FINDINGS

from the

ENGINEERING SUPPORT SERVICES CONTRACT
for implementation of the
RECORD OF DECISION
for the
FERNALD ENVIRONMENTAL MANAGEMENT PROGRAM
OPERABLE UNIT 4

FERMCO Contract Number 95SP004785

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For the
FERNALD ENVIRONMENTAL RESTORATION MANAGEMENT COMPANY

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1.0 INTRODUCTION

1.1 Background

The Department of Energy's (DOE) Fernald Site formerly served as the Feed Materials Production Center, making high purity uranium metal for use in national defense programs. Production operations have been shut down for environmental restoration, and the site is now referred to as the Fernald Environmental Management Project (FEMP). The current environmental restoration management contractor is Fernald Environmental Restoration Management Company (FERMCO). One activity at the FEMP involves the processing of low-level radioactive byproducts presently stored in three silos on the site. About two-thirds of the material is spent uranium ore and uranium decay products such as radium, and the other one-third is oxidized spent ores without significant quantities of decay products. The material is to be removed from the silos, mixed with glass forming additives, and vitrified in a glass melter. A conceptual design for the full-scale plant, called the Fernald Residues Vitrification Plant (FRVP), was completed in 1992 and a pilot vitrification plant is presently being constructed. These findings are based on the current status of these designs.

1.2 Purpose and Scope

The purpose of this study is to review FERMCO's implementation of DOE's Record of Decision for the FEMP Operable Unit 4 (OU4). OU4 consists of the existing silos, the pilot plant, the FRVP, and the land containing these facilities. The specific scope of this study is:

- Review and evaluate the OU4 vitrification pilot plant program relative to process and equipment scale-up. The review includes equipment design, facility design, and test plans for Phase I and Phase II operation as well as the conceptual design of the FRVP.

- Evaluate the OU4 vitrification pilot plant melter and glass forming equipment with respect to scale-up issues.

- Support ongoing melter and off-gas treatment system demonstration activities.

- Evaluate the glass melting process measurement and control system.

- Evaluate the system reliability, availability, maintainability, operability, and safety.
- Investigate corrosion issues in the melter.
- Assist with updating the pilot plant heat and material balance.
- Evaluate the proposed glass formulations.

1.3 Methodology

The author was the Process Design Manager at the PAMELA Vitrification Plant in Mol, Belgium for six years during the conceptual design, final design, and startup testing. A brief introduction to the PAMELA plant is included in Appendix A for background information. The experience gained at PAMELA was used as a basis for this review.

Multiple aspects of the pilot plant and the FRVP were evaluated. Evaluation materials came from many sources. Pilot plant drawings, data, and calculations were reviewed, field examinations of the pilot plant construction site were made; and discussions with cognizant engineers were held. GTS Duratek, the pilot plant melter vendor, was contacted and numerous melter drawings and data were reviewed. Finally, the PARSONS' Conceptual Design Report was reviewed.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Three areas of concern were identified in this study: the melter design and the gem maker design, which are the responsibility of GTS Duratek, and the off-gas system design, which is the responsibility of FERMCO and PARSONS.

The three-chamber arrangement of the melter will cause the temperature control system to be non-linear. Because of this controlling the waste glass temperature may be difficult. This issue should be monitored closely during Phase I of the pilot plant testing and corrective action taken if necessary.

The design of the melter pour spout and gem-making machine results in a direct connection between the melter off-gas and the building HVAC system. This connection has the potential to either choke the off-gas system or discharge melter off-gas into the HVAC system. During Phase II testing, radon could be released into the HVAC system. This design should be investigated carefully during Phase I testing and modifications made if necessary.

Glass is discharged from the melter pour spout onto the gob cutter. The gob cutter breaks the glass stream into gobs which land on the conveyor, cool, and solidify into gems. Cooling of the gob cutter wheels is by forced convection from the HVAC air. Experience at PAMELA found that after a couple of hours of operation, the gem maker metal temperature reached 400 °F to 500°F, at which time glass began sticking and caused a system shutdown. Gob cutter wheel temperature should be monitored closely during Phase I testing. Design modifications should be prepared in advance in case the PAMELA problem occurs at Fernald.

A heat and mass balance was prepared for the melter off-gas system that showed an excessively high velocity, and therefore pressure drop, in the 4-inch off-gas pipe. It is recommended that this line be replaced with an 8-inch pipe.

Heavy plateout of glass formers in the off-gas line is possible because of the potentially high off-gas temperature. If this occurs, plugging of the line could exacerbate the pressure drop problem. Several methods are proposed that should be considered for installation in the pilot plant off-gas piping.

3.0 PILOT PLANT MELTER DESIGN ISSUES

3.1 General Information

Appendix B presents relevant basic information about the Duratek melter in particular and the pilot plant in general that was used in the following evaluations and investigations. The quantities of reaction gasses (SO_x, NO_x, and CO_2) generated were calculated to support the off-gas evaluations. Comparisons of the pilot plant melter to the Minimum Additive Waste Stabilization (MAWS) melter and an 8-metric ton per day (MT/day) melter scaled up from the pilot plant melter design were made.

3.2 Melter Temperature Control

Appendix C evaluates the expected power distribution in the pilot plant melter. The melter is divided into three glass sections. Waste glass is in the center section and the molybdenum electrodes are located in the two outer sections, which contain benign glass. The three sections are separated by high-chromium refractory walls that act like electrodes. The waste glass is formulated to require melter operation at

1350°C, which, coupled with the waste content, makes it extremely corrosive. To minimize corrosion, the electrodes are immersed in benign glass.

As electric current flows between the electrodes, heat will be generated due to the resistance in the three glass pools and the two separating walls. The amount of heat generated in each section is dependent on upon its electrical resistivity. This can be visualized as an electrical circuit containing five resistors in a series as such:

```
+ ●--/\/\/\/\/--●--/\/\/\/\/--●--/\/\/\/\/--●--/\/\/\/\/--●--/\/\/\/\/--● -
    BENIGN        WALL        WASTE         WALL        BENIGN
    GLASS                     GLASS                     GLASS
```

Resistivity is, in turn, a function of temperature. Unfortunately, the functions (shape and slope of the temperature - resistivity curves) are different for each of the sections. The percentage of heat generated in each section at two different temperatures was determined to be as follows:

Relative Heat Generation (Percentage of Total)

Section	1000 °C	1250 °C
Benign Glass	1.4	1.5
High-Chromium Wall	19.7	10.7
Waste Glass	78.9	87.8

As can be seen, the relative heat generation in the high-chromium walls is cut nearly in half as temperature increases from 1000°C to 1250°C. This will result in non-linear plenum and benign glass temperatures as a function of waste glass temperature. This nonlinearity must be compensated for in the melter controller's algorhythm since waste glass temperature must be inferred from plenum and/or refractory temperatures. Indirect measurement is required because the lifetime of in-glass thermocouples is too short. The relationship between these indirect temperatures and the waste glass temperature must be determined during pilot plant testing in order to properly design the controller. Campaign 1 of the Phase I pilot plant test will establish this relationship.

3.3 Glass Temperature Measurement During Phase I Testing

An accurate measurement of the waste glass temperature during the Phase I test program is difficult but necessary to allow proper programming of the melter temperature control system. The problem is that electrical currents in the glass due to the Joule heating can interfere with the proper operation of thermocouples. All thermocouple designs are susceptible to electrical interference; however, some designs are more susceptible than others because of the bonding of the couple to the thermowell and the composition of the insulation between the two.

Appendix E presents a means to accurately calibrate glass thermocouples using optical pyrometry.

3.4 Refractory Corrosion

The equilibrium temperature of the high-chromium walls may be significantly higher than the waste glass temperature. Corrosion rates at these high temperatures are not known to the author; therefore, predicting their lifetime is not possible at this time.

3.5 Melter Draining

Duratek has predicted that complete melter draining via the bottom drains will be required several times during the life of the pilot plant melter. Thermal radiation from molten glass immediately after draining is an issue that needs to be addressed. There is a lot of equipment, especially electrical, that could be damaged by the high temperatures that would occur. Appendix G presents a conceptual design of an insulated bottom drain box that could mitigate these problems.

4.0 GEM-MAKING MACHINE

4.1 Gem-making Machine to Pour Spout Connection

Appendix J evaluates the gem-making machine which is directly connected to the melter pour spout. Molten glass flows out of the melter and drops upon the gob cutter wheel. Glass gobs then fall upon a conveyor belt where they solidify into gems. Cooling of the glass through the gob cutter and on the conveyor belt is done by circulating room air over the equipment and then exhausting it to the HVAC system.

Duratek has just recently revised their pour spout design to replace the three small, regulated spouts with a single, 3-inch diameter spout. The glass stream flowing through this spout will be approximately ¼-inch in diameter, leaving significant area for air flow. The melter plenum is also connected to the pour spout plenum via numerous leak paths that are believed to exist and refractory brick porosity. The net result is that the melter off-gas system will be directly connected to the HVAC system. Depending on the relative pressures in these systems, which will fluctuate frequently, either room air will leak into and possibly choke the melter off-gas system, or melter off-gas, containing radon and other contaminants, will flow into the HVAC system. A redesign of the cooling system or the melter pour spout, or closure of the numerous leak paths may be necessary to resolve this problem.

4.2 Gob Cutter Temperature

Tests at the PAMELA pilot plant with a bead making machine (similar to the gem-making machine) showed that when the gob cutter surface temperature reached 400°F to 500°F glass tended to stick to it and not roll off like it is supposed to do. This caused the glass to build up and make the equipment unusable. The melter had to be shut down, the bead making machine removed, and the glass mechanically chipped away. It was also found that it took several hours for the bead making machine to reach equilibrium temperature. This problem was not observed in the MAWS melter since, it has been stated by personnel that worked on the project, that the melter never operated continuously for more than a half an hour, thus the gob cutter never reached its equilibrium temperature.

For the pilot plant melter, the gob cutter equilibrium surface temperature is estimated to be between 400°C and 500°C. This is approaching the failure temperature. The pilot plant testing program should evaluate this issue. The test procedures need to ensure that the gob cutter reaches its equilibrium temperature during the evaluation.

A suggested modification to the gob cutter wheel is presented if testing proves temperature equilibrium to be a problem.

5.0 OFF-GAS SYSTEM

5.1 Measurement of In-Leakage During System Operational Testing

Minimizing the amount of in-leakage air into the melter plenum is important to the proper operation of the off-gas system. Too much in-leakage will overwhelm the off-gas system and result in a reduced glass production rate.

An accurate measurement of this flow and plugging of excessive leaks must be made during System Operational (SO) testing. Appendix D presents a proposal to conduct such a test prior to the first charge of glass.

5.2 Estimate of In-Leakage for a Full-Scale Melter

Appendix F estimated that an obtainable in-leakage for a properly designed 25 MT/day melter is approximately 50 ft^3/min. It is recommended that a maximum allowable air in-leakage value be put into the melter specification.

