("Arbitrary variation on average coolant temperature for the purpose of determining sensitivity: 1 °F.") Does it mean that the 1 °F value was chosen arbitrarily or that the 1 °F represents the arbitrary variation expected in the signal? In either case, the 1 °F seems large to me when compared to actual RCS average temperature fluctuations observed at full power but small when compared to a typical average temperature channel statistical analysis (CSA) value. Please provide clarification on the determination/basis of the 1 °F value.</p>	<p>The text in C-2.2 was modified to address this comment by WLG.</p> <p>RKE – In my view the use of 1 DegF used a unity multiplier to convert the sensitivity in Section C-3.1.3 (in units of gal/DegF) into gal. by multiplying by 1 DegF. As shown in the current document, this value plays no role in any of the results.</p>

Miscellaneous Utility Comments

Item	Name/Utility	Section	Comment	Westinghouse Response
149.	Mike Hess Millstone Point (4/18/06)	2.0	<p>Joe and Bob, I strongly recommend that we limit our statistical analyses to comparing data to the previous quarter. I'd also recommend that the data be taken daily and analyzed on a quarterly basis. Since you referenced t values consider that some Tables of "Student's" Distribution stop at D.F. = 30 since $n = 31$ is where the sample mean approximates the true mean. This supports using larger samples for comparison. Also, the inventory balance will probably not drive most actions as illustrated by the recent RCS leak at MP3. However, performing the quarterly might prevent slow creep causing another Davis Besse. I worry that statistical analysis on a daily basis will divert operator attention while adding little to the quality of the operation.</p> <p>I've attached an Excel file that shows the recent RCS leak at MP3. The charts illustrates why inventory balance is not a major input to finding small increases in RCS leakage. There are two charts showing trends at a time that RCS leakage increased from 0.04 gpm to 0.06 gpm. One chart is in-leakage into the containment unidentified leakage sump. The sump in-leakage is shown by the white line. The other two lines on the chart are CTMT particulate and gaseous activity. It was a water leak, so we didn't expect atmospheric activity to increase. The other chart shows the inventory balance leak rates. On the RCS Inventory Leak Rate chart I've included the mean, Mean plus 2 STDEV, and Mean plus 3 STDEV.</p> <p>The leak started on 4/7/06 and was isolated on 4/15/06. The leak took in-leakage from approximately 0.04 gpm to 0.06 gpm. When it was isolated, leakage returned to approximately 0.045 gpm. During the leak, only four of the five days had inventory leak rate above the Mean and all leak rates were below Mean + 2 STDEV.</p>	<p>In general, we agree. However, the daily ULR data value needs to be examined to make sure that no Action Level issue is present. Section 10.1 (Rule 3) describes this simple check. The value should also be "screened" to ensure that it is not an outlier. That is, each daily value should be classified as "good", "bad", or "indeterminate". We agree that any other statistical fiddling can be performed essentially once per Quarter as the time to update the Baseline Values approaches.</p> <p>We also responded as follows to Mike with an email dated 04/13/2006:</p> <p><i>Mike, I'm not sure we properly understood and answered the question you raised near the end of yesterday's telecon. I think the question was something like: "How many leak rate values do we need to average in order to make sure that we are getting close to the "true value" - followed by some comment about "Is 7 enough?" and a comment that you have made in past Telecons re. the fact that "20 is always enough".</i></p> <p><i>Pls. review the following & see if it helps out & let us know if we misunderstood the question/Thanks, Bob E.</i></p> <p><i>Joe & I discussed this today & he thought the "7" may have come from the Absolute Leak Rate description in 5.2.1. In any event, the "7" in that Section isn't really derived from any heavy duty statistical analysis. We picked that number because we know, from observation, that plants are seeing occasional values above +.1. At the same time, we have felt for some time that consistent leak rates above 1/10th of the Tech Spec limit ought to initiate some kind of action. The question was: how many do you need to see before you do something? We thought a 7 day "rolling average" was reasonable because, if things were normal on Sunday -> Wed & you started to get consistent values above .1 (but below .15) on Thursday -> Sat, the "rolling average" would approach .1 sometime early the following week & you would get into the Action Item. So, the plant gets a few days before</i></p>

