Final Report Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants

VSL-04R4800-1, Rev. 0, 5/6/04

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Office of River Protection

P.O. Box 450
Richland, Washington 99352

**Approved for Public Release,
Further Dissemination Unlimited**

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Final Report

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prepared by

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for

Duratek, Inc.

and

Bechtel National, Inc.

5/13/04
E. W. L. Tanosaitis

**ACCEPTED FOR
PROJECT USE**

March 8, 2004

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The Catholic University of America
Vitreous State Laboratory

DM1200 Melter Testing with Reductants
Final Report, VSL-04R4800-1, Rev. 0

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Test Exceptions: 24590-HLW-TEF-RT-03-038, 24590-HLW-TEF-RT-03-047
Test Plan: VSL-03T3800-1, Rev. 0
R&T Focus Area(s): HLW Vitrification, HLW Off-Gas
Test Scoping Statement(s): VH-4, VHO-3, VHO-2, VH-5

Completeness of Testing:

This report describes the results of work and testing specified by the above-listed Test Specification(s), Test Plan(s), and Text Exception(s). The work and any associated testing followed established quality assurance requirements and was conducted as authorized. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Results required by the Test Plan are reported. Also reported are any unusual or anomalous occurrences that are different from the starting hypotheses. The test results and this report have been reviewed and verified.

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VSL Program Director/Principal Investigator

Date: 5/6/04

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Date: 5/6/04

TABLE OF CONTENTS

List of Tables.....	5
List of Figures.....	8
List of Abbreviations.....	14
SUMMARY OF TESTING.....	15
SECTION 1.0 INTRODUCTION.....	27
1.1 Test Objectives.....	28
1.2 Test Overview.....	29
1.3 Quality Assurance.....	30
1.4 Melter System Description.....	30
1.4.1 Feed System.....	30
1.4.2 Melter System.....	31
1.4.3 Off-Gas System.....	32
SECTION 2.0 WASTE SIMULANT AND GLASS FORMULATIONS.....	35
2.1 AZ-101 Waste Simulant.....	35
2.2 AZ-101 Glass and Melter Feed Formulations.....	36
2.3 C-106/AY-102 Waste Simulant.....	37
2.4 C-106/AY-102 Glass and Melter Feed Formulations.....	38
2.5 Analysis of Feed Samples.....	39
2.5.1 General Properties.....	39
2.5.2 Rheology.....	39
2.5.3 Chemical Composition.....	40
SECTION 3.0 DM1200 OPERATIONS.....	42
SECTION 4.0 MELTER AND SBS ENERGY BALANCE.....	46
4.1 Introduction to Energy Balance.....	46
4.2 Methodology.....	46
4.2.1 Assumptions Used for Energy Balance Calculations.....	48
4.2.2 Calculation Details.....	50
4.3 Results of Energy Balance Analysis.....	52
4.3.1 Overview.....	52
4.3.2 Energy Balance Results for Test 5 (C-106/AY-102 Feed with Variable Amounts of Sugar).....	54
4.3.3 Energy Balance Results for Test 6 (C-106/AY-102 with Added Nitrate and Variable Amounts of Sugar).....	54
4.3.4 Energy Balance Results for Test 4 (AZ-101 with Variable Amounts of Sugar).....	54
4.3.5 Summary and Conclusions.....	55
SECTION 5.0 OFF-GAS SYSTEM PERFORMANCE.....	56
5.1 Off-Gas System Test Results.....	56
5.1.1 Melter Pressure.....	56
5.1.2 SBS Performance.....	59
5.1.3 WESP Performance.....	64
5.1.4 HEME #1.....	68
5.1.5 HEPA Filter.....	68
5.1.6 Thermal Catalytic Oxidizer and Selective Catalytic Reduction Unit.....	69
5.1.7 Silver Mordenite System.....	71
5.1.8 Packed Bed Scrubber (PBS).....	71
5.1.9 HEME #2.....	72
5.1.10 Effluent Liquid Treatment System.....	72
5.2 SBS, WESP, HEME, and PBS Process Fluids.....	73
5.2.1 SBS Fluids.....	73
5.2.2 WESP, PBS, and HEME Fluids.....	75
5.2.3 Estimates of Accumulations in SBS, WESP, HEME and PBS and Fluids.....	76
SECTION 6.0 GLASS PRODUCT.....	78
6.1 Compositional Analysis.....	78
6.2 Iron Redox State.....	79
SECTION 7.0 MONITORED OFF-GAS EMISSIONS.....	80
7.1 Particulate and Gaseous Emissions.....	80

7.2	Particle Size Distribution.....	82
7.3	FTIR Analysis.....	82
7.4	Hydrogen by Gas Chromatography	83
7.5	Silver Mordenite column and Iodine Mass Balance	84
SECTION 8 DM1200 TESTS WITH RUTHENIUM.....		86
8.1	Introduction	86
8.2	Ruthenium and Yttrium Spiking.....	86
8.2.1	Target Concentration of Ruthenium in the Glass.....	86
8.2.2	Selection of Ruthenium Source Chemical for Testing.....	87
8.2.3	Ruthenium Spike Solution.....	87
8.2.4	Yttrium Tracer	87
8.2.5	Spike Delivery System.....	88
8.3	Sampling and Analyses.....	88
8.3.1	Discharged Glass	88
8.3.2	Melt Pool	89
8.3.3	Cold Cap.....	89
8.3.4	Melter Feed.....	89
8.3.5	Off-gas System	90
8.4	Results	90
8.4.1	Ruthenium in the Discharged Glass.....	91
8.4.2	Ruthenium in the Melt Pool.....	91
8.4.3	Ruthenium in the Off-Gas System	92
8.5	Discussion.....	93
8.5.1	Ruthenium in Discharged Glass.....	93
8.5.2	Ruthenium in the Melt Pool.....	94
8.5.3	Ruthenium in the Off-Gas System	96
8.5.4	WTP Melter Lifetime Estimate.....	97
8.6	Summary and Conclusions	97
SECTION 9.0 SUMMARY AND CONCLUSIONS		99
SECTION 10.0 REFERENCES		101

List of Tables

Table 2.1	Compositional Summary of Different Waste Streams and Blended Solids.....	T-1
Table 2.2.	Compositional Summary (Oxide Basis) of the AZ-101 HLW Simulant, Glass Additives, Target Test Glass, and the Corresponding Crucible-Melt Glass (HLW98-77).....	T-2
Table 2.3	Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from AZ-101 HLW Simulant (22.6 wt% total solids)	T-3
Table 2.4	Compositional Summary of Different Waste Streams and Blended Solids for the C-106/AY-102 HLW Simulant.....	T-4
Table 2.5.	Compositional Summary (oxide basis) of the C-106/AY-102 HLW Simulant, Glass Additives, Target Test Glass, and the Reference Glass (HLW98-86).....	T-5
Table 2.6	Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from C-106/AY-102 HLW Simulant (20 wt% suspended solids).....	T-6
Table 2.7	Properties for DM1200 Melter Feed Samples	T-7
Table 2.8	XRF Analyzed Compositions (wt%) for Melter feed Samples from Test 5 (C-106/AY-102 with variable amounts of sugar)	T-8
Table 2.9	XRF Analyzed Compositions (wt%) for Melter Feed Samples from Test 6 (C-106/AY-102, with Added Nitrate and variable amounts of sugar).....	T-9
Table 2.10	XRF Analyzed Compositions (wt%) for Melter feed Samples from Test 4 (AZ-101 with variable amounts of sugar and Ru/Y spike).....	T-10
Table 3.1	Summary of Test Conditions and Results for Test 5	T-12
Table 3.2	Summary of Test Conditions and Results for Test 6	T-13
Table 3.3	Summary of Test Conditions and Results for Test 4	T-14
Table 3.4	DM1200 Melter System Measured Parameters for Test 5.....	T-15
Table 3.5	DM1200 Melter System Measured Parameters for Test 6.....	T-16
Table 3.6	DM1200 Melter System Measured Parameters for Test 4.....	T-17
Table 4.1	The DM1200 Melter Energy Balance Calculation Methodology	T-18
Table 4.2	Calibration Data for the Melter Shell Convection Heat Loss Calculation Derived from Transition Line Measurements	T-21
Table 4.3	Closure of Overall Energy Balance Calculations	T-21
Table 4.4	Comparison between the Process-Side and the Water-Side Approach for Calculating SBS Energy Transfer	T-22
Table 4.5	Water Balance Closure	T-22
Table 4.6	Individual Test Melter-Only Energy Balance, and Comparison between Melter-Only and Melter + SBS Energy Balances	T-23
Table 4.7	Melter and SBS Thermal Duties during Test 5.....	T-24
Table 4.8	Melter and SBS Thermal Duties during Test 6.....	T-25
Table 4.9	Melter and SBS Thermal Duties during Test 4.....	T-26
Table 5.1	Summary of Off-Gas Operational Events and Equipment Inspections and Modifications During the HLW Bubbler Configuration and Reductant Test Series	T-27
Table 5.2	Reductant Tests Measured Off Gas System Parameters	T-31
Table 5.3	Time Needed to Restore Power after Deluge of WESP during Tests 5 and 6	T-36
Table 5.4	Time Needed to Restore Power after Deluge of WESP and Duration of Spray Water Flow Interruption during Test 4.....	T-37
Table 5.5	Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR Catalytic Unit during Test 5.....	T-38
Table 5.6	Gas Residence Times in TCO.....	T-39
Table 5.7	Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR Catalytic Unit during Test 6.....	T-40
Table 5.8	Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR Catalytic Unit during Test 4.....	T-41
Table 5.9	Listing of Samples from SBS Blow-Downs.....	T-42
Table 5.10	Analytical Results for Selected SBS Blow-Down Fluids	T-48
Table 5.11	Anion Concentrations in SBS Blow-Down Liquids	T-49
Table 5.12	Listing of Samples from WESP Blow-Downs.....	T-50
Table 5.13	Listing of Samples from PBS Blow-Downs.....	T-52

Table 5.14	Listing of Samples from HEME 1 Blow-Downs.....	T-54
Table 5.15	Analytical Results for Dissolved Solids in Select WESP Blow-Down Fluids	T-55
Table 5.16	Anion Concentrations for PBS and HEME Blow-Down Liquids.....	T-56
Table 5.17	Upper Estimates of Accumulations in Off-Gas Liquids from Test 5.....	T-57
Table 5.18	Upper Estimates of Accumulations in Off-Gas Liquids from Test 6.....	T-58
Table 5.19	Upper Estimates of Accumulations in Off-Gas Liquids from Test 4.....	T-59
Table 6.1	Listing of Glass Discharged, Masses, and Analysis Performed.....	T-60
Table 6.2	XRF Analyzed Compositions of Discharged Glasses from Test 5	T-73
Table 6.3	XRF Analyzed Compositions of Discharged Glasses from Test 6	T-75
Table 6.4	XRF Analyzed Compositions of Discharged Glasses from Test 4	T-77
Table 6.5	Listing of Glass Grab Samples and Measured Iron Oxidation State	T-79
Table 6.6	Measured Iron Oxidation State of Discharge Glasses	T-82
Table 7.1	Summary of Method 29 Particulate Matter Results.....	T-83
Table 7.2	Results from Test 5B Emissions Sampling.....	T-84
Table 7.3	Results from Test 5C Emissions Sampling.....	T-85
Table 7.4	Results from Test 5D Emissions Sampling	T-86
Table 7.5	Results from Test 5E Emissions Sampling.....	T-87
Table 7.6	Results from Emissions Sampling Test 6B.....	T-88
Table 7.7	Results from Test 6C Emissions Sampling.....	T-89
Table 7.8	Results from Test 6D Emissions Sampling	T-90
Table 7.9	Results from Test 6E Emissions Sampling	T-91
Table 7.10	Results from Test 4B Emissions Sampling.....	T-92
Table 7.11	Results from Test 4C Emissions Sampling.....	T-93
Table 7.12	Results from Test 4D Emissions Sampling	T-94
Table 7.13	Results from Test 4E Emissions Sampling.....	T-95
Table 7.14	Particulate DFs for AZ-101 and C-106/AY-102 Tests at 65 lpm Bubbling	T-96
Table 7.15	Particle Size Distribution Results for Test 5 Melter Emissions.....	T-97
Table 7.16	Particle Size Distribution Results for Test 6 Melter Emissions.....	T-98
Table 7.17	Particle Size Distribution Results for Test 4 Melter Emissions.....	T-99
Table 7.18.a	Test 5 Average Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-100
Table 7.18.b	Test 5 Concentration [ppmv] Ranges of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-101
Table 7.19.a	Test 6 Average Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-102
Table 7.19.b	Test 6 Concentration [ppmv] Ranges of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-103
Table 7.20.a	Test 4 Average Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-104
Table 7.20.b	Test 4 Concentration [ppmv] Ranges of Selected Species in Off-Gas Measured by FTIR Spectroscopy.....	T-105
Table 7.21	Average Hydrogen Concentrations Measured by Gas Chromatography at the WESP Outlet.....	T-106
Table 7.22	Concentration of Iodine (µg/dscf) in Off-Gas Slipstream Around Silver Mordenite Column	T-106
Table 7.23	Halogen Concentrations (µg/dscf) in Off-Gas Slipstream Around Silver Mordenite Column while Feeding an Iodine-Free Composition (Test 6)	T-106
Table 7.24	Iodine Mass Balance Summary for Test 5.....	T-107
Table 8.1	Compilation of Information on Noble Metals Concentrations in Envelope D waste Streams (wt%)	T-108
Table 8.2	Metal Concentrations in RuNO(NO ₃) ₃ and Spike Solutions (DCP-AES)	T-109
Table 8.3	Y ₂ O ₃ and RuO ₂ Concentrations in Discharged Glass (XRF Results).....	T-110
Table 8.4	Identification of Samples from the Melt Pool.....	T-112
Table 8.5	Ruthenium in Melter Emission Samples (Sampling: EPA Method 29).....	T-113
Table 8.6	Ruthenium in selected SBS blow-down samples.....	T-113
Table 8.7	Semi-Quantitative Composition Analysis of Nickel Sulfide Phase (Sample 112-O-42A, Port C1).....	T-113

Table 8.8	Comparison of Ruthenium Volatility in DM1200 Tests with AZ-101 Feeds with and without Sugar.....	T-114
Table 8.9	Comparison of Ruthenium Retention in the Melter in DM1200 Tests with AZ-101 Feeds with and without Sugar.....	T-114

List of Figures

Figure 1.1	Cross-section of the DM1200 melter through the discharge chamber.....	F-1
Figure 1.2	Cross-section through the DM1200 melter showing electrodes	F-2
Figure 1.3	Schematic diagram of DM1200 off-gas system.....	F-3
Figure 1.4	Sulfur activated carbon and silver mordenite slipstream off-gas treatment system.....	F-4
Figure 2.1	Viscosity vs. shear rate of C-106/AY-102 (50 g glass/l) melter feed samples	F-5
Figure 2.2	Viscosity vs. shear rate of AZ-101 (400 g glass/l) melter feed samples.....	F-6
Figure 3.1.a	Production rate for Test 5 (C-106/AY-102, 550 g glass/l)	F-7
Figure 3.1.b	Production rates for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l)	F-8
Figure 3.1.c	Production rates for Test 4 (AZ-101, 400 g glass/l)	F-9
Figure 3.2.a	Glass temperatures (hourly averages) for Test 5 (C-106/AY-102, 550 g glass/l).....	F-10
Figure 3.2.b	Glass temperatures (hourly averages) for Test 6 (C-106/AY-102 with nitrates 550 g glass/l).....	F-11
Figure 3.2.c	Glass temperatures (hourly averages) for Test 4 (AZ-101, 400 g glass/l).....	F-12
Figure 3.3.a	Plenum temperatures and electrode power (hourly averages) for Test 5.....	F-13
Figure 3.3.b	Plenum temperatures and electrode power (hourly averages) for Test 6.....	F-14
Figure 3.3.c	Plenum temperatures and electrode power (hourly averages) for Test 4.....	F-15
Figure 3.4.a	Electrode temperatures and power (hourly averages) for Test 5	F-16
Figure 3.4.b	Electrode temperatures and power (hourly averages) for Test 6	F-17
Figure 3.4.c	Electrode temperatures and power (hourly averages) for Test 4	F-18
Figure 3.5.a	Electrode power and glass resistance for Test 5	F-19
Figure 3.5.b	Electrode power and glass resistance for Test 6	F-20
Figure 3.5.c	Electrode power and glass resistance for Test 4	F-21
Figure 3.6.a	Glass density and level for Test 5.....	F-22
Figure 3.6.b	Glass density and level for Test 6.....	F-23
Figure 3.6.c	Glass density and level for Test 4.....	F-24
Figure 3.7.a	Glass pool bubbling for Test 5.....	F-25
Figure 3.7.b	Glass pool bubbling for Test 6.....	F-26
Figure 3.7.c	Glass pool bubbling for Test 4.....	F-27
Figure 4.1	Schematic illustration of DuraMelter 1200 energy balance concept	F-28
Figure 4.2.a	Average DM1200 melter skin temperatures, north face	F-29
Figure 4.2.b	Average DM1200 melter skin temperatures, south face	F-29
Figure 4.2.c	Average DM1200 melter skin temperatures, west face	F-30
Figure 4.2.d	Average DM1200 melter skin temperatures, east face	F-30
Figure 4.2.e	Average DM1200 melter skin temperatures, top face	F-31
Figure 4.3	West side view of DM1200 melter.....	F-32
Figure 4.4	Top view of DM1200 melter	F-33
Figure 4.5	SBS energy transfer pathways schematic	F-34
Figure 4.6	Melter energy balance values during Test 5 with C-106/AY-102 feed	F-35
Figure 4.7	SBS energy balance values during Test 5 with C-106/AY-102 feed.....	F-36
Figure 4.8	Melter energy balance values during Test 6 with C-106/AY-102 feed	F-37
Figure 4.9	SBS energy balance values during Test 6 with C-106/AY-102 feed.....	F-38
Figure 4.10	Melter energy balance values during Test 4 2 with AZ-101 feed.....	F-39
Figure 4.11	SBS energy balance values during Test 4 with AZ-101 feed.....	F-40
Figure 5.1	Average gas temperatures along the DM1200 off-gas train during Test 5	F-41
Figure 5.2	Average gas temperatures along the DM1200 off-gas train during Test 6	F-42
Figure 5.3	Average gas temperatures along the DM1200 off-gas train during Test 4	F-43
Figure 5.4	Transition line and film cooler differential pressures (hourly average values) during Test 5.....	F-44
Figure 5.5	Melter pressure at instrument port and control air flow rate during Test 5	F-45
Figure 5.6	Transition line and film cooler differential pressures (hourly average values) during Test 6.....	F-46
Figure 5.7	Melter pressure at instrument port and control air flow rate during Test 6	F-47
Figure 5.8	Transition line and film cooler differential pressures (hourly average values) during Test 4.....	F-48
Figure 5.9	Melter pressure at instrument port and control air flow rate during Test 4	F-49
Figure 5.10	a) View from below SBS Downcomer	

	b) View of new "crown" installed on March 28, 2003 before Test 5	F-50
Figure 5.11	Layout of film cooler and transition line sections	F-51
Figure 5.12	SBS Y-piece connecting transition line bellows to the SBS inlet.....	F-52
Figure 5.13	SBS inlet and outlet gas temperatures during Test 5	F-53
Figure 5.14	SBS inlet, outlet and differential pressures (hourly average values) during Test 5	F-54
Figure 5.15	SBS cooling water and bed temperature (hourly average values) during Test 5	F-55
Figure 5.16	SBS jacket, inner coil and heat exchanger water flow rates (hourly average values) during Test 5	F-56
Figure 5.17	Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values) during Test 5	F-57
Figure 5.18	SBS inner coil and plate heat exchanger water temperatures (hourly average values) during Test 5	F-58
Figure 5.19	Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Test 5	F-59
Figure 5.20	View looking down SBS downcomer, immediately below Y-inlet, after Test 5.....	F-60
Figure 5.21	View looking down SBS downcomer, mid-body after Test 5	F-61
Figure 5.22	View looking down SBS downcomer, ~8" above downcomer base after Test 5.....	F-62
Figure 5.23	View looking down SBS downcomer, from base of downcomer, after Test 5.....	F-63
Figure 5.24	SBS inlet and outlet gas temperatures during Test 6	F-64
Figure 5.25	SBS inlet, outlet and differential pressures (hourly average values) during Test 6	F-65
Figure 5.26	SBS cooling water and bed temperatures (hourly average values) during Test 6.....	F-66
Figure 5.27	SBS jacket, inner coil and heat exchanger water flow rates (hourly average values) During Test 6.....	F-67
Figure 5.28	Calculated heat loads on the cooling jacket and plate heat exchanger (hourly Average values) during Test 6.....	F-68
Figure 5.29	SBS inner coil and plate heat exchanger water temperatures (hourly average Values) during Test 6	F-69
Figure 5.30	Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Tests 6.....	F-70
Figure 5.31	View of the SBS overflow tank residual solids after Test 6.....	F-71
Figure 5.32	IR image looking down SBS downcomer, ~8" above downcomer base, before Cleaning after Test 6.....	F-72
Figure 5.33	IR image looking down SBS downcomer, ~6" above downcomer base, after cleaning, after Test 6.....	F-73
Figure 5.34	IR image looking down SBS downcomer, ~5'6" down from top, after cleaning After Test 6.....	F-74
Figure 5.35	SEM micrograph of a particle in Sample W12-O-142B.....	F-75
Figure 5.36	General EDS spectra of sample W12-O-142B	F-76
Figure 5.37	EDS spectra of region #1 indicated in Figure 5.35.....	F-77
Figure 5.38	a) View from above SBS packed bed before installation	F-78
	b) After installation of SBS downcomer upper sleeve.....	F-79
Figure 5.39	SBS inlet and outlet gas temperatures during Test 4	F-80
Figure 5.40	SBS inlet, outlet and differential pressures (hourly average values) during Test 4	F-81
Figure 5.41	SBS cooling water and bed temperatures (hourly average values) during Test 4.....	F-82
Figure 5.42	SBS jacket, inner coil and heat exchanger water flow rates (hourly average Values) during Test 4	F-83
Figure 5.43	Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values) During Test 4.....	F-84
Figure 5.44	SBS inner coil and plate heat exchanger water temperatures (hourly average values) During Test 4.....	F-85
Figure 5.45	Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Test 4	F-86
Figure 5.46	IR image looking down from near top of downcomer (bottom of Y-inlet From transition line) after Test 4.....	F-87
Figure 5.47	IR image looking down from about 66" below top of downcomer after Test 4	F-88
Figure 5.48	IR image looking down about 8" above bottom of downcomer after Test 4	F-88

Figure 5.49	IR image looking down from bottom of downcomer after Test 4	F-89
Figure 5.50	WESP inlet and outlet temperatures during Test 5	F-90
Figure 5.51	WESP differential pressure and outlet gas flow rate (hourly average values) during Test 5	F-91
Figure 5.52	Accumulated WESP blow-down volume, accumulated fresh spray water and water removed From off-gas during Test 5	F-92
Figure 5.53	Voltage and current across the WESP during Test 5	F-93
Figure 5.54	View of WESP grid support: degradation of FEP heat-shrink after Test 5	F-94
Figure 5.55	WESP inlet sump, pre-deluge, thin layer of feed particulates in sump after Test 5	F-95
Figure 5.56	WESP view from bottom of grid/collectors, pre-deluge after Test 5	F-96
Figure 5.57	WESP view from bottom of grid/collectors, pre-deluge after Test 5	F-97
Figure 5.58	WESP view from bottom of grid/collectors, post-deluge after Test 5	F-98
Figure 5.59	WESP view from bottom of grid/collectors, post-deluge after Test 5	F-99
Figure 5.60	WESP inlet and outlet temperatures during Test 6	F-100
Figure 5.61	WESP differential pressure and outlet gas flow rate (hourly average values) during Test 6	F-101
Figure 5.62	Accumulated WESP blow-down volume, accumulated fresh spray water and water removed from off-gas during Test 6	F-103
Figure 5.63	Voltage and current across the WESP during Test 6	F-103
Figure 5.64	View looking at grid from bottom, pre-deluge after Test 6	F-104
Figure 5.65	View of WESP grid and collectors from below, post-deluge after Test 6	F-105
Figure 5.66	SEM micrograph of a sample removed from solids (Sample # W12-O-142A) accumulated at the bottom of WESP following deluge after Test 6	F-106
Figure 5.67	SEM micrograph of a sample removed from the WESP collector rods (Sample # W12-O-146A)	F-107
Figure 5.68	EDS spectra of regions #1 through region #5 indicated in Figure 5.67 (Sample # W12-O-146A)	F-108
Figure 5.69	EDS spectra of regions #5 through region #8 indicated in Figure 5.67 (Sample # W12-O-146A)	F-109
Figure 5.70	EDS spectra of region # 9 indicated in Figure 5.67 (Sample # W12-O-146A)	F-110
Figure 5.71	WESP inlet and outlet temperatures during Test 4. (Note: downward outlet temperature spikes are the result of WESP deluges)	F-111
Figure 5.72	WESP differential pressure and outlet gas flow rate (hourly average values) during Test 4	F-112
Figure 5.73	Accumulated WESP blow down volume, accumulated fresh spray water, and water Removed from off-gas during Test 4	F-113
Figure 5.74	Voltage and current across the WESP during Test 4	F-114
Figure 5.75	View from bottom of WESP grid, pre-deluge, after Test 4	F-115
Figure 5.76	View from bottom of WESP grid, pre-deluge, after Test 4	F-116
Figure 5.77	View from bottom of grid of WESP, post-deluge, after Test 4	F-117
Figure 5.78	View from bottom of WESP grid, post-deluge, after Test 4	F-118
Figure 5.79	Outlet temperature and differential pressure for HEME #1 during Test 5	F-119
Figure 5.80	Outlet temperature and differential pressure for HEME #1 during Test 6	F-120
Figure 5.81	Outlet temperature and differential pressure for HEME #1 during Test 4	F-121
Figure 5.82	Outlet temperature and differential pressure for HEPA #1 (hourly average Values) during Test 5	F-122
Figure 5.83	Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Test 6	F-123
Figure 5.84	Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Test 4	F-124
Figure 5.85	TCO/SCR heater gas inlet temperature during Test 5	F-125
Figure 5.86	TCO/SCR temperatures (hourly average values) during Test 5	F-126
Figure 5.87	TCO/SCR differential pressure (hourly average values) during Test 5	F-127
Figure 5.88	TCO/SCR heater gas inlet temperature during Test 6	F-128
Figure 5.89	TCO/SCR temperatures (hourly average values) during Test 6	F-129
Figure 5.90	TCO/SCR differential pressure (hourly average values) during Test 6	F-130
Figure 5.91	TCO/SCR heater gas inlet temperature during Test 4	F-131
Figure 5.92	TCO/SCR temperatures (hourly average values) during Test 4	F-132
Figure 5.93	TCO/SCR differential pressures (hourly average values) during Test 4	F-133

Figure 5.94	Silver mordenite column temperature during Test 5	F-134
Figure 5.95	Silver Mordenite column pressure during Test 5.....	F-135
Figure 5.96	Silver mordenite column temperature during Test 6	F-136
Figure 5.97	Silver Mordenite column pressure during Test 6.....	F-137
Figure 5.98	Inlet temperature and differential pressure for PBS (hourly average values) during Test 5	F-138
Figure 5.99	Sump temperature for PBS during Test 5	F-139
Figure 5.100	Inlet temperature and differential pressure for PBS (hourly average values) during Test 6.....	F-140
Figure 5.101	Sump temperature for PBS during Test 6.....	F-141
Figure 5.102	Inlet temperature and differential pressure for PBS (hourly average values) during Test 4.....	F-142
Figure 5.103	Sump temperature and pH for PBS during Test 4	F-143
Figure 5.104	Inlet and outlet temperatures and differential pressure for HEME #2 during Test 5.....	F-144
Figure 5.105	Inlet and outlet temperatures and differential pressure for HEME #2 during Test 6.....	F-145
Figure 5.106	Inlet and outlet temperatures and differential pressure for HEME #2 during Test 4.....	F-146
Figure 5.107	pH of SBS blow-down solutions	F-147
Figure 5.108	Accumulated SBS blow-down and feed water volume during Test 5	F-148
Figure 5.109	Accumulated SBS blow-down and feed water volume during Test 6	F-149
Figure 5.110	Accumulated SBS blow-down and feed water volume during Test 4	F-150
Figure 5.111	Test 5, C-106/AY-102 feed composition (excludes oxygen and carbon).....	F-151
Figure 5.112	Suspended solids composition from Test 5, SBS sample (U12-S-46A).....	F-152
Figure 5.113	Dissolved solids composition from Test 5, SBS sample (U12-S-46A).....	F-153
Figure 5.114	Test 6, C-106/AY-102 feed composition (excludes oxygen and carbon).....	F-154
Figure 5.115	Suspended solids composition from Test 6, SBS sample (W12-S-136A).....	F-155
Figure 5.116	Dissolved solids composition from Test 6, SBS sample (W12-S-136A)	F-156
Figure 5.117	Test 4, AZ-101 feed composition (excludes oxygen and carbon)	F-157
Figure 5.118	Suspended solids composition from Test 4, SBS sample (1I2-S-47A)	F-158
Figure 5.119	Dissolved solids composition from Test 4, SBS sample (1I2-S-47A).....	F-159
Figure 5.120	Dissolved solids composition from Test 5 WESP samples (U12-W-60A and B)	F-160
Figure 5.121	Dissolved solids composition from Test 6 WESP samples (W12-W-142A and B)	F-161
Figure 5.122	Dissolved solids composition from Test 4 WESP samples (1I2-W-47A and B).....	F-162
Figure 6.1	XRF analysis of sodium and silicon oxides in glasses from C-106/AY-102 testing	F-163
Figure 6.2	XRF analysis of selected oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).....	F-164
Figure 6.3	XRF analysis of manganese and strontium oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).....	F-165
Figure 6.4	XRF analysis of RCRA metal oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).....	F-166
Figure 6.5	XRF analysis of iodine and sulfur oxide in glasses from C-106/AY-102 testing (Tests 5 and 6).....	F-167
Figure 6.6	XRF analysis of sodium and silicon oxides in glasses from AZ-101 testing (Test 4)	F-168
Figure 6.7	XRF analysis of selected oxides in glasses from AZ-101 testing (Test 4)	F-169
Figure 6.8	XRF analysis of selected minor oxides in glasses from AZ-101 testing (Test 4).....	F-170
Figure 6.9	Measured divalent iron ratios in glasses from Test 5 (Test 5, C-106/AY-102 550 g glass/l).....	F-171
Figure 6.10	Measured iron ratios in glasses from Test 6	F-172
Figure 6.11	Measured divalent iron ratios in glasses from Test 4 (Test 4, AZ-101, 400 g glass/l)	F-173
Figure 7.1	Particulate melter emissions as a function of feed sugar content.....	F-174
Figure 7.2	Selenium melter emissions as a function of feed sugar content during C-106/AY-102 processing (Tests 5 and 6)	F-175
Figure 7.3	Arsenic and cesium melter emissions as a function of feed sugar content during C-106/AY-102 processing (Tests 5 and 6).....	F-176
Figure 7.4	Alkali and particulate melter emissions as a function of feed sugar content during AZ-101 processing (Test 4)	F-177
Figure 7.5	C-106/AY-102 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 5	F-178
Figure 7.6	Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 5E (C-106/AY-102 with 25 g sugar/L, 550 g glass/l)	F-179
Figure 7.7	SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 5E (C-106/AY-102 with 25 g sugar/L, 550 g glass/l)	F-180
Figure 7.8	WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds)	

	from Test Segments 5D and 5E (C-106/AY-102 and 20-25 g sugar/L, 550 g glass/l)	F-181
Figure 7.9	C-106/AY-102 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 6	F-182
Figure 7.10	Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test 6 (C-106/AY-102 with nitrates and 25 g sugar/L, 550 g glass/l)	F-183
Figure 7.11	SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test 6 (C-106/AY-102 with nitrates and 25 g sugar/L, 550 g glass/l)	F-184
Figure 7.12	WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds) for Test Segments 6D and 6E (C-106/AY-102 with nitrates and 25 g sugar/L, 550 g glass/l)	F-185
Figure 7.13	WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds) from Test Segment 6E during a WESP deluge (C-106/AY-102 with nitrates and 25 g sugar/L, 550 g glass/l)	F-186
Figure 7.14	AZ-101 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 4	F-187
Figure 7.15	Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4E (AZ-101, 12.5 g sugar/L, 400 g glass/l)	F-188
Figure 7.16	SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4E (AZ-101, 16 g sugar/L, 400 g glass/l)	F-189
Figure 7.17	WESP exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4C to 4D, (AZ-101, 10 and 12.5 g sugar/L, 400 g glass/l)	F-190
Figure 7.18	WESP exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4D to 4E (AZ-101, 12.5 and 16 g sugar/L, 400 g glass/l)	F-191
Figure 7.19	Concentration of NO at various points in the off-gas stream during Test 5 (C-106/AY-120, 550 g glass/l)	F-192
Figure 7.20	Concentration of CO at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l)	F-193
Figure 7.21	Concentration of water at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l)	F-194
Figure 7.22	Concentration of CO ₂ at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l)	F-195
Figure 7.23	Concentration of NO ₂ at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l)	F-196
Figure 7.24	Concentration of CO at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l)	F-197
Figure 7.25	Concentration of water at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l)	F-198
Figure 7.26	Concentration of CO ₂ at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l)	F-199
Figure 7.27	Concentration of ammonia at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l)	F-200
Figure 8.1	Flow sheet for injection of ruthenium into the DM1200 feed stream	F-201
Figure 8.2	Cumulative mass of RuO ₂ and Y ₂ O ₃ injected into the melter	F-202
Figure 8.3	Y ₂ O ₃ and RuO ₂ concentrations as a function of glass production	F-203
Figure 8.4	RuO ₂ and Y ₂ O ₃ concentrations as a function of glass produced during DM1200 testing with AZ-101	F-204
Figure 8.5	Ruthenium injection rate during DM1200 testing with AZ-101	F-205
Figure 8.6	Ratio of melter feed rate to ruthenium solution feed rate during DM1200 testing with AZ-101 ..	F-205
Figure 8.7	Comparison between measured and modeled increase of RuO ₂ and Y ₂ O ₃ concentration in DM1200	F-206
Figure 8.8	Glass redox and RuO ₂ concentration as a function of glass production	F-207
Figure 8.9	Backscattered electron image showing small Ru-containing particles present in a sample taken from middle level of the melter pool (112-O-42B, Port C1)	F-207
Figure 8.10	Backscattered electron image showing a cluster of RuO ₂ and perhaps spinel crystals in suction sample from the middle level of the melt pool (sample E12-B-104B)	F-208
Figure 8.11	Optical micrograph showing the macrostructure of a sample taken from the bottom of the melter (Sample 112-O-42D, port B3)	F-209

Figure 8.12	Backscattered electron image showing details of the microstructure in a sample taken from the bottom of the melter (1I2-O-42D, Port B3)	F-209
Figure 8.13	Backscattered electron image of a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1)	F-210
Figure 8.14	Chemical mapping of a sample taken from the bottom of the melter	F-211
Figure 8.15	EDS spectra of Ni sulfide (Ni_3S_2) in a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1).....	F-212
Figure 8.16	Backscattered electron image showing details of the microstructure in a sample taken from the bottom of the melter.....	F-213
Figure 8.17	EDS spectrum of Ru in a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1).....	F-214
Figure 8.18	Backscattered electron image of a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1	F-215
Figure 8.19	Backscattered electron image of a sample taken from the bottom of the melter	F-216
Figure 8.20	NiO and SO_3 concentrations as a function of glass production	F-217

List of Abbreviations

AA	Atomic Absorption Spectroscopy
ACM	Aspen Custom Modeler
ADS	Air Displacement Slurry
AOD	Air Operated Diaphragm
CFR	Code of Federal Regulation
DCP	Direct Current Plasma Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department Of Energy
FTIR	Fourier Transform Infrared Spectroscopy
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
i.d.	Inside Diameter
ISE	Ion Selective Electrode
LAW	Low Activity Waste
MS	Microsoft
MT	Metric Ton
ORP	Office of River Protection
PBS	Packed Bed Scrubber
PLC	Programmable Logic Controller
QAPjP	Quality Assurance Project Plan for Testing Programs Generating Environmental Regulatory Data
RPP	River Protection Project
RPP-WTP	River Protection Project-Waste Treatment Plant
SBS	Submerged Bed Scrubber
SCR	Selective Catalytic Reduction
TCO	Thermal Catalytic Oxidizer
TDS	Total Dissolved Solids
TFCOUP	Tank Farm Contractor Operation and Utilization Plan
TRU	Transuranic
TSS	Total Suspended Solids
VOC	Volatile Organic Compound
VSL	Vitreous State Laboratory
W.C.	Water Column
WESP	Wet Electrostatic Precipitator
WTP	Waste Treatment Plant
XRF	X-Ray Fluorescence

SUMMARY OF TESTING

A) Objectives

This report documents melter and off-gas performance results obtained on the DM1200 HLW Pilot Melter during processing of AZ-101 and C-106/AY-102 HLW simulants. The tests reported herein are a subset of three tests from a larger series of tests described in the Test Plan for the work; results from the remaining tests will be reported separately. Three nine day tests, one with AZ-101 and two with C-106/AY-102 feeds were conducted with variable amounts of added sugar to address the effects of redox. The test with AZ-101 included ruthenium spikes to also address the effects of redox on ruthenium volatility. One of tests addressed the effects of increased flow-sheet nitrate levels using C-106/AY-102 feeds. With high nitrate/nitrite feeds (such as WTP LAW feeds), reductants are required to prevent melt foaming and deleterious effects on glass production rates. Sugar is the baseline WTP reductant for this purpose. WTP HLW feeds typically have relatively low nitrate/nitrite content in comparison to the organic carbon content and, therefore, have typically not required sugar additions. However, HLW feed variability, particularly with respect to nitrate levels, may necessitate the use of sugar in some instances. The tests reported here investigate the effects of variable sugar additions to the melter feed as well as elevated nitrate levels in the waste. Variables held constant to the extent possible included melt temperature, bubbling rate, plenum temperature, cold cap coverage, the waste simulant composition, and the target glass composition.

The principal objectives of the DM1200 melter testing were to determine the achievable glass production rates for simulated HLW feeds with variable amounts of added sugar and increased nitrate levels; characterize melter off-gas emissions; characterize the performance of the prototypical off-gas system components as well as their integrated performance; characterize the feed, glass product, and off-gas effluents; and perform pre- and post test inspections of system components. The specific objectives (including test success criteria) of this testing, along with how each objective was met, are outlined in the following table. Test objectives are numbered from 1 to 14 and success criteria are listed under “a” through “k”.

Test Objective	Objective Met?	Discussion Section
1. Define melter testing matrices that provide sufficient coverage of the testing variables defined in Section 6, Test Conditions [8]. The test matrix for each variable is to be provided in the test plan. The test plan shall define each test variable and is to include a discussion of test variable development and basis by which the testing strategy and approach will provide a sufficient technical basis for WTP HLW melter processing constraints. The order in which the testing variables are performed should be done to optimize the testing and take into consideration predecessor activities such as glass formulation support and the maturity of the QGCR boundary definitions.	Yes	See Test Plan [13].

Test Objective	Objective Met?	Discussion Section
<p>2. Define the laboratory, small-scale melter (DM10 and DM100) and DM1200 pilot melter testing that are required for each variable defined in Section 6, Test Conditions. The maximum melter scale proposed should be based on the data quality requirements and the scale necessary to achieve that quality of data.</p> <p>(a) When completed, the test results data shall sufficiently define the effects of the test variables on melter throughput attainment and any deleterious processing conditions.</p>	Yes	Tables 3.1-3.3 provide glass production rate data and summary data for melter testing.
<p>3. Perform DM10, DM100 and DM1200 melter testing and associated feed handling and off-gas treatment equipment testing. The duration of each campaign or test period shall be sufficient to satisfy the objectives defined in the test plan.</p> <p>(a) When completed, the test results data shall sufficiently define the effects of the test variables on melter throughput attainment and any deleterious processing conditions.</p>	Yes	This report is limited to DM1200 testing. DM1200 data are provided in Tables 3.1-3.3 and Figure 3.1.
<p>4. Continue to assess the HLW bubbler design, operating life, modes of bubbler failure, and if necessary, alternative designs required to achieve a minimum two-month operating life.</p> <p>(b) Document the performance of the HLW bubbler design and placement recommended by the Duratek design staff and recommend alternative design or placement alternatives if deemed to be superior. Provide a mean time to failure estimate of the Inconel-690 bubbler or alternate design if used.</p>	No (future)	The recommended bubbler design and placement was employed for these tests. Information on bubbler operating lifetimes will be reported separately when it is available.
<p>5. For each test, establish and maintain melter throughput rates at the maximum steady state rate.</p> <p>(a) When completed, the test results data shall sufficiently define the effects of the test variables on melter throughput attainment and any deleterious processing conditions.</p>	Yes	Data are provided in Tables 3.1-3.3 and Figure 3.1. Cold-cap-limited, steady-state production rates between 650-870 kg/m ² /day were obtained for 550 g glass per liter C-106/AY-102 feed, which was lower than predicted due to poor cold cap characteristics. The same test was repeated with additional nitrates and showed a uniform, consistent cold cap, which resulted in a steady-state production rate of 1000 kg/m ² /day at all four sugar contents. Cold-cap-limited, steady-state production rates increased from 850 to 930 kg/m ² /day as the sugar content was increased in the test with 400 g glass per liter AZ-101 feed.

Test Objective	Objective Met?	Discussion Section
<p>6. Characterize the melter emissions (particulate, aerosol, and gaseous) under nominal steady-state operating conditions for inorganics and organic compounds. Measurement of organic compounds can be satisfied through the use of Fourier Transform Infra-Red Spectroscopy (FTIR), H₂ and CO monitors. Silver mordenite characterization will include assessment of the effects of off-gas stream constituents that can affect column performance, e.g., halides, acid gases, etc.</p> <p>(c) Obtain, report and assess melter emissions (particulate, aerosol, and gaseous) data under nominal steady state operating conditions for each test.</p>	Yes	Section 7.0 provides data and detailed description of melter emissions.
<p>7. Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.</p> <p>(d) Document the occurrence and associated operating conditions of any melter off-gas volume surging events.</p>	Yes	Section 5.0 provides melter pressure data and control air flow rates during testing. Occasional pressure spikes were observed during processing. These transient spikes were typically associated with breakup and rapid incorporation of cold cap sections into the melt. This was most frequent (three transient positive pressure values) during Test 5 (550 g glass per liter C-106/AY-102 feed) which had poor cold cap characteristics.
<p>8. Characterize the performance of the primary off-gas treatment equipment (SBS, WESP and HEME) to remove particulate, aerosol and gas phase emissions under steady state melter conditions. Measurement of organic compounds can be satisfied through the use of FTIR, H₂ and CO monitors.</p> <p>(e) Obtain, report and assess the ability of the primary off-gas treatment equipment (SBS, WESP and HEME) to remove particulate, aerosol and gas phase emissions under steady state melter conditions.</p>	Yes	Section 5.0 provides operational details of off-gas system components. Section 7.0 provides data and detailed description of SBS and WESP emissions as well as DF values for these components.

Test Objective	Objective Met?	Discussion Section
9. Characterize the performance of the secondary off-gas treatment equipment (SCR, TCO and small-scale silver mordenite column) to treat NO _x and capture iodine emissions under steady state melter conditions. Measurement of organic compounds can be satisfied through the use of FTIR, H ₂ and CO monitors. (A sulfur-impregnated activated carbon system is being added and will be similarly characterized.) (g) Measure and document the performance of the secondary off-gas treatment equipment (SCR, TCO and small-scale silver mordenite column) to treat NO _x and capture iodine emissions under steady state melter conditions. (A sulfur-impregnated activated carbon system is being added and will be similarly characterized.)	Yes (partially)	See Sections 5.0 and 7.0. Data are presented for the SCR, TCO, and small-scale silver mordenite column. The sulfur-impregnated activated carbon system was not used during these tests; therefore its performance will be reported in a future test report.
10. Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP, and caustic scrubber). (f) Measure and document the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP and caustic scrubber).	Yes	Sections 2.1 and 2.3 provide detailed feed analysis. Section 5.2 provides detailed off-gas fluid analyses.
11. Obtain the necessary process measurements to provide mass and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures. (h) Document process measurements that provide mass, and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.	Yes	Data for measured melter parameters are provided in Section 3.0 and data for measured off-gas parameters are in Section 5.0.
12. Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities. (i) Assess and document general equipment operations (reliability, availability, maintainability, etc.), especially non-routine equipment failure and replacement activities.	Yes	Data are presented and discussed in Sections 3.0, and 5.0.
13. Perform pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials, especially ammonium nitrate downstream of the SCR. (j) Document pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials.	Yes	Inspection information for off-gas equipment is provided in Section 5.0. Inspection downstream of the SCR was covered in a previous report [29].

Test Objective	Objective Met?	Discussion Section
14. Operate the melter plenum pressure control using the variable air-injection control method. Assess and document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings. (k) Document the performance of the melter plenum pressure control using the variable air-injection control method. Document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.	Yes	Sections 3.0 and 5.0 discuss melter pressure data and control air flow rates during testing.

B) Test Exceptions

Test Exception	Description
24590-HLW-TEF-RT-03-038	Modified some tests of the complete series to reflect new potential bubbler configurations.
24590-HLW-TEF-RT-03-047	Modified solids content of AZ-101 feed for Test 4.

C) R&T Testing Conditions

Testing was performed using flow-sheet based AZ-101 and C-106/AY-102 compositions provided by the WTP project, from which suitable simulants were developed for this work. Supporting glass formulation work was performed to develop compliant glass formulations. Based on these results, melter feed simulants for these tests were prepared by a chemical vendor.

The following tests are discussed in this report:

- Test 5:** Nine-day test with four, two-day run segments with C106/AY-102 (target glass yield = 0.372 kg/kg or 550 g/l) and variable amounts of sugar to determine cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content. Constant bubbling at 65 lpm from two lance bubblers with outlets located 6" from the bottom of the melter, placed in the corners, and pointed towards the melt pool center.
- Test 6:** Nine-day test with four, two-day run segments with C106/AY-102 (target glass yield = 0.372 kg/kg or 550 g/l), additional nitrates and variable amounts of sugar to determine cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content. Constant bubbling at 65 lpm from two lance bubblers with outlets located 6" from the bottom of the melter, placed in the corners, and pointed towards the melt pool center.
- Test 4:** Nine-day test with four, two-day run segments using an AZ-101 composition (target glass yield = 0.315 kg/kg or 400 g/l) and variable amounts of sugar to determine

cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content. The feed was also spiked with ruthenium to determine the effect of reductants on ruthenium behavior. Constant bubbling at 65 lpm from two lance bubblers with outlets 6" from the bottom of the melter, placed in the corners, and pointed towards the melt pool center.

The DM1200 HLW Pilot Melter is a Joule-heated melter with Inconel 690 electrodes. The melter shell is water-cooled and incorporates a jack-bolt thermal expansion system. The footprint of the melter is approximately 8 ft. by 6.5 ft. with a 4 ft. by 2.3 ft. air-lift discharge chamber appended to one end; the melter shell is almost 8 ft. tall. The melt surface area and the melt pool height are approximately 32 percent and 57 percent, respectively, of the corresponding values for the full-scale HLW melter. The discharge riser and trough are full-scale to verify pouring performance. The surface of the glass pool is about 1.2 m², and the volume is about 849 liters, corresponding to about 2 metric tonnes. The feed system consists of a mix tank and a feed tank, both of which are 750-gallon polyethylene tanks with conical bottoms that are fitted with mechanical agitators. The feed tank is also fitted with baffles to improve mixing and calibrated load cells that were electronically monitored to determine the feed rate to the melter. The feed is introduced into the melter using an air-displacement-slurry (ADS) pump, which is the present RPP-WTP baseline. Feed from the ADS pump flows into the melter through a prototypic un-cooled feed nozzle that is located above the center of the glass pool. The melter and entire off-gas treatment system are maintained under negative pressure by two Paxton external induced draft blowers. This negative pressure is necessary to direct the gases from the melter to the prototypical off-gas system. The off-gas treatment system consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME), a high-efficiency particulate air (HEPA) filter; a thermal catalytic oxidation unit (TCO); a NO_x removal system (SCR); a packed-bed caustic scrubber (PBS); and a second HEME. A silver mordenite column was used to treat a slip stream of about 10% of the off-gas stream exiting the SCR before returning it prior to the PBS. The second HEME is used to limit entrained particle carryover into the balance of the VSL ventilation system; the PBS and the second HEME are not part of the WTP off-gas train, which effectively ends at the SCR.

The following table outlines the specific testing conditions established in the Test Plan:

R&T Test Condition (from Test Plan [13])	Status
Melter	--
Bulk glass temperature target - 1150°C (typically allowed to vary $\pm 25^{\circ}\text{C}$ before power input changes are initiated). The bulk glass temperature is taken as the average of the readings from thermocouples located 13, 15.5, and 18 in. from the bottom.	Satisfied. See Tables 3.4, 3.5, and 3.6.
The total bubbling rate will be 65 lpm (64 from lances) in all tests except 3D.	Satisfied. Values reported in Tables 3.4, 3.5, and 3.6.
Plenum temperature - 400°C – 450°C (this is a dependent variable whose actual value is the result of cold cap coverage, air inleakage and other conditions).	Values were generally higher than target as reported in Tables 3.4, 3.5, and 3.6.
Feed rate – as-required to achieve plenum temperature range. This is expected to require a cold cap coverage of 80 to 90% of the glass surface.	Values reported in Tables 3.1, 3.2, and 3.3.

R&T Test Condition (from Test Plan [13])	Status
Melter plenum pressure is controlled by the air injection method described in Section 2.3. The air flow rate will be as required to maintain stable plenum pressure control without exceeding maximum SBS non-condensable gas flow rate. If compatible with melter and SBS operations, an air rate that is based on ~3X the melter condensable rate (essentially the steam rate) would be used to most closely simulate WTP assumptions. The typical control air flow rate on the DM1200 system is about 40 scfm.	Air injection method was used for plenum pressure control. Formation of cold cap mounds and ridges resulted in processing problems and occasional pressure spikes. See discussions in Sections 3.0 and 5.0.
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Film cooler: No special constraints; typically 70 scfm of air at about 100°C. Air flow to the film cooler will be maintained during idling or, alternatively, the film cooler will be removed. During operations, the film cooler will be washed down with water spray periodically (as directed by the operating procedures, presently every 12 hours).	Typical flow rates for the film cooler were about 70 scfm. The film cooler was periodically rinsed.
SBS	--
Tank temperature - 50°C unless condensation downstream requires lowering the temperature. Based on previous test results, a nominal sump temperature of 40°C is expected to be necessary to prevent downstream condensation.	Average SBS water temperatures ranged between 40-50°C as reported in Table 5.2.
Liquid level – utilize lower overflow point.	Satisfied.
Condensate purge rate – 100 to 150 gallons per day. This parameter is intended to simulate the expected SBS condensate dissolved and undissolved solids concentrations for the full-scale facility. To achieve this purge rate, a separate water supply is in place to meter make-up water into the SBS, as needed. This average purge rate will be accomplished in blow-downs of about 40 gallons, as needed. The variation in the purge rate should be within about +/- 20 gallons per day.	Average SBS blow-down rates for the tests were as follows: Test 5: 313 gal/day Test 6: 402 gal/day Test 4: 453 gal/day
All SBS blow-downs will be via the solids removal "square" pick-up wand to help minimize solids accumulation. Accumulation of solids on the bottom of the SBS tank will be assessed after each test. Any solids deposits will be allowed to remain between tests to determine whether the accumulation volume remains static or increases with time.	SBS blow-downs were via the pick-up wand. Infrared inspections of the SBS downcomer were performed after each test. Refer to Table 5.1 for inspection and cleanout summary.
Solids sparger lances will be operated on a timer cycle (10 seconds on, 20 seconds off, with lances operated in opposing pairs) throughout the tests.	Satisfied.
Perforated down-comer extension pipe that was in place for the preceding AZ-101 and AZ-102 tests will be removed for the present tests in order to evaluate the SBS behavior without it installed. However, the Project may later direct its reinstallation or the installation of an alternative design for testing.	A flared down-comer extension piece was added prior to Test 5, the first test in the series.

R&T Test Condition (from Test Plan [13])	Status
Inspect off-gas inlet pipe for accumulated solids. Due to the relatively short duration of each DM1200 campaign, R&T has directed VSL not to remove solids accumulations in the down-comer pipe so that longer-term buildups can be observed. However, if it is determined that continued accumulation will lead to unacceptable SBS performance (excessive pressure drop or plugging and melter pressurization, solids removal is permitted, following inspection and documentation of the buildup (e.g., by portable camera).	Infrared inspections of the SBS down-comer were performed after each test. Refer to Table 5.1 for inspection and cleanout summary.
WESP	--
Operate at maximum current to achieve maximum voltage without sparking. Based on previous experience this would be about 17 milliamps and 31 - 33 kilovolts.	WESP performance is discussed in Section 5.1.3. Deteriorating electrical characteristics were observed in Tests 5 and 6; repairs were conducted after Test 6, and the problems fixed. Average operating values were: Test 5: 30.7 kV, 16.1 mA Test 6: 30.1 kV, 11.1 mA Test 4: 29.6 kV, 17.0 mA
Inlet water spray – 2 gph $\pm$ 0.2 gph.	Satisfied. Data reported in Section 5.1.3.
As a part of normal operation for the first test that is conducted (Test 4), the WESP electrodes will be deluged with water from the internal overhead nozzle once a day at the nominal rate of 20 gpm for 2 minutes. This is being done to compare previous operation to spraying with a new spray nozzle (with a smaller spray angle). The nozzle was replaced to attempt to minimize water spray in the WESP tower areas housing the insulator standoffs. For the second test that is conducted (Test 5), the deluge will be conducted once every three days. For the third test that is conducted (Test 6), the deluge will be conducted at the end of the test. The time delay before being able to reinstate the initial voltage and current settings for stable operation will be recorded.	The three tests reported here are a subset of the entire series, which consisted of eight tests. For these three tests the WESP was deluged daily at a nominal rate of 12 gpm for 3.3 minutes. The WESP spray nozzle was changed after the first test (Test 5), and the deluge procedure was evaluated and changed to turn off the spray immediately before and after deluges. See Section 5.1.3. The time delays for reinstatement of stable operation are documented in Tables 5.3 and 5.4.
At end of each melter feeding test, inspect WESP internals prior to and after typical wash-down operation.	Discussion and photos provided. See Section 5.1.3.
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HEME: Operate with ~1 gph continuous water spray or per manufacturer's recommendations (< 50 mg/acfm of entrained liquid water).	HEME #1 operated with 0.2 gph spray. See Section 5.1.4.
HEPA Pre-heater: Operate to achieve a temperature rise between 10-20°C. Do not exceed a 20°C temperature rise unless condensation in the HEPA housing or downstream of the HEPA or increased pressure drop across the HEPA indicate higher temperatures are required to maintain stable operation.	HEME #1 outlet and HEPA outlet temperatures are reported in Table 5.2. Average temperature rise values for Tests 5, 6, and 4 were 22-23°C.
TCO: Bed temperature per the catalyst manufacturer's recommendation and previous test results (approximately 400°C). Based on previous tests, the gas residence time is about 0.16 sec	TCO and SCR inlet temperatures are reported in Table 5.2. Average TCO inlet temperatures ranged from 451-477°C. Average SCR inlet (TCO bed outlet) temperatures ranged from 388-405°C.

R&T Test Condition (from Test Plan [13])	Status
SCR	--
Bed temperature – per the catalyst manufacturer’s recommendation (350-400°C)	SCR inlet and outlet temperatures are reported in Table 5.2. Average SCR inlet temperatures ranged from 388-405°C. Average SCR outlet temperatures ranged from 365-402°C.
Ammonia slip (exit concentration) $\leq$ 25 ppm, if possible.	Ammonia slippages are discussed in Section 5.1.6. Ammonia SCR exit concentrations are less than 25 ppm, and are presented in Tables 7.18, 7.19, and 7.20.
Silver Mordenite System	--
Inlet gas temperature – 130 to 230°C	The average inlet temperature was 175°C for Tests 5 and 6. (The column was not used for Test 4.) See Section 5.1.7.
Inlet gas flow rate – 5 to 35 scfm	The average flow rates were 24.6 scfm for Test 5, and 24.9 scfm for Test 6. See Section 5.1.7.
Test conditions: <ul style="list-style-type: none"> • Test 4 (first test conducted): test will complete the exposure of the bed to iodine. • Test 5 (second test conducted): test without iodine and sample bed outlet to evaluate iodine release due to competition from HF and HCl. • Test 6 (third test conducted): test with fresh silver mordenite material without iodine in the feed and monitor bed for HF and HCl capture. 	The three tests reported here are a subset of the entire series, which consisted of eight tests. In Test 5 (the first of the series) samples were taken to check for iodine breakthrough. (However, little of the iodine in the feed remained in the off-gas at the column inlet.) For Test 6 (the second in the series), the feed contained no iodine, and data were taken at the column outlet to check for stripping from the loaded column. The silver mordenite column was not used in Test 4 (seventh in the series). See discussion in Section 7.0.
All other melter and off-gas treatment system unit operation process and control parameters will be within standard limits and reported in the test summary report.	See Tables 3.1-3.6, and Table 5.2. No significant deviations from expected limits were observed.

D) Results and Performance Against Objectives

Melter tests were conducted on the DM1200 to determine the effects of feed compositional changes namely sugar and nitrate content on glass production rate, iron oxidation state in the glass product, and off-gas system performance while processing HLW feed compositions at constant bubbling rates. Three nine-day tests, two with C-106/AY-102 and one with AZ-101 simulants, were conducted at four different sugar concentrations. One of the C-106/AY-102 tests included 30 g nitrate per kilogram glass in the feed. Each of the tests began with a day of feeding without sugar to establish the cold cap before conducting the two segments with sugar. Ruthenium was added to the test with AZ-101 simulant to investigate its behavior as a function of changing oxidation state of the glass. About seventy eight metric tons of feed was processed to produce about twenty eight metric tons of glass (nineteen from C-106/AY-102 composition and nine from the AZ-101 composition). Cold-cap-limited, steady-state production rates between 650-870 kg/m²/day were obtained for 550 g glass per liter C-106/AY-102 feed, which was lower than predicted due to poor cold cap characteristics. The same test was repeated with additional nitrates and showed a uniform, consistent cold cap, which resulted in a steady state production rate of 1000 kg/m²/day at all four sugar contents. Cold-cap-limited, steady-state

production rates increased from 850 to 930 kg/m²/day as the sugar content was increased in the test with 400 g glass per liter AZ-101 feed.

The general performance of the DM1200 melter and off-gas treatment system was good. The ADS pump worked well throughout testing. Extensive sets of process engineering data were collected during all three tests. Energy balances were conducted for each test segment around the melter and SBS with excellent closure. The glass product was close to the intended composition once the melt inventory was turned over. The amount of divalent iron approximated the target values for the C-106/AY-102 tests but exceeded the target concentrations in the AZ-101 test, despite the use of less carbon per unit of glass.

Isokinetic particulate samples were taken at the outlets of the melter and SBS for each feed sugar concentration and at least once per test at the WESP outlet. The purpose of these samples was to illustrate the effects changes in feed sugar and nitrate content on emissions, as well as to determine the efficiency of off-gas system components. Particulate carryover from the melter was higher than in previous tests without sugar (i.e. 1.75 vs. 0.75% of feed) but decreased with increasing feed sugar content. Elemental DF values were determined across the melter, SBS, and WESP. Calculated DFs across the primary off-gas system components were lower for the C-106/AY-102 tests than the AZ-101 tests as result of selenium inclusion in the feed and the inclusion of WESP deluges during the exhaust sampling interval. As a result, the cumulative DF (Melter+SBS+WESP) was lower (four to thirty five thousand) for C-106/AY-102 tests and higher (over half a million) for AZ-101 than previously for HLW tests. Additional emissions data collected during the tests were particle size distributions of the melter emissions, concentrations of various gaseous species throughout the off-gas system by FTIR, and hydrogen concentrations by gas chromatography at the WESP outlet.

The volumes of processing solutions generated in the SBS, WESP, HEME, and PBS were documented during testing, and representative samples were subjected to chemical analysis. The SBS solutions were close to neutral pH, due in large part to the lack of acid gases in the exhaust stream. The major dissolved species were selenium, halogens, boron, and alkali metals, while the suspended species closely resembled the feed composition. The measured SBS TSS concentration ranged from about 400 to 3200 mg/l, whereas measured TDS values were typically about 2 times higher. The WESP sump fluid was also in the neutral pH region but had negligible suspended solids. The WESP solutions contained significant concentrations of selenium, sulfate, and alkali halides. The WESP was sprayed continuously during this test and was deluged with 40 gallons of water once daily, resulting in a daily blow-down volume of about 80 gallons. The nearly 10,700 gallons of liquid that accumulated in the SBS during testing originated from the condensation of water from the melter feed.

A good mass balance was achieved for iodine around the melter, SBS, and WESP for the one test that used feed that contained iodine. Notably, after sugar was introduced into the melter feed, about 30% of the feed iodine was retained in the glass with the remainder captured in SBS fluids, in marked contrast to previous HLW tests without sugar additions.

In contrast to previous tests under oxidizing conditions, only about 1% of the total mass

of ruthenium injected into the melter feed reported to the off-gas stream. However, with sugar addition to the feed, ruthenium was reduced to the metallic state. In addition, portions of other elements such as nickel and copper were also reduced to the metallic state, and sulfate was reduced to sulfide. Glass samples taken from the bottom of the melter were rich in secondary phases, mostly ruthenium metal and a nickel sulfide. Nickel sulfide (most likely Ni_3S_2) is a corrosive liquid at temperatures prevailing at the bottom of the DM1200 melter. The data indicate that about 90% of the ruthenium fed to the melter was retained in the melter, probably as metal. Since there was only a very small effect of the progressive increases in sugar concentration on the volatility of ruthenium, a sugar concentration of 7.6 g/l feed was sufficient to limit ruthenium volatility to about 1%. However, it is not clear how much lower the concentration could be and still achieve the same effect. More particularly, it is not known whether it is possible to add sufficient sugar to diminish the volatility of ruthenium without reducing the ruthenium to the metallic state.

E) Quality Requirements

This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work. This work was not subject to DOE/RW-0333P or the requirements of the RPP-WTP QAPjP for environmental testing.

F) Simulant Use

This testing used both HLW AZ-101 and C-106/AY-102 simulants with compositions described in Section 2.0; these compositions were defined in the BNI Test Specification [21].

G) Issues

The results of post-test inspections showed that solids accumulation in the SBS down-comer continued to be an issue for these tests; the modified SBS down-comer extension design provided by the Project did not mitigate this problem. The effects of reductants on feed processing behavior were mixed, ranging from deleterious in terms of feed spreading and cold cap behavior, which led to reduced production rates, to modest increases in production rates, particularly with increased levels of nitrates in the feed. The addition of reductants decreased ruthenium volatility but increased its retention in the melter as a result of metal formation. In addition, nickel sulfide, which is corrosive, also formed. Further tests are needed to determine whether it is practical to achieve reductions in ruthenium volatility without these deleterious side effects. Given the importance of iodine in the facility emissions estimates, it may also be prudent

to pursue the surprising increases in the retention of iodine in the glass melt and the SBS scrubbing solutions that were observed in the tests with reductants.

SECTION 1.0 INTRODUCTION

The RPP-WTP Project has undertaken a "tiered" approach to vitrification development testing involving computer-based glass formulation, glass property-composition models, crucible melts, and continuous melter tests of increasing, more realistic scales. Melter systems ranging from 0.02 to 1.2 m² installed at VSL have been used for this purpose, which, in combination with the 3.3 m² LAW Pilot Melter at Duratek, Inc., span more than two orders of magnitude in melt surface area. In this way, less-costly small-scale tests can be used to define the most appropriate tests to be conducted at the larger scales in order to extract maximum benefit from the large-scale tests. For HLW vitrification development, a key component in this approach is the one-third scale DuraMelter™ 1200 (DM1200) HLW Pilot Melter system that has been installed at VSL with an integrated prototypical off-gas treatment system. That system has replaced the DM1000 system that was used for HLW throughput testing during Part B1 [1]. Both melters have similar melt surface areas (1.2 m²) but the DM1200 is prototypical of the present RPP-WTP HLW melter design whereas the DM1000 was not. In particular, the DM1200 system provides for testing on a vitrification system with the specific train of unit operations that has been selected for both HLW and LAW RPP-WTP off-gas treatment [2].

Previous testing with HLW simulants on the DM1000 [1] and DM1200 [3-6] indicated that while processing rates considerably above the project baseline (0.4 MT/m²/d) were possible with bubbling, the baseline rate was not achieved in tests performed without bubblers. As a result of this testing, it was concluded and recommended that the current WTP HLW melter design is not capable of achieving the baseline production rate of 1.5 Mt/d without the use of bubblers [7]. Testing has shown that the use of bubblers could also provide ORP the "performance enhancement" necessary to achieve the future expanded capacity per melter of 3.0 Mt/d, which is the present requirement under the so-called "2+2" revised baseline [8]. Following the Project decision to include bubblers in the reference HLW design, recent DM1200 testing has been conducted to determine the processing rates achievable with bubbling for each of the Phase 1 HLW feed compositions [9-12].

Per the WTP Test Specification [8], the next phase of DM1200 testing was intended to address bubbler configuration variations to optimize throughput and a variety of flow-sheet issues. This Final Report is the first of two reports on the results of tests that are described in a Test Plan [13] that was prepared in response to that Test Specification [8]. That Test Plan is one in a series responding to the Test Specification; consequently, only part of the scope described in the Test Specification [8] was addressed in the Test Plan. The Test Plan addresses bubbler configuration and operation effects, and glass redox effects, including the effects of higher flow-sheet nitrate levels, and ruthenium volatility; the results from tests designed to investigate bubbler placement and production rate enhancement will be addressed in a later report. Summary level results from all of the tests conducted per the Test Plan [13] and subsequent Test Exceptions [14, 15] have been presented previously in a Summary Report [16].

1.1 Test Objectives

As listed in the Test Specification for this work [8], the principal objectives of these tests are identified below. Section 6 of the Test Specification ("Test Conditions") [8] describes test "Variability Parameters" in the following nine areas:

- (1) *Effect of REDOX on throughput*
- (2) *Effect of "troublesome" components on processability and off-gas emissions*
- (3) *Assess impact of waste loading or $\pm 15\%$ GFCs variability on processability*
- (4) *Evaluate impact of 2+2 compositions and transitions on throughput*
- (5) *Simulant vs. precipitated hydroxide recipe methods on melt rate and/or throughput*
- (6) *Assess impact of different GFC sources (borax and Na_2CO_3) for B_2O_3 and Na_2O on melt stability and production rate*
- (7) *Assess impact of high viscosity glass on melt rate for HLW*
- (8) *Assess glass liquidus (T_L) vs. volume percent crystals criterion in terms of production rate or waste throughput*
- (9) *System configuration assessments*

The scope of the pertinent Test Plan included only areas (1), and (9), above. This final report addresses only area (1).

The objectives from the Test Specification [8] addressed fully or partially during tests described in this Final Report are:

1. Define melter testing matrices that provide sufficient coverage of the testing variables defined in Section 6, Test Conditions [8]. The test matrix for each variable is to be provided in the test plan. The test plan shall define each test variable and is to include a discussion of test variable development and basis by which the testing strategy and approach will provide a sufficient technical basis for WTP HLW melter processing constraints. The order in which the testing variables are performed should be done to optimize the testing and take into consideration predecessor activities such as glass formulation support and the maturity of the QGCR boundary definitions.
2. Define the laboratory, small-scale melter (DM10 and DM100) and DM1200 pilot melter testing that are required for each variable defined in Section 6, Test Conditions. The maximum melter scale proposed should be based on the data quality requirements and the scale necessary to achieve that quality of data.
3. Perform DM10, DM100 and DM1200 melter testing and associated feed handling and off-gas treatment equipment testing. The duration of each campaign or test period shall be sufficient to satisfy the objectives defined in the test plan.
4. Continue to assess the HLW bubbler design, operating life, modes of bubbler failure, and if necessary, alternative designs required to achieve a minimum two-month operating life.
5. For each test, establish and maintain melter throughput rates at the maximum steady state rate.
6. Characterize the melter emissions (particulate, aerosol, and gaseous) under nominal steady-state operating conditions for inorganics and organic compounds. Measurement of organic compounds can be satisfied through the use of Fourier Transform Infra-Red Spectroscopy

- (FTIR), H₂ and CO monitors. Silver mordenite characterization will include assessment of the effects of off-gas stream constituents that can affect column performance, e.g., halides, acid gases, etc.
7. Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.
 8. Characterize the performance of the primary off-gas treatment equipment (SBS, WESP and HEME) to remove particulate, aerosol and gas phase emissions under steady state melter conditions. Measurement of organic compounds can be satisfied through the use of FTIR, H₂ and CO monitors.
 9. Characterize the performance of the secondary off-gas treatment equipment (SCR, TCO and small-scale silver mordenite column) to treat NO_x and capture iodine emissions under steady state melter conditions. Measurement of organic compounds can be satisfied through the use of FTIR, H₂ and CO monitors. (A sulfur-impregnated activated carbon system is being added and will be similarly characterized.)
 10. Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP and caustic scrubber).
 11. Obtain the necessary process measurements to provide mass, and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.
 12. Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.
 13. Perform pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials, e.g., film cooler, off-gas jumper, SBS downcomer and tank (sump), WESP internals, post TCO/SCR lines for ammonium nitrate deposits, etc.
 14. Operate the melter plenum pressure control using the variable air-injection control method. Assess and document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.

1.2 Test Overview

The tests were performed with AZ-101 and C-106/AY-102 HLW simulants [9, 11]. The solids contents of the melter feeds were fixed based on the present WTP baseline value for the solids content of the feeds from pretreatment since the effect of feed solids content was addressed previously [9]. The effects of bubbling rate on glass production rates and the viable range of bubbling rates were also addressed in earlier tests [9]. Based on the results from those tests, the present tests were performed with a total bubbling rate of 65 lpm. Three nine-day tests, one with AZ-101 and two with C-106/AY-102 feeds, were conducted with variable amounts of added sugar to address the effects of redox. The test with AZ-101 included ruthenium spikes to also address the effects of redox on ruthenium volatility. One of the tests addressed the effects of increased flow-sheet nitrate levels using C-106/AY-102 feeds. With high nitrate/nitrite feeds (such as WTP LAW feeds) reductants are required to prevent melt foaming and deleterious effects on glass production rates. Sugar is the baseline WTP reductant for this purpose. WTP

HLW feeds typically have relatively low nitrate/nitrite content in comparison to the organic carbon content and, therefore, have typically not required sugar additions. However, HLW feed variability, particularly with respect to nitrate levels, may necessitate the use of sugar in some instances. Variables held constant to the extent possible included melt temperature, bubbling rate, plenum temperature, cold cap coverage, the waste simulant composition, and the target glass composition. The feed rate was increased to the point that a constant, essentially complete, cold cap was achieved, which was used as an indicator of a maximized feed rate for each test. The glass pool composition was adjusted to the appropriate composition by a turnover period, as needed, prior to conducting each of the nine-day tests. The first day of each test was used to build the cold cap and decrease the plenum temperature. The remainder of each test was split into two-day segments, each with a different feed sugar concentration. All of the data collected was intended for engineering and system design use and, therefore, no environmental sampling was performed during these tests.

1.3 Quality Assurance

This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work [17] that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work [18].

This work did not generate data to support waste form qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP [19] for environmental and regulatory data.