5.3 Off-gas Heat and Mass Balance

Appendix I presents an updated heat and mass balance for the melter off-gas temperature and flow. Using the current PARSONS/Duratek estimation of in-leakage, reaction gasses, bubbler flows, etc., the estimated flow velocity in this 4-inch pipe is 712 acfm which results in a velocity of 150 ft/sec, which is too high. It was estimated that in-leakage could be reduced and other modifications made that would reduce this flow to 309 acfm for a velocity of 65 ft/sec, which still results in 12-inches of water pressure drop when clean. A clean pressure drop this high is expected to cause melter pressure control problems during operation since it will increase dramatically as plugging occurs. The off-gas line should be replaced with an 8-inch pipe, as noted in Section 4.5.

5.4 Off-gas Piping and Plateout

It is possible that the equilibrium temperature of the benign glass could be higher than the waste glass due to the relationship of Joule heat input, heat losses, and volume of glass in each of the sections. If this occurs, it could lead to higher than expected off-gas temperatures due to the fact that the benign glass pool has no cold cap to limit radiation into the plenum. A high off-gas temperature adversely affects the metallurgy of the off-gas piping and increases the potential for plateout. Experience at PAMELA has shown that off-gas temperatures in excess of 500°C cause glass formers carried over into the off-gas piping to fuse to the metal, and become much more difficult to remove.

5.5 Off-gas Pipe Cleaning

Plugging of the off-gas line between the melter and the quench tower with glass formers carried over with the exhaust gasses is a real concern. Experience at the PAMELA plant showed that cleaning of this line with a mechanical brush was required every two to three weeks when the pressure drop in this 30-inch long line reached 12 inches of water. The current design of the pilot plant off-gas line uses 40-feet of 4-inch pipe, contains six elbows, and does not have provisions for cleaning. It is recommended that this line be replaced with an 8-inch pipe, routed as straight as possible with provisions for mechanical cleaning. Appendix H presents conceptual designs for numerous mechanical cleaning devices that could be considered.

6.0 Pilot Plant Testing

Appendices K and L evaluated the Phase I test plan. It was concluded that not all of the necessary tests were identified and that the time allotted to perform the tests was not sufficient. A revised test plan outline and 38-week schedule is presented in Appendix M. The original phase I test plan was 10 weeks.

Appendix N presents a similar 18-week schedule for the Phase II test program.

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APPENDIX A

PAMELA Vitrification Facility Description

Below is a description of the PAMELA Vitrification Plant where the author spent six years as the Process Design Manager. The following table compares the PAMELA plant to the Vitrification Pilot Plant (VITPP).

ITEM	PAMELA	VITPP
Type of Melter	Joule-heated, liquid-fed, ceramic-lined	Joule-heated, liquid-fed, ceramic-lined
Capacity	Approx. 25 kg/hr, actual	41.7 kg/hr, design
Feed	High-level liquid waste with dry frit	Naturally Occurring Radioactive Material (NORM) mixed with dry glass formers
Waste Loading in Glass	Approx 10 %, actual	57.75 %, design
Waste Form	Monolith in 150 L canisters	Gems in Concrete Boxes or Monolith in 55 gal drums

For the German, full-scale reprocessing plant planned in Wackersdorf[1] three facilities in the scale 1:1 were constructed:

1) The PAMELA plant for the vitrification of HLW in Mol[2], Belgium

2) The TEKO[3] test facility; to optimize, develop and demonstrate the mechanical and chemical process equipment for nuclear fuel reprocessing

3) The LAHDE[4] test facility; to develop and demonstrate the remote and process

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1 Name of the town

2 Name of the town

3 Acronym for pilot test plant

4 Name of the town

techniques for the reprocessing of spent fuel elements

Before the PAMELA plant was built, two test facilities which operated with simulated waste in the scale 1:1 were constructed, to obtain experience about vitrification of HLW. One facility was located in Mol, Belgium and the other one at the Nuclear Research Center in Karlsruhe[5] (Germany).

In the Federal Republic of Germany, the development of HLW vitrification started in 1965 at the Karlsruhe Nuclear Research Center (KFK). In November 1978 all German activities on the development of HLW vitrification were unified under the so called ***"Technology Program for High Active Waste."*** The primary objective of this program was to establish the basis process engineering and to support the planning of the PAMELA plant. In 1978 the planning of the PAMELA project started under the leadership of the German reprocessing company DWK. The German Federal Ministry for Research and Development (BMFT) sponsored 80% of the 150 Million DM project costs. Construction of the PAMELA plant started on the site of the former *EUROCHEMIC reprocessing plant* in Mol, in 1981 and cold testing of the PAMELA plant began in August 1984.

Table 1: PAMELA Basic Data

PAMELA	:	Pilotanlage Mol zur Erzeugung Lagerfähiger Abfälle (Pilot Plant Mol for the Production of Wastes suitable for Storage)
Start of planning	:	1978
Start of construction	:	1981
Start of cold tests	:	August 1984
Start of LEWC vitrification	:	October 1, 1985
End of LEWC vitrification	:	August , 1986
End of HEWC vitrification	:	August 19, 1991
Project costs	:	150 Million DM ($ 107 Million[6])

Vitrification started on October 1, 1985 with 50 m^3 Low Enriched Waste Concentrate

5 Name of the town

6 Basis 1995

(LEWC)[7].

Table 2: PAMELA Production Data

	LEWC	HEWC[8]	Total
High level waste solution [m^3]	47.2	860	907.2
[gal]	12,487	227,513	239,947
α-radioactivity [Ci]	$3.45*10^4$	$3.94*10^3$	$3.86*10^4$
β-radioactivity [Ci]	$7.5*10^6$	$2.5*10^6$	$1.0*10^7$
Specific radioactivity [Ci/L]	159.6	2.91	
[Ci/gal]	604.1	11.0	
Vitrified glass product [MT]	77.8	411.7	489.5
No. of canisters	542	939	1481
Cumulative dose rate [rem]	4	32.2	36.2
Dose rate per person and year [mrem]	113	132	129.6

The vitrification of a total amount of 907 m^3 HLW was finished at August 19, 1991. Today the plant is owned and operated by the Belgian company Belgoprocess.

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7 LEWC originated from the reprocessing of 181 MT of spent natural and low enriched uranium fuel elements with enrichment levels up to 4.3% U_{235}.

8 The HEWC resulted from the reprocessing of 30.6 MT of spent uranium - aluminum alloy fuel elements with a maximum enrichment of 93% U_{235}. Since Nov. 1988, Belgoprocess is using 150 L canisters for the vitrification of HEWC containing 385 Kg of glass each.

Conclusion:

What were the objectives of the PAMELA Project?

This project should demonstrate the feasibility to vitrify HLW from spent fuel elements in an industrial scale and deliver planning data for the full scale Wackersdorf plant.

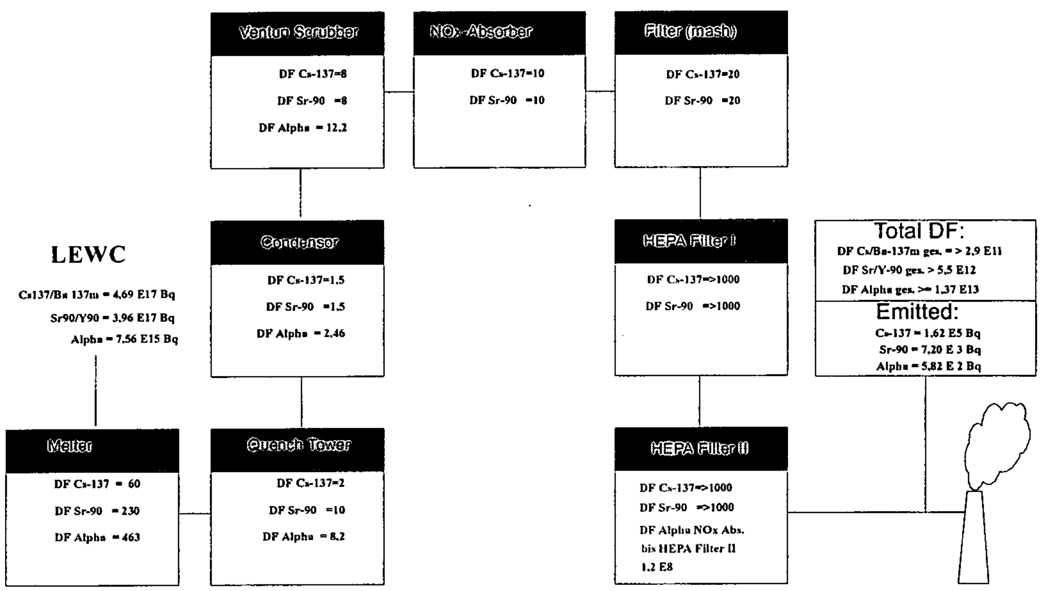
Furthermore:

- The development of equipment and tools for remote operations and maintenance
- Testing of this equipment
- Testing of remote dismantling of the melter and other highly contaminated equipment
- Training of operating staff

The plant operated for about six years; 907 m^3 of HLW were vitrified in 489 MT of glass product .

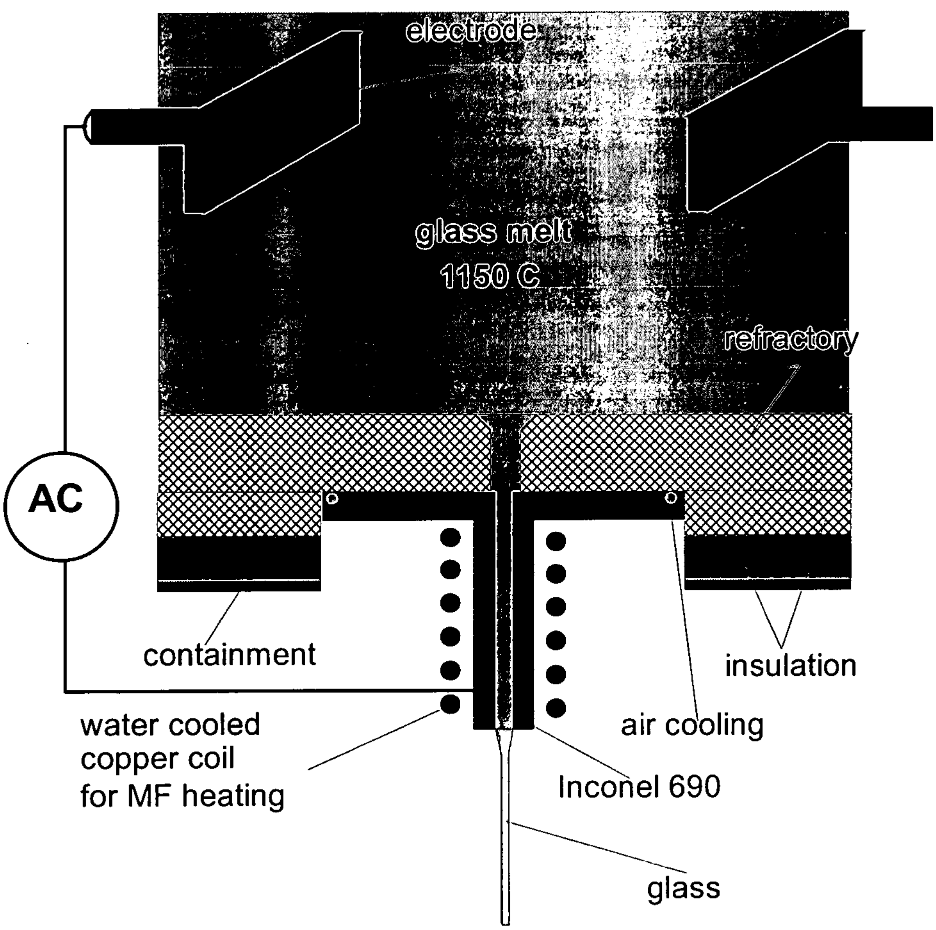
Viewgraphs:

PAMELA Decontamination Factors



pam_deco.drw

Bottom Drain System



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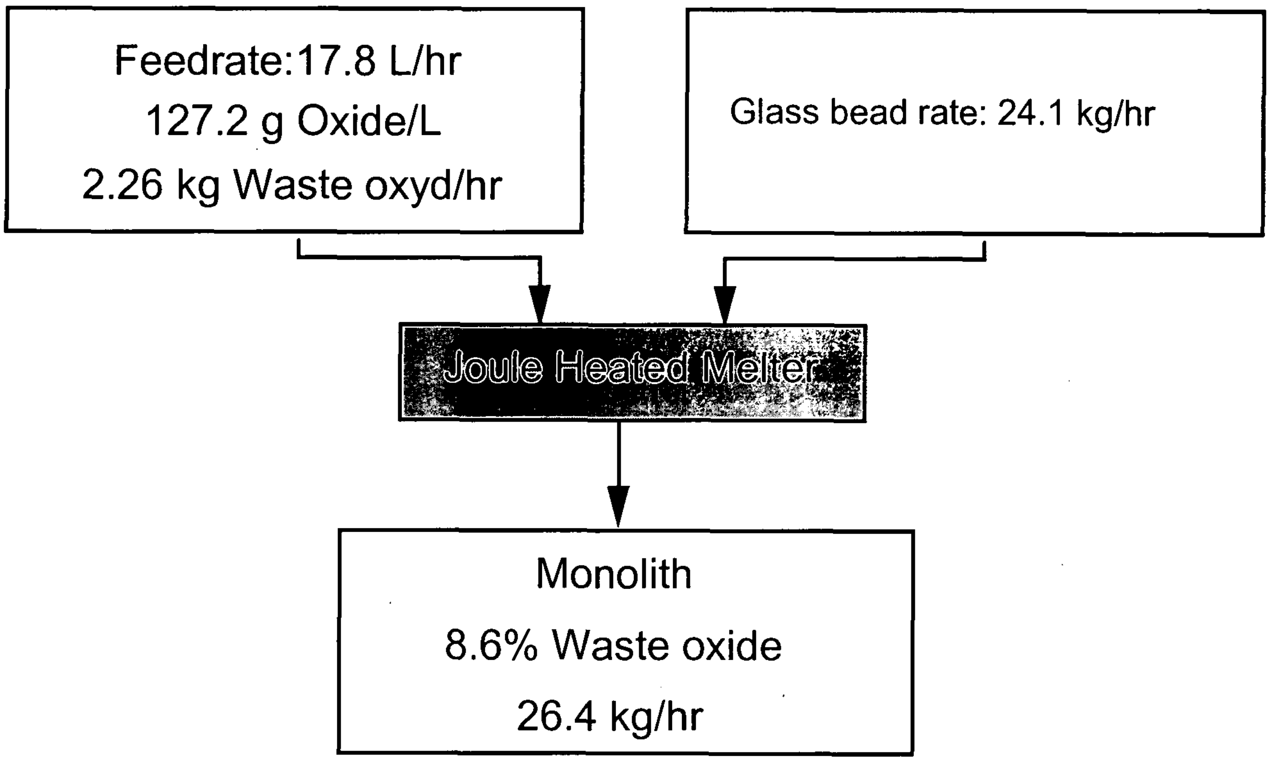
PAMELA Vitrification of LEWC Campaign I



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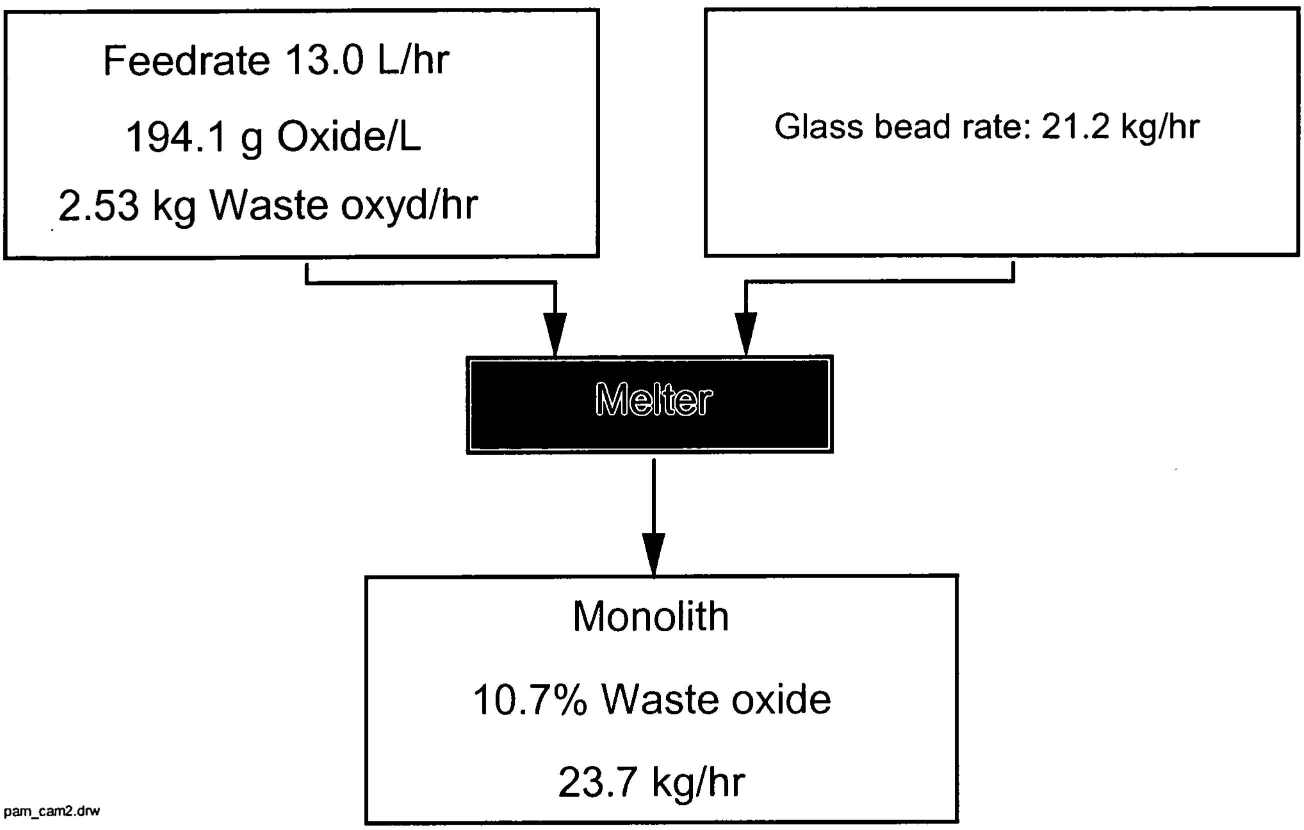
PAMELA Vitrification of LEWC Campaign II



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APPENDIX B

Pilot Plant Design Issues

Basic Data

Benign glass	1.0 S/cm = 1 Ω cm (melter chambers with Mo electrodes)
Cr-material	7 Ω cm (1250°C)
	4 Ω cm (1400°C)
waste glass	0.2 S/cm = 5 Ω cm

	Number of melters	Throughput glass (per melter)		Melt surface m^2	Feed	Spec. Surface rate kg/m^{2*} h	Operat. days	Mg glass (Total)
		Mg/d[1]	Kg/h					
Pilot	1	1.00	41.7	0.835	50% solids	49.9		
Full-scale	3	7.282 (8.01)	303.4				880	19,213
MAWS	1	0.65	27.1	0.30	35% solids	90.8		

[1] Metric tonnes

About 20 - 30 tons of material (70% from Silo 2 and 30% from Silo 3) should be vitrified in the pilot plant. The first scheduled runs take place with material only from Silo 2, than from Silo 3 and later on a mixture from Silo 2 and Silo 3 in 70:30 relationship.

Ratios (dry wt.)	Silo 1	Silo 2	Silo 3	Bento nite	All wastes	Addi-tives	Total in	Glass	Gase s	Total out
Mass balance in %	24.68	21.38	18.54	4.15	68.76	39.70	108.46	100.00	8.46	108. 46
Mg	5216	4519	3918	878						
Sum: Silo1+ Silo2+ Silo3+ Bentonite [Mg]	14531									

14531 Mg = 108.46%
13398 Mg = 100.00% = glass

1133 Mg = 8.46% = off-gas

Feed : 50% waste + 50% water

Component 1	Silo1 in %	Silo2 in %	Silo3 in %	Conversion factor	Component 2	Silo1 5216 Mg		Silo2 4519 Mg		Silo3 3918 Mg		Total Mg Component2	Total input kg/h	Total input sm^3/hr (0°C, 1bar)	Input one melter kg/hr
						%	Mg	%	Mg	%	Mg				
CO_2	3.72	4.02	2.19	1.00	CO_2	3.72	194.0	4.02	181.7	2.2	85.8	461.50	21.85	11.27	7.28
SO_3	2.09	2.01	17.26	0.80	SO_2	1.67	87.1	1.61	72.8	13.8	541.1	700.94	33.19	11.77	11.06
N_2O_5	0.34	0.73	7.02	0.43	NO_2	0.15	7.8	0.31	14.0	3.0	118.3	140.16	6.64	3.43	2.21
Cl	0.09	0.01	0.02	1.03	HCL	0.09	4.7	0.01	0.5	0.02	0.8	5.93	0.28	0.17	0.09
F	0.01	0.01	0.09	1.00	F	0.01	0.5	0.01	0.5	0.1	3.5	4.50	0.21	26.64	0.07

Input=output CO_2, SO_2, NO_2 = 1302.6 Mg = 26.64 sm^3/h for full scale plant. This amount off-gas produced per hour from a glass production rate of 303.4 kg/h.

100 kg/hr produced waste glass generates 8.780 sm^3/hr reaction gases (CO_2, SO_2, NO_2).