Item	Name/Utility	Section	Comment	Westinghouse Response																					
				<p>entering the Action Level to look into causes and ensure that the conditions of validity are being observed for all measurements. Of course, if two values above .15 or one above .3 are observed, that extra time is not available. In a general sense, how big a sample you need to take to "get close" to the "true" value depends on what thing you are looking for in the sample.</p> <p>As an example, it is well known (and documented in the 0189 writeup) that the largest value observed in a random sample of size 59 sets a "95/95" bound for the entire population which was used to supply the sample. However, the variation in the largest value in several samples of size 59 is large.</p> <p>I'm guessing that you are thinking about the mean value obtained from the sample. The mean value is probably the "best behaved" parameter provided that there are no outliers. In addition, normality isn't very important for bounding the population mean with a sample mean and sample standard deviation. The following equation summarizes the result:</p> <p>The population mean (i.e. the "true mean") has a high probability of being in the interval:</p> <p>{ sample mean +/-[(tstatistic x sample stddev) / sqrt(sample size)] }</p> <p>Typical values for t (at a typical significance level of 5%) are:</p> <table><tr><th><u>Sample Size</u></th><th><u>Degrees of Freedom</u></th><th><u>tstatistic</u></th></tr><tr><td>7</td><td>6</td><td>2.447</td></tr><tr><td>11</td><td>10</td><td>2.228</td></tr><tr><td>16</td><td>15</td><td>2.131</td></tr><tr><td>30</td><td>29</td><td>2.045</td></tr><tr><td>61</td><td>60</td><td>2.000</td></tr><tr><td>>120</td><td>>120</td><td>1.960 (Normal Distribution Value)</td></tr></table> <p>Using the above equation, you can see how the sample size controls the "bounds" on the population mean. Of course, a large standard deviation requires a larger sample to reduce the size of the interval.</p>	<u>Sample Size</u>	<u>Degrees of Freedom</u>	<u>tstatistic</u>	7	6	2.447	11	10	2.228	16	15	2.131	30	29	2.045	61	60	2.000	>120	>120	1.960 (Normal Distribution Value)
<u>Sample Size</u>	<u>Degrees of Freedom</u>	<u>tstatistic</u>																							
7	6	2.447																							
11	10	2.228																							
16	15	2.131																							
30	29	2.045																							
61	60	2.000																							
>120	>120	1.960 (Normal Distribution Value)																							

Item	Name/Utility	Section	Comment	Westinghouse Response
				With respect to the MP3 leak described in Mike's comment & his contention that "inventory balance is not a major input to finding small increases in RCS leakage", we don't fully agree. Examination of Mike's data shows that the rolling average of 7 values exceeds the limit of .1 gpm on both Apr. 13 th and Apr. 14 th . As a consequence MP3 was in the rolling average Action Level described in Section 5.2.1 of Ref. 25.(Ref. 25 was in draft form at that time.)
150.	Steve Mays Catawba Nuclear Station (05/11/06)		<p>Gentleman. During last nights run of the OAC program for determining unit 1 RCS operational leakage, one of two operating containment chilled water supply units tripped (i.e., these are chilled water units that supply the four containment air coolers). Within 30 minutes, a third standby chilled water supply unit was started. The short-term loss of chilled water caused a containment temperature increase of 1.5°F. There was a corresponding increase in "indicated" PRT Level of 0.1% (i.e., not much, but this equates to an input of approximately 12.5 gallons). From review of available data, the PRT input rate and level did not actually increase.</p> <p>As a result, RCS "identified" leakage increased by approximately 0.060 gpm. And, RCS "unidentified" leakage correspondingly decreased by 0.060 gpm. Thereby, the reported value for "unidentified" leakage is non-conservative. More importantly, this has a very negative influence on our effort in a standard, more repeatable, and reliable method of measuring RCS operational leakage.</p> <p>Does WCAP-16423-NP address need for a stable containment temperature? Should it?</p> <p>Do I have an equipment problem (i.e., bad transmitter)?</p>	<p>Comment accepted. Stability of containment pressure is addressed in section 5, Limits and Precautions. "and temperature" will be added to this L&P.</p> <p><u>Containment Conditions</u></p> <ol style="list-style-type: none"> 1. Maintain containment pressure and temperature stable. Change in containment pressure may affect leak rate or upset identified leakage collection tank equilibrium.

Final Review Comments

Item	Name/Utility	Section	Comment	Westinghouse Response
151.	Jack Patterson Beaver Valley (8/24/2006)	NA	Beaver Valley Power Station has reviewed the final draft of WCAP-16423 and has no additional comments.	NA
152.	Mark Handrick North Anna Dominion (8/23/2006)	NA	I have only minor editorial comments on the final drafts. These comments do not need to be included in the formal comment summary. I appreciate the work you and your team have done for this effort.	Incorporated
153.	Virgil Esquillo AREVA NP 8/30/2006	TOC	A couple of comments from my prelim scan: 1. The subsections of 4.1 are showing up in the Table of Contents, and these subsections are equations for the different leakage terms. Not sure if you wanted those in the TOC.	Comment accepted. TOC will be corrected..
154.	Virgil Esquillo AREVA NP 8/30/2006	General	I see that Davis-Besse is the only B&W plant represented. Be advised that they are sort of anomalous with respect to operational leakage, based on my past benchmarking as CR3's RCS engineer. They also happen to report to the thousandths (!), and consistently had reported near-zero values. In contrast, all other B&W units report unidentified leakage of less than 0.1 gpm on rolling-average bases. Interestingly too, Davis-Besse had deployed the FLUS leak detection system under the vessel (and I think on the RVH also). FLUS is a humidity change detection system for finding tiny leaks. I do not know how it has fared at D-B.	Comment accepted. No change
155.	Virgil Esquillo AREVA NP 8/30/2006	Section 8.3	In Section 8.3, you might want to amplify the SG notes to reflect that primary-secondary leakage is typically quantified using chemistry/isotopic methods, and as such, is outside the scope...	Comment accepted and incorporated as suggested. Note that any error in the chemistry/isotopic methods will show up as an increment or decrement in the value of the unidentified leakage rate since ULR is the "slack variable" in the overall leak rate calculation.