1.4 Melter System Description

1.4.1 Feed System

The feed material for these tests was prepared and controlled according to VSL specifications by a chemical supplier, as detailed in Section 2. Each batch of feed slurry was shipped to VSL in lined 55-gallon drums (approximately 16 per shipment), which were staged for unloading into the mix tank. Both the mix tank and the feed tank are 750-gallon polyethylene tanks with conical bottoms that are fitted with mechanical agitators; the feed tank is also fitted with baffles to improve mixing. Five calibrated load cells directly mounted on the legs of the feed tank were used to measure additions to and removal from the feed tank and were electronically monitored to determine the feed rate to the melter. The requisite amount of feed is pumped into the feed tank from the mix tank; measured amounts of water were combined by weight with the feed at this point to adjust the concentration of the melter feed. The material in the feed tank is constantly recirculated from the feed tank discharge outlet, at the tank bottom, to the tank inlet at the top, which provided additional mixing.

The feed is introduced into the melter using an ADS pump, which is the present WTP baseline. The feed transfer line extends from the outlet of the ADS pump in the feed tank to the top of the melter. Feed is introduced into the melter through a prototypic un-cooled feed nozzle that is located above the center of the glass pool. Only one feed tube is used to represent the planned number of feed tubes per unit melt surface area in the full-scale WTP HLW melter. The operation of the ADS pump is controlled from the melter computer control system. The ADS pump works by opening the pump reservoir to the feed tank using a double-acting air cylinder and mechanical link to actuate the poppet. The reservoir is filled with slurry by gravity. After sufficient time is allowed to fill the reservoir (a few seconds), the poppet is toggled to close the reservoir to the tank and open the transfer line. After a two second delay time, the reservoir is pressurized with air to transfer the slurry (about 1.6 liter/shot) to the melter. This cycle is repeated at the rate required to provide the desired feed rate.

When necessary, a backup system is used to introduce feed into the melter with an air operated diaphragm (AOD) pump system that simulates the pulsed feeding action of an ADS pump. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop into the melter through a Teflon-lined feed line and water-cooled feed tube. Two computer-operated pinch valves, one on the feed line and one on the recirculation loop, are activated in a timed sequence to introduce feed into the melter at the desired rate. The feed rate is regulated by adjusting the length of each pulse, the time between each pulse, and the pressure applied to the recirculation loop. A compressed air line is attached to each of the feed lines and can be used to automatically clear the feed line into the melter after each pulse; air at 40 psi is flowed for 3 seconds through the 0.275" i.d. line for this purpose.

1.4.2 Melter System

The DuraMelter™ 1200 (DM1200), which is the HLW Pilot Melter, was used for these tests. The DM1200 is shown schematically in Figures 1.1 and 1.2. The DM1200 is a Joule-heated melter with Inconel 690 electrodes and thus has an upper operating temperature of about 1200°C. The melter shell is water-cooled and incorporates a jack-bolt thermal expansion system. The footprint of the melter is approximately 8 ft. by 6.5 ft. with a 4 ft. by 2.3 ft. air-lift discharge chamber appended to one end; the melter shell is almost 8 ft. tall. The melt surface area and the melt pool height are approximately 32 percent and 57 percent, respectively, of the corresponding values for the full-scale HLW melter. The discharge riser and trough are full-scale to verify pouring performance. Other aspects of the discharge system are also prototypical such as the chamber ventilation scheme. The glass contact refractory is Monofrax® K-3 while the plenum area walls are constructed of Monofrax® H refractory. The surface of the glass pool is 34" by 54" with a glass depth of nominally 25". The resultant melt volume is approximately 45,000 cubic inches (735 liters), which represents a glass tank capacity of more than 1.7 metric tons of glass. However, since the typical operating glass level is closer to 29 inches, the effective glass volume during testing is actually about 849 liters, giving an inventory of about 2.0 metric tons, which is larger than had been previously assumed [20]. The DuraMelter™ 1200 is fitted with one pair of electrodes placed high on opposite walls of the melter as well as one bottom electrode. The side

electrodes are 11" by 34" giving an electrode area for the pair of about 750 sq. in. Depending on the glass level, the plenum space extends about 33" to 36" above the melt surface resulting in a plenum volume ranging from about 43 to 46 ft³. Cross-sectional diagrams of the melter illustrating the discharge chamber and electrode configuration are provided in Figures 1.1 and 1.2.

The single-phase power supply to the melter electrodes (250 kW design power) is derived from the DuraMelter™ 1000 transformers by wiring them in parallel and using a single large silicon controlled rectifier. Current can be passed either from the side electrodes to the bottom electrode or between the two side electrodes only, by rearranging jumpers; only side-to-side operation was used for the present tests. Programmable process controllers are installed and can be used to control temperature or power. The melt temperature is controlled by configuring the process controller to maintain constant power and adjusting the power set-point as needed to maintain the desired operating temperature. Alarms can be set to detect out-of-range temperatures or power in the melter. Backup process controllers are installed to be used in case of failure of the main controllers. The entire system is supported by a back-up generator that is tripped on in the event of a power outage.

The DuraMelter™ 1200 has several other features. The lid refractory is prototypic and also includes a two-piece construction, which simulates the seam needed for the LAW lid that was planned to be fabricated in three pieces. Nozzles are provided for the off-gas film cooler, a standby off-gas port, discharge airlift, along with 11 ports available for top-entering bubblers, start-up heaters and other components as needed. In addition, a bubbler arrangement is installed in the bottom electrode with the objective of developing permanent bubblers for possible use on future melters. For the present tests, two top-entering bubblers were used, located in diagonally opposite corners, six inches from the melter floor.

1.4.3 Off-Gas System

The melter and entire off-gas treatment system are maintained under negative pressure by two Paxton external induced draft blowers. This negative pressure is necessary to direct the gases from the melter to the prototypical off-gas system. The off-gas treatment system, shown schematically in Figure 1.3, consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME), a high-efficiency particulate air (HEPA) filter; a thermal catalytic oxidation unit (TCO); a NO_x removal system (SCR); a packed-bed caustic scrubber (PBS); and a second HEME. The second HEME is used to limit entrained particle carryover into the balance of the VSL ventilation system. Note that the PBS and the second HEME are not part of the WTP off-gas train, which effectively ends at the SCR. Subsequent to the AZ-101 and AZ-102 tests, a silver mordenite column was also installed to obtain engineering data on iodine capture efficiency on a 10% slip stream of the SCR/TCO exhaust. The system can be functionally divided into four subsystems:

<u>Particulate Removal:</u>	Components from the submerged bed scrubber (SBS) to the HEPA serve to remove essentially all of the particulate from the gas
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stream with an estimated removal efficiency of greater than 99.9999% for particles greater than 0.3 μm in size. In the RPP-WTP facility, this provision serves to segregate the radioactive from the non-radioactive components in the system for maintenance and handling purposes.

VOC Control/Acid Gas: The thermal catalytic oxidation (TCO) unit is designed to oxidize any hazardous organics that are present in the off-gas stream. This is followed by a SCR to remove NO_x gases and a packed-bed scrubber (PBS) to remove remaining acid gases.

Stack System: The emergency/bypass exhaust system, which includes a second HEPA, and the primary off-gas system both feed into the building stack system for exhausting to the atmosphere.

Liquid Processing: Components including the water spray lines, liquid sampling and water storage tanks, as well as the effluent evaporator, function to sample and process the system liquids for recycle or discharge.

With minor exceptions noted above, the DM1200 off-gas system processing sequence follows the proposed design for the full-scale WTP HLW melter system.

Initial quenching of the melter exhaust gas stream is effected by the film cooler. Immediately downstream of the film cooler is the injection point for control air, which is used to regulate melter pressure. The gas entering the balance of the off-gas system is at a temperature of about 250 to 350°C and a flow rate of about 100-250 scfm, of which about 10-80 scfm is water vapor. The off-gas is then rapidly quenched by direct liquid water contact in the Submerged Bed Scrubber (SBS), which also effects removal of most of the larger particulates. The piping between the film cooler and SBS has a high superficial gas velocity to minimize particulate deposition. The gas stream leaving the SBS is at a low temperature (typically between 40-50°C). Further mist and particulate removal is effected in the WESP, HEME, and HEPA. The TCO and SCR follow the particle removal components and serve to destroy organic compounds and nitrogen oxides. Finally, the PBS provides acid gas removal. Water sprays are located in the WESP, flow sheet HEME, PBS, and facility HEME to wash down deposits and dissolved species into their respective collection sumps from which they can be sampled. The system components are fabricated from corrosion resistant materials including AL6XN in the SBS and 316L stainless steel and various plastics in less demanding locations. There are extensive provisions for sampling both the gas and liquid streams throughout the system in order to collect mass balance information and removal efficiency data for each treatment stage.

The off-gas system maintains the melter plenum under slight negative pressure, typically about -5 in. W.C. The plenum pressure is controlled by means of an air injection system that introduces a controlled air flow into the off-gas jumper just after the film cooler. The air is supplied by a blower through a diverter valve. The setting of the diverter valve, and therefore the air flow rate, is controlled by a process controller that responds to the signal from a melter

pressure transducer. When the plenum pressure becomes more positive, the air injection flow rate is decreased, which tends to restore the pressure to the set-point. Conversely, the flow rate is increased when the plenum pressure becomes more negative.

As noted above, a silver mordenite system has been installed to obtain engineering data on iodine capture efficiency. This system treats a slip-stream of up to about 10% of the off-gas stream entering the TCO, which is then returned to the PBS. A sulfur-impregnated activated carbon column was added ahead of the silver mordenite column subsequent to these tests. A schematic diagram of the combined slip-stream system is shown in Figure 1.4. The slip-stream gas is heated before entering the top of a glass column that is loaded with 1/16" pellets of C-Chem Ag-900 silver-impregnated zeolite. The active part of the column is a cylinder, 32" long and 6" in diameter containing about 30 lb of the zeolite packing (57.4 lb/ft³ bulk density). C-Chem claims an external void fraction of 37% for this material. Temperatures at both the inlet and the outlet, the differential pressure across the column, and the flow at the outlet of the column are monitored continuously. The gas exiting at the bottom of the column is cooled to protect the down-stream blower. Design ranges of flow conditions at specific points along the system are indicated in Figure 1.4. There are four analytical sampling ports provided in each column: one at the inlet, one each located at 1/3 and 2/3 of the column length, and one at the outlet of the column. The sulfur impregnated activated carbon column, which is identical to the silver mordenite column, is packed with Calgon HGR media. As shown in Figure 1.4, this column is inserted ahead of the silver mordenite column and before the heater. The carbon column was not used during these tests.

SECTION 2.0 WASTE SIMULANT AND GLASS FORMULATIONS

The AZ-101 and C-106/AY-102 waste data, blending assumptions, and glass formulations that were used for these tests are the same as those used in previous melter tests [9, 11]. The compositions of the AZ-101 and C-106/AY-102 HLW simulants were derived and specified in a corresponding BNI Test Specification [21]. This section summarizes the compositions of both simulants and describes the corresponding glass formulations selected for melter testing.

2.1 AZ-101 Waste Simulant

Formulation of the AZ-101 waste simulant makes use of inventory data from the TFCOUP Rev. 3A [22], calculated data from ACM modeling, and analytical data on Cs- and Tc-removal eluates¹ from LAW pretreatment [21].

The composition of the AZ-101 Envelope D solids (Stream FRP02) is based on the inventory data found in Revision 3A of the TFCOUP [22]. As seen in Table 2.1, in addition to updated information, Revision 3A of the TFCOUP also provides information on minor components that were not included in earlier revisions [23] and the Best Basis Inventory (BBI) database (e.g., cadmium). The use of other data sources (e.g., HLW Feed Staging Plan [24]) to supplement the TFCOUP, as was done in previous tests, is therefore no longer necessary. The ACM model calculates the composition of the recycle stream (PWD01), which is then blended with the Envelope D solids based on the expected daily processing rates (i.e., 1.30E+04 lb/day for Envelope D solids and 1.28E+03 lb/day for the recycle stream on a dry solid basis). The resulting material is concentrated and pretreated before ultra-filtration to produce the pretreated HLW solids. The separation factors due to HLW pretreatment and ultra-filtration are given in Table 2.1.

To complete the simulant formulation, the pretreated HLW solids must be blended with wastes from LAW pretreatment. In contrast to the blending scenario used in Part B1 tests, Sr/TRU removal products from pretreatment of Envelope C wastes will be omitted since the current processing schedule indicates that AN-102 (first Envelope C tank) waste will be processed after AZ-101. Analytical data on eluates from Cs- and Tc-removal on an Envelope B sample (AZ-102) [13] provide the compositional bases for the respective feed streams CNP12 and TEP12. The blending proportions are determined by the projected daily processing rate of sodium in the eluates (i.e., 1.71E+01 lb/day for Cs-removal and 3.32E-01 lb/day for Tc-removal). It can be seen in Table 2.1 that incorporation of these streams primarily leads to increase of sodium and nitrate in the HLW simulant.

¹ It is recognized that technetium removal in pretreatment is no longer part of the WTP flow-sheet; however, for practical purposes, this stream has a negligible impact on the overall melter feed composition.

The calculated composition of the blended HLW solids (HLP09b) is shown in Table 2.1, which lists a total of 53 components. Similar to the approach taken during previous testing, radionuclides, noble metals (including silver), and minor components (< 0.05 wt% oxide basis) are omitted from the simulant formulations. Exceptions include cesium, which is included for analytical purpose, and praseodymium, which is replaced with another rare earth element, neodymium. Iodine is also added for analytical purposes, at an amount equivalent to 0.1 wt% in glass. The resulting HLW simulant formulation, which is given in Table 2.2, consists of 28 components, 24 of which are non-volatile (compared with 32 and 28, respectively, for the previous AZ-101 simulant). Note that, as detailed in Section 8, ruthenium was spiked into the feed to track ruthenium volatility.

2.2 AZ-101 Glass and Melter Feed Formulations

With the elimination of Sr/TRU pretreatment products from the HLW AZ-101 simulant, new glass formulations have been developed and tested at VSL to support these tests. The glass composition selected as the basis for these tests, HLW98-77, is presented in Table 2.2. On an oxide basis, this glass incorporates 24.65 wt% of Envelope D waste and 25.25 wt% of all wastes. These can be compared with the respective values of 27.00 wt% and 30.49 wt% for HLW98-31, the AZ-101 reference glass used in Part B1. The difference is due to the increased limiting component ($\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{ZrO}_2$) in the new HLW simulant (84 wt% vs. 79 wt%). The glass HLW98-77 meets the contract specification by incorporating 21.20 wt% of ($\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{ZrO}_2$) from Envelope D waste.

Crucible melts of HLW98-77 have been prepared and tested to determine that it meets the necessary processing requirements. The measured viscosity and conductivity at 1150°C are 50 P and 0.36 S/cm, respectively. Heat treatment of HLW98-77 at 950°C results in <0.5 vol% of spinel crystals. The target glass formulation for these tests, which is also given in Table 2.2, differs slightly from HLW98-77 by the removal of silver and the addition of small amounts of barium from the projected waste composition.

The additional constituents required to form the target test glass from the AZ-101 HLW simulant are boron, lithium, sodium, silicon, and zinc. The corresponding chemical additives that are the sources for these elements were selected based on previous testing and with direction of the RPP-WTP Project. Table 2.3 lists the starting materials and amounts required to produce the target AZ-101 simulant and melter feed. Note that all of the TOC is assumed to be oxalate and that more carbonate (0.429 g/100 g oxide) is present in the simulant than that required per the basis documents (0.106 g/100 g oxide). The small excess in carbonate is not expected to impact the tests since much greater amounts are present in the glass forming additives. The theoretical glass yield of the resulting feed is about 360 g of glass/kg of feed ((450-500) g/l of feed, dependent on feed density), when the total solids content of the *simulant* is assumed to be 20 wt%.

Melter feeds were produced by NOAH Technologies Corporation, the supplier of simulant and feed samples used in previous testing on the DM100 and DM1200 melter systems.

Sugar and additional water to achieve the target glass yield of 400 g glass per liter was added to the feed at VSL.

2.3 C-106/AY-102 Waste Simulant

Formulation of the C-106/AY-102 waste simulant makes use of inventory data from the TFCOUP [14], calculated data from ACM modeling, and analytical data on Cs- and Tc-removal eluates² from LAW pretreatment [21]. In addition, products from Sr/TRU removal for pretreatment of LAW are also included in the waste blend.

The composition of the C-106/AY-102 Envelope D solids (Stream FRP02) is based on the inventory data found in Revision 3A of the TFCOUP [22]. As seen in Table 2.4, in addition to updated information, Revision 3A of the TFCOUP also provides information on minor components that were not included in earlier revisions [23] and the Best Basis Inventory (BBI) database (e.g., cadmium). The use of other data sources (e.g., HLW Feed Staging Plan [24]) to supplement the TFCOUP, as was done in previous tests, is therefore no longer necessary. The ACM model calculates the composition of the recycle stream (PWD01), which is then blended with the Envelope D solids based on the expected daily processing rates (i.e., 3.79E+04 lb/day for Envelope D solids and 1.31E+03 lb/day for the recycle stream on a dry solid basis). The resulting material is concentrated and pretreated through caustic leaching/water washing and ultra-filtration to produce the pretreated HLW solids. The separation factors due to caustic leaching and ultra-filtration are given in Table 2.4. Note that some of the separation factors are larger than unity (many of which were ignored in derivation of the waste composition, which is used as-provided [21] in the present work) and that the ACM model predicts mass increases for Fe and Zr after ultra-filtration (75 lb/day and 68 lb/day, respectively) [21].

To complete the simulant formulation, the pretreated HLW solids are blended with wastes from LAW pretreatment. Similar to the blending scenario used in Part B1 tests [25], Sr/TRU removal products from pretreatment of Envelope C wastes was added for these tests, although the amounts of Sr and Mn (449 lb/day and 499 lb/day, respectively) blended are considerably less than those used in earlier tests, which results in lower concentrations of SrO and MnO in the current test glass (e.g., 0.92 wt% vs. 7.35 wt% for SrO) [25]. Analytical data on eluates from Cs- and Tc-removal on an Envelope B sample (AN-102) [26] provide the compositional bases for the respective ACM-model feed streams CNP12 and TEP12 although that was not the case for the SR/TRU stream. The blending proportions are determined by the projected daily processing rate of sodium in the eluates (i.e., 2.02E+01 lb/day for Cs-removal and 9.14E-01 lb/day for Tc-removal). It can be seen in Table 2.4 that waste blending primarily leads to increase of manganese, strontium, sodium, chloride and nitrate in the HLW simulant.

The calculated composition of the blended HLW solids (HLP09b), which is shown in Table 2.4, lists a total of 55 components. A few of the components, however, were left out of the blended solids in the Test Specification [21] because of missing separation factors, low

² It is recognized that technetium removal in pretreatment is no longer part of the WTP flow-sheet; however, for practical purposes, this stream has a negligible impact on the overall melter feed composition.

concentrations and other unspecified reasons (e.g., Be, Co and Mo). In addition, similar to the approach taken in previous melter tests, radionuclides, noble metals (including silver), and minor components (< 0.02 wt% in glass on an oxide basis) are omitted from the simulant formulations. Cesium and iodine are spiked for analytical purposes, at an amount equivalent to 0.05 wt% and 0.10 wt%, respectively, in glass. The resulting HLW simulant formulation, which is given in Table 2.5, consists of 30 components, 26 of which are non-volatile (compared with 33 and 29, respectively, for the previous C-106/AY-102 simulant [25]).

2.4 C-106/AY-102 Glass and Melter Feed Formulations

With updated compositions for the C-106/AY-102 Envelope D solids and a different waste blending scenario, new glass formulations have been developed and tested at VSL to support these tests. The glass composition selected as the basis for these tests, HLW98-86, is presented in Table 2.5. On an oxide basis, this glass has a total waste loading of 27.75 wt%, of which 25.13 wt% is Envelope D waste. These can be compared with the respective values of 51.00 wt% and 39.42 wt% for HLW98-34, the reference glass used in Part B1 [25]. The difference is primarily due to the presence of much more Na₂O in the Part B1 simulant (20.61 wt% vs. 2.11 wt% for the current simulant). The current target glass (HLW98-86) is also different from HLW98-34 in that it meets the contract minimum component limit by incorporating 12.56 wt% of Fe₂O₃ [25], instead of > 21 wt% of (Al₂O₃+Fe₂O₃+ZrO₂).

Crucible melts of HLW98-86 and related formulations have been prepared and tests performed to determine that the target glass meets the necessary processing requirements. Heat treatment of HLW98-86 at 950 °C for over 70 hours results in a homogeneous dark brown glass that is free of secondary phases. The viscosity and electrical conductivity measured for HLW98-86AG which has the same composition as HLW98-86 except with Ag₂O excluded, are 44 P and 0.36 S/cm, respectively, at 1150 °C. The target glass formulation for these tests, which is also given in Table 2.5, differs slightly from HLW98-86, with the removal of silver and the addition of small amounts of cesium and iodine (only feed for Test 5 contained iodine). In Test 6, the effects of higher flow-sheet levels of nitrate were investigated using the maximum expected levels of nitrate provided by the WTP Project [27]. The additional nitrate, 30 g/kg glass, was achieved by substituting some of the magnesium hydroxide shown in Table 2.6 with magnesium nitrate.

The additional constituents required to form the target test glass from the C-106/AY-102 HLW simulant are aluminum, boron, lithium, sodium, silicon, and zinc. The raw materials that are the sources for the glass-forming additives are selected based on previous testing and with direction of the RPP-WTP Project. Table 2.6 lists the starting materials and amounts required to produce the target C-106/AY-102 simulant and melter feed. Note that all of the TOC is assumed to be oxalate and that only 1.23 (g/100 g oxide) of carbonate is present in the simulant, instead of the required 1.29 (g/100 g oxide). The small discrepancy in carbonate does not impact the tests since much greater amounts are present in the glass forming additives. The suspended solids in the *simulant* is assumed to be 20 wt%, which is equivalent to 21.49 wt% total solids, based on

the data from AZ-102 testing [10]. The theoretical glass yield of the resulting feed is 372 g of glass/kg of feed (about 550 g/l of feed, dependent on feed density).

Melter feeds were produced by NOAH Technologies Corporation, the supplier of simulant and feed samples used in previous testing on the DM100 and DM1200 melter systems. Sugar was added to the feed at VSL.

2.5 Analysis of Feed Samples

2.5.1 General Properties

Feed samples were analyzed from each distinct feed tank charging or at least once per day of operation to confirm the chemical composition and physical properties. Sample names, sampling dates, and measured properties are provided for all AZ-101 and C-106/AY-102 feed samples in Table 2.7. Data from samples with the same target compositions and water contents [9, 11] are provided for comparison. All samples were taken from the feed line immediately upstream of the entrance point to the melter. Only two samples from Test 6 were converted to glass due to the severe corrosion of the platinum crucibles from the combination of reducible metals in the HLW feed and sugar. The average measured glass yields for samples from each test were within three percent of the target glass yields of 372 and 314.5 g of glass per kg of feed for the C-106/AY-102 and AZ-101, respectively. Average glass yields expressed in g glass per liter of feed were also equally close to target values (550 vs. 553 and 535; 400 vs. 408). The target glass yields were therefore used for calculating glass production rates. For each test, all measured parameters, including glass conversion ratio, water content, density, and pH, fall within narrow ranges, confirming the relative consistency of the melter feed within each test. Few differences in measured feed properties were observed as a consequence of the intended changes in sugar concentration, nitrate concentration, or addition of the noble metals spike solution. Measured properties are also very similar to those measured for feeds in previous studies that did not contain sugar or additional nitrate. In previous AZ-101 tests [9], lower pH values (about a tenth of a unit) were measured for feed samples with the noble metals spike, as was the case in this study (10.48 vs. 10.31-10.42). The addition of nitrate to feed in Test 6 resulted in a drop in pH of about a quarter of a unit.

2.5.2 Rheology

Samples of the melter feeds that were used for these tests were also subjected to rheological characterization. The results from rheological characterization of a variety of other melter feeds and waste simulants, as well as the effects of a range of test variables, are described in detail in a separate report [28]. Melter feeds were characterized using a Haake RS75 rheometer, which was equipped with either a Z40DIN or a FL22-SZ40 sensor. A typical set of measurements consists of identifying the flow characteristics of the slurry by measuring the shear stress on the slurry at controlled shear rates and temperatures. In these measurements, the shear rate values are preset and are increased stepwise from 0.01 s⁻¹ to 200 s⁻¹ (70 s⁻¹ for FL22-SZ40) with a sufficient delay (typically 15 to 30 seconds) between steps to ensure that shear

stress is allowed to fully relax and therefore measured at equilibrium. The viscosity of the sample as a function of the shear rate is then calculated as the ratio of the shear stress to the shear rate. All of the measurements in this work were made at 25°C; previous work [28], which examined a range of temperatures, showed a relatively weak effect of temperature.

Rheograms, which show the feed viscosity versus shear rate for the C-106/AY-102 and AZ-101 feeds, are presented in Figures 2.1 and 2.2, respectively. Included in the figures for comparison are data from previously reported [9, 11] feed samples of the same composition that do not contain sugar or additional nitrate. Measured values for viscosity at selected shear rates and the yield stress values are shown in Table 2.7. Additions of sugar and nitrate increased the viscosity for C-106/AY-102 samples but had little effect on viscosity for AZ-101 samples; this difference may be a result of the higher water content and lower sugar content in the case of the AZ-101 feed. The small changes in pH observed with added sugar and nitrate to the C-106/AY-102 feed samples may be responsible for the changes in measured viscosity. The measured yield stress for AZ-101 was unchanged by the addition of sugar but increased in the C-106/AY-102 feed with added sugar and nitrate.

2.5.3 Chemical Composition

Feed samples collected during these tests were subjected to chemical analysis using x-ray fluorescence (XRF). The chemical compositions of the feed samples from the test were determined by first making a glass from the feed samples via crucible melt. The glass was subsequently crushed and analyzed directly by XRF. Target values for boron and lithium oxide were used for normalizing the XRF data since they were not determined by XRF. The data are presented in Tables 2.8 - 2.10 and are compared to the target composition.

The compositional analysis results can be discussed by dividing the elements into four categories: major elements with measured oxide concentrations greater than 3%, intermediate elements with measured oxide concentrations between 0.5 and 3%, minor elements with target concentrations less than 0.5%, and contaminants that are not in the target composition. The major elements constitute the bulk of the glass and, therefore, largely determine its properties. The average measured concentration for all the major elements in the C-106/AY-102 formulation (Al, Fe, Mn, Na, and Si) were within 10 percent of the target composition. In the AZ-101 feed samples, aluminum and zirconium of the five major elements (Al, Fe, Na, Si, and Zr) were within 10 to 20 percent of the target composition. The aluminum excess was also observed in samples from the latter portion of the previous AZ-101 tests [9] but not the beginning of those tests suggesting that the additive batch and purity were changed. The zirconium surplus observed in the feed samples was also observed in glass discharge samples as well as in previous HLW tests [9, 10, 12] for both feed samples and product glasses. This uniform excess indicates that the purity of the zirconium used by NOAH was somewhat higher than assumed. The absolute deviations were only about 0.7 wt% and therefore no effect on the glass properties is expected. Elements in the intermediate concentration range for C-106/AY-102 samples (Mg, Sr and ZnO) were all within 10% of the target values. Samples of AZ-101 feed had both elements from that range (Ni and Zn) at concentrations that were 10 to 15% below their

target values; however, the absolute deviations were no more than 0.13 wt% and 0.35 wt% for nickel and zinc oxides, respectively. The large number of minor elements (As, Ba, Ca, Cd, Cl, Cr, Cs, Cu, F, I, K, La, Mg, Mn, Nd, P, Pb, Ru, S, Sb, Se, Sr, Ti and Y) are all contributed by the simulated waste or spiked into the feed at low levels. Deviations were not calculated for these oxides due to the high volatility of many of the constituents and the uncertainty associated with deviation calculations on very low concentrations. As expected, highly volatile elements such as halogens and selenium are under-represented in the glasses. Conversely, common elements such as calcium and potassium, which are typical impurities in bulk chemicals, are over-represented when the constituent is a minor component. Elements not included in the glass formulations but detected at low levels in the feed as impurities were chlorine, titanium, and phosphorus for the AZ-101 samples, and cadmium, potassium, and sulfur for the C-106/AY-102 samples. It is to be expected that small amounts of common elements such as chlorine, potassium, and phosphorus are present in additive sources whereas the small amount of cadmium in select samples probably originated from contamination. An excess in titanium oxide has been observed in previous studies [9-12, 29, 30], suggesting that titanium is a common contaminant in the source chemicals.

SECTION 3.0 DM1200 OPERATIONS

Two melter tests were conducted on the DM1200 with the HLW C-106/AY-102 simulant and variable amounts of sugar between 4/30/03 and 5/24/03, producing about 19 metric tons of glass. Subsequently, after four tests with the HLW AZ-101 simulant, another test was conducted with that simulant with variable amounts of sugar between 8/19/03 and 8/28/03, producing about 9 metric tons of glass. The total testing duration, including the time for water feeding and cold-cap burn-off, was 670 hours during which over 78 metric tons of feed was processed. A summary of the test conditions and results is provided in Tables 3.1 – 3.3. The tests were designed to show the effects of reductants and flow-sheet variations on glass production rate, glass chemistry, and melter emissions. The tests are summarized below in the order that they were conducted:

- Test 5: Nine-day test with four, two-day run segments with C-106/AY-102 (target glass yield = 0.372 kg/kg or 550 g/l) and variable amounts of sugar to determine cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content.
- Test 6: Nine-day test with four, two-day run segments with C-106/AY-102 (target glass yield = 0.372 kg/kg or 550 g/l), additional nitrates and variable amounts of sugar to determine cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content.
- Test 4: Nine-day test with four, two-day run segments using an AZ-101 composition (target glass yield = 0.315 kg/kg or 400 g/l) and variable amounts of sugar to determine cold-cap-limited glass production rates and the relationship between iron oxidation state and feed sugar content. The feed was also spiked with ruthenium to determine the effect of reductants on noble metal behavior.

The tests employed a prototypical ADS feed system, a single feed tube in the center of the melter, a nominal glass temperature of 1150°C, and a side-to-side electrode firing pattern. Bubbling was provided by two top-entering, “J” bubbling lances located six inches from the melter bottom in corners diagonally across the melt pool. A constant total bubbling rate of 65 lpm was used throughout the tests with near-equal flow through each of the two lances. In each test, the cold-cap-limited production rate was determined by visual observations of the cold cap and confirmed by the plenum temperature. The ADS feed system performed well throughout testing causing no interruptions in feeding. During Test 5, feeding was interrupted three times; once for about half an hour to repair the bypass off-gas system valve and twice (1.35 hours at 53 hours run time and 4.6 hours at 141 hours run time) to reduce excessive mounding of the cold cap. Feeding was interrupted twice during Test 6; once to repair the pump that services the melter cooling panels (4.4 hours at 26 hours run time) and once due to failure of the SBS recirculation pump (1.5 hours at 141 hours run time). None of the brief feed stoppages compromised the objectives of the tests. No interruptions occurred during Test 4.

The effect of sugar on glass production rates is difficult to discern from these tests. The relationship between feed sugar content and production rate depicted in Figures 3.1.a – 3.1.c each suggest different conclusions: production rate decreases with increasing feed sugar content (Test 5), production rate is unaffected by feed sugar content (Test 6), and production rate increases with increasing feed sugar content (Test 4). Steady-state rates achieved from previous tests with feed of comparable solids content were higher than that achieved in Test 5 (970 vs. 650-870 kg/m²/day), similar to that achieved in Test 6 (970 vs. 1000 kg/m²/day), and lower than that achieved in Test 4 (750 vs. 850-930 kg/m²/day). However, these comparisons are compromised by the fact that improvement in rate may be due in part to the use of a new feed tube design that was fully implemented prior to these tests but which was not in place for the earlier tests using C-106/AY-102 [11] and AZ-101 [9] simulants. The lower rate observed for Test 5 was due in large part to feed characteristics that resulted in it not spreading evenly over the melt surface. Formation of large ridges and mounds obscured the view of the cold cap and created the potential for off-gas surges as large sections of cold cap fell into the melt pool. Therefore feed rates were lowered and in two instances the feed was stopped from one to over four hours to allow the excess feed accumulations to subside. No such problems were encountered during Test 6, for which a uniform cold cap existed throughout. During Test 4, ridges formed that frequently partitioned the melt surface into areas with exposed glass surface and areas with bubbling liquid feed. Although these ridges were not as extensive as those observed in Test 5, they did limit the effective melt surface area during the test. Significant foaming was not observed in any of the tests.

A variety of operational measurements recorded during these tests, including temperatures throughout the melter system, are given in Tables 3.4 – 3.6. The target glass temperature of 1150°C was successfully maintained for most of the glass pool during each test segment, as illustrated in Figures 3.2.a -3.2.c. Bulk glass temperatures were relatively constant throughout the glass pool except near the surface (27" from the floor), where temperatures were lower due to the thermocouples being in or near the cold cap. Brief deviations of about 25°C were observed during pump repairs that were performed in Test 6. Plenum temperatures (Figures 3.3.a-3.3.c) were an excellent indicator of cold cap coverage; Test 6, which had the most uniform cold cap, had plenum temperatures within a narrow range around 550°C while Test 5, which had poor cold cap coverage with excessive mounding, had highly variable plenum temperatures ranging between 400 - 800°C. Also notice that the difference between the three plenum temperature measurements (8" below ceiling, 17" below ceiling, and 17" below ceiling exposed) is greatest for Test 5 and least for Test 6. Other noteworthy features of the plenum temperature profile from Test 5 are the increases in temperature at about 50 and 140 hours run time in response to intentional feed interruptions in order to breakdown excessive feed mounds and the increase in temperature variability as more sugar was added to the feed and the cold cap became less manageable. Variability in plenum temperatures measured during Test 4 was significantly less than for Test 5 but more than for Test 6, corroborating the cold cap observations. Higher plenum temperatures at the beginning of each test were observed during initial cold cap formation, as expected.

Electrode temperatures averaged below 1150°C during each test segment. The east and west side electrode temperatures varied between the narrow range of 1025 – 1100°C after the

cold cap was established and typically varied no more than 25°C from each other during each test, as shown in Figures 3.4.a -3.4.c. Conversely, the bottom electrode, which was not powered in these tests, experienced temperatures ranging from 850 – 1050°C. During the tests with C-106/AY-102 simulant, the difference between the bottom and side electrode was 150 – 200°C, which is considerably larger than the 50 – 75°C differential in previous tests with the same feed [11]. The electrode temperature profile for Test 4 more closely resembled that observed in previous tests, with the bottom electrode being about 35°C colder than the West electrode, which was in turn about 25°C colder than the East electrode [3, 6, 9-12]. Differences between side and bottom electrode temperatures are greater in HLW tests, which do not use the bottom bubbler [3, 6, 9-12], than in the LAW tests, which do employ them [20, 29, 30]. The larger temperature differential between the bottom and side electrodes in Tests 5 and 6 cannot be explained by differences in bubbling since the bottom bubblers were not used in any of the HLW tests and the same total bubbling rate of 65 lpm was used in these and the previous test with C-106/AY-102 simulants [11]. The discharge chamber and riser temperatures were largely maintained above 950°C throughout the tests. Gas temperatures after the film-cooler were 150 - 200°C lower than the plenum temperature as a result of film-cooler and control-air dilution. Also, the film cooler is cleaned by a water spray every 12 hours, resulting in a short-duration reduction to about 75°C in the film cooler outlet temperature. As expected, test segments with the highest plenum temperatures also have the highest transition line temperatures (i.e., during the initial segment of each test).

Conditions in the glass pool are illustrated for electrical properties in Figures 3.5.a – 3.5.c, level and density in Figures 3.6.a – 3.6.c, and bubbling in Figures 3.7.a – 3.7.c. Supplied electrode power was proportional to glass production rate and therefore a gradual decrease of power occurred in Test 5, little change occurred during Test 6, and a gradual increase of power occurred in Test 4. Also of note are the variations in power during Tests 5 and 4 that were necessary due to the difficulty in maintaining a uniform cold cap. Glass resistance did not vary greatly over the tests due to consistency in melter operation. A slight trend of increasing resistance was observed in Test 5 and decreasing resistance in Tests 6 and 7. The glass level was mostly within an inch of the average of about 30 inches from the floor in Tests 6 and 4. The glass level varied over a much larger range (27 – 32) in Test 5 due to the difficulty in establishing a uniform cold cap. Glass density varied little during each test (average of about 2.34 and 2.41 g/cc for C-106/AY-102 and AZ-101, tests respectively), which is in part a result of the constant bubbling rate. The target total bubbling rate of 65 lpm was maintained throughout testing, as shown in Figures 3.7.a – 3.7.c. Lance bubbler flow rates were skewed slightly to reduce excessive accumulations of feed in portions of the melt pool. In Test 5, the tendency of the feed to form ridges and mounds was such that skewing was not sufficient to alleviate the difficulties, whereas the degree of skewing permitted to the operators (5 lpm) was sufficient in Tests 6 and 4. Power per unit glass production did not change significantly over the course of each test as a result of the relatively small production rate changes during each test. A small increase was observed in Test 5 as the production rate decreased over the course of the test. Power utilization in Test 4 was mostly higher than in the other two tests due to the higher feed water content, as expected. Comparison of power utilization with previous tests that used HLW AZ-101 [9] and C-106/AY-102 [11] feeds that had comparable water contents and glass pool bubbling rates demonstrates that power usage decreases as a function of production rate. For example,

C-106/AY-102 glass was produced at about 900 kg/m²/day requiring 3.5 kW per kg of glass, whereas in Test 5, which had a production rate of 650 kg/m²/day, 3.8 kW was required per kg of glass. Significantly more power was used than in the previous LAW tests (3.0-4.3 vs. 1.6-2.0 kW/kg glass) [20, 29, 30] due to the higher feed water content and much lower glass production rates.

SECTION 4.0

MELTER AND SBS ENERGY BALANCE

This section provides an analysis of the energy balance for the DM1200 based on data from Tests 5, 6, and 4. The energy balance envelope includes the melter box, transition line, and SBS. An additional computation involving the melter box only is also reported.

4.1 Introduction to Energy Balance

The purpose of the melter energy balance is to better understand the energy flow pathways in the DM1200 melter to underpin the basis for optimization of design, operation, and control of the WTP HLW melter. One specific potential application would be to determine the required electrode power and other required utilities for a given set of conditions such as the slurry type, slurry feed rate, air flow rates, melt pool and plenum temperatures, and SBS discharge temperatures. The objectives of this section are to document the details of the calculation and the results obtained together with an assessment of the sources and magnitudes of the associated uncertainties.

An energy balance around the DM1200 melter was constructed for tests with C-106/AY-102 feed (Tests 5 and 6) and with AZ-101 feed (Test 4). Each segment of the three tests had a different feed sugar concentration and, therefore, separate energy balances are provided for each test segment. Two separate calculations were performed within different system boundaries, both of which compared the melter electrode power to the sum of all other heat gains and losses. The two energy balance envelopes considered were:

- a) Boundary including both the melter and the SBS. The overall agreement (or “closure”) between the electrode power and all of the other energy streams was 108.7%, based on the average of all fifteen test segments (five segments from each of the three tests).
- b) Melter only, with boundary at the discharge from the film cooler. In this case the overall energy balance closure defined above was 105.5%.

4.2 Methodology

Figure 4.1 illustrates conceptually elements included in the melter energy balance calculations. The energy balance boundary (or “envelope”) surrounds the melter, transition line, and SBS or, the melter only. In both cases, this envelope excludes the discharge chamber of the melter while including the molten glass discharged from the melter melt pool. The role of the discharge chamber heaters is to maintain the discharging glass temperature constant, which has no net contribution to the overall heat balance.

The SBS is included within the energy balance herein, for two reasons:

- In the present configuration, the overall system thermal capacity is limited by both melter and SBS utility subsystems. In fact, about 50% of the melter electrode power is dissipated in the SBS and, therefore, no significant change can be made to one of these components without affecting the other.
- The flow measurements made around the SBS allow a check of the material balance, and hence, the energy balance around the melter. Furthermore, there is no continuous measurement allowing determination of the air inleakage into the system earlier than at the WESP exhaust.

The overall energy balance compares the melter electrode power to the sum of all of the other energy streams entering, leaving, consumed, and generated within the envelope. Some of these energy streams are associated with material flows, e.g., the melter slurry and air streams, or the SBS exhaust streams. Some of the energy streams are direct energy (non-material) transfers such as the melter electrode electrical power and skin convection losses to the surrounding air; some of the energy streams crossing the envelope border are indirect, such as cooling water; and finally, some of the energies are internal, such as combustion and other chemical reactions and phase transitions taking place within the melter.

Energy balances for each period of each test, as well as the overall balance for each test, are provided. A period for the purpose of the energy balance calculation begins with the initiation and ends with the termination of the slurry feed to the melter. Data were excluded whenever an interruption in the slurry feed into the melter exceeded 30 minutes. The start-up water feed (i.e., water fed to the melter before the introduction of the slurry) is always included in the energy and material balances since the first blow-down from the SBS does not occur until after the feed slurry has started.

The following is a list of all of the energy streams included in the energy balance:

- Electric power to melter electrodes.
- Air streams, including control air, film cooler air, and melter inleakage. The temperatures of the inlet control air and film cooler air were measured continuously.
- SBS blow-down.
- Melter feed slurry (assumed at 80°F/26.7°C). The actual heats of reaction involved in the decomposition of the feed slurry components as well as phase transition energy required to form glass were calculated.
- SBS exhaust.
- Energy transferred to cooling water streams including the melter cooling panels, the SBS internal coil, and the SBS jacket. The actual cooling water flow rates and temperatures were measured.
- Discharged molten glass, the temperature of which was taken as equal to the measured temperature at the bottom of the melt pool.
- Convection energy loss from the melter shell.
- Convection energy loss from the transition line.
- Combustion of organic feed components (such as sugar).

Implicit in the material streams listed above (and explicitly included in the energy balance) is the relative thermal energy of feed and product streams. (These are referred to in the tables as the “feed vs. product energies.”) For example, one component of the balance is the temperature difference between the water in the feed slurry and the water in the SBS blow-down. Similarly the difference in the temperatures of the air feed streams versus the temperature of the SBS exhaust (the “sensible” heat) is taken into consideration. The latent (i.e., phase transition) heat of the water fed into the melter as a liquid and leaving as water vapor is a major included component. The “feed vs. product energies” refer to the air and water fed to the melter system and leaving from the SBS; the energy carried away by the molten glass and the contribution from chemical reactions that occur within the melter are calculated separately.

Table 4.1 provides more detailed information on the calculation method. The first column, the *Calculated Value*, lists values required to assemble the energy balance. Column two identifies the specific input information (either calculated or measured) immediately determining the magnitude of the value in column one. The subsequent columns show actual data sets from which column two values were derived.

4.2.1 Assumptions Used for Energy Balance Calculations

The assumptions associated with the energy balance model are:

1. The melter is assumed to be at steady state within each period. This means the melter is capable of processing all the feed at the given rate (i.e., there are no significant cold cap changes).
2. Gas streams are considered to be composed of air and water vapor only for the purpose of estimating heat transfer properties, such as specific heat, density, or viscosity. The specific heat of the dry air component of these streams is assumed constant at 0.25 cal/gram/°C. The specific heat of the water vapor portion of the gas streams is assumed constant at 0.5 cal/gram/°C.
3. Cooling water heat transfer properties were corrected for the measured ethylene glycol content.
4. Ambient air temperature of 26.7°C (80°F) and relative humidity of 30% were assumed for calculations involving air in-leakage and convection. The actual inlet temperatures of the film cooler air and control air are considerably above 26.7°C and therefore the measured temperatures were used in calculations, taking the absolute water content as that defined by 30% relative humidity at 26.7°C.
5. The heat carried away by the discharge glass was estimated by using the temperature of the melt pool, the slurry feed temperature (assumed to be the ambient air temperature), and a calculated heat capacity of the glass. The calculation method for the heat capacity for a similar nuclear waste glass up to its glass transition temperature (T_g) was given in a previous report [54]:

$$C_p \text{ [Joules/(gram-atom * K)]} = 0.3119 (a + bT + c/T^2 + d/T^{1/2} + eT^2)$$

and the coefficients are:

$$a = 112.897 \quad b = 2.34243 \times 10^{-3} \quad c = -54243.9$$

$$d = -966.796 \quad e = 1.5 \times 10^{-7}$$

The above heat capacity equation was based on a glass with a gram-atom weight of 21.28 grams, whereas the gram-atom weight of the AZ-101 glass is 20.20 grams and the gram-atom weight of the C-106/AY-102 glass is 20.71 grams. As a result, the calculated (solid) glass heat capacity per unit mass is higher by 2.7% for the C-106/AY-102 feed and 5.1% for the AZ-101 feed. For comparison, Reference [55], dealing with a different nuclear waste glass, utilizes a melt pool heat capacity which differs by 5% for a gram atom weight that differs by 13%.

The sensible heat of the glass discharged from the melter relative to the feed slurry is calculated in two steps, due to different methods of calculating heat capacities:

- a. From feed slurry temperature to T_g : Integrate the above expression for heat capacity, between the feed slurry temperature, 26.7°C, and the T_g , 468°C for AZ-101 and 464°C for C-106/AY-102, adjusted for the gram-atom weights.
- b. From T_g to glass discharge temperature: Utilize a constant heat capacity, 30.5 Joules/(gram-atom x K), from the T_g to the melt pool temperature, 1152°C for Test 5, 1151°C for Test 6, and 1153°C for Test 4. (The heat capacity is not adjusted for the gram-atom weight.)

In typical engineering units, the integrated average heat capacity of the solid C-106/AY-102 glass is 0.26 calories/(gram °C), and of the molten glass pool, 0.35 calories/(gram °C). For the AZ-101 glass, the solid glass heat capacity is 0.27 calories/(gram °C), and of the molten glass pool, 0.36 calories/(gram °C).

6. To calculate the melter shell convective heat loss, skin temperature measurements were made during idling. A linear relationship between this convection heat loss and the melter plenum temperature was assumed (based on 970°C during idling and the actual plenum operating temperature, around 600°C, during operation).
7. Heat due to feed decomposition reactions (an endothermic process) in the melter was calculated from standard formation enthalpies of various feed components using commonly accepted stoichiometries. The values obtained in the case of AZ-101 feed were 1092.6 kJ/(kg of glass formed) and 52.8 kJ/(kg of glass formed) for the decomposition and the phase transitions, respectively. All the reactions were assumed proceeding to completion.

8. Calculation of feed decomposition heat for C-106/AY-102 yielded 1050.3 kJ/(kg of glass formed) (Test 5) and 1144.2 kJ/(kg of glass formed) with the added nitrate (Test 6). The phase transition heat was 51.2 kJ/(kg of glass formed) in both cases.
9. Complete combustion of any feed sugar in the melter was assumed. The standard heat of sugar combustion (1232.5 kcal/(gram mole)) was corrected for combustion conditions in the plenum.
10. Gases leaving both the SBS and the WESP were assumed to be saturated with water vapor.
11. Empirical natural convection heat loss methodology, based on Nusselt, Grasshof, and Prandtl numbers [31, 32], was used for estimating the melter shell convective heat loss. These calculations were calibrated using values of the transition line heat loss, which were calculated from available data.

4.2.2 Calculation Details

The dry air flow rate, as calculated from the WESP exhaust flow, temperature, and pressure measurements, is the critical tie-component in the melter energy balance evaluation. The WESP exhaust temperature was used to calculate the saturation pressure of water there. The assumption of water saturation and the total static pressure at the WESP exhaust determine the molar (volumetric) ratio of dry air to water vapor in this stream. This ratio and the wet flow rate (wscfm) yield the flow rate of dry air (dscfm). This dry air flow rate is assumed to be constant downstream of the film cooler.

Similar to the method used for the WESP exhaust stream, the temperature at the SBS exit is used to determine the water saturation pressure there. This, along with the dry air flow rate determined at the WESP, compound the water mass flow in the SBS exhaust stream. The SBS exhaust water, combined with the SBS blow-down equal the total water mass flow from the melter. The result can be verified by comparison with the total water contained in the slurry feed and melter air streams. The proper water material balance is critical to the total energy balance, since about 1/3 of the melter electrode power dissipation is associated with water condensation and cooling in the SBS.

There are four sources of the dry air in the melter:

- Film cooler air, containing the same amount of water vapor as ambient air but supplied at higher temperature due to the use of a regenerative blower.
- Control air, with the same water content as in ambient air and elevated in temperature due to the use of a turbo-blower.
- Bubbling air, dehydrated (from a compressor) but supplied at ambient temperature.
- Ambient in-leakage air. Inleakage air is calculated by difference as (WESP Air – Film Cooler Air – Control Air – Bubbling Air).

The off-gas temperature at the entrance to the transition line is calculated assuming an adiabatic mixture of the control air, feed related emissions (at the plenum temperature), and the film cooler air.

Given the calculated transition line inlet temperature and the measured SBS inlet temperature along with the dry air and water vapor mass flow rates, the actual ‘convective’ heat loss from the transition line can be estimated. Natural convection heat transfer calculations for the transition line (surface area: 2.6 m^2) were performed assuming the transition line external skin temperature to be the same as the average internal gas temperature. This assumes that the internal film heat transfer coefficient, where there is high turbulence and mixing, is much higher than the external film heat transfer coefficient, where only natural convection is present. As an allowance for the surface area of flanges that are present on the transition line, as well as the impact of melter fans that force some external air flow along the transition line, the calculated convection heat transfer of the transition line was increased by 10%.

Table 4.2 contains a comparison of calculated and actual transition line convection heat losses for the purpose of calibrating the melter shell convection calculations where only the surface area and several skin temperature values are known. A relatively wide range is observed in the ratio of the actual to the calculated heat loss values in Table 4.2 (81% to 228%). The transition line was cleaned between Test 6 and Test 4 and the removal of internal deposits (fouling) might account for the actual convective heat transfer increase by 84% $[(28,000 \text{ BTU/hr})/(15,000 \text{ BTU/hr})]$ when the skin (internal gas) temperature dropped from 286°C to 283°C . The fact that the (actual convection)/(calculated convection) ratio rapidly increases with increasing temperature suggests there may be a significant radiant heat transfer contribution to the heat loss. Radiant heat loss is proportional to the fourth power of absolute temperature, whereas convection is proportional to the $5/4$ power of temperature difference. Preliminary attempts were made to quantitatively blend these effects for the purpose of melter convection calculations, but no satisfactory method was found. Even after attributing the 84% change as due to fouling after Test 6 and then simply blending radiation and convection calculations to best fit the data available would still require the emissivity of the transition line to increase by 25% over the temperature range of $285\text{-}329^\circ\text{C}$, which is probably not plausible. In the face of these uncertainties, a simple calibration approach was used, which involved applying a “global average” (i.e., average of arithmetic and geometric averages) factor of 142% to the melter skin convection calculations. While the “142% factor” approach is very crude, a significant amount of calculation time for its refinement is probably not justified, since:

- the transition line convection loss is known by another method;
- the melter skin convection apparently accounts for only about 2-3% of the total energy balance; and
- the total melter energy balance closure is around 105-109%.

During a melter-idling period, 258 surface (skin) temperature measurements of the melter were systematically collected with a non-contact IR thermometer. Figures 4.2.a-4.2.e provide a summary depiction of the skin temperatures measured for each of the side faces and for the top face of the melter. An average of 1.5 measurements was made for every square foot of

(superficial) surface area for the sides and 2 measurements per square foot for the top. “Superficial area” is defined here as the overall length times the width of the face. The bottom of the melter was assumed to be at 45°C, based on 100% coverage by cooling panels, with an average cooling water discharge temperature of 41°C. The convective heat loss was calculated, based on the average temperature from each melter face. An overall correction factor of 1.25 was used as an allowance for the melter shell geometry being more complex than a flat plane (i.e., 25% more convective heat loss than if calculated for a rectangular box the size of the melter). The 25% factor was a visual (not calculated) judgment of how much bracing structural members (angles and I-beams) and other structural support elements added to the superficial area of the melter box. The 25% factor includes also an allowance for the three discharge chamber fans that force air over the top and west faces of the melter. Figures 4.3 and 4.4 are photographs of the west and top sides of the DM1200 melter illustrating the surface complexity. The 142% calibration factor from the transition line convection was applied in addition to the 125% surface area correction.

4.3 Results of Energy Balance Analysis

4.3.1 Overview

One measure of the melter heat balance accuracy is its “closure,” defined as the sum of the heat generated, consumed, and lost in unit time divided by the melter electrode power. The overall average closure for all of the test segments considered is 108.7%. This result suggests that the calculation was successful in the inclusion and understanding of all major energy flow pathways, considering the simplifying assumptions used in the development of the balance and the $\pm 3\%$ overall accuracy of the process monitoring instrumentation. Table 4.3 provides additional details of the closure data for each test, as well as the variability of the closure between the segments in each test.

In all three tests considered in energy balance calculations, the SBS accounts for 50% - 54% of the total melter energy exchanged. The SBS heat transfer value can be approached in two ways:

- a) From the process side, by determining the energy lost in the SBS by the off-gas stream.
- b) From the cooling side, by determining the energy absorbed by the two cooling water streams exchanging heat with the SBS.

Both methods should yield the same results and, for these tests, the average energy from the process side does equal the energy of the water side, as expected.

Water is the major component in the energy balance calculations accounting for about 1/3 of the total energy flow in the melter/off-gas system. In the process, water vapor leaving the melter is partially condensed in the SBS. Consequently, the sum of the SBS blow-down stream and the water content of the SBS exhaust should equal the total water entering the melter. Melter water includes both the feed slurry water and the water vapor contained in the various air

streams. This air moisture typically adds about 3% to the overall melter water intake. The ambient conditions during operations were constant at 80°F and 30% relative humidity. Table 4.5 summarizes the water balance in the system.

The energy balance at the discharge of the film cooler can be drawn using the water and the dry air flow rates obtained from the foregoing analyses around the SBS. The latent and sensible heats for the water and air are estimated utilizing the respective inlet temperatures: the ambient of 27°C, film cooler air of around 82°C, and the measured film cooler discharge temperature (approximately 350 - 410°C) as the envelope's discharge temperature. Table 4.6 illustrates the components of this calculation. The distinction is made between the "melter-only" and "melter+SBS" values. This is useful as an integrity check of the entire calculation method since these values should be equal. Melter electrode power is listed in the first row of the table. The second row shows the enthalpy changes of the film cooler air, and the third row gives the enthalpy of the bubbling air and the in-leakage air streams. Most (97%) of the water is fed to the melter as a liquid with the feed slurry at ambient temperature. Because of the large temperature change between the ambient air and the film cooler discharge, the heat capacity of the gaseous stream cannot be considered constant, thus the enthalpies were calculated utilizing the polynomial dependency on temperature of the heat capacity [33].

The remaining rows in Table 4.6, i.e., the melter cooling panels, the sensible heat of the glass discharged from the melter (relative to the feed), combustion, etc., identify, for each test, the melter-only calculated heat losses, and compare the average values, when possible, with the average values obtained from the melter+SBS calculation.

The melter-only calculation, using information from all test segments, returns the average value for the non-electrode energy streams of 155.6 kW, which amounts to 105.5% of the average electrode power input. The melter+SBS calculation, results in 160.1 kW, or 108.7% of the electrode input power. Consequently, both cases give reasonable closure.

Figure 4.5 is a conceptual representation of the energy transfer pathways around the SBS. Figures 4.7, 4.9, and 4.11 indicate that within the SBS, the energy transferred through the cooling coil accounts for about 75% of the total SBS heat load, and the energy transferred through the jacket amounts to about 25% of it. Tables 4.7, 4.8, and 4.9 indicate an average approach temperature* in the coil of about 5.6°C and about 16.3°C in the jacket, suggesting that the coil is a more efficient heat transfer device than the jacket.

The effect of increasing sugar concentration in the feed is apparent from the combustion energy values shown in Tables 4.7 – 4.9 for each of the segments A through E. The highest sugar content in the feed represents about 4% – 6% of the of the electrode input power. This is an exothermic contribution, denoted in the tables by a negative number. The combustion takes place in the cold cap area and is primarily passed through the off-gas to the SBS, as evident from the data presented in the previous Section (electrode power and plenum temperature values were practically unchanged during Test 6). The additional water content in the AZ-101 feed (Test 4)

* - *approach temperature* is defined as the difference in temperature between the discharge from a cooler and the inlet temperature of the cooling medium; usually air or water.

as compared to the C-106/AY-102 feed results in a slightly higher electrode power for boiling off the water, and consequently, slightly higher amount of heat transferred into the SBS in Test 6. It is noted that the lower amounts of power in Test 5 are partly the result of processing difficulties with that feed (poor spreading and mounding, as discussed earlier).

Comparison of Figures 4.6, 4.8, and 4.10 indicates stable and consistent energy transfer behavior for the C-106/AY-102 and the AZ-101 feed streams, despite increasing sugar amounts present in the later test segments. No significant effect of added nitrate in the C-106/AY-102 feed on the overall behavior can be seen by comparing Figures 4.5 and 4.7. The additional energy required to decompose the nitrates in Test 6 was about 1.3 kW.

4.3.2 Energy Balance Results for Test 5 (C-106/AY-102 Feed with Variable Amounts of Sugar)

Figure 4.6 shows the contribution of the component energy streams to the overall energy balance for Test 5. Table 4.7 lists the actual duties (individual kW contributions) for each of the components, as well as details about the heat transfer within the SBS. Figure 4.7 illustrates the role of the two heat exchangers in the overall SBS heat transfer. In this test, the average recorded differential temperature (outlet – inlet) of the water passing through melter cooling panels was 0.3°C, far below the usual differential temperature of 6.0°C. Typically, in all other campaigns the cooling panels account for about 20% of the melter energy balance, compared to 1.5% for Test 5. The melter cooling panel water flow during this run remained the same (25-29 gpm) as in the other runs. In addition, no such changes in operation of the melter cooling panels were previously observed for any run. As a result, this data set was rejected entirely. Instead, in further analysis of Test 5, the average cooling panel heat duty from the three subsequent runs was used. The plot in Figure 4.6 reflects actual recorded data showing melter cooling panel contribution of 1.5%.

4.3.3 Energy Balance Results for Test 6 (C-106/AY-102 with Added Nitrate and Variable Amounts of Sugar)

Figure 4.8 illustrates the contributions of the various component energy pathways to the overall energy balance for this run. Table 4.8 shows the actual duties (kW) for each of the components, as well as details of the heat transfer within the SBS. Figure 4.9 shows the relative contributions of the two heat exchangers to the overall heat transfer in the SBS.

4.3.4 Energy Balance Results for Test 4 (AZ-101 with Variable Amounts of Sugar)

Figure 4.10 illustrates contributions of the various component energy pathways to the overall energy balance for this run. Table 4.9 shows the actual duties (kW) for each of the components, as well as details of the heat transfer within the SBS. Figure 4.11 shows the relative contributions of the two heat exchangers to the overall heat transfer in the SBS.

4.3.5 Summary and Conclusions

Energy balance calculations were performed around the DM1200 melter for tests with two different feeds: C-106/AY-102 (Tests 5 and 6) and AZ-101 feed (Test 4). Each segment of the three tests had a different feed sugar concentration, thus separate energy balance calculations were performed for each test segment. Two different system boundaries were considered and for both cases, the melter electrode power was compared to the sum of all other heat gains and losses. In particular:

- a) Energy balance involving both the melter and the SBS completed with the closure value of 108.7%, based on all fifteen of the test segments (five segments in each of three tests).
- b) Energy balance around the melter only, with the boundary at the discharge from the film cooler. The overall average closure value was about 105.5% for all fifteen of the test segments (five segments in each of three tests).

The closure values are satisfactory given the simplifying assumptions and data used in the model calculations. The average accuracy of data acquisition was estimated to be in the order of 2-3% based on nominal performance of the instrumentation. The main uncertainties in the model are:

- a) Water temperature measurements around the melter cooling panels. The precision of these measurements was 10-20%, or about 2-4% of the overall energy balance.
- b) Water temperature measurements around the SBS. The precision of these measurements was 5-10%, or about 1.5-4% of the overall energy balance.
- c) The melter shell convective heat loss, which does not appear to be verifiable to better than within -20% to +100%. This represents 2-3% of the overall energy balance.

SECTION 5.0 OFF-GAS SYSTEM PERFORMANCE

The off-gas treatment system, shown schematically in Figure 1.3 consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME 1); a heater; a high-efficiency particulate arrestor (HEPA); a TCO/SCR catalytic unit, which includes a heater, a thermal catalytic oxidation unit (TCO), and a selective catalytic reduction unit (SCR) equipped with an ammonia injection system; a packed-bed caustic scrubber (PBS); a second high-efficiency mist eliminator (HEME 2); and a second HEPA on the bypass off-gas system. A silver mordenite column treats a slip stream of about 10% of the off-gas stream entering the TCO before returning it prior to the PBS. Data on the off-gas system performance collected during the tests with C-106/AY-102 and AZ-101 HLW feeds are presented and discussed in this section.

The tests reported herein (Tests 4, 5, and 6, together referred to as the "reductant tests") represent a subset of the entire test series. For context, Table 5.1 provides an overview of the complete test series in the sequence in which they were performed, including major post-test inspections and equipment modifications. The table also includes key operational events that affected the off-gas system during the tests. As discussed in Section 3.0, the formation of cold cap ridges and mounds affected melter processing and the off-gas system, particularly in Test 5 and, to a lesser degree, in Test 4. A number of additional equipment or operational items affecting the off-gas system are listed in Table 5.1. Results for tests other than Test 4-6 will be reported separately.

5.1 Off-Gas System Test Results

Data for each of the off-gas system components, logged by the LabVIEW data acquisition and control software, were imported into MS Excel files for data manipulation and plotting. Time "0" on the x-axis of each data plot corresponds to the start of water feed into the melter at the beginning of each test. Where indicated, data were smoothed by time averaging instantaneous measurements logged at two minute intervals to reduce data scatter and the number of data points for the plots. The average, minimum, and maximum values of the measured off-gas system parameters are given in Table 5.2. The plots of the typical sequence of gas temperatures through the DM 1200 off-gas system at various locations are given in Figures 5.1 through 5.3.

5.1.1 Melter Pressure

Test 5: C-106/AY-102 Feed with Variable Amounts of Sugar

The differential pressures across the transition line and film cooler are given in Figure 5.4. The response of the transition line differential pressure sensor shows the effects of clogging of the sensor itself. As a result of the periodic clogging problems, the transition line differential pressure is not considered reliable during this test. (Because of the sensor problems, a pressure

sensor was added to the inlet side of the transition line later in the test series, after Test 1, as indicated in Table 5.1. This additional sensor allowed determination of the transition line differential pressure as the calculated difference between the inlet and outlet pressure measurements.) The film cooler and transition line sections were not inspected during or after this test.

The computer logged melter pressures measured at the instrument port and calculated control air flow rates are plotted in Figure 5.5. The average melter pressure was -3.8 in. W.C and the melter pressure ranged from -6.9 in. W.C. to 1.2 in. W.C. The control air system, to control melter pressure, was operational during this test. The control air flow rate averaged 63.7 scfm. A review of the data files showed that four positive pressure values were recorded by LabVIEW as shown on Figure 5.5. As described in Section 3.0, large cold cap ridges and mounds formed during Test 5, resulting in transient off-gas surges as sections of the cold cap broke and fell into the melt pool; three transient plenum positive pressure spikes were noted between 165 and 200 hours of runtime.

In addition to the positive pressure spikes recorded by LabVIEW, operators recorded other occasional off-gas surges resulting from breakup of cold cap ridges and mounds. Six positive pressure spikes were noted in the operations logbook between 65 and 200 hours of runtime. Comparison of logbook records with LabVIEW data files indicates that the two minute recording interval for LabVIEW does not capture all the pressure variations within the melter plenum. When pressure changes occur, the deviation from the set-point of the control air system results in throttling of control airflow until the pressure returns to its set-point. The system response is fast enough that the two minute data recording interval is insufficient to capture all such variations. Therefore, the LabVIEW data are supplemented with operations logbook information when evaluating melter plenum pressure response.

Test 6: C-106/AY-102 with Additional Nitrate and Variable Amounts of Sugar

The differential pressures across the transition line and film cooler are given in Figure 5.6. (Note that these are hourly average values, which may not show maximum values identified in the logbook entries or two-minute data files.). At 9.9 hours, the differential pressure rose to 9.8 in. W.C. and solid blockage seen visually in the film cooler was removed. At 22.1 hours, the film cooler was rodded out to remove solids buildup. The film cooler and transition line sections were not inspected after this test.

The computer logged melter pressures measured at the instrument port and calculated control air flow rates are plotted in Figure 5.7. The average melter pressure was -4.0 in. W.C and melter pressure ranged from -7.3 in. W.C. to 0.8 in. W.C. The control air system was operational during this test with the control air flow rate averaging 62.8 scfm. At 90.1 hours, the melter pressure control set point was changed from -3.75 in. W.C. to -4.0 in. W.C., which reduced the control air flow rate.

A review of the data files showed that two positive pressure values were recorded by LabVIEW as shown on Figure 5.7. The first of these (at 10.3 hours), measured 0.7 in. W.C. and occurred when the film cooler was rodged to remove buildup. The second positive pressure reading (at 142.2 hours), measured 0.1 in. W.C. and occurred when a large piece of cold-cap dislodged and suddenly came in contact with the hot glass melt. In addition to the positive pressure values recorded by LabVIEW, five positive pressure values were recorded by operations between 50 and 200 hours of runtime, all of which occurred during off-gas sampling. The sampling procedure requires opening a port in the transition line which increases inleakage and reduces the effectiveness of the downstream blowers in maintaining plenum vacuum.

Test 4: AZ-101 Feed with Variable Amounts of Sugar

The differential pressures across the transition line and film cooler are given in Figure 5.8. As noted earlier, during Test 6 the transition line differential pressure sensor experienced periodic clogging and therefore an additional pressure sensor was added to the transition line inlet. The additional sensor allows an alternate method of determining the differential pressure across the transition line as the difference between the individual pressure readings from the transition line inlet and outlet sides. Both results (calculated difference and direct sensor measurements) are presented in Figure 5.8. The measurements are consistent with each other, allowing for the fact that hourly average values are shown. It is noted that the calculated values are about an inch of water column greater than the direct sensor values. Although not shown in the figure, a spike of the film cooler differential pressure to 8.7 in. W.C. was recorded by operators at 155.9 hours when a piece of cold cap shelf collapsed into the melt. A spike in film cooler differential pressure is evident in the Figure at 218 hours.

The computer logged melter pressures measured at the instrument port and calculated control air flow rates are plotted in Figure 5.9. The melter pressure averaged -3.8 in. W.C and ranged from -6.9 in. W.C. to 0.1 in. W.C. The control air system was operational during this test with an average flow rate of 66.1 scfm. A review of the data files showed that two positive pressure values were recorded, as shown on Figure 5.9. The first of these (at 117.4 hours) measured 0.04 in. W.C. and occurred during off-gas sampling. The second positive pressure reading (at 220.4 hours) measured 0.04 in. W.C. and occurred during cold cap sampling. Four additional positive pressure values were recorded in the operations logbook between 33 and 220 hours of runtime as resulting from collapse of cold cap sections into the melt pool.

The film cooler and transition line sections were not inspected during or after this test.

Melter Pressure Comparison to Previous Tests

Previous results for melter processing of C-106/AY-102 feed are reported in Reference [11] and for AZ-101 feed in Reference [9]. The occurrence of positive melter pressures for the previous C-106/AY-102 tests were minor and attributed to operational actions such as off-gas sampling or ADS pump maintenance. By contrast, multiple pressure spikes during Test 5

appeared to result from formation of cold cap ridges with subsequent breakup and consequent release of steam. The poor cold cap formation also resulted in poor processing as well as variable melter plenum temperatures, as discussed earlier. For Test 6, the C-106/AY-102 feed with higher nitrates, the general performance in the test was better than for Test 5. For the AZ-101 feed with reductants (Test 4), a comparison can be made with the earlier tests [9]. Test 4 of the previous series had the same solids content and comparable feed rate and was run at three bubbling rates (8, 40, and 65 lpm), as compared to the current feed in Test 4 containing reductant and processed at one bubbling rate, 65 lpm. The current test had a number of positive pressure spikes attributed to formation and collapse of cold cap ridges, whereas the previous test had only minor positive pressure recordings as a result of operational activity such as off-gas sampling.

None of these reductant tests (Tests 5, 6, and 4), or the previous C-106/AY-102 tests [11], or AZ-101 tests [9] experienced blockages of the transition line requiring cleanout. Similarly, blockage of the film cooler was not a particular problem, although one rod-out was required early in Test 6. In the previous tests [11, 9], no film cooler rod-outs were required. The generally comparable deposition behavior suggests that the addition of sugar to these two feeds does not result in a more significant formation of sticky off-gas products depositing in the film cooler or transition line.

5.1.2 SBS Performance

SBS inlet and outlet gas temperatures, pressures, and flow rates, the pressure drop across the SBS, SBS water temperature, heat exchanger inlet and outlet water temperatures and flow rates were recorded during the tests. The amounts of heat removed by the SBS jacket cooling water and the plate heat exchanger/SBS inner cooling coil were calculated from the measured data.

A design variation of the SBS down-comer extension pipe was tested during this series of tests in an attempt to reduce the plugging experienced in many previous tests. Prior to the tests the down-comer extension was removed and replaced with a flared extension piece. Views before and after addition of the flared extension piece are provided in Figure 5.10.

For reference, the connection pieces between the melter and SBS are shown in Figure 5.11 and 5.12. Figure 5.11 shows the sequence of transition line pieces connecting to the melter side. The transition line bellows shown on Figure 5.11 connects to the SBS side Y-piece shown in Figure 5.12; this piece then connects to the top of the SBS. The Y-piece allows access to the SBS down-comer for inspections and cleaning, and was used for post-test inspections, as described in the following sections. (The area of occasional blockage, outside the off-gas flow-path, is indicated on the figure.)

Data on the performance of the SBS regarding solids removal from the off-gas stream are presented and discussed in Section 7.0. Results from the analysis of fluids accumulated in the SBS are presented and discussed in Section 5.2

Test 5: C-106/AY-102 Feed with Variable Amounts of Sugar

As mentioned in Section 3, three feed interruptions occurred during Test 5. The first interruption lasted about half an hour and occurred at approximately 27 hours of runtime; this was due to repair of the bypass off-gas system valve. The other two interruptions, between 52.5 and 53.8 hours of operation, and between 141.1 and 145.7 hours of operations, were due to cold cap ridge formation. At 45.0 hours, two of the four SBS isolation pinch valves failed and were replaced.

Test 5 SBS inlet and outlet gas temperatures are plotted in Figure 5.13. The inlet gas temperature peaked at 443°C and averaged 261°C; the outlet gas temperature peaked at 56.2°C and averaged 40.3°C. The downward spikes in SBS inlet gas temperatures are due to periodic cleaning of the film cooler with water. The inlet, outlet, and differential pressures are shown in Figure 5.14. At 215.0 hours, the SBS pressure sensor ports were cleaned and the differential pressure reading then dropped. The drop in inlet and differential pressures suggests that the inlet side sensor was experiencing some clogging. The inlet gas pressure averaged -5.3 in. W.C., the outlet pressure averaged -47.2 in. W.C. and the pressure drop across the SBS averaged about 43.0 in. W.C. The pressure drop across the SBS increased by about 6.1 in. W.C. over the nine days of testing with C-106/AY-102 feed.