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APPENDIX C

GTS Duratek Melter

Power Distribution in the Duratek Melter

Power Distribution in Pilot-Melter

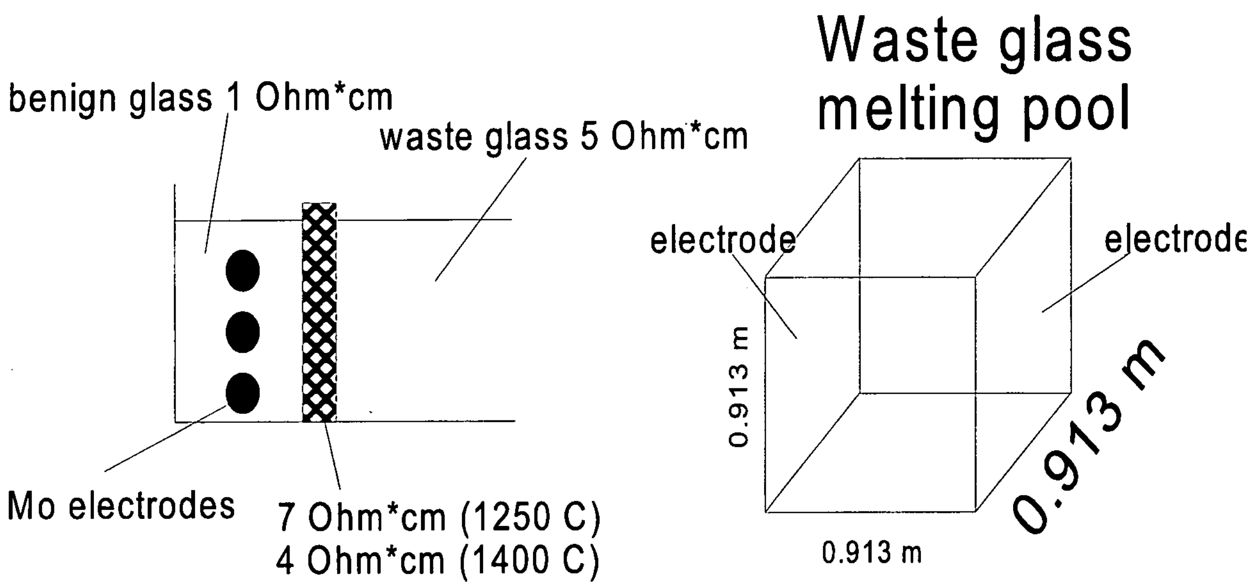

Figure 1

Melter data

Total melting pool surface:	1.12 m^2 (100%)
Melting pool surface main chamber (waste glass):	0.835 m^2 (75%)
Melting pool volume (waste glass) :	0.840 m^3
Melting pool surface (benign glass):	0.277 m^2 (25%, both chambers)
Benign glass volume (both chambers):	0.253 m^3

Basics

Resistivity of glass pool, ceramic electrodes

$R = \rho * l/a$ ρ = spec. resistivity in Ω * cm

l = length in cm

a = area in cm^2

Power, voltage, current, resistance

V=R*I P=V*I

$P=R*I^2=V^2/R$ I=SQRT(P/R) V=SQRT(P*R)

Estimated power consumption:

≈ 80 kW /m^3 glass (only heat loss for good insulated melter at 1150°C glass melt)

≈ 44 kW to evaporate 45.2 kg of water/h and superheat it to about 500°C

8098

Total estimated power consumption for FERMCO pilot melter

150 - 200 kW use 150,000 watts

Power consumption

$P = V * I$ $V = R * I$

$P = R * I^2$

Calculation of the current and voltage

I = SQRT(P/R) = SQRT(150,000/0.0627) = 1547 A

V = 150,000/1547 = 97 V

How does current, voltage and power in the melter change as a function of glass/electrode resistance for current, voltage and power controlled modes?

<table>
<tr><th>Control Mode of the Melter</th><th>Resistance</th><th>Current</th><th>Voltage</th><th>Power</th></tr>
<tr><td rowspan="2">Current controlled</td><td>Increasing</td><td rowspan="2">Constant</td><td>Increasing</td><td>Increasing</td></tr>
<tr><td>Decreasing</td><td>Decreasing</td><td>Decreasing</td></tr>
<tr><td rowspan="2">Voltage controlled</td><td>Increasing</td><td>Decreasing</td><td rowspan="2">Constant</td><td>Decreasing</td></tr>
<tr><td>Decreasing</td><td>Increasing</td><td>Increasing</td></tr>
<tr><td rowspan="2">Power controlled</td><td>Increasing</td><td>Decreasing</td><td>Decreasing</td><td rowspan="2">Constant</td></tr>
<tr><td>Decreasing</td><td>Increasing</td><td>Increasing</td></tr>
</table>

Calculation of resistance and power consumption at T = 1250°C (see Fig. 2)

$R1 = 1*4/91.3^2 = 4.8\ E\text{-}4\ \Omega$ $R2 = 7*4/91.3^2 = 3.36\ E\text{-}3\ \Omega$ $R3 = 5*91.3/91.3^2 = 0.055\ \Omega$

$R5 = 1*4/91.3^2 = 4.8\ E\text{-}4\ \Omega$ $R4 = 7*4/91.3^2 = 3.36\ E\text{-}3\ \Omega$

$P1 = 1547^2 * R1 = 1149\ W$ $P2 = 1547^2 * R2 = 8041\ W$ $P3 = 1547^2 * R3 = 131626\ W$

$P5 = 1547^2 * R1 = 1149\ W$ $P4 = 1547^2 * R2 = 8041\ W$

$\sum$ R1 until R5 = 0.0627 Ω

<u>At 1250°C the consumed electrical power is distributed in the melter as follows:</u>

Benign glass	1.5%
Cr-electrodes	10.7%
Waste glass	87.8%

Calculation of resistance and power consumption at T = 1000°C

spec. resistivity for benign and waste glass about factor 2.8 higher than at 1250°C

$R1+R5 = 0.0027\ \Omega$ $R2+R4 = 2*40*4/91.3^2 = 0.0384\ \Omega$ $R3 = 0.154\ \Omega$

$\sum$ R1 until R5 = 0.195 Ω

<u>At 1000°C the consumed electrical power is distributed in the melter as follows:</u>

Benign glass	1.4%
Cr-electodes	19.7%
Waste glass	78.9%

Chromium oxide electrode spec. electrical surface density

$a = 0.913 * 0.913 = 0.835\ m^2$

$d = 1547/8350 = 0.185$ A/cm2

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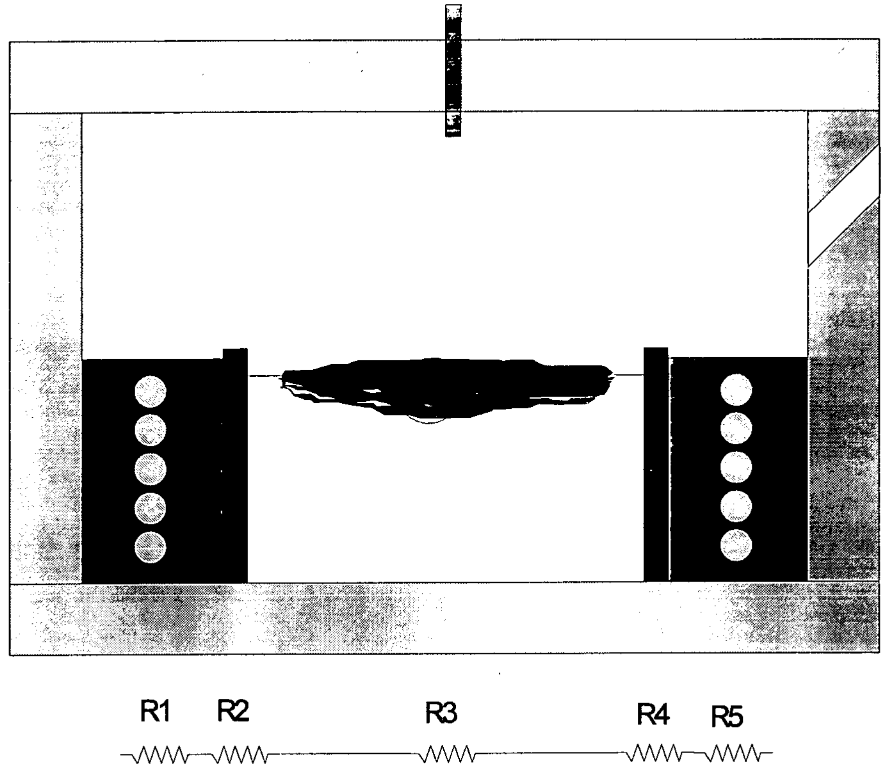

Fig. 2

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APPENDIX D

Determination of In-leakage Air into the Duratek Melter

1. Determination of Melter In-leakage Air

The amount of in-leakage air into the melter (plenum) is a very important quantity and has to be known before the melter start up. High volume of in-leakage air increases the off-gas from the melter and decreases the feed slurry input (and the glass throughput), because of higher water evaporation. This additional air stresses the off-gas treatment system. This is described in a separate paper.

1.1 Measuring of the In-leakage Air without Overflow System

The arrangement of flow and pressure measurement is shown in Fig. 1. The melter off-gas outlet is connected via a flow meter with a fan. The entrance for the film cooler air is closed. The pour spout (1) is closed by a rubber plug. Now the air flow is measured for different pressures in the melter plenum, i. e. -1, -2, -3 inches WC. If the in-leakage air is too high[1], it has to be find out, where the air is sucked into the melter. These gaps have than to be tightened up.

1.2 Measuring of the In-leakage Air with Overflow System

Fig. 2 shows the procedure to measure the additional in-leakage air via the overflow system. The riser is closed by an inflatable sealing (2) and the pour spout (1) is open. This arrangement is used to measure the additional air which is sucked in through the 3-inch diameter pour spout. The tightness of the melter plenum refractory and its insulation is a very important factor. If that refractory is not tight enough, the in-leakage air into the melter cannot be reduced! When pressure drops occur in the melter plenum, the off-gas can purge into the gem-making machine. The cooling air for the gem-making machine is purged without any further treatment into the HVAC system!!!

---

[1] A suitable number would be 15 cfm=25 m^3/hr

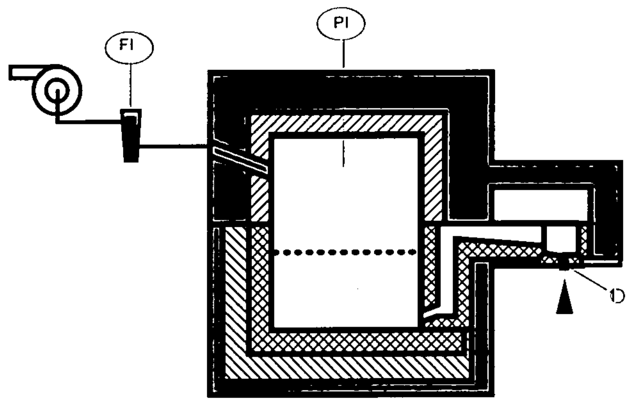

Fig. 1

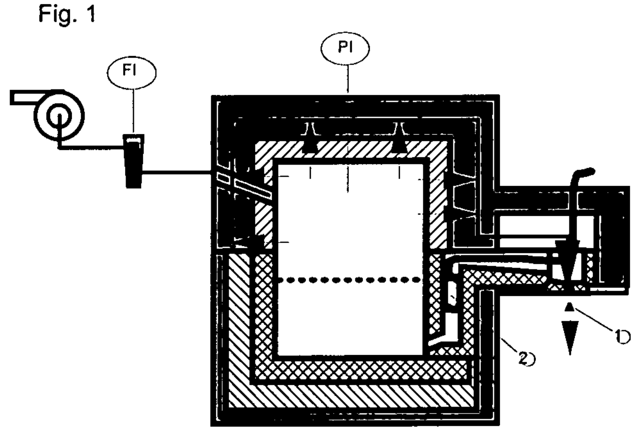

Fig. 2

melter4.drw

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APPENDIX E

Thermocouple Calibration

Recommended Melter - SOT

Calibration of Thermocouples

Thermocouple measurements in the glass melt can be influenced by the electric field in the melter. Faulty measurements can also occur if the wrong thermocouples are used or if there is any electrical connection between the glass melt and the Pt/Rh thermocouple wires.[1]

Another temperature measurement method, e.g., an optical pyrometer should be used to verify the thermocouple measurement. This comparison between thermocouple and pyrometric measurement needs to be done only once. To estimate the temperature with a pyrometer, a pipe with a closed bottom is dipped into the glass melt next to the thermocouple (see Fig. 1). By looking at the bottom of the pipe with a micro-pyrometer, the black body temperature is measured which is approximately equal to the glass temperature. By moving this pipe to different positions, the temperature profile in the melt pool can be determined.