156.	Virgil Esquillo AREVA NP 8/30/2006	Section 8.4	In Section 8.4, fitting, gasket, or mechanical joint leakage is not considered pressure boundary leakage; suggest using the more generic 'RCS leakage' phrase.	Comment accepted. Revised 8.4 to read: Other Known RCS LEAKAGE <u>Other Known LEAKAGE</u> is the sum of all leakage that is both known and documented, and <u>not</u> accounted for in RCDT LEAKAGE, PRT LEAKAGE, or Steam Generator LEAKAGE. Other Known LEAKAGE may include: - documented Reactor Coolant Pressure Isolation Valve (PIV) Leakage (<i>see def.</i>) - documented fitting or gasket leaks from the RCPB that are collected and measured
157.	Virgil Esquillo AREVA NP 8/30/2006	Section 11	In Section 11, you emphasize the importance of a daily RCS leak rate average. Be advised that not all plants are required by their technical specifications to conduct daily leak surveillances. CR3 for instance has a 72 hour interval as allowed by the Improved Technical Specification standard.	Comment accepted. No change This issue has been addressed in Section 5.2.2 of WCAP-16465
158.	Virgil Esquillo AREVA NP 8/30/2006	Section 11.13	Section 11.13 brings back fond memories... Sort of. I also looked into Kalman filtering, and yes, I concur with your engineers that implementation would be difficult, and I would go so far as to say questionable for the problem at hand.	Comment accepted. No change
159.	Virgil Esquillo AREVA NP 8/30/2006	App G	I see a real-world validation with the Seabrook, Fort Calhoun, and Comanche Peak data. This is good. Again, I'm sure you know CVCS controls somewhat differently from plant to plant, not to mention from vendor to vendor. It might be useful to have a representative CE and B&W unit (not D-B, please! ;) to round out this validation.	Comment accepted. Too late to include other units in the evaluations. Ft. Calhoun did provide input in support of the Standard plant activity.
160.	Virgil Esquillo AREVA NP 8/30/2006	Defs.	Nice example for the definition of "Median." Thanks for letting me see this. Again, fond memories.	Comment accepted. No change

Appendix I

Peer Review Comments (R. K. Perdue)



Westinghouse
Electric Company
412-256-2674



Science & Technology Department
Bldg. 401-2X27D
1340 Beulah Road
Pittsburgh, Pennsylvania 15235-5082

perduerk@westinghouse.com

To: Joseph R. Congdon
From: Robert K. Perdue
CC: Robert K. Endter
Date: August 25, 2006
Re: Review of RCS Leak Rate Standard Guidelines

In response to an email request from Joe Congdon dated August 10, 2006, this memo documents my review of the following documents:

- WCAP-16423
 - Section 11.0 Statistical Analysis of Unidentified Leak Rate
 - Appendix B, Derivations of Statistical Relationships (Note: not available at this time)
 - Appendix D, Figures and Plots from Section 11
 - Appendix F, NRC Final Guidelines
 - Appendix G, Standard Process and Methods for Calculating RCS Leak Rate for Pressurized Water Reactors, rev 0 (per email from Robert Endter, August 8, 2006).
- WCAP-16465 (Section 5, Action Levels and Response Guidelines)

Bob, thanks very much for the comments. We appreciate the time and effort you put into this review given the tight time schedule. (Our responses and associated actions are shown below in bold.)

Comments on WCAP-16423: Section 11.0

Page 43: "Handwritten derivations" of reference 24 are not actually attached to this report.

RESPONSE:

Reference 24 is currently being prepared. The handwritten derivations are included therein to simplify the final report. These derivations are not considered to be of fundamental importance to the accuracy of the final report.

Page 48: The report states that ... "Table G-5 of Appendix G compares the baseline standard deviations for the three Standard Plant members that rigorously carried out the daily "two-hour snapshot method". All three plants show the same standard deviation (.03 gpm) which is more or less expected given similar plant instrumentation, similar tight control of the limits of validity for the two hour period, and the same method of measurement.)"

In fact, Table G-5 compares 4 plants, three of which have similar standard deviations (0.03 when rounded to 2 places), but dissimilar means (Comanche Peak 2 is very different). The fourth plant (Ginna) is an outlier vis a vis

the others in both mean and standard deviation. The table does not offer convincing evidence to support the hypothesis that similar variances should be observed across plants.