Water temperatures in the SBS, SBS chilled cooling water supply temperature, water cooling jacket outlet temperature, and water outlet temperature from the plate heat exchanger are shown in Figure 5.15. Oscillations in temperatures in this figure, and in heat exchanger flow rates in Figure 5.16, can be seen, particularly between 40 – 60 hours. Fluctuations in the SBS off-gas outlet temperature from about 35°C to 50°C resulted in operational adjustment of SBS heat exchanger flow rates as needed to bring SBS outlet temperatures back to target. (The off-gas temperature oscillations are also seen in downstream measurements at the WESP and HEME #1.) For Test 5, there was an average of about 2.6°C difference in water temperatures measured at four depths (48, 60, 72 and 78 inches) within the SBS. The liquid in the SBS was heated to a maximum temperature of 65.1°C during the initial period of water feeding, while the average SBS sump temperature was 44.5°C.

The SBS jacket, inner coil, and heat exchanger water flow rates are plotted in Figure 5.16. The average SBS jacket, inner coil, and heat exchanger water flow rates were 7.9, 24.5, and 9.7 gpm, respectively. The amounts of heat removed by the SBS cooling jacket and the plate heat exchanger are shown in Figure 5.17. The heat load data for SBS cooling jacket and plate heat exchanger are calculated based on hourly averaged cooling water temperature increases (outlet temperature minus supply temperature) across the cooling jacket and plate heat exchanger multiplied by the time-averaged flow rate through each. For this test, heat removal averaged 45.5 kW by the plate heat exchanger and 16.9 kW by the cooling jacket. About 73% of the heat load to the SBS was removed by the plate heat exchanger and about 27% by the cooling jacket. SBS inner coil and plate exchanger water temperatures are plotted in Figure 5.18. The heat load data for SBS inner coil was also calculated based on hourly averaged cooling coil water temperature increases (coil water outlet minus its inlet temperature) multiplied by the hourly averaged flow rate of inner cooling coil water. The average SBS inner coil heat load was

48.0 kW. The heat load difference between SBS plate heat exchanger and inner coil, plotted in Figure 5.19, shows that, as expected, the heat removed from the SBS liquid by the cooling coil is in reasonable agreement with the primary-to-secondary heat transfer in the plate heat exchanger.

At the end of this test, the SBS was blown down; 344 gallons of liquid were removed from the SBS and 25 gallons were removed from the SBS overflow tank. No solids were removed from the SBS or the SBS overflow tank at the end of the run. An infra-red video inspection was made of the SBS down-comer. The Y-transition piece attached to the top of the SBS is shown in Figure 5.12; this piece is made from 4" piping. The top of the Y-inlet (in the area labeled on the figure) was completely blocked; however, this did not affect the gas flow into the SBS. Figure 5.20 shows the thin layer of uniform, smooth deposits that were visible on the inside surface of the pipe immediately below the Y-inlet. Figure 5.21 shows the many small nodules, perhaps 1/8" in size that covered the rest of the down-comer from a few inches below the Y-inlet to the base of the down-comer. Figure 5.22 shows the ring of deposits that blocked about 10% of the down-comer area at about 3" to 4" above the base of the down-comer. The down-comer below this point was clean. Figure 5.23 shows the blow-down wand, the liquid surface, and some ceramic packing rings that were visible in the SBS sump. The ring of deposits visible in Figure 5.22 was relatively soft and was knocked free by the camera during its downward traverse. These deposits appear to be in the same location as observed in previous tests.

Test 6: C-106/AY-102 with Additional Nitrate and Variable Amounts of Sugar

During Test 6, between 27.7 and 30.8 hours of operations, the feed was turned off due to replacement of the seal on the melter cooling pump, MCL-CW-P-402A. Between 140.6 and 142.1 hours of operations the feed was turned off to replace the SBS recirculation pump, SBS-PW-P-501, which had a seal failure.

The SBS inlet and outlet gas temperatures are plotted in Figure 5.24. Inlet and outlet gas temperatures decreased during the time period when feeding was stopped. At 120.7 hours, the building chilled water system malfunctioned and, therefore, the supply was switched to city water until the building system was repaired. The supply water temperature was therefore high until 122 hours when the chilled water system maintenance was completed. The effect of increased supply water temperature can be seen in most of SBS related figures between 120 and 122 hours of operations. The inlet gas temperature peaked at 470°C and averaged 276°C and the outlet gas temperature peaked at 54.4°C and averaged 39.9°C. The downward spikes in SBS inlet gas temperatures are due to periodic cleaning of the film cooler with water. The inlet, outlet, and differential pressures are shown in Figure 5.25. The inlet gas pressure averaged -8.5 in. W.C.; the outlet pressure averaged -50.4 in. W.C.; the pressure drop across the SBS averaged about 42.3 in. W.C. The pressure drop across the SBS increased by about 6.8 in. W.C. over nine days of testing with the C-106/AY-102 feed. At 69.0, 114.8, 138.1 and 218.8 hours, the SBS pressure sensor ports were cleaned in response to the observed trends in the readings and the differential pressure readings subsequently dropped.

Water temperatures in the SBS, SBS chilled cooling water supply temperature, water cooling jacket outlet temperature, and water outlet temperature from the plate heat exchanger, are shown in Figure 5.26. There was an average of about 3.6°C difference in water temperatures measured at four depths (48, 60, 72 and 78 inches) within the SBS. The liquid in the SBS was heated to a maximum temperature of 64.1°C during the initial period of water feeding, while the average SBS sump temperature was 44.8°C.

The SBS jacket, inner coil, and heat exchanger water flow rates are plotted in Figure 5.27. Average SBS jacket, inner coil and heat exchanger water flow rates were 16.0, 24.4 and 13.1 gpm, respectively. The amounts of heat removed by the SBS cooling jacket and the plate heat exchanger are shown in Figure 5.28. The heat load data for the SBS cooling jacket and plate heat exchanger are calculated based on hourly averaged cooling water temperature increases (outlet temperature minus supply temperature) across the cooling jacket and plate heat exchanger multiplied by the time-averaged flow rate through each. For this test, heat removal averaged 52.7 kW by the plate heat exchanger and 22.7 kW by the cooling jacket. About 70% of the heat load to the SBS was removed by the plate heat exchanger and about 30% by the cooling jacket. SBS inner coil and plate exchanger water temperatures are plotted in Figure 5.29. The heat load data for SBS inner coil was also calculated based on hourly averaged cooling coil water temperature increases (coil water outlet minus its inlet temperature) multiplied by the hourly averaged flow rate of inner cooling coil water. The average SBS inner coil heat load was 56.6 kW. The heat load difference between SBS inner coil and plate heat exchanger, plotted in Figure 5.30, shows that, as expected, the heat removed from the SBS liquid by the cooling coil is in reasonable agreement with the primary to secondary heat transfer in the plate heat exchanger.

At the end of Test 6, the SBS was blown down; 351 gallons were drained from the SBS itself, and 36.94 gallons were drained from the SBS overflow tank. Figure 5.31 shows the wet solids removed from the SBS overflow tank. The solids dry mass was 42.7 kg. In addition, 0.68 kg of wet solids (0.46 kg dry) was removed from the SBS down-comer. An infra-red video inspection was made of the SBS down-comer. The top of the Y-inlet (from the transition line) to the SBS down-comer was initially 95% blocked; however, this did not affect the gas flow into the SBS. Similar to Figures 5.20 and 5.21, which were taken at the end of the previous run, a thin layer of uniform, smooth deposits were visible on the inside surface of the pipe immediately below the Y-inlet and almost all of the down-comer surface was covered by many small nodules, perhaps 1/16" to 1/8" in size. Figure 5.32 shows the ring of deposits, about 3" to 4" above the base of the down-comer, which blocked about 32% of the down-comer; the down-comer below this point was clean. Figure 5.33 shows that the blow-down wand and the liquid surface were visible in the sump but, unlike the previous run, no other solids were visible in the SBS sump from the bottom of the down-comer. The ring of deposits visible in Figure 5.32 was moderate in hardness; these deposits could not be knocked free by the camera during its downward traverse but were removed by wire brushing from the top. Figure 5.34 shows a ridge of deposits located about 5'-6" below the top of the down-comer and about 1/16"-1/8" in thickness that remained after wire-brush cleaning performed from the top of the SBS. This ridge was much smaller, although present, than that at the end of the previous run.

Figure 5.35 is an SEM micrograph of the dried sample (W12-O-142B) from the SBS

down-comer. Figure 5.36 shows an SEM/EDS spectrum of this sample, which revealed the presence of primarily iron, selenium, and silicon ($\text{Fe}_2\text{O}_3 \sim 45\%$, $\text{SeO}_2 \sim 1.3\%$, $\text{SiO}_2 \sim 7\%$); Ti, Zn, Mn, and Ni were also observed in lesser amounts in addition to Na, Ca, Cl, Pb, Te, S and As. Many small Se oxide phases were observed throughout but only one of the phases observed was present as a well-formed crystal, as can be seen in Figure 5.35 (spectrum 1 crystal). The EDS spectrum of region #1, given in Figure 5.37, revealed mainly Se.

Test 4: AZ-101 Feed with Variable Amounts of Sugar

Prior to this test, a down-comer sleeve was added to the SBS, as noted in Table 5.1. After the conclusion of Test 2, diagnostic tests indicated that a weld sealing the pre-existing lower sleeve to the outside of the lower portion of the down-comer (through the packed bed) was cracked, essentially allowing this sleeve to fill with the SBS fluid. Figure 5.38(a) shows this lower sleeve. This weld was repaired, and a pressure tap was permanently installed to provide an indication of any future leaks. Figure 5.38(b) shows the new insulating sleeve that was installed on the down-comer, which insulates the down-comer from the top of the packed bed to the top lid of the SBS shell (i.e., above the level of the pre-existing lower sleeve). At the time of the installation of the upper sleeve, 15.1 kg of packing was added to the top of the SBS bed.

The SBS inlet and outlet gas temperatures for Test 4 are plotted in Figure 5.39. The inlet gas temperature peaked at 353°C and averaged 266°C ; the outlet gas temperature peaked at 51.0°C and averaged 40.8°C . The downward spikes in SBS inlet gas temperatures are due to periodic cleaning of the film cooler with water. The inlet, outlet, and differential pressures are shown in Figure 5.40. The inlet gas pressure averaged -6.6 in. W.C., the outlet pressure averaged -45.8 in. W.C., and the pressure drop across the SBS averaged about 38.8 in. W.C. The pressure drop across the SBS increased by about 0.5 in. W.C. over the nine days of testing with AZ-101 feed.

Water temperatures in the SBS, SBS chilled cooling water supply temperature, water cooling jacket outlet temperature, and water outlet temperature from the plate heat exchanger are shown in Figure 5.41. There was an average of about 3.6°C difference in water temperatures measured at four depths (48, 60, 72 and 78 inches) within the SBS. The liquid in the SBS was heated to a maximum temperature of 63.7°C , while the average SBS sump temperature was 47.5°C .

The SBS jacket, inner coil, and heat exchanger water flow rates are plotted in Figure 5.42. The average SBS jacket, inner coil, and heat exchanger water flow rates were 24.7, 24.1 and 20.4 gpm, respectively. The amounts of heat removed by the SBS cooling jacket and the plate heat exchanger are shown in Figure 5.43. The heat load data for SBS cooling jacket and plate heat exchanger are calculated based on hourly averaged cooling water temperature increases (outlet temperature minus supply temperature) across the cooling jacket and plate heat exchanger multiplied by the time-averaged flow rate through each. For this test, heat removal averaged 58.6 kW by the plate heat exchanger and 23.7 kW by the cooling jacket. About 71% of the heat load to the SBS was removed by the plate heat exchanger and about 29% by the cooling

jacket. The SBS inner coil and plate exchanger water temperatures are plotted in Figure 5.44. The heat load data for the SBS inner coil was also calculated based on hourly averaged cooling coil water temperature increases (coil water outlet minus its inlet temperature) multiplied by the hourly averaged flow rate of inner cooling coil water. The average SBS inner coil heat load was 62.8 kW. The heat load difference between SBS plate heat exchanger and inner coil, plotted in Figure 5.45, shows that, as expected, the heat removed from the SBS liquid by the cooling coil matches the primary to secondary heat transfer in the plate heat exchanger.

At the end of Test 4, the SBS was blown down and 338.7 gallons of liquid was drained from the SBS. The volume blown down from the SBS overflow tank was not recorded. Post-run dry solids removed from the SBS overflow tank totaled 25.4 kg. Figure 5.46 illustrates the fairly smooth, thin deposits at the top of the SBS down-comer at 30 inches down from the top of the viewport (at the bottom of the Y-inlet from the transition line). Figure 5.47, taken about 66 inches down from the top viewport, shows that the deposits were thinner than at the top of the down-comer, apparently becoming large friable flakes, which ended at this depth. Figure 5.48 shows a ring of deposits, which blocked approximately 7% of the flow area near the base of the down-comer. The calculated average height of this ridge is 1/8".

Figure 5.49 indicates that the blow-down wand was approximately half-buried in solids in the SBS bowl. At least in part, this is attributed to failure of the discharge pressure gauge of the SBS recirculation pump, which indicated decreasing pressure. In response to this, the operators partially closed the flow valve, which manually controls the recirculation rate in order to maintain a constant flow of around 20 gpm. However, the consequence of the reduced circulation was lower turbulence and more settling of solids in the SBS bowl. The pressure gauge was recalibrated at the conclusion of this test, and presumably the turbulence was restored within the SBS bowl during the following test run (Test 10). Since a large volume of solids was recovered at the conclusion of that test, apparently, once solids settle out in the SBS bowl, they cannot be easily re-suspended.

5.1.3 WESP Performance

The inlet and outlet gas temperatures and differential pressure across the WESP were measured and recorded by the computer data acquisition system during each test, while the WESP current and voltage were recorded manually.

Data on the performance of WESP regarding solids removal from the off-gas stream are presented and discussed in Section 7.0. Results of the analysis of fluids that accumulated in the WESP are presented and discussed in Section 5.2.

Test 5: C-106/AY-102 Feed with Variable Amounts of Sugar

The WESP inlet and outlet gas temperatures are plotted in Figure 5.50. The WESP inlet gas temperature averaged 39.7°C and the outlet temperature averaged 41.9°C, indicating a 2.2°C temperature increase across the WESP during this test. The downward spikes in the WESP outlet

temperature are a result of the daily deluge of the WESP. The WESP differential pressure and outlet gas flow rate are plotted in Figure 5.51. The pressure drop across the WESP averaged 3.0 in. W.C. The average WESP wet gas flow rate was 204.5 scfm.

The amount of liquid accumulated in the WESP is plotted as a function of run time in Figure 5.52 where it is compared with the amount of fresh water sprayed into the WESP. The inlet spray water was set to 2.0 ± 0.2 gph, as specified by the Test Plan. The actual average spray water flow rate was 2.03 gph. As evident from Figure 5.52, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is the liquid removed from the off-gas, which is also plotted in Figure 5.52. The WESP electrodes were deluged daily with water at a nominal rate of 12 gpm for 3.33 minutes, as planned.

The WESP voltage and current are plotted as a function of run time in Figure 5.53. The average operating voltage and current were about 30.7 kV and 16.1 mA, respectively. The voltage remained steady throughout the test; however the current was not steady between 48 and 121 hours. Note that WESP repairs were made at the end of Tests 5 and 6 and, after that, subsequent tests showed more steady operating characteristics. For Test 5, the time required to manually stabilize power to operating values after deluge of the WESP ranged from 6 to 25 minutes and averaged 14.5 minutes, as shown in Table 5.3.

At the end of the test, 38 gallons of liquid were initially blown down. After a final deluge, another 63 gallons of liquid were blown down. Figure 5.54 shows that the fluorinated ethylene propylene (FEP) heat-shrink sleeve installed on the top south WESP grid support had degraded by the end of Test 5, exposing the underlying glass-filled PTFE support. The sleeve and the PTFE support were installed on July 22, 2002, replacing a CPVC support that was installed on March 1, 2002. As a temporary repair at the end of Test 5, the sleeve was removed, and the post was covered with silicone grease. The post was replaced with a UHMW polyethylene post at the conclusion of the following run. Also at the conclusion of Test 5, the WESP spray nozzle was replaced and a new 10 micron filter was installed upstream.

Figure 5.55 indicates the WESP sump condition prior to the final pre-deluge WESP blow-down. A thin layer of particles, having the same appearance as feed, covered the bottom of the sump. Figures 5.56 and 5.57 show photographs of the WESP collector plates and grids taken from the bottom, indicating a thin lacy, spider-web-like pattern of particulates observable on most of the hex-walls of the collector plates. Figures 5.58 illustrates that the deluge apparently washed off the lace surface pattern of particulates. Figure 5.59 indicates that an apparently very thin but tenacious layer remained on the hex walls following the deluge. However, pre- and post-deluge videos from the end of each run suggest there is no significant accumulation. Typically, some of this material (a thin slurry, but having the obvious reddish color of most of the feed and SBS blow-down) is present pre-deluge, and essentially all of the material is gone post-deluge.

Test 6: C-106/AY-102 with Additional Nitrate and Variable Amounts of Sugar

The WESP inlet and outlet gas temperatures are plotted in Figure 5.60. The WESP inlet gas temperature averaged 39.3°C and the outlet temperature averaged 39.8°C, indicating a 0.5°C temperature increase across the WESP during this test. The high WESP inlet and outlet gas temperatures between 120.7 and 122 hours of operations are due to the building chilled water maintenance during that time period. The downward spikes in the WESP outlet temperature are a result of the daily deluge of the WESP. WESP differential pressure and gas flow rates out of the WESP are plotted in Figure 5.61. The pressure drop across the WESP averaged 3.2 in. W.C. The average WESP wet gas flow rate was 197.3 scfm. The maximum differential pressure between 188 and 199 hours may be due to numerous off-gas sampling performed from the same WESP ports (used for the pressure measurements) during that time period. The high values are inconsistent with other data and it seems likely that the sampling activities may have interfered with the adjacent differential pressure sensor causing erroneous readings during that time.

The amount of liquid accumulated in the WESP is plotted as a function of run time in Figure 5.62, where it is compared with the amount of fresh water sprayed into the WESP. The inlet spray water was set to 2.0 ± 0.2 gph, as specified by the Test Plan. The actual average spray water flow rate was 2.04 gph. As evident from Figure 5.62, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is the liquid removed from the off-gas, which is also plotted in Figure 5.62. The WESP electrodes were deluged daily with water at a nominal rate of 12 gpm for 3.33 minutes, as planned.

The WESP voltage and current are plotted as a function of run time in Figure 5.63. The average operating voltage and current were about 30.1 kV and 11.1 mA, respectively. The voltage remained steady throughout the test. However the current fluctuated, often around a lower value than anticipated. The deteriorating electrical characteristics were addressed by replacing a grid support post at the end of the test. The time required to manually stabilize power to operating values after deluge of the WESP ranged from 6 to at least 46 minutes and averaged >22 minutes, as shown in Table 5.3. Because of the problematic electrical characteristics, the time required for power stabilization after a deluge could not be accurately determined in several instances.

Figures 5.64 and 5.65 indicate the pre- and post-deluge conditions; there is no salient difference. Figures 5.64 and 5.65 are from the same tubes, before and after the deluge. The overall condition indicates fairly light buildup of scattered nodular deposits on both the rods and the hex walls. The total buildup is less than 1/16". A two-hour recirculating acid wash/deluge of the WESP grid was conducted after Test 6. This wash solution was made from 15 gallons of water, 1 gallon of hydrochloric acid, a half-gallon of nitric acid, 500 grams of sodium phosphate and 250 grams of sodium pyrophosphate decahydrate. The photographic documentation does not clearly indicate whether this acid wash was effective.

At the end of the test, 29 gallons of liquid was initially blown down. After a final deluge, another 41 gallons of liquid was blown down. 70 grams of solids (W12-O-142A) were collected

from the bottom of the WESP. An SEM micrograph of a dried particle in sample W12-O-142A is shown in Figure 5.66. EDS analysis revealed that the sample consists of Se and Pb with various metals (presumably oxides), especially iron and sodium. At the end of the test, during the video inspections, 1.25 grams of solids (W12-O-146A) were removed from the WESP collector rods. An SEM micrograph of a particle in sample W12-O-146A (which looked dry) is given in Figure 5.67. SEM/EDS spectra of nine regions from this sample are presented in Figures 5.68, through Figure 5.70. EDS analysis revealed that the sample consists of predominantly Fe with small or trace amounts of Se, Pb, Te, Zn, Na, C, and Cl.

Test 4: AZ-101 Feed with Variable Amounts of Sugar

The WESP inlet and outlet gas temperatures are plotted in Figure 5.71. The WESP inlet gas temperature averaged 40.1°C and the outlet temperature averaged 42.4°C, indicating a 2.3°C temperature increase across the WESP during this test. The downward spikes in the WESP outlet temperature are a result of the daily deluge of the WESP. The WESP differential pressure and gas flow rate out of the WESP are plotted in Figure 5.72. The increase in the gas flow rate and differential pressure at about 46.9 hours is due to the increased Blower 701 and Blower 801 speeds. (These are the “Paxton Blower” and “ID Fan” identified on Figure 1.3.) The pressure drop across the WESP averaged 2.8 in. W.C. The average WESP wet gas flow rate was 217.2 scfm.

The amount of liquid accumulated in the WESP is plotted as a function of run time in Figure 5.73, where it is compared with the amount of fresh water sprayed into the WESP. The inlet spray water was set to 2.0 ± 0.2 gph as specified by the Test Plan. The actual average spray water flow rate was 2.04 gph. As evident from Figure 5.73, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is the liquid removed from the off-gas, which is also plotted in Figure 5.73. The WESP electrodes were deluged daily with water at a nominal rate of 12 gpm for 3.33 minutes, as planned.

The WESP voltage and current are plotted as a function of run time in Figure 5.74. The average operating voltage and current were about 29.6 kV and 17.0 mA, respectively. The voltage and current remained steady throughout the test. The WESP current and voltage were very stable as compared to Tests 5 and 6. The time required to manually stabilize power to operating values after deluge of the WESP ranged from 1 to 2 minutes and averaged 2 minutes, as shown in Table 5.4. Note that after Tests 5 and 6, the spraying procedure was changed. During Test 4, the WESP spray water was turned off 5 minutes before the deluge and was restored 5 minutes after stability returned. This drastically reduced the time required to manually stabilize power in the WESP. During Test 4, the duration of spray water flow interruption ranged from 8 to 11 minutes and averaged 11.3 minutes, as shown in Table 5.4.

At the end of the test, 99 gallons of liquid was initially blown down. After a final deluge, another 42 gallons of liquid was blown down. Figures 5.75 and 5.76 illustrate the condition of the WESP collectors and grid prior to the final WESP pre-deluge blow-down. Figures 5.77 and

5.78 were taken after the final WESP deluge. Surprisingly, the loose flakes seen in Figures 5.75 and 5.76 survived the deluge. These flakes were visible only in one of the hex cells and were documented to persist through several months of campaigns. Similarly, the thin tenacious deposits seen in Figure 5.76 have persisted in all of the cells for several months, including through the acid wash conducted at the end of Test 6.

5.1.4 HEME #1

A HEME (HEME #1) that follows the WESP in the off-gas system removes any water droplets that may be present in the water saturated gas exiting the WESP. There is a water spray in the HEME of 0.2 gallons per hour. The HEME was not cleaned and not flushed between tests.

For Test 5, the outlet gas temperature and differential pressure are plotted in Figure 5.79. The average HEME #1 gas outlet temperature was 40.2°C. The downward temperature spikes result from WESP deluges, which cooled the off-gas stream. The average pressure drop across HEME #1 was 2.2 in. W.C. At the end of the test, 31 gallons of liquid was blown down from HEME #1.

For Test 6, the outlet gas temperature and differential pressure are plotted in Figure 5.80. The average HEME #1 gas outlet temperature was 38.5°C. The average pressure drop across HEME #1 was 2.5 in. W.C. The differential pressure across HEME #1 increased with run time. The average differential pressure was slightly higher than that for the previous tests. At the end of the test, 45.8 gallons of liquid was blown-down from HEME #1.

For Test 4, the outlet gas temperature and differential pressure are plotted in Figure 5.81. The average HEME #1 gas outlet temperature was 40.6 °C. The average pressure drop across HEME #1 was 2.2 in. W.C. At the end of the test, 38.3 gallons of liquid was blown-down from HEME #1.

5.1.5 HEPA Filter

HEME #1 is followed in the off-gas system by a heater, a HEPA filter (HEPA #1), and a Paxton blower (Blower #1). The purpose of the heater is to ensure that water saturated gas exiting HEME #1 is heated above its dew point before passing through the HEPA filter in order to prevent moisture condensation in the HEPA filter. The outlet gas temperature and the pressure differential across HEPA #1 are the only two parameters that were monitored by the off-gas data acquisition system; these are given in Figures 5.82 through Figure 5.84 for Tests 5, 6, and 4, respectively.

For the Tests 5, 6, and 4, the average HEPA #1 outlet temperatures were 62.7°C, 62.0°C and 63.0°C. For the Tests 5, 6, and 4, the average differential pressures across HEPA #1 were 0.1, 0.2, and 0.1 in. W.C., respectively. The small differential pressures observed throughout the tests indicate that no significant particulate loading or moisture blinding of HEPA #1 filter

occurred during these three tests.

5.1.6 Thermal Catalytic Oxidizer and Selective Catalytic Reduction Unit

The TCO/SCR unit consists of a heater, a Thermal Catalytic Oxidizer (TCO), and a Selective Catalytic Reduction (SCR) unit with an ammonia injection system. After the off-gas is heated in the TCO/SCR heater, organics are catalytically oxidized in the TCO. The off-gas is then mixed with ammonia before entering the SCR unit where NO_x is reduced to nitrogen.

Test 5: C-106/AY-102 Feed with Variable Amounts of Sugar

For Test 5, the TCO/SCR heater gas inlet temperature is plotted in Figure 5.85. The inlet gas temperature averaged 83.1°C . Prior to 48 hours runtime, both blowers 701 and 702 were operating. (The single Paxton blower identified on Figure 1.3 is actually comprised of two parallel blowers, which provide redundant capacity.) When operating both blowers, each at somewhat reduced flow capacity, one effect was to raise the off-gas temperature, via fan energy, from about 61°C to 95°C prior to 48 hours. In order to reduce this heating, blower 702 was shut down and the same flow rate and pressure conditions established using only blower 701. The result, shown in Figure 5.85, was an approximate 10 degree drop in the outlet temperature.

The TCO inlet, SCR inlet and outlet, and post SCR temperatures during the test are plotted in Figure 5.86. The average TCO inlet gas temperature was 477°C , while the average SCR inlet gas temperature was 391°C . The average SCR outlet gas temperatures were 359°C and 340°C at two locations, one foot apart, at the outlet of the SCR. The average temperature after the SCR was 308°C . The cause of the temperature drop within the SCR at around 48 hours is not known.

The differential pressures across the TCO, SCR, and TCO/SCR are plotted in Figure 5.87. The average differential pressures were 2.7 in. W.C., 5.7 in. W.C., and 8.6 in. W.C., respectively. Between 99.9 and 115.8 hours, the ammonia PLC unit was turned off inadvertently. Therefore the differential pressures were not recorded by the LabVIEW during that time period.

Information on NO_x and CO removal in the TCO/SCR is provided in Table 5.5. During test segments B, C, D, and E, nitrogen oxide removals were $\sim 78.8\%$, $>61.1\%$, $\sim 29.1\%$, and $\sim 15.7\%$ respectively. Gas residence times in the TCO during Test 5 are given in Table 5.6 and averaged 0.21 seconds. Average ammonia injections into the SCR during test segments A, B, C, D and E were 0.05, 0.025, 0.025, 0.00 and 0.00 lbs/hr, respectively. Ammonia slippages during the test segments B and C were 12.6% and 8.4% respectively. Average ammonia concentration after the SCR unit, during test segments A, B, C, D, and E, were 4.5 ppm, 6.0 ppm, 3.9 ppm, 6.0 ppm, and <1.0 ppm, respectively.

Test 6: C-106/AY-102 with Additional Nitrate and Variable Amounts of Sugar

For Test 6, the TCO/SCR heater gas inlet temperature is plotted in Figure 5.88. The inlet gas temperature averaged 80.6°C. The TCO inlet, SCR inlet and outlet, and post SCR temperatures during the test are plotted in Figure 5.89. The average TCO inlet gas temperature was 467°C, while the average SCR inlet gas temperature was 400°C. The average SCR outlet gas temperatures were 389°C and 368°C at two locations, one foot apart, at the outlet of the SCR. The average temperature after the SCR was 348°C. During Test 6, between 27.7 and 30.8 hours of operations, and 140.6 and 142.1 hours of operations the feed was turned off. Since the first time period was longer, its effect can be seen on the TCO/SCR off-gas temperatures. At 142.6 hours, the set point for heater 801 was lowered to 450°C and gas temperatures decreased. The downward peak at 202.3 hours is due to the delay in resetting the TCO/SCR heater by the melter operators after a restart of LabVIEW.

The differential pressures across the TCO, SCR, and TCO/SCR are plotted in Figure 5.90. Average differential pressures were 2.7 in. W.C., 5.6 in. W.C., and 8.6 in. W.C., respectively.

Information on NO_x and CO removal in the TCO/SCR is provided in Table 5.7. During test segments A and B, nitrogen oxide removals were 46.9%, and 41.0% respectively. Average ammonia injections into the SCR during test segments A, B, C, D and E were 0.08, 0.09, 0.017, 0.00 and 0.00 lbs/hr, respectively. Ammonia slippages during the test segments A and B were ~0.7% and ~0.6% respectively. Average ammonia concentration after the SCR unit, during both test segments A and B was <1.0 ppm. Gas residence time in the TCO during Test 6 is given in Table 5.6 and averaged 0.21 seconds.

Test 4: AZ-101 Feed with Variable Amounts of Sugar

For Test 4, the TCO/SCR heater gas inlet temperature is plotted in Figure 5.91; the inlet gas temperature averaged 81.4°C. The TCO inlet, SCR inlet and outlet, and post SCR temperatures during the test are plotted in Figure 5.92. The average TCO inlet gas temperature was 475 °C, while the average SCR inlet gas temperature was 406°C. The average SCR outlet gas temperatures were 398°C and 379°C at two locations, one foot apart, at the outlet of the SCR. The average temperature after the SCR was 369°C.

The differential pressures across the TCO, SCR, and TCO/SCR are plotted in Figure 5.93. The average differential pressures were 3.2 in. W.C., 6.4 in. W.C. and 9.8 in. W.C. respectively.

Information on NO_x and CO removal in the TCO/SCR is provided in Table 5.8. During test segments B, C, D and E nitrogen oxide removals were about 69.8%, 52.5%, 65.7%, and 56.8%, respectively. During test segments B, C, D, and E, carbon monoxide removals were about 99.2%, 98.2%, >99.0% and >99.5 %, respectively. Gas residence times in the TCO during Test 4 are given in Table 5.6 and averaged 0.19 seconds. Average ammonia injections into the

SCR during test segments A, B, C, D, and E were 0.070, 0.046, 0.04, 0.04, and 0.042 lbs/hr, respectively. NH₃ removal percentages also are shown in Table 5.8. Ammonia slippages during test segments B, C, D, and E were about 15.4%, 6.1%, 3.7%, and 3.6%, respectively. Average ammonia concentrations after the SCR unit, during test segments A, B, C, D, and E, were <1 ppm, 13 ppm, 4.8 ppm, 2.8 ppm, and 3.1 ppm, respectively. These are much lower than the Test Plan [13] target maximum ammonia slippage of 25 ppm.

5.1.7 Silver Mordenite System

A silver mordenite system was used for iodine removal from a slip stream of about 10% of the off-gas stream entering the TCO, which was then returned to the PBS. The silver mordenite system consists of packed-bed of silver mordenite pellets in a glass column fitted with sampling ports.

The column inlet and outlet temperatures for Test 5 are plotted in Figure 5.94. The average column inlet and outlet temperatures were 175°C and 129°C, respectively. The gas inlet temperature falls within the range specified in the Test Plan of 130°C to 230°C. The inlet, outlet, and differential pressures are shown in Figure 5.95 and averaged -8.9 in. W.C., -65.1 in. W.C., and 56.4 in. W.C., respectively. The column average flow rate was 24.6 scfm.

The column inlet and outlet temperatures for Test 6 are plotted in Figure 5.96. The average column inlet and outlet temperatures were 175°C and 125°C, respectively. The gas inlet temperature falls within the range specified in the Test Plan of 130°C to 230°C. The inlet, outlet, and differential pressures are shown in Figure 5.97 and averaged -9.0 in. W.C., -59.5 in. W.C., and 50.7 in. W.C., respectively. The column average flow rate was 24.9 scfm.

5.1.8 Packed Bed Scrubber (PBS)

The TCO/SCR is followed in the off-gas train by a packed bed caustic scrubber (PBS) to remove iodine and acid gases from the off-gas stream. The effluent solution can be pumped out of the PBS sump and process water and caustic solution (25% NaOH) added to control the solid content and pH of the scrubber liquid.

The inlet gas temperature and the pressure drop across the PBS during Test 5 are shown in Figure 5.98. The average PBS differential pressure was 3.2 in. W.C. The PBS was blown down from 17.5" to 15" level and 24.6 gallons of liquid was removed at the end of Test 5. The average PBS inlet temperature was 287°C. The PBS sump temperature is plotted in Figure 5.99 and averaged 24.1°C. The pH sensor connected to the data acquisition system was not operational during this test; pH values were, therefore, measured and recorded manually. During this test, the pH was controlled in the range of 9 ± 0.5 .

For Test 6, the inlet gas temperature and the pressure drop across the PBS are shown in Figure 5.100. The average PBS differential pressure was 3.1 in. W.C.. The PBS was blown down

from 18.8" to 13.5" level and 48.4 gallons of liquid was removed at the end of Test 6. The average PBS inlet temperature was 325°C. The PBS sump temperature is plotted in Figure 5.101 and averaged 25.3°C. The pH sensor connected to the data acquisition system was not operational during this test; pH values were, therefore, measured and recorded manually

For Test 4, the inlet gas temperature and the pressure drop across the PBS are shown in Figure 5.102. The average PBS differential pressure was 3.2 in. W.C. The PBS was blown down from 18" to 14" level and 33.2 gallons of liquid was removed at the end of Test 4. The average PBS inlet temperature was 344°C. The PBS sump temperature and pH are plotted in Figure 5.103; the temperature averaged 33.2°C. The temperature spike at 191 hours was caused by a temporary local cut in cold water flow. The pH sensor connected to the data acquisition system was not operational after 135 hours.

5.1.9 HEME #2

A HEME (HEME # 2) that follows the PBS in the off-gas system removes any water droplets that may be present in the water-saturated gas exiting the PBS.

For Test 5, inlet and outlet gas temperatures and differential pressure are plotted in Figure 5.104. The average HEME #2 gas inlet temperature was 26.9°C and the average outlet temperature was 28.9°C. The average pressure drop across HEME #2 was 4.8 in. W.C. At the end of the test, 39.9 gallons of liquid was blown-down from HEME #2.

For Test 6, inlet and outlet gas temperatures and differential pressure are plotted in Figure 5.105. The average HEME #2 gas inlet temperature was 27.8°C and the average outlet temperature was 29.6°C. The average pressure drop across HEME # 2 was 5.6 in. W.C. At the end of the test, 40.8 gallons of liquid was blown-down from HEME #2.

For Test 4, inlet and outlet gas temperatures and differential pressure are plotted in Figure 5.106. The average HEME #2 gas inlet temperature was 35.0°C and the average outlet temperature was 35.8 °C. The average pressure drop across HEME #2 was 5.7 in. W.C. At the end of the test, 47.4 gallons of liquid was blown-down from HEME #2.

5.1.10 Effluent Liquid Treatment System

Effluent liquids from the SBS, WESP, PBS, and HEME #2 are all piped to a series of sampling tanks that discharge to three 500-gallon storage tanks for neutralization, mixing, and storage. The largest effluent volume is overflow (blow-down) from the SBS, which is pumped to one of two "SBS sampling" tanks. Caustic solution (25% NaOH) from the same caustic tank that supplies the PBS can also be added to the 500-gallon storage tank that receives acidic effluents from SBS sampling tanks; this storage tank is therefore referred to as the "neutralization tank."

The various effluent liquid sampling and storage tanks were visually monitored during

periodic operator rounds and effluent liquid transfers were made as needed. The only parameter of the effluent liquid treatment system monitored by the computer data acquisition system during this test was the pH of the storage tank designated as the neutralization tank.

5.2 SBS, WESP, HEME, and PBS Process Fluids

5.2.1 SBS Fluids

One-liter samples were collected from the SBS sump each time liquids were blown down and at the end of each test. Selected samples were subjected to total dissolved solids (TDS) and total suspended solids (TSS) determinations by gravimetric analysis of filtered material and the evaporated filtrate. An additional sample was filtered to generate solids and filtrate for complete chemical analysis, which included pH determination, direct current plasma emission spectroscopy (DCP) analysis for metals, atomic absorption (AA) for cesium, ion selective electrode (ISE) for ammonium, and ion chromatography for all other anions; the dried filtered solids underwent microwave-assisted acid dissolution prior to chemical analysis. The only anions determined in the filtered solids were sulfate and iodide due to interference from the acids required to dissolve the filtered solids.

All of the SBS sump samples that were taken throughout the DM1200 tests are listed in Table 5.9; the middle letter in the sample name is "S" for the SBS samples. The table provides pH values for each sample, as well as the blow-down volume from which each SBS sample was taken and the cumulative SBS blow-down volume. The analyzed chemical compositions for samples taken at or near the end of each test are provided in Table 5.10. Anion, TDS, and TSS concentrations are given for samples from the end of each test segment in Table 5.11. The pH values for the SBS liquids for each test are plotted in Figure 5.107 as a function of the amount of glass produced. For Test 5, with C-106/AY-102 feed containing added sugar, the SBS pH shows some variation, which is not unexpected given the problems in maintaining production rate as the feed sugar amount was increased over the course of the test. For Test 6, which used C-106/AY-102 feed with added nitrates and added sugar, the effect of the added nitrates can be seen in the early stages where the pH dropped as a result of the slight acidification from the nitrates in the off-gas. The increasing sugar content eventually resulted in a generally stable plateau of SBS pH values between 8.0 – 8.5. The pH of the SBS solution for Test 4, with AZ-101 feed and added sugar, ranged between 8.0 and 8.5 with a slight decrease over time. The AZ-101 feed has a higher water content than the C-106/AY-102 feed, and this extra water dilutes the SBS sump slightly over the test period; therefore, a slight decrease in pH over time (towards neutral pH) is expected. However, it appears that the sugar moderates the effect and tends to maintain the conditions slightly basic.

Figures 5.108 – 5.110 compare the amount of water fed to the total volumetric accumulations in the SBS over the course of each test. Included is the water fed to cool the melter plenum at the start of each test to create a cold cap and thereby minimize subsequent off-gas surges due to pulsed feeding onto bare glass (this is the same feed start-up protocol as that used at West Valley). Tests 5 and 6 both used C-106/AY-102 feed; however, the problems maintaining production rates in Test 5 also resulted in significantly less water fed to the melter

(3287 gallons) as compared to Test 6 (4022 gallons). The difference between the amounts of SBS water coming from the feed and the amounts blown down were 765 gallons in Test 5 and 703 gallons in Test 6. This difference represents the amount of water carried out in the off-gas stream as a result of it being saturated at the SBS sump temperature, as well as a small amount of entrained droplets. The amount is largely determined by the SBS sump water temperature and a set-point lower than the approximate 40°C used in these tests would decrease the amount of moisture in the exiting off-gas stream. Note that there was some difficulty, particularly in Test 5, in maintaining the SBS off-gas outlet temperature at target conditions because of the steam surges arising in the melter. For Test 4, the total amount of water entering the SBS in the feed was 4721 gallons. This greater amount is due to the greater water content of the AZ-101 feed as compared to the C-106/AY-102 feed used in Tests 5 and 6. The amount of moisture carried over from the SBS in the exiting off-gas stream in Test 4 was 642 gallons.

Figures 5.111 - 5.119 compare the feed composition to the SBS dissolved and suspended fractions determined from samples taken at or near the end of each of the three tests. As might be expected, the dissolved solids consist mainly of soluble species such as halogens, boron, alkali metals and, when processing C-106/AY-102 simulants, selenium. These species are readily volatilized from the glass and cold cap in the melter as soluble salts. Similar results were obtained from analysis of SBS solutions in tests with other HLW simulants (3, 6, 9-12). Dissolved chlorine and sulfate were observed in significant proportions in all three tests, even though these were not present in the target feed recipes indicating, as did the feed and glass analysis (see Sections 2.5.3 and 6.1), that chlorine and sulfur were present in the feed as contaminants. Nitrite and nitrate constitute a large fraction of the dissolved SBS solids in LAW melter tests [20, 29, 30] but are present only in small quantities in these samples due to their much lower concentrations in the melter feeds. Also contributing to the low nitrate and nitrite concentrations in the SBS solutions is the high carbon to nitrate/nitrite ratios in the feed, which result in the majority of the nitrates being converted to molecular nitrogen. Notice in Table 5.11 that as the sugar is increased over the course of Test 6, the nitrite concentration decreases from 120 to 7 mg/L. The higher sugar to nitrate/nitrite ratios also result in more dissolved ammonia than in HLW tests that lack sugar additions [9-12]. This is particularly apparent over the course of Test 6, where the ammonia concentration increases from 116 to 616 mg/L as the feed sugar concentration increases. The iodine concentration (only present in the dissolved fraction) increased over the course of Test 5 and decreased during Test 6 as a result of it being removed from the feed recipe after the end of Test 5. The TDS as well as most anion concentrations do not change significantly or systematically over the course of each test, suggesting that the dissolved concentrations are in steady state with respect to emissions and blow down rate. The suspended solids more closely resemble the feed and consist primarily of iron, silicon, zinc, and aluminum, as well as high concentrations (relative to those in the feed) of the more volatile constituents, selenium (Tests 5 and 6) and cadmium (Test 4). In the samples from C-106/AY-102 tests, the dissolved fraction was about two times greater than the suspended fraction, whereas the two fractions were about the same concentration in the samples from the AZ-101 tests due perhaps to the higher concentration of volatile, soluble compounds in the C-106/AY-102 feed.

5.2.2 WESP, PBS, and HEME Fluids

One-liter samples were collected from the WESP, PBS, and HEME sumps each time liquids were blown down and at the end of the test. All of the WESP and PBS sump samples that were taken throughout the test are listed in Tables 5.12 - 5.14; the middle letter in the sample name is “W”, “P”, and “H” for the WESP, PBS, and HEME samples, respectively. The tables provide pH values for each sample, as well as the blow-down volume from which each sample was taken and the cumulative blow-down volumes. About 80 gallons of liquid was blown down from the WESP daily: the first 40 gallons from the previous day’s accumulation of water from spraying and condensation (typically, the sample with suffix “A” in the name) and the second from the 40-gallon deluge (typically, the sample with suffix “B” in the name). The PBS was blown down as required to maintain constant volume. The first HEME (immediately downstream of the WESP) was continuously sprayed at 0.2 gal./hr, resulting in the addition of about 45 gallons of water during each test. The liquid accumulated during each of the three tests either approximated this volume (Test 6) or was less than the total sprayed volume, indicating that essentially no water from the feed or carried over from the WESP accumulated in the first HEME.

Results from the analysis of sump samples from the WESP taken at the end of each test, before and after the deluge, are given in Tables 5.15. The composite (pre- and post-deluge) chemical composition of these samples is illustrated in Figures 5.120-5.122. The WESP solution pH values were higher (6 to 9 vs. 2 to 7) than for the previous HLW tests [3, 6] due to dilution from the added deluge, higher than for the previous LAW Sub-Envelope B1 tests [29] (6 to 9 vs. 2 to 4) due to the lower concentrations of nitrates/nitrites in the feed, and comparable to more recent HLW tests that also employed a daily deluge for cleaning the WESP electrodes [9 - 12]. Solutions with pH values lower than 6 at the start of Tests 5 and 6 were collected prior to the addition of sugar, which reduces nitrogen oxide emissions. Near the end of Test 5, solutions had pH values between 3 and 6; the reasons for this are not known. A near total absence of suspended material was measured in both the pre-deluge blow-down solutions. Higher, but still low concentrations of suspended material were found in post-deluge solutions; this material was presumably material that was dislodged from the electrodes. Volatile salts (alkali halides, borates) carried over from the SBS and sulfate from either previous tests, feed impurities, or the AZ-101 simulant, are major constituents in the WESP solutions from each of the three tests. Consistent with previous tests with C-106/AY-102 simulants [11], selenium is the principal constituent in the WESP blow-down solutions. The observed solution chemistry supports the expectation that the majority of the coarser, less-soluble species were removed by the SBS leaving predominantly highly soluble species for accumulation in the WESP. The concentrations of most elements are higher in the solutions prior to the deluge, although the relative proportion of elements is very similar. As expected, nitrate and nitrite concentrations were higher in samples from Test 6 as a result of the additional nitrate in the feed recipe and in Test 4 due to the nitric acid, noble metals spike solution that was used.

Anion analysis of the PBS and HEME 1 blow-down solutions taken at the end of each test is given in Table 5.16. The pH of the PBS sump is maintained between 9 and 10 during testing by the addition of 25% sodium hydroxide solution. Conversely, the pH of HEME solutions is a result of constituents removed from the exhaust stream. It is important to note that

while various anions were present at measurable concentrations in the PBS solutions, they certainly are not removed quantitatively from the exhaust stream by the PBS in the 9 to 10 pH range. Also, the scrubber sump is not changed after each test resulting in carry-over from previous tests. Significant concentrations of several anions including ammonium, sulfate, and nitrate were measured in HEME solutions; however, the HEME plays only a small role in the mass balance as a result of the small volumes of liquids collected.

5.2.3 Estimates of Accumulations in SBS, WESP, HEME and PBS and Fluids

Estimates of elemental accumulations in the SBS, WESP, and PBS blow-down solutions for each test are provided in Tables 5.17 – 5.19. The accumulation totals are the product of the analyses given in Tables 5.10, 5.15, and 5.16 and the total accumulated liquids given in Tables 5.9, 5.12 - 5.14. Single sample concentrations from the end of the each test were used for the estimates. The accumulations given therefore are mostly upper estimates since the concentration values were taken near the end of tests and the concentrations certainly increased over the course of the test segment. They do not include the solids in the SBS bowl or in the down-comer that were removed at the end of the test (see Section 5.1.2). The accumulations estimated from blow-down data are also compared to estimates calculated from test average emissions data as percent of feed. The equivalent of one to seven kilograms of boron, iron, sodium, chlorine, and sulfate accumulated during each of the three tests. This is of particular note since no sulfate is included in the C-106/AY-102 recipe and chlorine is not included in the AZ-101 recipe. In the tests processing C-106/AY-102 simulant, over one kilogram of arsenic and over sixteen kilograms of selenium accumulated in SBS liquids. Significant accumulations of iodine were only observed in SBS solutions (6.4 kg) from Test 5, since it was only included in the feed for that test. Ammonia accumulations ranged from just below one kilogram to almost eight kilograms and increased with increasing feed nitrate and sugar content. Hundreds of grams of aluminum, fluorine, lithium, silicon, and zinc are estimated to have accumulated in the SBS liquids during each test with varying amounts of all other feed components in proportion to their abundance in the feed and their volatility. Despite the significant accumulated masses, the SBS liquids constitute a significant proportion of the elemental mass balance only for sulfur and halogens, as well as for arsenic and selenium in the tests with C-106/AY-102 simulant. Constituents with lesser accumulations in the SBS fluids, between one and eight percent in at least one test, were B, Ca, Cd, Cs, K, nitrate/nitrite, Pb, Sb, and Ti. Estimates of accumulations in WESP solutions are smaller than for the SBS solutions although similar in that they are dominated by halogens, sulfur and, in the case of tests with C-106/AY-102 simulants, large amounts of selenium and arsenic. Other constituents with accumulations of at least 100 g in a test were B, Ca, nitrate/nitrite, and ammonium reporting to the WESP fluids. Selenium was the only element to have accumulations in WESP greater than one kilogram and percent of feed accumulations greater than eight percent. Agreement between the two methods for estimating accumulations in the SBS (analyzed solution concentration x accumulated liquid amounts vs. feed percent calculated from emissions data) was excellent for tests with C-106/AY-102 simulant but not as good in tests with the AZ-101 simulant. Curiously, this was also observed in previous tests with the two feeds [9, 11]. Emissions data from the test with AZ-101 feed suggest that three to twelve times more of some elements (Al, Ba, Cd, Cu, Fe, Ni, Si, Sr, and Zn) should be present in SBS

solutions. Differences are much smaller or nonexistent for elements that constitute the bulk of the emissions, such as alkali metals, boron, halogens, and sulfur. A difference between the two estimates is that the solids on the bottom of the SBS or in the down-comer were not included in the estimate based on blow-down solutions but were certainly derived from melter emissions. This may be why agreement is much better for the soluble elements than for the insoluble elements. Both estimation methods indicate little feed accumulation in the WESP. Some of the calcium, fluorine, and magnesium in the WESP solutions originated from city water used to constantly spray the WESP and conduct the deluge, which would not be reflected in the exhaust sampling estimates. Finally, as expected, the PBS and first HEME sump fluids account for only a modest percentage of feed anions.

SECTION 6.0 GLASS PRODUCT

Almost twenty five metric tons of glass product was discharged from the melter through an airlift system into 55-gallon drums. The discharged product glass was sampled from each drum by removing sufficient glass from the top for total inorganic analysis. Product glass masses, discharge date, and the analyses performed are listed in Table 6.1.

6.1 Compositional Analysis

Glass samples were crushed and analyzed directly by XRF. The target value for the boron and lithium oxide concentrations were used for normalizing the XRF data since boron and lithium were not determined by XRF. Analyzed compositions for discharged glass samples are provided in Tables 6.2 – 6.4. There was good agreement with the target composition for the majority of oxides and, in particular, for the major oxides, as described for feed samples in Section 2.3. In both tests with C-106/AY-102 simulants, all major and intermediate oxides were within 10% of the target composition. In the test with the AZ-101 simulant, aluminum, zirconium, and zinc showed about the same deviations from target in the discharged glass as in the feed samples. The deficit in nickel increased as a result of nickel sulfide precipitation on the melter floor during the tests with higher sugar additions (see Section 8.0). Chlorine, chromium, phosphorous, potassium, sulfur, and titanium were measured at low levels in the glasses from tests in which they were not included in the target composition. Chromium was generated by corrosion of melter components and the others originated as contaminants in the glass forming additives. Ruthenium and yttrium were introduced as a spike in Test 4 to trace the behavior of these elements in melt pool and, therefore, they are observed in the results for these tests. Note, however, that with respect to these elements, data of much higher sensitivity and precision were obtained from a separate set of analyses given in Section 8.0. Contrary to previous melter tests using lower alkali glass [6, 9-12, 29], up to 30 percent of the feed iodine was retained in the glass product during Test 5. No measurable iodine was observed in glass product from the previous tests and the increase in iodine concentrations in the present tests coincides with the introduction of sugar to the feed, suggesting that iodine retention is affected by the redox conditions in the cold cap or glass pool.

Compositional trends from the XRF data are plotted for selected elements from tests using C-106/AY-102 simulants in Figures 6.1-6.5 and for tests using AZ-101 simulants in Figures 6.6 – 6.8. The figures illustrate many of the points apparent in the tabular summaries of the data: good agreement with target after the melt pool has experienced three turnovers (~5000 kg of glass produced), compositional consistency of major oxides over each test (Figures 6.1, 6.2, 6.6, 6.7), only minor compositional changes at the beginning of Test 5 due to the similarity of the target C-106/AY-102 composition to the former AZ-101 composition [6] that was used to turn over the melt pool from the C-104/AY-101 composition [12] (Figures 6.2 and 6.3), a lack of compositional change during Test 4 due to it being preceded by several tests [16] with the same AZ-101 composition (Figures 6.6 and 6.7), and the loss of volatile elements such as selenium and halogens (Figures 6.4 and 6.5). A trend of special note is the effect of sugar

additions on iodine (Figure 6.5): rapid increase in iodine concentration to 30% of feed immediately after the addition of sugar, no change in the iodine concentration as the sugar concentration was increased, and the rapid decrease of iodine as an iodine-free feed is processed in Test 6. Another interesting trend is the decrease in sulfur and nickel concentrations in Test 4 (Figure 6.8) due to deposition of nickel sulfide on the bottom of the melter (see Section 8.0).

6.2 Iron Redox State

The iron oxidation state for glasses sampled throughout the tests was measured using colorimetric methods to assess the effect of the sugar additions. In addition to glass samples taken from the top of the drums listed in Table 6.1, grab samples from the discharge stream were taken to provide more rapid analysis of the iron oxidation state while the tests were ongoing. Although the redox analyses are time consuming, they were expedited to the extent possible and performed concurrently with the melter testing to provide feedback as rapidly as possible with respect to the redox state of the glass pool during the test in order to trim the feed sugar content. Measured iron oxidation states and the associated sample names, sampling times, and amount of sugar added to the feed are given in Tables 6.5 and 6.6 for grab and discharge samples respectively. The iron oxidation state and feed sugar content over the course of the three tests are compared in Figures 6.9 – 6.11. As expected, the percent of divalent iron in the samples increased as the amount of sugar in the feed increased in both tests. During the tests using C-106/AY-102 simulants, the amount of divalent iron was largely in the 5 to 25% range. Only at the end of the test did the divalent iron concentration exceed 25%; it decreased rapidly from this value after feeding had stopped, as can be seen from the samples taken at the end of Test 5 (from 35% to 3% in the discharged glass samples). The additional nitrates added to the feed in Test 6 resulted in lower concentrations of divalent iron than in Test 5 for most of the sugar concentrations. This difference decreased as the sugar concentration increased, due perhaps in part to the drop in production rate over Test 5.

The AZ-101 composition was considerably more sensitive to changes in sugar content than was the C-106/AY-102 feed, perhaps as a result of the much lower manganese content. After initial sample analysis, which showed a larger change in redox than anticipated based on the C-106/AY-102 results, the amount of sugar added to the feed was reduced to 7.6 g/l and subsequently incremented in smaller steps. Despite this change, divalent iron concentrations exceeded 40% of total iron even at the modest sugar addition level of 16 g/l. Unfortunately, the analytical equipment used for measuring the iron oxidation state experienced downtime during the latter portion of the test and therefore the iron oxidation state was not known until after the test was completed. The lower solids content would have contributed towards increasing the effect of sugar on a per-unit-volume-of-feed basis; however, the AZ-101 composition was much more sensitive to sugar additions even on a mass-of-glass-produced basis: The data indicate that sugar additions as low as 10 g/l (25 mg/g glass) to this AZ-101 composition resulted in concentrations of divalent iron exceeding 25%; in comparison, the C-106/AY-102 feed required sugar additions of about 25 g/l (45 mg/g glass) to achieve a similar iron redox ratio. Assuming that this may be due to the difference in manganese contents, the difference corresponds to about 1.6 times the amount of carbon required to reduce all of the MnO_2 present in the C-106/AY-102 feed to MnO if it is assumed that CO, rather than CO_2 , is the reaction product.

SECTION 7.0 MONITORED OFF-GAS EMISSIONS

7.1 Particulate and Gaseous Emissions

Seven exhaust samples were taken from the melter and various off-gas system components using 40-CFR-60 Methods 3, 5, and 29 to examine particulate and certain gaseous fluxes. All samples were taken during the steady-state portion of the third test segment. Sampling durations were one to three hours for the melter and SBS exhaust, whereas sampling durations of up to 36 hours were required for the WESP exhaust due to the low particle concentration. Teflon filters were used to allow for analysis of all feed components. The majority of the off-gas analyte concentrations were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. The volume of air sampled and the rate at which it can be sampled are defined in 40-CFR-60 and SW-846. Isokinetic sampling, which entails removing gas from the exhaust at the same velocity that the air is flowing in the duct (40-CFR-60, Methods 1-5), was used. Typically, a sample size of 30 dscf is taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was determined by gravimetric analysis of the standard particle filter and of probe-rinse solutions. Downstream of the particulate filter in the sampling train are iced impingers with acidic (5% concentrated nitric acid plus 10% hydrogen peroxide) and basic (2 N sodium hydroxide) solutions. The analysis of these solutions permits the determination of total gaseous emissions of several elements, notably halides and sulfur. An additional procedure was required for particulate samples containing ruthenium (Test 4). Undissolved ruthenium particles were filtered from the nitric/hydrofluoric acid digestate, fused with sodium hydroxide, and dissolved with hydrochloric acid. A list of all inorganic isokinetic samples taken is provided in Table 7.1, including sampling location, air sample volume, air flow rates, particulate emission rates, and air moisture content. All samples were within 10% of isokinetic. It is noted that the emission rates of particulate from the SBS were highest at the highest sugar ratios in Tests 4 and 6. However this trend was not present in Test 5 and, therefore, it is not possible to generalize regarding the effect of the feed sugar ratio on SBS emissions.

Elemental emission rates and DFs obtained during the tests are provided in Tables 7.2-7.13 for the melter, SBS, and WESP. Notice the distinction that is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.3 μm heated filter. Since melter conditions, most notably bubbling rate, were held constant, the data generated are a good opportunity to show the effect of compositional variations, particularly sugar content, on melter emissions and primary off-gas system performance. Figures 7.1 – 7.4 illustrate melter emission trends as a function of feed sugar content and include data from previous tests conducted under the same conditions but without sugar [9, 11]. No comprehensive trend of emissions with feed sugar content was observed when the data are normalized to feed rate. The percent solids carryover from the melter in Figure 7.1 are indicative of most of the elemental particulate emissions: emissions were considerably lower for the previous tests

without sugar and emissions decreased from the lowest to the highest feed sugar concentration with outliers at 20 g sugar per liter during the tests with HLW C-106/AY-102 simulants. The outliers at 20 g sugar per liter may be due to the inherent variability in melter emissions as a result of continuing changes in the cold cap; however, the data from the previous tests were the average of three similar replicate samples during steady-state processing and therefore the data cannot be attributed to short duration events. Data from Test 4 and 6 exhibit a more apparent trend than data from Test 5 due to the more uniform cold caps maintained during the tests. One of the most volatile elements, selenium, did not follow the same pattern as particulate emissions, with emissions increasing to about 70 – 90 percent of feed as the sugar content was increased to 15-20 g/L, then decreasing at the higher feed sugar concentrations. Except at 20 g/L sugar, selenium carryover from the melter was remarkably similar for feeds at the two nitrate concentrations at each sugar level. Two other volatile elements from tests with C-106/AY-102 simulant that did not follow the same pattern as particulate emissions, arsenic and cesium, are shown in Figure 7.3. The dramatic increase in arsenic emissions with increasing feed sugar content in Test 6 is particularly curious since no such increase was observed in Test 5. Alkali emissions during Test 4, as shown in Figure 7.4, are typical of most feed constituents in that they follow particulate emissions. Also of note is that the volatility of the alkali metals increases with increasing atomic weight as expected, although potassium volatility is exaggerated due to additional potassium in the feed as a contaminant.

A comparison of melter system DF values from comparable tests using C-106/AY-102 and AZ-101 simulants is shown in Table 7.14. All of the values shown are from tests using the same melter conditions, most notably bubbling rate (65 lpm). No clear trend was observed other than a decrease in cumulative DF for the C-106/AY-102 formulation with increasing feed sugar and nitrate content. The SBS and WESP performance appeared to increase by factors of about 2 to 3. Much of this increase can be attributed to not sampling the WESP emissions during the daily deluge, since the deluge contributes a large fraction to the WESP emissions. This is also why the WESP DF values during Tests 5 and 6, which had sampling periods that included the daily deluge, were about half of those from Test 4. The SBS DF values were much lower for the C-106/AY-102 formulation due to presence of volatiles that form fine particles which are not effectively removed by the SBS. The cumulative DF values, which are calculated from feed fluxes into the melter and emissions from the WESP, were also affected by the exclusion of the WESP deluge in the sampling period (132,755 vs. over half million if the deluge is excluded) and the difficulty of removing selenium in the primary off-gas system.

The average compositions of feed, melter emissions, SBS, and WESP emissions (excluding oxygen, carbon, nitrate, and nitrite) for samples taken during testing are displayed in Figures 7.5-7.18. Notice that the relative percentages of volatiles, such as halides, increase downstream as the major constituents decrease. For example, silicon which constitutes about 40% of the C-106/AY-102 glass (Figure 7.5 and 7.9), comprises 7 – 9 percent of melter emissions (Figures 7.6 and 7.10), less than 1 percent of SBS emissions, and less than 0.01 – 1.2 percent of WESP emissions (Figures 7.7 and 7.11). Conversely, selenium which only which constitutes only half a percent of the glass, constitutes about a third of the melter emissions and half to three quarters of the SBS and WESP emissions. Iodine constituted the majority of WESP emissions as a result of no retention in the glass and poor iodine removal in the SBS and WESP

in previous melter tests [9]. However, in Test 5, iodine was very poorly represented in SBS and WESP exhaust due to significant incorporation into the glass and removal by the SBS. Aside from iodine, the composition of the particles and gases in the melter, SBS, and WESP exhaust is very similar for Tests 5 and 6, indicating that the inclusion of nitrates in the C-106/AY-102 composition did not have an observable effect on the elemental content of the emissions. Emissions during the AZ-101 tests are very different from those during C-106/AY-102 tests due to the lack of several volatile elements, mainly selenium and iodine. The same trend of non-volatile elements, such as silica, decreasing in proportion as the exhaust is treated and more volatile constituents, such as alkali metals, boron, sulfur, halides, and cadmium, increasing in proportion is evident. Impinger solutions from off-gas sampling were analyzed for all of the elements in the feed but only halides, boron, selenium, and sulfur were detected. The presence of these elements in the gas fraction is consistent with observations from previous studies [3, 6, 9-12, 29, 30]. The amount of particulate collected on sampling filters was not sufficient to conduct both metals and total halide analysis and, therefore, some sample analyses (mainly SBS and WESP) only account for gaseous chlorine and fluorine.

7.2 Particle Size Distribution

Samples were taken using a University of Washington cascade impactor, which separates particles into particle size ranges, enabling the determination of particle size distributions. The melter exhaust stream was sampled during most test segments of each test. Data for the particle size distributions are provided in Tables 7.15 – 7.17. In each sample, the greatest amount of material was collected as the coarsest size fraction ($> 8.03 - 16.1 \mu\text{m}$). From 42 to 77 percent of the total particulate mass was observed in this size fraction with the remainder being spread out over the remaining seven finer size fractions. The same observations have been made in melter emission samples from previous tests [9-12] indicating that particles are typically greater than about 10 microns or that sub-micron particles readily coalesce and the sampling method is incapable of making the distinction between the two. No obvious trend of changing particle size with composition was observed although on average less material was present in the coarsest fraction for samples from the test with AZ-101 simulants than the tests with C-106/AY-102 simulants.

7.3 FTIR Analysis

Off-gas analysis by Fourier Transform Infrared (FTIR) spectroscopy was performed using an On-Line Technologies Inc. Model 2010 Multi-GasTM Analyzer. Data were recorded at 71 s intervals, corresponding to an average of 128 scans at 0.5 cm^{-1} spectral resolution. The melter off-gas supplied to the FTIR spectrometer was extracted using a heated sampling and transfer loop, which removed a gas sample stream from the off-gas system at 5 liters per minute. The sampling and transfer loop was maintained at 150°C throughout in order to prevent analyte loss due to condensation.

Off-gas emissions were monitored by FTIR spectroscopy throughout each test for a set of selected species over discrete time intervals at specified off-gas system locations. An interruption

in data collection occurred during Test 6 due to equipment down-time and therefore only limited data is available for the beginning and end of the test. Tables 7.18 – 7.20 display summaries of the average and range of analyte concentrations measured over the course of the tests. Real-time concentrations of NO, NO₂, CO, CO₂, and water are presented in Figures 7.19-7.22 for Test 5, while concentrations of NO₂, CO, CO₂, water, and ammonia are presented in Figures 7.23-7.27 for Test 4. The data show the expected trends with decrease in the concentration of nitrogen oxides as the sugar content of the feed is increased, increase in the concentration of byproducts from sugar decomposition, such as carbon monoxide, as the sugar content of the feed increased, reduction of nitrogen oxides across the catalyst, water emissions from the melter proportional to the feed rate, and water emissions downstream of the SBS constant due to a constant SBS sump temperature. Similar to water, carbon dioxide concentrations were proportional to feed rate and high enough that differences from the combustion of sugar could not be discerned. Nitrogen oxide concentrations from the melter were less than 20 ppmv after the first sugar addition in Tests 4 and 5, leaving little emissions for the SCR to treat. The persistence of low levels of nitrogen dioxide throughout Test 4 was a result of the use of the nitrate-rich noble metals spike. The spike and the nitrates added to the feed in Test 6 also explain the presence of ammonia after the introduction of sugar to feed in Tests 4 and 5, as compared to the lack of ammonia generation in Test 5. As expected, nitrogen oxide emissions were higher during Test 6 due the added nitrate in the feed; however, data for much of the test are limited as a result of the equipment down-time. Another aspect of the emissions is the high degree of variation during testing, as can be observed in the figures and the tables, which give the concentration ranges. Notice that, even over short periods of time, CO and CO₂ emissions can vary by factors of 2 to 6.

7.4 Hydrogen by Gas Chromatography

Monitoring for hydrogen was performed using Gas Chromatography (GC). The GC was equipped with a 3' × 1/8" stainless-steel column packed with molecular sieve 5A and a thermal conductivity detector operated with an argon carrier gas at 4 psi and a column temperature of 40°C. The unit was calibrated against a certified standard gas (1090 ppmv hydrogen in air) that was progressively diluted using mass-flow controllers to obtain six different hydrogen concentrations ranging between 1090 ppmv and 10 ppmv. The limit of detection of this system was below the 10-ppmv lower calibration point but was not further quantified. Measurements were made only at the WESP outlet and are indicative of melter emissions since no hydrogen is removed by the SBS or WESP. Hydrogen values are compared to data from previous tests with the same feed stream and melter operating conditions in Table 7.21. Hydrogen concentrations were low while processing C-106/AY-102 simulants and, unexpectedly, higher while processing AZ-101 simulants. Also unexpected, was the lack of a comprehensive increase in hydrogen concentration with increasing feed carbon content. In all three tests, hydrogen concentrations actually decrease when the feed transitions to the highest sugar level, even though hydrogen concentrations increased with increasing sugar content over the earlier portion of the tests. Higher hydrogen concentrations cannot be attributed to the higher water content in the AZ-101 feed since data from previous tests with the AZ-101 simulant [9] suggested that hydrogen concentrations decrease with increasing water content. Also in the same test, hydrogen concentrations of only 6 ppmv were measured while feeding the noble metals spike solution

indicating that the the presence of those species cannot explain the higher hydrogen concentrations. Overall, the increased hydrogen concentrations appear to be due mostly to the redox conditions in the cold cap, even though not all of the data fit the expected trend. Measured hydrogen concentrations in tests with much higher feed carbon contents were between 30-80 ppmv and 111-180 ppmv for the LAW Sub-Envelope B1 tests [29] and LAW Sub-Envelope A1 tests [30], respectively. Even though the sugar feed content was higher in the LAW tests, the glass was almost fully oxidized due the presence of oxidants (nitrate and nitrites) in the feed, which also limited the amount of hydrogen emitted.

7.5 Silver Mordenite Column and Iodine Mass Balance

A silver mordenite column for the removal of iodine was installed downstream of TCO/SCR catalyst units and operated in two previous tests [11, 12]. Per Project direction to reflect the change in the WTP flow-sheet, prior to the current tests the intake to the column was moved to before the TCO unit, with the outlet flow still routed to the PBS. An off-gas slip-stream of about 25 scfm was passed through the column, which was maintained at 150°C. Air was sampled simultaneously at four locations on the column (inlet, one-third down, two-thirds down, and outlet) and scrubbed in impingers containing 2 M sodium hydroxide solution. These solutions were analyzed for iodide, which, with the known solution and air volumes, allows calculation of the iodine concentrations and DF across the column at three different locations. Data from the previous tests showed no iodine at the column outlet, resulting in DF values of over 1000. Additional samples were taken during Test 5 to show column break-through, and Test 6 to determine whether iodine is stripped from a loaded column when feeding an iodine-free composition. The results from Tests 5 and 6 are given in Tables 7.22 and 7.23, respectively. Unlike previous tests with iodine-spiked feed, little iodine was measured entering the column. Also, unlike all previous HLW tests, as discussed earlier, iodine was measured in the glass product. The principal difference was the addition of reductants to the feed, suggesting that iodine speciation in the cold cap was modified to a form that was better incorporated into the glass matrix while the remainder was almost totally removed in the SBS and WESP. At the beginning of Test 6, a small amount of iodine appears to have been stripped from the column as the melter is fed an iodine-free composition. Samples taken two days later showed no iodine being emitted from the column. No fluorine and low concentrations of chlorine were detected at all sampling locations.

Iodine mass balance closure has been an objective of a large number of melter runs. Deficits of iodine occurred in many tests due to the neutralization of basic impinger solutions and the inability of off-gas system components to quantitatively remove iodine from the exhaust stream. Test 5 provided a good opportunity to measure iodine emission rates due to the low concentrations of acid gases in the exhaust stream, which tend to neutralize basic impinger solutions. A detailed iodine mass balance for Test 5 and the previous C-104/AY-101 test [11] is presented in Table 7.24 in terms of percent feed iodine. All of the feed iodine in Test 5 can be accounted for in the glass and SBS blow-down solutions ($30 + 74 = 104\%$). This is consistent with the lack of iodine downstream of the SBS in process solutions or measured emissions. The measured melter emissions do not account for all of the iodine estimated in the SBS solutions;

this discrepancy is thought to be due in part to the fact that the emissions data are the average of four, one-hour samples (one per segment) at selected points in time, whereas the SBS sump solutions are an integrated average of the entire testing period. In the previous test without sugar, all of the iodine was emitted from the melter and most of it was not retained in any of the processing solutions. This change in behavior is difficult to reconcile since the manner in which iodine was detected in the off-gas sampling train was consistent with previous tests, i.e., no particulate and less than 1 percent of iodine in the acidic impinger catch, indicating that the iodine is emitted predominantly as a molecular gas (I_2) as opposed to HI or particles.

SECTION 8

DM1200 TESTS WITH RUTHENIUM

The overall strategy for noble metals testing to support the WTP HLW facility is based on a series of small- and intermediate-scale experiments and melter tests in combination with computer modeling [34-38]. The results are intended to provide the basis for reducing the uncertainty in the estimate of the lifetime of the WTP HLW melter as well as for identifying potential approaches for increasing that lifetime. Results from previous DM1200 melter tests were reported earlier. Per the Test Plan for the present DM1200 tests [13], ruthenium was included in the AZ-101 feed in order to assess the effects of redox on ruthenium volatility. This also provided the opportunity to investigate the effects on the retention of ruthenium in the melter. Information obtained from these tests with respect to these issues is presented in this section.

8.1 Introduction

One of the nine-day DM1200 melter tests (Test 4; see Table 3.3) was conducted with HLW AZ-101 feed that was spiked with ruthenium during the last four test segments (B through E; see Table 3.3). Yttrium, which should remain dissolved in the glass melt and not partition appreciably to the melter floor or to the off-gas stream, was added as a tracer. Sugar was added to the feed as a reductant at various concentrations. Samples of the feed, cold-cap, melt pool, melter emissions, and SBS blow-down were collected and analyzed to determine the behavior of ruthenium in the melter system under reducing conditions. Following a description of the testing, the results are presented and discussed below.

8.2 Ruthenium and Yttrium Spiking

This section describes the selection of the ruthenium target concentration in the glass, the make-up of the spike solution, the use of the yttrium tracer, and the spike delivery system.