---

1 During the Component Acceptance Test, the thermocouple should be checked with an oscilloscope to determine if an AC component is present, which would indicate an influence by the melter's electric field. When the conductivity of the insulation between the thermocouple measuring point and the thermowell is too high at temperatures >1000°C it would also indicate that the wrong thermocouple is being used.

Calibration of thermocouple (principle arrangement)

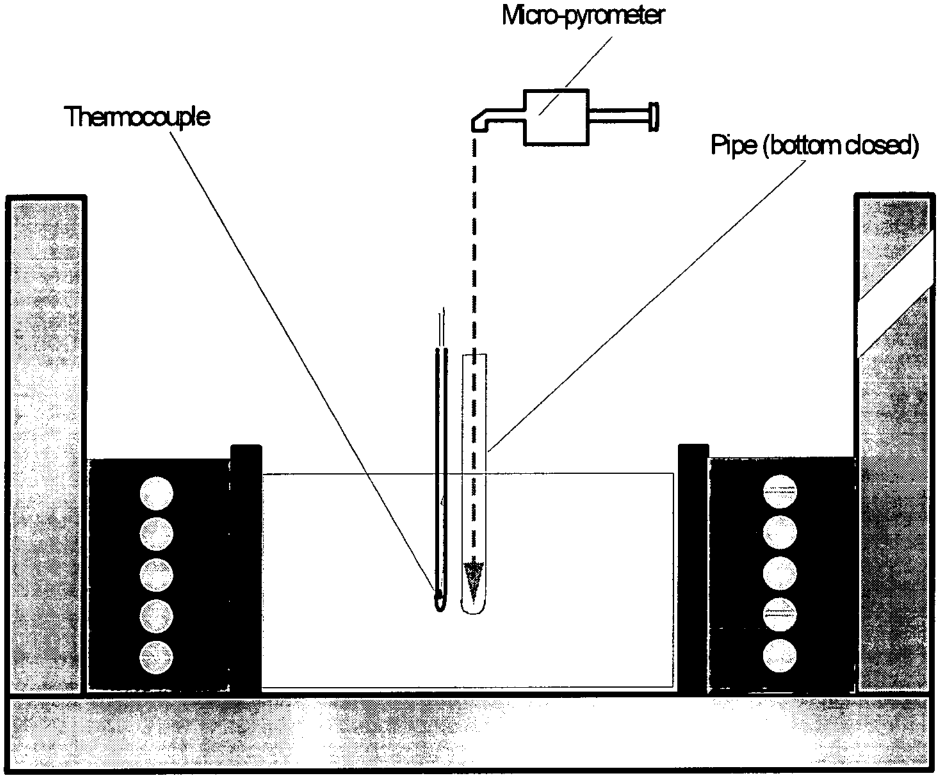

Fig. 1

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APPENDIX F

Estimation of In-leakage Air in a Full Scale Joule Heated Melter (25 Mg/d)

Estimation of In-leakage Air in a Full Scale Melter (25 Mg/d)

The outer melter shell for one full scale Joule heated melter is about 8m x 5m x 3 m (l x w x h). It should be feasible to manufacture the shell with all penetrations gas tight. Gas tight means the melter has a certain leakage rate measured in mbar-L/sec.

Ultra high vacuum systems (operating pressure 10^{-6} to 10^{-9} mbar) should have a leakage rate < 10^{-6} mbar-L/sec. Commercial vacuum systems (operating pressure 10^{0} to 10^{-2} mbar) should have a leakage rate of about 10^{-2} mbar-L/sec.

A leakage rate of 10 to 100 mbar-L/sec for a melter shell with all its penetrations seems to be reasonable. A leakage rate of 10 mbar-L/sec at a negative pressure of 12.85 mbar (5"WC) results in an amount of in-leakage air of 3 m^3/hr; and 30 m^3/hr for a leakage rate of 100 mbar-L/sec respective.

The only uncontrollable variable in this estimation is the in-leakage air via the overflow system. When a monolith is produced, the canister closes gas tight against the overflow pour spout and minimizes the in-leakage air flow. When an "open" system is used, such as when making gems, the amount of in-leakage air depends on the leak tightness between the melter plenum and the overflow compartment.

An in-leakage airflow of about 50 m^3/hr is estimated from the overflow system.

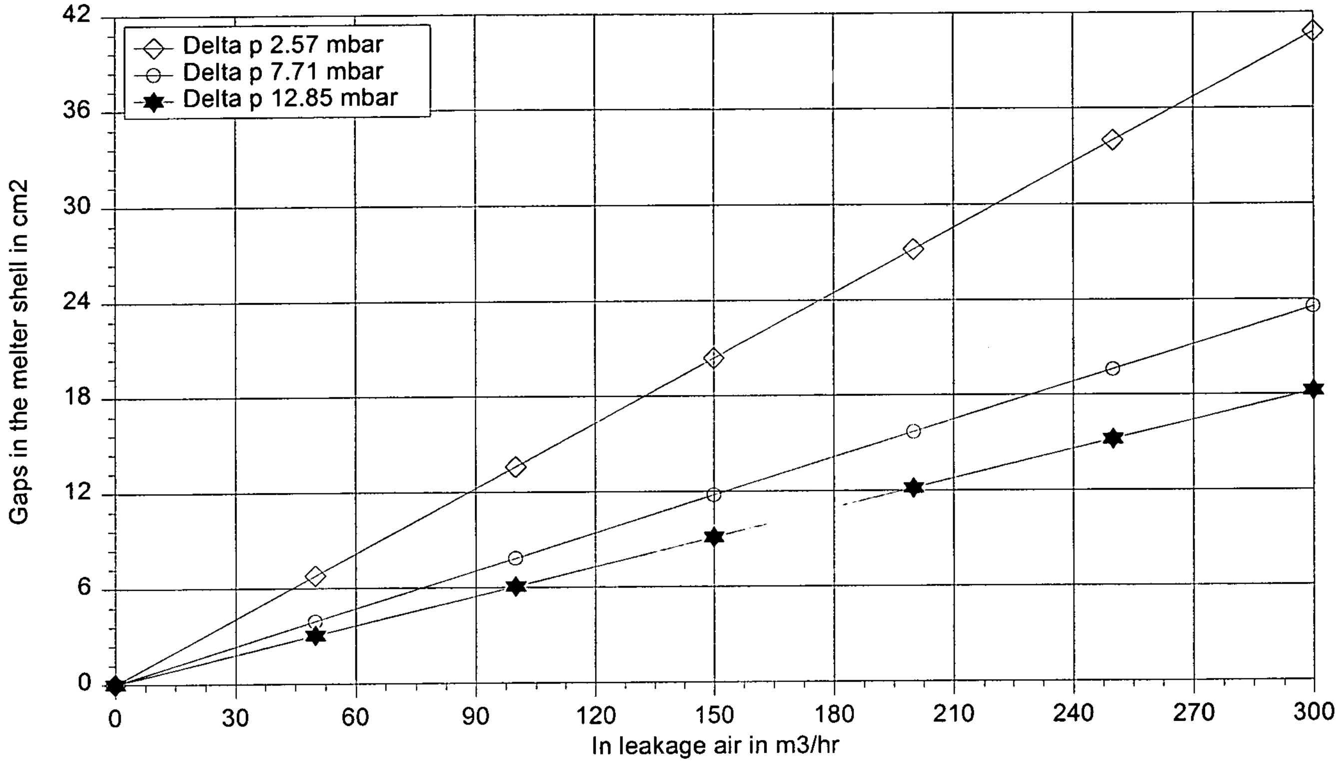
Fig. 1 shows the amount of in-leakage air in an evacuated system depending on the gaps in that system.

In Fig. 2 a pipe with an equivalent diameter instead of the gap area is shown.

Assuming a leakage rate for the melter shell of 100 mbar-L/sec the resulting volume/hr of in-leakage air is about 30 m^3/hr.

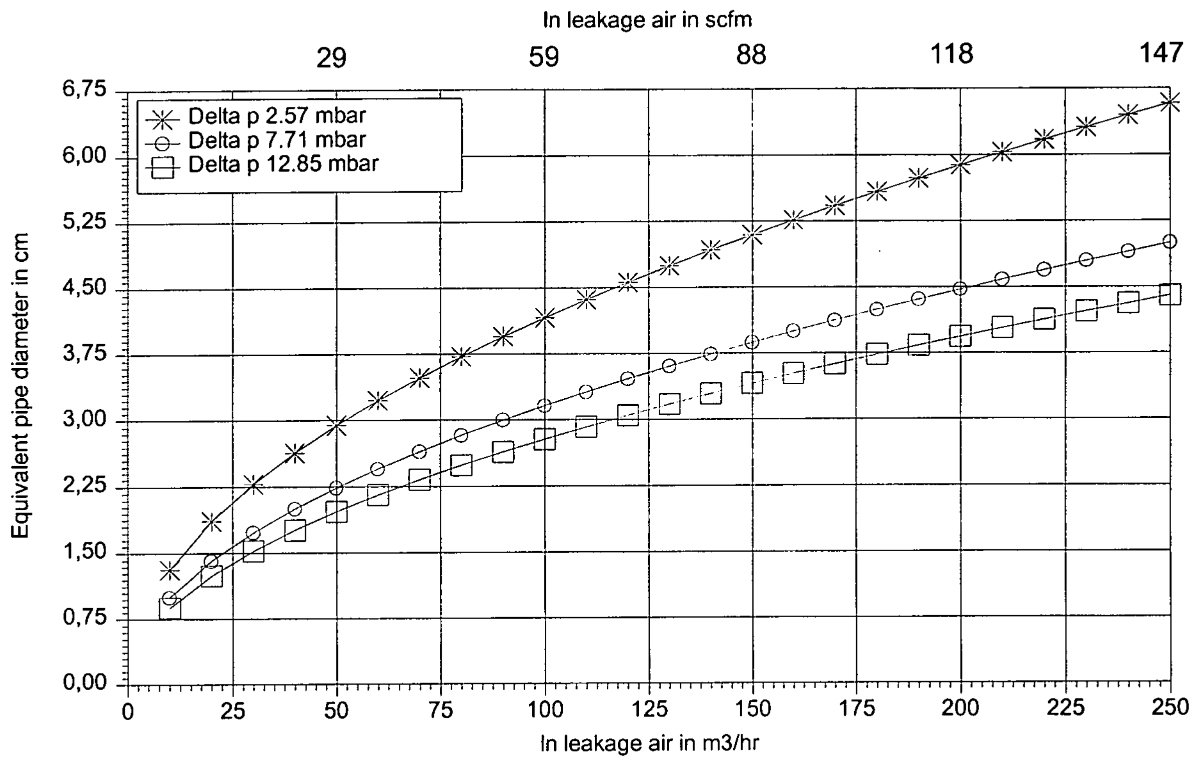
The total amount of in-leakage air is then:

	50 m^3/hr	for the overflow system
	30 m^3/hr	for the melter shell
total :	80 m^3/hr	



Delta p = Atmospheric pressure minus
pressure in melter plenum
1"WC = 2.57 mbar

Fig. 1



Delta p = Atmosperic pressure minus
pressure in the melter plenum

1"WC = 2.57 mbar

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APPENDIX G

Melter Drain

Melter Drain

In case of an irreversible power loss for the electrode heating system, the melter should be drained via the bottom draining systems. The time to drain 90% of the glass volume of the three chambers of the melter is estimated between five and 20 minutes. The volume of the glass melt is:

Main Chamber:	0.776 m^3
Side Chamber:	0.253 m^3 (both chambers)

	1.029 m^3

Assuming an average glass density of 2.7 g/cm^3, the total glass weight is:

2.778 Mg.

The total heat content is:

$$Q = m * c_p * \Delta T = 2778 * 0.26 * 1300\text{-}30 = 1067 \text{ kWhr}$$

The main chamber is equipped with two bottom draining systems and each one of the side chambers with one bottom draining system.

Assuming that this amount of glass is dumped in a non insulated box and cooled down from 1300°C to 200°C in 100 hr, then the average heat transfer rate is:

$$H = 2778 * 0.26 * (1300\text{-}200)/100 = 9.2 \text{ kW}$$

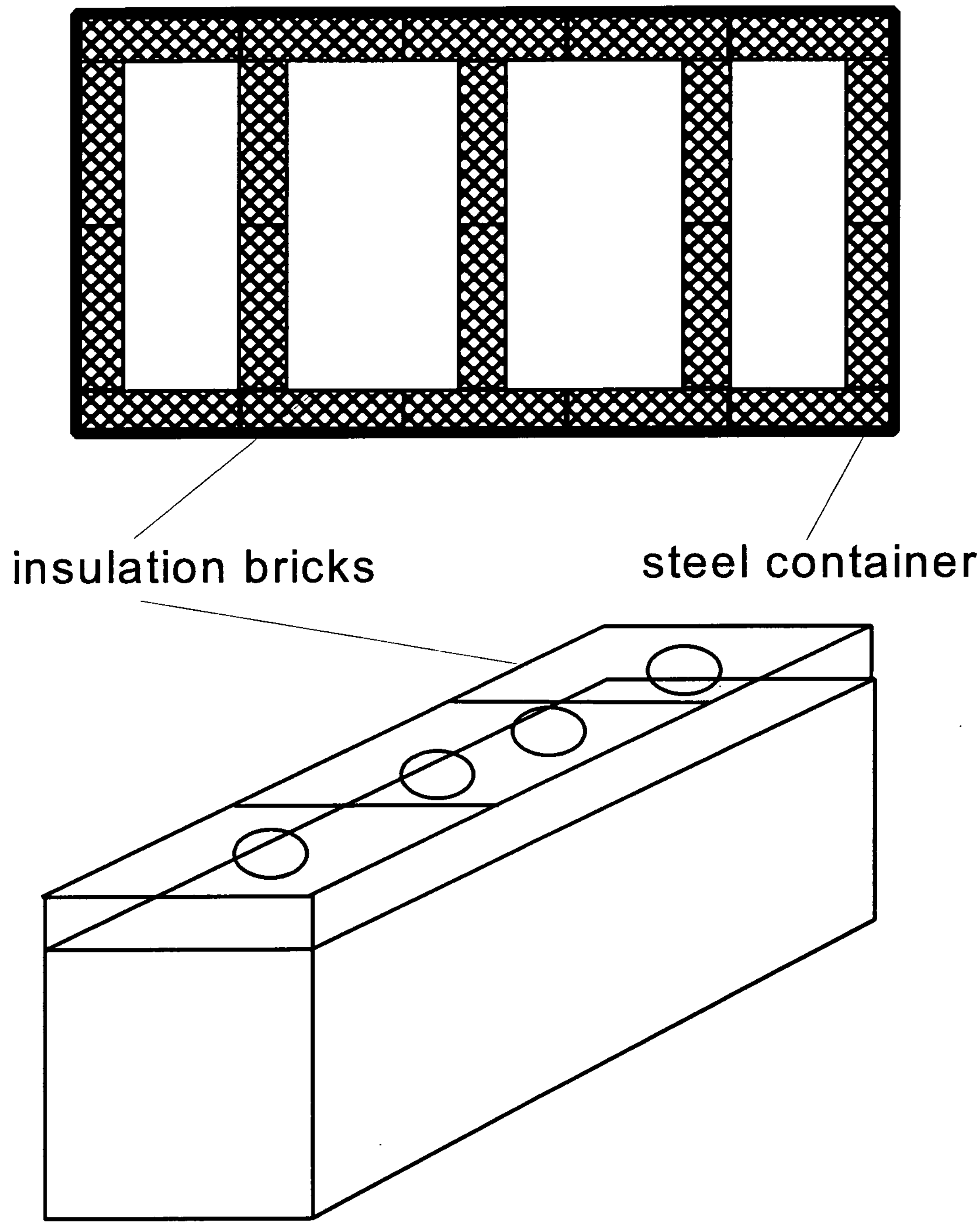
During the first hours the heat transfer rate is accordingly larger. This enormous heat will burn all the plastic material and the painting in the neighborhood and possibly damage the concrete.

Therefore that box has to be insulated to avoid the tremendous heat transfer to the environment.

Fig. 1 shows a proposal for a draining box. The inside of the box is lined with 6-inch thick insulation bricks, made of Al_2O_3, and divided into three or four compartments. The lid consists of three or four pieces of the same insulation bricks with holes in the middle to pick up the bottom drain device and the liquid glass.

After the glass is solidified, the soft insulation material between the cubes can be removed to get three or four smaller glass cubes.

Box for melter draining



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APPENDIX H

Design Proposals for Off-Gas Pipe Between the Melter and Quench Tower

Design Proposals for Off-gas Pipe between Melter and Quench Tower

1. Avoid, Mitigate Plugging of the Off-Gas Pipe (General Construction Recommendations)

- Construct off-gas pipe between melter and quench tower as short as possible
- Construct pipe straight without elbows or narrow parts
- Keep off-gas temperature as low as possible ☞ create a cold cap which covers most of the melting pool surface

2. Recommendation for Pilot Plant

Arrange the off-gas pipe from the film cooler to the quench tower in a nearly straight line and use slight bends only if necessary. An on-site inspection showed that it is possible to locate such pipe.

Install an off-gas pipe with ≈ 8-inch diameter to avoid high off-gas velocities and a high pressure drop in this pipe. Provide the two ends of the pipe with flanges to allow mechanical cleaning of the pipe. The quench tower should be equipped with a flange directly opposite to the off-gas inlet. The pipe then can be cleaned up from both directions. Perhaps equipment as shown in Fig. 2 can be used.

Install pressure gauges or taps in at least three positions in the pipe—after the film cooler, in the middle of the pipe, and at the entrance into the quench tower—in order to get information about the differential pressure increase (build up).

3. General Design Proposals

This section describes some general design proposals to keep the off-gas pipe between melter and quench tower clean.

- Install a mechanical device, i. e., brush, screw, etc., to push built-up solids into the melter or pull the solids into the quench tower (see Fig. 1). The quench tower is connected with the melter as close as possible. The device is installed at the back side of the quench tower. The brush, screw, etc., moves through the quench tower into the off-gas pipe. Not in use, the brush, a screw, etc., is drawn back in a box, outside of the quench tower.

- Install a mechanical device, i. e., brush, screw, etc., at each elbow to push built up solids into a designated vessel, see Fig. 2. That equipment can be used for each elbow connected with a gas-light lock to avoid contamination of the environment.

- Install high pressure blasters at critical points of plugging, and blow the solids into the quench tower, provided that the built-up solids don't stick in the pipe (Fig. 3). The blasters are opened in a certain sequence (1-2-3-4-etc.), which depends on air pressure in the blasters, distance between two blasters, and diameter of the off-gas pipe.

- Cover the inside of the pipe with short cylindrical pipes made of glass, carbon, etc., which is feed continuously from a magazine into this pipe (Fig. 4). These cylindrical pieces with the built-up solids at the inside are pushed continuously back into the melter. The glass used for these cylindrical pieces has the same composition as the start-up glass. If carbon is used, it will burn on the melt surface.

- Cover the inside of the off-gas pipe with a material which doesn't react with the off-gas components to avoid or minimize the effect of glass former sticking on the off-gas pipe. That material could be graphite paper, matrix graphite or vitreous carbon.

- Install rods or similar devices with cutting teeth, made of carbon steel, which are covered by a high corrosion and temperature resistant material in the critical parts of the off-gas pipe and move them by magnetic force from the outside of the pipe to loosen the build-up (see Fig. 5). Arrange the pipe with a slope so that the loosened material can fall back either into the melter or into the quench tower by gravity force.

- Blast the built-up solids with glass frit.

- High off-gas temperatures can melt the surface or the total built up solids in the pipe. Cleaning these pipes becomes difficult or nearly impossible.

- Put view ports (pieces of glass pipes) in the off-gas pipe between melter and quench tower at different positions to watch the built-up solids.

- Construct bellows in the off-gas pipe as seen in Fig. 6 to avoid contact of the off-gas with the thin bellow material.