RESPONSE:

Ginna did not use the two hour snapshot method to perform their measurements. (They used surveillance intervals which varied from less than 1 hour to more than 13 hours.) However, this variation does not explain the extremely low observed standard deviation relative to the other Participants.

Our statement about the same standard deviation for the other three plants was not intended to imply that all plants performing two hour measurements would see the same standard deviation. The statement was made because the RCS Tave fluctuation is likely to be the primary source of instrumentation error (based on App. C) and these plants typically have similar RTD instrumentation. The fact that all 3 plants used two hour measurements with tight control of plant conditions implies that process fluctuations are similar for all 3 plants. Therefore, it was not too surprising that the observed standard deviations were about the same. Of course, if Seabrook had implemented the 60 second Tave “average value” scheme shown in Figure G-14 prior to the Standard Plant activity, the three values would not be in good agreement.

There is no reason to believe that the mean values should be in good agreement because the mean is an indication of the “true” unidentified leakage which should vary plant by plant. Based on the answer to comment # 43 in App. H, we would expect a relatively small baseline mean (like those observed) if there is no reason to suspect that significant leaks have developed since the start of the current operating cycle. On the other hand, should we conclude that CP Unit 1 is really leaking about .03 gpm somewhere and CP Unit 2 is not leaking an unidentified single drop anywhere based on Table G-5? We don’t think so. It would be easier to discount small positive baseline values if some units had negative values of similar magnitude. In any event, it is conservative to assume the small positive values are real.

ACTION:

We will add a statement to p. 48 to note that we are not suggesting that all plants using the two hour method are expected to have standard deviations of .03 and also add a pointer to this discussion.

Page 60: The statement that Equation 11.8.b represents a “95/95 non-parametric pointer” requires more explanation. The reference given (“Ref. 17, page 172”) is to Feller, *Introduction to Probability and Statistics*. Page 172 of this reference does not explain why Eq. 11.8.b leads us to a non-parametric 95/95 upper tolerance limit. Indeed, as shown it is required that we estimate the parameters of the normal approximation to the binomial – what is “non-parametric” about that?

RESPONSE:

We oversimplified the way the nonparametric “pointer” in Eqn. 11.8.b is obtained. We did include Reference 11 in Appendix A to show the exact development for a simple case (i.e., 59 data points).

Pages 18-28 of Ref. 28 (which is in the Westinghouse Electronic Data Retrieval System) documents that the exact calculation of the non-parametric pointer (i.e., 961 for a sample of size 1000) is based on the binominal probability distribution (i.e., Eqn. 11, p. 20 of Ref. 28). Because the individual terms in the binominal distribution involve complicated factorial terms, the “exact” (computer code) calculation of the pointer uses an identity between the incomplete beta function and the binominal distribution as described in Eqn. 17 on p. 23 of Ref. 28. (Evaluation of the incomplete beta function is easily carried out using routines from the IMSL Library documented in Ref. 21.)

Ref. 17 simply documents that the normal probability distribution provides suitable approximations to the binominal probability distribution (i.e., the “exact” model) when the sample size (N) is large. (A typical rule of thumb for the approximation is that $N \times (1 - p)$ where p is .95 should exceed 5. Here $N \times (1 - p)$ is 50.) (The “approximate” value of 961 documented in Eqn. 11.8.b was checked for accuracy against the computer code evaluation which uses the incomplete beta function identity and the values agree.)

ACTION:

A pointer to this discussion will be added to p. 60 of the document. We will also include the observation (shown below) that “Non-parametric tolerances will generally be more conservative than parametric counterparts.”

More generally, the report needs a more precise definition of “95/95.” On page 69 and 70 it is defined as a “95% probability and a 95% confidence level.” It might more helpfully be defined by the statement that we are 95% confident that *at least* 95% of the population will be below this value. Non-parametric tolerances will generally be more conservative than parametric counterparts.

RESPONSE:

We’ve oversimplified the “95/95” concept to mean “almost always”.

ACTION:

We will add your clarification to the definition of the Limit of Detectability and to p. 70 as well.

Finally, why not try various data transformations, such as taking logs (log10, lnx, etc.) or Box-Cox transformations, in order to achieve normality? These are easily done in statistical packages like MINITAB 14 and not that hard in Excel. Once transformed, the data is tested again for normality and it passes, then the transformed data is used for whatever statistical tests that require normality. This would probably allow less conservative statistical tolerances.

RESPONSE:

Given the type of data shown in Figure D-7, a data transformation might be difficult. However, we were satisfied that the “Minimum Level of Detectability” turned out to be no greater than about .1 gpm as discussed in Section 11.4. If we needed further improvement we would probably have simply increased the sample size from 1000 to 100000 or 1000000.

Page 71: Section 11.6 boils down to saying that a regression model is used to estimate expected (mean) values of starting and ending distributions on TAVE to filter out the noise. Equations 11.11 to 11.13 seem to add little to either clarify or support this approach.