8.2.1 Target Concentration of Ruthenium in the Glass

The concentrations of noble metals in Envelope D waste are not known exactly. A compilation of analytical data and other information on noble metals concentrations is given in Table 8.1. The noble metals oxide concentration used for previous DM1200 melter testing [37] using Ru, Rh and Pd totaled 0.17 wt% (0.09, 0.03, and 0.05 wt% for RuO₂, Rh₂O₃ and PdO, respectively). For the current test, Ru was the only noble metal added to the feed. The RuO₂ concentration was maintained at the same value as used in the previous tests (0.09 wt%) for comparison purposes. In addition, a review of the waste analysis data and expected relative fission yields (RuO₂ : Rh₂O₃ : PdO $\approx$ 4 : 1 : 2) [46] indicate that the total noble metals oxide concentration of 0.17 wt% and RuO₂ concentration of 0.09 wt% are reasonable values for testing purposes.

8.2.2 Selection of Ruthenium Source Chemical for Testing

Several ruthenium nitrosyl (RuNO) species form upon dissolution of spent reactor fuel in nitric acid. These species have been investigated in detail because of their significance in reactor fuel reprocessing plants and during calcination of HLW [47, 48, 49]. These complexes have the general formula $[\text{RuNO}(\text{NO}_3)_x(\text{OH})_y(\text{H}_2\text{O})_z]^n$, where $x+y$ can be 3, 4, or 5; $z = 5 - (x + y)$; and $n = 3 - (x + y)$. The RuNO group in these complexes is considered very stable. Ru complexes in alkaline solutions have been studied very little and reliable speciation information for WTP tank waste samples does not appear to be available. For the present tests, ruthenium was added in the form of $\text{RuNO}(\text{NO}_3)_3$.

Upon heating a solution containing ruthenium nitrosyl complexes, decomposition begins near 250°C when NO and NO₂ are released. At 400°C, decomposition is complete and a grayish black residue of RuO₂ remains. Tests were conducted at VSL with the as-purchased $\text{RuNO}(\text{NO}_3)_3$ solution to determine its behavior when injected into the alkaline AZ-101 melter feed [37]. The as-purchased solution was titrated with NaOH from an initial pH = 1 to pH = 10. Ruthenium precipitated as a brown solid compound at pH ≈ 5. Upon further increase of the pH the precipitate dissolved almost instantaneously at pH ≈ 8. Titration of the same solution from pH = 10 with nitric acid shows that ruthenium re-precipitates at pH ≈ 8 and dissolves again at pH ≈ 5. When the pH was raised from about 1 to 10 instantaneously, no precipitation was seen and the solution stayed clear. Hence, in the present tests, ruthenium is expected to enter the melter in dissolved form but not necessarily as $\text{RuNO}(\text{NO}_3)_3$.

8.2.3 Ruthenium Spike Solution

Ruthenium was added to the AZ-101 feed as $\text{RuNO}(\text{NO}_3)_3$ (ruthenium nitrosyl nitrate) in aqueous solution at room temperature. The chemical was a commercial product procured as a nitric acid solution. The concentration of the spike solution was such that the steady-state target concentration of RuO₂ in the product glass would be 0.09 wt%. The yttrium spike was added by dissolving yttrium nitrate in the spike solution. The chemicals were added on a mass basis to a 120-liter plastic container. After adding both the chemicals, the container was placed on a scale and water was added with stirring until the total mass reached 100 kg. The decrease of mass during spike solution injection is then proportional to the mass of each element injected into the feed.

The concentration of yttrium in the final solution was such that a steady-state concentration of $\text{C}_{\text{Y}_2\text{O}_3} = 0.1$ wt% was reached in the glass. The results of confirmatory analyses by DCP-AES of the ruthenium and yttrium spike solutions used in these tests are provided in Table 8.2.

8.2.4 Yttrium Tracer

The yttrium tracer was added to the spike solution to track the spiking process from the point of feed entry into the melter to the point of discharge of melt from the melter and into the

55-gallon drums. Unlike ruthenium, since yttrium is dissolved in the glass melt and essentially involatile, it is neither retained in the melter or partitioned to the off-gas stream to any significant extent; yttrium therefore provides a baseline against which to compare the behavior of ruthenium. There was no yttrium in the feed or in the melter before its injection as part of the ruthenium spike solution.

Previous tests have shown that the concentration increase of yttrium in the discharged glass follows very closely the mathematically predicted pattern of a well-mixed reactor [37]. Any deviation of the measured relative ruthenium concentration, $C_{Ru}(m)/C_{Ru,\infty}$, from the measured relative yttrium concentration, $C_Y(m)/C_{Y,\infty}$, would indicate “non-ideal” behavior of ruthenium due to settling and/or volatilization; here, $C_i(m)$ is the concentration of oxide ‘i’ ($i = RuO_2$ or Y_2O_3) in the melt after discharge of mass m (kg) of glass; and $C_{i,\infty}$ is the target steady-state concentration of oxide i . if there were no losses from the glass melt due to volatilization or settling ($C_{Ru,\infty} = 0.09$ wt% RuO_2 and $C_{Y,\infty} = 0.1$ wt% Y_2O_3).

8.2.5 Spike Delivery System

Injection of the spike solution into the melter was effected by the arrangement shown in Figure 8.1. The spike solution is contained in a 120-liter plastic tank placed on an electronic scale and flows from this reservoir from the bottom through a ball valve. The flow rate is controlled by a calibrated ceramic piston pump, which transports solution continuously through a check valve into a stainless steel 1-liter bottle. This bottle also receives the HLW AZ-101 feed from the ADS pump. Mixing of feed and spike solution takes place in the bottle while the feed pulse enters and leaves the bottle. The spiked feed then flows along the feed line and into the DM1200 melter. Using the distance between the lower end of the exit pipe and the bottom of the bottle and its radius, a heel volume of about 10 ml was estimated.

The device was operated such that the flow rate of the spike solution (g/min) was controlled by adjusting the piston pump setting in proportion to the feed rate to the melter. The mass of spike solution injected into the melter was calculated from the recorded mass loss of the tank. Prior to operating the system, a blank test was conducted with water to verify proper operation of the system.

8.3 Sampling and Analyses

A variety of samples were collected from the discharged glass, the melt pool, the cold cap, the feed, and in the off-gas system during testing. This section describes the sampling methods used and the samples collected that are relevant to analysis of noble metals behavior.

8.3.1 Discharged Glass

Sampling was done manually by introducing an all-thread metallic rod into the melt

stream during discharge. The rod and the captured glass were placed in a ceramic crucible and cooled in the open air. The glass shattered upon cooling and was easily separated from the rod. In this way, 10 g to 20 g of glass was collected for each sample. The glass was powdered and analyzed for ruthenium, yttrium, and other constituents by XRF. Sample identifications along with the test number, the concentration of sugar in the feed, the sampling date, the total mass of glass discharged, and the measured concentrations of yttrium and ruthenium in the glass are given in Table 8.3. Complete XRF analyses of the discharged glasses are given in Table 6.4.

8.3.2 Melt Pool

Several suction samples were taken from the DM1200 melt pool during tests with ruthenium. Suction samples were taken from different locations in the melt pool through ports in the lid of the melter. A ceramic pipe (4 feet long, 1/3 inch inner diameter), connected to a stainless steel pipe, was lowered into the melt. A three-way valve allowed application of either suction or pressure to the ceramic pipe. Upon introduction into the melt, sufficient pressure was applied to yield an air flow rate of 1 scfh to prevent melt from entering the pipe. The distance of the lower end of the ceramic pipe from the bottom of the melter was estimated and, when the desired position was reached, suction was applied. Glass entered the ceramic pipe to a level above the cold cap inside the melter where it froze. The ceramic pipe was then withdrawn and cooled to room temperature. Table 8.4 lists the six suction samples that were collected at the end of the test.

The uppermost part of the ceramic pipe, i.e., the glass that was drawn in first, was sampled for further characterization. A section about 1/2-inch long was cut from the ceramic pipe, polished and prepared for SEM analysis. The glass matrix and secondary phases in the samples were analyzed by SEM/EDS.

8.3.3 Cold Cap

Samples were taken from the cold cap using a "spoon" device with a hole in the bowl that was introduced into the melter from the top. The spoon penetrated the cold cap and was lowered into the melt. The spoon was then withdrawn in such a way that it captured a piece of the broken cold cap while allowing the glass melt to drain as much as possible. The spoon was then withdrawn from the melter, allowed to cool to room temperature and the cold cap sample was retrieved. Initial results from characterization of the cold cap samples along with comparison to relevant gradient furnace testing were reported earlier [38].

8.3.4 Melter Feed

Melter feed samples were taken from the feed line. Samples were taken downstream of the point of spike introduction by disconnecting the feed pipe from the melter and diverting the feed into a vessel for collection. Each sample weighed about 1 kg. The samples along with analyses for water content, density, glass yield, and pH are given in Table 2.7. The results from

XRF composition analyses of the melter feeds are presented in Table 2.10 and discussed in Section 2.

8.3.5 Off-Gas System

During the course of melter testing, a series of off-gas samples were collected and analyzed for ruthenium. The melter emission and SBS blow-down sample identifications along with ruthenium analysis results are listed in Tables 8.5 and 8.6, respectively. Ruthenium emission as a percentage of the ruthenium feed rate is given in Table 8.5. Data used to calculate the RuO_2 loss from the melter as a percentage of the total amount of RuO_2 fed are given in the last row of Table 8.6.

Methods to analyze ruthenium quantitatively in the off-gas emission samples and SBS blow-down liquids were reported earlier [37] and are reproduced here for convenience. The particulates emitted from the melter were collected on a heated filter and in the probe rinse and analyzed for ruthenium. If black particles were still present after acid digestion, a second digestion using molten NaOH flux was applied to these particles. The ruthenium amounts measured in these samples was combined with those measured after the first digestion to obtain the total. The gaseous emission (after the filter) collected in the impinger solution was analyzed in selected samples; no ruthenium was found in these samples. Results of emissions sampling for other constituents are reported in Section 7.0.

Aliquots of SBS blow-down samples, with the solids fully suspended, were dried, weighed, and digested in a nickel crucible using a molten NaOH flux. After dissolution of the digested material in concentrated HCl and adjustment of the HCl concentration to 10%, the solution was analyzed for ruthenium by DCP-AES. The emptied crucible was subjected to a second digestion with NaOH to ensure that any undigested ruthenium from the first treatment was captured. The final result of the analysis comprises the findings from both digestions. Several samples were run as duplicates to determine reproducibility and samples that were spiked with known amounts of ruthenium were digested in parallel to determine recoveries.

8.4 Results

The results from ruthenium and yttrium spike testing are presented in this section. The results are discussed in Section 8.5.

Figure 8.2 shows the cumulative masses of RuO_2 and Y_2O_3 fed into the melter as a function of time. The masses of RuO_2 and Y_2O_3 fed were 7.4 kg and 8.2 kg, respectively. For the first 24 hours and 15 minutes, during which conditions in the melter were allowed to approach their steady-state values, the spike solution was not injected into the feed. During this time about 700 kg of glass was discharged. The total mass of glass produced during spiking was about 8,200 kg.

8.4.1 Ruthenium in the Discharged Glass

Table 8.3 shows the concentrations of RuO_2 and Y_2O_3 in the discharged glass. Except for the first segment, there is a stepwise increase in the concentration of sugar in the feed as testing proceeds through test segments B through E (see Table 3.3). The measured concentrations of RuO_2 and Y_2O_3 in the discharged glass along with the sugar concentrations are plotted in Figure 8.3. RuO_2 and Y_2O_3 concentrations as a function of time are given in Figure 8.4. The instantaneous and cumulative rates at which ruthenium was injected into the melter feed as a function of time are shown in Figure 8.5. Steady-state melter feed and spike solution injection rates are given in Figure 8.6. The measured and modeled concentrations of RuO_2 and Y_2O_3 in the glass (melt) as a function of the mass of glass discharged are given in Figure 8.7. The modeled concentrations are those expected on the basis of a well-stirred-tank model assuming no losses to the melter floor or the off-gas stream, as described previously [37]. Consequently, deviations from the model expectations reflect the extent of deviations from those assumptions.

Figure 8.8 shows the glass redox expressed as the ratio of $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ and the concentration of ruthenium in the discharged glass plotted against the mass of glass discharged. The $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ ratio depends on the sugar concentration in the feed, which is shown in Table 8.3. The measured redox values are given in Table 6.5. It is evident from Figure 8.8 that the progressive increases glass redox ratio did not significantly change the concentration of ruthenium in the glass during the course of the test.

8.4.2 Ruthenium in the Melt Pool

Four of the six samples taken from the melt pool (see Table 8.4) were characterized by SEM. Figure 8.9 shows an SEM micrograph of a glass sample taken from the middle of the melt pool. This glass sample contains a few tiny Ru-containing particles dispersed in an otherwise homogeneous glass phase. For comparison, an SEM micrograph of an oxidized glass sample from previous melter testing [37] is reproduced in Figure 8.10. The size and morphology of the Ru-containing phase in the oxidized melt is quite different from those in the reduced melt.

Figure 8.11 shows an optical image of a glass sample taken from the bottom of the melter through port B3. The sample appears inhomogeneous with a number of bubbles and other secondary phases. Figure 8.12 shows an SEM micrograph of a small area from Figure 8.11 showing several phases, including large particles of metallic ruthenium.

Figure 8.13 shows a back-scattered electron image of a sample taken from the bottom of the melter through port C1. The dark matrix phase on the right side of the micrograph is glass, which contains various crystalline phases. The gray matrix phase on the left side of the image is a nickel sulfide, which contains various other crystalline phases including metallic ruthenium. Figure 8.14 shows chemical mapping of the sample shown in Figure 8.13. An SEM ‘chemical mapping’ image is created by scanning a selected area of the sample surface with the electron beam and measuring and recording only the characteristic X-rays of an element expected to be present, e.g., Ni $K\alpha$. In the such an image, the brightness is related to the concentration of the

element in question and areas remaining dark are those where that element is not present. Colors are artificial but help distinguish between elements if more than one element is shown in the same image. The intensity distributions of characteristic K_{α} X-rays of Ni, S, Fe, and Si and the L_{α} X-rays of Ru and Zr are shown. The complete match of Ni and S mappings indicate the presence of a nickel sulfide. The EDS spectrum shown in Figure 8.15 suggests that the chemical composition of this nickel sulfide is Ni_3S_2 . A semi-quantitative analysis of this nickel sulfide phase given in Table 8.7 indicates a Ni:S ratio of 3:2. No attempt was made to obtain further confirmation of this stoichiometry by other techniques such as X-ray diffraction.

Figure 8.16 shows another back-scattered electron image of the sample from the melter bottom (Figure 8.13) at a higher magnification. Both small and large metallic ruthenium particles are visible in the figure. A cluster of spherical ruthenium particles in the lower left side of the image may be the precursor to the formation of a large ruthenium metal particle. Besides nickel sulfide, Ni-Ru particles (alloys) were also detected in the sample. An EDS spectrum of a Ru-Ni alloy consisting mostly of ruthenium is shown in Figure 8.17.

Figure 8.18 shows an enlarged image of the glass phase in Figure 8.13. ZrO_2 (zirconia) and $ZrSiO_4$ (zircon) crystals of considerable size and some small Ni-Fe-spinel crystals are visible in the figure.

The framed area in Figure 8.16 with the spinel crystals is shown in Figure 8.19 at a higher magnification. Other phases identified in this sample include nickel sulfide, a Ni-Ru alloy, metallic nickel, and ruthenium.

Figure 8.20 shows the concentrations of nickel as NiO and sulfur as SO_3 in the glass as a function of the mass of glass discharged. Both concentrations decrease with time indicating the formation of substantial amounts of nickel sulfide. Note that nickel sulfide formed despite the very low concentrations of both species in the feed.

8.4.3 Ruthenium in the Off-Gas System

The results of ruthenium measurements in off-gas samples are given in Tables 8.5 and 8.6. On average, about 1% of the ruthenium was detected in the melter emissions. The slight but steady decrease of ruthenium loss shown in Table 8.5 indicates a small effect of progressive increases in the glass redox ratio on ruthenium volatility.

Table 8.6 shows ruthenium volatility as determined by analysis of SBS blow-down liquids. The measured overall ruthenium loss of 0.92% from the SBS liquid analysis agrees well with the average loss of 1.13% determined from melter off-gas emissions samples, given in Table 8.5.

8.5 Discussion

The results from DM1200 melter testing with ruthenium presented in Section 8.4 are discussed in this section. Overall, the behavior of ruthenium in this test was markedly different from that observed in previous tests [37], presumable as a direct result of the addition of sugar to the feed, which resulted in a more reduced glass.

8.5.1 Ruthenium in Discharged Glass

In previous tests, [37] yttrium was used successfully as a tracer to predict the expected Ru, Rh, and Pd concentrations that would have been expected had these noble metals been completely soluble in the glass and subject to no volatilization losses. The measured concentrations of yttrium in the melt as a function of glass discharged was very well reproduced by a well-stirred-tank model [37]. However, agreement between modeling and measurement was demonstrated only up to about 38% of the steady-state concentration because noble metals injection was limited to a short period due to budget constraints.

In the tests reported here, yttrium and ruthenium were injected into the melter feed until their calculated concentrations in the glass, assuming no losses, were within 1% of the target steady-state concentrations ($C_{RuO_2,\infty} = 0.09$ wt% and $C_{Y_2O_3,\infty} = 0.1$ wt%). Equation (1), which was used for modeling yttrium concentration previously [37], was also used in the present work:

$$C_i(m) = C_{i,\infty} \times (1 - \exp(-(m-m_0)/M)) \quad (1)$$

where m_0 is the mass of glass (kg) produced in this melter test prior to injection of ruthenium into the feed, m is the mass of glass (kg) produced ($m = m_0$ at the beginning of ruthenium injection), and M is the mass of glass melt (kg) in the melter. The mass of glass melt in the melter is about 2,000 kg but varies a little with test conditions. “ M ” was estimated in previous tests with noble metals and ranged between 1942 kg and 1953 kg. For the current calculations, an “ M ” value of 1950 kg was used.

The measured and calculated concentrations of yttrium and ruthenium are given in Figure 8.7. During the course of testing, the melter glass inventory of 1950 kg was turned over more than four times, resulting in calculated yttrium and ruthenium concentrations within about 1% of the target values by the end of testing. For the purpose of comparison, the test results from Figure 8.3 are reproduced in Figure 8.7. The measured increase in yttrium concentration shows the general trend and magnitude expected on the basis of the model but the agreement is not nearly as good as that obtained in previous tests [37]. The yttrium concentrations fluctuate around the calculated curve, which might reflect variations in the spike rate. Figure 8.6 shows a slight over-feeding of yttrium at the beginning of the test and a slight under-feeding of yttrium towards the end of the test, though these variations do not appear to be large enough to explain the deviations shown in Figure 8.7. Despite this discrepancy, the overall behavior of the measured Y_2O_3 concentration in the glass clearly follows the calculated curve in Figure 8.7 confirming its utility as a tracer.

In Figure 8.7 the measured concentration of ruthenium in the glass is compared to the concentration calculated using Equation (1). The comparison shows early deviation of ruthenium from ‘ideal’ behavior, i.e., complete dissolution or suspension in the melt. The deviation is already apparent at about 5% of the target-steady state concentration. Beyond this point, an apparent steady-state concentration is reached at about 10% of the target value. As reported in Tables 8.5 and 8.6, there is very little volatilization (about 1%) of ruthenium. Consequently, these results indicate that the remainder, about 90% of the ruthenium introduced into the melter, is retained in the melter, presumably due to settling. Neglecting the fact that retention was slightly less in the very beginning, about 5.6 kg of ruthenium (calculated as RuO_2) must have accumulated in the melter.

The $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ ratio and the ruthenium concentration (calculated as RuO_2) in the glass are plotted versus the mass of discharged glass in Figure 8.8. These results indicate the steady-state ruthenium concentration is already reached when the $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ ratio was around 0.15; it is difficult to tell from these data how much lower the redox ratio could have been and still achieved the same result. Above this value, there is no significant effect of the $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ ratio on the concentration of ruthenium in the glass, with the possible exception of a slight decrease in the ruthenium concentration above a redox ratio of about 0.3. Gradient furnace testing [38] has shown that ruthenium is reduced to its metallic state when sugar is added to HLW feeds that do not contain significant amounts of nitrate. The same was observed in the current DM1200 melter tests in that essentially all of the ruthenium introduced into the melter was reduced to ruthenium metal in the presence of sugar. Further melter testing would be necessary to better define the redox ratio (and sugar concentration in the feed) below which ruthenium will not be reduced to the metallic state.

8.5.2 Ruthenium in the Melt Pool

The sample taken from the middle of the melt pool, shown in Figure 8.9, contains ruthenium particles that are round and very small. Ruthenium particles in samples from the top part of the melt near the cold-cap looked similar. Though a definitive determination could not be made by SEM/EDS, indications are that they are metallic. This is also suggested when comparing the ruthenium particle morphology in samples from this test with those from previous melter tests [37] under more oxidizing conditions. Under oxidizing conditions, ruthenium-containing particles are on average larger and most likely exist as RuO_2 .

To determine the fate of ruthenium not detected in the melt pool nor in the discharged glass, samples were taken by suction from the bottom of the melter and analyzed by SEM/EDS. Samples were taken through different ports in the lid of the melter to access and sample various locations on the floor of the melter. Figure 8.11 shows an optical image of a sample from the melter bottom. The glass sample is very inhomogeneous and contains bubbles and various secondary phases. Arrows in Figure 8.11 point to ruthenium metal and a nickel sulfide phases the sample.

Figure 8.12 is a backscattered electron image showing details of the microstructure and

phase compositions within one of the spherulites in Figure 8.11. As described in Section 8.4, semi-quantitative EDS analysis of the nickel sulfide phase suggests that its stoichiometry is close to Ni_3S_2 . Further investigation of the nickel sulfide phase, by techniques such as X-ray diffraction, may be useful because its melting point depends on its chemical composition. For example, Ni_3S_2 melts at 787 °C, while NiS melts at 976°C. Both phases are much denser than the glass melt (Ni_3S_2 5900 kg/m³, NiS 5500 kg/m³) and are therefore likely to accumulate on the melter floor. Depending on the composition of the nickel sulfide phase and the temperature near the bottom of the melter, any accumulated nickel sulfide may exist as a solid or a liquid. It is likely that liquid phases would be much more corrosive towards melter materials. The presence of sulfide in the nickel phase shows that sulfate (S^{6+}) in the feed was reduced to sulfide (S^{2-}) under the conditions during the DM1200 melter test.

The formation of nickel sulfide and nickel metal under sufficiently reducing conditions is not unexpected and Schreiber [50-53] has investigated the range of equilibrium redox conditions that this occurs for selected HLW glass compositions. Those findings would suggest that nickel sulfide should have formed only during the test segments with the highest sugar additions and highest redox ratios. It should be noted, however, that in an actual melter environment, transient conditions can occur in the cold cap that are more reducing than those that prevail in the equilibrium melt. Any sulfides that are formed under such conditions are typically very slow to re-oxidize and are quickly partitioned to the bottom of the melter.

Large round particles of ruthenium metal (up to 40 µm) are visible in Figure 8.12. It appears that smaller ruthenium particles coalesce and form larger particles at the bottom of the melter. The density of ruthenium metal is 12,450 kg/m³ or about five times the density of the glass melt, resulting in ruthenium settling to the bottom of the melter. Ruthenium metal seems to be a nucleating agent for precipitation of metallic Ni, as can be seen in Figure 8.12, which shows nickel crystals with a ruthenium-rich core. Metallic nickel and copper were also identified in this sample.

Since Ni_3S_2 was an abundant constituent in samples from the melter bottom, nickel and sulfate concentrations in the glass were plotted as a function of the mass of glass produced to identify significant trends (Figure 8.20). Both concentrations decreased significantly during the course of testing. NiO concentration in the glass decreased from 0.54 wt% to 0.42 wt%. Taking an average concentration of 0.47 wt% NiO in the glass, the equivalent of about 0.07 wt% of NiO was retained in the melter. With 8197.9 kg of glass produced during the test, this equates to 4.51 kg of metallic nickel that is most likely part of the sludge at the bottom of the melter. The sulfur (expressed as SO_3) concentration in the glass decreases from 0.08 wt% to 0.02 wt% during the course of testing. Taking an average concentration of 0.04 wt% SO_3 , yields a loss of 0.04 wt%, corresponding to 1.31 kg of S. This amount of sulfur as sulfide would consume 3.61 kg of nickel to form 4.92 kg Ni_3S_2 . This leaves about 900 g nickel in other chemical forms such as pure metal or alloys with copper and ruthenium. The relative abundance of Ni_3S_2 versus other nickel phases in the samples from the melter bottom (e.g. Figures 8.13 and 8.14) is in consistent with this calculation. A similar calculation can be made for ruthenium. Table 8.6 shows that 7379.6 g of ruthenium, calculated as RuO_2 , entered the melter. About 10% of this mass was discharged with the glass (Figure 8.7). Neglecting the approximately 1% of volatilized ruthenium (Tables 8.4 and

8.5), analysis show that about 5.04 kg ruthenium was reduced to metal and should be contained in the sludge. Consequently, the total mass of sludge on the floor of the DM1200 from these two sources for this melter test is estimated to be 10.83 kg. The contribution of minor phases, e.g., ZrO_2 , ZrSiO_4 , and spinel are not included in this estimate.

Figure 8.13 shows glass and nickel sulfide phases side by side. The glass phase contains ZrO_2 and ZrSiO_4 as dispersed phases. The nickel sulfide phase contains ruthenium metal and metallic phases such as nickel and ruthenium, perhaps an alloy. An EDS spectrum of the ruthenium phase in Figure 8.13 is shown in Figure 8.18. The phase consists mainly of ruthenium, with a small amount of nickel dissolved. Oxygen was not detected in this phase. RuO_2 was not found in samples from the bottom of the melter in this test. In contrast, RuO_2 was ubiquitous in melter floor samples from DM1200 noble metals testing without sugar [37].

Very few spinel crystals were observed in the melter samples from this test as compared to previous tests [37]. These results suggest that spinel does not contribute significantly to the formation of sludge when the AZ-101 feed is vitrified under reducing conditions. Figure 8.19 shows a dendritic crystal of spinel, several hundred micrometers long, embedded in nickel sulfide. The morphology of this spinel crystal is different from the ones seen under oxidizing conditions [37]. It is possible that the yield of spinel may vary because there is less Ni in the melt than under oxidizing conditions. However, another possible cause is the higher concentration of Fe^{2+} under reducing compared with oxidizing conditions. It is known that the yield of certain spinels (e.g. magnetite) will vary with $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio, i.e., with glass redox.

8.5.3 Ruthenium in the Off-Gas System

As shown in Tables 8.5 and 8.6, the loss of ruthenium to the off-gas system is on the order of only 1%, even though the melt was bubbled with air at a rate of 65 l/min. The ruthenium loss under reducing conditions with bubbling is much smaller than the loss under oxidizing conditions without bubbling [37]. Since other results indicate that the ruthenium was reduced to the metallic state, it appears that local re-oxidation by the air bubbled through the melt does is not significant. It is not clear from the present data whether a similar reduction in ruthenium volatility could be achieved with less reducing conditions such that formation of metallic ruthenium is avoided.

There appears to be a small effect of the sugar concentration in the feed (glass redox state) on ruthenium volatility. This is seen in the data in Table 8.5, which show a slight decrease of the fraction of ruthenium volatilized with increasing sugar concentration.

The data show that vitrification under reducing conditions is an effective method for reducing ruthenium volatilization into the off-gas; this effect is utilized to control ruthenium volatility in several HLW vitrification facilities, including those in the UK, France and Russia. This potential advantage, however, is offset by the formation of Ni_3S_2 , which settles to the bottom of the melter. Such molten sulfide phases can be highly corrosive to melter materials of construction.

8.5.4 WTP Melter Lifetime Estimate

The calculation of the total mass of sludge formed during the production of about 8,200 kg of glass (Section 8.5.2) was used to estimate the lifetime of the WTP HLW melter for operation under reducing operation conditions (≥ 7.6 g/l sugar in the HLW AZ-101 feed).

For the melter life time calculation, it is assumed that the production rate is 3,000 kg glass/day and the cavity for sludge accumulation has a volume of 2,250 liters. Operating conditions, including bubbling conditions, are assumed to be comparable to those employed in the present tests. It is also assumed that the feed is alkaline HLW AZ-101 with at least 7.6 g/l sugar added and the ruthenium concentration in the glass is 0.09 wt% RuO₂. Other noble metals were neglected in this calculation. The calculation in Section 8.5.2 yielded a sludge mass of 10.83 kg for 8,197.9 kg glass produced or 1.32 kg of sludge per 1,000 kg of glass. Using a density of 6,364 kg/m³ for nickel-containing phases (Ni₃S₂ - 4.92 kg at 5,900 kg/m³ and Ni - 0.9 kg at 8,900 kg/m³), yields a volumetric sludge production rate of $4.92/8.1979/6,364 = 0.0000943$ m³ per 1000 kg of glass. Using a density of 12,450 kg/m³, ruthenium metal yields a volumetric accumulation rate of $5.04/8.1979/12,450 = 0.0000494$ m³ per 1000 kg of glass. Hence, the volumetric sludge production rate is $0.0000943 + 0.0000494 = 0.000144$ m³/1000 kg or 0.144 liter/1000 kg glass. Assuming a maximum volume fraction $VF_{\max} = 0.1$ (the best estimate in the literature is $VF = 0.06$ for sludge produced under oxidizing melter operating conditions), we obtain an effective sludge production rate of 1.44 liter/1000 kg glass. $VF_{\max}$ is the maximum volume fraction of nickel sulfide plus ruthenium metal in the sludge. Hence, 2,250 liters divided by 1.44 liters provides for production of 1.563×10^6 kg of glass in the WTP HLW melter until the cavity is full. This yields a lifetime of $1.563 \times 10^6/3,000 = 521$ days (1.4 years).

If the temperature in the cavity exceeds 787°C, Ni₃S₂ will exist as a liquid. The volume of liquid Ni₃S₂ would be only about 106 liters, or about 5 vol% of the cavity volume after 521 days. The high densities of Ni₃S₂ and of ruthenium metal suggest that these phases will separate from the glass and accumulate on the bottom of the melter. It is possible, therefore, that in this situation VF may be close to one. In that case, the cavity would be filled much later and the lifetime of the melter based on this analysis would be much longer. However, from a more practical perspective, the presence of a substantial volume of a highly corrosive liquid phase in the cavity would deleteriously impact the expected melter life to an extent that cannot be easily estimated.

8.6 Summary and Conclusions

DM1200 melter tests were completed with ruthenium injection into an AZ-101 feed with varying sugar concentration. The ruthenium concentration in the feed was such that the steady-state target concentration in the glass would be 0.09 wt% RuO₂ if there were no ruthenium losses due to either retention or volatilization. The major conclusions from the test results are listed below.

- Only about 1% of the total mass of ruthenium injected into the melter feed reported to the

off-gas stream.

- With sugar addition to the feed, ruthenium was reduced to the metallic state. Portions of other elements such as nickel and copper were also reduced to the metallic state, and sulfate was reduced to sulfide.
- About 90% of the ruthenium fed to the melter was retained in the melter, probably as metal.
- An apparent steady-state concentration of about 0.009 wt% RuO₂ (10% of the target value) in the glass melt was reached quickly at sugar concentrations ≥ 7.6 g/l. (Note that the apparent steady-state concentration has been calculated as RuO₂ but the chemical form of ruthenium in the melt is most likely metal.)
- Ruthenium particles suspended in the melt and discharged with the glass are small ($\leq 1\mu\text{m}$).
- Larger ruthenium metal particles ($> 1\mu\text{m}$) were found at the bottom of the melter.
- Glass samples taken from the bottom of the melter were rich in secondary phases, mostly ruthenium metal and a nickel sulfide. Nickel sulfide (most likely Ni₃S₂) is liquid at temperatures prevailing at the bottom of the DM1200 melter.

In light of these results, the following can be concluded.

- Addition of sugar to the melter feed reduces the volatility of ruthenium drastically, particularly in comparison to melter tests that were also bubbled with air but run under oxidizing conditions. This is evident from the data comparison provided in Table 8.8.
- Since there was only a very small effect of the progressive increases in sugar concentration on the volatility of ruthenium, a sugar concentration of 7.6 g/l feed was sufficient to limit ruthenium volatility to about 1%. It is not clear how much lower the concentration could be and still achieve the same effect. More particularly, it is not known whether it is possible to add sufficient sugar to diminish the volatility of ruthenium without reducing the ruthenium to the metallic state.
- Retention of ruthenium in the melter increases substantially with sugar addition to the feed as can be seen by the data comparison provided in Table 8.9.
- Under sufficiently reducing conditions, reduction of sulfate and nickel leads to formation of nickel sulfide (Ni₃S₂). The high density (5,900 kg/m³) and the low melting temperature (787°C) of Ni₃S₂ result in accumulation of a corrosive liquid at the bottom of the melter. The production rate of Ni₃S₂ was estimated to be 0.094 liter per 1000 kg of AZ-101 glass.

SECTION 9.0 SUMMARY AND CONCLUSIONS

Melter tests were conducted on the DM1200 to determine the effects of feed compositional changes namely sugar and nitrate content on glass production rate, iron oxidation state in the glass product, and off-gas system performance while processing HLW feed compositions at constant bubbling rates. Three nine-day tests, two with C-106/AY-102 and one with AZ-101 simulants, were conducted at four different sugar concentrations. One of the C-106/AY-102 tests included 30 g nitrate per kilogram glass in the feed. Each of the tests began with a day of feeding without sugar to establish the cold cap before conducting the two segments with sugar. Ruthenium was added to the test with AZ-101 simulant to investigate its behavior as a function of changing oxidation state of the glass. About seventy eight metric tons of feed was processed to produce about twenty eight metric tons of glass (nineteen from C-106/AY-102 composition and nine from the AZ-101 composition). Cold-cap-limited, steady-state production rates between 650-870 kg/m²/day were obtained for 550 g glass per liter C-106/AY-102 feed, which was lower than predicted due to poor cold cap characteristics. The same test was repeated with additional nitrates and showed a uniform, consistent cold cap, which resulted in a steady state production rate of 1000 kg/m²/day at all four sugar contents. Cold-cap-limited, steady-state production rates increased from 850 to 930 kg/m²/day as the sugar content was increased in the test with 400 g glass per liter AZ-101 feed.

The general performance of the DM1200 melter and off-gas treatment system was good. However, the results of post-test inspections showed that solids accumulation in the SBS down-comer continued to be an issue for these tests; the modified SBS down-comer extension design provided by the Project did not mitigate this problem. Film cooler blockage requiring mechanical clean-out occurred during Test 6. The ADS pump worked well throughout testing. Extensive sets of process engineering data were collected during all three tests. Energy balances were conducted for each test segment around the melter and SBS with excellent closure. The glass product was close to the intended composition once the melt inventory was turned over. The amount of divalent iron approximated the target values for the C-106/AY-102 tests but exceeded the target concentrations in the AZ-101 test, despite the use of less carbon per unit of glass.

Isokinetic particulate samples were taken at the outlets of the melter and SBS for each feed sugar concentration and at least once per test at the WESP outlet. The purpose of these samples was to illustrate the effects of changes in feed sugar and nitrate content on emissions, as well as to determine the efficiency of off-gas system components. Particulate carryover from the melter was higher than in previous tests without sugar (i.e. 1.75 vs. 0.75% of feed) but decreased with increasing feed sugar content. Elemental DF values were determined across the melter, SBS, and WESP. Calculated DFs across the primary off-gas system components were lower for the C-106/AY-102 tests than the AZ-101 tests as result of selenium inclusion in the feed and the inclusion of WESP deluges during the exhaust sampling interval. As a result, the cumulative DF (Melter+SBS+WESP) was lower (four to thirty five thousand) for C-106/AY-102 tests and higher (over half a million) for AZ-101 than previously for HLW tests. Additional emissions data collected during the tests were particle size distributions of the melter emissions,

concentrations of various gaseous species throughout the off-gas system by FTIR, and hydrogen concentrations by gas chromatography at the WESP outlet.

The volumes of processing solutions generated in the SBS, WESP, HEME, and PBS were documented during testing and representative samples were subjected to chemical analysis. The SBS solutions were close to neutral pH, due in large part to the lack of acid gases in the exhaust stream. The major dissolved species were selenium, halogens, boron, and alkali metals, while the suspended species closely resembled the feed composition. The measured SBS TSS concentration ranged from about 400 to 3200 mg/l, whereas measured TDS values were typically about 2 times higher. The WESP sump fluid was also in the neutral pH region but had negligible suspended solids. The WESP solutions contained significant concentrations of selenium, sulfate, and alkali halides. The WESP was sprayed continuously during this test and was deluged with 40 gallons of water once daily, resulting in a daily blow-down volume of about 80 gallons. The nearly 10,700 gallons of liquid that accumulated in the SBS during testing originated from the condensation of water from the melter feed.

A good mass balance was achieved for iodine around the melter, SBS, and WESP for the one test that used feed that contained iodine. Notably, after sugar was introduced into the melter feed, about 30% of the feed iodine was retained in the glass with the remainder captured in SBS fluids, in marked contrast to previous HLW tests without sugar additions.

In contrast to previous tests under oxidizing conditions, under reducing conditions only about 1% of the total mass of ruthenium injected into the melter feed reported to the off-gas stream. However, with sugar addition to the feed, ruthenium was reduced to the metallic state. In addition, portions of other elements such as nickel and copper were also reduced to the metallic state, and sulfate was reduced to sulfide. Glass samples taken from the bottom of the melter were rich in secondary phases, mostly ruthenium metal and a nickel sulfide. Nickel sulfide (most likely Ni_3S_2) is a corrosive liquid at temperatures prevailing at the bottom of the DM1200 melter. The data indicate that about 90% of the ruthenium fed to the melter was retained in the melter, probably as metal. Since there was only a very small effect of the progressive increases in sugar concentration on the volatility of ruthenium, a sugar concentration of 7.6 g/l feed was sufficient to limit ruthenium volatility to about 1%. However, it is not clear how much lower the concentration could be and still achieve the same effect. More particularly, it is not known whether it is possible to add sufficient sugar to diminish the volatility of ruthenium without reducing the ruthenium to the metallic state.

SECTION 10.0 REFERENCES

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Table 2.1. Compositional Summary of Different Waste Streams and Blended Solids.

Chemical Species	AZ-101 Solids	Recycle Stream	Separation Factor*	Cs-Eluate	Tc-Eluate	Blended Solids
	FRP02	PWD01	-	CNP12	TEP12	HLP09b
	(lb/day)	(lb/day)	(fraction remained)	(lb/day)	(lb/day)	(lb/day)
Ag	4.66E+00	4.17E-21	1.00E+00	-	-	4.66E+00
Al	1.49E+03	1.77E+00	4.20E-01	5.27E-01	2.11E-02	6.26E+02
As	1.43E+00	1.21E-01	1.00E+00	-	-	1.56E+00
B	6.44E+00	3.11E+00	1.00E+00	6.60E-01	6.80E-02	1.03E+01
Ba	1.58E+01	1.64E-04	2.42E-01	1.71E-03	1.33E-04	3.82E+00
Be	2.24E-01	0.00E+00	1.00E+00	-	-	2.24E-01
Bi	1.49E+00	2.34E-04	1.00E+00	-	-	1.49E+00
Ca	4.60E+01	8.14E-02	9.88E-01	3.75E-02	2.29E-03	4.56E+01
Cd	1.54E+02	6.19E-04	8.27E-02	5.12E-03	-	1.27E+01
Ce	1.88E+01	5.88E+00	7.72E-02	-	-	1.90E+00
Cl	1.15E+00	9.42E-02	7.95E-02	-	1.28E-02	1.12E-01
Co	1.00E+00	0.00E+00	1.00E+00	-	-	1.00E+00
Carbonate	4.46E+01	2.24E+00	1.31E-01	-	-	6.12E+00
Cr	7.33E+00	2.15E-01	1.52E-01	6.31E-02	3.18E-03	1.21E+00
Cs	7.06E-01	0.00E+00	1.15E-01	2.80E-01	-	3.61E-01
Cu	5.20E+00	2.37E-44	1.00E+00	2.94E-01	-	5.50E+00
F	1.01E+02	1.27E+00	8.25E-02	-	-	8.42E+00
Fe	1.96E+03	1.41E+00	9.94E-01	1.28E-01	2.22E-02	1.95E+03
Hg	4.55E-02	1.90E-05	1.00E+00	-	-	4.55E-02
K	4.64E+01	6.82E-01	9.29E-02	1.86E+00	4.16E-02	6.28E+00
La	8.02E+01	1.80E-02	9.85E-01	-	-	7.90E+01
Li	1.45E+00	8.15E-01	1.00E+00	-	-	2.26E+00
Mg	1.46E+01	7.28E-06	1.00E+00	-	2.98E-04	1.46E+01
Mn	2.44E+01	8.20E-02	9.99E-01	1.71E-03	2.98E-04	2.45E+01
Mo	1.25E+00	0.00E+00	1.00E+00	-	-	1.25E+00
Na	1.18E+03	3.59E+02	1.15E-01	1.71E+01	3.32E-01	1.94E+02
Nd	4.88E+01	0.00E+00	1.00E+00	-	-	4.88E+01
Ni	1.11E+02	1.07E-01	9.83E-01	2.61E-01	2.65E-03	1.10E+02
Nitrite	3.04E+02	2.56E-01	7.84E-02	-	-	2.38E+01
Nitrate	2.03E+02	8.21E+02	7.77E-02	4.92E+01	-	1.29E+02
Hydroxide	1.85E+03	3.16E+01	5.97E-01	-	-	1.12E+03
Hydroxide(Bound)	4.15E+03	0.00E+00	7.68E-02	-	-	3.19E+02
Pb	7.00E+00	2.00E-02	1.00E+00	1.14E-01	-	7.14E+00
Pd	0.00E+00	1.95E-09	1.00E+00	-	-	1.95E-09
Phosphate	5.10E+00	5.01E-03	2.20E-01	-	-	1.16E+00
Pr	1.16E+01	0.00E+00	1.00E+00	-	-	1.16E+01
Rb	3.18E-01	0.00E+00	1.00E+00	-	-	3.18E-01
Rh	3.85E+00	0.00E+00	1.00E+00	-	-	3.85E+00
Sb	1.76E-01	0.00E+00	-	-	-	0.00E+00
Se	6.48E-01	0.00E+00	-	-	-	0.00E+00
Si	3.60E+01	6.46E+00	9.97E-01	4.57E-01	9.29E-02	4.29E+01
Sulfate	2.36E+02	2.46E+01	7.86E-02	-	-	2.05E+01
Sr	6.46E+00	0.00E+00	9.58E-01	-	-	6.18E+00
Ta	1.76E-01	0.00E+00	-	-	-	0.00E+00
Te	1.93E+00	0.00E+00	-	-	-	0.00E+00
Th	6.35E+00	0.00E+00	-	-	-	0.00E+00
Ti	7.84E-01	1.39E-03	1.00E+00	-	-	7.85E-01
Tl	1.76E-01	0.00E+00	-	-	-	0.00E+00
TOC	7.02E+01	0.00E+00	7.67E-02	-	-	5.39E+00
U	1.34E+02	0.00E+00	-	6.13E-01	-	6.13E-01
V	7.13E-01	0.00E+00	-	-	-	0.00E+00
Zn	2.09E+00	4.71E-01	1.00E+00	5.29E-02	2.32E-04	2.61E+00
Zr	6.42E+02	3.13E-01	9.99E-01	-	-	6.41E+02
TOTAL	1.30E+04	1.26E+03 [#]	-	7.16E+01	5.99E-01	5.50E+03

* Analytes with undetermined separation factors are omitted.

[#] 1.28E+03 of H⁺ is included.

"-" Empty data field.

Table 2.2. Compositional Summary (Oxide Basis) of the AZ-101 HLW Simulant, Glass Additives, Target Test Glass, and the Corresponding Crucible-Melt Glass (HLW98-77).

Constituent	HLW Simulant	Glass Former (as wt% of glass)	Melter Test Target Glass	HLW98-77
Ag ₂ O	-	-	-	0.02%
Al ₂ O ₃	20.64%	-	5.21%	5.20%
B ₂ O ₃	0.58%	11.75%	11.91%	11.91%
BaO	0.07%	-	0.02%	-
CaO	1.11%	-	0.28%	0.28%
CdO	0.25%	-	0.06%	0.06%
Cs ₂ O	0.01%	-	0.00%	-
CuO	0.12%	-	0.03%	0.03%
F	0.15%	-	0.04%	0.04%
Fe ₂ O ₃	48.56%	-	12.26%	12.22%
K ₂ O	0.13%	-	0.03%	0.03%
La ₂ O ₃	1.62%	-	0.41%	0.41%
Li ₂ O	0.08%	3.50%	3.52%	3.53%
MgO	0.42%	-	0.11%	0.11%
MnO	0.67%	-	0.17%	0.17%
Na ₂ O	4.56%	10.50%	11.65%	11.66%
Nd ₂ O ₃	1.22%	-	0.31%	0.31%
NiO	2.44%	-	0.62%	0.61%
PbO	0.13%	-	0.03%	0.03%
SiO ₂	1.61%	47.00%	47.40%	47.45%
SO ₃	0.30%	-	0.08%	0.08%
SrO	0.13%	-	0.03%	0.03%
ZnO	0.06%	2.00%	2.02%	2.02%
ZrO ₂	15.12%	-	3.82%	3.81%
TOTAL	100.00%	74.75%	100.00%	100.00%
<i>Volatiles (g/100 g oxide)</i>	-	-	-	-
Carbonate	0.106	-	-	-
Nitrite	0.414	-	-	-
Nitrate	2.237	-	-	-
TOC	0.093	-	-	-

"-" Empty data field.

Table 2.3. Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from AZ-101 HLW Simulant (22.6 wt% total solids).

AZ-101 HLW Simulant		Glass-Forming Additives	
Starting Materials	Target Weight (kg)	Starting Materials	Target Weight (kg)
Al(OH) ₃	83.61	-	-
H ₃ BO ₃	2.63	Na ₂ B ₄ O ₇ ·10H ₂ O	325.08
Ba(OH) ₂ ·8H ₂ O	0.37	-	-
Ca(OH) ₂	3.78	-	-
CdO	0.64	-	-
CsOH (solution)	0.05	-	-
CuO	0.31	-	-
NaF	0.84	-	-
Fe(OH) ₃ (13% slurry)	1257.25	-	-
KNO ₃	0.71	-	-
La(OH) ₃ ·3H ₂ O	6.15	-	-
Li ₂ CO ₃	0.51	Li ₂ CO ₃	88.78
Mg(OH) ₂	1.55	-	-
MnO ₂	2.09	-	-
NaOH	9.24	Na ₂ CO ₃	91.03
Nd ₂ O ₃	3.11	-	-
Ni(OH) ₂	7.89	-	-
PbO	0.33	-	-
SiO ₂	4.08	SiO ₂	474.75
Na ₂ SO ₄	1.36	-	-
Sr(OH) ₂ ·8H ₂ O	0.86	-	-
ZnO	0.15	ZnO	20.20
Zr(OH) ₄ ·xH ₂ O	98.27	-	-
NaNO ₂	1.61	-	-
NaNO ₃	7.19	-	-
H ₂ C ₂ O ₄ ·2H ₂ O	1.24	-	-
Water	60.00	-	-
TOTAL	1555.84	TOTAL	999.84
-	-	FEED TOTAL	2555.67

"-" Empty data field.

Table 2.4. Compositional Summary of Different Waste Streams and Blended Solids for the C-106/AY-102 HLW Simulant.

Waste Component	C-106/AY-102 Solids	Recycle Stream	Separation Factor	Sr/TRU Product	Cs-Eluate	Tc-Eluate	Blended Solids
	FRP02	PWD01	-	-	CNP12	TEP12	HLP09b
	(lb/day)	(lb/day)	(fraction remained)	(lb/day)	(lb/day)	(lb/day)	(lb/day)
Ag	9.20E+01	5.49E-21	4.885*	-	-	-	9.20E+01
Al	3.19E+03	2.17E+00	0.395	-	5.13E+00	7.54E-02	1.27E+03
As	9.77E+01	1.32E-01	1.825*	-	-	-	9.78E+01
B	1.83E+01	2.88E+00	2.759*	-	7.27E+00	-	2.84E+01
Ba	6.59E+01	2.69E-04	0.054	-	6.24E-03	2.10E-03	3.55E+00
Be	4.89E+00	0.00E+00	1.000	-	-	-	4.89E+00
Bi	1.71E+00	2.58E-04	5.303*	-	-	-	1.71E+00
Ca	4.01E+02	9.03E-02	0.360	-	9.31E-01	2.22E-02	1.45E+02
Cd	1.07E+01	1.57E-04	0.028	-	1.19E-02	2.05E-03	3.10E-01
Ce	5.08E+01	5.90E+00	0.041	-	-	-	2.33E+00
Cl	3.83E+01	2.13E+00	0.064	-	5.94E+01	1.14E+01	7.34E+01
Co	2.05E+01	0.00E+00	1.000	-	-	5.59E-03	2.05E+01
Carbonate	4.73E+03	2.41E+00	0.185	-	-	-	8.74E+02
Cr	1.27E+02	2.01E-01	0.281	-	1.38E-01	5.45E-03	3.58E+01
Cs	7.84E-01	0.00E+00	0.186	-	6.33E-02	3.35E-07	2.09E-01
Cu	2.34E+01	6.86E-33	200.513*	-	3.75E-01	3.89E-03	2.38E+01
F	1.30E+01	7.49E-01	0.037	-	-	-	5.07E-01
Fe	5.87E+03	1.49E+00	1.897*	-	9.57E-02	5.63E-03	5.95E+03
Hg	2.56E+01	2.09E-05	4.438*	-	-	-	2.56E+01
K	2.09E+01	9.11E-01	0.134	-	9.77E-01	2.03E-02	3.91E+00
La	1.39E+02	1.98E-02	2.753*	-	-	2.00E-02	1.39E+02
Li	0.00E+00	7.57E-01	2.848	-	-	5.65E-03	2.16E+00
Mg	2.21E+02	4.89E-06	2.154	-	1.50E-01	4.17E-03	4.76E+02
Mn	1.26E+03	9.01E-02	1.000	4.49E+02	8.20E-03	7.73E-04	1.71E+03
Mo	3.94E+00	0.00E+00	1.000	-	-	2.07E-03	3.94E+00
Na	4.28E+03	3.65E+02	0.059	-	2.02E+01	9.14E-01	2.93E+02
Nd	8.71E+01	0.00E+00	1.000	-	-	-	8.71E+01
Ni	2.20E+02	1.10E-01	0.411	-	5.85E-01	6.68E-03	9.13E+01
Nitrite	4.47E+01	5.06E-01	0.050	-	-	-	2.28E+00
Nitrate	2.93E+01	8.67E+02	0.037	-	1.14E+02	-	1.47E+02
Hydroxide	8.33E+03	3.16E+01	0.114	-	-	-	9.56E+02
Hydroxide(Bound)	5.34E+03	0.00E+00	0.076	-	-	-	4.06E+02
Pb	2.56E+02	2.27E-02	0.353	-	0.00E+00	2.11E-02	9.04E+01
Pd	0.00E+00	2.15E-09	5.392	-	-	-	1.16E-08
Phosphate	1.15E+03	1.66E-02	0.074	-	-	-	8.53E+01
Pr	0.00E+00	0.00E+00	1.000	-	-	-	0.00E+00
Rb	0.00E+00	0.00E+00	1.000	-	-	-	0.00E+00
Rh	0.00E+00	0.00E+00	1.000	-	-	-	0.00E+00
Ru	0.00E+00	0.00E+00	1.000	-	-	-	0.00E+00
Sb	5.91E+01	0.00E+00	2.434	-	-	-	1.44E+02
Se	9.77E+01	0.00E+00	1.825	-	-	-	1.78E+02
Si	6.36E+02	6.02E+00	4.398*	-	2.13E+00	5.69E-02	6.44E+02
Sulfate	3.48E+01	5.45E-01	0.034	-	-	-	1.20E+00
Sr	2.52E+01	0.00E+00	0.985	4.99E+02	-	1.05E-03	5.24E+02
Ta	0.00E+00	0.00E+00	-	-	-	-	0.00E+00
Te	5.83E+00	0.00E+00	-	-	-	-	0.00E+00
Th	0.00E+00	0.00E+00	-	-	-	-	0.00E+00
Ti	1.07E+01	1.53E-03	5.306	-	-	5.02E-03	5.69E+01
Tl	1.97E+02	0.00E+00	-	-	-	-	0.00E+00
TOC	2.96E+02	0.00E+00	0.017	-	-	-	4.92E+00
U	2.18E+02	0.00E+00	-	-	2.01E-01	-	2.01E-01
V	4.89E+01	0.00E+00	-	-	-	9.14E-03	9.14E-03
Y	0.00E+00	0.00E+00	-	-	-	-	0.00E+00
Zn	1.30E+01	4.36E-01	2.843	-	4.66E-02	2.87E-03	3.81E+01
Zr	6.14E+01	3.44E-01	4.576*	-	-	6.94E-03	1.30E+02
TOTAL	3.79E+04	1.31E+03**	-	9.48E+02	2.12E+02	1.26E+01	1.49E+04

* Separation Factors not Used in Calculation (see text). "-" Empty Data Field. ** Includes negligible components that are omitted.

Table 2.5. Compositional Summary (oxide basis) of the C-106/AY-102 HLW Simulant, Glass Additives, Target Test Glass, and the Reference Glass (HLW98-86).

Oxide	C-106/AY-102 HLW Simulant	Glass Former (as wt% of glass)	C-106/AY-102 Melter Test Target Glass	HLW98-86
Ag ₂ O	—	—	—	0.15%
Al ₂ O ₃	12.77%	1.75%	5.29%	5.29%
As ₂ O ₃	0.69%	—	0.19%	0.19%
B ₂ O ₃	0.49%	9.25%	9.39%	9.39%
CaO	1.09%	—	0.30%	0.30%
Cl	0.39%	—	0.11%	0.11%
Cr ₂ O ₃	0.28%	—	0.08%	0.08%
Cs ₂ O	0.18%	—	0.05%	—
CuO	0.16%	—	0.04%	0.04%
Fe ₂ O ₃	45.35%	—	12.58%	12.56%
I	0.36%	—	0.10%	—
La ₂ O ₃	0.87%	—	0.24%	0.24%
Li ₂ O	0.02%	3.00%	3.01%	3.01%
MgO	4.21%	—	1.17%	1.17%
MnO*	14.41%	—	4.00%	3.99%
Na ₂ O	2.11%	11.25%	11.83%	11.84%
Nd ₂ O ₃	0.54%	—	0.15%	0.15%
NiO	0.62%	—	0.17%	0.17%
P ₂ O ₅	0.34%	—	0.09%	0.09%
PbO	0.52%	—	0.14%	0.14%
Sb ₂ O ₃	0.92%	—	0.25%	0.26%
SeO ₂	1.34%	—	0.37%	0.37%
SiO ₂	7.35%	45.00%	47.04%	47.07%
SrO	3.31%	—	0.92%	0.92%
TiO ₂	0.51%	—	0.14%	0.14%
ZnO	0.25%	2.00%	2.07%	2.07%
ZrO ₂	0.93%	—	0.26%	0.26%
TOTAL	100.0%	72.25%	100.00%	100.00%
Volatiles (g/100 g oxide)	—	—	—	—
Carbonate	4.650	—	—	—
Nitrite	0.034	—	—	—
Nitrate	2.174	—	—	—
TOC	0.073	—	—	—

"—" Empty Data Field. *MnO₂ in Reference [13]

Table 2.6. Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from C-106/AY-102 HLW Simulant (20 wt% suspended solids).

C-106/AY-102 HLW Simulant		Glass-Forming Additives	
Starting Materials	Target Weight (kg)*	Starting Materials	Target Weight (kg)
Al(OH) ₃	57.08	Al ₂ O ₃	17.68
As ₂ O ₃	1.93	-	-
H ₃ BO ₃	2.43	Na ₂ B ₄ O ₇ ·10H ₂ O	255.91
CaCO ₃	5.49	-	-
NaCl	1.81	-	-
Cr ₂ O ₃	0.78	-	-
CsOH (50% solution)	1.06	-	-
CuO	0.45	-	-
Fe(OH) ₃ (13% slurry)	1287.78	-	-
NaI	1.19	-	-
La(OH) ₃ ·3H ₂ O	3.66	-	-
Li ₂ CO ₃	0.18	Li ₂ CO ₃	76.10
Mg(OH) ₂	17.25	-	-
MnO ₂	49.49	-	-
Na ₂ CO ₃	6.12	Na ₂ CO ₃	123.20
Nd ₂ O ₃	1.52	-	-
Ni(OH) ₂	2.21	-	-
FePO ₄ ·xH ₂ O (80%)	2.51	-	-
PbO	1.46	-	-
Sb ₂ O ₃	2.57	-	-
SeO ₂	3.75	-	-
SiO ₂	20.61	SiO ₂	454.55
SrCO ₃	13.41	-	-
TiO ₂	1.42	-	-
ZnO	0.71	ZnO	20.20
Zr(OH) ₄ ·xH ₂ O (50%)	6.70	-	-
NaNO ₂	0.05	-	-
NaNO ₃	3.00	-	-
H ₂ C ₂ O ₄ ·2H ₂ O	0.38	-	-
Water	233.50	-	-
TOTAL	1727.24	TOTAL	947.64
-	-	FEED TOTAL	2674.88

*Target weights adjusted for assay information of starting materials; "-" Empty data field

Table 2.7. Properties of DM1200 Melter Feed Samples.

Test	Date	Name	wt% Water	Density (g/ml)	Glass Yield		pH	Yield Stress (Pa)	Viscosity (Poise)		
					kg/kg	g/l			@1/s	@10/s	@100/s
Test 5 (C-106/AY-102 with variable amounts of sugar)	4/30/2003	R12-F-143A	54.02	1.45	0.392	568	10.17	NA	NA	NA	NA
	5/1/2003	S12-F-34A	53.86	1.45	0.3875	562	10.07	NA	NA	NA	NA
	5/2/2003	S12-F-71A	53.96	1.45	0.381	552	10.08	NA	NA	NA	NA
	5/3/2003	S12-F-114A	53.95	1.45	0.385	558	10.22	NA	NA	NA	NA
	5/4/2003	S12-F-154A	54.19	1.44	0.372	536	10.14	NA	NA	NA	NA
	5/5/2003	T12-F-45A	53.80	1.46	0.387	564	10.14	NA	NA	NA	NA
	5/6/2003	T12-F-86A	53.50	1.46	0.378	551	10.17	NA	NA	NA	NA
	5/7/2003	T12-F-125A	53.65	1.45	0.370	537	10.13	NA	NA	NA	NA
	5/8/2003	U12-F-15A	53.6	1.46	0.377	550	10.15	NA	NA	NA	NA
	5/9/2003	U12-F-47A	53.78	1.46	0.376	549	10.09	11.2	63.0	14.51	1.80
Average			53.83	1.45	0.380	553	10.14	11.2	63.0	14.51	1.80
C-106/AY-102 with no sugar [11]			54.20	1.42	0.389	553	10.23	5.5	23.28	2.62	0.42
Test 6 (C-106/AY-102, with Added Nitrate and variable amounts of sugar)	5/14/2003	U12-F-94A	54.36	1.44	0.385	554	9.94	NA	NA	NA	NA
	5/15/2003	U12-F-133A	57.51	1.45	0.356	516	9.85	NA	NA	NA	NA
	5/16/2003	V12-F-22A	56.08	1.43	NA	NA	9.85	NA	NA	NA	NA
	5/17/2003	V12-F-59A	55.36	1.44	NA	NA	9.92	NA	NA	NA	NA
	5/18/2003	V12-F-98A	55.43	1.44	NA	NA	9.88	NA	NA	NA	NA
	5/19/2003	V12-F-135A	54.84	1.44	NA	NA	9.88	NA	NA	NA	NA
	5/20/2003	W12-F-22A	54.97	1.44	NA	NA	9.95	NA	NA	NA	NA
	5/21/2003	W12-F-60A	54.59	1.46	NA	NA	9.97	12.3	115	15.24	2.65
	5/22/2003	W12-F-96A	53.50	1.45	NA	NA	9.94	NA	NA	NA	NA
Average			55.2	1.44	0.370	535	9.91	12.3	115	15.24	2.65
Test 4 (AZ-101 with variable amounts of sugar and Ru/Y spike)	8/19/2003	1F2-F-150A	62.60	1.31	0.305	400	10.48	NA	NA	NA	NA
	8/20/2003	1G2-F-41A	62.30	1.33	0.310	412	10.35	NA	NA	NA	NA
	8/21/2003	1G2-F-78A	62.10	1.31	0.310	406	10.40	NA	NA	NA	NA
	8/22/2003	1G2-F-103A	62.90	1.32	0.298	393	10.39	NA	NA	NA	NA
	8/23/2003	1G2-F-128A	62.47	1.33	0.315	419	10.30	NA	NA	NA	NA
	8/24/2003	1H2-F-35A	62.07	1.33	0.317	422	10.32	NA	NA	NA	NA
	8/25/2003	1H2-F-59A	62.32	1.34	0.310	416	10.39	NA	NA	NA	NA
	8/26/2003	1H2-F-93A	62.98	1.33	0.308	410	10.40	NA	NA	NA	NA
	8/26/2003	1H2-F-106A	62.92	1.33	0.307	409	10.35	NA	NA	NA	NA
	8/27/2003	1H2-F-138A	62.65	1.33	0.304	405	10.31	NA	NA	NA	NA
	8/27/2003	1I2-F-21A	62.86	1.33	0.305	406	10.41	NA	NA	NA	NA
	8/28/2003	1I2-F-42A	63.01	1.33	0.305	405	10.42	1.9	9.83	1.34	0.23
Average			62.62	1.33	0.307	408	10.37	1.9	9.83	1.34	0.23
AZ-101 with no sugar and Ru/Y spike [9]			63.8	1.33	0.304	403	10.40	1.9	12.53	1.60	0.26

**Table 2.8. XRF Analyzed Compositions (wt%) for Melter feed Samples from Test 5
(C-106/AY-102 with variable amounts of sugar).**

Constituent	Target	R12-F-143A	S12-F-34A	S12-F-71A	S12-F-114A	S12-F-154A	T12-F-45A	T12-F-86A	T12-F-125A	U12-F-15A	U12-F-47A	Average	%Dev
Al ₂ O ₃	5.29	5.73	5.61	5.73	5.68	5.61	6.18	5.91	6.19	5.65	5.80	5.81	9.78
As ₂ O ₃	0.19	0.18	0.19	0.19	0.17	0.19	0.18	0.19	0.18	0.19	0.13	0.18	NC
B ₂ O ₃ *	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	NC	NC
CaO	0.30	0.45	0.46	0.46	0.53	0.46	0.45	0.45	0.46	0.46	0.47	0.46	NC
CdO	§	0.02	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
Cl	0.11	0.03	0.05	0.05	0.04	0.05	0.06	0.05	0.05	0.05	0.05	0.05	NC
Cr ₂ O ₃	0.08	0.08	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	NC
Cs ₂ O	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.06	0.05	0.05	0.05	NC
CuO	0.04	0.04	0.02	0.02	0.02	0.04	0.04	0.05	0.02	0.02	0.03	0.03	NC
Fe ₂ O ₃	12.58	11.68	12.04	12.11	11.96	12.02	11.55	11.96	11.80	12.04	12.00	11.92	-5.29
I	0.10	<0.01	0.06	0.05	0.04	0.01	0.03	0.03	0.05	0.04	0.04	0.04	NC
K ₂ O	§	0.12	0.11	0.11	0.12	0.10	0.12	0.11	0.11	0.11	0.12	0.11	NC
La ₂ O ₃	0.24	0.26	0.26	0.26	0.26	0.25	0.24	0.25	0.26	0.25	0.26	0.26	NC
Li ₂ O*	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	NC	NC
MgO	1.17	1.00	1.16	1.17	1.18	1.15	1.14	1.17	1.21	1.24	1.15	1.16	-1.17
MnO	4.00	3.82	3.89	3.92	3.87	3.87	3.70	3.86	3.83	3.94	3.99	3.87	-3.33
Na ₂ O	11.83	11.49	11.66	11.01	11.26	11.38	11.20	11.40	10.91	11.11	10.70	11.21	-5.24
Nd ₂ O ₃	0.15	0.16	0.14	0.16	0.14	0.15	0.13	0.14	0.14	0.15	0.15	0.15	NC
NiO	0.17	0.14	0.11	0.12	0.10	0.14	0.13	0.14	0.12	0.12	0.12	0.12	NC
P ₂ O ₅	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.11	0.10	0.11	NC
PbO	0.14	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.09	0.12	NC
Sb ₂ O ₃	0.25	0.31	0.28	0.30	0.26	0.33	0.30	0.30	0.29	0.27	0.23	0.29	NC
SeO ₂	0.37	0.06	0.04	0.04	0.05	0.11	0.12	0.12	0.05	0.04	0.06	0.07	NC
SiO ₂	47.05	48.38	47.68	48.10	48.08	47.97	48.44	47.77	48.27	48.19	48.62	48.15	2.34
SO ₃	§	0.04	0.05	0.03	0.03	0.05	0.05	0.04	0.02	0.02	0.02	0.04	NC
SrO	0.92	0.81	0.86	0.86	0.86	0.85	0.80	0.84	0.83	0.86	0.87	0.84	-8.36
TiO ₂	0.14	0.22	0.21	0.22	0.24	0.22	0.22	0.23	0.23	0.22	0.22	0.22	NC
ZnO	2.07	1.88	1.93	1.93	1.96	1.91	1.82	1.89	1.86	1.90	1.87	1.89	-8.53
ZrO ₂	0.26	0.43	0.41	0.39	0.41	0.36	0.33	0.35	0.36	0.37	0.38	0.38	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target values

NA – Not analyzed

NC – Not calculated

§ Not a target constituent

Table 2.9. XRF Analyzed Compositions (wt%) for Melter Feed Samples from Test 6 (C-106/AY-102, with Added Nitrate and variable amounts of sugar).

Constituent	Target	U12-F-94A	U12-F-133A	Average	%Dev.
Al ₂ O ₃	5.30	5.62	5.96	5.79	9.33
As ₂ O ₃	0.19	0.22	0.20	0.21	NC
B ₂ O ₃ *	9.40	9.40	9.40	NC	NC
CaO	0.30	0.48	0.46	0.47	NC
Cl	0.11	0.04	0.04	0.04	NC
Cr ₂ O ₃	0.08	0.08	0.08	0.08	NC
Cs ₂ O	0.05	0.05	0.05	0.05	NC
CuO	0.04	0.06	0.05	0.05	NC
Fe ₂ O ₃	12.60	12.43	11.99	12.21	-3.07
K ₂ O	§	0.11	0.12	0.12	NC
La ₂ O ₃	0.24	0.26	0.26	0.26	NC
Li ₂ O*	3.01	3.01	3.01	NC	NC
MgO	1.17	1.19	1.27	1.23	4.96
MnO	4.00	4.11	3.91	4.01	0.11
Na ₂ O	11.84	10.34	12.23	11.28	-4.73
Nd ₂ O ₃	0.15	0.15	0.15	0.15	NC
NiO	0.17	0.15	0.14	0.15	NC
P ₂ O ₅	0.09	0.12	0.11	0.11	NC
PbO	0.14	0.13	0.12	0.13	NC
Sb ₂ O ₃	0.25	0.36	0.31	0.33	NC
SeO ₂	0.37	0.07	0.10	0.09	NC
SiO ₂	47.10	48.10	46.60	47.35	0.54
SO ₃	§	0.05	0.04	0.04	NC
SrO	0.92	0.89	0.86	0.88	-4.88
TiO ₂	0.14	0.22	0.23	0.22	NC
ZnO	2.07	2.00	1.93	1.97	-5.07
ZrO ₂	0.26	0.36	0.37	0.37	NC
Sum	100.00	100.00	100.00	100.00	NC

* Target values

NA – Not analyzed

NC – Not calculated

§ Not a target constituent

Table 2.10. XRF Analyzed Compositions (wt%) for Melter feed Samples from Test 4 (AZ-101 with variable amounts of sugar and Ru/Y spike).

Constituent	Target	1G2-F-41A	1G2-F-78A	1G2-F-102A	1G2-F-128A	1H2-F-35A	1H2-F-59A	1H2-F-93A	1H2-F-106A
Al ₂ O ₃	5.21	5.86	5.68	5.51	6.24	5.74	5.84	5.60	5.55
B ₂ O ₃ *	11.90	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91
BaO	0.02	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.05
CaO	0.28	0.40	0.41	0.40	0.39	0.38	0.39	0.42	0.41
CdO	0.06	0.08	0.06	0.06	0.05	0.05	0.05	0.00	0.05
Cl	§	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	0.01
CuO	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.04
F	0.04	NA	NA	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	12.26	10.96	11.32	11.65	11.13	10.82	10.91	11.50	11.43
K ₂ O	0.03	0.16	0.13	0.12	0.15	0.16	0.16	0.13	0.12
La ₂ O ₃	0.41	0.41	0.42	0.43	0.41	0.40	0.40	0.41	0.42
Li ₂ O*	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52
MgO	0.11	0.11	0.12	0.07	0.07	0.11	0.11	0.12	0.09
MnO	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.17	0.17
Na ₂ O	11.65	11.42	11.40	10.77	10.82	11.20	11.15	11.14	11.57
Nd ₂ O ₃	0.31	0.29	0.29	0.32	0.30	0.29	0.29	0.31	0.30
NiO	0.62	0.52	0.49	0.57	0.52	0.51	0.52	0.48	0.58
P ₂ O ₅	§	<0.01	<0.01	<0.01	0.05	<0.01	0.01	<0.01	<0.01
PbO	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.02	0.03
RuO ₂	¶	<0.01	0.03	0.03	0.05	0.02	0.03	0.02	0.02
SiO ₂	47.41	47.72	47.32	47.44	47.84	48.34	48.17	47.44	47.01
SO ₃	0.08	0.07	0.05	0.08	0.06	0.07	0.07	0.05	0.07
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
TiO ₂	§	0.09	0.09	0.09	0.11	0.09	0.09	0.10	0.09
Y ₂ O ₃	¶	0.10	0.06	0.06	0.10	0.05	0.09	0.07	0.06
ZnO	2.02	1.66	1.75	1.82	1.70	1.66	1.68	1.75	1.77
ZrO ₂	3.82	4.38	4.63	4.82	4.24	4.36	4.31	4.74	4.68
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values

NA – Not analyzed

§ Not a target constituent

¶ Added at expense of all other constituents (targets: RuO₂, 0.09 wt% and Y₂O₃, 0.10 wt%)

**Table 2.10. XRF Analyzed Compositions (wt%) for Melter Feed Samples
(AZ101 with variable amounts of sugar) (continued).**

Constituent	Target	1H2-F-138A	1I2-F-21A	1I2-F-42A	Average	%Dev
Al ₂ O ₃	5.21	5.73	6.24	6.08	5.83	11.82
B ₂ O ₃ *	11.91	11.91	11.91	11.91	NC	NC
BaO	0.02	0.06	0.05	0.05	0.05	NC
CaO	0.28	0.40	0.40	0.40	0.40	NC
CdO	0.06	0.06	0.05	0.06	0.05	NC
Cl	§	0.02	<0.01	0.01	0.01	NC
CuO	0.03	0.03	0.03	0.04	0.03	NC
F	0.04	NA	NA	NA	NA	NC
Fe ₂ O ₃	12.26	11.42	11.20	11.39	11.27	-8.04
K ₂ O	0.03	0.13	0.15	0.14	0.14	NC
La ₂ O ₃	0.41	0.42	0.42	0.42	0.41	0.78
Li ₂ O*	3.52	3.52	3.52	3.52	NC	NC
MgO	0.11	0.08	0.12	0.06	0.09	NC
MnO	0.17	0.17	0.17	0.17	0.17	NC
Na ₂ O	11.65	11.41	10.86	10.93	11.09	-4.76
Nd ₂ O ₃	0.31	0.30	0.30	0.30	0.30	NC
NiO	0.62	0.56	0.53	0.55	0.53	-14.17
P ₂ O ₅	§	<0.01	0.02	0.02	0.01	NC
PbO	0.03	0.03	0.03	0.03	0.03	NC
RuO ₂	¶	0.01	0.03	0.02	0.02	NC
SiO ₂	47.40	47.00	47.70	47.32	47.59	0.38
SO ₃	0.08	0.08	0.08	0.07	0.07	NC
SrO	0.03	0.03	0.03	0.03	0.03	NC
TiO ₂	§	0.10	0.10	0.10	0.10	NC
Y ₂ O ₃	¶	0.04	0.07	0.05	0.06	NC
ZnO	2.02	1.76	1.67	1.73	1.73	-14.56
ZrO ₂	3.82	4.73	4.32	4.61	4.54	18.88
Sum	100.00	100.00	100.00	100.00	100.00	NC

* Target values

NA – Not analyzed

NC – Not calculated

§ Not a target constituent

¶ Added at expense of all other constituents (targets: RuO₂, 0.09 wt% and Y₂O₃, 0.10 wt%)

"-" Empty data field

Table 3.1. Summary of Test Conditions and Results for Test 5.