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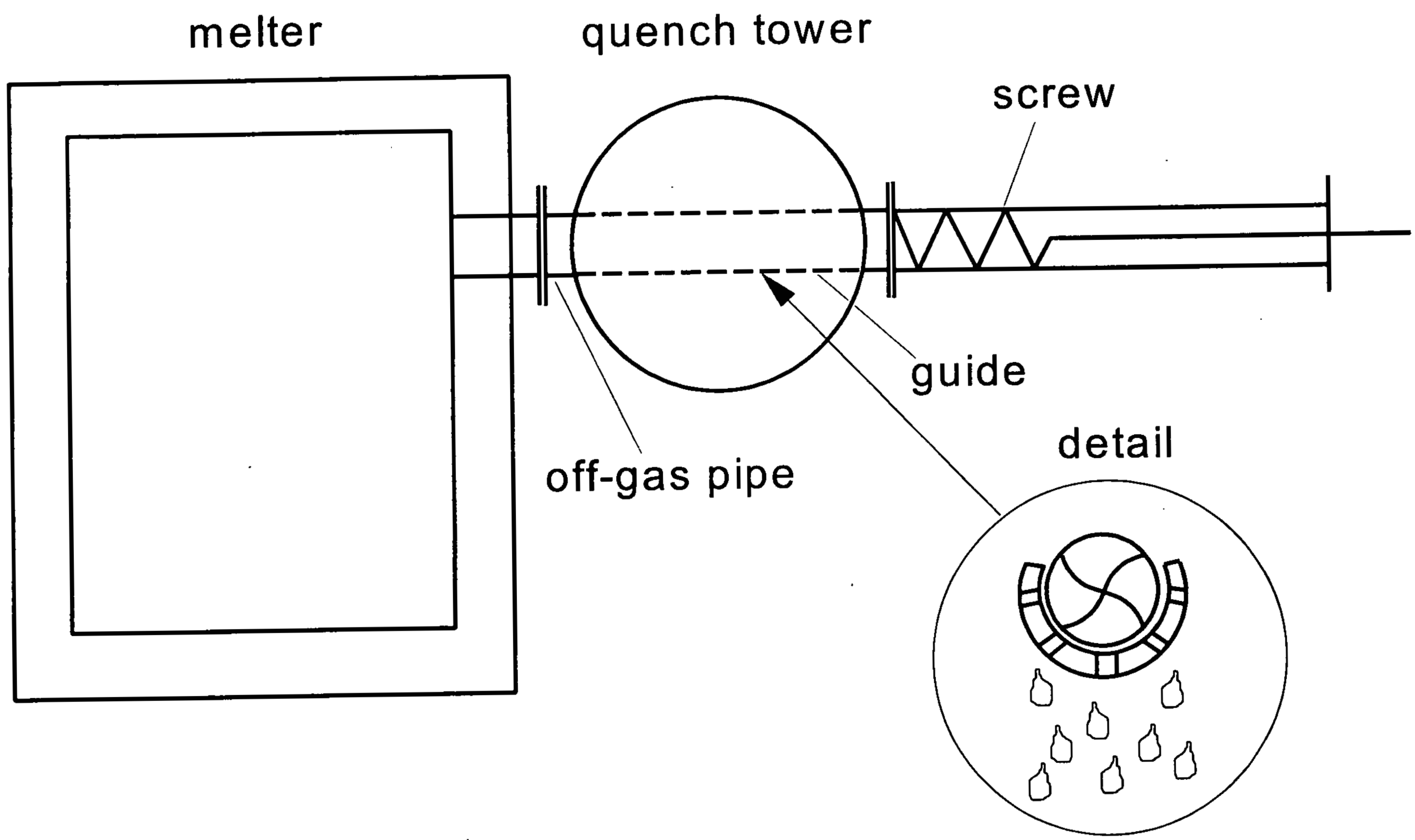

Fig. 1

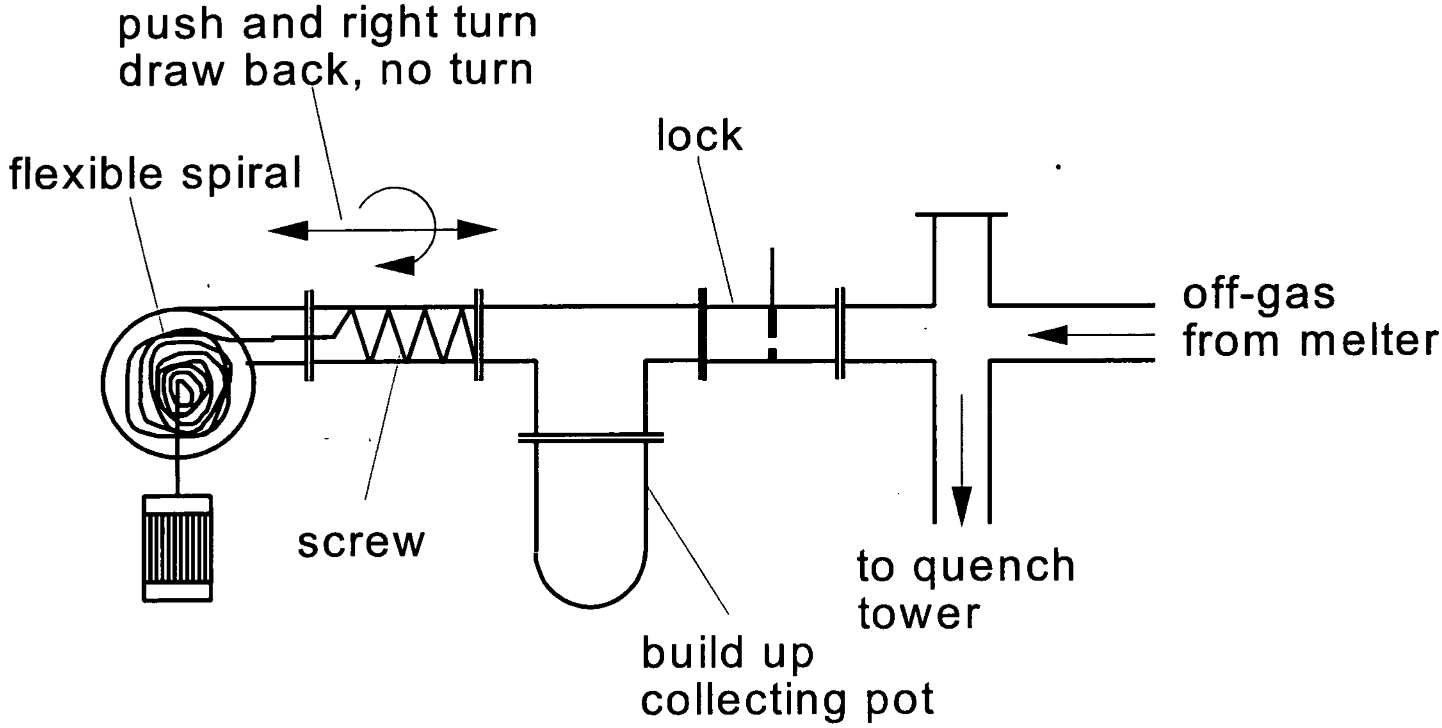
push and right turn
draw back, no turn
flexible spiral
lock
off-gas
from melter
screw
to quench
tower
build up
collecting pot

Fig. 2

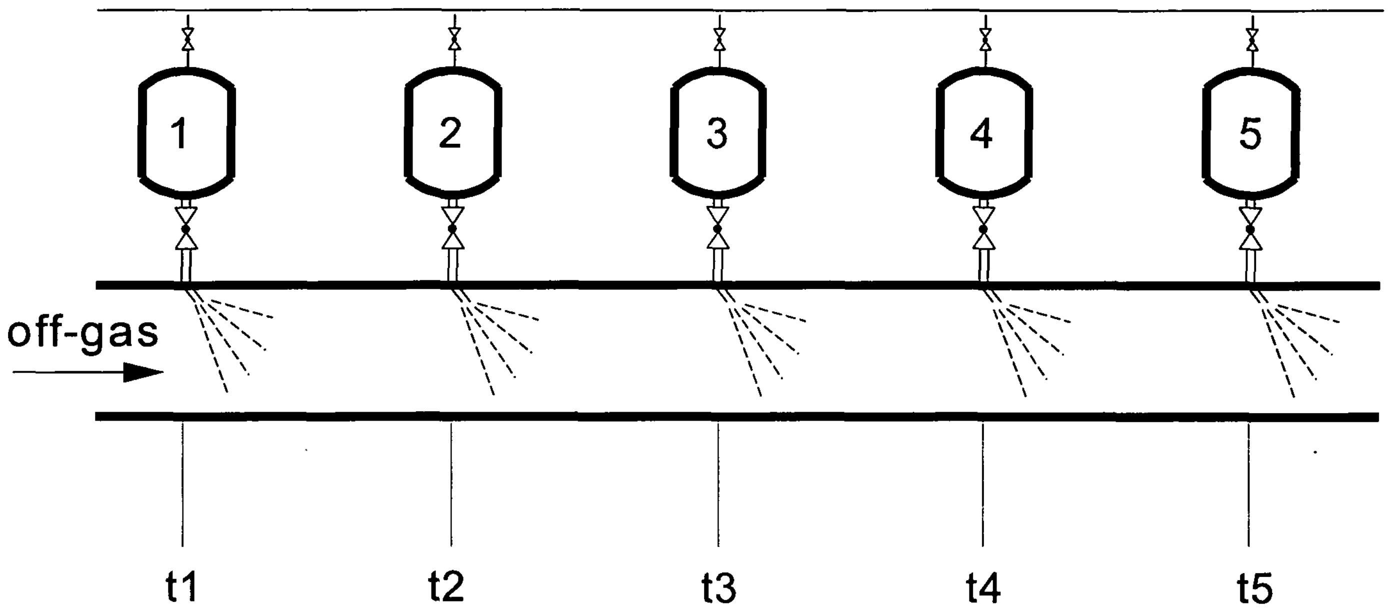

Fig. 3

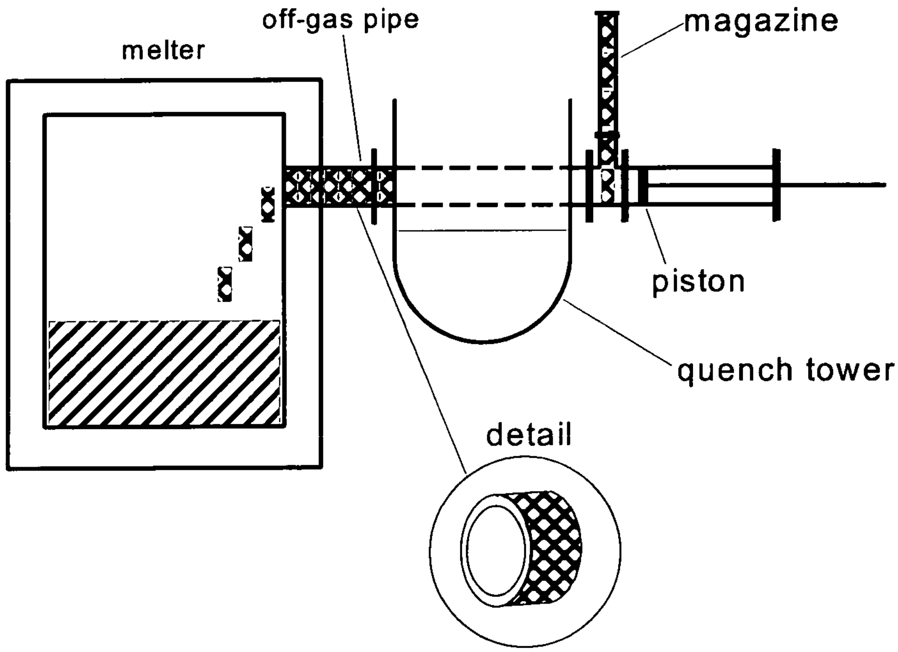
melter
off-gas pipe
magazine
piston
quench tower
detail