Page 72-73: This section is intended to justify the use of linear regression estimates in place of actual TAVE values. An alternative pedagogical approach could be to note that discussions of measurement error in regression data show that if the dependent variable has random measure error but the independent variable (time in this case) is free of such error, then the regression of TAVE on time will yield unbiased estimates of the slope and intercept parameters. Moreover, the resulting prediction equation will yield unbiased estimates of the mean TAVE for each time period. Larger samples will then reduce the amount of random error (i.e., improve the standard errors associated with the estimated regression coefficients). If the random error in TAVE changes systematically over time, then corrections for this “heteroscedasticity” can be made. In short, the discussion could be conducted in terms of measurement error in variables (a topic much-analyzed in texts on regression).

RESPONSE:

A good bit of Section 11.6 was devoted to showing why the linear fit values could, in principle, result in better estimates than the actual starting and ending values. This fact is illustrated in Eqn. 11.13. (As an aside, this fact was the subject of numerous internal “discussions” when the Project started. In spite of Section 11.6, it is fair to say that there is still some doubt regarding this conclusion for some unnamed individuals.)

We know that a number of Participants use linear fitting in one form or another. The remainder of Section 11.6 is intended to provide those Members with some cautions regarding the use of linear regression. Of course, the principal caution is that linear regression may lead to erroneous results if the data is not linear.

(Note to the Reader: Heteroscedasticity refers to a situation where the dependent variable y is fit (i.e., using linear regression) against the independent variable x when the variance of y is not constant but depends on the x variable. This topic is discussed in Section 18.6 of Ref. 7. The usual situation where the variance of y is independent of x is known as “homoscedasticity”).

We wouldn’t expect that the Tave errors would change systematically over short periods of time. However, poor control of the conditions of validity (i.e., the process) might make it appear that such variation is present if a derived variable such as the RCS Mass inventory (which depends on Tave as shown in App. C) is used in the regression.

ACTION:

We will add a pointer to this comment in Section 11.6.

Page 75: Before resorting to spline fitting, try various (easy) data transformations, like taking logs, to achieve linearity (not to mention normality of residuals).

RESPONSE:

We've used the "generalized cross-validation spline smoothing" technique in a number of applications. The most interesting feature is that it can often identify time-dependent phenomena which were previously unrecognized in the "noisy" data. This seems to be the case in Figure D-16 although we didn't fully resolve the source of the apparent 2 hour waxing and waning in the data. Ref. 20 indicates that the residual errors using this approach are likely to be normally distributed if the original data is contaminated with white noise.

Page 76-78: Mention that modern standard practice (as embodied in modern statistical software like MINITAB 14) is to use several diagnostic measures (notably, leverages, Cook's Distance, and DFITS) to identify outliers. In any case, "outliers" should (in principle) not be thrown out unless some physical or conceptual reason for their generation can be identified or conjectured.

RESPONSE:

We recommended a simple method (i.e., "extrinsic outlier screening" -see Definitions) to identify "suspect" or "potential" outliers. Because of the "slack variable" nature of the unidentified leakage (i.e., it reflects the net impact of all the small errors in the entire calculation described in Sections 7 and 8), it requires the expertise of plant personnel familiar with the information available and the likely suspects for each individual plant. That is, outlier screening and subsequent rejection has to be carried out by the engineering staff of the Utility.

Keeping or rejecting a significant number of "suspect" outliers can effect the baseline mean and standard deviation and thus effect the potential for correctly setting the NRC App. D Action Level triggers in the forthcoming quarter. In all likelihood, this is an issue only for small increases in the leak rate since minor setting errors will not effect the detection of large leaks.

ACTION:

We will add a comment regarding "some physical or conceptual reason" to Section 11.7 and add a pointer to this discussion.

Page 82-83: It might be added that Kalman filter methods are much used in such engineering applications as signal processing to filter out noise data to find a true signal and also to automate both estimation and forecasting as new data becomes available. The Kalman model's also allow monitoring of model stability over time (i.e., as new data

becomes available). This approach (or a similar type of time series statistical approach, such as autoregressive moving average (ARMA) models) might be usefully applied in this domain.

RESPONSE:

See the additional comment regarding Kalman filtering in Comment # 174, App. H.

ACTION:

We will add a pointer to this discussion in Section 11.13.

Comments on Appendix B, Derivations of Statistical Relations

Not available for review.

Comments on Appendix D, Figures and Plots from Section 11

No comments.

Comments on Appendix F, NRC Final Guidelines

This is actually a set of comments on the NRC Final Guidelines. The issue of whether to retain negative leak rates in the data base for computing mean and standard deviation is a key difference between Westinghouse and the NRC – the former wants to keep them in and the latter wants to remove them before calculating means and standard deviations. It is certainly hard, at first blush, to understand why we would not remove such obvious symptoms of measurement error (if only because it is potentially non-conservative with respect to mean leak rate calculations). The rationale given for the Westinghouse position on page F6 (Comment 6, with Customer Comment #16 included) is that, first, negative values are a valuable indicator of cumulative measurement error and second that they help render the data “normal” because they allow the data to extend to the negative quadrant. The underlying assumption in both assertions is that we are attempting to measure the degree of error in the readings. This would “hold water” if we were intent on calibrating our measurement instruments. In this case, however, we are attempting to measure and track the *real* change in the leak rate. This being the case, I find our arguments for including data that obscures the real change to be puzzling.