C-106/AY-102 (Target Glass Yield = 0.372 kg/kg or 550 g/l) with Variable Amounts of Sugar, Bubbling = 65 lpm						
-		A	B	C	D	E
Time	Feed Start	4/30/03 11:32	5/01/03 14:34	5/03/03 14:49	5/05/03 14:59	5/07/03 15:12
	Feed End	5/01/03 14:34	5/03/03 14:49	5/05/03 14:59	5/07/03 15:12	5/09/03 15:45
	Interval	27 hr	48.3 hr	48.2 hr	48 hr	48.6 hr
Water Feeding for Cold Cap		2.6 hr	NA	NA	NA	NA
Slurry Feeding		24.4 hr	48.25 hr	48.2 hr	48 hr	48.6 hr
Cold cap burn		NA	NA	NA	NA	3.6 hr
Feed	Sugar Concentration	0	10 g/l	15 g/l	17.5 - 20 g/l	25 g/l
	Used	3035 kg	4714 kg	5630 kg	4334 kg	4253 kg
	Average Rate	124.4 kg/hr	97.6 kg/hr	116.8 kg/hr	90.3 kg/hr	87.5 kg/hr
Glass Produced	Poured	1093 kg	2020 kg	2001 kg	1720 kg	1836 kg
	Average Rate ^{\$}	896 kg/m ² /day	836 kg/m ² /day	830 kg/m ² /day	717 kg/m ² /day	756 kg/m ² /day
	Average Rate [*]	926 kg/m ² /day	726 kg/m ² /day	869 kg/m ² /day	672 kg/m ² /day	651 kg/m ² /day
	Steady State Rate [*]	Not Attained	Not Attained	870 kg/m ² /day	700 kg/m ² /day	650 kg/m ² /day
	Average Power Use	3.3 kW.hr/ kg glass	3.8 kW.hr/ kg glass	3.3 kW.hr/ kg glass	3.7 kW.hr/ kg glass	3.8 kW.hr/ kg glass

\$ - Rates calculated from glass poured.

*- Rates calculated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

NA: Not applicable.

"-" Empty data field

Table 3.2. Summary of Test Conditions and Results for Test 6.

C-106/AY-102 (Target Glass Yield = 0.372 kg/kg or 550 g/l) with Additional Nitrate and Variable Amounts of Sugar, Bubbling = 65 lpm						
-		A	B	C	D	E
Time	Feed Start	5/14/03 12:05	5/15/03 14:00	5/17/03 15:03	5/19/03 16:00	5/21/03 16:20
	Feed End	5/15/03 14:00	5/17/03 15:03	5/19/03 16:00	5/21/03 16:20	5/23/03 16:30
	Interval	25.9 hr	49 hr	49 hr	48.3 hr	48.2 hr
Water Feeding for Cold Cap		0.7 hr	NA	NA	NA	NA
Slurry Feeding		25.3 hr	49 hr	49 hr	48.3 hr	48.2 hr
Cold cap burn		NA	NA	NA	NA	3.5 hr
Feed	Sugar Concentration	0	10 g/l	15 g/l	20 g/l	25 g/l
	Used	2643 kg	5885 kg	6738 kg	6385 kg	6502 kg
	Average Rate	104.5 kg/hr	120.1 kg/hr	137.5 kg/hr	132.2 kg/hr	134.9 kg/hr
Glass Produced	Poured	1022 kg	2244 kg	2437 kg	2395 kg	2513 kg
	Average Rate ^{\$}	808 kg/m ² /day	916 kg/m ² /day	995 kg/m ² /day	992 kg/m ² /day	1043 kg/m ² /day
	Average Rate [*]	777 kg/m ² /day	894 kg/m ² /day	1023 kg/m ² /day	984 kg/m ² /day	1004 kg/m ² /day
	Steady State Rate [*]	Not Attained	1000 kg/m ² /day	1000 kg/m ² /day	1000 kg/m ² /day	1000 kg/m ² /day
	Average Power Use	3.6 kW.hr/ kg glass	3.4 kW.hr/ kg glass	3.0 kW.hr/ kg glass	3.0 kW.hr/ kg glass	3.0 kW.hr/ kg glass

\$ - Rates calculated from glass poured.

*- Rates calculated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

NA: Not applicable.

"-" Empty data field

Table 3.3. Summary of Test Conditions and Results for Test 4.

AZ-101 (Target Glass Yield = 0.3145 kg/kg or 400 g/l) with Variable Amounts of Sugar and Ruthenium, Bubbling = 65 lpm						
-		A	B [#]	C [#]	D [#]	E [#]
Time	Feed Start	8/19/03 11:15	8/20/03 12:43	8/22/03 13:07	8/24/03 13:27	8/26/03 13:31
	Feed End	8/20/03 12:43	8/22/03 13:07	8/24/03 13:27	8/26/03 13:31	8/28/03 13:31
	Interval	25.5 hr	48.4 hr	48.3 hr	48.1 hr	48 hr
Water Feeding for Cold Cap		1.5 hr	NA	NA	NA	NA
Slurry Feeding		24 hr	48.4 hr	48.3 hr	48.1 hr	48 hr
Cold cap burn		NA	NA	NA	NA	3.3 hr
Feed	Sugar Concentration	0	13.3 – 7.6 g/l	10 g/l	12.5 g/l	16 g/l
	Used	2266 kg	6026 kg	6332 kg	6624 kg	6847 kg
	Average Rate	94.4 kg/hr	124.5 kg/hr	131.1 kg/hr	137.7 kg/hr	142.6 kg/hr
Glass Produced	Poured	708 kg	1841 kg	2055 kg	2039 kg	2313 kg
	Average Rate ^{\$}	590 kg/m ² /day	761 kg/m ² /day	851 kg/m ² /day	848 kg/m ² /day	964 kg/m ² /day
	Average Rate [*]	594 kg/m ² /day	783 kg/m ² /day	825 kg/m ² /day	866 kg/m ² /day	897 kg/m ² /day
	Steady State Rate [*]	Not Attained	850 kg/m ² /day	850 kg/m ² /day	900 kg/m ² /day	930 kg/m ² /day
	Average Power Use	4.3 kW.hr/ kg glass	3.9 kW.hr/ kg glass	3.8 kW.hr/ kg glass	3.8 kW.hr/ kg glass	3.7 kW.hr/ kg glass

- Test segments B-E included ruthenium and yttrium spiked into the feed.

\$ - Rates calculated from glass poured.

*- Rates calculated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

NA: Not applicable.

"-" Empty data field

Table 3.4. DM1200 Melter System Measured Parameters for Test 5.

			A			B			C			D			E		
			avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1139	1069	1204	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		15.5" from floor E	1138	1065	1201	1154	1131	1173	1148	1121	1173	1151	1125	1176	1150	1118	1172
		18" from floor E	1138	1065	1202	1153	1127	1173	1145	1117	1171	1148	1124	1174	1149	1117	1171
		27" from floor E	1124	880	1209	963	719	1160	1055	882	1107	1027	784	1123	1073	909	1133
		13" from floor W	1136	86	1202	1155	1106	1179	1151	1122	1176	1157	1121	1180	1153	1117	1179
		15.5" from floor W	1133	104	1204	1151	1103	1177	1149	1120	1175	1154	1118	1177	1151	1118	1175
		18" from floor W	1128	52	1205	1147	1103	1174	1145	1116	1170	1150	1110	1174	1148	1110	1173
		27" from floor W	1116	464	1213	959	563	1145	1046	652	1108	1019	616	1121	1063	833	1129
	Plenum	8" below ceiling	610	511	783	525	415	644	567	458	647	584	407	725	571	466	649
		17" below ceiling	617	495	1090	528	331	710	556	477	616	538	266	790	606	500	709
		Exposed	613	529	741	585	391	794	636	552	743	658	385	846	660	382	847
	Discharge	TC 1	1015	966	1050	986	941	1022	991	918	1068	973	952	1004	963	896	1010
		TC 2	1078	1043	1103	1046	1005	1074	1056	1008	1113	1033	1016	1053	1032	998	1063
		Air Flow	109	103	117	108	99	116	107	97	113	104	88	111	109	94	117
		Riser	1042	923	1157	1029	972	1144	1023	973	1151	1012	964	1140	1018	976	1147
	Electrode	East	1147	1108	1174	1081	1055	1140	1071	1056	1088	1058	1030	1077	1070	1049	1088
		West	1129	1056	1173	1080	1058	1115	1076	1053	1095	1076	1048	1093	1075	1054	1094
		Bottom	1005	915	1037	982	937	1026	905	893	937	885	867	896	877	871	882
	Film Cooler	Added Air	85	83	86	85	84	87	84	66	87	84	83	89	82	78	85
		Outlet	417	82	605	351	69	442	370	76	422	345	64	446	381	67	478
Glass	Density (g/cc)		2.32	2.21	2.48	2.37	2.28	2.43	2.34	2.23	2.43	2.36	2.22	2.44	2.34	1.97	2.43
	Level (" from floor)		29.85	27.99	31.04	28.81	26.76	30.76	29.84	27.67	31.73	29.17	27.07	32.27	30.23	27.95	35.86
	Resistance (ohms)		0.1007	0.0000	0.1103	0.1150	0.1037	0.1283	0.1171	0.1065	0.1312	0.1160	0.1070	0.1356	0.1140	0.1061	0.1522
Electrodes	Current (A)		1237	0	1650	1090	1034	1117	1099	1076	1117	1029	969	1017	1047	999	1026
	Voltage (V)		124	0	161	125	114	135	129	121	138	119	105	133	119	110	135
	Power (kW)		153	0	265	137	118	150	141	131	154	123	101	135	125	110	138
Lance Bubblers	1	Rate (lpm)	25.0	1.6	60.0	31.9	24.0	37.1	32.1	24.0	37.1	31.2	26.8	37.1	33.3	26.8	37.6
		Temp. (°C)	1133	1103	1176	1097	1054	1119	1087	1056	1123	1095	1054	1125	1092	1037	1121
	2	Rate (lpm)	25.1	1.4	32.4	31.8	26.7	37.2	31.7	26.7	37.9	32.4	16.9	37.1	30.5	26.6	37.8
		Temp. (°C)	1085	1026	1200	1027	971	1071	1021	979	1072	1033	976	1132	1044	972	1092
Total Bubbling (lpm)			51.2	4.2	93.3	64.8	58.7	65.2	64.8	58.8	67.1	64.5	44.8	66.8	64.8	62.9	75.0

"- Empty data field

ND – No Data Available due to failed thermocouple.

Table 3.5. DM1200 Melter System Measured Parameters for Test 6.

			A			B			C			D			E		
			avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1148	1106	1180	1148	1097	1175	1153	1133	1169	1154	1132	1189	1155	1138	1168
		15.5" from floor E	1146	1102	1180	1144	1093	1174	1148	1130	1165	1150	1130	1186	1151	1136	1166
		18" from floor E	1147	1101	1178	1145	1091	1178	1148	1115	1165	1151	1128	1185	1151	1135	1167
		27" from floor E	1096	792	1163	1080	957	1177	1036	897	1152	1051	934	1140	1050	913	1111
		13" from floor W	1148	1115	1186	1148	1105	1172	1153	1136	1169	1152	1135	1189	1151	1139	1165
		15.5" from floor W	1148	1110	1186	1146	1097	1172	1150	1132	1166	1150	1131	1187	1149	1137	1162
		18" from floor W	1146	1108	1181	1142	1091	1173	1145	1123	1166	1146	1127	1182	1145	1133	1159
		27" from floor W	1083	943	1155	1072	951	1173	1023	893	1160	1036	898	1132	1024	906	1106
	Plenum	8" below ceiling	626	569	808	591	517	781	534	502	580	541	508	697	553	515	587
		17" below ceiling	630	559	835	595	533	786	527	500	591	534	484	698	548	519	582
		Exposed	621	524	817	600	418	799	556	448	605	574	511	784	584	533	634
	Discharge	TC 1	985	958	1037	966	942	1001	971	925	1025	978	930	1012	976	881	1014
		TC 2	1046	1023	1088	1028	1004	1054	1032	988	1076	1042	1012	1066	1039	1005	1065
		Air Flow	108	89	117	102	84	112	99	91	114	98	91	112	94	86	110
		Riser	1007	870	1137	1058	977	1151	1069	1028	1168	1066	1009	1158	1082	1038	1159
	Electrode	East	1103	1047	1123	1116	1057	1132	1084	1069	1129	1076	1055	1086	1092	1079	1101
		West	1089	1048	1107	1104	1036	1119	1097	1085	1121	1090	1074	1098	1094	1084	1102
		Bottom	902	827	952	957	895	979	942	925	977	920	903	928	922	916	926
	Film Cooler	Added Air	82	78	85	82	74	87	82	80	86	82	66	86	81	77	83
		Outlet	414	79	640	396	80	488	376	80	419	390	76	454	389	74	465
Glass	Density (g/cc)		2.34	2.21	2.48	2.34	2.10	2.47	2.36	2.28	2.41	2.35	2.28	2.43	2.33	2.28	2.37
	Level (" from floor)		30.07	28.89	31.51	29.84	28.87	31.90	29.56	28.43	30.76	29.95	29.06	31.54	29.94	29.15	31.15
	Resistance (ohms)		0.1178	0.1105	0.1251	0.1124	0.1071	0.1279	0.1115	0.1051	0.1167	0.1091	0.0972	0.1168	0.1074	0.1035	0.1125
Electrodes	Current (A)		1086	977	1133	1165	829	1217	1173	1165	1223	1171	971	1166	1190	1189	1201
	Voltage (V)		128	111	137	130	91	137	131	126	136	128	95	136	128	126	131
	Power (kW)		138	109	155	151	76	167	153	147	167	149	92	159	152	149	157
Lance Bubblers	1	Rate (lpm)	23.8	2.1	32.1	28.2	1.6	36.0	30.4	26.0	33.1	30.2	2.5	35.0	30.7	27.9	36.0
		Temp (°C)	1107	1065	1140	1112	1068	1141	1119	1095	1140	1119	1089	1165	1115	1089	1136
	2	Rate (lpm)	25.0	1.9	37.1	30.0	1.4	37.1	33.4	30.7	37.1	32.1	2.4	35.1	33.2	27.8	36.1
		Temp.(°C)	1063	1004	1143	1062	1009	1154	1062	1043	1085	1068	1021	1167	1068	1045	1092
Total Bubbling (lpm)			49.8	5.0	65.2	59.2	4.0	70.9	64.9	60.8	65.2	63.3	5.9	65.2	64.9	63.8	66.7

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Table 3.6. DM1200 Melter System Measured Parameters for Test 4.

			A			B			C			D			E		
			avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1150	1103	1175	1156	1139	1171	1157	1136	1176	1164	1141	1188	1161	1130	1192
		15.5" from floor E	1148	1099	1176	1153	1135	1167	1154	1134	1173	1160	1137	1184	1157	1116	1188
		18" from floor E	1149	1103	1183	1153	1135	1168	1154	1127	1173	1160	1137	1184	1155	1108	1186
		27" from floor E	984	573	1175	1027	745	1118	1053	709	1144	1066	860	1140	1081	470	1147
		13" from floor W	1149	1090	1182	1151	1124	1166	1141	170	1167	1148	1119	1173	1150	1112	1178
		15.5" from floorW	1150	1096	1175	1153	1130	1169	1141	437	1169	1141	1093	1167	1142	1088	1173
		18" from floor W	1147	1080	1181	1147	1091	1163	1139	31	1171	1137	1065	1165	1136	1056	1166
		27" from floor W	1088	916	1182	1045	851	1122	1058	924	1131	1072	984	1128	1065	819	1142
	Plenum	8" below ceiling	566	514	688	580	516	665	555	505	607	587	528	659	607	510	750
		17" below ceiling	564	502	676	553	488	640	561	462	639	587	528	666	542	469	640
		Exposed	551	490	666	573	453	662	551	471	621	597	482	713	628	495	786
	Discharge	TC 1	1009	953	1056	998	933	1065	983	963	1015	979	908	1017	971	921	1021
		TC 2	1073	1016	1110	1062	999	1121	1047	1030	1068	1048	1017	1070	1046	1022	1073
		Air Flow	82	77	91	83	69	92	83	76	90	84	75	98	85	77	92
		Riser	1060	922	1273	1037	918	1196	1024	969	1184	1049	969	1223	1107	1031	1279
	Electrode	East	1088	1045	1111	1039	1010	1134	1030	1003	1049	1037	1022	1056	1037	1017	1064
		West	1077	1015	1103	1066	1050	1107	1061	1042	1078	1068	1051	1088	1076	1050	1100
		Bottom	997	950	1031	1005	989	1032	1003	984	1019	1017	1003	1030	1034	1023	1050
	Film Cooler	Added Air	86	84	89	86	84	88	86	84	88	86	75	92	85	82	87
		Outlet	397	80	509	402	82	464	383	81	431	402	77	448	403	81	491
Glass	Density (g/cc)		2.36	2.14	2.51	2.41	2.31	2.51	2.42	2.33	2.50	2.41	2.33	2.48	2.40	2.30	2.46
	Level (" from floor)		29.73	28.65	31.45	29.66	28.82	30.48	29.70	28.47	30.73	29.93	28.65	31.13	29.98	28.87	31.33
	Resistance (ohms)		0.1148	0.1082	0.1316	0.1106	0.1049	0.1180	0.1102	0.1010	0.1173	0.1061	0.0965	0.1140	0.1018	0.0935	0.1101
Electrodes	Current (A)		1054	922	1137	1174	1122	1235	1194	1141	1215	1248	1213	1267	1275	1241	1328
	Voltage (V)		120	103	128	130	121	139	131	121	139	132	125	140	130	119	140
	Power (kW)		127	95	146	152	136	171	157	138	169	165	152	177	165	148	186
Lance Bubblers	1	Rate (lpm)	22.7	2.1	32.3	31.3	23.2	36.3	32.3	23.2	37.3	32.2	25.2	36.3	31.3	25.2	36.4
		Temp. (°C)	1112	1085	1146	1114	1097	1133	1115	1097	1134	1122	1101	1146	1124	1099	1158
	2	Rate (lpm)	23.0	1.9	36.2	32.9	27.1	37.4	31.9	25.1	37.3	32.2	28.2	36.4	33.0	25.2	38.5
		Temp. (°C)	1118	1087	1148	1116	1089	1139	1120	73	1144	1129	1108	1160	1130	1101	1158
Total Bubbling (lpm)			31.0	5.0	53.5	64.7	51.3	67.4	65.3	51.2	69.3	65.4	58.4	66.6	65.3	51.4	65.7

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Table 4.1. The DM1200 Melter Energy Balance Calculation Methodology.

Value to be Calculated	Necessary Calculated or Recorded Information	Test Data Sets Used		
SBS(=Melter) Exhaust Dry Air Flow (dscfm or lb/hr)	Water Vapor Pressure (psia)	WESP Exhaust Wet Air Flow (wscfm)	WESP Exhaust Air Temperature (°C)	WESP Exhaust Air Pressure (in. W.C.)
SBS Exhaust Water Flow (lb/hr)	Water Vapor Pressure (psia)	SBS Exhaust Air Temperature (°C)	SBS Exhaust Air Pressure (in. W.C.)	--
Melter Exhaust Water Flow (lb/hr)	SBS Blowdown (lb/hr) SBS Exhaust Water Flow (lb/hr)	--	--	--
SBS Dry Air Sensible Heat (BTU/hr)	SBS Exhaust Dry Air Flow (lb/hr)	SBS Inlet Air Temperature (°C)	SBS Exhaust Air Temperature (°C)	--
SBS Total Water Vapor Sensible Heat (BTU/hr)	Melter Exhaust Water Flow (lb/hr)	SBS Inlet Air Temperature (°C)	SBS Exhaust Air Temperature (°C)	--
SBS Condensed Water Latent Heat (BTU/hr)	SBS Blowdown (lb/hr)	SBS Recirculation Pump Temperature (°C)	--	--
Total SBS Gas Side Duty (BTU/hr)	SBS Air Sensible Heat SBS Water Sensible & Latent Heats (BTU/hr)	--	--	--
SBS Coil Duty (BTU/hr)	--	SBS Coil Flow Rate (gal/min)	Coil Inlet Temperature (°C)	Coil Exit Temperature (°C)
SBS Jacket Duty (BTU/hr)	Cooling Water Ethylene Glycol Concentration	SBS Jacket Cooling Water Flow Rate (gal/min)	Jacket Inlet Temperature (°C)	Jacket Exit Temperature (°C)
Total SBS Water Side Duty (BTU/hr)	SBS Coil and Jacket Duties (BTU/hr)	--	--	--
SBS Plate/Frame Heat Exchanger CW duty (BTU/hr)	Cooling Water Ethylene Glycol Concentration	Cooling Water to SBS Plate/Frame Flow (gal/min)	Cooling Water to SBS Plate Frame Inlet Temperature (°C)	Cooling Water from SBS Plate Frame Exit Temperature (°C)
Transition Line Inlet Temperature (°F)	Melter Exhaust Air Flow (lb/hr) Melter Exhaust Water Vapor Flow (lb/hr) Adiabatic Mixture Temperature	Control Air Feed Temperature (°F); and Flow (scfm)	Control Air flow (scfm)	Film Cooler Discharge Temperature (°C)

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Table 4.1. The DM1200 Melter Energy Balance Calculation Methodology (cont.).

Calculated Value	Other Calculated or Recorded Information	Test Data Files		
Transition Line Actual Convection Heat Loss (BTU/hr)	Melter Exhaust Air Flow lb/hr; Melter Exhaust Water Vapor Flow, lb/hr; Transition Line Inlet Temperature (°F)	SBS Inlet Air Temperature (°C)	--	--
Transition Line Calculated Convection Heat Loss (BTU/hr)	Transition Line Inlet Temperature (°C)	SBS Inlet Air Temperature (°C)	--	--
Melter Skin Convection Heat Loss (BTU/hr)	Melter Skin Temperature Measurements; Transition Line Heat Losses (Actual and Calculated)	--	--	--
Melter Electrode Power (BTU/hr)	--	Melter Electrode Power (kW)	--	--
Combustion in Melter (BTU/hr)	Melter Reductant (Sugar) Feed (kg/hr)	Average Plenum Temperature (°F)	--	--
Salt Decomposition Chemical Reaction Heats in Melter (BTU/hr)	Melter Glass Discharge Rate (kg/hr)	--	--	--
Glass Phase Transition Heats in Melter (BTU/hr)	Melter Glass Discharge Rate (kg/hr)	--	--	--
Molten Glass Sensible Heat (BTU/hr)	Melter Glass Discharge Rate (kg/hr) Melter Slurry Feed Temperature (°F)	Average Melt Pool Bottom Temperature (°C)	--	--
Melter Cooling Panel Duty (BTU/hr)	--	Melter Cooling Panel Total CW Flow (gal/min)	Melter Cooling Panel CW Inlet Temperature (°C)	Melter Cooling Panel CW Exit Temperature (°C)
Control Air Component Feed vs. Product Energy (BTU/hr)	--	Control Air Inlet Temperature (°C)	Control Air Flow Rate (SCFM)	SBS Exhaust Temperature (°C)

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Table 4.1. The DM1200 Melter Energy Balance Calculation Methodology (cont.).

Calculated Value	Other Calculated or Recorded Information	Test Data Sets Used		
Film Cooler Air Component Feed vs. Product Energy (BTU/hr)	--	Film Cooler Air Inlet Temperature (°F)	Film Cooler Air Flow Rate (SCFM or lb/hr)	SBS Exhaust Temperature (°F)
Inleakage Air Flow Rate (scfm)	SBS Dry Air Rate (dscfm)	Control Air Rate (scfm)	Film Cooler Air Rate (scfm)	Bubbling Air Rate (lpm)
Inleakage Air Component Feed vs. Product Energy (BTU/hr)	Ambient Air Temperature (°F) Inleakage Air Flow Rate (scfm)	SBS Exhaust Temperature (°C)	--	--
Bubbling Air Component Feed vs. Product Energy (BTU/hr)	Ambient Air Temperature (°F)	SBS Exhaust Temperature (°C)	Bubbling Air Rate (lpm)	--
Liquid Water Component Feed vs. Product Energy (BTU/hr)	Slurry Feed Temperature (°F)	SBS Recirculation Pump Temperature (°C)	--	--
Water Vapor Content in Control Air, Film Cooler Air and Inleakage Air (kg/hr)	Ambient Air Temperature (°F) and Relative Humidity Inleakage Air Rate (scfm)	Film Cooler Air Rate (scfm)	Control Air Rate (scfm)	--
Water Material Balance	Water in Melter Feed Slurry Water in SBS Blowdown Water in SBS Exhaust Water in Control, Film Cooler and Inleakage Air (kg/hr)	--	--	--

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**Table 4.2. Calibration Data for the Melter Shell Convective Heat Loss Calculation
Derived from Transition Line Measurements.**

Test	Transition Line Average Gas Temperature (°C)	Actual [#] Convection Heat Loss (BTU/hr)	Calculated Convection Heat Loss (BTU/hr)	Ratio of Heat Losses: <u>Actual</u> Calculated
5	265	11,000	13,900	81%
6	286	15,000	15,100	101%
8 *	329	41,000	17,800	228%
4	283	28,000	15,000	185%
--	Arithmetic average of ratios	--	--	149%
--	Geometric average of ratios	--	--	136%

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[#] Actual loss is based on energy lost by off-gas between the transition line inlet and outlet.

* Test 8 was not a part of the reductant tests, but is germane to the calibration calculations of the melter shell convective loss vs. the transition line convective loss.

Table 4.3. Closure of Overall Energy Balance Calculations.

Test	Energy Balance Closure, %	Range of closures of component test segments, %
5	107.4%	104.5% - 111.9%
6	107.5%	105.0% - 110.1%
4	111.2%	108.3% - 118.5%
Average	108.7% *	(average deviation from overall test closure for run component periods is 3.5%)

*Closure value greater than 100% imply that there were fewer energy losses than have been accounted for.

Table 4.4. Comparison between the Process-Side and the Water-Side Approach for Calculating SBS Energy Transfer.

Test	Cooling-Water-side Heat Transfer (kW)	Process-side Heat Transfer (kW)	Difference Between Process and Water Side	Range of differences between process and water sides
5	66.2	63.0	4.8%	0.0% to +11.0%
6	79.6	77.7	2.4%	-3.1% to + 7.2%
4	85.9	85.5	0.5%	-1.3% to + 1.4%
Average	--	--	2.6%	(average standard deviation: 3.1 %)

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Table 4.5. Water Balance Closure.

Test	Ratio: (Water Exiting SBS) (Water fed to Melter)
5	108.6%
6	109.8%
4	111.1%
Average	109.8% *

* The water fed to the melter (denominator in the ratio in the above table) does not include purge or film cooler water. Inclusion of this data is expected to slightly improve the closure.

Table 4.6. Individual Test Melter-Only Energy Balance, and Comparison Between Melter-Only and Melter + SBS Energy Balances.

Energy Component	Test 5	Test 6	Test 4	Average [Melter Only]	Average [Melter+SBS]
Melter Electrode Power, kW	134.2	151.2	156.2	147.2	147.2
Film Cooler Air Sensible Heat, kW	11.4	12.5	12.8	12.2	NC
Bubbling and Inleakage Air Sensible Heat, kW	10.9	13.3	13.3	12.5	NC
Water Latent Heat, kW	43.9	53.3	62.7	53.3	NC
Water Sensible Heat, kW	12.3	15.9	19.0	15.8	NC
Transition Line Heat Loss, kW	--	--	--	--	5.6
Total SBS Duties, kW	--	--	--	--	77.2
Exhaust vs. Feed Energies*	--	--	--	--	15.1
Melter Cooling Panels, kW	30.2 [#]	28.2	32.5	30.2	30.2
Glass Sensible Heat, kW	16.9	20.3	17.6	18.3	18.3
Sugar Combustion, kW	-3.9	-5.5	-4.4	-4.6	-4.6
Melter Skin Convection, kW	3.9	3.9	3.9	3.9	3.9
Reaction & Transition Heats, kW	12.5	16.4	13.1	14.0	14.0
Total "Melter-Only" Energy, kW (excluding electrode power)	138.1	158.2	170.5	155.6	--
% Difference between "Melter-Only" & Electrode Power	+2.9%	+4.6%	+9.2%	+5.5%	--
Total "Melter + SBS" Energy, kW (excluding electrode power)	144.1	162.6	173.7	--	160.1
% Difference between "Melter + SBS" & Electrode Power	+7.4%	+7.5%	+11.2%	--	+8.7%

* Value associated with the SBS exhaust being slightly warmer (40°C) than the feed slurry (27°C) and the fact that about 98% of the water enters the melter in the liquid state and 25-30% leaves the SBS as water vapor. All material flow streams, e.g., film cooler, control, bubbling, and inleakage air, are included in this calculation.

[#] adopted value, as described in text Section 4.3.2.

-- Empty cell. Value is not a part of the specific energy balance.

NC Not calculated. Because of the different envelope boundaries employed in the "Melter-Only" and "Melter + SBS" calculations, comparison is meaningless. These heat flow components are lumped into the SBS and Transition Line values.

Table 4.7. Melter and SBS Thermal Duties during Test 5.

Component		Test Segment					
		A	B	C	D	E	Average
Glass, kg/hr		44.8	41.9	41.5	35.8	37.8	39.9
Melter (kW)	Heat Transferred in SBS (water side)	85.6	70.8	69.4	61.2	53.9	66.2
	Heat Transferred in SBS (gas-side)	84.8	63.9	64.7	57.3	54.5	63.0
	Cooling Panels Heat	30.2	30.2	30.2	30.2	30.2	30.2
	Heat Carried Away by Discharge Glass	18.2	17.9	17.1	16.3	15.6	16.9
	Salt/Organics Decomposition and Transition Heat	13.7	13.2	12.7	12.1	11.6	12.5
	Transition Line Heat Loss	5.0	2.3	2.5	2.8	5.9	3.6
	Melter Skin Heat Loss	3.9	3.9	3.9	3.9	3.9	3.9
	Feed vs. Product Energies	14.6	13.6	15.0	13.7	14.6	14.6
	Sugar Combustion Heat	0.0	-2.7	-4.6	-4.6	-5.8	-3.9
	Total of Melter Energy Streams Other than Electrodes	171.3	149.4	149.3	135.7	129.9	144.1
	Average Melter Electrode Power	153.1	136.9	141.2	124.3	124.3	134.2
SBS (kW)	Water Side: Coil Heat	62.3	48.7	52.8	42.5	47.3	49.6
	Water Side: Jacket Heat	23.3	23.2	16.6	18.7	6.6	16.9
	Water Side: Total Heat	85.6	70.8	69.4	61.2	53.9	66.2
	Gas Side Water Latent Heat	44.6	32.6	31.5	26.4	22.3	30.1
	Gas Side: Water Vapor Sensible Heat	12.9	8.4	8.8	7.4	7.3	8.5
	Gas Side: Sensible Air Heat	27.3	22.9	24.3	23.4	24.9	24.3
	Gas Side: Total Heat	84.8	63.9	64.7	57.3	54.5	63.0
SBS (°C)	Coil Approach Temperature	5.8	4.6	5.1	4.2	4.5	4.7
	Jacket Approach Temperature	15.4	15.0	11.1	15.9	19.0	15.3

Table 4.8. Melter and SBS Thermal Duties during Test 6.

Component		Test Segment					
		A	B	C	D	E	Average
Glass, kg/hr		40.4	45.8	49.7	49.6	52.1	48.2
Melter (kW)	Heat Transferred in SBS (water side)	70.5	78.1	79.8	83.1	82.4	79.6
	Heat Transferred in SBS (gas-side)	73.5	76.6	78.2	78.0	80.0	77.7
	Cooling Panels Heat	27.7	28.7	28.7	27.6	28.0	28.2
	Heat Carried Away by Discharge Glass	16.6	20.1	20.6	21.1	21.6	20.3
	Salt/Organics Decomposition and Transition Heat	13.4	16.2	16.5	17.0	17.3	16.4
	Transition Line Heat Loss	6.0	4.7	3.3	5.9	4.8	4.8
	Melter Skin Heat Loss	3.9	3.9	3.9	3.9	3.9	3.9
	Feed vs. Product Energies	15.5	15.4	14.8	14.3	15.0	15.0
	Sugar Combustion Heat	0.0	-3.4	-5.5	-7.3	-9.0	-5.5
	Total of Melter Energy Streams Other than Electrodes	153.6	163.8	162.2	165.7	164.0	162.6
	Average Melter Electrode Power	138.4	156.0	153.3	150.5	152.0	151.2
SBS (kW)	Water Side: Coil Heat	58.0	62.3	66.0	51.3	48.3	57.2
	Water Side: Jacket Heat	12.6	15.8	13.8	31.8	34.9	22.6
	Water Side: Total Heat	70.5	78.1	79.8	83.1	82.4	79.6
	Gas-Side Water Latent Heat	34.2	37.4	41.5	40.1	39.3	39.0
	Gas Side: Water Vapor Sensible Heat	10.5	10.8	11.0	11.2	12.0	11.2
	Gas Side: Sensible Air Heat	28.7	28.4	25.7	26.8	28.7	27.5
	Gas Side: Total Heat	73.5	76.6	78.2	78.0	80.0	77.7
SBS (°C)	Coil Approach Temperature	5.7	6.1	6.8	5.6	5.6	6.0
	Jacket Approach Temperature	17.2	10.7	8.5	19.0	20.6	15.0

Table 4.9. Melter and SBS Thermal Duties during Test 4.

Component		Test Segment					
		A	B	C	D	E	Average
Glass, kg/hr		29.5	38.0	42.5	42.4	48.2	41.2
Melter (kW)	Heat Transferred in SBS (water side)	67.8	81.9	86.5	91.4	92.7	85.9
	Heat Transferred in SBS (gas-side)	69.1	83.6	86.0	91.2	92.6	86.2
	Cooling Panels Heat	32.3	32.7	32.1	32.5	32.8	32.5
	Heat Carried Away by Discharge Glass	12.6	16.2	18.1	18.1	20.6	17.6
	Salt/Organics Decomposition and Transition Heat	9.4	12.1	13.5	13.5	15.3	13.1
	Transition Line Heat Loss	9.4	9.6	7.1	7.9	8.9	8.5
	Melter Skin Heat Loss	3.9	3.9	3.9	3.9	3.9	3.9
	Feed vs. Product Energies	14.8	15.3	15.4	16.5	16.4	16.6
	Sugar Combustion Heat	0.0	-4.5	-3.7	-4.9	-6.5	-4.4
	Total of Melter Energy Streams Other than Electrodes	150.2	167.1	172.9	178.9	183.2	173.7
	Average Melter Electrode Power	126.8	152.1	156.8	165.2	165.4	156.2
SBS (kW)	Water Side: Coil Heat	48.1	62.1	61.4	67.7	68.0	62.9
	Water Side: Jacket Heat	20.0	22.1	25.2	24.9	24.7	23.8
	Water Side: Total Heat	67.9	81.9	86.6	91.4	92.8	85.9
	Gas-Side Water Latent Heat	35.3	45.9	47.9	50.2	52.2	47.5
	Gas Side: Water Vapor Sensible Heat	9.2	11.9	12.2	13.6	13.5	12.4
	Gas Side: Sensible Air Heat	24.6	25.8	26.0	27.4	26.8	26.3
	Gas Side: Total Heat	69.1	83.6	86.0	91.2	92.6	86.2
SBS (°C)	Coil Approach Temperature	4.6	6.1	6.0	6.7	6.8	6.2
	Jacket Approach Temperature	16.6	17.9	18.8	18.8	19.6	18.5

Table 5.1. Summary of Off-Gas Operational Events and Equipment Inspections and Modifications During the HLW Bubbler Configuration and Reductant Test Series.

Test	Operational notes		Post-test inspections and cleanings	Post-test equipment modifications
	Run time (hours)	Run time note		
Prior to Test 5	-	-	-	Before test: flared extension piece added to bottom of SBS down-comer.
5	Feed started: 4/30/03 11:32 (Silver mordenite column used. Carbon column not yet installed.)		1. Infrared inspection of SBS downcomer.	1. WESP heat shrink sleeve on top south grid support removed due to degradation, and post greased with silicone grease as a temporary measure. 2. WESP spray nozzle replaced. Spraying procedure changed – WESP spray turned off right before and after deluges.
	26.6 – 27.1	Feed interrupted due to repair of emergency off-gas vent valve.		
	45.0	Two (out of four) SBS isolation pinch valves replaced.		
	52.5 – 53.8	Feed interrupted due to cold cap ridges.		
	141.1 - 145.7	Feed interrupted due to cold cap ridges.		
	Feed ended: 5/9/03 15:45			
6	Feed started 5/14/03 12:05 (Silver mordenite column used. Carbon column not yet installed.)		1. Infrared inspection of SBS downcomer. 2. SBS downcomer solid sample analyzed by SEM. 3. WESP solid sample analyzed by SEM. 4. SBS downcomer cleaned from top with wire brush. 5. Acid wash of WESP grid.	1. WESP top south grid support post replaced with a UHMW polyethylene post.
	27.7 - 30.8	Feed turned off due to the seal replacement on the melter cooling pump, MCL-CW-P-402A.		
	120 - 122	Problems with chilled water supply which affected cooling within the SBS.		
	140.6 – 142.1	Feed turned off to replace the SBS recirculation pump, SBS-PW-P-501, which had a seal failure.		
	Feed ended 5/23/03 16:30			

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Table 5.1. Summary of Off-Gas Operational Events and Equipment Inspections and Modifications During the HLW Bubbler Configuration and Reductant Test Series (continued).

Test	Operational notes		Post-test inspections and cleanings	Post-test equipment modifications
	Run time (hours)	Run time note		
2	Feed started 5/28/03 13:42 (Silver mordenite column NOT used. Carbon column not yet installed.)		1. Infrared inspection of SBS downcomer. 2. SBS bowl dropped and solids cleaned. 3. Film cooler and transition line cleaned, and solids sampled. 4. WESP solid sample removed and analyzed. 5. Blowers 701 and 702 (Paxton) examined. Solids sample collected. 6. HEPA filter and housing inspected.	1. Sleeve welded to SBS down-comer due to cracked down-comer pipe being noticed. 2. 15.1 kg of packing added to the top of the SBS bed.
	Feed ended 6/06/03 14:40			
1	Feed started 6/25/03 12:00 (Silver mordenite column NOT used. Carbon column not yet installed.)		1. Infrared inspection of SBS downcomer. 2. Film cooler and transition line inspected and small amount of solids removed. 3. Solids sample removed for analysis from PBS recirculation pump head.	1. Additional pressure measurement added to transition line inlet to allow calculation of transition line differential pressure by difference, as an alternate method. 2. Sulfur-impregnated carbon bed installed for use. (Used in Tests 3 and 10.) 3. SBS recirculation pump SBS-PW-501 replaced due to leaking seal.
	44.2 – 44.8	Failure of solenoid valve in feed system. Feed system rodded.		
	Feed ended 7/2/03 13:01			

Table 5.1. Summary of Off-Gas Operational Events and Equipment Inspections and Modifications During the HLW Bubbler Configuration and Reductant Test Series (continued).

Test	Operational notes		Post-test inspections and cleanings	Post-test equipment modifications
	Run time (hours)	Run time note		
3	Feed started 7/15/03 12:15 (Carbon and silver mordenite columns used.)		1. Infrared inspection of SBS downcomer. 2. Film cooler inspected.	1. Film cooler replaced.
	17 - 174	Frequent clogging of film cooler and transition line. Cleanouts by rodding.		
	72.8 – 73.3	Stopped feed to reduce cold cap.		
	115 - 117	Problems with TCO/SCR heater controller. Controller replaced at 117 hours.		
	116.8 – 117.8	Stopped feed to adjust bubbling rate.		
	161.1 – 162.3	Blockage in transition line. Bellows removed to clear blockage.		
	Feed ended 7/22/03 20:20			
8	Feed started 8/5/03 12:16 (Carbon and silver mordenite columns NOT used.)		1. Infrared inspection of SBS downcomer.	1. Replaced TCO/SCR heater main control board.
	34.9 – 35.7	Stuck poppet on ADS pump, feed stopped.		
	50 - 188	Frequent clogging of film cooler. Cleanouts by rodding.		
	91.5	Ammonia system secured, due to TCO/SCR heater failure.		
	121.2 – 122.8	Stopped feed to rod out the film cooler.		
	Feed ended 8/13/03 15:01			

Table 5.1. Summary of Off-Gas Operational Events and Equipment Inspections and Modifications During the HLW Bubbler Configuration and Reductant Test Series (continued).

Test	Operational notes		Post-test inspections and cleanings	Post-test equipment modifications
	Run time (hours)	Run time note		
4	Feed started 8/19/03 11:15 (Carbon and silver mordenite columns NOT used.)		1. Infrared inspection of SBS downcomer.	1. Recalibrated the SBS recirculation pump pressure gauge.
	Throughout test.	Problems experienced with the SBS recirculation pump pressure reading. Reduction of SBS recirculation flow. (Problem diagnosed after test completion.)		
	Feed ended 8/28/03 13:31			
10	Feed started 9/3/03 12:46 (Carbon and silver mordenite columns used.)		1. Infrared inspection of SBS downcomer. 2. SBS bowl dropped and solids cleaned. 3. Film cooler and transition line cleaned and solid samples removed and photographed. 4. HEME #1 interior and connecting piping examined. 5. HEPA housing examined. 6. Final blower examined and solids removed.	1. Blower 801 head, belt, and tensioner replaced (after 2243 hours of operation since last replacement).
	55.0 – 56.4	Feed stopped due to cold cap imbalance.		
	73.0 – 73.7	Feed stopped to add sodium sulfate solution to feed tank.		
	115.7 – 117.1	Feed stopped to burn off cold cap ridge in the melter.		
	Feed ended 9/10/03 15:30			

Table 5.2. Reductant Tests Measured Off-Gas System Parameters.

Test Segment		5A			5B			5C		
-		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Detector Port ("water)	-3.7	-5.4	-1.5	-3.7	-5.7	-1.0	-3.7	-5.5	1.2
	Press. at Instrument Port ("water)	-3.8	-5.5	-1.6	-3.8	-5.8	-1.1	-3.8	-5.6	1.1
	Control Air Flow Rate (scfm)	65.4	37.5	109.1	72.8	15.7	111.7	73.3	12.9	87.4
Film cooler differential pressure ("water)		0.9	0.2	2.1	0.7	0.1	5.3	0.9	0.2	4.0
Transition line differential pressure ("water)		NA	NA	NA	NA	NA	NA	NA	NA	NA
SBS	Differential Pressure ("water)	40.4	37.2	43.0	41.4	31.9	46.6	43.4	39.3	53.1
	Inlet gas pressure ("water)	-6.9	-11.7	-3.2	-5.6	-13.1	-2.9	-5.9	-12.4	-3.3
	Outlet gas pressure ("water)	-45.2	-48.6	-41.8	-45.9	-55.3	-37.5	-47.6	-63.7	-44.1
	Inlet gas Temp. (°C)	293	181	443	247	106	334	258	132	328
	Outlet gas Temp. (°C)	40.7	33.9	49.2	39.9	33.2	56.2	40.8	38.0	44.1
	Chilled Water Inlet Temp (°C)	15.5	11.9	19.1	15.2	10.7	19.7	14.9	9.1	17.9
	Chilled Water Outlet Temp (°C)	24.8	19.3	33.7	24.7	17.3	37.9	29.5	21.4	34.5
	Submerged 48" Temp (°C)	47.3	35.3	62.4	44.1	34.0	62.9	43.9	39.7	51.1
	Submerged 60" Temp (°C)	46.8	35.3	62.4	43.8	34.1	62.9	43.7	39.7	51.4
	Submerged 72" Temp (°C)	50.1	37.0	65.1	46.6	36.3	64.1	46.3	41.7	55.9
	Submerged 78" Temp (°C)	48.0	36.4	64.0	44.9	35.1	63.2	44.8	40.9	53.0
	Recirc. pump discharge Temp (°C)	40.3	33.8	45.5	39.7	33.5	52.5	40.6	38.3	43.7
	Heat Exchanger Outlet Temp (°C)	32.1	23.3	42.0	33.7	24.9	52.2	34.4	31.4	38.5
	Chilled Water Flow (gal/min)	10.9	3.3	38.9	13.6	2.4	41.0	4.7	3.0	22.3
	Heat Exchanger Flow (gal/min)	13.7	2.5	25.8	9.9	2.5	22.7	9.9	7.6	17.4
	Recirc. pump discharge Pressure	37.3	31.2	39.4	37.3	0.1	42.1	38.0	31.3	40.2
	Inner C. Coil W. Inlet Temp (°C)	25.2	19.0	44.2	28.1	18.3	55.8	27.3	23.8	31.8
	Inner C. Coil W. Outlet Temp (°C)	34.5	27.5	44.2	35.2	27.0	55.8	35.5	33.0	39.4
	Inner C. Coil W. Flow (gal/min)	24.4	23.8	25.1	24.5	23.7	25.4	24.5	24.0	25.0
WESP	Differential Pressure ("water)	2.3	1.0	2.8	2.7	1.2	4.2	3.8	1.8	5.4
	Inlet gas Temp. (°C)	40.6	35.3	51.0	39.3	32.6	54.6	40.1	37.3	43.0
	Outlet gas Temp. (°C)	43.0	25.2	47.4	42.0	23.6	53.4	41.7	23.6	44.3
	Wet Gas Flow Rate (scfm)	201.9	195.1	207.3	205.1	196.6	217.5	207.7	204.4	210.8
HEME #1, Outlet Gas Temp. (°C)		42.0	34.9	48.0	40.4	30.9	52.2	40.3	31.9	43.0
HEPA 1	Differential Pressure ("water)	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.0	0.2
	Outlet Gas Temp. (°C)	63.2	62.1	64.4	62.9	61.1	65.2	62.7	61.4	63.4
TCO/SCR Heater Inlet Gas Temp. (°C)		91.7	89.3	95.5	86.5	79.6	95.6	80.3	78.9	81.3
TCO	Inlet Gas Temp. (°C)	477	473	490	477	450	489	477	468	492
	Differential Pressure ("water)	2.9	2.0	3.2	2.8	2.0	3.9	2.6	1.5	2.7
SCR	Inlet Gas Temp. (°C)	388	382	394	388	375	397	391	381	397
	Outlet Gas Temp. Right (°C)	362	350	370	360	347	374	357	348	362
	Outlet Gas Temp. Left (°C)	347	335	354	341	327	359	337	330	346
	Differential Pressure ("water)	6.3	4.2	6.8	6.0	4.1	8.3	5.6	2.9	5.9
	Post Outlet Gas Temp. (°C)	331	326	335	316	292	339	300	294	304
PBS	Inlet Gas Temp. (°C)	307	299	311	294	273	317	280	275	284
	PBS Sump Temp. (°C)	25.6	22.6	28.9	25.4	22.0	30.2	24.1	20.9	25.8
	Differential Pressure ("water)	3.3	1.1	4.1	3.4	1.4	10.3	3.2	1.4	3.6
HEME #2	Inlet Gas Temp. (°C)	28.4	26.2	31.4	27.9	25.2	31.8	26.6	24.4	28.1
	Outlet Gas Temp. (°C)	31.1	29.3	34.9	30.0	27.3	33.9	28.6	26.7	30.1
Exhaust Stack Absolute Pressure ("water)		-8.3	-8.5	-7.6	-8.3	-8.6	-7.8	-8.5	-8.8	-8.4

NA: Not available due to sensor malfunction.

"-" Empty data field

Table 5.2. Reductant Tests Measured Off-Gas System Parameters (continued).

Test #		5D			5E			6A		
-		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Detector Port ("water)	-3.7	-6.8	0.4	-3.8	-5.2	0.3	-3.7	-5.3	0.8
	Press. at Instrument Port ("water)	-3.8	-6.9	0.3	-3.9	-5.3	0.2	-3.8	-5.5	0.7
	Control Air Flow Rate (scfm)	60.5	15.8	90.2	47.6	9.1	70.4	72.3	9.1	128.8
Film cooler differential pressure ("water)		0.8	0.2	5.2	0.7	0.2	3.6	1.4	0.1	10.1
Transition line differential pressure ("water)		NA	NA	NA	NA	NA	NA	2.8	0.7	7.8
SBS	Differential Pressure ("water)	43.8	39.9	49.6	44.7	39.0	58.1	40.0	35.7	44.2
	Inlet gas pressure ("water)	-4.5	-13.4	1.2	-4.6	-10.3	-1.6	-8.6	-19.7	-2.6
	Outlet gas pressure ("water)	-47.6	-58.6	-39.7	-48.6	-67.6	-44.8	-48.4	-57.8	-44.9
	Inlet gas Temp. (°C)	249	125	341	270	154	380	285	161	470
	Outlet gas Temp. (°C)	39.7	35.3	44.8	40.3	34.5	47.9	40.3	32.8	54.4
	Chilled Water Inlet Temp (°C)	14.6	10.8	19.4	14.5	12.1	19.4	15.1	12.3	19.0
	Chilled Water Outlet Temp (°C)	23.6	17.4	27.9	20.8	18.2	38.1	22.8	18.5	39.4
	Submerged 48" Temp (°C)	42.3	36.3	50.6	42.4	35.0	51.9	43.7	32.8	59.8
	Submerged 60" Temp (°C)	42.1	36.4	50.3	42.3	35.0	52.8	43.4	32.8	59.7
	Submerged 72" Temp (°C)	44.8	37.6	55.2	44.8	37.6	55.6	46.6	34.0	64.1
	Submerged 78" Temp (°C)	43.3	37.0	52.8	43.6	36.2	54.1	45.2	34.0	62.0
	Recirc. pump discharge Temp (°C)	39.5	35.6	42.9	39.9	35.2	46.6	40.0	33.3	49.4
	Heat Exchanger Outlet Temp (°C)	34.5	28.0	40.8	34.1	23.2	44.1	32.6	26.5	45.2
	Chilled Water Flow (gal/min)	8.0	2.5	37.9	4.0	2.4	10.7	7.3	2.4	41.0
	Heat Exchanger Flow (gal/min)	7.8	2.5	14.3	8.9	2.5	24.7	12.4	2.5	24.9
	Recirc. pump discharge Pressure	38.1	31.5	40.2	38.1	31.5	40.2	38.1	31.5	43.5
	Inner C. Coil W. Inlet Temp (°C)	28.8	21.5	41.3	28.2	17.2	47.5	25.6	20.1	44.2
	Inner C. Coil W. Outlet Temp (°C)	35.3	29.8	41.8	35.3	27.7	47.5	34.3	28.6	45.5
	Inner C. Coil W. Flow (gal/min)	24.5	23.9	25.0	24.5	23.9	25.2	24.4	23.8	25.0
WESP	Differential Pressure ("water)	3.2	1.3	5.3	2.8	0.6	3.3	2.9	2.2	4.3
	Inlet gas Temp. (°C)	39.1	34.8	44.3	39.6	34.2	47.4	39.9	33.8	53.8
	Outlet gas Temp. (°C)	41.2	24.5	44.3	42.0	23.7	47.4	41.5	26.0	48.1
	Wet Gas Flow Rate (scfm)	206.6	201.0	211.3	200.2	193.2	205.3	200.1	181.5	205.5
HEME #1, Outlet Gas Temp. (°C)		39.2	32.4	42.3	40.0	31.0	45.1	41.3	33.4	52.6
HEPA 1	Differential Pressure ("water)	0.2	0.1	0.2	0.1	0.0	0.2	0.2	0.1	0.2
	Outlet Gas Temp. (°C)	62.4	58.7	63.3	62.6	56.5	63.7	62.6	61.8	64.5
TCO/SCR Heater Inlet Gas Temp. (°C)		80.0	78.8	83.1	81.1	76.3	82.0	80.8	79.7	86.5
TCO	Inlet Gas Temp. (°C)	477	416	511	476	289	527	477	459	486
	Differential Pressure ("water)	2.6	1.7	3.0	2.5	0.9	2.8	3.0	2.5	3.7
SCR	Inlet Gas Temp. (°C)	394	376	409	395	311	416	402	379	416
	Outlet Gas Temp. Right (°C)	358	345	372	358	287	377	394	376	401
	Outlet Gas Temp. Left (°C)	339	329	351	340	281	355	371	353	379
	Differential Pressure ("water)	5.6	3.5	6.7	5.4	1.9	6.1	6.1	5.0	7.8
	Post Outlet Gas Temp. (°C)	301	291	310	302	256	332	363	345	369
PBS	Inlet Gas Temp. (°C)	281	276	286	281	253	303	339	312	344
	PBS Sump Temp. (°C)	23.3	20.6	26.5	22.9	21.1	25.4	25.4	22.0	30.4
	Differential Pressure ("water)	3.1	1.2	4.3	2.9	0.6	3.4	4.1	2.4	8.0
HEME #2	Inlet Gas Temp. (°C)	26.1	24.1	28.8	26.0	24.3	28.1	28.1	25.5	32.8
	Outlet Gas Temp. (°C)	28.1	25.9	30.2	27.9	26.4	29.9	31.1	29.1	37.5
Exhaust Stack Absolute Pressure ("water)		-8.5	-8.7	-8.2	-8.1	-8.6	0.0	-8.5	-8.6	-7.4

NA : Not available due to sensor malfunction.

"-" Empty data field

Table 5.2. Reductant Tests Measured Off-Gas System Parameters (continued).

Test #		6B			6C			6D		
-		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Detector Port ("water)	-3.7	-6.0	-1.5	-3.9	-6.1	-0.3	-4.0	-5.6	0.2
	Press. at Instrument Port ("water)	-3.8	-6.1	-1.7	-4.0	-7.3	-0.4	-4.1	-5.7	0.1
	Control Air Flow Rate (scfm)	81.7	12.9	103.8	65.7	12.9	99.4	51.1	9.1	77.0
Film cooler differential pressure ("water)		0.8	0.1	1.9	0.9	0.3	3.2	0.8	0.3	2.4
Transition line differential pressure ("water)		2.1	0.8	4.1	1.4	0.1	4.9	2.4	0.6	5.7
SBS	Differential Pressure ("water)	41.9	36.1	46.5	41.2	36.2	46.1	42.3	37.9	47.1
	Inlet gas pressure ("water)	-6.9	-11.7	-2.5	-8.8	-13.3	-3.2	-8.9	-12.5	-6.1
	Outlet gas pressure ("water)	-48.5	-53.8	-44.7	-49.3	-55.2	-44.4	-50.7	-58.0	-46.3
	Inlet gas Temp. (°C)	276	189	336	265	179	317	276	178	336
	Outlet gas Temp. (°C)	39.8	36.4	43.8	39.9	36.9	50.7	39.6	34.2	42.7
	Chilled Water Inlet Temp (°C)	15.1	11.7	21.4	15.8	12.0	35.1	15.1	12.1	28.7
	Chilled Water Outlet Temp (°C)	28.7	19.3	38.5	31.2	20.6	43.0	20.2	16.8	32.0
	Submerged 48" Temp (°C)	43.1	36.9	48.0	44.6	38.4	56.9	43.5	37.8	48.5
	Submerged 60" Temp (°C)	42.9	36.8	48.7	44.3	37.8	56.1	43.3	37.1	48.5
	Submerged 72" Temp (°C)	46.6	37.2	53.6	48.2	40.9	58.9	47.1	41.1	54.6
	Submerged 78" Temp (°C)	45.0	37.1	51.5	45.3	39.3	56.0	44.1	38.0	49.3
	Recirc. pump discharge Temp (°C)	39.4	36.4	43.0	39.7	36.7	49.4	39.2	35.8	41.5
	Heat Exchanger Outlet Temp (°C)	31.0	26.0	38.9	29.9	26.7	43.3	32.3	30.2	39.8
	Chilled Water Flow (gal/min)	5.1	2.4	39.1	4.6	2.4	31.0	25.8	2.9	39.6
	Heat Exchanger Flow (gal/min)	14.8	2.5	28.9	17.3	3.8	32.1	10.8	2.5	21.1
	Recirc. pump discharge Pressure	41.1	32.3	43.6	38.1	32.0	40.3	38.2	31.7	40.2
	Inner C. Coil W. Inlet Temp (°C)	23.6	19.4	42.1	22.5	19.3	38.3	25.7	22.8	39.5
	Inner C. Coil W. Outlet Temp (°C)	33.3	29.5	42.2	32.8	30.1	45.5	33.6	31.6	41.6
	Inner C. Coil W. Flow (gal/min)	24.3	23.9	24.9	24.3	23.8	25.1	24.4	23.9	25.0
	Differential Pressure ("water)	3.1	2.3	5.7	2.9	1.9	4.1	3.2	2.2	4.7
	Inlet gas Temp. (°C)	39.2	35.9	42.7	39.2	36.3	50.1	38.9	33.5	42.0
	Outlet gas Temp. (°C)	40.6	24.4	43.9	39.6	23.3	49.0	39.2	22.7	41.4
	Wet Gas Flow Rate (scfm)	206.8	201.1	213.7	205.6	189.6	228.4	189.1	183.6	193.7
	HEME #1, Outlet Gas Temp. (°C)	39.5	32.4	42.7	37.2	29.8	46.7	37.8	31.0	39.6
HEPA 1	Differential Pressure ("water)	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2
	Outlet Gas Temp. (°C)	62.2	59.1	63.2	61.9	59.5	63.9	61.8	60.1	62.6
TCO/SCR Heater Inlet Gas Temp. (°C)		80.4	78.9	81.4	79.6	77.1	81.7	80.5	79.0	82.5
TCO	Inlet Gas Temp. (°C)	475	261	500	477	435	501	461	425	485
	Differential Pressure ("water)	2.9	2.1	3.3	2.6	2.1	3.0	2.7	2.1	3.0
SCR	Inlet Gas Temp. (°C)	398	277	407	399	385	408	402	387	417
	Outlet Gas Temp. Right (°C)	390	280	402	390	379	400	389	375	403
	Outlet Gas Temp. Left (°C)	369	262	378	369	356	379	367	353	382
	Differential Pressure ("water)	5.9	4.1	6.7	5.3	4.1	6.1	5.5	4.4	6.3
Post Outlet Gas Temp. (°C)		345	268	369	333	321	340	355	330	370
PBS	Inlet Gas Temp. (°C)	324	268	346	312	298	318	330	308	343
	PBS Sump Temp. (°C)	24.7	21.5	29.3	25.1	22.0	44.3	25.6	22.4	34.5
	Differential Pressure ("water)	3.8	3.0	5.0	3.1	1.8	4.5	2.4	1.4	3.5
HEME #2	Inlet Gas Temp. (°C)	27.9	25.9	31.7	27.7	25.0	45.4	27.8	25.1	35.7
	Outlet Gas Temp. (°C)	29.8	27.9	34.0	29.1	26.7	45.5	29.2	26.5	36.9
Exhaust Stack Absolute Pressure ("water)		-8.6	-8.8	-8.2	-8.6	-8.9	-8.3	-8.7	-8.9	-8.4

"-" Empty data field

Table 5.2 Reductant Tests Measured Off-Gas System Parameters (continued).

Test #		6E			4A			4B		
-		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Detector Port ("water)	-4.0	-5.5	-1.0	-3.7	-5.7	-1.6	-3.7	-6.3	-1.7
	Press. at Instrument Port ("water)	-4.1	-5.6	-1.2	-3.8	-5.6	-1.6	-3.8	-6.1	-1.9
	Control Air Flow Rate (scfm)	48.1	0.0	77.3	65.3	50.2	84.3	63.8	14.5	84.3
Film cooler differential pressure ("water)		0.8	0.3	2.1	0.8	0.1	2.5	1.0	0.1	7.0
Transition line differential pressure ("water)		4.1	0	10.1	1.2	0.1	4.1	1.7	0.2	7.7
SBS	Differential Pressure ("water)	44.8	37.9	55.4	38.7	34.0	41.9	38.8	34.8	42.2
	Inlet gas pressure ("water)	-9.3	-12.3	0.3	-5.9	-10.5	-3.6	-6.4	-15.0	-3.4
	Outlet gas pressure ("water)	-54.0	-62.3	-40.7	-44.7	-47.7	-41.5	-45.4	-55.5	-42.6
	Inlet gas Temp. (°C)	285	163	337	251	171	353	264	185	323
	Outlet gas Temp. (°C)	40.1	37.5	42.7	40.1	35.1	51.0	40.7	36.8	47.3
	Chilled Water Inlet Temp (°C)	15.0	9.9	19.5	17.2	13.7	25.3	17.7	14.8	24.7
	Chilled Water Outlet Temp (°C)	19.1	14.6	22.9	23.2	20.2	31.7	22.5	20.2	28.2
	Submerged 48" Temp (°C)	43.8	38.4	50.0	45.7	38.7	58.5	47.5	40.7	60.1
	Submerged 60" Temp (°C)	43.6	38.4	50.0	45.1	38.1	58.5	46.9	40.7	60.1
	Submerged 72" Temp (°C)	46.8	41.4	55.8	48.6	41.6	60.9	50.7	44.2	63.7
	Submerged 78" Temp (°C)	43.9	39.6	51.5	45.3	38.4	57.3	47.1	40.7	60.1
	Recirc. pump discharge Temp (°C)	39.7	37.4	41.7	39.8	34.2	49.0	40.4	37.5	45.4
	Heat Exchanger Outlet Temp (°C)	33.1	30.2	35.7	33.2	25.4	38.3	30.6	27.2	36.0
	Chilled Water Flow (gal/min)	32.9	2.9	34.0	14.8	2.6	31.1	20.3	5.0	35.3
	Heat Exchanger Flow (gal/min)	9.7	3.9	30.1	13.1	4.7	26.4	19.8	6.1	23.8
	Recirc. pump discharge Pressure	NA	NA	NA	31.0	22.7	35.6	30.3	23.6	34.1
	Inner C. Coil W. Inlet Temp (°C)	26.6	24.0	29.6	27.6	21.3	35.3	24.6	21.8	29.1
	Inner C. Coil W. Outlet Temp (°C)	34.1	31.2	36.6	35.2	29.4	43.3	34.3	31.1	40.1
	Inner C. Coil W. Flow (gal/min)	24.4	23.9	24.9	24.1	23.4	24.6	24.1	23.5	24.5
WESP	Differential Pressure ("water)	3.8	1.3	9.3	2.7	2.2	3.2	2.7	1.7	3.2
	Inlet gas Temp. (°C)	39.3	33.2	41.5	39.6	35.7	51.4	40.0	36.9	46.0
	Outlet gas Temp. (°C)	39.2	23.8	41.0	41.9	31.9	49.0	42.4	29.7	46.0
	Wet Gas Flow Rate (scfm)	186.7	180.3	194.6	215.9	204.2	228.4	214.9	153.9	228.3
HEME #1, Outlet Gas Temp. (°C)		38.3	31.1	39.7	40.8	35.7	50.1	40.6	35.4	44.3
HEPA 1	Differential Pressure ("water)	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2
	Outlet Gas Temp. (°C)	61.8	52.8	62.4	62.9	61.9	64.4	63.0	61.5	63.8
TCO/SCR Heater Inlet Gas Temp. (°C)		81.6	76.2	82.6	80.7	80.1	81.6	81.1	80.1	82.2
TCO	Inlet Gas Temp. (°C)	451	301	472	475	462	488	475	459	494
	Differential Pressure ("water)	2.6	2.1	3.5	3.1	2.9	3.3	3.1	2.5	3.3
SCR	Inlet Gas Temp. (°C)	399	319	403	399	395	412	405	396	412
	Outlet Gas Temp. Right (°C)	385	317	389	393	390	402	397	391	404
	Outlet Gas Temp. Left (°C)	365	297	368	375	372	386	378	374	384
	Differential Pressure ("water)	5.4	4.2	7.3	6.3	5.8	6.7	6.3	5.0	6.7
	Post Outlet Gas Temp. (°C)	353	302	357	365	362	373	368	364	374
PBS	Inlet Gas Temp. (°C)	328	301	332	341	339	346	343	340	347
	PBS Sump Temp. (°C)	25.5	22.5	28.0	30.6	28.1	38.1	32.5	30.3	38.7
	Differential Pressure ("water)	2.4	1.3	4.1	3.3	2.6	3.8	3.1	1.9	3.7
HEME #2	Inlet Gas Temp. (°C)	27.8	25.1	30.2	32.8	30.7	40.4	34.5	32.3	40.0
	Outlet Gas Temp. (°C)	29.6	27.3	31.6	34.3	32.8	41.7	35.5	33.5	40.1
Exhaust Stack Absolute Pressure ("water)		-8.7	-8.9	-8.5	-8.7	-8.8	-8.5	-8.6	-8.8	-8.4

NA: Not available due to sensor malfunction.

"-" Empty data field

Table 5.2. Reductant Tests Measured Off-Gas System Parameters (cont.).

Test #		4C			4D			4E		
-		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Detector Port ("water)	-3.7	-6.4	0.1	-3.8	-6.9	-0.9	-3.7	-6.1	-0.4
	Press. at Instrument Port ("water)	-3.8	-6.3	0.0	-3.8	-6.8	-1.1	-3.8	-6.0	-0.5
	Control Air Flow Rate (scfm)	67.7	43.3	81.5	65.3	24.2	84.9	67.8	26.7	83.4
Film cooler differential pressure ("water)		1.0	0.1	7.0	1.1	0.2	4.5	1.1	0.3	3.0
Transition line differential pressure ("water)		1.9	0.0	9.1	2.1	0.2	5.2	2.0	0.0	5.4
SBS	Differential Pressure ("water)	38.8	34.5	42.0	38.6	33.9	42.3	39.0	34.3	42.8
	Inlet gas pressure ("water)	-6.5	-16.3	0.2	-6.9	-13.1	-3.5	-6.7	-11.8	-1.9
	Outlet gas pressure ("water)	-45.7	-57.8	-37.2	-46.1	-52.0	-43.0	-46.3	-52.4	-41.9
	Inlet gas Temp. (°C)	262	170	307	276	187	331	269	171	320
	Outlet gas Temp. (°C)	40.3	35.8	44.5	41.4	37.5	46.8	41.0	35.6	45.5
	Chilled Water Inlet Temp (°C)	17.7	14.0	19.8	18.0	15.1	24.2	17.3	14.2	21.5
	Chilled Water Outlet Temp (°C)	21.3	18.6	23.2	22.3	19.6	27.7	21.2	18.7	24.8
	Submerged 48" Temp (°C)	46.6	39.5	52.0	47.4	39.5	55.2	46.7	38.5	53.0
	Submerged 60" Temp (°C)	46.2	39.1	52.4	47.2	39.7	56.2	46.6	37.5	54.4
	Submerged 72" Temp (°C)	49.8	41.8	58.2	50.6	42.8	59.9	50.1	40.0	60.3
	Submerged 78" Temp (°C)	46.2	39.3	52.1	47.0	39.5	56.2	46.4	38.5	52.6
	Recirc. pump discharge Temp (°C)	40.1	36.3	44.4	41.1	37.3	45.9	40.8	35.8	44.2
	Heat Exchanger Outlet Temp (°C)	30.4	26.6	33.7	29.8	26.8	33.8	29.4	25.8	32.0
	Chilled Water Flow (gal/min)	30.1	4.3	31.3	25.6	2.6	38.8	27.7	3.1	32.3
	Heat Exchanger Flow (gal/min)	19.6	2.8	22.5	22.9	2.6	25.6	22.7	3.3	24.9
	Recirc. pump discharge Pressure	29.3	22.6	31.7	27.5	21.0	30.6	25.3	18.6	27.8
	Inner C. Coil W. Inlet Temp (°C)	24.4	21.9	26.9	23.8	21.5	28.4	23.3	20.9	26.9
	Inner C. Coil W. Outlet Temp (°C)	34.1	30.0	37.8	34.5	31.1	38.2	34.0	29.1	37.4
	Inner C. Coil W. Flow (gal/min)	24.1	23.5	24.5	24.1	23.4	24.6	24.1	23.4	24.7
WESP	Differential Pressure ("water)	2.9	1.5	4.8	2.9	2.3	3.5	3.0	2.3	3.4
	Inlet gas Temp. (°C)	39.6	35.8	43.7	40.7	36.7	45.5	40.3	34.9	44.4
	Outlet gas Temp. (°C)	42.2	14.2	44.4	43.1	31.5	45.6	42.2	31.6	44.6
	Wet Gas Flow Rate (scfm)	218.2	199.2	239.8	218.2	176.4	231.1	218.1	169.0	229.4
HEME #1, Outlet Gas Temp. (°C)		40.1	35.2	42.5	41.1	36.5	44.1	40.7	36.9	42.8
HEPA 1	Differential Pressure ("water)	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2
	Outlet Gas Temp. (°C)	63.1	61.9	63.8	63.2	61.8	64.1	63.0	62.3	63.6
TCO/SCR Heater Inlet Gas Temp. (°C)		81.5	81.0	82.2	81.7	81.0	82.8	81.6	81.0	82.1
TCO	Inlet Gas Temp. (°C)	475	465	489	475	460	495	475	461	497
	Differential Pressure ("water)	3.2	2.5	3.6	3.2	2.9	3.4	3.2	2.9	3.4
SCR	Inlet Gas Temp. (°C)	406	399	410	406	395	412	410	397	421
	Outlet Gas Temp. Right (°C)	398	393	402	398	390	403	402	393	411
	Outlet Gas Temp. Left (°C)	378	376	382	379	373	383	383	376	392
	Differential Pressure ("water)	6.4	4.8	7.4	6.4	5.8	6.9	6.5	5.9	7.0
	Post Outlet Gas Temp. (°C)	368	366	371	369	364	372	373	366	379
PBS	Inlet Gas Temp. (°C)	344	342	346	344	340	347	347	342	352
	PBS Sump Temp. (°C)	33.5	31.4	34.9	34.0	32.2	36.8	34.0	32.7	40.1
	Differential Pressure ("water)	3.2	1.9	3.9	3.3	2.4	3.9	3.2	2.5	3.7
HEME #2	Inlet Gas Temp. (°C)	35.2	33.8	36.4	35.7	34.6	39.1	35.8	34.5	41.6
	Outlet Gas Temp. (°C)	35.9	34.7	36.9	36.3	34.7	39.2	36.2	35.3	41.4
Exhaust Stack Absolute Pressure ("water)		-8.6	-8.8	-8.4	-8.6	-8.8	-8.4	-8.6	-8.8	-8.5

"-" Empty data field

Table 5.3. Time Needed to Restore Power after Deluge of WESP during Tests 5 and 6.

-	DATE	TIME	Time Required to Restore Power (Minutes)
Test 5	5/1/2003	12:10	10
	5/2/2003	12:00	2
	5/3/2003	12:44	16
	5/4/2003	12:32	23
	5/5/2003	12:40	25
	5/6/2003	13:24	6
	5/7/2003	12:30	14
	5/8/2003	12:45	20
	-	Avg.	14.5
Test 6	5/15/2003	12:50	6
	5/16/2003	12:31	13
	5/17/2003	12:43	37+*
	5/18/2003	12:58	14
	5/19/2003	12:51	46
	5/20/2003	13:37	12
	5/21/2003	12:54	21+*
	5/22/2003	13:03	27+*
	-	Avg.	>22*

* - WESP electrical characteristics were problematic and therefore the time required for power stabilization was difficult to determine.

"-" Empty data field

Table 5.4. Time Needed to Restore Power after Deluge of WESP and Duration of Spray Water Flow Interruption during Test 4.

DATE	TIME	Time Required to Restore Power (Minutes)	Duration of Spray Water Flow Interruption (Minutes)
8/20/2003	11:08	1	11
8/21/2003	11:03	2	13
8/22/2003	10:54	2	8
8/23/2003	11:00	2	11
8/24/2003	11:12	2	11
8/25/2003	10:54	2	13
8/26/2003	10:56	2	11
8/27/2003	10:55	2	12
-	Avg.	2	11.3

"-" Empty data field

**Table 5.5. Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR
Catalytic Unit during Test 5.**

Test Segment	Gaseous Species	Conc. at Melter Outlet (ppmv)	Conc. at SBS Outlet (ppmv)	Flux at WESP outlet (mol/hr)	Flux at TCO-SCR outlet (mol/hr)	NO _x , CO, NH ₃ removal* (%)	DF
5A	N ₂ O	1.4	1.8	-	0.020	-	-
	NO	70	99	-	0.437	-	-
	NO ₂	1.4	<1	-	0.553	-	-
	Total NOx	-	-	-	1.010	-	-
	CO	1.4	2.5	-	<0.015	-	-
	CO ₂	6900	7600	-	67.0	-	-
	NH ₃	exhaust	7.8	10	-	-	-
		injected	-	-	1.342	-	-
		Total	-	-	0.066	-	-
5B	N ₂ O	1.1	1.3	0.022	<0.015	-	-
	NO	16	7.0	0.173	0.015	-	-
	NO ₂	<1	<1	<0.014	<0.015	-	-
	Total NOx	-	-	<0.209	<0.044	~78.8	~4.7
	CO	22	23	0.447	<0.015	>96.7	>30.3
	CO ₂	7600	7500	124.1	84.3	-	-
	NH ₃	exhaust	3.8	10	0.036	-	-
		injected	-	-	0.666	-	-
		Total	-	-	0.703	87.4	7.9
5C	N ₂ O	<1	<1	0.015	<0.015	-	-
	NO	<1	5.8	0.086	<0.015	-	-
	NO ₂	<1	<1	<0.015	<0.015	-	-
	Total NOx	-	-	<0.115	<0.045	~61.1	~2.6
	CO	45	85	1.228	0.064	94.8	19.1
	CO ₂	5900	7300	112.6	58.4	-	-
	NH ₃	exhaust	3.3	5.0	0.026	-	-
		injected	-	-	0.666	-	-
		Total	-	-	0.693	91.6	11.9
5D	N ₂ O	<1.0	<1.0	<0.015	<0.015	-	-
	NO	1.0	<2.9	0.038	<0.015	-	-
	NO ₂	<1.0	<1.0	<0.015	<0.018	-	-
	Total NOx	-	-	<0.067	<0.047	~29.1	1.4
	CO	100	230	1.599	0.099	93.8	16.1
	CO ₂	5400	7000	100.3	45.9	-	-
	NH ₃	exhaust	<1.0	2.4	0.031	-	-
		injected	-	-	0.000	-	-
		Total	-	-	0.031	0.089	-
5E	N ₂ O	<1.0	<1.0	<0.014	<0.014	-	-
	NO	<1.0	2.9	0.045	0.033	-	-
	NO ₂	<1.0	<1.0	<0.014	<0.014	-	-
	Total NOx	-	-	<0.073	<0.062	~15.7	~1.2
	CO	120	220	3.804	0.345	90.9	11.0
	CO ₂	4700	6600	107.1	57.5	-	-
	NH ₃	exhaust	1.0	1.2	0.015	-	-
		injected	-	-	0.000	-	-
		Total	-	-	0.015	7.3	1.1

"-" Empty data field

Table 5.6. Gas Residence Times in TCO.

Test Segment	Residence Time (seconds)
5A	0.21
5B	0.21
5C	0.20
5D	0.21
5E	0.21
6A	0.21
6B	0.20
6C	0.20
6D	0.23
6E	0.23
4A	0.19
4B	0.20
4C	0.19
4D	0.19
4E	0.19

**Table 5.7. Nitrogen Oxides and Carbon Monoxide Destruction
across TCO-SCR Catalytic Unit during Test 6.**

Test Segment	Gaseous Species	Conc. at Melter Outlet (ppmv)	Conc. at SBS Outlet (ppmv)	Flux at WESP outlet (mol/hr)	Flux at TCO-SCR outlet (mol/hr)	NO _x , CO, NH ₃ removal (%)	DF
6A	N ₂ O	2.7	2.7	0.042	0.026	-	-
	NO	730	630	8.028	3.049	-	-
	NO ₂	72.0	100.0	1.831	2.178	-	-
	Total NO _x	-	-	9.901	5.253	46.9	1.9
	CO	1.6	1.9	0.021	0.015	31.3	1.5
	CO ₂	5800	4900	69.0	42.1	-	-
	NH ₃	exhaust	<1.0	<0.014	-	-	-
		injected	-	2.133	-	-	-
		Total	-	<2.147	<0.015	~99.3	~147.9
6B	N ₂ O	29	33	0.277	0.287	-	-
	NO	320	340	3.348	0.755	-	-
	NO ₂	6.4	14	0.218	1.224	-	-
	Total NO _x	-	-	3.843	2.266	41.0	1.7
	CO	18	19	0.160	0.015	90.6	10.6
	CO ₂	8200	8100	74.2	72.5	-	-
	NH ₃	exhaust	<1.0	<0.015	-	-	-
		injected	-	2.434	-	-	-
		Total	-	<2.449	<0.015	~99.4	~162.1
6E	N ₂ O	8.3	-	-	-	-	-
	NO	53	-	-	-	-	-
	NO ₂	1.3	-	-	-	-	-
	Total NO _x	-	-	-	-	-	-
	CO	120	-	-	-	-	-
	CO ₂	6700	-	-	-	-	-
	NH ₃	exhaust	130	-	-	-	-
		injected	-	0.000	-	-	-
		Total	-	-	-	-	-

"-" Empty data field

**Table 5.8. Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR
Catalytic Unit during Test 4.**

Test Segment	Gaseous Species	Conc. at Melter Outlet (ppmv)	Conc. at SBS Outlet (ppmv)	Flux at WESP outlet (mol/hr)	Flux at TCO-SCR outlet (mol/hr)	NO _x , CO, NH ₃ removal (%)	DF
4A	N ₂ O	1.1	-	-	0.030	-	-
	NO	106	-	-	0.124	-	-
	NO ₂	6.6	-	-	0.377	-	-
	Total NO _x	-	-	-	0.531	-	-
	CO	2.0	-	-	<0.016	-	-
	CO ₂	5600	-	-	34.6	-	-
	NH ₃	exhaust	<1.0	-	<0.016	-	-
		injected	-	1.866	-	-	-
		Total	-	-	-	-	-
4B	N ₂ O	5.4	9.2	0.166	0.124	-	-
	NO	<1.0	<1.0	<0.015	<0.016	-	-
	NO ₂	6.0	17	0.333	0.016	-	-
	Total NO _x	-	-	<0.514	<0.155	~69.8	~3.3
	CO	38	87	1.875	<0.016	>99.2	>120.7
	CO ₂	7600	4700	83.2	76.1	-	-
	NH ₃	exhaust	32	0.076	-	-	-
		injected	-	1.233	-	-	-
		Total	-	1.309	0.202	84.6	6.5
4C	N ₂ O	6.6	7.3	0.123	0.103	-	-
	NO	<1.0	1.8	<0.015	<0.016	-	-
	NO ₂	10	8.4	0.144	<0.016	-	-
	Total NO _x	-	-	<0.282	<0.134	~52.5	~2.1
	CO	56	57	0.890	<0.016	>98.2	>56.4
	CO ₂	7100	4500	72.2	58.4	-	-
	NH ₃	exhaust	30	0.184	-	-	-
		injected	-	1.066	-	-	-
		Total	-	1.251	0.076	93.9	16.5
4D	N ₂ O	7.6	11	0.143	0.102	-	-
	NO	<1.0	<1.0	<0.015	<0.016	-	-
	NO ₂	14	18	0.230	<0.016	-	-
	Total NO _x	-	-	<0.388	<0.133	~65.7	~2.9
	CO	119	114	1.520	<0.016	>99.0	>95.8
	CO ₂	7900	5300	86.0	58.7	-	-
	NH ₃	exhaust	33	0.147	-	-	-
		injected	-	1.066	-	-	-
		Total	-	1.214	0.044	96.3	27.3
4E	N ₂ O	6.9	5.8	0.094	0.088	-	-
	NO	<1.0	<1.0	<0.015	<0.016	-	-
	NO ₂	14	11	0.169	<0.016	-	-
	Total NO _x	-	-	<0.278	<0.120	~56.8	~2.3
	CO	201	242	3.162	<0.016	>99.5	>200.3
	CO ₂	7200	6000	87.5	69.5	-	-
	NH ₃	exhaust	34	0.261	-	-	-
		injected	-	1.116	-	-	-
		Total	-	1.377	0.049	96.4	28.1

"-" Empty data field

Table 5.9. Listing of Samples from SBS Blow-Downs.

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 5 (C-106/AY-102)	A (0 g/l sugar)	4/30/2003	R12-S-135A	7.31	40.11	40.11
			R12-S-137A	7.33	40.16	80.27
			R12-S-142A	7.41	39.80	120.07
			R12-S-147A	7.25	40.00	160.07
		5/1/2003	S12-S-6A	7.17	40.00	200.07
			S12-S-8A	7.04	40.02	240.09
			S12-S-10A	6.97	40.11	280.20
			S12-S-12A	6.91	40.07	320.27
			S12-S-17A	6.92	40.02	360.29
			S12-S-19A	6.84	40.00	400.29
			S12-S-28A	6.9	40.01	440.30
			S12-S-30A	7.25	41.83	482.13
			S12-S-32A	7.43	40.29	522.42
			S12-S-34A	7.50	40.26	562.68
	B (10 g/l sugar)	5/2/2003	S12-S-37A	7.56	40.32	603.00
			S12-S-46A	7.57	40.02	643.02
			S12-S-49A	7.58	40.10	683.12
			S12-S-51A	7.61	40.09	723.21
			S12-S-54A	7.59	40.04	763.25
			S12-S-58A	7.6	40.01	803.26
			S12-S-71A	7.65	39.79	843.05
			S12-S-75A	7.65	40.15	883.20
		5/3/2003	S12-S-88A	7.72	40.16	923.36
			S12-S-92A	7.68	40.02	963.38
			S12-S-96A	7.57	40.01	1003.39
			S12-S-109A	7.52	40.00	1043.39
			S12-S-112A	7.42	40.02	1083.41
			S12-S-117A	7.28	40.02	1123.43
	C (15 g/l sugar)	5/4/2003	S12-S-128A	6.97	39.90	1163.33
			S12-S-131A	6.77	40.04	1203.37
			S12-S-133A	6.72	40.00	1243.37
			S12-S-137A	6.77	40.01	1283.38
			S12-S-147A	6.64	40.00	1323.38
			S12-S-151A	6.52	40.05	1363.43
			S12-S-154A	6.25	39.56	1402.99
			T12-S-17A	6.22	40.08	1443.07
		5/5/2003	T12-S-22A	6.80	39.98	1483.05
			T12-S-23A	6.76	40.40	1523.45
			T12-S-27A	6.71	39.99	1563.44
			T12-S-30A	6.58	40.01	1603.45

Table 5.9. Listing of Samples from SBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 5 (C-106/AY-102)	D (17.5-20 g/l sugar)	5/5/2003	T12-S-40A	6.45	36.54	1639.99
			T12-S-43A	6.62	40.07	1680.06
			T12-S-48A	6.85	40.09	1720.15
		5/6/2003	T12-S-50A	6.93	40.10	1760.25
			T12-S-61A	6.96	40.03	1800.28
			T12-S-65A	7.19	40.06	1840.34
			T12-S-81A	6.57	40.05	1880.39
			T12-S-87A	6.67	40.20	1920.59
			T12-S-98A	6.75	40.20	1960.79
		5/7/2003	T12-S-103A	6.73	40.46	2001.25
			T12-S-107A	6.92	40.25	2041.50
			T12-S-120A	6.77	40.00	2081.50
	T12-S-123A		6.21	40.01	2121.51	
	T12-S-128A		6.08	40.57	2162.08	
	T12-S-140A		6.54	40.13	2202.21	
	E (25 g/l sugar)	5/8/2003	T12-S-142A	6.64	40.00	2242.21
			T12-S-147A	6.75	40.06	2282.27
			U12-S-11A	7.02	40.03	2322.30
			U12-S-15A	7.07	40.12	2362.42
		5/9/2003	U12-S-27A	8.65	40.00	2402.42
			U12-S-30A	7.13	40.00	2442.42
			U12-S-36A	7.06	40.00	2482.42
			U12-S-46A	6.96	40.01	2522.43
	5/13/2003	U12-S-62A	4.74	343.72	2866.15	
Test 6 (C-106/AY-102 Added Nitrate)	A (0 g/l sugar)	5/14/2003	U12-S-88A	7.11	40.01	40.01
			U12-S-91A	7.50	40.02	80.03
			U12-S-94A	7.22	40.17	120.20
			U12-S-99A	7.14	40.03	160.23
		5/15/2003	U12-S-109A	6.68	40.08	200.31
			U12-S-111A	6.27	40.00	240.31
			U12-S-114A	5.92	40.00	280.31
			U12-S-118A	5.91	40.06	320.37
			U12-S-127A	5.73	40.02	360.39
			U12-S-135A	6.99	40.00	400.39
	B (10 g/l sugar)	5/16/2003	U12-S-146A	7.34	40.08	440.47
			U12-S-148A	7.48	40.01	480.48
			U12-S-152A	7.67	40.00	520.48
			U12-S-155A	7.71	40.00	560.48
			V12-S-16A	7.97	40.01	600.49
			V12-S-19A	7.93	39.99	640.48
			V12-S-20A	7.98	39.53	680.01
			V12-S-22A	8.00	40.05	720.06
			V12-S-24A	7.39	40.75	760.81

Table 5.9. Listing of Samples from SBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 6 (C-106/AY-102 Added Nitrate)	B (10 g/l sugar)	5/17/2003	V12-S-34A	7.32	39.33	800.14
			V12-S-36A	7.24	40.08	840.22
			V12-S-37A	7.23	40.05	880.27
			V12-S-39A	7.88	40.01	920.28
			V12-S-43A	7.91	40.00	960.28
			V12-S-44A	7.94	40.01	1000.29
			V12-S-54A	7.93	40.00	1040.29
			V12-S-58A	7.97	40.00	1080.29
			V12-S-61A	8.03	40.02	1120.31
			V12-S-63A	8.10	40.69	1161.00
	C (15 g/l sugar)	5/18/2003	V12-S-72A	8.07	40.01	1201.01
			V12-S-73A	8.09	40.11	1241.12
			V12-S-76A	8.12	40.02	1281.14
			V12-S-80A	8.08	40.20	1321.34
			V12-S-82A	7.91	40.00	1361.34
			V12-S-93A	7.87	40.00	1401.34
			V12-S-94A	8.12	40.00	1441.34
			V12-S-95A	8.13	40.00	1481.34
			V12-S-98A	8.18	40.00	1521.34
			V12-S-100A	8.15	40.04	1561.38
		5/19/2003	V12-S-110A	8.17	40.00	1601.38
			V12-S-112A	8.15	40.10	1641.48
			V12-S-115	8.19	40.00	1681.48
			V12-S-117A	8.18	40.00	1721.48
			V12-S-119A	8.14	40.00	1761.48
			V12-S-130A	8.14	37.50	1798.98
			V12-S-131A	8.17	40.00	1838.98
			V12-S-134A	8.14	40.10	1879.08
	D (20 g/l sugar)	5/20/2003	V12-S-138A	8.01	39.80	1918.88
			V12-S-147A	8.09	40.00	1958.88
			V12-S-149A	8.13	40.00	1998.88
			V12-S-151A	8.18	40.00	2038.88
			V12-S-153A	8.20	40.00	2078.88
			W12-S-16A	8.16	40.00	2118.88
			W12-S-18A	8.13	40.00	2158.88
			W12-S-21A	8.20	40.00	2198.88
			W12-S-22A	8.15	39.90	2238.78
			W12-S-24A	8.19	40.00	2278.78
		5/21/2003	W12-S-26A	8.30	40.00	2318.78
			W12-S-35A	8.21	40.50	2359.28
			W12-S-38A	8.15	40.10	2399.38
			W12-S-42A	8.12	39.90	2439.28

Table 5.9. Listing of Samples from SBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 6 (C-106/AY-102 Added Nitrate)	D (20 g/l sugar)	5/21/2003	W12-S-43A	8.21	40.00	2479.28
			W12-S-45A	8.17	40.00	2519.28
			W12-S-54A	NA	39.50	2558.78
	E (25 g/l sugar)	5/21/2003	W12-S-57A	8.17	40.00	2598.78
			W12-S-60A	8.17	40.00	2638.78
			W12-S-64A	8.28	40.10	2678.88
		5/22/2003	W12-S-72A	8.32	40.00	2718.88
			W12-S-75A	8.31	40.00	2758.88
			W12-S-76A	8.22	40.10	2798.98
			W12-S-78A	8.33	40.00	2838.98
			W12-S-78A	8.33	40.20	2879.18
			W12-S-92A	8.38	40.00	2919.18
			W12-S-94A	8.43	40.00	2959.18
			W12-S-95A	8.45	40.00	2999.18
			W12-S-98A	8.33	40.00	3039.18
		5/23/2003	W12-S-108A	8.37	40.10	3079.28
			W12-S-112A	NA	40.00	3119.28
			W12-S-119A	8.15	40.00	3159.28
			W12-S-121A	8.41	40.10	3199.38
			W12-S-124A	8.44	39.80	3239.18
			W12-S-133A	8.46	40.00	3279.18
			W12-S-136A	8.12	40.00	3319.18
		No sample	NA	351.00	3670.18	
		5/24/2003	No sample	NA	26.00	3696.18
Test 4 (AZ-101)	4A (0 g/l sugar)	8/19/2003	1F2-S-144A	8.43	40.00	40.00
			1F2-S-147A	8.25	40.00	80.00
			1F2-S-150A	8.19	40.00	120.00
		8/20/2003	1F2-S-153A	8.30	40.10	160.10
			1G2-S-12A	8.32	40.10	200.20
			1G2-S-16A	8.33	40.00	240.20
			1G2-S-18A	8.31	39.10	279.30
			1G2-S-19A	8.30	40.00	319.30
			1G2-S-21A	8.30	40.00	359.30
	1G2-S-22A		8.28	40.00	399.30	
	B (13.3-7.6 g/l, Ru/Y spike)	8/21/2003	1G2-S-40A	8.24	40.00	439.30
			1G2-S-42A	8.19	40.00	479.30
			1G2-S-44A	8.27	40.00	519.30
			1G2-S-46A	8.19	40.00	559.30
			1G2-S-47A	8.12	40.00	599.30
			1G2-S-51A	8.16	39.90	639.20
	1G2-S-52A		8.32	40.10	679.30	
	1G2-S-57A		8.22	39.90	719.20	

NA – Not analyzed

Table 5.9. Listing of Samples from SBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 4 (AZ-101)	B (13.3-7.6 g/l Sugar, Ru/Y spike)	8/21/2003	1G2-S-58A	8.28	40.00	759.20
			1G2-S-60A	8.21	40.00	799.20
			1G2-S-62A	8.21	40.00	839.20
			1G2-S-79A	8.18	40.00	879.20
			1G2-S-80A	8.22	40.00	919.20
		8/22/2003	1G2-S-82A	8.22	40.10	959.30
			1G2-S-86A	8.25	40.00	999.30
			1G2-S-87A	8.21	40.50	1039.80
			1G2-S-90A	8.26	40.00	1079.80
			1G2-S-91A	8.25	39.90	1119.70
			1G2-S-100A	8.20	40.00	1159.70
			1G2-S-103A	8.22	40.00	1199.70
			1G2-S-105A	8.35	39.90	1239.60
			1G2-S-108A	8.28	40.10	1279.70
			1G2-S-117A	8.28	40.00	1319.70
	1G2-S--121A	8.23	40.00	1359.70		
	8/23/2003	1G2-S-123A	8.21	40.00	1399.70	
		1G2-S-124A	8.28	40.70	1440.40	
		1G2-S-125A	8.28	40.10	1480.50	
		1G2-S-128A	8.12	40.00	1520.50	
		1G2-S-137A	8.22	39.90	1560.40	
		1G2-S-140A	8.21	40.00	1600.40	
		1G2-S-144A	8.23	39.20	1639.60	
		1G2-S-145A	8.22	40.00	1679.60	
		1G2-S-149A	8.19	40.00	1719.60	
		1G2-S-150A	8.14	40.00	1759.60	
		1G2-S-152A	8.21	40.00	1799.60	
		1G2-S-154A	8.15	40.00	1839.60	
		8/24/2003	1G2-S-155A	8.21	40.10	1879.70
			1H2-S-9A	8.18	40.10	1919.80
			1H2-S-11A	8.14	40.00	1959.80
	1H2-S-12A		8.17	40.00	1999.80	
	1H2-S-27A		8.14	40.00	2039.80	
	1H2-S-30A		8.06	40.00	2079.80	
	1H2-S-32A		8.12	40.00	2119.80	
	1H2-S-37A		8.11	39.90	2159.70	
	1H2-S-38A		8.00	40.00	2199.70	
	1H2-S-39A		8.14	40.00	2239.70	
	1H2-S-48A		8.12	40.00	2279.70	
	1H2-S-51A		8.06	40.40	2320.10	
1H2-S-54A	8.10		39.70	2359.80		
1H2-S-56A	8.00		40.00	2399.80		
D (12.5 g/l sugar, Ru/Y spike)						

Table 5.9. Listing of Samples from SBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 4 (AZ-101)	D (12.5 g/l Sugar, Ru/Y spike)	8/25/2003	1H2-S-57A	8.00	40.10	2439.90
			1H2-S-59A	8.01	40.00	2479.90
			1H2-S-62A	8.05	40.00	2519.90
			1H2-S-64A	8.07	40.00	2559.90
			1H2-S-65A	8.10	40.00	2599.90
			1H2-S-70A	8.00	39.80	2639.70
			1H2-S-72A	8.17	40.00	2679.70
			1H2-S-74A	8.11	40.00	2719.70
			1H2-S-91A	8.09	40.00	2759.70
			1H2-S-92A	8.15	40.00	2799.70
		8/26/2003	1H2-S-95A	8.10	40.10	2839.80
			1H2-S-97A	8.13	40.20	2880.00
			1H2-S-99A	8.12	40.00	2920.00
			1H2-S-100A	8.05	40.00	2960.00
			1H2-S-103A	8.09	40.00	3000.00
			1H2-S-105A	8.00	40.00	3040.00
			1H2-S-106A	8.08	40.50	3080.50
			1H2-S-110A	8.19	39.60	3120.10
			1H2-S-119A	8.12	40.00	3160.10
			1H2-S-120A	8.06	40.00	3200.10
			1H2-S-128A	8.11	39.60	3239.70
			1H2-S-131A	8.12	40.00	3279.70
		8/27/2003	1H2-S-133A	8.10	40.20	3319.90
			1H2-S-135A	8.08	40.00	3359.90
			1H2-S-137A	8.11	40.10	3400.00
			1H2-S-138A	8.00	40.00	3440.00
	E (16 g/l Sugar, Ru/Y spike)	8/27/2003	1H2-S-142A	8.15	40.00	3480.00
			1H2-S-144A	8.17	40.00	3520.00
			1H2-S-146A	8.10	40.00	3560.00
			1H2-S-148A	8.08	40.00	3600.00
			1I2-S-9A	8.13	40.00	3640.00
			1I2-S-10A	8.11	40.00	3680.00
			1I2-S-18A	8.10	40.00	3720.00
			1I2-S-19A	8.16	39.30	3759.30
		8/28/2003	1I2-S-21A	8.15	40.00	3799.30
			1I2-S-23A	8.12	40.30	3839.60
			1I2-S-26A	8.08	39.80	3879.40
			1I2-S-27A	8.11	40.00	3919.40
			1I2-S-36A	8.14	39.90	3959.30
			1I2-S-37A	8.15	40.00	3999.30
			1I2-S-38A	8.13	40.00	4039.30
			1I2-S-42A	8.10	40.00	4079.30
			1I2-S-47A	8.16	38.70	4118.00

Table 5.10. Analytical Results for Selected SBS Blow-Down Fluids (mg/l).

Test	5 (C-106/AY-102)			6 (C-106/AY-102 with added nitrate)			4 (AZ-101)		
Sample ID	U12-S-46A			W12-S-136A			112-S-47A		
Glass (kg)	8405			10612			8956		
pH	6.96			8.12			8.16		
-	Sus*	Dis.#	Total	Sus*	Dis.#	Total	Sus*	Dis.#	Total
Total	3216	4972	8188	2780	4420	7200	428	2360	2788
Al	96.70	0.45	97.15	59.39	0.17	59.56	11.42	0.12	11.54
As	76.16	47.81	123.97	76.31	110.67	186.98	0.13	<0.2	0.13
B	12.41	321.69	334.10	22.16	367.58	389.74	5.18	331.34	336.52
Ba	0.48	0.01	0.49	0.41	0.01	0.42	0.08	0.01	0.09
Ca	11.18	6.13	17.31	10.85	7.73	18.58	1.80	3.72	5.52
Cd	5.33	0.06	5.39	0.43	<0.03	0.43	22.41	0.24	22.65
Cr	0.16	0.03	0.19	0.60	0.06	0.66	0.06	0.04	0.10
Cs	3.94	7.73	11.67	1.74	9.87	11.61	<0.1	0.24	0.24
Cu	1.55	<0.02	1.55	1.35	0.33	1.68	0.14	<0.02	0.14
Fe	468.84	0.80	469.64	423.78	10.15	433.93	71.29	<0.05	71.29
K	1.15	2.91	4.06	0.96	2.55	3.51	0.23	3.09	3.32
Li	4.97	58.49	63.46	6.78	60.49	67.27	0.90	32.62	33.52
Mg	14.20	37.20	51.40	17.53	28.37	45.90	0.68	2.55	3.23
Mn	29.18	2.07	31.25	24.87	0.45	25.32	0.22	<0.04	0.22
Na	33.77	644.30	678.07	46.35	480.53	526.88	8.58	376.92	385.50
Ni	5.48	0.13	5.61	6.56	0.59	7.15	1.83	0.10	1.93
P	2.31	<0.06	2.31	1.51	0.92	2.43	0.11	<0.06	0.11
Pb	27.07	0.69	27.76	32.15	1.36	33.51	0.46	0.52	0.98
Sb	14.41	5.89	20.30	13.50	7.26	20.76	0.07	<0.05	0.07
Se	233.58	1497.30	1730.88	98.44	1237.40	1335.84	0.36	1.56	1.92
Si	475.18	28.77	503.95	416.81	19.38	436.19	56.63	5.80	62.43
Sr	32.97	12.27	45.24	27.59	11.19	38.78	0.19	0.22	0.41
Ti	7.90	<0.02	7.90	6.82	0.04	6.86	0.47	<0.02	0.47
Zn	81.41	2.57	83.98	71.71	7.05	78.76	12.83	0.06	12.89
Zr	7.78	<0.02	7.78	5.43	0.05	5.48	4.65	<0.02	4.65
F	NA	26.60	26.60	NA	20.01	20.01	NA	132.23	132.23
Cl	NA	434.18	434.18	NA	346.93	346.93	NA	125.74	125.74
I	NA	670.68	670.68	NA	<0.1	<0.1	NA	<0.1	<0.1
NH ₄ ⁺	NA	102.50	102.50	NA	615.70	615.70	NA	114.60	114.60
Nitrate	NA	0.98	0.98	NA	14.97	14.97	NA	18.67	18.67
Nitrite	NA	<0.1	<0.1	NA	7.34	7.34	NA	48.22	48.22
Sulfate	NA	447.34	447.34	NA	417.92	417.92	NA	378.01	378.01

"-" Empty data field

NA – Not analyzed

Table 5.11. Anion Concentrations in SBS Blow-Down Liquids (mg/l).

Test	Segment	ID	Glass (kg)	pH	TSS	TDS	F	Cl	I	NH ₄ ⁺	Nitrate	Nitrite	Sulfate
5 (C-106/AY-101)	B	S12-S-96A	3060	7.57	2712	4304	41.50	368.56	496.75	61.40	14.96	0.64	433.03
	C	T12-S-30A	5113	6.58	2048	4076	26.82	419.76	555.34	98.20	5.81	0.49	423.32
	D	T12-S-120A	6833	6.77	2636	4404	23.76	400.23	585.34	86.40	1.77	<0.1	407.37
	E	U12-S-46A	8405	6.96	3216	4972	26.60	434.18	670.68	102.50	0.98	<0.1	447.34
6 (C-106/AY-102 with added Nitrate)	B	V12-S-44A	3121	7.94	2396	4148	21.44	338.18	13.60	116.50	14.93	120.79	182.48
	C	V12-S-130A	5653	8.14	2988	4040	5.54	278.68	3.51	251.20	15.06	31.12	262.20
	D	W12-S-54A	8072	8.12	3092	4068	20.97	423.79	2.16	476.60	19.59	15.25	387.62
	E	W12-S-136A	10546	8.12	2780	4420	20.01	346.93	<0.1	615.70	14.07	7.34	417.92
4 (AZ-101)	B	1G2-S-103A	2601	8.22	2024	2548	101.21	111.79	<0.1	84.90	23.33	37.70	408.54
	C	1H2-S-32A	4604	8.12	1816	2292	99.90	101.01	<0.1	88.50	21.50	37.44	326.47
	D	1H2-S-106A	6694	8.08	2132	2548	99.93	105.34	<0.1	109.1	73.69	90.97	315.12
	E	1I2-S-47A	8956	8.16	428	2360	132.23	125.74	<0.1	114.6	18.67	48.22	378.01

Table 5.12. Listing of Samples from WESP Blow-Downs.

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. per Test (gal)
Test 5 (C-106/AY-102)	A	05/01/03	S12-W-18A	4.06	63.88	63.88
			S12-W-18B	3.18	40.56	104.44
	B	05/02/03	S12-W-56A	6.36	56.42	160.86
			S12-W-56B	7.04	39.98	200.84
		05/03/03	S12-W-97A	6.82	63.17	264.01
			S12-W-97B	7.05	45.06	309.07
	C	05/04/03	S12-W-146A	6.65	61.80	370.87
			S12-W-146B	7.10	40.67	411.54
		5/5/2003	T12-W-37A	6.19	58.92	470.46
			T12-W-37B	7.07	41.26	511.72
	D	5/6/2003	T12-W-79A	5.67	61.79	573.51
			T12-W-79B	3.83	41.43	614.94
		5/7/2003	T12-W-109A	6.53	56.67	671.61
			T12-W-109B	7.08	40.55	712.16
	E	5/8/2003	T12-W-148A	5.88	61.07	773.23
			T12-W-148B	7.21	42.28	815.51
		5/10/2003	U12-W-60A	3.29	38.44	853.95
			U12-W-60B	3.23	62.74	916.69
		5/13/2003	U12-W-62A	4.13	44.61	961.30
Test 6 (C-106/AY-102 Added Nitrate)	A	5/15/2003	U12-W-118A	2.83	52.60	52.60
			U12-W-118B	3.07	41.51	94.11
	B	5/16/2003	V12-W-8A	3.68	58.35	152.46
			V12-W-8B	6.79	47.06	199.52
		5/17/2003	V12-W-44A	7.03	60.13	259.65
			V12-W-44B	7.23	41.17	300.82
	C	5/18/2003	V12-W-82A	7.15	63.70	364.52
			V12-W-82B	7.17	44.10	408.62
		5/19/2003	V12-W-119A	7.56	67.30	475.92
			V12-W-119B	7.68	43.90	519.82
	D	5/20/2003	W12-W-16A	7.48	64.70	584.52
			W12-W-16B	7.64	41.30	625.82
		5/21/2003	W12-W-44A	7.61	63.00	688.82
			W12-W-44B	7.56	37.80	726.62
	E	5/22/2003	W12-W-91A	7.81	64.50	791.12
			W12-W-91B	7.90	40.40	831.52
		5/23/2003	W12-W-133A	8.12	61.90	893.42
			W12-W-142A	7.74	29.29	922.71
		5/24/2003	W12-W-142B	7.54	40.70	963.41

Table 5.12. Listing of Samples from WESP Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. (gal)
4 (AZ-101)	A	8/20/2003	1G2-W-19A	7.92	61.90	61.90
			1G2-W-19B	7.61	38.70	100.60
	B	8/21/2003	1G2-W-54A	7.91	57.80	158.40
			1G2-W-54B	7.78	39.10	197.50
		8/22/2003	1G2-W-101A	8.05	56.90	254.40
			1G2-W-101B	7.83	39.50	293.90
	C	8/23/2003	1G2-W-140A	8.21	54.90	348.80
			1G2-W-140B	7.92	40.80	389.60
		8/24/2003	1H2-W-30A	8.11	55.60	445.20
			1H2-W-31A	7.87	40.40	485.60
	D	8/25/2003	1H2-W-62A	8.09	56.60	542.20
			1H2-W-62B	7.86	39.40	581.60
		8/26/2003	1H2-W-103A	7.89	57.60	639.20
			1H2-W-103B	7.86	39.10	678.30
	E	8/27/2003	1H2-W-144A	7.81	56.70	735.00
			1H2-W-145A	7.73	40.10	775.10
		8/28/2003	1I2-W-47A	7.81	99.30	874.40
		8/29/2003	1I2-W-47B	7.80	42.20	916.60

Table 5.13. Listing of Samples from PBS Blow-Downs.

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. (gal)	
5 (C-106/AY-102)	A	04/30/03	R12-P-141A	8.70	40.16	40.16	
		5/1/2003	S12-P-9A	8.78	38.70	78.86	
	B		S12-P-30A	8.60	28.18	107.04	
		5/2/2003	S12-P-49A	8.60	31.02	138.06	
			S12-P-70A	8.51	24.93	162.99	
			S12-P-90A	8.62	41.11	204.10	
	C	5/3/2003	S12-P-109A	8.60	16.46	220.56	
			S12-P-117A	8.53	27.85	248.41	
		5/4/2003	S12-P-131A	8.70	26.62	275.03	
			S12-P-151A	8.54	22.10	297.13	
			T12-P-17A	8.92	29.43	326.56	
		D	5/5/2003	T12-P-39A	8.63	34.75	361.31
	5/6/2003		T12-P-48A	8.57	23.66	384.97	
			T12-P-64A	8.53	26.03	411.00	
			T12-P-82A	8.59	19.59	430.59	
	E		5/7/2003	T12-P-99A	8.62	35.10	465.69
				T12-P-120A	8.60	29.62	495.31
		5/8/2003	T12-P-130A	8.82	39.14	534.45	
			U12-P-11A	8.68	29.25	563.70	
		5/9/2003	U12-P-27A	7.17	35.29	598.99	
	U12-P-47A		8.46	19.69	618.68		
	U12-P-48A		8.93	24.56	643.24		
6 (C-106/AY-102 Added Nitrate)	A		5/14/2003	U12-P-88A	9.07	36.21	36.21
		5/15/2003	U12-P-99A	8.42	28.72	64.93	
	B		U12-P-126A	8.52	30.00	94.93	
		U12-P-134A	10.00	24.69	119.62		
		5/16/2003	U12-P-146A	9.11	9.69	129.31	
			U12-P-153A	9.04	18.29	147.60	
	V12-P-23A		9.01	26.95	174.55		
	C	5/17/2003	V12-P-39A	8.77	31.39	205.94	
			V12-P-59A	9.29	26.64	232.58	
		5/18/2003	V12-P-76A	9.22	25.94	258.52	
			V12-P-97A	9.65	33.29	291.81	
		5/19/2003	V12-P-115A	9.63	26.80	318.61	
			V12-P-130A	12.65	9.90	328.51	
	D		5/20/2003	V12-P-134A	10.36	33.00	361.51
		V12-P-151A		9.21	25.50	387.01	
		5/21/2003	W12-P-21A	9.13	24.30	411.31	
			W12-P-26A	9.90	36.00	447.31	
			W12-P-45A	9.06	23.30	470.61	
		E	5/22/2003	W12-P-73A	9.36	33.20	503.81
	W12-P-94A			9.21	28.00	531.81	
	5/23/2003		W12-P-119A	9.19	38.10	569.91	
	5/24/2003		W12-P-142A	9.34	48.40	618.31	

Table 5.13. Listing of Samples from PBS Blow-Downs (continued).

Test	Segment	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. (gal)
4 (AZ101)	A	8/19/2003	1F2-P-152A	9.30	28.10	28.10
	B	8/20/2003	1G2-P-22A	9.17	24.80	52.90
		8/21/2003	1G2-P-49A	9.22	24.40	77.30
		8/22/2003	1G2-P-83A	9.04	26.80	104.10
	C	8/22/2003	1G2-P-121A	9.10	26.40	130.50
		8/23/2003	1G2-P-154A	9.04	25.00	155.50
	D	8/24/2003	1H2-P-48A	9.16	26.90	182.40
		8/25/2003	1H2-P-66A	9.11	16.30	198.70
	E	8/26/2003	1H2-P-99A	9.10	25.30	224.00
		8/27/2003	1H2-P-135A	9.16	31.30	255.30
		8/28/2003	1I2-P-23A	9.17	26.10	281.40
		8/29/2003	1I2-P-47A	9.20	33.20	314.60

Table 5.14. Listing of Samples from HEME 1 Blow-Downs.

Test	Date	Name	pH	BLD Vol. (gal)	Cumulative BLD Vol. (gal)
5 (C-106/AY-102)	5/10/2003	U12-H1-62A	2.21	22.59	30.90
6 (C-106/AY-102 with added Nitrate)	5/23/2003	W12-H1-142A	8.10	45.80	45.80
4 (AZ-101)	8/29/2003	1I2-H1-47A	8.25	38.30	38.30

Table 5.15. Analytical Results for Dissolved Solids in Select WESP Blow-Down Fluids (mg/l).

Waste Type	C-106/AY-102				AZ-101	
Test	5		6		4	
Sample I.D.	U12-W-60B	U12-W-62A	W12-W-142A	W12-W-142B	1I2-W-47A	1I2-W-47B
Glass (kg)	8669	8669	10612	10612	8956	8956
TSS (mg/l)	<1	12	10	106	<1	56
TDS (mg/l)	2782	674	4748	360	500	248
pH	3.23	4.10	7.74	7.54	7.81	7.80
Al	0.49	0.58	0.13	0.04	0.06	0.08
As	81.47	9.01	147.97	6.24	<0.2	0.22
B	40.70	4.77	74.11	3.09	43.48	7.86
Ba	0.05	0.06	0.03	0.02	0.04	0.03
Ca	38.72	37.48	22.48	29.81	29.93	33.13
Cd	5.60	11.89	0.19	0.04	0.11	2.43
Cr	0.02	0.04	0.06	<0.01	0.04	<0.01
Cs	12.55	3.63	13.67	1.08	0.28	0.08
Cu	0.63	0.49	0.66	<0.02	0.07	0.05
Fe	<0.05	<0.05	0.19	<0.05	<0.05	0.3
K	3.92	3.28	4.19	2.58	5.97	3.83
Li	10.76	2.66	13.61	0.73	8.65	1.97
Mg	8.25	6.33	5.40	5.27	8.24	6.88
Mn	0.13	0.11	0.07	<0.04	<0.04	<0.04
Na	186.67	54.01	197.64	20.27	109.82	30.14
Ni	0.06	0.06	0.15	<0.04	0.10	<0.04
P	<0.06	<0.6	<0.06	<0.06	<0.06	<0.6
Pb	3.96	0.24	1.46	<0.1	<0.1	<0.5
Sb	0.62	<0.5	2.73	<0.05	<0.05	<0.5
Se	2608.9	348.1	6953.2	343.4	<0.9	<0.9
Si	2.88	0.95	4.20	3.62	4.06	3.55
Sr	0.40	0.27	0.24	0.11	0.21	0.18
Ti	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Zn	7.66	6.66	15.08	0.70	0.08	0.78
Zr	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
F	1.80	0.71	14.49	1.86	23.87	7.9
Cl	217.74	69.28	411.30	59.98	132.95	59.02
I	16.11	0.66	<0.1	<0.1	<0.1	<0.1
NH ₄ ⁺	22.00	30.40	98.00	<6.0	91.00	11.4
Nitrate	13.41	37.83	13.46	54.17	45.02	61.55
Nitrite	<0.1	<0.1	16.05	13.40	9.79	0.17
Sulfate	176.00	67.23	210.14	48.96	203.39	73.53

Table 5.16. Anion Concentrations for PBS and HEME Blow-Down Liquids (mg/l).

Sample Type	Test	ID	pH	F	Cl	I	NH ₄ ⁺	Nitrate	Nitrite	Sulfate
HEME 1	5	U12-H1-62A	7.64	0.9	76.2	3.3	127	1073	0.1	95.6
	6	W12-H1-142A	8.10	3.3	73.3	1.2	834	1757	<0.1	205
	4	1I2-H1-47A	8.25	2.3	32.1	<0.1	103	105	58.0	54.8
PBS	5	U12-P-48A	8.93	0.4	22.1	6.9	3.8	24.9	105	0.9
	6	W12-P-142A	9.34	<0.1	108.4	2.0	38.8	472	607	5.7
	4	1I2-P-47A	9.20	0.5	71.0	<0.1	125	92.0	109	4.2

Table 5.17. Upper Estimates of Accumulations in Off-Gas Liquids from Test 5.

Analyte	Feed (kg)	SBS			WESP			HEME 1		PBS	
		Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Mass (g)	Percent Feed
Al	243	928	0.4	0.5	2.0	< 0.1	< 0.1	Not Available	Not Available	Not Available	Not Available
As	12.5	1184	9.5	6.8	165	1.3	1.5				
B	253	3190	1.3	1.8	82.7	< 0.1	0.1				
Ba	0	4.7	NC	NA	0.2	NC	NA				
Ca	18.6	165	0.9	0.8	139	0.7	< 0.1				
Cd	0	51.5	NC	NA	31.8	NC	NC				
Cr	4.7	1.8	< 0.1	0.1	0.1	< 0.1	< 0.1				
Cs	4.1	111	2.7	3.5	29.4	0.7	0.6				
Cu	2.8	14.8	0.5	0.7	2.4	0.1	< 0.1				
Fe	763	4484	0.6	0.7	< 0.2	< 0.1	< 0.1				
K	0	38.8	NC	NC	13.1	NC	NC				
Li	121	606	0.5	0.4	24.4	< 0.1	< 0.1				
Mg	61.2	491	0.8	0.7	26.5	< 0.1	< 0.1				
Mn	269	298	0.1	0.2	0.4	< 0.1	< 0.1				
Na	761	6475	0.9	0.7	438	0.1	0.1				
Ni	11.6	53.6	0.5	0.5	0.2	< 0.1	< 0.1				
P	3.4	22.1	0.7	2.5	< 0.2	< 0.1	< 0.1				
Pb	11.3	265	2.4	2.1	7.6	0.1	0.3				
Sb	18.1	194	1.1	0.9	1.1	< 0.1	< 0.1				
Se	22.8	16527	72.5	42.5	5380	23.6	16.2				
Si	1907	4812	0.3	0.3	7.0	< 0.1	< 0.1				
Sr	67.4	432	0.6	0.7	1.2	< 0.1	< 0.1				
Ti	7.3	75.4	1.0	1.3	< 0.1	< 0.1	< 0.1				
Zn	144	802	0.6	0.7	26.1	< 0.1	< 0.1				
Zr	16.7	74.3	0.4	0.4	< 0.1	< 0.1	< 0.1				
F	0	254	NC	NC	4.6	NC	NC	0.11	NC	1.0	NC
Cl	9.5	4146	43.6	16.1	522	8.1	5.9	8.9	< 0.1	53.8	0.6
I	8.7	6404	73.6	57.0	30.5	0.4	0.4	0.4	< 0.1	16.8	0.2
Ammonium	0	979	NC	NA	95.3	NC	NA	14.9	NC	9.3	NC
Nitrate & Nitrite	53.1	9.4	< 0.1	NA	92.2	0.2	NA	125.5	0.2	316.6	32.1
Sulfate	0	4271	NC	NA	443	NC	NC	11.2	NC	2.2	NC

NA – Data Not Available.

NC – Not Calculated.

Table 5.18. Upper Estimates of Accumulations in Off-Gas Liquids from Test 6.

Analyte	Feed (kg)	SBS			WESP			HEME 1		PBS	
		Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Mass (g)	Percent Feed
Al	297	748	0.3	0.4	0.3	<0.1	<0.1	Not Available	Not Available	Not Available	Not Available
As	15.3	2349	15.4	11.0	281	1.8	2.5				
B	309	4897	1.6	1.7	141	<0.1	<0.1				
Ba	0	5.3	NC	NA	0.1	NC	NC				
Ca	22.8	233	1.0	0.7	95.4	0.4	<0.1				
Cd	0	5.4	NC	NA	0.4	NC	NC				
Cr	5.8	8.3	0.1	0.5	<0.1	<0.1	<0.1				
Cs	5.0	146	2.9	2.5	26.9	0.5	0.5				
Cu	3.4	21.1	0.6	0.8	<0.1	<0.1	<0.1				
Fe	933	5452	0.6	0.8	<0.2	<0.1	<0.1				
K	0	44.1	NC	NC	12.3	NC	NC				
Li	148	845	0.6	0.5	26.2	<0.1	<0.1				
Mg	74.9	577	0.8	0.9	19.5	<0.1	<0.1				
Mn	329	318	0.1	0.3	<0.2	<0.1	<0.1				
Na	931	6620	0.7	0.8	397	<0.1	0.1				
Ni	14.2	89.8	0.6	0.8	<0.2	<0.1	<0.1				
P	4.2	30.5	0.7	1.3	<0.2	<0.1	0.5				
Pb	13.8	421	3.1	1.9	2.8	<0.1	0.6				
Sb	22.2	261	1.2	0.9	<0.2	<0.1	<0.1				
Se	27.9	16784	60.2	51.9	13305	47.7	19.2				
Si	2333	5481	0.2	0.3	14.3	<0.1	<0.1				
Sr	82.5	487	0.6	0.7	0.6	<0.1	<0.1				
Ti	8.9	86.2	1.0	1.4	<0.1	<0.1	<0.1				
Zn	177	990	0.6	0.8	28.8	<0.1	<0.1				
Zr	20.4	68.9	0.3	0.5	0.1	<0.1	<0.1				
F	0	251	NC	NC	29.8	NC	NC	0.6	NC	<0.1	NC
Cl	11.7	4359	37.3	8.4	860	7.3	4.3	12.7	0.1	254	2.2
I	0	<0.1	<0.1	NC	<0.4	NC	NC	0.2	NC	4.7	NC
Ammonium	0	7736	NC	NA	357	NC	NA	145	NC	90.8	NC
Nitrate & Nitrite	319	280	<0.1	NA	176.7	<0.1	NA	305	0.1	1532	0.5
Sulfate	0	5251	NC	NC	472	NC	NC	<0.1	NC	13.3	NC

NA – Data Not Available.

NC – Not Calculated

Table 5.19. Upper Estimates of Accumulations in Off-Gas Liquids from Test 4.

Analyte	Feed (kg)	SBS			WESP			HEME 1		PBS	
		Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Percent Feed Calculated From Emissions Data	Mass (g)	Percent Feed	Mass (g)	Percent Feed
Al	246	180	0.1	0.8	0.2	< 0.1	< 0.1	Not Available	Not Available	Not Available	Not Available
As	0	2.0	NC	NA	< 0.7	NC	NA				
B	331	5246	1.6	2.1	89.1	< 0.1	< 0.1				
Ba	1.6	1.4	0.1	1.0	0.1	< 0.1	< 0.1				
Ca	17.9	86.0	0.5	1.5	109	0.6	< 0.1				
Cd	4.8	353	7.4	24	4.4	0.1	3.56				
Cr	0	1.6	NC	NA	< 0.1	NC	NA				
Cs	0	3.7	NC	NC	0.62	NC	NC				
Cu	2.1	2.2	0.1	1.1	0.2	< 0.1	NC				
Fe	765	1111	0.1	1.2	< 0.6	< 0.1	< 0.1				
K	2.2	51.8	2.4	3.5	17.0	0.8	0.27				
Li	146	523	0.4	0.5	18.4	< 0.1	< 0.1				
Mg	5.9	50.4	0.9	2.3	26.2	0.4	< 0.1				
Mn	11.8	3.4	< 0.1	0.7	< 0.2	< 0.1	< 0.1				
Na	774	6009	0.8	1.1	243	0.0	< 0.1				
Ni	42.9	30.1	0.1	1.0	< 0.3	< 0.1	< 0.1				
P	0	1.7	NC	NA	< 0.2	NC	NA				
Pb	2.5	15.3	0.6	2.0	< 1.0	< 0.1	< 0.1				
Sb	0	1.1	NC	NA	< 1.0	NC	NA				
Se	0	29.9	NC	NA	< 3.1	NC	NA				
Si	1985	973	< 0.1	0.7	13.2	< 0.1	< 0.1				
Sr	2.3	6.4	0.3	1.4	0.7	< 0.1	< 0.1				
Ti	0	7.3	NC	NA	< 0.1	NC	NA				
Zn	145	201	0.1	1.1	1.5	< 0.1	< 0.1				
Zr	252	72.5	< 0.1	1.1	< 0.1	< 0.1	< 0.1				
F	3.6	2061	57	109	55.1	1.5	NA	0.33	< 0.1	0.60	< 0.1
Cl	0	1960	NC	NA	333	NC	NC	4.7	NC	84.6	NC
I	0	< 0.1	NC	NC	< 0.4	NC	NC	< 0.1	NC	< 0.1	NC
Ammonium	0	1786	NC	NA	178	NC	NA	14.9	NC	149	NC
Nitrate & Nitrite	60	1043	1.7	NA	202	0.3	NA	23.6	< 0.1	240	0.4
Sulfate	6.3	5893	94	90	480	7.6	5.61	7.9	0.1	5.0	0.1

NA – Data Not Available.

NC – Not Calculated

Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed.

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per test (kg)
5 (C-106/AY-102)	A (0 g/l sugar)	04/30/03	R12-G-138A	-	521.0	521.0	521.0
			R12-G-140A	-			
			R12-G-142A	-			
			R12-G-143A	-			
			R12-G-144A	-			
			R12-G-145A	-			
		05/01/03	R12-G-148A	-	514.5	1035.5	1035.5
			S12-G-6A	-			
			S12-G-6B	-			
			S12-G-7A	XRF			
			S12-G-8A	-			
			S12-G-9A	-			
			S12-G-10A	-			
			S12-G-11A	-			
			S12-G-12A	-			
			S12-G-12B	-			
			S12-G-15A	-			
			S12-G-17A	-			
			S12-G-18A	-			
			S12-G-19A	XRF			
			S12-G-27A	-			
	B (10 g/l sugar)	S12-G-28A	-				
		S12-G-28B	-				
		S12-G-28C	-				
		S12-G-30A	-				
		S12-G-31A	-				
		S12-G-32A	-				
		S12-G-34A	-				
		S12-G-34B	XRF				
	S12-G-35A	-	523.5	2074.0	2074.0		
	05/02/03	S12-G-36A				-	
		S12-G-37A				-	
		S12-G-46A				-	
S12-G-46B		-					
S12-G-47A		-					
S12-G-49A		-					
S12-G-50A		-					
S12-G-53A		-					
S12-G-54A		XRF					
S12-G-56A		-	-	-	-		
S12-G-57A	-						
S12-G-58A	-						
S12-G-69A	-						

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)			
5 (C-106/AY-102)	B (10 g/l sugar)	05/02/03	S12-G-70A	-	515.5	2589.5	2589.5			
			S12-G-71A	-						
			S12-G-72A	-						
			S12-G-73A	-						
			S12-G-73B	-						
			S12-G-75A	XRF						
		05/03/03	S12-G-86A	-	523.0	3112.5	3112.5			
			S12-G-87A	-						
			S12-G-88A	-						
			S12-G-90A	-						
			S12-G-91A	-						
			S12-G-93A	-						
			S12-G-93B	-						
			S12-G-94A	-						
			S12-G-96A	-						
			S12-G-107A	XRF						
	C (15 g/l sugar)	05/04/03	S12-G-109A	-	524.5	3637.0	3637.0			
			S12-G-109B	-						
			S12-G-110A	-						
			S12-G-112A	-						
			S12-G-114A	-						
			S12-G-116A	-						
			S12-G-118A	-						
			S12-G-126A	-				507.0	4144.0	4144.0
			S12-G-127A	-						
			S12-G-127B	XRF						
	S12-G-129A		-							
	S12-G-129B		-							
	S12-G-131A		-							
	S12-G-132A		-							
	S12-G-134A		-							
	S12-G-134B		-							
S12-G-136A	-									
S12-G-136B	-									
S12-G-138A	XRF									
S12-G-147A	-	-	-	-						
S12-G-149A	-									
S12-G-151A	-									
S12-G-151B	-									
S12-G-155A	-									
S12-G-155B	-									
T12-G-16A	-									

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
5 (C-106/AY-102)	C (15 g/l sugar)	05/04/03	T12-G-17A	-	519.0	4663.0	4663.0
		05/05/03	T12-G-18A	-			
			T12-G-19A	XRF			
			T12-G-22A	-			
			T12-G-23A	-			
			T12-G-24A	-			
			T12-G-25A	-			
			T12-G-25B	-			
			T12-G-26A	-			
			T12-G-28A	-			
			T12-G-30A	-			
			T12-G-38A	XRF			
		D (17.5-20 g/l sugar)	05/06/03	T12-G-40A	-	500.0	5669.5
	T12-G-42A			-			
	T12-G-43A			-			
	T12-G-44A			-			
	T12-G-45A			-			
	T12-G-48A			-			
	T12-G-49A			-			
	T12-G-58A			-			
	05/07/03		T12-G-58B	-	502.0	6171.5	6171.5
			T12-G-60A	XRF			
			T12-G-62A	-			
			T12-G-62B	-			
			T12-G-64A	-			
			T12-G-66A	-			
			T12-G-71A	-			
			T12-G-71B	-			
			T12-G-79A	-			
			T12-G-81A	-			
	05/07/03	T12-G-82A	XRF	506.5	6678.0	6678.0	
		T12-G-87A	-				
T12-G-88A		-					
T12-G-90A		-					
T12-G-99A		-					
T12-G-102A		-					
T12-G-102B		-					
05/07/03	T12-G-103A	-	506.5	6678.0	6678.0		
	T12-G-105A	-					
	T12-G-105B	-					
05/07/03	T12-G-108A	XRF	506.5	6678.0	6678.0		
	T12-G-110A	-					

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
5 (C-106/AY-102)	E (25 g/l sugar)	05/07/03	T12-G-110B	-	516.0	7194.0	7194.0
			T12-G-120A	-			
			T12-G-122A	-			
			T12-G-123A	-			
			T12-G-124A	-			
			T12-G-127A	-			
			T12-G-128A	-			
			T12-G-128B	-			
		05/08/03	T12-G-130A	XRF	510.0	7704.0	7704.0
			T12-G-139A	-			
			T12-G-140A	-			
			T12-G-142A	-			
			T12-G-142B	-			
			T12-G-144A	-			
			T12-G-146A	-			
			T12-G-148A	-			
			U12-G-10A	-			
			U12-G-11A	-			
			U12-G-13A	XRF			
			U12-G-14A	-	525.0	8229.0	8229.0
			U12-G-17A	-			
			U12-G-18A	-			
		05/09/03	U12-G-27A	-			
			U12-G-28A	-			
			U12-G-29A	-			
			U12-G-30A	-			
			U12-G-31A	-			
			U12-G-34A	-			
			U12-G-35A	XRF			
			U12-G-37A	-	439.5	8668.5	8668.5
		05/10/03	U12-N-46A	-			
			U12-N-47A	-			
			U12-N-48A	-			
			U12-G-60A	XRF			
6 (C-106/AY-102 with Added Nitrate)	A (0 g/l sugar)	05/14/03	U12-G-90A	-	519.0	9187.5	519.0
			U12-G-91A	-			
			U12-G-92A	-			
			U12-G-93A	-			
			U12-G-94A	-			
			U12-G-95A	-			
			U12-G-98A	-			
		05/15/03	U12-G-99A	-			
			U12-G-100A	-			
			U12-G-108A	XRF			

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
6 (C-106/AY-102 with Added Nitrate)	A (0 g/l sugar)	05/15/03	U12-G-109A	-	503.0	9690.5	1022.0
			U12-G-110A	-			
			U12-G-111A	-			
			U12-G-112A	-			
			U12-G-114A	-			
			U12-G-114A	-			
			U12-G-114B	-			
			U12-G-115A	-			
			U12-G-116A	-			
			U12-G-116B	-			
			U12-G-118A	XRF			
	B (10 g/l sugar)	05/16/03	U12-G-127A	-	519.0	10209.5	1541.0
			U12-G-130A	-			
			U12-G-134A	-			
			U12-G-136A	-			
			U12-G-136B	-			
			U12-G-145A	-			
		05/16/03	U12-G-146A	-	507.5	10717.0	2048.5
			U12-G-147A	-			
			U12-G-148A	-			
			U12-G-148B	XRF			
			U12-G-150A	-			
			U12-G-151A	-			
			U12-G-152A	-			
			U12-G-153A	-			
			U12-G-155A	-			
			V12-G-8A	-			
			V12-G-16A	-			
			V12-G-16B	-			
			V12-G-17A	-			
			V12-G-19A	XRF			
		05/17/03	V12-G-20A	-	519.0	11236.0	2567.5
			V12-G-20B	-			
			V12-G-21A	-			
			V12-G-22A	-			
			V12-G-23A	-			
			V12-G-23B	-			
			V12-G-24A	-			
			V12-G-24B	-			
			V12-G-33A	-			
			V12-G-34A	XRF			
			V12-G-34B	-			
			V12-G-36A	-	-	-	-

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
6 (C-106/AY-102 with Added Nitrate)	B (10 g/l Sugar)	05/17/03	V12-G-36B	-	504.5	11740.5	3072.0
			V12-G-37A	-			
			V12-G-38A	-			
			V12-G-38B	-			
			V12-G-39A	-			
			V12-G-42A	-			
			V12-G-42A	-			
			V12-G-43A	XRF			
	C (15 g/l sugar)	05/17/03	V12-G-44A	-	485.5	12226.0	3557.5
			V12-G-45A	-			
			V12-G-45B	-			
			V12-G-54A	-			
			V12-G-56A	-			
			V12-G-56B	-			
			V12-G-58A	-			
			V12-G-58B	-			
		05/18/03	V12-G-61A	-	525.5	12751.5	4083.0
			V12-G-62A	XRF			
			V12-G-62B	-			
			V12-G-63A	-			
			V12-G-63B	-	497.0	13248.5	4626.9
			V12-G-64A	-			
			V12-G-72A	-			
			V12-G-73A	-			
			V12-G-73B	-			
			V12-G-75A	-			
			V12-G-76A	-			
			V12-G-77A	XRF			
			V12-G-80A	-			
			V12-G-81A	-			
			V12-G-82A	-			
			V12-G-79A	-			
			V12-G-93A	-			
			V12-G-93B	-			
			V12-G-94A	-			
			V12-G-94B	XRF			
		05/19/03	V12-G-95A	-	-	-	-
			V12-G-97A	-			
			V12-G-97B	-			
			V12-G-98A	-			
			V12-G-99A	-			
		05/19/03	V12-G-100A	-	-	-	-
		05/19/03	V12-G-100B	-			

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
6 (C-106/AY-102 with Added Nitrate)	C (15 g/l sugar)	05/19/03	V12-G-109A	-	516.0	13764.5	5096.0
			V12-G-110A	-			
			V12-G-110B	XRF			
			V12-G-112A	-	506.0	14270.5	5652.7
			V12-G-112B	-			
			V12-G-111A	-			
			V12-G-114A	-			
			V12-G-115A	-			
			V12-G-117A	-			
			V12-G-117B	-			
			V12-G-118A	-			
			V12-G-119A	-			
			V12-G-128A	XRF			
			V12-G-128B	-	507.0	14777.5	6109.0
			V12-G-131A	-			
			V12-G-132A	-			
			V12-G-132B	-			
			V12-G-134A	-			
			V12-G-134B	-			
			V12-G-135A	-			
			V12-G-139A	-			
			V12-G-138B	-			
			V12-G-139A	XRF			
	D (20 g/l sugar)	05/20/03	V12-G-147A	-	505.0	15282.5	6614.0
			V12-G-147B	-			
			V12-G-148A	-			
			V12-G-149A	-			
			V12-G-149B	-			
			V12-G-151A	-			
			V12-G-152A	-			
			V12-G-152B	-			
			V12-G-155A	-			
			W12-W-5A	XRF	509.0	15791.5	7123.0
			W12-G-5B	-			
			W12-G-18A	-			
			W12-G-18B	-			
			W12-G-19A	-			
			W12-G-19B	-			
			W12-G-21A	-			
			W12-G-21B	-			
			W12-G-22A	-			
			W12-G-22B	-			
			W12-G-23A	XRF			

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
(C-106/AY-102 with Added Nitrate)	D (20 g/l sugar)	05/20/03	W12-G-23B	-	511.0	16302.5	7680.4
			W12-G-24A	-			
		05/21/03	W12-G-26A	-			
			W12-G-34A	-			
			W12-G-34B	-			
			W12-G-35A	-			
			W12-G-35B	-			
			W12-G-38A	-			
			W12-G-39A	-			
			W12-G-39B	XRF			
			W12-G-40A	-	510.5	16813.0	8144.5
			W12-G-42A	-			
			W12-G-43A	-			
			W12-G-43B	-			
			W12-G-44A	-			
			W12-G-45A	-			
			W12-G-45B	-			
			W12-G-54A	-			
			W12-G-56A	-			
			W12-G-57A	XRF			
	E (25 g/l sugar)	05/22/03	W12-G-59A	-	527.5	17340.5	8672.0
			W12-G-59B	-			
			W12-G-60A	-			
			W12-G-60B	-			
			W12-G-64A	-			
			W12-G-72A	-			
			W12-G-73A	-			
			W12-G-73B	XRF			
			W12-G-75A	-	514.0	17854.5	9186.0
			W12-G-76A	-			
			W12-G-77A	-			
			W12-G-77B	-			
			W12-G-78A	-			
			W12-G-79A	-			
			W12-G-79B	-			
			W12-G-91A	-			
			W12-G-92A	-			
			W12-G-92B	XRF			
		05/22/03	W12-G-93A	-	-	-	-
			W12-G-93B	-			
			W12-G-94A	-			
			W12-G-95A	-			
			W12-G-96A	-			

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
6 (C-106/AY-102 with Added Nitrate)	E (25 g/l sugar)	05/22/03	W12-G-96B	-	518.5	18373.0	9704.5
			W12-G-97A	-			
			W12-G-98A	-			
			W12-G-98B	-			
			W12-G-99A	XRF			
		05/23/03	W12-G-108A	-	512.5	18885.5	10217.0
			W12-G-116A	-			
			W12-G-116B	-			
			W12-G-117A	-			
			W12-G-119A	-			
			W12-G-120A	-			
			W12-G-121A	-			
			W12-G-122A	-			
			W12-G-122B	-			
			W12-G-124A	XRF			
			W12-G-125A	-			
			W12-G-133A	-			
			W12-G-133B	-			
			W12-G-135A	-			
			W12-G-136A	-			
W12-G-137A	XRF						
4 (AZ-101)	A (0 g/l sugar)	08/19/03	1F2-G-146A	-	508.5	10788.5	508.5
			1F2-G-146B	-			
			1F2-G-147A	-			
			1F2-G-150A	-			
			1F2-G-152A	-			
			1F2-G-153A	-			
			1F2-G-154A	-			
			1F2-G-155A	-			
		08/20/03	1G2-G-12A	-	398.5	20187.0	907.0
			1G2-G-16A	XRF			
			1G2-G-17A	-			
			1G2-G-18A	-			
			1G2-G-19A	-			
			1G2-G-19B	-			
			1G2-G-21A	-			
	B	1G2-G-21B	-				
		1G2-G-22A	-				
		1G2-G-24A	XRF				

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Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
4 (AZ-101)	B (13.3-7.6 g/l sugar, Ru/Y spike)	08/20/03	1G2-G-40A	-	406.0	20593.0	1313.0
			1G2-G-41A	-			
			1G2-G-42A	-			
			1G2-G-44A	-			
		08/21/03	1G2-G-45A	-	411.0	21004.0	1724.0
			1G2-G-46A	-			
			1G2-G-46B	-			
			1G2-G-47A	XRF			
			1G2-G-49A	-			
			1G2-G-51A	-			
			1G2-G-54A	-			
			1G2-G-57A	-			
			1G2-G-57B	-			
			1G2-G-58A	-			
			1G2-G-59A	-			
			1G2-G-60A	XRF			
			1G2-G-61A	-			
			1G2-G-62A	-			
			1G2-G-78A	-			
			1G2-G-79A	-			
			1G2-G-79B	-			
			1G2-G-80A	-			
	C (10 g/l sugar, Ru/Y spike)	08/22/03	1G2-G-82A	-	413.0	21417.0	2137.0
			1G2-G-83A	XRF			
			1G2-G-86A	-			
			1G2-G-87A	-			
			1G2-G-87B	-			
			1G2-G-90A	-			
			1G2-G-91A	-			
			1G2-G-99A	-			
			1G2-G-100A	-			
			1G2-G-102A	XRF			
			1G2-G-103A	-			
			1G2-G-104A	-	412.0	21829.0	2549.0
			1G2-G-105A	-			
			1G2-G-107A	-			
			1G2-G-108A	-			
			1G2-G-117A	-			
			1G2-G-118A	-			
			1G2-G-121A	XRF			
			1G2-G-122A	-	419.0	22248.0	2968.0

"-" Empty data field

Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
4 (AZ-101)	C (10 g/l sugar, Ru/Y spike)	08/23/03	1G2-G-123A	-	409.5	22657.5	3377.5
			1G2-G-124A	-			
			1G2-G-125A	-			
			1G2-G-125B	-			
			1G2-G-128A	-			
			1G2-G-129A	-			
			1G2-G-138A	XRF	405.0	23062.5	3782.5
			1G2-G-139A	-			
			1G2-G-140A	-			
			1G2-G-142A	-			
			1G2-G-144A	-			
			1G2-G-145A	-			
			1G2-G-146A	-			
			1G2-G-149A	-			
			1G2-G-150A	XRF	419.5	23482.0	4202.0
			1G2-G-151A	-			
			1G2-G-152A	-			
			1G2-G-154A	-			
		1G2-G-154B	-				
		1G2-G-155A	-				
		08/24/03	1H2-G-5A	-	402.0	23884.0	4604.0
			1H2-G-5B	-			
			1H2-G-9A	XRF			
			1H2-G-9B	-			
			1H2-G-11A	-			
			1H2-G-12A	-			
			1H2-G-27A	-			
	1H2-G-29A		-				
	1H2-G-30A		-				
	08/24/03	1H2-G-31A	-	409.5	24293.5	5013.5	
		1H2-G-32A	XRF				
		1H2-G-36A	-				
		1H2-G-37A	-				
		1H2-G-37B	-				
		1H2-G-38A	-				
		1H2-G-39A	-				
		1H2-G-48A	-				
		1H2-G-48B	-				
	1H2-G-51A	XRF					

"-" Empty data field

Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
4 (AZ-101)	D (12.5 g/l sugar, Ru/Y spike)		1H2-G-51B	-	409.0	24702.5	5422.5
		08/25/03	1H2-G-53A	-			
			1H2-G-54A	-			
			1H2-G-56A	-			
			1H2-G-57A	-			
			1H2-G-58A	-			
			1H2-G-58B	-			
			1H2-G-60A	XRF			
			1H2-G-60B	-			
			1H2-G-62A	-			
			1H2-G-63A	-			
			1H2-G-64A	-			
			1H2-G-65A	-			
			1H2-G-66A	-			
			1H2-G-70A	-			
			1H2-G-72A	XRF			
			1H2-G-74A	-			
		1H2-G-90A	-				
		1H2-G-91A	-				
		1H2-G-92A	-				
		1H2-G-92B	-				
		08/26/2003	1H2-G-93A	-			
			1H2-G-95A	-			
			1H2-G-97A	XRF			
	1H2-G-99A		-				
	1H2-G-99B		-				
	1H2-G-100A		-				
	1H2-G-101A		-				
	1H2-G-101B		-				
	1H2-G-103A		-				
	1H2-G-103B		-				
	1H2-G-105A		XRF				
1H2-G-106A	-						
E (16 g/l Sugar, Ru/Y spike)	1H2-G-109A	-					
	1H2-G-109B	-					
	1H2-G-110A	-					
	1H2-G-119A	-					
	1H2-G-120A	-					
	1H2-G-128A	-					
	1H2-G-128B	XRF					
	1H2-G-131A	-					
	1H2-G-132A	-					
		-					
		-					
		-					

"- Empty data field

Table 6.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)	Cumulative Mass per Test (kg)
4 (AZ-101)	E (16 g/l sugar, Ru/Y spike)	08/27/2003	1H2-G-133A	-	433.5	26767.5	7487.5
			1H2-G-134A	-			
			1H2-G-135A	-			
			1H2-G-135B	-			
			1H2-G-137A	-			
			1H2-G-138A	XRF			
			1H2-G-139A	-	409.5	27177.0	7897.0
			1H2-G-142A	-			
			1H2-G-145A	-			
			1H2-G-146A	-			
			1H2-G-147A	-			
			1H2-G-148A	-			
			1I2-G-5A	-			
			1I2-G-9A	XRF			
			1I2-G-10A	-	401.0	27578.0	8298.0
			1I2-G-10B	-			
			1I2-G-18A	-			
			1I2-G-19A	-			
			1I2-G-20A	-			
			1I2-G-21A	-			
		08/28/2003	1I2-G-23A	-			
			1I2-G-25A	XRF			
			1I2-G-25B	-	410.0	27988.0	8708.0
			1I2-G-27A	-			
			1I2-G-27B	-			
			1I2-G-35A	-			
			1I2-G-36A	-			
			1I2-G-37A	-			
			1I2-G-37B	-			
			1I2-G-38A	XRF			
			1I2-G-41A	-	247.5	28235.5	8955.5
			1I2-G-42A	-			
			1I2-G-47A	XRF			

"-" Empty data field

**Table 6.2. XRF Analyzed Compositions of Discharged Glasses from Test 5
 (C-106/AY-102 with variable amounts of sugar).
 (wt%)**