RESPONSE:

If the NRC draft Guidelines that we used extensively in Section 11 had included this “rule” we would have examined the consequences in a more quantitative fashion. However, that is not the case. If we simply adopted the final NRC App. D Guidelines it would potentially invalidate much of the simulation work reported in Section 11.

This issue was discussed in a number of Telecons with the Customers and no one protested the inclusion of valid negative values in the determination of the baseline values. In addition, two members of the Project Team are ex-operators and have been involved in discussions of this topic many times in the past. That is, this is a historical issue with informed opinions on both sides of the issue.

Finally, if we postulate a case with a “0.0” baseline mean (such as Comanche Peak Unit 2 in App. G), it seems that the “spurious” negative readings simply offset the equivalent

“spurious” positive readings – that is, there are “spurious” negative and positive readings of roughly equal magnitude so that the resulting “real” leakage is determined to be about “0.0”. Any step change in the “real” leakage would then show up as an upward shift in the mean.

Note also Customer Comment #163 in Appendix H which points out that there are situations in which negative readings are not spurious. That is, real in-leakage can occur (and has occurred) in some plants. Clearly these values potentially indicate a malfunctioning component and can not be disregarded. (We were unaware of the potential for real in-leakage and therefore non-spurious negative leaks until this comment was received.)

After Customer Comment #163 was received we requested more information regarding the details. The following added information was recently obtained from the Utility:

“We have had at least two [non-spurious in-leakage events] that I can recall. One was a case of a primary makeup water valve leaking by to the suction of the charging pumps. This occurred many years ago. It was noted by the operators questioning the fact that we were not having to dilute as much as we expected. The other event was last cycle and the beginning of the latest cycle. The in leakage was from the primary makeup water through a manual valve for the CVCS demineralizers for flushing. The valve was cracked open. It was pinpointed using sampling of the demineralizer effluent and noting the change in the boron concentration from previous samples. We were seeing low leak rates and negative leak rates.”

ACTION:

We will add a pointer to this discussion in Section 11.8.

In addition, we then performed a brief investigation of the number of Action Level I, II, and III events that are likely to be observed using the PWROG approach (i.e., retain valid negative ULR values) and the NRC App. D approach (i.e., censor negative ULR values). Full results of this investigation (which was carried out on the Westinghouse workstations using the IMSL Library routines documented in Ref. 21) are in Ref. 24. A summary follows.

Define the “baseline parent normal distribution” to be the (normal) distribution of daily ULR values observed when carrying out the daily two-hour measurement(s). (Appendix G herein documents that these observations are essentially normal. Table G-5 of Appendix G shows typical values for Seabrook, Comanche Peak Unit 1 and Comanche Peak Unit 2.) These observations will typically include both negative and positive values as shown in Figures G-3, G-15, and G-18. Denote the mean and standard deviation of the baseline parent distribution as: (μ , σ). When all negative values are removed or “censored”, the

resulting value of the mean and standard deviation will change. Denote the mean of the censored data as: $MEAN_{\text{censored}}$ and the standard deviation as $STDDEV_{\text{censored}}$.

Intuitively, $MEAN_{\text{censored}}$ will always be greater than μ and the two will tend to be closer together as μ increases for a given value of σ (i.e., as μ increases, there will be fewer negative ULR values). Similarly, $STDDEV_{\text{censored}}$ will always be smaller than σ since the censored data is less “spread out”. Finally, for a given positive μ , the two standard deviations will tend to be closer together as σ decreases since fewer negative values will be observed. (For example, if μ is +.05 gpm and σ is +.005 gpm, a daily value will have to be 10 standard deviations below the mean to be censored.)

Equations 79 and 80 of Chapter 13 of Ref. 29 give formulas which express the mean and standard deviation of the censored (i.e., NRC App. D) data in terms of the baseline parent normal distribution parameters (i.e., (μ, σ)) and integrals of the normal probability distribution. These formulas are more manageable if the baseline parent mean (μ) is expressed as a multiple (α) of the baseline parent standard deviation (σ) as shown in Eqn. I.1:

Eqn. I.1 $\mu = \alpha \sigma$ where α is defined as: μ / σ

In this case, the censored baseline mean and standard deviation can be written as:

Eqn. I.2 $MEAN_{\text{censored}} = f(\alpha) \sigma$

Eqn. I.3 $STDDEV_{\text{censored}} = g(\alpha) \sigma$

The functions f and g were numerically evaluated on the Westinghouse workstations for values of α from 0.0 to 5.0 in steps of .01. All values are documented in Ref. 24. In addition, Equations I.2 and I.3 were confirmed using direct simulation for several selected values of α (i.e., censored means and standard deviations were calculated by generating normal deviates with specified parent values and deleting all negative observations). Two values of f and g which were used in downstream simulations of the PWROG and NRC App. D Action Levels are:

Eqn. I.4 ($\mu = 0.0, \sigma = \text{any positive value}$) $MEAN_{\text{censored}} = .79788 \sigma$

Eqn. I.5 ($\mu = 0.0, \sigma = \text{any positive value}$) $STDDEV_{\text{censored}} = .60281 \sigma$

Eqn. I.6 ($\mu = \sigma, \sigma = \text{any positive value}$) $MEAN_{\text{censored}} = 1.2876 \sigma$

Eqn. I.7 ($\mu = \sigma, \sigma = \text{any positive value}$) $STDDEV_{\text{censored}} = .79353 \sigma$

Note that Eqn. I.4 and I.5 describe Comanche Peak Unit 2 which had essentially a zero parent mean and that Eqn. I.6 and I.7 describe Seabrook and Comanche Peak Unit 1

which had baseline means and standard deviations which were approximately equal (see Table G-5 of Appendix G).

A series of simulations examined a sample of 10,000 daily ULR values from the above two parent distributions (i.e., $\alpha = 0.0$ and $\alpha = 1.0$). In principle, all 3 Action Levels could occur every one of the 10,000 days for the PWROG and every day that had a positive leak rate for NRC App. D.

Simulations were performed for “step jumps” of varying size starting on Day 1 of 10000 and persisting at the Day 1 value throughout. The size of the “step jumps” were expressed as a multiple of the baseline parent standard deviation (i.e., $\lambda\sigma$) as in Section 11. That is, if the baseline parent mean and standard deviation are (μ, σ) then the mean and standard deviation of the daily ULR values after the jump will be normally distributed with parameters $(\{\mu + \lambda\sigma\}, \sigma)$ – that is, the mean of the data will increase by $\lambda\sigma$ and the standard deviation about the increased mean will remain at the baseline value of σ exactly as described in Sec. 11.

Note that the NRC App. D algorithm will see exactly the same normally distributed ULR data as the PWROG algorithm. The difference is that the NRC App. D algorithm will ignore negative daily ULR values and will use different baseline mean and standard deviation values (i.e., Eqn. I.2 and I.3) to see if Action Levels I,II,III are entered.

The simulations used values of $\{0.0, 0.25, 0.50, 1.0, 2.0, 3.0, 4.0, 5.0\}$ for λ . In all cases, the number of Action Level I, II, and III events for each approach (i.e., PWROG and NRC App. D) were tallied. In addition, the total number of positive daily values was tallied for use in comparing PWROG and NRC App. D results.

All results are documented in Ref. 24. Herein, we restrict our attention to one “interesting” case where the baseline mean is exactly 0.0 (i.e., $\mu = 0.0$) and the “step jump” is 1.0σ (i.e., λ is 1.0). This case is “interesting” because the baseline mean has about the “worst” value it can have in terms of causing differences between the two approaches and the “step jump” of 1.0σ closely corresponds to the “minimum level of detectability” documented in section 11.4. The number of events for each Action Level are:

- Action Level I: PWROG (2136 events out of 10,000 days)
- Action Level I: NRC App. D (240 events out of 8412 days) & (1588 negative values)

- Action Level II: PWROG (650 events out of 10,000 days)
- Action Level II: NRC App. D (758 events out of 8412 days)

- Action Level III: PWROG (229 events out of 10,000 days)
- Action Level III: NRC App. D (499 events out of 8412 days)

Comments regarding these results are:

- The PWROG results would be identical for any choice of the baseline parent values of μ and σ provided that the “step jump” remains at “1.0 σ ” as discussed in Section 11.3.2.1. However, the NRC App. D results would continuously change (and come into closer agreement with the PWROG results) as μ increases from the “worst” value of 0.0. For example, when $\mu = \sigma$ as in Eqns. I.6 and I.7, the PWROG Action Level I values remain unchanged (i.e., 2136 events out of 10,000 days) and the NRC Action Level I events increase to 1031 out of 9756 (non-negative) days.
- When the baseline mean remains fixed at 0.0 and the “step jump” increases, the two algorithms come into closer agreement and all counts approach 10,000. For example, when the “step jump” is 3.0 σ , the PWROG Action Level I count is 9928 events out of 10,000 days and the NRC App. D count is 8837 events out of 9992 (non-negative) days.
- Overall, it appears that the NRC App. D algorithm is significantly less likely to enter into Action Level I (240/8412 –or- 2.85%) versus 21.36% for the PWROG algorithm and is slightly more likely to enter Action Level III (499/8412 –or- 5.93%) versus 2.29%. Of course, it is a simple matter to “adjust” any algorithm to enter a given Action Level more or less frequently (i.e., the number of exceedences above the baseline mean can be reduced to 7 or 8 instead of 9 or, conversely, increased to 10 or 11). The key issue is to have a high probability of entering the correct Action Level for a given event so that the severity of the event is commensurate with the associated actions invoked by the Action Level. WCAP-16423-NP together with WCAP-16465-NP document that this objective is achieved for the PWROG algorithm(s).
- As in all stochastic simulations, these results will vary slightly with the starting random number seed used in the simulation. The large number of days (i.e., 10,000) minimizes this variability.