Test Segment		A		B				C			
Sugar added (g/l)		0		10				15			
Glass (kg)		521.0	1035.5	1550.5	2074.0	2589.5	3112.5	3637.0	4144.0	4663.0	5169.5
Constituent	Target	S12-G-7A	S12-G-19A	S12-G-34B	S12-G-54A	S12-G-75A	S12-G-107A	S12-G-127B	S12-G-138A	T12-G-19A	T12-G-38A
Al ₂ O ₃	5.29	6.94	6.50	6.61	6.64	6.18	6.06	6.08	6.02	5.69	5.62
As ₂ O ₃	0.19	0.07	0.11	0.12	0.13	0.14	0.16	0.16	0.17	0.16	0.17
B ₂ O ₃ *	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39
CaO	0.30	0.38	0.40	0.40	0.41	0.42	0.43	0.44	0.44	0.45	0.45
CdO	§	0.27	0.21	0.17	0.11	0.09	0.07	0.05	0.04	0.03	0.02
Cl	0.11	0.02	0.03	0.04	0.04	0.04	0.05	0.06	0.05	0.05	0.05
Cr ₂ O ₃	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.07
Cs ₂ O	0.05	0.09	0.08	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.05
CuO	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.05	0.05
Fe ₂ O ₃	12.58	10.63	11.09	11.16	10.76	11.18	11.63	11.45	11.64	11.61	11.74
I	0.10	<0.01	<0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03
K ₂ O	§	0.25	0.20	0.20	0.18	0.15	0.14	0.13	0.12	0.12	0.11
La ₂ O ₃	0.24	0.21	0.22	0.20	0.20	0.22	0.23	0.23	0.24	0.25	0.24
Li ₂ O*	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01
MgO	1.17	1.05	1.01	0.99	1.06	1.08	1.04	1.15	1.16	1.11	1.15
MnO	4.00	3.03	3.29	3.37	3.36	3.52	3.68	3.67	3.73	3.75	3.75
Na ₂ O	11.83	8.84	9.29	9.35	10.61	10.97	10.38	11.15	11.09	11.13	11.45
Nd ₂ O ₃	0.15	0.05	0.08	0.09	0.10	0.11	0.12	0.13	0.12	0.13	0.14
NiO	0.17	0.30	0.26	0.23	0.20	0.18	0.18	0.17	0.16	0.16	0.14
P ₂ O ₅	0.09	0.22	0.19	0.18	0.16	0.15	0.15	0.12	0.12	0.14	0.12
PbO	0.14	0.12	0.13	0.13	0.11	0.12	0.12	0.12	0.12	0.12	0.12
Sb ₂ O ₃	0.25	0.20	0.23	0.26	0.25	0.26	0.29	0.27	0.29	0.31	0.30
SeO ₂	0.37	0.04	0.06	0.07	0.06	0.06	0.07	0.04	0.03	0.02	0.02
SiO ₂	47.05	47.06	47.32	47.80	48.05	47.75	48.04	47.83	47.77	48.33	48.08
SO ₃	§	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.04	0.03	0.02
SrO	0.92	1.49	1.35	1.22	1.04	1.01	1.00	0.93	0.92	0.88	0.87
TiO ₂	0.14	0.15	0.17	0.18	0.18	0.19	0.20	0.20	0.21	0.20	0.20
ZnO	2.07	1.93	1.96	1.91	1.79	1.85	1.91	1.87	1.87	1.86	1.87
ZrO ₂	0.26	4.00	3.22	2.63	1.91	1.66	1.38	1.12	1.03	0.86	0.75
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values

NA – Not analyzed

§ Not a target constituent

**Table 6.2. XRF Analyzed Compositions of Discharged Glasses from Test 5
(C-106/AY-102 with variable amounts of sugar) (continued).
(wt%)**

Test Segment		D			E				Average (>5000kg)	%Dev.
Sugar added (g/l)		17.5-20			25					
Glass (kg)		5669.5	6171.5	6678.0	7194.0	7704.0	8229.0	8668.5		
Constituent	Target	T12-G-60A	T12-G-82A	T12-G-108A	T12-G-130A	U12-G-13A	U12-G-35A	U12-G-60A		
Al ₂ O ₃	5.29	5.69	5.63	5.64	5.55	5.62	5.61	5.73	5.64	6.52
As ₂ O ₃	0.19	0.17	0.16	0.16	0.17	0.17	0.18	0.17	0.17	NC
B ₂ O ₃ *	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	NC	NC
CaO	0.30	0.45	0.45	0.45	0.46	0.45	0.46	0.46	0.45	NC
CdO	§	0.02	0.01	0.01	<0.01	<0.01	0.01	0.01	0.01	NC
Cl	0.11	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.05	NC
Cr ₂ O ₃	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	NC
Cs ₂ O	0.05	0.05	0.06	0.04	0.06	0.05	0.05	0.06	0.05	NC
CuO	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	NC
Fe ₂ O ₃	12.58	11.93	11.63	11.53	12.23	11.61	11.99	11.92	11.82	-6.05
I	0.10	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.03	NC
K ₂ O	§	0.11	0.11	0.10	0.11	0.11	0.11	0.12	0.11	NC
La ₂ O ₃	0.24	0.24	0.24	0.24	0.26	0.24	0.24	0.25	0.24	NC
Li ₂ O*	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	NC	NC
MgO	1.17	1.16	1.17	1.30	1.17	1.20	1.15	1.15	1.18	0.94
MnO	4.00	3.86	3.80	3.75	3.95	3.79	3.89	3.86	3.83	-4.27
Na ₂ O	11.83	11.02	11.27	11.88	10.77	11.86	11.28	10.93	11.31	-4.42
Nd ₂ O ₃	0.15	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.14	NC
NiO	0.17	0.15	0.14	0.14	0.15	0.14	0.14	0.15	0.14	NC
P ₂ O ₅	0.09	0.13	0.12	0.11	0.09	0.10	0.11	0.11	0.11	NC
PbO	0.14	0.12	0.11	0.12	0.13	0.12	0.12	0.12	0.12	NC
Sb ₂ O ₃	0.25	0.29	0.31	0.29	0.31	0.29	0.31	0.32	0.30	NC
SeO ₂	0.37	0.02	0.03	0.03	0.02	0.02	0.02	0.04	0.03	NC
SiO ₂	47.05	48.10	48.41	48.07	48.15	48.07	48.09	48.33	48.16	2.36
SO ₃	§	0.02	0.03	0.03	0.02	0.02	0.02	0.05	0.03	NC
SrO	0.92	0.89	0.85	0.82	0.89	0.82	0.86	0.86	0.86	-6.88
TiO ₂	0.14	0.21	0.20	0.21	0.22	0.21	0.21	0.21	0.21	NC
ZnO	2.07	1.91	1.87	1.83	1.97	1.86	1.92	1.90	1.89	-8.60
ZrO ₂	0.26	0.69	0.62	0.54	0.56	0.50	0.49	0.52	0.58	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target values

NA – Not analyzed

§ Not a target constituent

**Table 6.3. XRF Analyzed Compositions of Discharged Glasses from Test 6
(C-106/AY-102 with added nitrate and variable amounts of sugar) (continued).
(wt%)**

Test Information		With Nitrate Added										
		6A		6B				6C				6D
Sugar added (g/l)		0		10				15				20
Glass (kg)		9187.5	9690.5	10209.5	10717.0	11236.0	11740.5	12226.0	12751.5	13764.5	14270.5	14777.5
Constituent	Target	U12-G-108A	U12-G-118A	U12-G-148B	V12-G-19A	V12-G-34A	V12-G-43A	V12-G-62A	V12-G-77A	V12-G-110B	V12-G-128A	V12-G-139A
Al ₂ O ₃	5.30	5.81	5.66	5.68	5.64	5.59	5.64	5.60	5.71	5.70	5.70	5.66
As ₂ O ₃	0.19	0.18	0.18	0.18	0.19	0.20	0.19	0.19	0.19	0.19	0.19	0.19
B ₂ O ₃ *	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
CaO	0.30	0.46	0.45	0.45	0.45	0.46	0.46	0.46	0.46	0.47	0.51	0.47
CdO	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cl	0.11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cr ₂ O ₃	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Cs ₂ O	0.05	0.04	0.04	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.05
CuO	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fe ₂ O ₃	12.60	11.71	11.81	11.84	11.88	12.16	12.08	11.93	11.95	12.02	12.05	12.07
I	§	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K ₂ O	§	0.11	0.11	0.11	0.11	0.11	0.12	0.10	0.11	0.12	0.12	0.11
La ₂ O ₃	0.24	0.25	0.25	0.25	0.24	0.25	0.25	0.26	0.26	0.26	0.24	0.26
Li ₂ O*	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01
MgO	1.17	1.19	1.20	1.16	1.20	1.19	1.19	1.28	1.24	1.17	1.18	1.22
MnO	4.00	3.84	3.88	3.90	3.93	3.99	3.93	3.90	3.90	3.94	3.92	3.93
Na ₂ O	11.84	11.26	11.30	11.24	11.11	11.16	10.87	11.30	11.07	11.05	11.23	11.30
Nd ₂ O ₃	0.15	0.14	0.14	0.15	0.14	0.15	0.15	0.14	0.16	0.15	0.15	0.15
NiO	0.17	0.14	0.15	0.15	0.14	0.15	0.15	0.14	0.15	0.14	0.14	0.14
P ₂ O ₅	0.09	0.11	0.11	0.11	0.12	0.11	0.10	0.11	0.10	0.10	0.10	0.11
PbO	0.14	0.12	0.12	0.12	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.13
Sb ₂ O ₃	0.25	0.28	0.29	0.30	0.32	0.33	0.32	0.32	0.31	0.32	0.29	0.28
SeO ₂	0.37	0.05	0.07	0.05	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
SiO ₂	47.10	48.32	48.19	48.20	48.22	47.78	48.24	48.07	48.19	48.14	47.88	47.84
SO ₃	§	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.04
SrO	0.92	0.82	0.84	0.85	0.85	0.87	0.86	0.84	0.84	0.86	0.86	0.86
TiO ₂	0.14	0.21	0.21	0.21	0.22	0.22	0.22	0.22	0.22	0.21	0.22	0.21
ZnO	2.07	1.86	1.89	1.89	1.90	1.94	1.91	1.89	1.89	1.91	1.94	1.94
ZrO ₂	0.26	0.46	0.44	0.46	0.43	0.43	0.42	0.40	0.39	0.39	0.41	0.37
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values

§ Not a target constituent

**Table 6.3. XRF Analyzed Compositions of Discharged Glasses from Test 6
(C-106/AY-102 with added nitrate and variable amounts of sugar) (continued).
(wt%)**

Test Segment		D				E					Average	%Dev.
Sugar added (g/l)		20				25						
Glass (kg)		15282.5	15791.5	16302.5	16813.0	17340.5	17854.5	18373.0	18885.5	19280.0		
Constituent	Target	W12-G-5A	W12-G-23A	W12-G-39B	W12-G-57A	W12-G-73B	W12-G-92B	W12-G-99A	W12-G-124A	W12-G-137A		
Al ₂ O ₃	5.30	5.65	5.73	5.66	5.72	5.56	5.64	5.33	5.24	5.27	5.61	5.92
As ₂ O ₃	0.19	0.17	0.18	0.17	0.16	0.17	0.16	0.17	0.17	0.17	0.18	NC
B ₂ O ₃ *	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	NC	NC
CaO	0.30	0.46	0.46	0.46	0.46	0.48	0.46	0.47	0.47	0.46	0.46	NC
CdO	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
Cl	0.11	0.05	0.06	0.05	0.06	0.06	0.05	0.06	0.05	0.07	0.05	NC
Cr ₂ O ₃	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.26	0.29	0.26	0.11	NC
Cs ₂ O	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	NC
CuO	0.04	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	NC
Fe ₂ O ₃	12.60	12.01	11.82	12.16	11.58	11.93	12.21	13.08	13.23	12.74	12.11	-3.83
I	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
K ₂ O	§	0.12	0.11	0.12	0.11	0.11	0.11	0.09	0.09	0.09	0.11	NC
La ₂ O ₃	0.24	0.25	0.25	0.26	0.25	0.26	0.26	0.26	0.28	0.26	0.26	NC
Li ₂ O*	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	NC	NC
MgO	1.17	1.18	1.18	1.17	1.29	1.24	1.15	1.18	1.20	1.25	1.20	2.75
MnO	4.00	3.94	3.86	3.95	3.79	3.90	3.98	4.11	4.11	4.00	3.93	-1.81
Na ₂ O	11.84	11.23	11.23	10.90	11.62	11.49	10.99	10.97	10.89	11.59	11.19	-5.52
Nd ₂ O ₃	0.15	0.15	0.14	0.15	0.14	0.15	0.15	0.16	0.15	0.15	0.15	NC
NiO	0.17	0.13	0.14	0.14	0.14	0.13	0.14	0.21	0.22	0.19	0.15	NC
P ₂ O ₅	0.09	0.10	0.10	0.11	0.10	0.11	0.11	0.11	0.11	0.10	0.11	NC
PbO	0.14	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.12	NC
Sb ₂ O ₃	0.25	0.30	0.31	0.32	0.30	0.29	0.32	0.33	0.34	0.33	0.31	NC
SeO ₂	0.37	0.05	0.04	0.03	0.03	0.02	0.02	0.03	0.02	0.05	0.05	NC
SiO ₂	47.10	48.11	48.37	48.22	48.37	48.03	48.12	46.96	46.89	46.89	47.95	1.81
SO ₃	§	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.04	0.04	NC
SrO	0.92	0.86	0.83	0.86	0.82	0.85	0.87	0.91	0.92	0.88	0.86	-7.00
TiO ₂	0.14	0.21	0.21	0.21	0.20	0.21	0.21	0.22	0.21	0.21	0.21	NC
ZnO	2.07	1.90	1.86	1.92	1.80	1.90	1.92	2.03	2.06	1.98	1.92	-7.38
ZrO ₂	0.26	0.37	0.36	0.37	0.34	0.37	0.37	0.39	0.39	0.38	0.40	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target values

NC – Not calculated

§ Not a target constituent

**Table 6.4. XRF Analyzed Compositions of Discharged Glasses from Test 4
(AZ-101 with variable amounts of sugar).
(wt%)**

Test#		4A	4B					4C					4D
Sugar Added (g/l)		0.0	13.3			7.6		10.0					12.5
Glass (kg)		508.5	907.0	1313.0	1724.0	2137.0	2549.0	2968.0	3377.5	3782.5	4202.0	4604.0	5013.5
Constituent	Target	1G2-G-16A	1G2-G-24A	1G2-G-47A	1G2-G-60A	1G2-G-83A	1G2-G-102A	1G2-G-121A	1G2-G-138A	1G2-G-150A	1H2-G-9A	1H2-G-32A	1H2-G-51A
Al ₂ O ₃	5.21	5.86	6.12	5.77	6.01	6.13	6.01	6.10	6.01	5.62	5.98	6.03	5.96
B ₂ O ₃ *	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91
BaO	0.02	0.06	0.05	0.06	0.05	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06
CaO	0.28	0.39	0.40	0.40	0.41	0.40	0.39	0.39	0.40	0.40	0.39	0.39	0.38
CdO	0.06	0.07	0.07	0.08	0.08	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06
Cl	§	0.01	0.01	0.01	0.01	<0.01	0.01	0.01	<0.01	0.01	0.01	0.01	0.01
Cr ₂ O ₃	§	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.01	<0.01	<0.01	0.01
Cs ₂ O	§	<0.01	0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01
CuO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03
F	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	12.26	11.10	10.93	11.37	11.50	10.96	11.03	10.73	11.20	11.06	11.07	11.00	10.75
K ₂ O	0.03	0.17	0.19	0.13	0.14	0.20	0.19	0.20	0.14	0.12	0.14	0.14	0.16
La ₂ O ₃	0.41	0.41	0.41	0.42	0.42	0.41	0.40	0.40	0.42	0.41	0.41	0.40	0.39
Li ₂ O*	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52
MgO	0.11	0.09	0.10	0.06	0.04	0.10	0.06	0.08	0.05	0.06	0.08	0.07	0.08
MnO	0.17	0.17	0.17	0.18	0.19	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17
Na ₂ O	11.65	11.38	11.21	11.45	11.05	11.09	11.03	11.50	11.08	12.07	11.34	11.50	11.63
Nd ₂ O ₃	0.31	0.29	0.30	0.31	0.30	0.29	0.30	0.29	0.30	0.28	0.29	0.30	0.30
NiO	0.62	0.54	0.51	0.53	0.53	0.49	0.49	0.48	0.50	0.48	0.48	0.47	0.45
P ₂ O ₅	§	0.01	0.02	0.01	0.02	0.01	<0.01	0.01	0.01	<0.01	0.02	0.01	0.02
PbO	0.03	0.02	0.03	0.03	0.03	0.01	0.03	0.03	0.03	0.03	0.02	0.03	0.03
RuO ₂	¶	<0.01	<0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01
SiO ₂	47.40	47.50	47.67	46.99	47.01	47.77	47.81	47.77	47.55	47.18	47.52	47.41	47.81
SO ₃	0.08	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.04	0.05	0.04	0.03	0.04
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
TiO ₂	§	0.09	0.09	0.10	0.11	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.09
Y ₂ O ₃	¶	<0.01	0.01	0.03	0.04	0.05	0.06	0.06	0.08	0.08	0.08	0.08	0.09
ZnO	2.02	1.71	1.67	1.75	1.78	1.68	1.70	1.65	1.74	1.71	1.70	1.70	1.65
ZrO ₂	3.82	4.54	4.45	4.72	4.71	4.47	4.53	4.35	4.55	4.54	4.51	4.51	4.35
SUM	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values

NA – Not analyzed

§ Not a target constituent

¶ Added at expense of all other constituents (targets: RuO₂, 0.09 wt% and Y₂O₃, 0.10 wt%)

**Table 6.4. XRF Analyzed Compositions of Discharged Glasses from Test 4
 (AZ-101 with variable amounts of sugar) (continued).
 (wt%)**

Test#		4D				4E						Whole Test	
Sugar added (g/l)		12.5				16.0							
Glass (kg)		5422.5	5826.5	6232.5	6642.5	7054.0	7487.5	7897.0	8298.0	8708.0	8955.5		
Constituent	Target	1H2-G-60A	1H2-G-72A	1H2-G-97A	1H2-G-105A	1H2-G-128B	1H2-G-138A	1I2-G-9A	1I2-G-25A	1I2-G-38A	1I2-G-47A	Avg.	%Dev.
Al ₂ O ₃	5.21	5.60	5.90	5.89	5.99	5.67	6.07	6.08	6.12	6.09	6.01	5.95	14.31
B ₂ O ₃ *	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91	NC	NC
BaO	0.02	0.06	0.06	0.06	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	NC
CaO	0.28	0.40	0.39	0.38	0.39	0.40	0.40	0.39	0.41	0.39	0.40	0.40	NC
CdO	0.06	0.06	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	NC
Cl	§	0.01	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	NC
Cr ₂ O ₃	§	<0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01	0.01	0.01	<0.01	0.01	NC
Cs ₂ O	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	NC
CuO	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	NC
F	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NC	NC
Fe ₂ O ₃	12.26	11.22	11.05	10.82	11.36	11.14	11.11	10.84	11.14	11.07	11.42	11.08	-9.58
K ₂ O	0.03	0.13	0.18	0.18	0.14	0.13	0.15	0.14	0.15	0.15	0.15	0.16	NC
La ₂ O ₃	0.41	0.41	0.41	0.40	0.41	0.40	0.41	0.41	0.40	0.42	0.42	0.41	-0.21
Li ₂ O*	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	NC	NC
MgO	0.11	0.07	0.11	0.12	0.07	0.06	0.09	0.07	0.11	0.06	0.04	0.08	NC
MnO	0.17	0.18	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	NC
Na ₂ O	11.65	11.46	10.87	11.35	10.99	11.40	11.28	11.79	11.29	11.46	10.93	11.33	-2.78
Nd ₂ O ₃	0.31	0.29	0.28	0.29	0.30	0.30	0.28	0.28	0.30	0.30	0.31	0.29	NC
NiO	0.62	0.47	0.45	0.42	0.44	0.43	0.44	0.41	0.41	0.40	0.42	0.47	-24.83
P ₂ O ₅	§	<0.01	0.01	<0.01	0.01	<0.01	0.01	0.02	0.01	<0.01	0.01	0.01	NC
PbO	0.03	0.03	0.02	0.03	0.01	0.03	0.03	0.02	0.03	0.02	0.03	0.03	NC
RuO ₂	¶	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NC
SiO ₂	47.40	47.56	48.12	48.13	47.56	47.79	47.52	47.58	47.40	47.48	47.46	47.57	0.35
SO ₃	0.08	0.03	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.04	NC
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	NC
TiO ₂	§	0.10	0.09	0.09	0.11	0.09	0.10	0.10	0.10	0.10	0.10	0.10	NC
Y ₂ O ₃	¶	0.10	0.10	0.10	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.07	NC
ZnO	2.02	1.74	1.71	1.65	1.76	1.71	1.71	1.66	1.70	1.70	1.74	1.70	-15.69
ZrO ₂	3.82	4.59	4.48	4.41	4.59	4.59	4.56	4.36	4.57	4.52	4.72	4.53	18.54
SUM	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target values

NA – Not analyzed

NC – Not calculated

§ Not a target constituent

¶ Added at expense of all other constituents (targets: RuO₂, 0.09 wt% and Y₂O₃, 0.10 wt%)

Table 6.5. Listing of Glass Grab Samples and Measured Iron Oxidation State.

Test	Segment	g/l Sugar	Date	Time	Name	Glass (kg)	Fe ²⁺ / Total Fe
C-106/AY-102	5A	0.0	05/01/03	07:15	S12-N-11A	726.8	0.04
	5B	10.0	05/02/03	06:58	S12-N-50A	1969.3	0.07
			05/03/03	05:35	S12-N-90A	2798.7	0.05
				07:16	S12-N-91A	2851.0	0.07
	5C	15.0	05/04/03	06:34	S12-N-131A	3806.0	0.09
			05/05/03	07:01	T12-N-25A	4888.1	0.12
				07:34	T12-N-25B	4944.4	NA
	5D	17.5	05/06/03	06:17	T12-N-64A	5920.5	0.22
				07:55	T12-N-66A	5962.3	0.17
				12:56	T12-N-71B	6046.0	0.22
		20.0	05/07/03	06:15	T12-N-105A	6576.7	NA
				07:15	T12-N-105B	6627.3	0.27
				20:49	T12-N-127A	7039.2	0.25
	5E	25.0	05/08/03	06:33	T12-N-142A	7347.0	NA
			05/09/03	04:44	U12-N-31A	8124.0	0.21
				14:39	U12-N-46A	8404.5	NA
				15:36	U12-N-47A	8492.7	0.24
				19:19	U12-N-48A	8580.6	0.18
		0.0	05/10/03	03:45	U12-N-60A	8668.5	0.06
C-106/AY-102 Added Nitrate	6A	0.0	05/15/03	06:35	U12-N-111A	656.2	0.03
	6B	10.0	05/16/03	07:47	U12-N-151A	1642.5	0.03
			05/17/03	07:24	V12-N-38A	2819.8	0.04
				08:54	V12-N-39A	2920.7	0.04
	6C	15.0	05/18/03	07:33	V12-N-79A	4145.1	0.07
			05/19/03	06:49	V12-N-114A	5298.4	0.06
				07:48	V12-N-115A	5349.0	0.06
	6D	20.0	05/20/03	06:57	V12-N-152A	6462.5	0.11
				11:44	W12-N-5A	6614.0	0.08
			05/21/03	07:16	W12-N-39A	7680.4	0.10
				08:01	W12-N-40A	7726.8	0.10
	6E	25.0	05/22/03	07:31	W12-N-77A	8826.7	0.22
				08:20	W12-N-77B	8878.1	0.22
			05/23/03	07:11	W12-N-121A	10063.3	0.29
				08:10	W12-N-122A	10114.5	0.33
				16:10	W12-N-136A	10545.8	0.28
				20:30	W12-N-137A	10611.5	0.35

NA – Not analyzed

Table 6.5. Listing of Glass Grab Samples and Measured Iron Oxidation State (continued).

Test	Segment	g/l Sugar	Date	Time	Name	Glass (kg)	Fe ²⁺ / Total Fe
AZ-101	4B	13.3	08/20/03	12:40	1G2-N-21A	756.6	NA
				15:49	1G2-N-22A	857.2	NA
				18:38	1G2-N-40A	957.8	NA
				21:26	1G2-N-42A	1059.3	0.07
		13.3	08/21/03	00:28	1G2-N-45A	1160.8	0.18
				03:44	1G2-N-46B	1262.3	0.10
				06:38	1G2-N-49A	1364.4	0.15
				10:08	1G2-N-54A	1467.1	0.21
				11:47	1G2-N-57A	1569.9	NA
				14:39	1G2-N-59A	1672.6	0.25
				16:35	1G2-N-61A	1775.6	0.13
				19:17	1G2-N-78A	1878.9	0.20
				20:41	1G2-N-79A	1930.5	0.21
		7.6	08/22/03	00:26	1G2-N-82A	2085.4	0.24
				02:44	1G2-N-86A	2188.5	0.14
				03:58	1G2-N-87A	2240.0	0.19
				07:32	1G2-N-91A	2394.5	0.18
				09:49	1G2-N-100A	2497.5	0.15
				12:25	1G2-N-103A	2601.4	0.29
				14:58	1G2-N-105A	2706.1	0.27
				17:52	1G2-N-108A	2810.9	0.26
				20:05	1G2-N-118A	2915.6	NA
				22:58	1G2-N-122A	3019.2	0.28
	4C	10.0	08/23/03	01:38	1G2-N-124A	3121.6	NA
				03:02	1G2-N-125B	3172.8	0.28
				06:55	1G2-N-129A	3326.3	0.28
				09:05	1G2-N-139A	3428.1	NA
				11:33	1G2-N-142A	3529.4	NA
				13:44	1G2-N-145A	3630.6	0.24
				16:41	1G2-N-149A	3731.9	0.24
				19:44	1G2-N-151A	3834.9	0.25
			08/24/03	21:39	1G2-N-154A	3939.8	NA
				23:55	1G2-N-155A	4044.7	NA
				00:49	1H2-N-5A	4097.1	0.29
				03:04	1H2-N-9A	4202.0	NA
				07:11	1H2-N-12A	4352.8	0.27
				09:23	1H2-N-29A	4453.3	NA
				11:41	1H2-N-31A	4553.8	0.26

NA – Not analyzed

Table 6.5. Listing of Glass Grab Samples and Measured Iron Oxidation State (continued).

Test	Segment	g/l Sugar	Date	Time	Name	Glass (kg)	Fe ²⁺ / Total Fe
AZ-101	4D	12.5	08/24/03	14:11	1H2-N-36A	4655.2	0.25
				15:25	1H2-N-37A	4706.4	0.29
				19:18	1H2-N-39A	4859.9	0.26
				20:44	1H2-N-48A	4911.1	0.31
				22:57	1H2-N-51A	5013.5	0.25
			08/25/03	02:46	1H2-N-54A	5166.9	0.24
				05:05	1H2-N-57A	5269.1	0.29
				06:49	1H2-N-58B	5371.4	NA
				08:16	1H2-N-60A	5422.5	NA
				11:33	1H2-N-63A	5574.0	NA
				13:26	1H2-N-65A	5675.0	0.33
				16:37	1H2-N-70A	5776.0	0.38
				18:59	1H2-N-74A	5877.3	0.24
				20:53	1H2-N-91A	5978.8	0.31
				22:26	1H2-N-92A	6029.5	0.33
			08/26/03	02:06	1H2-N-95A	6181.8	0.34
				04:15	1H2-N-99A	6283.8	0.41
				06:35	1H2-N-100A	6386.3	0.34
				07:34	1H2-N-101A	6488.8	0.31
				10:34	1H2-N-103A	6591.3	0.33
				13:03	1H2-N-106A	6693.9	NA
				14:27	1H2-N-109A	6796.8	NA
				18:06	1H2-N-119A	6899.7	0.36
				20:44	1H2-N-128A	7002.6	NA
				22:53	1H2-N-131A	7108.2	NA
	4E	16.0	08/27/03	00:53	1H2-N-133A	7216.6	NA
				03:14	1H2-N-135A	7334.9	0.38
				05:31	1H2-N-137A	7433.3	NA
				07:47	1H2-N-139A	7538.7	0.39
				10:52	1H2-N-145A	7641.1	NA
				12:54	1H2-N-147A	7743.4	0.41
				15:45	1I2-N-5A	7845.8	NA
				18:11	1I2-N-10A	7947.1	0.46
				20:01	1I2-N-18A	8047.4	0.51
				22:46	1I2-N-20A	8147.6	0.41
			08/28/03	01:33	1I2-N-23A	8247.9	NA
				02:43	1I2-N-25A	8349.3	NA
				05:40	1I2-N-27A	8451.8	NA
				08:16	1I2-N-36A	8554.3	0.48
				09:15	1I2-N-37A	8656.8	0.34
				12:42	1I2-N-41A	8790.5	0.38
				13:56	1I2-N-42A	8873.0	NA
				18:29	1I2-N-47A	8955.5	NA

NA – Not analyzed

Table 6.6. Measured Iron Oxidation State of Discharge Glasses.

Test	Segment	g/l Sugar	Date	Time	Name	Glass (kg)	Fe ²⁺ /Total Fe
C-106/AY-102	5B	10.0	05/01/03	22:00	S12-G-34B	1550.5	0.07
			05/02/03	11:11	S12-G-54A	2074.0	0.03
				23:40	S12-G-75A	2589.5	0.06
			05/03/03	13:46	S12-G-107A	3112.5	0.05
	5C	15.0	05/04/03	02:34	S12-G-127B	3637.0	0.09
			05/05/03	01:32	T12-G-19A	4663.0	0.17
				12:50	T12-G-38A	5169.5	0.25
	5D	17.5	05/06/03	02:41	T12-G-60A	5795.0	0.21
		20.0		17:29	T12-G-82A	6171.5	0.23
		05/07/03	11:11	T12-G-108A	6678.0	0.25	
	5E	25.0	05/08/03	01:04	T12-G-130A	7194.0	0.23
				17:04	U12-G-13A	7704.0	0.24
			05/09/03	09:40	U12-G-35A	8229.0	0.36
		0.0	05/10/03	03:45	U12-G-60A	8668.5	0.03
C-106/AY-102 Added Nitrate	6A	0.0	05/15/03	02:03	U12-G-108A	519.0	0.01
				13:20	U12-G-118A	1022.0	0.02
	6B	10.0	05/16/03	05:35	U12-G-148B	1489.1	0.05
				16:30	V12-G-19A	2048.5	0.05
			05/17/03	02:09	V12-G-34A	2567.5	0.08
				12:26	V12-G-43A	3072.0	0.03
				21:15	V12-G-62A	3557.5	0.02
	6C	15.0	05/18/03	06:55	V12-G-77A	4083.0	0.04
			05/19/03	02:37	V12-G-110B	5096.0	0.05
				12:57	V12-G-128A	5602.0	0.04
				23:38	V12-G-139A	6119.5	0.19
	6D	20.0	05/20/03	21:02	W12-G-23A	7123.0	0.15
				07:16	W12-G-39B	7690.9	0.14
	6E	25.0	05/22/03	03:46	W12-G-73B	8672.5	0.19
				14:02	W12-G-92B	9186.5	0.15
				23:41	W12-G-99A	9705.5	0.26
			05/23/03	10:16	W12-G-124A	10218.5	0.36
AZ-101	4A	0.0	08/20/03	05:29	1G2-G-16A	508.5	0.03
	4B	13.3		17:28	1G2-G-24A	907.0	0.11

Table 7.1. Summary of Method 29 Particulate Matter Results.

	Outlet Location / Run	Sampling Interval	Total wt. gain (mg)	Meter Volume (dscf)	Conc. (mg/dscf)	Flow Rate (dscfm)	Emission Rate (mg/min)	Moisture (% Vol.)	% Isokinetic
Test 5	Melter R1	05/02/03 15:30 16:00, 18:05 - 18:35	939.5	19.885	47.2	196.36	9268	19.5	92.4
	Melter R2	05/04/03 15:08 - 16:08	788.5 ^{\$}	21.972	35.9	160.23	5750	24.1	106.8
	Melter R3	05/06/03 18:45 - 19:45	326.3	20.277	16.1	163.53	2633	18.1	96.6
	Melter R4	05/08/03 10:19 - 10:29, 11:28 - 11:56	347.4	16.405	21.2	214.24	4542	19.5	94.8
	SBS R1	05/02/03 14:49 - 15:59	100.2	47.497	2.11	250.83	529	7.41	93.6
	SBS R2	05/04/03 14:50 - 16:50	209.8	57.672	3.64	223.3	812	8.06	102.8
	SBS R3	05/06/03 16:03 - 18:03	131.5	58.057	2.30	221.91	503	8.91	104.2
	SBS R4	05/08/03 11:20 - 13:20	126.8	52.777	2.40	219.63	528	7.98	95.7
	WESP R1a-c	05/06/03 14:58 - 05/08/03 03:50	86.5	1522.88	0.0634	224.25	14.2	7.26*	93.3 / 96.9 / 94.6
Test 6	Melter R1	05/16/03 15:57 - 16:35	645.2	14.803	43.6	203.06	8853	26.4	103.9
	Melter R2	05/18/03 16:04 - 16:21	309.6	6.744	45.9	184.98	8491	27.1	102.9
	Melter R3	05/20/03 16:40 - 16:58	400.2	7.043	56.8	174.35	9903	29.2	104.9
	Melter R4	05/22/03 17:55 - 18:10	397.6	9.158	43.4	161.94	7028	32.2	176.2
	SBS R1	05/16/03 15:51 - 17:01	83.1	37.498	2.22	232.63	516	8.10	98.9
	SBS R2	05/18/03 15:52 - 17:26	150.7	49.659	3.03	227.39	690	7.97	100.2
	SBS R3	05/20/03 16:23 - 17:09	95.9	22.031	4.40	206.79	900	8.78	100.4
	SBS R4	05/22/03 17:55 - 19:00	188.3	30.936	6.10	220.40	1342	8.85	100.2
	WESP R1a-b	05/21/03 08:47 - 05/22/03 08:45	128.0	991.34	0.129	209.60	27.1	7.06	98.3
	WESP R1c	05/22/03 10:55 - 13:38	92.7	122.457	0.757	230.960	174.8	7.27	96.7
Test 4	Melter R1	08/22/03 10:42 - 11:42	2065.5	36.024	57.3	179.78	10308	28.7	100.1
	Melter R2	08/24/03 09:09 - 10:09	1905.8	37.357	51.0	178.53	9108	27.8	104.6
	Melter R3	08/26/03 07:38 - 09:38	1506.6	36.520	41.3	170.41	7030	30.1	107.1
	Melter R4	08/27/03 14:55 - 15:55	1413.5	39.288	36.0	185.35	6669	30.6	105.9
	SBS R1	08/22/03 09:45 - 11:45	25.2	63.607	0.396	224.38	88.9	8.97	99.4
	SBS R2	08/24/03 08:38 - 10:38	1.9	64.838	0.029	230.40	6.75	8.04	100.7
	SBS R3	08/26/03 07:38 - 09:38	16.4	64.160	0.256	225.78	57.7	8.59	101.7
	SBS R4	08/27/03 14:24 - 16:24	49.3	58.322	0.845	221.50	187.0	9.27	94.3
	WESP R1a-b	08/22/03 13:14 - 08/24/03 20:16	2.7	772.673	0.0035	226.28	0.79	7.56	105.4 / 98.8
	WESP R2a-b	08/25/03 08:11 - 08/27/03 13:28	4.9	761.135	0.0064	223.54	1.44	8.31	100.3 / 100.2

* - Represents average of WESP Runs

\$ - Mass is calculated from DCP analysis of front-half nitric acid rinse instead of water drydown.

Table 7.2. Results from Test 5B Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total [§]	508300	9268	1.8	54.8	529	5.71	17.5
	Al	16931	177.60	1.05	95.3	1.04	0.59	170.8
	As	871	74.77	8.59	11.6	11.8	15.78	6.3
	B	17631	326.94	1.85	53.9	4.89	1.50	66.9
	Ca	1297	28.50	2.20	45.5	< 0.10	< 0.35	> 285.0
	Cd	0	15.57	NC	NC	2.98	19.14	5.2
	Cl	666	NA	NA	NA	NA	NA	NA
	Cr	331	0.63	0.19	525.4	0.11	17.46	5.7
	Cs	285	21.28	7.46	13.4	1.28	6.02	16.6
	Cu	193	2.40	1.24	80.4	< 0.10	< 4.17	> 24.0
	Fe	53219	779.54	1.46	68.3	2.08	0.27	374.8
	I	605	< 0.10	< 0.01	> 6050	< 0.10	NC	NC
	Li	8459	70.93	0.84	119.3	1.72	2.42	41.2
	Mg	4268	60.25	1.41	70.8	< 0.10	< 0.20	> 602.5
	Mn	18742	69.14	0.37	271.1	0.16	0.23	432.1
	Na	53101	729.29	1.37	72.8	25.93	3.56	28.1
	Ni	808	7.67	0.95	105.3	0.28	3.65	27.4
	P	238	9.57	4.02	24.9	0.63	6.58	15.2
	Pb	786	18.72	2.38	42.0	2.05	10.95	9.1
	S	0	86.66	NC	NC	9.83	11.34	8.8
	Sb	1264	24.27	1.92	52.1	< 0.10	< 0.41	> 242.7
	Se	1593	915.61	57.48	1.7	313.69	34.26	2.9
	Si	133037	793.55	0.60	167.6	5.46	0.69	145.3
	Sr	4707	66.53	1.41	70.8	< 0.10	< 0.15	> 665.3
	Ti	508	14.39	2.83	35.3	0.16	1.11	89.9
	Zn	10061	152.48	1.52	66.0	1.34	0.88	113.8
	Zr	1164	9.18	0.79	126.8	0.22	2.40	41.7
Gas	B	17631	129.34	0.73	136.3	12.83	9.92	10.1
	Cl	666	86.56	13.01	7.7	53.56	61.88	1.6
	F	0	54.44	NC	NC	< 0.10	< 0.18	> 544.4
	I	605	319.54	52.82	1.9	7.23	2.26	44.2
	S	0	66.99	NC	NC	2.11	3.15	31.7
	Se	1593	35.97	2.26	44.3	34.51	95.94	1.0

[§] - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

NC – Not calculated

NA – Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.3. Results from Test 5C Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total ^s	609300	5750	0.94	106.0	812	14.12	7.1
	Al	20289	75.06	0.37	270.3	1.12	1.49	67.0
	As	1043	83.86	8.04	12.4	12.59	15.01	6.7
	B	21128	97.47	0.46	216.8	3.00	3.08	32.5
	Ca	1555	8.94	0.58	173.9	< 0.10	< 1.12	> 89.4
	Cd	0	12.26	NC	NC	2.21	18.03	5.5
	Cl	798	NA	NA	NA	NA	NA	NA
	Cr	397	0.39	0.10	1018	< 0.10	< 25.64	> 3.9
	Cs	342	8.86	2.59	38.6	2.83	31.94	3.1
	Cu	232	1.41	0.61	164.5	< 0.10	< 7.09	> 14.1
	Fe	63775	289.77	0.45	220.1	1.7	0.59	170.5
	I	725	< 0.10	< 0.02	> 7250	< 0.10	NC	NC
	Li	10137	28.39	0.28	357.1	1.4	4.93	20.3
	Mg	5115	29.48	0.58	173.5	< 0.10	< 0.34	> 294.8
	Mn	22459	57.50	0.26	390.6	0.23	0.40	250.0
	Na	63634	331.38	0.52	192.0	32.47	9.80	10.2
	Ni	969	4.54	0.47	213.4	< 0.10	< 2.20	> 45.4
	P	285	2.50	0.88	114.0	0.13	5.20	19.2
	Pb	942	33.87	3.59	27.8	3.91	11.54	8.7
	S	0	39.68	NC	NC	7.35	18.52	5.4
	Sb	1515	16.37	1.08	92.5	0.49	2.99	33.4
	Se	1909	1277.55	66.93	1.5	290.79	22.76	4.4
	Si	159424	419.93	0.26	379.6	5.2	1.24	80.8
	Sr	5640	28.51	0.51	197.8	0.17	0.60	167.7
	Ti	608	5.46	0.90	111.4	0.23	4.21	23.7
	Zn	12057	63.60	0.53	189.6	2.11	3.32	30.1
	Zr	1395	5.08	0.36	274.6	< 0.10	< 1.97	> 50.8
Gas	B	21128	101.84	0.48	207.5	6.78	6.66	15.0
	Cl	798	241.55	30.29	3.3	21.15	8.76	11.4
	F	0	16.69	NC	NC	< 0.10	< 0.60	> 166.9
	I	725	419.76	57.90	1.7	< 0.10	< 0.03	> 4198
	S	0	100.06	NC	NC	0.23	0.23	435.0
	Se	1909	64.25	3.37	29.7	22.65	35.25	2.8

^s - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.4. Results from Test 5D Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS Emissions	DF Across WESP	Cumulative DF
Particulate	Total [§]	490200	2633	0.54	186.2	503	19.10	5.2	14.2	2.82	35.4	34521
	Al	16325	27.00	0.17	604.6	0.95	3.52	28.4	< 0.10	> 10.53	> 9.5	>163250
	As	839	54.13	6.45	15.5	11.88	21.95	4.6	0.31	0.03	38.3	2707
	B	16999	46.12	0.27	368.6	1.25	2.71	36.9	< 0.10	> 8.00	> 12.5	> 169990
	Ca	1251	1.24	0.10	1009	< 0.10	< 8.06	> 12.4	< 0.10	NC	NC	> 12510
	Cd	0	3.24	NC	NC	1.07	33.02	3.0	< 0.10	> 9.35	> 10.7	NC
	Cl	642	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cr	319	0.42	0.13	759.5	< 0.10	< 23.81	> 4.2	< 0.10	NC	NC	> 3190
	Cs	275	8.00	2.91	34.4	1.67	20.88	4.8	< 0.10	> 5.99	> 16.7	> 2750
	Cu	186	0.56	0.30	332.1	< 0.10	< 17.86	> 5.6	< 0.10	NC	NC	> 1860
	Fe	51313	133.39	0.26	384.7	2.61	1.96	51.1	< 0.10	> 3.83	> 26.1	> 513130
	I	583	< 0.10	< 0.02	> 5830	< 0.10	NC	NC	< 0.10	NC	NC	> 5830
	Li	8156	16.50	0.20	494.3	1.68	10.18	9.8	< 0.10	> 5.95	> 16.8	> 81560
	Mg	4115	10.19	0.25	403.8	< 0.10	< 0.98	> 101.9	< 0.10	NC	NC	> 41150
	Mn	18071	10.00	0.06	1807	2.18	21.80	4.6	< 0.10	> 4.59	> 21.8	> 180710
	Na	51200	201.85	0.39	253.7	31.41	15.56	6.4	0.69	2.20	45.5	74203
	Ni	779	1.91	0.25	407.9	< 0.10	< 5.24	> 19.1	< 0.10	NC	NC	> 7790
	P	229	< 0.10	< 0.04	> 2290	< 0.10	NC	NC	< 0.10	NC	NC	> 2290
	Pb	758	14.97	1.97	50.6	2.88	19.24	5.2	< 0.10	> 3.47	> 28.8	> 7580
	S	0	36.48	NC	NC	11.57	31.72	3.2	0.18	1.56	64.3	NC
	Sb	1219	4.73	0.39	257.7	0.28	5.92	16.9	< 0.10	> 35.71	> 2.8	> 12190
	Se	1536	560.58	36.50	2.7	172.17	30.71	3.3	1.40	0.81	123.0	1097
	Si	128273	118.57	0.09	1082	7.88	6.65	15.0	< 0.10	> 1.27	> 78.8	> 1282730
	Sr	4538	10.74	0.24	422.5	0.12	1.12	89.5	< 0.10	> 83.33	> 1.2	> 45380
Ti	490	2.49	0.51	196.8	0.13	5.22	19.2	< 0.10	> 76.92	> 1.3	> 4900	
Zn	9701	26.70	0.28	363.3	1.43	5.36	18.7	< 0.10	> 6.99	> 14.3	> 97010	
Zr	1123	1.02	0.09	1101	< 0.10	< 9.80	> 10.2	< 0.10	NC	NC	> 11230	
Gas	B	16999	67.94	0.40	250.2	6.13	9.02	11.1	0.49	7.99	12.5	34692
	Cl	642	200.68	31.28	3.2	44.37	22.11	4.5	0.92	2.07	48.2	697.8
	F	0	6.97	NC	NC	< 0.10	< 1.43	> 69.7	< 0.10	NC	NC	NC
	I	583	294.45	50.48	2.0	0.75	0.25	392.6	0.14	18.67	5.4	4164
	S	0	52.21	NC	NC	0.72	1.38	72.5	0.15	20.83	4.8	NC
	Se	1536	117.94	7.68	13.0	89.71	76.06	1.3	6.93	7.72	12.9	221.6

[§] - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

- WESP sampling was approximately 24 hours during Test 5D and approximately 12 hours during Test 5E, one deluge occurred during sampling.

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.5. Results from Test 5E Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total ^{\$}	455200	4542	1.00	100.2	528	11.62	8.6
	Al	15159	55.10	0.36	275.1	0.38	0.69	145.0
	As	779	79.28	10.17	9.8	16.62	20.96	4.8
	B	15785	100.15	0.63	157.6	1.16	1.16	86.3
	Ca	1162	4.10	0.35	283.4	< 0.10	< 2.44	> 41.0
	Cd	0	2.98	NC	NC	0.91	30.54	3.3
	Cl	596	NA	NA	NA	NA	NA	NA
	Cr	296	0.31	0.10	954.8	< 0.10	< 32.26	> 3.1
	Cs	255	9.44	3.70	27.0	1.66	17.58	5.7
	Cu	173	1.10	0.63	157.3	< 0.10	< 9.09	> 11.0
	Fe	47648	253.96	0.53	187.6	0.94	0.37	270.2
	I	542	< 0.10	< 0.02	> 5420	< 0.10	NC	NC
	Li	7574	26.87	0.35	281.9	1.8	6.70	14.9
	Mg	3821	21.65	0.57	176.5	< 0.10	< 4.62	> 216.5
	Mn	16780	23.09	0.14	726.7	0.12	0.52	192.4
	Na	47543	345.78	0.73	137.5	30.86	8.92	11.2
	Ni	724	2.88	0.40	251.4	< 0.10	< 3.47	> 28.8
	P	213	< 0.10	< 0.05	> 2130	< 0.10	NC	NC
	Pb	704	13.96	1.98	50.4	2.26	16.19	6.2
	S	0	42.23	NC	NC	7.78	18.42	5.4
	Sb	1132	4.83	0.43	234.4	0.34	7.04	14.2
	Se	1426	862.81	60.50	1.7	132.46	15.35	6.5
	Si	119110	250.35	0.21	475.8	2.57	1.03	97.4
	Sr	4214	22.15	0.53	190.2	< 0.10	< 0.45	> 221.5
	Ti	455	4.46	0.98	102.0	< 0.10	< 2.24	> 44.6
	Zn	9008	51.02	0.57	176.6	1.38	2.70	37.0
	Zr	1043	2.34	0.22	445.7	< 0.10	< 4.27	> 23.4
Gas	B	15785	86.57	0.55	182.3	5.77	6.67	15.0
	Cl	596	83.49	14.01	7.1	38.12	45.66	2.2
	F	0	11.08	NC	NC	< 0.10	< 0.90	> 110.8
	I	542	370.23	68.35	1.5	0.87	0.23	425.6
	S	0	46.92	NC	NC	0.68	1.45	69.0
	Se	1426	30.92	2.17	46.1	31.48	101.81	1.0

^{\$} - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.6. Results from Emissions Sampling Test 6B.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total [§]	688000	8853	1.29	77.7	516	5.83	17.2
	Al	23321	91.63	0.39	254.5	0.34	0.37	269.5
	As	1199	35.20	2.94	34.1	7.64	21.70	4.6
	B	24284	202.75	0.83	119.8	2.38	1.17	85.2
	Ca	1787	14.14	0.79	126.4	0.31	2.19	45.6
	Cd	0	2.85	NC	NC	0.16	5.61	17.8
	Cl*	917	250.2	27.3	3.7	NA	NA	NA
	Cr	456	6.54	1.43	69.7	1.00	15.29	6.5
	Cs	393	12.16	3.09	32.3	2.61	21.46	4.7
	Cu	266	2.13	0.80	124.9	< 0.10	< 4.69	> 21.3
	F*	0	471.7	NC	NC	NA	NA	NA
	Fe	73305	568.27	0.78	129.0	0.85	0.15	668.6
	I	0	< 0.10	NC	NC	< 0.10	NC	NC
	Li	11652	69.00	0.59	168.9	3.61	5.23	19.1
	Mg	5879	56.25	0.96	104.5	0.2	0.36	281.3
	Mn	25815	70.51	0.27	366.1	< 0.10	< 0.14	> 705.1
	Na	73142	638.03	0.87	114.6	51.65	8.10	12.4
	Ni	1113	7.99	0.72	139.3	< 0.10	< 1.25	> 79.9
	P	327	3.19	0.97	102.5	2.06	64.58	1.5
	Pb	1083	4.19	0.39	258.5	0.38	9.07	11.0
	S	0	83.90	NC	NC	19.95	23.78	4.2
	Sb	1741	8.71	0.50	199.9	0.43	4.94	20.3
	Se	2194	1356.12	61.81	1.6	234.46	17.29	5.8
	Si	183246	643.24	0.35	284.9	1.56	0.24	412.3
	Sr	6483	51.21	0.79	126.6	< 0.10	< 0.20	> 512.1
	Ti	699	10.26	1.47	68.1	< 0.10	< 0.97	> 102.6
	Zn	13859	114.57	0.83	121.0	0.75	0.65	152.8
	Zr	1604	8.15	0.51	196.8	< 0.10	< 1.23	> 81.5
Gas	B	24284	231.04	0.95	105.1	13.02	5.64	17.7
	Cl	917	120.50	13.15	7.6	44.66	37.06	2.7
	F	0	34.43	NC	NC	< 0.10	< 0.29	> 344.3
	I	0	< 0.10	NC	NC	< 0.10	NC	NC
	S	0	17.94	NC	NC	4.43	24.69	4.0
	Se	2194	36.31	1.65	60.4	91.94	253.21	0.4

[§] - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

^{*} - From water dissolution of filter particulate

NC – Not calculated

NA – Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.7. Results from Test 6C Emissions Sampling.

		-	Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total ^{\$}	688000	8491	1.23	81.0	690	8.13	12.3	
	Al	23321	91.46	0.39	255.0	0.25	0.27	365.8	
	As	1199	116.62	9.73	10.3	23.98	20.56	4.9	
	B	24284	195.42	0.80	124.3	5.31	2.72	36.8	
	Ca	1787	5.24	0.29	341.0	0.11	2.10	47.6	
	Cd	0	4.94	NC	NC	0.34	6.88	14.5	
	Cl	917	NA	NA	NA	NA	NA	NA	
	Cr	456	2.45	0.54	186.1	0.24	9.80	10.2	
	Cs	393	6.48	1.65	60.6	2.1	32.41	3.1	
	Cu	266	2.03	0.76	131.0	< 0.10	< 4.93	> 20.3	
	Fe	73305	653.79	0.89	112.1	1.51	0.23	433.0	
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	
	Li	11652	67.81	0.58	171.8	3.98	5.87	17.0	
	Mg	5879	56.01	0.95	105.0	0.14	0.25	400.1	
	Mn	25815	72.59	0.28	355.6	< 0.10	< 0.14	> 725.9	
	Na	73142	653.28	0.89	112.0	51.37	7.86	12.7	
	Ni	1113	8.97	0.81	124.1	< 0.10	< 1.11	> 89.7	
	P	327	8.83	2.70	37.0	2.14	24.24	4.1	
	Pb	1083	6.88	0.64	157.4	1.82	26.45	3.8	
	S	0	42.86	NC	NC	16.02	37.38	2.7	
	Sb	1741	6.91	0.40	252.0	0.25	3.62	27.6	
	Se	2194	1609.78	73.37	1.4	302.04	18.76	5.3	
	Si	183246	691.18	0.38	265.1	1.47	0.21	470.2	
	Sr	6483	49.57	0.76	130.8	< 0.10	< 0.20	> 495.7	
	Ti	699	11.52	1.65	60.7	< 0.10	< 0.87	> 115.2	
	Zn	13859	120.56	0.87	115.0	1.7	1.41	70.9	
	Zr	1604	8.40	0.52	191.0	< 0.10	< 1.19	> 84.0	
Gas	B	24284	242.23	1.00	100.3	15.57	6.43	15.6	
	Cl	917	31.88	3.48	28.8	37.41	117.35	0.9	
	F	0	< 0.10	NC	NC	< 0.10	NC	NC	
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	
	S	0	62.07	NC	NC	0.53	0.85	117.1	
	Se	2194	5.35	0.24	410.1	82.26	1537.57	0.1	

^{\$} - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.8. Results from Test 6D Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS Emissions	DF Across WESP	Cumulative DF
Particulate	Total ^{\$}	688000	9903	1.44	69.5	900	9.09	11.0	27.1	3.01	33.2	25388
	Al	23321	106.43	0.46	219.1	0.35	0.33	304.1	0.12	34.29	2.9	194342
	As	1199	191.00	15.93	6.3	33.83	17.71	5.6	1.33	3.93	25.4	901.5
	B	24284	208.15	0.86	116.7	5.43	2.61	38.3	0.17	3.13	31.9	142847
	Ca	1787	17.05	0.95	104.8	0.54	3.17	31.6	0.27	50.00	2.0	6619
	Cd	0	3.69	NC	NC	0.54	14.63	6.8	0.18	33.33	3.0	NC
	Cl	917	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cr	456	1.54	0.34	296.1	0.14	9.09	11.0	< 0.10	< 71.43	> 1.4	> 4560
	Cs	393	15.59	3.97	25.2	1.47	9.43	10.6	< 0.10	< 6.80	> 14.7	> 3930
	Cu	266	2.74	1.03	97.1	< 0.10	< 3.65	> 27.4	< 0.10	NC	NC	> 2660
	Fe	73305	615.27	0.84	119.1	0.91	0.15	676.1	0.24	26.37	3.8	305438
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	< 0.10	NC	NC	NC
	Li	11652	73.65	0.63	158.2	2.94	3.99	25.1	0.22	7.48	13.4	52964
	Mg	5879	62.04	1.06	94.8	0.23	0.37	269.7	< 0.10	< 43.48	> 2.3	> 5879
	Mn	25815	82.33	0.32	313.6	< 0.10	< 0.12	> 823.3	< 0.10	NC	NC	> 258150
	Na	73142	668.59	0.91	109.4	44.54	6.66	15.0	2.21	4.96	20.2	33096
	Ni	1113	10.02	0.90	111.1	< 0.10	< 1.00	> 100.2	< 0.10	NC	NC	> 11130
	P	327	5.90	1.80	55.4	2.02	34.24	2.9	1.09	53.96	1.9	300.0
	Pb	1083	42.23	3.90	25.6	9.15	21.67	4.6	0.23	2.51	39.8	4709
	S	0	57.97	NC	NC	13.9	23.98	4.2	2.32	16.69	6.0	NC
	Sb	1741	29.29	1.68	59.4	1.16	3.96	25.3	< 0.10	< 8.62	> 11.6	> 17410
	Se	2194	1937.62	88.31	1.1	429.02	22.14	4.5	14.93	3.48	28.7	147.0
	Si	183246	731.84	0.40	250.4	0.92	0.13	795.5	0.42	45.65	2.2	436300
	Sr	6483	55.37	0.85	117.1	< 0.10	< 0.18	> 553.7	< 0.10	NC	NC	> 64830
	Ti	699	10.99	1.57	63.6	0.64	5.82	17.2	< 0.10	< 15.6	> 6.4	> 6990
	Zn	13859	119.75	0.86	115.7	1.99	1.66	60.2	0.16	8.04	12.4	86619
	Zr	1604	9.32	0.58	172.1	< 0.10	< 1.07	> 93.2	< 0.10	NC	NC	> 1604
Gas	B	24284	217.50	0.90	111.7	13.96	6.42	15.6	0.85	6.09	16.4	28569
	Cl	917	22.79	2.49	40.2	59.96	263.10	0.4	1.48	2.47	40.5	619.6
	F	0	< 0.10	NC	NC	< 0.10	NC	NC	0.18	NC	NC	NC
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	< 0.10	NC	NC	NC
	S	0	106.70	NC	NC	0.34	0.32	313.8	0.24	70.59	1.4	NC
	Se	2194	7.26	0.33	302.2	36.84	507.44	0.2	7.47	20.28	4.9	293.7

^{\$} - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

- WESP sampled 8 hours during Test 6D and 16 hours during Test 6E, one deluge occurred during sampling.

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.9. Results from Test 6E Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS Emissions	DF Across WESP	Cumulative DF
Particulate	Total [§]	688000	7028	1.02	97.9	1342	19.10	5.2	174.8	13.03	7.7	3936
	Al	23321	53.12	0.23	439.0	0.42	0.79	126.5	< 0.10	< 23.81	> 4.2	> 233210
	As	1199	304.85	25.42	3.9	55.51	18.21	5.5	4.29	7.73	12.9	279.5
	B	24284	180.61	0.74	134.5	5.99	3.32	30.2	< 0.10	< 1.67	> 59.9	> 242840
	Ca	1787	11.74	0.66	152.2	0.78	6.64	15.1	< 0.10	< 12.82	> 7.8	> 17870
	Cd	0	2.14	NC	NC	0.34	15.89	6.3	< 0.10	< 29.41	> 3.4	NC
	Cl	917	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cr	456	0.45	0.10	1013	< 0.10	< 22.22	> 4.5	< 0.10	NC	NC	> 4560
	Cs	393	12.90	3.28	30.5	2.14	16.59	6.0	0.14	6.54	15.3	2807
	Cu	266	1.66	0.62	160.2	0.14	8.43	11.9	< 0.10	< 71.43	> 1.4	> 2660
	Fe	73305	378.95	0.52	193.4	0.61	0.16	621.2	< 0.10	< 16.39	> 6.1	> 733050
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	< 0.10	NC	NC	NC
	Li	11652	53.21	0.46	219.0	3.38	6.35	15.7	0.27	7.99	12.5	43156
	Mg	5879	39.78	0.68	147.8	0.23	0.58	173.0	< 0.10	< 17.24	> 5.8	> 58790
	Mn	25815	34.94	0.14	738.8	< 0.10	< 0.29	> 349.4	0.14	NC	NC	184393
	Na	73142	571.88	0.78	127.9	49.44	8.65	11.6	3.84	7.77	12.9	19047
	Ni	1113	7.92	0.71	140.5	0.18	2.27	44.0	< 0.10	< 55.56	> 1.8	> 11130
	P	327	5.69	1.74	57.5	0.78	13.71	7.3	0.25	32.05	3.1	1308
	Pb	1083	58.71	5.42	18.4	16.7	28.44	3.5	1.49	8.92	11.2	726.8
	S	0	34.08	NC	NC	15.93	46.74	2.1	1.07	6.72	14.9	NC
	Sb	1741	22.30	1.28	78.1	1.58	7.09	14.1	0.12	7.59	13.2	14508
	Se	2194	1282.06	58.43	1.7	508.39	39.65	2.5	39.15	7.70	13.0	56.0
	Si	183246	299.98	0.16	610.9	2.13	0.71	140.8	< 0.10	< 4.69	> 21.3	> 1832460
	Sr	6483	34.35	0.53	188.7	< 0.10	< 0.29	> 343.5	< 0.10	NC	NC	> 64830
	Ti	699	6.37	0.91	109.7	< 0.10	< 1.57	> 63.7	< 0.10	NC	NC	> 6990
	Zn	13859	77.00	0.56	180.0	3.07	3.99	25.1	0.32	10.42	9.6	43309
	Zr	1604	3.08	0.19	520.8	< 0.10	< 3.25	> 30.8	< 0.10	NC	NC	> 16040
Gas	B	24284	210.62	0.87	115.3	14.71	6.98	14.3	1.89	12.85	7.8	12849
	Cl	917	40.31	4.40	22.7	16.32	40.49	2.5	5.48	33.58	3.0	167.3
	F	0	< 0.10	NC	NC	< 0.10	NC	NC	1.23	NC	NC	NC
	I	0	< 0.10	NC	NC	< 0.10	NC	NC	< 0.10	NC	NC	NC
	S	0	127.77	NC	NC	0.28	0.22	456.3	< 0.10	NC	NC	NC
	Se	2194	7.14	0.33	307.3	4.26	59.66	1.7	4.58	107.51	0.9	479.0

§ - From gravimetric analysis of filters and rinse dry downs

+ - Calculated from target concentrations and steady state production rates

- WESP sampled during Test 6E, sampled during deluge.

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.10. Results from Test 4B Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS
Particulate	Total [§]	476300	10308	2.2	46.2	88.9	0.86	116.0
	Al	19448	221.67	1.14	87.7	0.42	0.19	527.8
	B	26159	506.44	1.94	51.7	3.26	0.64	155.3
	Ba	127	1.65	1.30	77.0	< 0.10	< 6.06	> 16.5
	Ca	1418	30.15	2.13	47.0	0.75	2.49	40.2
	Cd	381	85.97	22.59	4.4	10.71	12.46	8.0
	Cl*	0	278.69	NC	NC	NA	NA	NA
	Cs	0	0.17	NC	NC	0.11	64.71	1.5
	Cu	170	1.77	1.04	96.0	< 0.10	< 5.65	> 17.7
	F*	283	335.43	118.53	NC	NA	NA	NA
	Fe	60476	881.92	1.46	68.6	2.02	0.23	436.6
	K	176	8.19	4.64	21.5	0.41	5.01	20.0
	Li	11582	86.22	0.74	134.3	1.96	2.27	44.0
	Mg	470	14.50	3.09	32.4	< 0.10	< 0.69	> 145.0
	Mn	933	7.87	0.84	118.6	0.13	1.65	60.5
	Na	61225	925.56	1.51	66.1	24.52	2.65	37.7
	Ni	3395	39.71	1.17	85.5	0.12	0.30	330.9
	Pb	197	4.64	2.35	42.5	< 0.10	< 2.16	> 46.4
	S	199	96.43*	48.46	2.1	9.83	10.19	9.8
	Si	156952	1209.72	0.77	129.7	2.43	0.20	497.8
	Sr	180	3.24	1.80	55.6	< 0.10	< 3.09	> 32.4
	Zn	11438	163.05	1.43	70.2	1.53	0.94	106.6
	Zr	19926	254.32	1.28	78.4	0.16	0.06	1590
Gas	B	26159	180.83	0.69	144.7	6.00	3.32	30.1
	Cl	0	0.51	NC	0.0	< 0.10	< 19.61	> 5.1
	F	283	1.58	0.56	179.1	< 0.10	< 6.33	> 15.8
	S	199	134.62	67.75	1.5	0.75	0.56	179.5

[§] - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

^{*} - From water dissolution of filter particulate

NC – Not calculated

NA – Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.11. Results from Test 4C Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS Emissions	DF Across WESP	Cumulative DF
Particulate	Total ^{\$}	476300	9108	1.91	52.3	80.9	0.89	113	0.79	0.98	102	602911
	Al	19448	190.33	0.98	102.2	0.28	0.15	679.8	< 0.10	< 35.71	> 2.8	> 194480
	B	26159	373.20	1.43	70.1	1.14	0.31	327.4	< 0.10	< 8.77	> 11.4	> 261590
	Ba	127	1.51	1.19	84.1	< 0.10	< 6.62	> 15.1	< 0.10	NC	NC	> 1270
	Ca	1418	24.56	1.73	57.7	0.74	3.01	33.2	< 0.10	< 13.51	> 7.4	> 14180
	Cd	381	80.52	21.16	4.7	6.13	7.61	13.1	0.18	2.94	34.1	2117
	Cl*	0	239.64	NC	NC	NA	NA	NA	NA	NA	NA	NA
	Cs	0	0.16	NC	0.0	< 0.10	< 62.5	> 1.6	< 0.10	NC	NC	NC
	Cu	170	2.58	1.52	65.9	< 0.10	< 3.88	> 25.8	< 0.10	NC	NC	> 1700
	F*	283	329.25	116.34	NC	NA	NA	NA	NA	NA	NA	NA
	Fe	60476	763.01	1.26	79.3	0.72	0.09	1060	< 0.10	< 13.89	> 7.2	> 604760
	K	176	7.46	4.23	23.6	0.53	7.10	14.1	< 0.10	< 18.87	> 5.3	> 1760
	Li	11582	66.35	0.57	174.6	1.16	1.75	57.2	< 0.10	< 8.62	> 11.6	> 115820
	Mg	470	12.04	2.56	39.0	0.11	0.91	109.5	< 0.10	< 90.91	> 1.1	> 4700
	Mn	933	7.62	0.82	122.4	0.29	3.81	26.3	< 0.10	< 34.48	> 2.9	> 9330
	Na	61225	783.65	1.28	78.1	18.43	2.35	42.5	0.38	2.06	48.5	161118
	Ni	3395	41.82	1.23	81.2	< 0.10	< 0.24	> 418.2	< 0.10	NC	NC	> 33950
	Pb	197	4.44	2.25	44.4	< 0.10	< 2.23	> 44.4	< 0.10	NC	NC	> 1970
	S	199	59.50*	29.90	3.3	9.07	15.24	6.6	0.12	1.32	75.6	1658
	Si	156952	1329.04	0.85	118.1	1.20	0.09	1108	< 0.10	< 8.33	> 12.0	> 1569520
	Sr	180	2.76	1.53	65.2	< 0.10	< 3.62	27.6	< 0.10	NC	NC	> 1800
	Zn	11438	141.97	1.24	80.6	0.78	0.55	182.0	< 0.10	< 12.82	> 7.8	> 114380
	Zr	19926	287.51	1.44	69.3	< 0.10	< 0.03	2875	< 0.10	NC	NC	> 199260
Gas	B	26159	196.60	0.75	133.1	5.32	2.71	37.0	0.66	12.41	8.1	39635
	Cl	0	1.51	NC	NC	< 0.10	< 6.62	> 15.1	0.29	NC	NC	NC
	F	283	1.43	0.51	197.9	< 0.10	< 6.99	> 14.3	< 0.10	NC	NC	> 2830
	S	199	123.28	62.04	1.6	0.86	0.70	143.3	0.16	18.60	5.4	1244

^{\$} - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

[#] - WESP sampled approximately 15 hours during Test 4C and approximately 9 hours during Test 4D, no deluge occurred during sampling.

^{*} - From water dissolution of filter particulate

NC - Not calculated

NA - Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.12. Results from Test 4D Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS	DF Across WESP	Cumulative DF
Particulate	Total ^{\$}	504300	7030	1.39	71.7	57.7	0.82	121.8	1.44	2.50	40.1	350208
	Al	20592	138.77	0.67	148.4	0.28	0.20	495.6	< 0.10	< 35.71	> 2.8	> 205920
	B	27698	324.80	1.17	85.3	4.02	1.24	80.8	< 0.10	< 2.49	> 40.2	> 276980
	Ba	134	1.14	0.85	117.5	< 0.10	< 8.77	> 11.4	< 0.10	NC	NC	1340
	Ca	1501	19.85	1.32	75.6	0.85	4.28	23.4	< 0.10	< 11.76	> 8.5	> 15010
	Cd	403	124.27	30.84	3.2	15.47	12.45	8.0	0.25	1.62	61.9	1612
	Cl*	0	231.53*	NC	NC	NA	NA	NA	NA	NA	NA	NC
	Cs	0	0.18	NC	NC	< 0.10	< 55.56	> 1.8	< 0.10	NC	NC	NC
	Cu	180	1.75	0.97	102.9	< 0.10	< 5.71	> 17.5	< 0.10	NC	NC	1800
	F*	300	216.45*	72.15	1.4	NA	NA	NA	NA	NA	NA	NA
	Fe	64034	650.75	1.02	98.4	0.92	0.14	707.3	< 0.10	< 10.87	> 9.2	> 640340
	K	187	6.18	3.31	30.3	0.67	10.84	9.2	< 0.10	< 14.93	> 6.7	> 1870
	Li	12263	52.47	0.43	233.7	1.66	3.16	31.6	< 0.10	< 6.02	> 16.6	> 122630
	Mg	497	9.56	1.92	52.0	0.15	1.57	63.7	< 0.10	< 66.67	> 1.5	> 4970
	Mn	987	5.79	0.59	170.5	0.16	2.76	36.2	< 0.10	< 62.50	> 1.6	> 9870
	Na	64827	661.54	1.02	98.0	21.64	3.27	30.6	0.44	2.03	49.2	147334
	Ni	3595	29.22	0.81	123.0	0.17	0.58	171.9	< 0.10	< 58.82	> 1.7	> 35950
	Pb	209	3.84	1.84	54.4	< 0.10	< 2.60	> 38.4	< 0.10	NC	NC	2090
	S	210	84.53*	40.25	2.5	12.65	14.97	6.7	0.11	0.87	115.0	1909
	Si	166184	898.33	0.54	185.0	1.59	0.18	565.0	< 0.10	< 6.29	> 15.9	> 1661840
	Sr	190	2.15	1.13	88.4	< 0.10	< 4.65	> 21.5	< 0.10	NC	NC	1900
	Zn	12111	118.08	0.97	102.6	1.97	1.67	59.9	< 0.10	< 5.08	> 19.7	> 121110
	Zr	21099	172.80	0.82	122.1	< 0.10	< 0.06	> 1728	< 0.10	NC	NC	210990
Gas	B	27698	182.15	0.66	152.1	5.53	3.04	32.9	0.82	14.83	6.7	33778
	Cl	0	0.83	NC	NC	< 0.10	< 12.05	> 8.3	0.33	NC	NC	NC
	F	300	4.14	1.38	72.5	< 0.10	< 2.42	> 41.4	< 0.10	NC	NC	3000
	S	210	105.45	50.12	2.0	0.38	0.36	277.5	0.18	47.37	2.1	1167

^{\$} - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

[#] - WESP sampled approximately 13.5 hours during Test 4D and approximately 12 hours during Test 4E, no deluge occurred during sampling.

* - From water dissolution of filter particulate

NC – Not calculated

NA – Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.13. Results from Test 4E Emissions Sampling.

-		Feed Flux ⁺ (mg/min)	Melter Emissions (mg/min)	Percent of Feed	DF Across Melter	SBS Emissions (mg/min)	Percent of Melter Emissions	DF Across SBS	WESP [#] Emissions (mg/min)	Percent of SBS	DF Across WESP	Cumulative DF
Particulate	Total ^s	520000	6669	1.28	78.0	187	2.8	35.7	1.44	0.77	129.9	361111
	Al	21278	119.43	0.56	178.2	0.25	0.21	477.7	< 0.10	< 40.0	> 2.5	> 212780
	B	28622	308.89	1.08	92.7	4.76	1.54	64.9	< 0.10	< 2.10	> 47.60	> 286220
	Ba	139	1.00	0.72	139.0	< 0.10	< 10.00	> 10.0	< 0.10	NC	NC	> 1390
	Ca	1551	17.44	1.12	88.9	0.56	3.21	31.1	< 0.10	< 17.86	> 5.60	> 15510
	Cd	416	147.78	35.49	2.8	24.83	16.80	6.0	0.25	1.01	99.3	1664
	Cl*	0	217.44	NC	NC	NA	NA	NA	NA	NA	NA	NC
	Cs	0	0.25	NC	NC	0.13	52.00	1.9	< 0.10	< 76.92	> 1.30	NC
	Cu	186	1.61	0.87	115.5	< 0.10	< 6.21	> 16.1	< 0.10	NC	NC	> 1860
	F*	310	396.94	128.05	NC	NA	NA	NA	NA	NC	NC	> 3100
	Fe	66168	609.93	0.92	108.5	0.91	0.15	670.3	< 0.10	< 10.99	> 9.10	> 661680
	K	193	5.83	3.02	33.1	0.39	6.69	14.9	< 0.10	< 25.64	> 3.90	> 1930
	Li	12672	52.48	0.41	241.5	1.89	3.60	27.8	< 0.10	< 5.29	> 18.90	> 126720
	Mg	514	9.11	1.77	56.4	< 0.10	< 1.10	> 91.1	< 0.10	NC	NC	> 5140
	Mn	1020	5.31	0.52	192.1	0.14	2.64	37.9	< 0.10	< 71.43	> 1.40	> 10200
	Na	66988	600.67	0.90	111.5	26.67	4.44	22.5	0.44	1.65	60.6	152246
	Ni	3715	25.80	0.69	144.0	< 0.10	< 0.39	> 258.0	< 0.10	NC	NC	> 37150
	Pb	216	3.68	1.71	58.7	0.12	3.26	30.7	< 0.10	< 83.33	> 1.20	> 2160
	S	217	78.50*	36.18	2.8	12.1	15.41	6.5	0.11	0.91	110.0	1973
	Si	171723	757.67	0.44	226.6	2.56	0.34	296.0	< 0.10	< 3.91	> 25.60	> 1717230
	Sr	197	2.12	1.08	92.9	< 0.10	< 4.72	> 21.2	< 0.10	NC	NC	> 1970
Zn	12515	108.14	0.86	115.7	2.59	2.40	41.8	< 0.10	< 3.86	> 25.90	> 125150	
Zr	21802	142.34	0.65	153.2	0.11	0.08	1294	< 0.10	< 90.91	> 1.10	> 218020	
Gas	B	28622	208.30	0.73	137.4	6.61	3.17	31.5	0.82	12.41	8.1	34905
	Cl	0	1.50	NC	NC	< 0.10	< 6.67	> 15.0	0.33	NC	NC	NC
	F	310	4.33	1.40	71.6	< 0.10	< 2.31	> 43.3	< 0.10	NC	NC	> 3100
	S	217	101.31	46.60	2.1	0.75	0.74	135.1	0.18	24.00	4.2	1206

^s - From gravimetric analysis of filters and rinse dry downs

⁺ - Calculated from target concentrations and steady state production rates

[#] - WESP sampled approximately 13.5 hours during Test 4D and approximately 12 hours during Test 4E, no deluge occurred during sampling.

^{*} - From water dissolution of filter particulate

NC – Not calculated

NA – Not available due to insufficient particulate loading for separate anion analysis

"-" Empty data field

Table 7.14 Particulate DFs for AZ-101 and C-106/AY-102 Tests at 65 lpm Bubbling.

-	AZ-101			C-106/AY-102		
Feed Solids Content (g/l)	400			550		
Feed Sugar Content (g/l)	0 [9]	10 -12.5	12.5 - 16	0 [11]	20 - 25	20 - 25
Additional Nitrate (g/l)	0	0	0	0	0	16.5
Melter DF	129	62	75	148	143	84
SBS DF	40	117	79	12	7.0	8.1
WESP DF	26	71	85	60	35	33
Cumulative DF	132,755	515,397	503,625	104,797	34,929	22,453

"-" Empty data field

Table 7.15. Particle Size Distribution Results for Test 5 Melter Emissions.

-	Cutpoint (μm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction
Test 5B 05/02/03 17:33 – 17:38	> 12.8	56.10	25.49	68.1
	9.6 – 12.8	6.34	2.88	7.7
	3.7 – 9.6	6.53	2.97	7.9
	1.9 – 3.7	2.48	1.13	3.0
	1.1 – 1.9	3.55	1.61	4.3
	0.6 – 1.1	4.92	2.23	6.0
	0.4 – 0.6	0.88	0.40	1.1
	< 0.4	1.54	0.70	1.9
Test 5C 05/04/03 17:06 – 17:10	> 16.1	40.40	34.80	63.0
	12.2 – 16.1	4.18	3.60	6.5
	4.7 – 12.2	4.47	3.85	7.0
	2.4 – 4.7	2.45	2.11	3.8
	1.4 – 2.4	2.32	1.99	3.6
	0.8 – 1.4	4.54	3.91	7.1
	0.5 – 0.8	0.93	0.80	1.4
	< 0.5	4.85	4.18	7.6
Test 5D 05/06/03 16:50 – 16:54	> 10.5	26.50	9.18	60.1
	7.9 – 10.5	3.46	1.20	7.9
	3.06 – 7.9	3.34	1.16	7.6
	1.5 – 3.06	2.31	0.80	5.2
	0.9 – 1.5	1.27	0.44	2.9
	0.5 – 0.9	4.27	1.48	9.7
	0.3 – 0.5	0.56	0.19	1.3
	< 0.3	2.35	0.81	5.3

"-" Empty data field

Table 7.16. Particle Size Distribution Results for Test 6 Melter Emissions.

-	Cutpoint (µm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction
Test 6B 05/16/03 15:38 – 15:42	> 11.1	135.90	56.60	76.7
	8.36 – 11.1	11.75	4.90	6.6
	3.23 – 8.36	9.00	3.75	5.1
	1.63 – 3.23	6.44	2.68	3.6
	0.93 – 1.63	2.34	0.98	1.3
	0.52 – 0.93	7.43	3.10	4.2
	0.32 – 0.52	0.86	0.36	0.5
	< 0.32	3.55	1.48	2.0
Test 6C 05/18/03 16:41 – 16:44	> 11.7	37.56	28.65	68.1
	8.79 – 11.7	4.29	3.27	7.8
	3.40 – 8.79	3.76	2.87	6.8
	1.71 – 3.40	3.24	2.47	5.9
	0.99 – 1.71	1.46	1.11	2.6
	0.55 – 0.99	1.58	1.21	2.9
	0.34 – 0.55	0.35	0.27	0.6
	< 0.34	2.88	2.20	5.2
Test 6D 05/20/03 16:07 – 16:10	> 11.8	27.40	22.37	69.8
	8.93 – 11.8	2.50	2.04	6.4
	3.45 – 8.93	1.72	1.40	4.4
	1.74 – 3.45	1.48	1.21	3.8
	1.00 – 1.74	0.73	0.60	1.9
	0.57 – 1.00	2.59	2.11	6.6
	0.34 – 0.57	0.81	0.66	2.1
	< 0.34	2.05	1.67	5.2
Test 6E 05/22/03 16:39 – 16:42	> 12.3	59.94	45.34	65.7
	9.2 – 12.3	4.86	3.68	5.3
	3.57 – 9.2	5.85	4.43	6.4
	1.80 – 3.57	4.46	3.37	4.9
	1.03 – 1.80	2.10	1.59	2.3
	0.58 – 1.03	6.35	4.80	7.0
	0.34 – 0.58	2.70	2.04	3.0
	< 0.34	4.98	3.77	5.5

"-" Empty data field

Table 7.17. Particle Size Distribution Results for Test 4 Melter Emissions.

-	Cutpoint (µm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction (%)
Test 4B 08/22/03 12:12 – 12:13	> 10.6	25.70	42.13	68.0
	8.03 – 10.6	4.42	7.25	11.7
	3.11 – 8.03	1.51	2.48	4.0
	1.56 – 3.11	1.08	1.77	2.9
	0.90 – 1.56	0.62	1.02	1.6
	0.51 – 0.90	0.50	0.82	1.3
	0.31 – 0.51	0.84	1.38	2.2
	< 0.31	3.14	5.15	8.3
Test 4C 08/24/03 10:28 – 10:29	> 8.03	5.95	10.88	48.3
	6.05 – 8.03	1.87	3.42	15.2
	2.34 – 6.05	1.58	2.89	12.8
	1.18 – 2.34	1.41	2.58	11.4
	0.68 – 1.18	0.72	1.32	5.8
	0.39 – 0.68	0.27	0.50	2.2
	0.24 – 0.39	0.07	0.13	0.6
	< 0.21	0.46	0.84	3.7
Test 4D 08/26/03 09:32 – 09:33	> 9.94	5.52	7.92	42.1
	7.50 – 9.94	2.56	3.67	19.5
	2.89 – 7.50	1.69	2.43	12.9
	1.46 – 2.89	1.12	1.61	8.5
	0.84 – 1.46	0.63	0.90	4.8
	0.48 – 0.84	0.83	1.19	6.3
	0.29 – 0.48	0.33	0.47	2.5
	< 0.29	0.42	0.60	3.2
Test 4E 08/27/03 16:07 – 16:08	> 9.87	8.44	15.24	64.4
	7.45 – 9.87	1.58	2.85	12.1
	2.88 – 7.45	0.99	1.79	7.6
	1.45 – 2.88	0.47	0.85	3.6
	0.84 – 1.45	0.55	0.99	4.2
	0.47 – 0.84	0.63	1.14	4.8
	0.29 – 0.47	0.05	0.09	0.4
	< 0.29	0.40	0.72	3.1

"-" Empty data field

**Table 7.18.a. Test 5 Average Concentrations [ppmv] of Selected Species in Off-Gas
Measured by FTIR Spectroscopy.**

Port	Melter Outlet					SBS Outlet					WESP Outlet				TCO Outlet				
Test	A	B	C	D	E	A	B	C	D	E	B	C	D	E	A	B	C	D	E
N ₂ O	1.4	1.1	< 1.0	< 1.0	< 1.0	1.8	1.3	< 1.0	< 1.0	< 1.0	1.5	1.0	< 1.0	< 1.0	1.4	< 1.0	< 1.0	< 1.0	< 1.0
NO	70	16	< 1.0	< 1.0	< 1.0	99	7.0	5.8	2.9	2.9	12	5.9	2.6	3.2	30	1.0	< 1.0	< 1.0	2.3
NO ₂	1.4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	38	< 1.0	< 1.0	1.2	< 1.0
NH ₃	7.8	3.8	3.3	< 1.0	1.0	10	10	5.0	2.4	1.2	2.5	1.8	2.1	1.1	4.5	6.0	3.9	< 1.0	< 1.0
H ₂ O [%]	17	17	14	9.5	8.4	6.6	7.6	5.8	5.9	5.2	5.8	5.9	5.6	5.6	4.3	4.6	3.1	3.0	3.4
CO ₂	6900	7600	5900	5400	4700	7600	7500	7300	7000	6600	8600	7700	6900	7600	4600	5700	3900	3100	4000
HCN	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
SO ₂	3.2	3.7	3.6	3.2	2.4	2.6	2.3	2.0	2.2	2.0	2.4	2.5	1.7	2.4	7.1	2.7	1.5	< 1.0	< 1.0
CO	1.4	22	45	100	120	2.5	23	85	230	220	31	84	110	270	< 1.0	< 1.0	4.3	6.7	24.0
HCl	1.0	< 1.0	< 1.0	< 1.0	< 1.0	3.3	< 1.0	1.5	< 1.0	< 1.0	< 1.0	1.2	< 1.0	< 1.0	1.1	< 1.0	< 1.0	< 1.0	< 1.0
HF	2.3	1.3	< 1.0	< 1.0	< 1.0	4.6	< 1.0	< 1.0	< 1.0	< 1.0	1.3	< 1.0	< 1.0	< 1.0	2.2	< 1.0	< 1.0	< 1.0	< 1.0

**Table 7.18.b. Test 5 Concentration [ppmv] Ranges of Selected Species in Off-Gas
 Measured by FTIR Spectroscopy.**

Port	Melter Outlet					SBS Outlet					WESP Outlet				TCO Outlet				
Test	A	B	C	D	E	A	B	C	D	E	B	C	D	E	A	B	C	D	E
N ₂ O	<1.0 – 2.1	<1.0 – 2.0	<1.0 – 1.4	<1.0 – 1.9	<1.0	1.3 – 2.5	<1.0 – 3.0	<1.0 – 1.7	<1.0 – 1.3	<1.0	<1.0 – 3.3	<1.0 – 1.7	<1.0 – 1.8	<1.0 – 1.6	<1.0 – 2.3	<1.0 – 2.0	<1.0	<1.0	<1.0
NO	17 – 113	<1.0 – 81	<1.0 – 5.2	<1.0 – 5.8	<1.0 – 3.7	60– 163	<1.0 – 13.4	1.0 – 14.3	<1.0 – 7.7	<1.0 – 8.9	<1.0 – 31.4	<1.0 – 13.4	<1.0 – 8.1	<1.0 – 9.2	<1.0 – 56.7	<1.0 – 3.5	<1.0 – 4.1	<1.0 – 3.5	<1.0 – 6.6
NO ₂	<1.0 – 4.9	<1.0 – 2.2	<1.0 – 1.9	<1.0 – 1.8	<1.0	<1.0 – 1.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0 – 1.2	<1.0 – 1.4	<1.0 – 66.9	<1.0 – 1.2	<1.0 – 4.0	<1.0 – 3.1	<1.0 – 1.8
NH ₃	<1.0 – 22.3	<1.0 – 9.7	1.8 – 7.4	<1.0 – 1.0	<1.0 – 1.8	<1.0 – 23.2	<1.0 – 24.5	<1.0 – 10.3	<1.0 – 5.1	<1.0 – 2.1	<1.0 – 7.4	<1.0 – 4.2	<1.0 – 3.5	<1.0 – 2.1	1.1 – 13.1	1.1 – 13.1	<1.0 – 7.5	<1.0 – 1.4	<1.0 – 1.0
H ₂ O [%]	7.7 – 29.9	7.3 – 26.6	5.5 – 22.0	1.2 – 20.2	4.0 – 17.1	5.1 – 7.9	5.3 – 14.4	4.0 – 8.0	4.6 – 7.4	4.6 – 6.9	1.2 – 8.1	3.9 – 7.6	4.8 – 7.0	3.5 – 7.8	2.7 – 5.1	3.0 – 6.7	2.0 – 3.8	1.2 – 4.7	1.2 – 5.0
CO ₂	4800– 10,700	5200 – 12,000	4500 – 8700	1100 – 11,100	2800 – 8100	4500 – 12,500	3300 – 13,100	5100 – 11,800	3500 – 11,600	4700 – 10,600	700 – 13,200	5200 – 11,100	4300 – 10,600	5100 – 12,100	500 – 8100	3100 – 13000	2500 – 6800	700 – 7600	600 – 8600
NITROUS A	<1.0 – 2.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
NITRIC ACI	<1.0 – 1.3	<1.0	<1.0	<1.0	<1.0	1.0 – 9.9	<1.0	<1.0 – 3.4	<1.0	<1.0	<1.0 – 1.2	<1.0 – 1.7	<1.0	<1.0	<1.0 – 4.9	<1.0	<1.0 – 1.0	<1.0	<1.0
HCN	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
SO ₂	<1.0 – 8.3	<1.0 – 8.6	1.5 – 6.0	<1.0 – 5.3	<1.0 – 5.0	<1.0 – 5.3	1.2 – 4.1	<1.0 – 3.2	1.0 – 3.6	1.2 – 3.4	<1.0 – 3.7	<1.0 – 3.7	<1.0 – 2.9	1.2 – 4.0	<1.0 – 11.0	1.4 – 4.4	<1.0 – 2.4	<1.0 – 1.6	<1.0 – 2.1
CO	<1.0 – 3.1	<1.0 – 52.6	22 – 109	17 – 259	56 – 206	1.3 – 4.7	2.4 – 60.4	21 – 166	68 – 381	104 – 573	6.6 – 60.8	39 – 128	16 – 228	52 – 676	<1.0	<1.0 – 3.0	<1.0 – 10.9	<1.0 – 26.1	<1.0 – 104
HCl	<1.0 – 1.4	<1.0 – 1.3	<1.0 – 1.8	<1.0	<1.0	<1.0 – 11.5	<1.0	<1.0 – 5.2	<1.0	<1.0	<1.0 – 1.3	<1.0 – 1.8	<1.0	<1.0	<1.0 – 4.1	<1.0 – 1.0	<1.0 – 1.0	<1.0	<1.0
HF	1.3 – 4.4	<1.0 – 3.6	<1.0 – 1.2	<1.0 – 1.0	<1.0	1.7 – 7.6	<1.0 – 1.0	<1.0	<1.0	<1.0	<1.0 – 1.9	<1.0	<1.0	<1.0	<1.0 – 5.0	<1.0 – 1.8	<1.0	<1.0	<1.0

**Table 7.19.a. Test 6 Average Concentrations [ppmv] of Selected Species in Off-Gas
Measured by FTIR Spectroscopy.**

Port	Melter Outlet			SBS Outlet		WESP Outlet		TCO Outlet	
Test	A	B	E	A	B	A	B	A	B
N ₂ O	2.7	29	8.3	2.7	33	3.0	19	1.8	19
NO	730	320	53	630	340	570	230	210	50
NO ₂	72	6.4	1.3	100	14	130	15	150	81
NH ₃	< 1.0	< 1.0	130	< 1.0	6.0	< 1.0	< 1.0	< 1.0	< 1.0
H ₂ O [%]	18	20	15	5.8	5.3	5.0	5.5	2.9	3.6
CO ₂	5800	8200	6700	4900	8100	4900	5100	2900	4800
HCN	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
SO ₂	< 1.0	1.0	59	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
CO	1.6	18	120	1.9	19	1.5	11	1.0	< 1.0
HCl	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

**Table 7.19.b. Test 6 Concentration [ppmv] Ranges of Selected Species in Off-Gas
Measured by FTIR Spectroscopy.**

<i>Port</i>	Melter Outlet			SBS Outlet		WESP Outlet		TCO Outlet	
Test	A	B	E	A	B	A	B	A	B
N ₂ O	1.4 – 3.6	23 – 36	4.1 – 17	< 1.0 – 3.9	26 – 44	2.5 – 3.8	< 1.0 – 45	< 1.0 – 3.0	< 1.0 – 29
NO	360 - 1100	250 – 420	14 – 130	130 – 1000	250 – 490	450 – 620	< 1.0 – 440	36 – 300	< 1.0 – 99
NO ₂	19 – 130	2.6 – 9.9	< 1.0 – 3.0	4.4 – 204	6.2 – 25	88 – 160	1.0 – 43	33 – 220	< 1.0 – 190
NH ₃	< 1.0	< 1.0	< 1.0 – 210	< 1.0	< 1.0 – 9.3	< 1.0	< 1.0 – 7.7	< 1.0	< 1.0 – 1.6
H ₂ O [%]	8.6 – 23.5	16 – 25	8.0 – 24	4.0 – 8.5	5.0 – 6.6	4.1 – 5.6	3.8 – 7.2	2.2 – 3.2	2.6 – 4.6
CO ₂	3000 - 8200	6800 – 9400	3900 – 12300	4000 – 7500	6900 – 11000	4100 – 5800	500 – 10000	1000 – 4100	500 - 7200
HCN	< 1.0	< 1.0	< 1.0 – 1.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
CO	< 1.0 – 3.9	11 – 22	62 - 280	< 1.0 – 3.8	12 - 28	< 1.0 – 3.3	< 1.0 – 28.5	< 1.0 – 3.1	< 1.0
HCl	< 1.0	< 1.0 – 1.4	< 1.0	< 1.0 – 1.3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HF	< 1.0 – 1.0	< 1.0 – 1.2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

**Table 7.20.a. Test 4 Average Concentrations [ppmv] of Selected Species in Off-Gas
Measured by FTIR Spectroscopy.**

Port	Melter Outlet					SBS Outlet				WESP Outlet				TCO Outlet				
Test	A	B	C	D	E	B	C	D	E	B	C	D	E	A	B	C	D	E
N ₂ O	1.1	5.4	6.6	7.6	6.9	9.2	7.3	11	5.8	11	8.0	9.3	6.1	1.9	8.0	6.5	6.4	5.6
NO	106	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	7.9	<1.0	<1.0	<1.0	<1.0
NO ₂	6.6	6.0	10	14	14	17	8.4	18	11	22	9.4	15	11	24	<1.0	<1.0	<1.0	<1.0
NH ₃	<1.0	32	30	33	34	7.4	14	13	18	5.0	12	9.6	17	<1.0	13	4.8	2.8	3.1
H ₂ O [%]	19	21	20	20	18	5.1	4.8	5.5	5.1	5.0	4.8	5.2	4.8	4.5	5.0	3.7	3.9	4.0
CO ₂	5600	7600	7100	7900	7200	4700	4500	5300	6000	5500	4700	5600	5700	2200	4900	3700	3700	4400
HCN	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
CO	2.0	38	56	119	201	87	57	114	242	124	58	99	206	<1.0	<1.0	<1.0	<1.0	<1.0
HCl	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
HF	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

**Table 7.20.b. Test 4 Concentration [ppmv] Ranges of Selected Species in Off-Gas
Measured by FTIR Spectroscopy.**

Port	Melter Outlet					SBS Outlet				WESP Outlet				TCO Outlet				
Test	A	B	C	D	E	B	C	D	E	B	C	D	E	A	B	C	D	E
N ₂ O	< 1.0 – 1.3	3.8 – 10	4.1 – 11	2.9 – 12	2.9 – 14	5.9 – 13	3.5 – 13	6.3 – 14	< 1.0 – 12	5.4 – 15	3.6 – 14	7.1 – 13	< 1.0 – 14	< 1.0 – 2.8	4.1 – 14	3.1 – 12	2.6 – 12	1.6 – 14
NO	78 – 140	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 – 7.4	< 1.0 – 5.2	< 1.0	< 1.0	< 1.0 – 5.3	< 1.0 – 12	< 1.0	< 1.0	< 1.0 – 23	< 1.0	< 1.0 – 26	< 1.0	< 1.0
NO ₂	4.4 – 9.7	1.6 – 19	5.0 – 16	5.2 – 20	4.5 – 23	4.1 – 25	1.3 – 19	7.5 – 24	2.4 – 24	7.0 – 28	< 1.0 – 20	7.8 – 24	1.5 – 25	< 1.0 – 64	< 1.0	< 1.0 – 2.9	< 1.0	< 1.0
NH ₃	< 1.0	17 – 62	21 – 49	16 – 73	16 – 55	< 1.0 – 12	8.4 – 18	11 – 14	3.0 – 21	< 1.0 – 11	8.4 – 16	< 1.0 – 13	5.3 – 23	< 1.0 – 11	3.0 – 34	< 1.0 – 7.9	< 1.0 – 5.3	1.3 – 8.5
H ₂ O [%]	15 – 24	17 – 25	16 – 23	17 – 24	10 – 22	4.2 – 5.6	4.0 – 5.7	5.3 – 5.7	1.2 – 5.8	3.6 – 6.1	3.4 – 5.5	4.1 – 6.3	3.1 – 5.8	3.2 – 6.3	3.1 – 5.7	3.1 – 4.2	3.1 – 4.3	3.0 – 5.1
CO ₂	2400 – 7500	2600 – 9700	3000 – 9800	3100 – 10000	2800 – 9900	3600 – 6800	2800 – 7400	4000 – 6800	400 – 8200	2600 – 7500	2200 – 8000	4500 – 7100	1800 – 8100	100 – 3900	2500 – 8300	1700 – 6300	2500 – 5400	2200 – 7400
HCN	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
CO	< 1.0 – 3.5	17 – 110	25 – 86	45 – 250	87 – 390	18 – 180	18 – 110	66 – 180	81 – 420	39 – 230	18 – 150	66 – 180	87 – 410	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HCl	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

Table 7.21. Average Hydrogen Concentrations Measured by Gas Chromatography at the WESP Outlet.

--	Test 5 (C-106/AY-102)					Test 6 (C-106/AY-102 with nitrates)					Test 4 (AZ-101)				
Sugar Conc. (g/L)	0 [11]	10	15	20	25	0	10	15	20	25	0 [9]	7.6	10	12.5	16
H ₂ Conc. (ppmv)	31	< 5	11	16	11	< 5	< 5	6.6	17	< 5	7	19	201	430	274

"--" Empty data field

Table 7.22. Concentration of Iodine (µg/dscf) in Off-Gas Slipstream Around Silver Mordenite Column.

-	C-104/AY-101 Ref. [12]	C-106/AY-102, Test 5	
Sampling Point	02/26/03 07:50 – 15:50	05/03/03 10:22 – 18:28	05/05/03 10:03 – 18:10
Inlet	2151	4	6
1/3 into column	1721	NA	NA
2/3 into column	75.6	< 2	< 2
Outlet	< 2	< 2	< 2

"-" Empty data field

NA – Not Analyzed.

Table 7.23. Halogen Concentrations (µg/dscf) in Off-Gas Slipstream Around Silver Mordenite Column while Feeding an Iodine-Free Composition (Test 6).

Sampling Point	05/17/03 08:50 – 16:56			05/19/03 09:00 – 17:06		
	Cl	F	I	Cl	F	I
Inlet	11	< 1	3	7	< 1	< 2
2/3 into column	5	< 1	74	12	< 1	< 2
Outlet	4	< 1	16	7	< 1	< 2

Table 7.24. Iodine Mass Balance Summary for Test 5.
(% Feed Iodine)

Location:	Product Glass	Melter Emissions	SBS Blow-Down Solutions	SBS Emissions	WESP Blow-Down Solutions	WESP Emissions	TCO/SCR*	PBS Blow-Down Solutions
No added sugar [11]	< 1	85	15	77	< 1	73	60	18
20 - 25 g sugar / l	30	57	74	< 1	0.7	< 1	< 1	< 1

* - Extrapolated from slip stream entering silver mordenite system.

"-" Empty data field

Table 8.1. Compilation of Information on Noble Metals Concentrations in Envelope D Waste Streams (wt%).

Waste Group	Waste Basis	Pd	Rh	Ru	Reference
		Weight percent (Oxide Basis)			
AZ-101	Inventory/Best Basis	(a)	0.05	(a)	22
AZ-101	Actual Waste (leached)	0.33	0.08	0.25	39
AZ-101	Actual Waste (washed)	ND	<0.08	<0.08	40
AZ-101	Actual Waste (washed)	ND	<0.19	0.34	40
AZ-102	Inventory/Best Basis	0.01	0.01	0.04	22
AZ-102	Actual Waste (leached)	<0.41	<0.17	<0.39	41
AZ-102	Actual Waste (washed)	ND	<0.12	<0.13	40
AZ-102	Actual Waste (centrifuged)	ND	<0.04(b)	<0.02(b)	42
C-106/AY-102	Inventory/Best Basis	(a)	(a)	(a)	22
C-106/AY-102	Actual Waste (leached)	ND	ND	ND	43
C-106	Actual Waste (leached)	ND	ND	ND	44
C-104/AY-101	Inventory/Best Basis	(a)	(a)	(a)	22
C-104	Actual Waste (leached)	(c)	0.13	0.07	45
AN-107 SR/TRU ppt	Actual Waste	0.16	ND	ND	45

(a) Entries show 0.00 in TFCOUP but no estimates were available

(b) Elemental basis, i.e., weight percent element in centrifuged sludge

(c) About 1% from initial analysis, which was later rescinded. No new data were provided

ND – Not Determined

Table 8.2. Metal Concentrations in RuNO(NO₃)₃ and Spike Solutions (DCP-AES).

Spike	RuNO(NO ₃) ₃ Solution (from Alfa Aesar)					Spike Solution				
	Target** (wt%)	CUA#11108		CUA#11110		Target*	Ru1L (8/14/03)		Ru1L (2/19/04)	
		wt%	%Dev.	wt%	%Dev.		wt%	%Dev.	wt%	%Dev.
Ru	13.94	12.72	-8.74	12.54	-10.00	1.41	1.29	-8.51	1.31	-7.18
Y	NA	NA	NA	NA	NA	1.63	1.52	-6.34	1.63	0.05

NA – Not applicable

** Value given by Alfa Aesar

* Calculated using the producer's value

Table 8.3. Y₂O₃ and RuO₂ Concentrations in Discharged Glass (XRF Results).

Test #	Sugar (g/l)	Date	Discharged Glass (kg)	Sample	Y ₂ O ₃ (wt%)	RuO ₂ (wt%)
4B	13.3	8/20/03	757.6	1G2-N-21A	0.0021	0.0010
			857.3	1G2-N-22A	0.0056	0.0030
			907.1	1G2-G-24A	0.0099	0.0048
			957.8	1G2-N-40A	0.0120	0.0047
			1059.3	1G2-N-42A	0.0188	0.0066
		8/21/03	1160.8	1G2-N-45A	0.0254	0.0057
			1262.3	1G2-N-46B	0.0308	0.0088
			1313.1	1G2-G-47A	0.0328	0.0064
			1364.4	1G2-N-49A	0.0350	0.0072
			1415.8	1G2-N-51A	0.0411	0.0068
	1467.2		1G2-N-54A	0.0395	0.0070	
	1672.7		1G2-N-59A	0.0425	0.0075	
	1724.1		1G2-G-60A	0.0438	0.0095	
	7.6	1775.7	1G2-N-61A	0.0440	0.0067	
		1878.9	1G2-N-78A	0.0471	0.0076	
		1930.6	1G2-N-79A	0.0491	0.0072	
		8/22/03	2085.4	1G2-N-82A	0.0512	0.0073
			2137.1	1G2-G-83A	0.0519	0.0097
			2188.6	1G2-N-86A	0.0521	0.0096
			2240.1	1G2-N-87A	0.0539	0.0094
			2394.6	1G2-N-91A	0.0550	0.0083
			2497.6	1G2-N-100A	0.0558	0.0098
			2549.1	1G2-G-102A	0.0566	0.0088
	2601.4		1G2-N-103A	0.0567	0.0081	
2706.2	1G2-N-105A		0.0587	0.0097		
2810.9	1G2-N-108A		0.0612	0.0112		
4C	10.0	8/23/03	2915.7	1G2-N-118A	0.0636	0.0114
			2968.1	1G2-G-121A	0.0655	0.0188
			3019.3	1G2-N-122A	0.0665	0.0108
			3121.6	1G2-N-124A	0.0701	0.0127
			3224.0	1G2-N-125B	0.0712	0.0110
			3326.4	1G2-N-129A	0.0740	0.0173
			3377.6	1G2-G-138A	0.0757	0.0109
			3428.2	1G2-N-139A	0.0764	0.0111
			3529.4	1G2-N-142A	0.0776	0.0123
			3630.7	1G2-N-145A	0.0746	0.0104
		3731.9	1G2-N-149A	0.0808	0.0127	
		3782.6	1G2-G-150A	0.0814	0.0175	
		3835.0	1G2-N-151A	0.0817	0.0104	
		3939.9	1G2-N-154A	0.0827	0.0111	
		4044.8	1G2-N-155A	0.0828	0.0107	
		8/24/03	4097.2	1H2-N-5A	0.0827	0.0110
			4202.1	1H2-N-9A	0.0824	0.0107

**Table 8.3. Y₂O₃ and RuO₂ Concentrations in Discharged Glass (XRF Results)
(continued).**

Test #	Sugar (g/l)	Date	Discharged Glass (kg)	Sample	Y ₂ O ₃ (wt%)	RuO ₂ (wt%)
4C	10.0	8/24/03	4352.8	1H2-N-12A	0.0826	0.0101
			4453.3	1H2-N-29A	0.0824	0.0104
			4553.8	1H2-N-31A	0.0819	0.0105
			4604.1	1H2-G-32A	0.0821	0.0128
4D	12.5	8/24/03	4655.3	1H2-N-36A	0.0811	0.0107
			4706.4	1H2-N-37A	0.0840	0.0110
			4860.0	1H2-N-39A	0.0886	0.0131
			4911.2	1H2-N-48A	0.0911	0.0125
			5013.6	1H2-N-51A	0.0929	0.0114
			5166.9	1H2-N-54A	0.0969	0.0190
			5269.2	1H2-N-57A	0.0998	0.0130
			5371.4	1H2-N-58B	0.1016	0.0122
		8/25/03	5422.6	1H2-N-60A	0.1024	0.0113
			5574.1	1H2-N-63A	0.1034	0.0111
			5675.1	1H2-N-65A	0.1030	0.0111
			5776.1	1H2-N-70A	0.1033	0.0114
			5826.6	1H2-G-72A	0.1013	0.0113
			5877.3	1H2-N-74A	0.1013	0.0105
			5978.8	1H2-N-91A	0.1004	0.0110
			6029.6	1H2-N-92A	0.0998	0.0101
		8/26/03	6181.8	1H2-N-95A	0.0986	0.0103
			6232.6	1H2-G-97A	0.0979	0.0110
			6283.8	1H2-N-99A	0.0968	0.0101
			6386.3	1H2-N-100A	0.0968	0.0113
			6437.6	1H2-N-101A	0.0950	0.0096
			6540.1	1H2-N-103A	0.0938	0.0098
			6642.6	1H2-G-105A	0.0933	0.0100
			6694.0	1H2-N-106A	0.0929	0.0100
4E	16.0	8/26/03	6745.4	1H2-N-109A	0.0916	0.0089
			6899.8	1H2-N-119A	0.0891	0.0091
			7002.6	1H2-N-128A	0.0882	0.0097
			7054.1	1H2-G-128B	0.0886	0.0088
			7108.3	1H2-N-131A	0.0874	0.0092
		8/27/03	7216.6	1H2-N-133A	0.0862	0.0094
			7325.0	1H2-N-135A	0.0851	0.0088
			7433.4	1H2-N-137A	0.0836	0.0088
			7487.6	1H2-G-138A	0.0832	0.0076
		8/27/03	7538.8	1H2-N-139A	0.0827	0.0076
			7641.1	1H2-N-145A	0.0850	0.0072
			7743.5	1H2-N-147A	0.0852	0.0071

**Table 8.3. Y₂O₃ and RuO₂ Concentrations in Discharged Glass (XRF Results)
(continued).**

Test #	Sugar (g/l)	Date	Discharged Glass (kg)	Sample	Y ₂ O ₃ (wt%)	RuO ₂ (wt%)
4E	16.0	8/27/03	7845.9	1I2-N-5A	0.0873	0.0088
			7897.1	1I2-G-9A	0.0879	0.0084
			7947.2	1I2-N-10A	0.0881	0.0084
			8047.4	1I2-N-18A	0.0863	0.0088
			8147.7	1I2-N-20A	0.0903	0.0081
		8/28/03	8247.9	1I2-N-23A	0.0883	0.0075
			8298.1	1I2-N-25A	0.0906	0.0087
			8400.6	1I2-N-27A	0.0910	0.0088
			8554.3	1I2-N-36A	0.0891	0.0085
			8605.6	1I2-N-37A	0.0912	0.0087
			8708.1	1I2-G-38A	0.0915	0.0100
			8790.6	1I2-N-41A	0.0914	0.0079
			8846.3	1I2-N-42A	0.0910	0.0084
			8955.5	1I2-N-47A	0.0913	0.0088

Table 8.4. Identification of Samples Suctioned from the Melt Pool.

Sampling Date	Sample	Port#	Melter Location	Analysis
8/28/03	1I2-O-42A	C1	Bottom	SEM
	1I2-O-42B	C1	Middle	SEM
	1I2-O-42C	C1	Top	SEM
	1I2-O-42D	B3	Bottom	SEM
	1I2-O-42E	B3	Middle	NA
	1I2-O-42F	C2	Bottom	NA

NA – Not analyzed

Table 8.5. Ruthenium in Melter Emission Samples (EPA Method 29).

Test #	Sampling Interval	Ru Feed Rate (mg/min)	Emission Rate (mg/min)		Ru Loss as % of Ru Fed
			Particles*	Ru	
4B	8/22/03 10:42 – 11:42	489.12	10308	7.52	1.54
4C	8/24/03 09:09 – 10:09	483.62	9108	5.93	1.23
4D	8/26/03 08:18 – 09:18	553.56	7030	5.05	0.91
4E	8/27/03 14:55 – 15:55	523.12	6669	4.40	0.84
-	Average emission rate	512.36	8279	5.72	1.13

*see Table 7.1

Table 8.6. Ruthenium in Selected SBS Blow-Down Samples.

Test #	Date	Sample	Ru Concentration (mg/l)
4B	08/22/03	1G2-S-103A	4.00
4C	08/24/03	1H2-S-32A	3.40
4D	08/26/03	1H2-S-106A	3.95
4E	08/28/03	1I2-S-47A	1.75
Average			3.28
Total RuO ₂ fed (g)	Total SBS liquid (liter)*	Total RuO ₂ in SBS in solutions (g)	RuO ₂ loss as % of RuO ₂ fed (g)
7379.6	15742.3	67.878	0.92

*Blow-down volumes from Test#4B, C, D, and E plus 360 gallons residing in the SBS

Table 8.7. Semi-Quantitative Composition Analysis of Nickel Sulfide Phase (Sample 1I2-O-42A, Port C1).

-	Ni ₃ S ₂		Analysis 1		Analysis 2	
Element	Mole%	wt%	Mole%	wt%	Mole%	wt%
S	40.00	26.70	38.89	25.79	37.46	24.65
Ni	60.00	73.30	61.11	74.21	62.54	75.35
Total	100.00	100.00	100.00	100.00	100.00	100.00

"-" Empty data field

Table 8.8. Comparison of Ruthenium Volatility in DM1200 Tests with AZ-101 Feeds with and without Sugar.

Test	Melter Feed	Sugar Conc. (g/l)	Bubbling Rate (l/min)	Ru Volatilized (%)
This work	AZ-101	7.6 – 16.0	65	1
Previous work [37]	AZ-101	0	0	3.9
Previous work [37]	AZ-101	0	40	15.6
Previous work [37]	AZ-101	0	65	32.8

Table 8.9. Comparison of Ruthenium Retention in the Melter in DM1200 Tests with AZ-101 Feeds with and without Sugar.

Test	Melter Feed	Sugar Conc. (g/l)	Bubbling Rate (l/min)	Ru Retention (%)
This work	AZ-101	7.6 – 16.0	65	90
Previous work [37]	AZ-101	0	0	20.9
Previous work [37]	AZ-101	0	40	13.3-17.7
Previous work [37]	AZ-101	0	65	ND

ND – Not determined

Figure 1.1. Cross-section of the DM1200 melter through the discharge chamber.

Figure 1.2. Cross-section through the DM1200 melter showing electrodes.

Figure 1.3. Schematic diagram of DM1200 off-gas system. “Sx” indicates sampling point.

Figure 1.4. Sulfur activated carbon and silver mordenite slipstream off-gas treatment system.

Figure 2.1. Viscosity vs. shear rate of C-106/AY-102 (550 g glass/ l) melter feed samples.

Figure 2.2. Viscosity vs. shear rate of AZ-101 (400 g glass / l) melter feed samples.

Figure 3.1.a. Production rate (1-hr moving average) for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.1.b. Production rates (1-hr moving average) for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l).

Figure 3.1.c. Production rates (1-hr moving average) for Test 4 (AZ-101, 400 g glass/l).

Figure 3.2.a. Glass temperatures (hourly averages) for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.2.b. Glass temperatures (hourly averages) for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l).

Figure 3.2.c. Glass temperatures (hourly averages) for Test 4 (AZ-101, 400 g glass/l).

Figure 3.3.a. Plenum temperatures and electrode power (hourly averages) for Test 5 (C-107/AY-102, 550 g glass/l).

Figure 3.3.b. Plenum temperatures and electrode power (hourly averages) for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l).

Figure 3.3.c. Plenum temperatures and electrode power (hourly averages) for Test 4 (AZ-101, 400 g glass/l).

Figure 3.4.a. Electrode temperatures and power (hourly averages) for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.4.b. Electrode temperatures and power (hourly averages) for Test 6 (C-106/AY-102 with nitrates. 550 g/l).

Figure 3.4.c. Electrode temperatures and power (hourly averages) for Test 4 (AZ-101, 400 g glass/l).

Figure 3.5.a. Electrode power and glass resistance for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.5.b. Electrode power and glass resistance for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l).

Figure 3.5.c. Electrode power and glass resistance for Test 4 (AZ-101, 400 g glass/l).

Figure 3.6.a. Glass density and level for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.6.b. Glass density and level for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l.

Figure 3.6.c. Glass density and level for Test 4 (AZ-101, 400 g glass/l).

Figure 3.7.a. Glass pool bubbling for Test 5 (C-106/AY-102, 550 g glass/l).

Figure 3.7.b. Glass pool bubbling for Test 6 (C-106/AY-102 with nitrates, 550 g glass/l).

Figure 3.7.c. Glass pool bubbling for Test 4 (AZ-101, 400 g glass/l).

Figure 4.1. Schematic illustration of DuraMelter 1200 energy balance concept.

Figure 4.2.a. Average DM1200 melter skin temperatures North Face.

Figure 4.2.b. Average DM1200 melter skin temperatures South (discharge) face.

Figure 4.2.c. Average DM1200 melter skin temperatures West (open) face.

Figure 4.2.d. Average DM1200 melter skin temperatures East (wall) face.

Figure 4.2.e. Average DM1200 melter skin temperatures top face.

Figure 4.3. West side view of DM1200 melter.

Figure 4.4. Top view of DM1200 melter.

Figure 4.5. SBS energy transfer pathways schematic.

Figure 4.6. Melter energy balance values during Test 5 with C-106/AY-102 feed.

Figure 4.7. SBS energy balance values during Test 5 with C-106/AY-102 feed.

Figure 4.8. Melter energy balance values during Test 6 with C-106/AY-102 feed.

Figure 4.9. SBS energy balance values during Test 6 with C-106/AY-102 feed.

Figure 4.10. Melter energy balance values during Test 4 with AZ-101 feed.

Figure 4.11. SBS energy balance values during Test 4 with AZ-101 feed.

Figure 5.1. Average gas temperatures along the DM 1200 off-gas train during Test 5.

Figure 5.2. Average gas temperatures along the DM 1200 off-gas train during Test 6

Figure 5.3. Average gas temperatures along the DM 1200 off-gas train during Test 4.

Figure 5.4. Transition line and film cooler differential pressures (hourly average values) during Test 5.

Figure 5.5. Melter pressure at instrument port and control air flow rate during Test 5.

Figure 5.6. Transition line and film cooler differential pressures (hourly average values) during Test 6.

Figure 5.7. Melter pressure at instrument port and control air flow rate during Test 6.

Figure 5.8. Transition line and film cooler differential pressures (hourly average values) during Test 4.

Figure 5.9. Melter pressure at instrument port and control air flow rate during Test 4.

Figure 5.10. a) View from below SBS Down-comer, b) View of new "crown" installed on March 28, 2003 before Test 5.

Figure 5.11. Layout of film cooler and transition line sections.

Figure 5.12. SBS Y-piece connecting transition line bellows to the SBS inlet.

Figure 5.13. SBS inlet and outlet gas temperatures during Test 5.

Figure 5.14. SBS inlet, outlet and differential pressures (hourly average values) during Test 5.

Figure 5.15. SBS cooling water and bed temperatures (hourly average values) during Test 5.

Figure 5.16. SBS jacket, inner coil and heat exchanger water flow rates (hourly average values) during Test 5.

Figure 5.17. Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values) during Test 5.

Figure 5.18. SBS inner coil and plate heat exchanger water temperatures (hourly average values) during Test 5.

Figure 5.19. Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Test 5.

Figure 5.20. View looking down SBS down-comer, immediately below Y-inlet, after Test 5.

Figure 5.21. View looking down SBS down-comer, mid-body after Test 5.

Figure 5.22. View looking down SBS down-comer, ~8" above down-comer base after Test 5.

Figure 5.23. View looking down SBS down-comer, from base of down-comer, after Test 5.

Figure 5.24. SBS inlet and outlet gas temperatures during Test 6.

Figure 5.25. SBS inlet, outlet and differential pressures (hourly average values) during Test 6.

Figure 5.26. SBS cooling water and bed temperatures (hourly average values) during Test 6.

Figure 5.27. SBS jacket, inner coil and heat exchanger water flow rates (hourly average values) during Test 6.

Figure 5.28. Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values) during Test 6.

Figure 5.29. SBS inner coil and plate heat exchanger water temperatures (hourly average values) during Test 6.

Figure 5.30. Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Tests 6.

Figure 5.31. View of the SBS overflow tank residual solids after Test 6.

Figure 5.32. IR image looking down SBS down-comer, ~8" above down-comer base, before cleaning after Test 6.

Figure 5.33. IR image looking down SBS down-comer, ~6" above down-comer base, after cleaning, after Test 6.

Figure 5.34. IR image looking down SBS down-comer, ~5'-6" down from top, after cleaning, after Test 6.

Figure 5.35. SEM micrograph of a particle in Sample W12-O-142B.

Figure 5.36. General EDS spectra of sample W12-O-142B.

Figure 5.37. EDS spectra of region #1 indicated in Figure 5.35.

(a)

(b)

Figures 5.38. a) View from above SBS packed bed before installation, b) After installation of SBS down-comer upper sleeve.

Figure 5.39. SBS inlet and outlet gas temperatures during Test 4.

Figure 5.40. SBS inlet, outlet and differential pressures (hourly average values) during Test 4.

Figure 5.41. SBS cooling water and bed temperatures (hourly average values) during Test 4.

Figure 5.42. SBS jacket, inner coil and heat exchanger water flow rates (hourly average values) during Test 4.

Figure 5.43. Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values) during Test 4.

Figure 5.44. SBS inner coil and plate heat exchanger water temperatures (hourly average values) during Test 4.

Figure 5.45. Calculated heat load difference between plate heat exchanger and SBS inner coil (hourly average values) during Test 4.

Figure 5.46. IR image looking down from near top of down-comer (bottom of Y-inlet from transition line) after Test 4.

Figure 5.47. IR image looking down from about 66" below top of down-comer after Test 4.

Figure 5.48. IR image looking down about 8" above bottom of down-comer after Test 4.

Figure 5.49. IR image looking down from bottom of down-comer after Test 4.

Figure 5.50. WESP inlet and outlet temperatures during Test 5. (Note: downward outlet temperature spikes are the result of WESP deluges.)

Figure 5.51. WESP differential pressure and outlet gas flow rate (hourly average values) during Test 5.

Figure 5.52. Accumulated WESP blow-down volume, accumulated fresh spray water and water removed from off-gas during Test 5.

Figure 5.53. Voltage and current across the WESP during Test 5.

Figure 5.54. View of WESP grid support: degradation of FEP heat-shrink sleeve after Test 5.

Figure 5.55. WESP inlet sump, pre-deluge, thin layer of feed particulates in sump after Test 5.

Figure 5.56. WESP view from bottom of grid/collectors, pre-deluge after Test 5.

Figure 5.57. WESP view from bottom of grid/collectors, pre-deluge after Test 5.

Figure 5.58. WESP view from bottom of grid/collectors, post-deluge after Test 5.

Figure 5.59. WESP view from bottom of grid/collectors, post-deluge after Test 5.

Figure 5.60. WESP inlet and outlet temperatures during Test 6.
(Note: downward outlet temperature spikes are the result of WESP deluges.)

Figure 5.61. WESP differential pressure and outlet gas flow rate (hourly average values) during Test 6.

Figure 5.62. Accumulated WESP blow-down volume, accumulated fresh spray water and water removed from off-gas during Test 6.

Figure 5.63. Voltage and current across the WESP during Test 6.

Figure 5.64. View looking at grid from bottom, pre-deluge after Test 6.

Figure 5.65. View of WESP grid and collectors from below, post-deluge after Test 6.

Figure 5.66. SEM micrograph of a sample removed from solids (Sample # W12-O-142A) accumulated at the bottom of WESP following deluge after Test 6.

Figure 5.67. SEM micrograph of a sample removed from the WESP collector rods (Sample # W12-O-146A).

Figure 5.68. EDS spectra of regions #1 through region #5 indicated in Figure 5.67 (Sample # W12-O-146A).

Figure 5.69. EDS spectra of regions #5 through region #8 indicated in Figure 5.67 (Sample # W12-O-146A).

Figure 5.70. EDS spectra of region # 9 indicated in Figure 5.67 (Sample # W12-O-146A).

Figure 5.71. WESP inlet and outlet temperatures during Test 4. (Note: downward outlet temperature spikes are the result of WESP deluges).

Figure 5.72. WESP differential pressure and outlet gas flow rate (hourly average values) during Test 4.

Figure 5.73. Accumulated WESP blow down volume, accumulated fresh spray water, and water removed from off-gas during Test 4.

Figure 5.74. Voltage and current across the WESP during Test 4. (Note: during the deluges WESP was turned off).

Figure 5.75. View from bottom of WESP grid, pre-deluge, after Test 4.

Figure 5.76. View from bottom of WESP grid, pre-deluge, after Test 4.

Figure 5.77. View from bottom of grid of WESP, post-deluge, after Test 4.

Figure 5.78. View from bottom of WESP grid, post-deluge, after Test 4.

Figure 5.79. Outlet temperature and differential pressure for HEME #1 during Test 5.

Figure 5.80. Outlet temperature and differential pressure for HEME #1 during Test 6.

Figure 5.81. Outlet temperature and differential pressure for HEME #1 during Test 4.

Figure 5.82. Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Test 5.

Figure 5.83. Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Test 6.

Figure 5.84. Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Test 4.

Figure 5.85. TCO/SCR heater gas inlet temperature during Test 5.

Figure 5.86. TCO/SCR temperatures (hourly average values) during Test 5.

Figure 5.87. TCO/SCR differential pressures (hourly average values) during Test 5.

Figure 5.88. TCO/SCR heater gas inlet temperature during Test 6.

Figure 5.89. TCO/SCR temperatures (hourly average values) during Test 6.

Figure 5.90. TCO/SCR differential pressures (hourly average values) during Test 6.

Figure 5.91. TCO/SCR heater gas inlet temperature during Test 4.

Figure 5.92. TCO/SCR temperatures (hourly average values) during Test 4.

Figure 5.93. TCO/SCR differential pressures (hourly average values) during Test 4.

Figure 5.94. Silver mordenite column temperature during Test 5.

Figure 5.95. Silver mordenite column pressure during Test 5.

Figure 5.96. Silver mordenite column temperature during Test 6.

Figure 5.97. Silver mordenite column pressure during Test 6.

Figure 5.98. Inlet temperature and differential pressure for PBS (hourly average values) during Test 5.

Figure 5.99. Sump temperature for PBS during Test 5.

Figure 5.100. Inlet temperature and differential pressure for PBS (hourly average values) during Test 6.

Figure 5.101. Sump temperature for PBS during Test 6.

Figure 5.102. Inlet temperature and differential pressure for PBS (hourly average values) during Test 4.

Figure 5.103. Sump temperature and pH for PBS during Test 4.

Figure 5.104. Inlet and outlet temperatures and differential pressure for HEME #2 during Test 5.

Figure 5.105. Inlet and outlet temperatures and differential pressure for HEME #2 during Test 6.

Figure 5.106. Inlet and outlet temperatures and differential pressure for HEME #2 during Test 4.

Figure 5.107. pH of SBS blow-down solutions.

Figure 5.108. Accumulated SBS blow-down and feed water volume during Test 5.

Figure 5.109. Accumulated SBS blow-down and feed water volume during Test 6.

Figure 5.110. Accumulated SBS blow-down and feed water volume during Test 4.

Figure 5.111. Test 5, C-106/AY-102 feed composition (excludes oxygen and carbon).

Figure 5.112. Suspended solids composition from Test 5, SBS sample (U12-S-46A).

Figure 5.113. Dissolved solids composition from Test 5, SBS sample (U12-S-46A).

Test 6: C-106/AY-102 Feed Composition

Figure 5.114. Test 6, C-106/AY-102 feed composition (excludes oxygen and carbon).

Figure 5.115. Suspended solids composition from Test 6, SBS sample (W12-S-136A).

Figure 5.116. Dissolved solids composition from Test 6, SBS sample (W12-S-136A).

Figure 5.117. Test 4, AZ-101 feed composition (excludes oxygen and carbon).

Figure 5.118. Suspended solids composition from Test 4, SBS sample (1I2-S-47A).

Figure 5.119. Dissolved solids composition from Test 4, SBS sample (1I2-S-47A).

Figure 5.120. Dissolved solids composition from Test 5 WESP samples (U12-W-60A and B).

Figure 5.121. Dissolved solids composition from Test 6 WESP samples (W12-W-142A and B).

Figure 5.122. Dissolved solids composition from Test 4 WESP samples (1I2-W-47A and B).

Figure 6.1. XRF analysis of sodium and silicon oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).

Figure 6.2. XRF analysis of selected oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).

Figure 6.3. XRF analysis of manganese and strontium oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).

Figure 6.4. XRF analysis of minor component oxides in glasses from C-106/AY-102 testing (Tests 5 and 6).

Figure 6.5. XRF analysis of iodine and sulfur oxide in glasses from C-106/AY-102 testing (Tests 5 and 6).

Figure 6.6. XRF analysis of sodium and silicon oxides in glasses from AZ-101 testing (Test 4).

Figure 6.7. XRF analysis of selected oxides in glasses from AZ-101 testing (Test 4).

Figure 6.8. XRF analysis of selected minor oxides in glasses from AZ-101 testing (Test 4).

Figure 6.9. Measured divalent iron ratios in glasses from Test 5 (Test 5, C-106/AY-102 550 g glass/l).

Figure 6.10. Measured iron ratios in glasses from Test 6 (Test 6, C-106/AY-102 with nitrates, 550 g glass/l).

Figure 6.11. Measured divalent iron ratios in glasses from Test 4 (Test 4, AZ-101, 400 g glass/l).

Figure 7.1. Particulate melter emissions as a function of feed sugar content.

Figure 7.2. Selenium melter emissions as a function of feed sugar content during C-106/AY-102 processing (Tests 5 and 6).

Figure 7.3. Arsenic and cesium melter emissions as a function of feed sugar content during C-106/AY-102 processing (Tests 5 and 6).

Figure 7.4. Alkali and particulate melter emissions as a function of feed sugar content during AZ-101 processing (Test 4).

Figure 7.5. C-106/AY-102 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 5.

Figure 7.6. Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 5E (C-106/AY-102 with 25 g sugar/l, 550 g glass/l).

Figure 7.7. SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 5E (C-106/AY-102 with 25 g sugar/l, 550 g glass/l).

Figure 7.8. WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds) from Test Segments 5D and 5E (C-106/AY-102 and 20-25 g sugar/l, 550 g glass/l).

Test 6: C-106/AY-102 Feed Composition

Figure 7.9. C-106/AY-102 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 6.

Figure 7.10. Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test 6 (C-106/AY-102 with nitrates and 25 g sugar/l, 550 g glass/l).

Figure 7.11. SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test 6 (C-106/AY-102 with nitrates and 25 g sugar/l, 550 g glass/l).

Figure 7.12. WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds) for Test Segments 6D and 6E (C-106/AY-102 with nitrates and 25 g sugar/l, 550 g glass/l).

Figure 7.13. WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds) from Test Segment 6E during a WESP deluge (C-106/AY-102 with nitrates and 25 g sugar/l, 550 g glass/l).

Figure 7.14. AZ-101 Feed composition (excludes oxygen, nitrogen and carbon compounds) from Test 4.

Figure 7.15. Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4E (AZ101, 12.5 g sugar/l, 400 g glass/l).

SBS Emissions from Test Segment 4E

Figure 7.16. SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4E (AZ101, 16 g sugar/l, 400 g glass/l).

Wesp Emissions from Test Segments 4C to 4D

Figure 7.17. WESP exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4C to 4D (AZ101, 10-12.5 g sugar/l, 400 g glass/l).

Figure 7.18. WESP exhaust composition (excludes oxygen, nitrogen and carbon compounds) from Test Segment 4D to 4E (AZ101, 12.5-16 g sugar/l, 400 g glass/l).

Figure 7.19. Concentration of NO at various points in the off-gas stream during Test 5 (C-106/AY-120, 550 g glass/l).

Figure 7.20. Concentration of CO at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l).

Figure 7.21. Concentration of water at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l).

Figure 7.22. Concentration of CO₂ at various points in the off-gas stream during Test 5 (C-106/AY-102, 550 g glass/l).

Figure 7.23. Concentration of NO₂ at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l).

Figure 7.24. Concentration of CO at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l).

Figure 7.25. Concentration of water at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l).

Figure 7.26. Concentration of CO₂ at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l).

Figure 7.27. Concentration of ammonia at various points in the off-gas stream during Test 4 (AZ-101, 400 g glass/l).

Figure 8.1. Flow sheet for injection of ruthenium into the DM1200 feed stream.

Figure 8.2. Cumulative mass of RuO₂ and Y₂O₃ injected into the melter.

Figure 8.3. Y_2O_3 and RuO_2 concentrations as a function of glass production.

Figure 8.4. RuO_2 and Y_2O_3 concentrations as a function of glass produced during DM1200 testing with AZ-101.

Figure 8.5. Ruthenium injection rate during DM1200 testing with AZ-101.

Figure 8.6. Ratio of melter feed rate to ruthenium spike solution feed rate during DM1200 testing with AZ-101.

Figure 8.7. Comparison between measured and modeled increase of RuO_2 and Y_2O_3 concentration in DM1200 glass product.

Figure 8.8. Glass redox and RuO₂ concentration as a function of glass production.

Figure 8.9. Backscattered electron image showing small Ru-containing particles present in a sample taken from middle level of the melter pool (1I2-O-42B, Port C1).

Figure 8.10. Backscattered electron image showing a cluster of RuO_2 and perhaps spinel crystals in suction sample from the middle level of the melt pool (sample E12-B-104B), from ref. [37].

Figure 8.11. Optical micrograph showing the macrostructure of a sample taken from the bottom of the melter (Sample 1I2-O-42D, port B3).

Figure 8.12. Backscattered electron image showing details of the microstructure in a sample taken from the bottom of the melter (1I2-O-42D, Port B3).

Figure 8.13. Backscattered electron image of a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1).

Figure 8.14. Chemical mapping of a sample taken from the bottom of the melter (Sample 112-O-42A, port C1).
The mapping area is shown in Figure 8.13. The width of each frame is 885 μm .

Figure 8.15. EDS spectra of Ni sulfide (Ni_3S_2) in a sample taken from the bottom of the melter (Sample 1I2-O-42A, port C1).

Figure 8.16. Backscattered electron image showing details of the microstructure in a sample taken from the bottom of the melter (Sample 112-O-42A, port C1). This is an enlarged view of the framed area in Figure 8.13.

Figure 8.17. EDS spectrum of Ru in a sample taken from the bottom of the melter (Sample 112-O-42A, port C1).

Figure 8.18. Backscattered electron image of a sample taken from the bottom of the melter (Sample 112-O-42A, port C1).

Figure 8.19. Backscattered electron image of a sample taken from the bottom of the melter (Sample 112-O-42A, port C1). This is an enlarged view of the framed area in Figure 8.16.

Figure 8.20. NiO and SO₃ concentrations as a function of glass production

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Page 1 of 1

1) To Be Completed by Cognizant R&T Personnel				
Document Number VSL-04R4800-1	Revision A	Document Title Final Report - Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants		
Test Spec: 24590-HLW-TSP-RT-02-015, Rev 0		Scoping Statement(s): VH-4, VHO-3, VHO-2, VH-5		
R&T Contact: Lawrence Petkus Name (Print)		MS1B MSIN	371-8436 Telephone Number	March 11, 2004 Date

Review Distribution			
Organization	Contact	MSIN	Required?
Process Operations	L Suarez	MS4-B2	Yes ☒ No ☐
Quality Assurance	S Sunday	MS14-4B	Yes ☐ No ☒
Environmental and Nuclear Safety	E Saucedo	MS4-C1	Yes ☐ No ☒
Commissioning and Training	K Vacca	MS12-B	Yes ☐ No ☒
Engineering	M Ongpin	MS4-A2	Yes ☒ No ☐
R&T Functional Manager	S. Barnes	MS1-B	Yes ☒ No ☐
HLW APM	Phil Schuetz	MS5-L	Yes ☐ No ☒
			Yes ☐ No ☐
			Yes ☐ No ☐
			Yes ☐ No ☐

Comments Due By: March 25, 2004

Required Reviewers are required to respond to the R&T Contact.

2) To be Completed by Reviewer			
Reviewer _____			
Name (Print)		Organization	Date
☐	☐	☐	☐
Accepted, No Comments	Accepted, Comments Not Significant	Significant Comments, Form 24590-MGT-F00006 Attached	Significant Comments, Comments Marked on Document

3) To be Completed by Reviewer*			
My significant comments have been addressed.			
Acceptance: _____			
Print/Type Name	Signature	Date	
* An e-mail to the R&T contact stating that significant comments are addressed can substitute for this acceptance.			

Petkus, Lawrence

From: Hyman, Marve
Sent: Tuesday, April 27, 2004 8:00 AM
To: Petkus, Lawrence
Cc: Amistad, Stephanie; Ongpin, Maria; Grazzini, Janice; Nurdogan, Yakup
Subject: FW: FW: Comment Resolution VSL-04R4800-1, Redox effects DM1200 report

Attachment
information.

Follow-up Comment
Responses.do...

Comment
Responses, VSL-04R4800-1

VSL-04R4800-1

Larry: On behalf of Engineering I concur
with Document VSL-04R4800-1 Rev A.

Yakup: Tom Valenti at first contended some responses to your comments, which they finally modified to his acceptance.

Marve

-----Original Message-----

From: Carl, Daniel
Sent: Monday, April 26, 2004 4:05 PM
To: Amistad, Stephanie; Hyman, Marve; Petkus, Lawrence
Cc: Eaton, William; Peters, Richard D (WTP); Pullen, Jeff; Rouse, James; 'rmeigs@duratekinc.com'
Subject: FW: FW: Comment Resolution VSL-04R4800-1, Redox effects DM1200 report

Marve,

Modified responses are acceptable. Previous responses are attached for information.

Dan

-----Original Message-----

From: Petkus, Lawrence
Sent: Monday, April 26, 2004 3:31 PM
To: Hyman, Marve; Carl, Daniel
Subject: FW: FW: Comment Responses to VSL-04R4800-1, Redox effects report

Dan, Marve

Responses. Are they acceptable?

Larry

-----Original Message-----

From: ianp@vsl.cua.edu [mailto:ianp@vsl.cua.edu]
Sent: Monday, April 26, 2004 2:53 PM
To: Petkus, Lawrence
Cc: ioseph@duratekinc.com; dcallow@duratekinc.com; keithm
Subject: Re: FW: Comment Responses to VSL-04R4800-1, Redox effects report

Larry:

Please find attached our responses to the follow-up comments that

you sent.

Regards,

Ian.

On 21 Apr 2004 at 15:28, Petkus, Lawrence wrote:

From: "Petkus, Lawrence" <llpetkus@bechtel.com>
 To: "Ian Pegg (E-mail)" <ianp@vsl.cua.edu>
 Subject: FW: Comment Responses to VSL-04R4800-1, Redox effects report
 Date sent: Wed, 21 Apr 2004 15:28:38 -0700

> Ian,
 > To update the information below, all other comments have been resolved.
 >
 > Larry
 >
 > > -----Original Message-----
 > > From: Petkus, Lawrence
 > > Sent: Thursday, April 15, 2004 5:42 PM
 > > To: Ian Pegg (E-mail); Innocent Joseph (E-mail)
 > > Cc: Perez, Joseph; Knighton, David; Doyle, Jeanette; PK Brockman
 > > (E-mail)
 > > Subject: Comment Responses to VSL-04R4800-1, Redox effects report
 > >
 > > Ian,
 > > I sent you Dan Carl's rebuttal earlier. The following exceptions were
 > > taken by Engineering:
 > > Responses to MH comments are accepted except as follows:
 > > MH1: Change Response 2nd paragraph to read "The tests reported herein
 > > are for a subset of 3 tests of a larger series . . ."
 > > MH3: Objective 7: Is it possible to report quantitatively the percent
 > > rise in pressure for the worst spike?
 > >
 > > In addition there were some other questions, which I am trying to resolve
 > > here. If any issues arise, you should those tomorrow.
 > >
 > >
 > > Larry Petkus
 > > R&T, Main L-179
 > > Ph. 371-3258
 > >
 > >
 >

COMMENT RESOLUTION FORM

Page 1 of 2

Return to: Lawrence Petkus

Comments Due: March 25, 2004

Document Title: Final Report - Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants		Document No. VSL-04R4800-1		Revision: A	Date: March 11, 2004
Reviewer: Lawrence Petkus for S Barnes	Date: 3/30/03	Response by:	Date:	Comments Resolved: <i>Lawrence Petkus</i>	Date: 5/12/04

Item No.	Section/ Paragraph	Comment	Significance ^a	"M" Comment Justification ^B	Response	Resolution
1	8.5.2	Do the metallic phases that collected in the sludge under reducing conditions, oxidize back into the glass when idle or more oxidizing melter conditions are encountered?	I		We have taken samples from the bottom of the melter to see whether the amount of deposited Ru metal decreases when oxidizing conditions are reestablished and production continues without feeding RuNO(NO3)3. We have however analyzed the off-gas and found that RuO2 was detectable in SBS samples even after producing 7,000 kg of glass. This finding would be hard to explain if only the melt were the source of Ru. The concentration of Ru in the melt was small (about 200 g) at the end of RuNO(NO3)3 injection and probably too small to detect RuO2 in the off-gas after three melt turnover. The deposited 5 kg of Ru metal on the floor could have been oxidized slowly thereby contributing to the release of RuO2.	
2	Summary, objective table, Objective 3	References need updating , Section 4 provides Mass Balance info, table 4.1 and figures do not address off gas data. Provide data and explanation of how data shows that the test duration was sufficient.	m	Show that test objectives are met.	Revise the Discussion Section for Objective 3 to clarify the following items. This report is limited to testing on the DM1200. The correct tables to reference are 3.1-3.3. The correct Figure is 3.1.	
3	Summary, objective table, Objective 5	References need updating , Section 4 provides Mass Balance info, table 4.1 and figures do not address steady state throughput. Provide data and explanation of how data shows that the steady state was	m	Show that test objectives are met.	Correct to refer to Tables 3.1-3.3 and Figure 3.1. Steady-state is usually regarded as being achieved after the production of about three	

ORP-51441, Rev. 0

COMMENT RESOLUTION FORM

Page 2 of 2

Item No.	Section/ Paragraph	Comment	Significance ^a	"M" Comment Justification ^b	Response	Resolution
		achieved.			melter inventories of glass (i.e, three turnovers).	
4	Summary, objective table, Objective 12 and 14	Section 4.0 does not seem to be a relevent reference	m	Show that test objectives are met.	Correct references in both cases. The correct sections to reference are 3.0 and 5.0.	

^a **Significance:** M = Mandatory; I = Improvement. Definitions for these terms are provided at the end of the form instructions and in Appendix B of procedure "WTP Document Administration".

^b Justification required for Mandatory Comments.

ORP-51441, Rev. 0

Petkus, Lawrence

From: Beaumier, Cynthia
Sent: Thursday, March 25, 2004 3:44 PM
To: Petkus, Lawrence
Subject: RE: Review of VSL-04R4800-1, Final Report - Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants

Larry,

There are no operations comments on the document referenced below.

Thanks.

-----Original Message-----

From: Petkus, Lawrence
Sent: Thursday, March 11, 2004 10:23 AM
To: Suarez, Linda; Sunday, Sean M; Saucedo, Ermelinda; Vacca, Karen; Ongpin, Maria; Barnes, Steven M; Schuetz, Phillip; Perez, Joseph; Furlong, Peter
Cc: Knighton, David; Doyle, Jeanette; Lee, Ernest D; Hyman, Marve; Carl, Daniel; Damerow, Frederick; Winkler, Clifford; Schneider, John; Gimpel, Rod; Beaumier, Cynthia
Subject: Review of VSL-04R4800-1, Final Report - Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants

We have received the draft report VSL-04R4800-1, Final Report - Integrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants. The report is located on the R&T share drive at the following link:

<\\Wtps0166\R&T\Vitrification\HLW Mltr Tstg\DM1200\Redox & Bubbler Testing\Draft A Rpt for Review\VSL-04R4800-1, Rev A - DM1200 Reductant.pdf>

The controlling documents for this work, Test Specification, 24590-HLW-TSP-RT-02-015, and the Test Plan VSL-03T3800-1, can be found on the R&T share drive at the following links:

<\\Wtps0166\R&T\Vitrification\HLW Mltr Tstg\DM1200\Redox & Bubbler Testing\Draft A Rpt for Review\24590-HLW-TSP-RT-02-015_Rev_000.pdf>

<\\Wtps0166\R&T\Vitrification\Test Plans Specs & Procedures\HLW\Variability Testing\Test Plan\DM1200-C106AZ101-tpl-Rev0.doc>

The R&T Subcontractor Document Review Record and the Comment Resolution Form are attached for your use. Please review the subject document and provide any comments to me by March 25, 2004.
 Thank you.

Larry Petkus

R&T, Sigma IV
 Ph. 371-8436

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Petkus, Lawrence

From: Bostic, Lee
Sent: Thursday, April 15, 2004 12:39 PM
To: Petkus, Lawrence
Subject: RE: Comments on VSL-04R4800-1 Final Report - Integrated DM1200 Melter Testing of Redox effects Using HLW AZ-101 and C-106/AY-102 Simulants

With your explanation, I can accept your response. No need to add anything else to the report.

Lee

-----Original Message-----

From: Petkus, Lawrence
Sent: Thursday, April 15, 2004 11:22 AM
To: Bostic, Lee
Cc: Perez, Joseph
Subject: RE: Comments on VSL-04R4800-1 Final Report - Integrated DM1200 Melter Testing of Redox effects Using HLW AZ-101 and C-106/AY-102 Simulants

Lee,

The pressure spikes experienced by VSL will be a rare event at WTP, but I cannot say it will not ever happen. The plant pressure control system will be much more robust than the one at VSL. Engineering has modeled the pressure control system and they are experts on the subject. However, here are a few of the differences: 1) The plant system is design to handle a 7X surge, while VSL can handle about a 3X surge; 2) The plant system has faster control response with at least two levels of control and high pressure interlocks to cut off feed and air addition; 3) The plant has a secondary vent to the SBS, which VSL does not have; 4) Finally, during testing we are pushing the operating limits for a particular feed, plant operation will be more conservative.

I hope this helps. Do we to add anything else to this report?

-----Original Message-----

From: Bostic, Lee
Sent: Thursday, April 15, 2004 10:07 AM
To: Petkus, Lawrence
Subject: RE: Comments on VSL-04R4800-1 Final Report - Integrated DM1200 Melter Testing of Redox effects Using HLW AZ-101 and C-106/AY-102 Simulants

Larry,

I didn't get from your response whether you think the same thing will happen in the full scale melter operation. If it will, we need to decide how to determine the frequency and emissions for comparison with the RCRA/air permit emission estimates.

Lee Bostic

-----Original Message-----

From: Petkus, Lawrence
Sent: Thursday, April 15, 2004 8:43 AM
To: Hyman, Marve; Carl, Daniel; Reynolds, Jacob; Nurdogan, Yakup; Bostic, Lee; Knauss, Craig
Cc: Valenti, Thomas; Perez, Joseph; Knighton, David; Doyle, Jeanette
Subject: Comments on VSL-04R4800-1 Final Report - Integrated DM1200 Melter Testing of Redox effects Using HLW AZ-101 and C-106/AY-102 Simulants

Attached are the responses from VSL today on your comments to VSL-04R4800-1, Final Report - Integrated DM1200 Melter Testing of Redox effects Using HLW AZ-101 and C-106/AY-102 Simulants. I will be looking for a response on comment acceptability by COB today, so that VSL can then incorporate the comments and finalize the report.

Thank you.

Note that the Process Operations comments are included twice, as a separate file and combined with the engineering comments.

Larry Petkus

R&T, Main L-179

Ph. 371-3258

<< File: Reduct CRF_ENG_dc-a.doc >> << File: Reduct CRF_ENG_dec_dc-a.doc >> << File:
Reduct_CRF_ENS_dc-a.doc >> << File: Reduct_CRF_PrOps_dc-a.doc >>

R&T Technology Issues Summary

Page 1 of 1

Test Report Title: Final Report - Intergrated DM1200 Melter Testing of Redox Effects Using HLW AZ-101 and C-106/AY-102 Simulants

Test Report Number: VSL-04R4800-1

Prepared By: Lawrence Petkus **Date:** May 12, 2004

Signature: Lawrence Petkus

Does the Testing or Report reveal any new discoveries, technology issues, or suggest potential follow-on work?	Yes	No
	☐	☒

If yes, describe the suggested activity.

If appropriate, is a Request for Technology Development attached.	Yes	No
	☐	☒

Additional comments (include researcher recommendations):

1) SBS solids accumulation is the subject of continuing work. A new prototypic SBS bed has been installed for testing. 2) Work with ruthenium and low sugar additions to for supression of volititlity is continuing as part of other tests. 3) Mitigation of iodine in the off gas train is planned. There are no plans to pursue iodine retention in glass.