These results do not account for the sampling error associated with the determination of the baseline mean and standard deviation. That is, these values are typically obtained from 3 months of daily observations and will vary slightly from one quarter to the next even if there is no change in the leak rate. Note that about 50% of the values will be censored when the baseline mean is near 0.0 so the quarterly NRC App. D mean would be based on about 45 values rather than 90.

Comments on Appendix G

Both the section appended to the draft report and the separate PDF file labeled *WCAP-16423 Appendix G Rev 0* contain additional tabular and graphical exhibits, with some comment, supplied by 5 member utilities. Section G-3 summarizes the same methodology presented in Section 11.0 and reviewed above, which is applied to the aforementioned data. Table G-5 summarizes results for Seabrook, the two Comanche Peak units and Ginna. I have already commented on this table in my review of Section 11, page 48. I have no further comments on this Appendix.

Comments on WCAP-16465-Section 5

This section defines action levels and response guidance. The statistical methodology discussion duplicates (in less detail) what has already been reviewed in Section 11 of WCAP-16423. What follows are primarily editorial or clarification comments.

Page 18: Section 5. 1 does not specify that negative leak rates should be retained (despite the admonition to do so in WCAP-16423).

ACTION:

We will add a comment regarding the fact that negative leak rates should be retained along with a reference to the appropriate Section of WCAP-16423.

Page 19: Steps 1 and 2 should clearly define the null hypothesis (H_0) and alternative hypothesis being tested. For example, the t-test examines the null of $H_0: \mu(i) = \mu(i-1)$; that is the i th quarter's mean relative to the previous quarter. If the alternative is $H_a: \mu(i) \neq \mu(i-1)$, this will lead to different actions than if only upward changes are of concern ($H_a: \mu(i) > \mu(i-1)$). Presumably, the latter 1-tail test is to be preferred.

RESPONSE:

The six items shown on p. 19 in this draft are “out of date”. They will be replaced by the seven “suggestions” shown in Section 11.12 of Ref. 2. However, “Suggestion 3” is about the same as Item 1 on p. 19. We included pp. A-23 to A-37 in App. A of Ref. 2 and a detailed discussion of the F and t-test in App. G of Ref. 2 (including numerous examples of Excel outputs).

We agree that the most likely and potentially significant reason for failing these tests is a slowly creeping mean. However, poor control of the process parameters can also result in failing both tests (with the newest mean significantly lower than the oldest mean). The examples shown in App. G center on testing to see if one mean is significantly higher than the other.

There have been very few comments about these tests from the Members. Our real objective in this area is to have Members examine their Quarterly (or Monthly) mean and standard deviation values using these tests or by simply looking for graphical trends before they blindly update the baseline values.

ACTION:

We will add a pointer to this discussion in Section 11.12 of Ref. 2 (and herein).

Page 21: With regard to Absolute Unidentified Leak Rate Limits, it is stated that “The {7} day rolling average should be calculated by setting any negative values to 0.0 prior to performing the average.”

This seems less conservative than simply removing them from the rolling average calculations. It has the potential effect of partially masking large leak rate entries by averaging with one or more zero entries.

RESPONSE:

The rationale for setting negative values to “0.0” in Sections 5.2.1 and 5.2.3 is discussed in Customer Comments # 12, 16, 28 in Attachment 11.1. In summary, whenever “absolute limits” are stated (i.e., limits in gpm or gal), no credit is taken for negative values which are considered “not real” since these negative values would move the parameter under consideration away from the (positive) limit. However, credit is taken for the fact that a valid (i.e., within the limits of validity stated in Ref. 2) measurement was performed. This credit is applied by including a value of “0.0” for the valid measurement. (Note that if we simply rejected the valid measurement and had a “missing value” for that day, Sections 5.2.1 and 5.2.3 state that the value from the previous day be used in place of the missing value.) As discussed in Customer Comment #16, this issue doesn’t seem very relevant when a large step change in the leak rate has occurred since it would be unlikely to get significant negative readings in that case.

ACTION:

We will add a pointer to this discussion in Sections 5.2.1 and 5.2.3.

Page 23: Note at the beginning of Section 5.2.2 that these “run” measures (adapted from statistical quality control of production processes) are designed to pick up a sudden, sustained shift in the process generating the data. A subsequent section (5.3) will talk about looking for evolving trends.

ACTION:

We will add this comment to Section 5.2.2.

Page 28-30: The action guidelines seem clear and actionable to me. Presumably, they pass muster with the people who will implement them.