Fig. 4

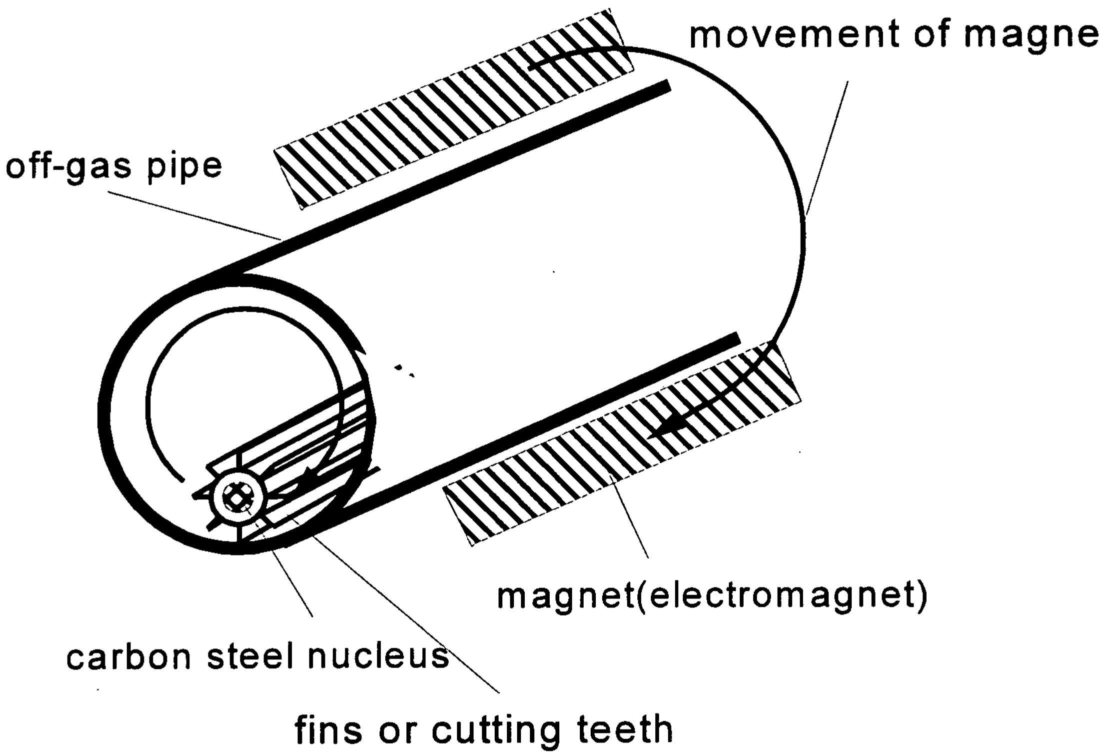
movement of magne
off-gas pipe
magnet(electromagnet)
carbon steel nucleus
fins or cutting teeth

Fig. 5

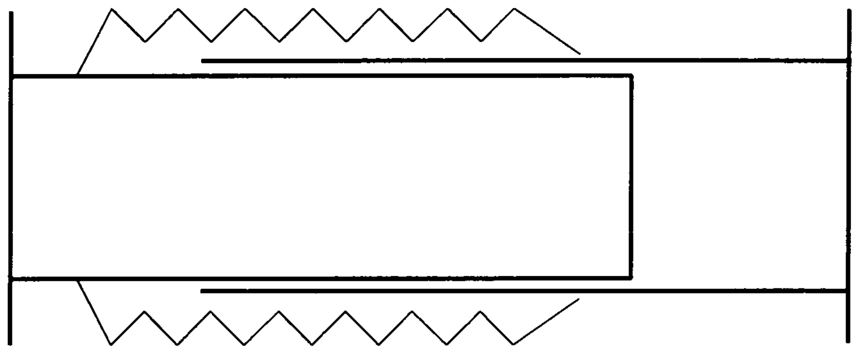

Fig. 6

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APPENDIX J

GTS Duratek Gem-Making Machine/Melter

Heat Balance and Gas Flow

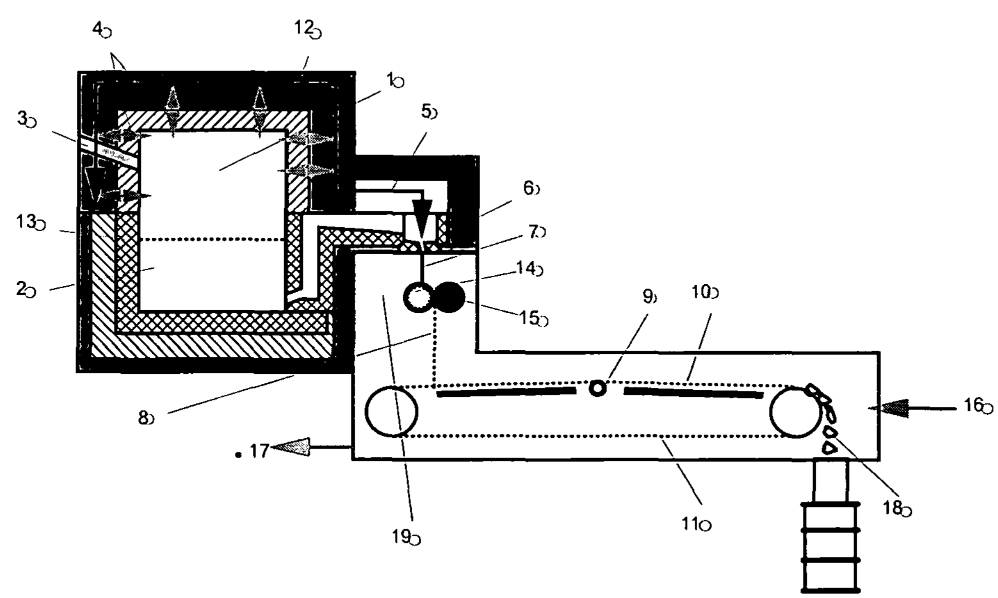
Melter/Gem-Making Machine

1. Gas Flow Between Melter Plenum and Gem-Making Machine

This Duratek melter design doesn't allow a gas tightness between the melter plenum (1), see Fig.1, and the overflow compartment. Gas (radon) can penetrate through the joints of the melter plenum bricks (4) and the insulation into the overflow compartment (5). Depending on the pressure difference between the melter plenum and in the Gem-Making machine a gasflow in both directions via this 3-inch pour spout is possible. The gems in the Gem-Making machine are cooled by air which is sucked in via (16) and controllable openings in the lids on both sides of the gob cutter/graphite roller. The hot air leaves the Gem-Making machine via (17) and is released into the atmosphere after passing a filter.

Therefore the radon can flow through the Gem-Making machine into the HVAC system without any treatment!

Fig. 2



melter3.drw

Legend for Fig. 2

(1) melter plenum	(10) water cooled heat exchanger
(2) melt pool (1250 - 1350 °C in center)	(11) conveyer belt (stainless steel mash)
(3) off-gas	(12) refractory
(4) melter plenum refractory	(13) K-3 refractory
(5) in-leakage air through pour spout and insulation	(14) stainless steel cutter
	(15) graphite roller
(6) pour spout 76.2 mm (3")	(16) inlet cooling air
(7) glass stream ≈ 1250°C	(17) outlet cooling air
(8) cut off glass stream ≈ 800°C	(18) gems
(9) roller	

One proposal is to regulate the air pressure in the Gem-Making machine depending on the pressure in the melter plenum. But this is not realistic. The air flow through the Gem-Making machine is adjusted depending on the amount of air which is necessary to cool the gob cutter and graphite roller and the gems on the conveyer belt. Therefore the pressure in the Gem-Making machine is a function of that flow and cannot be controlled by the melter plenum pressure! Also, from a safety standpoint, that design is not acceptable! Fig.2 shows an almost gas tight overflow system. That system consists of at least two refractory bricks (1) and (2). In leakage air can pass only through the joint (4) and (3). By selecting the suitable combination of insulation at (3), this area can be manufactured almost gas tight. The brick (4) is heated by the glass from the glass pool and brick (1) is heated by an Resistance High Frequency System and Canthal heaters.

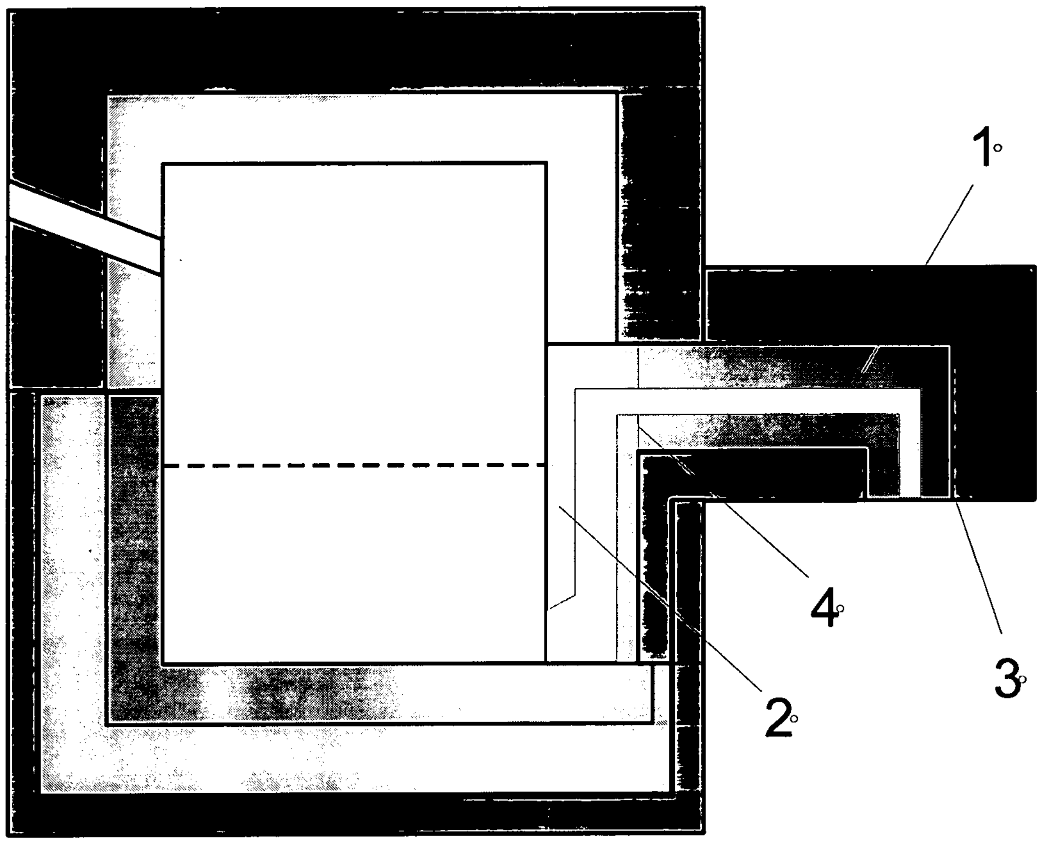
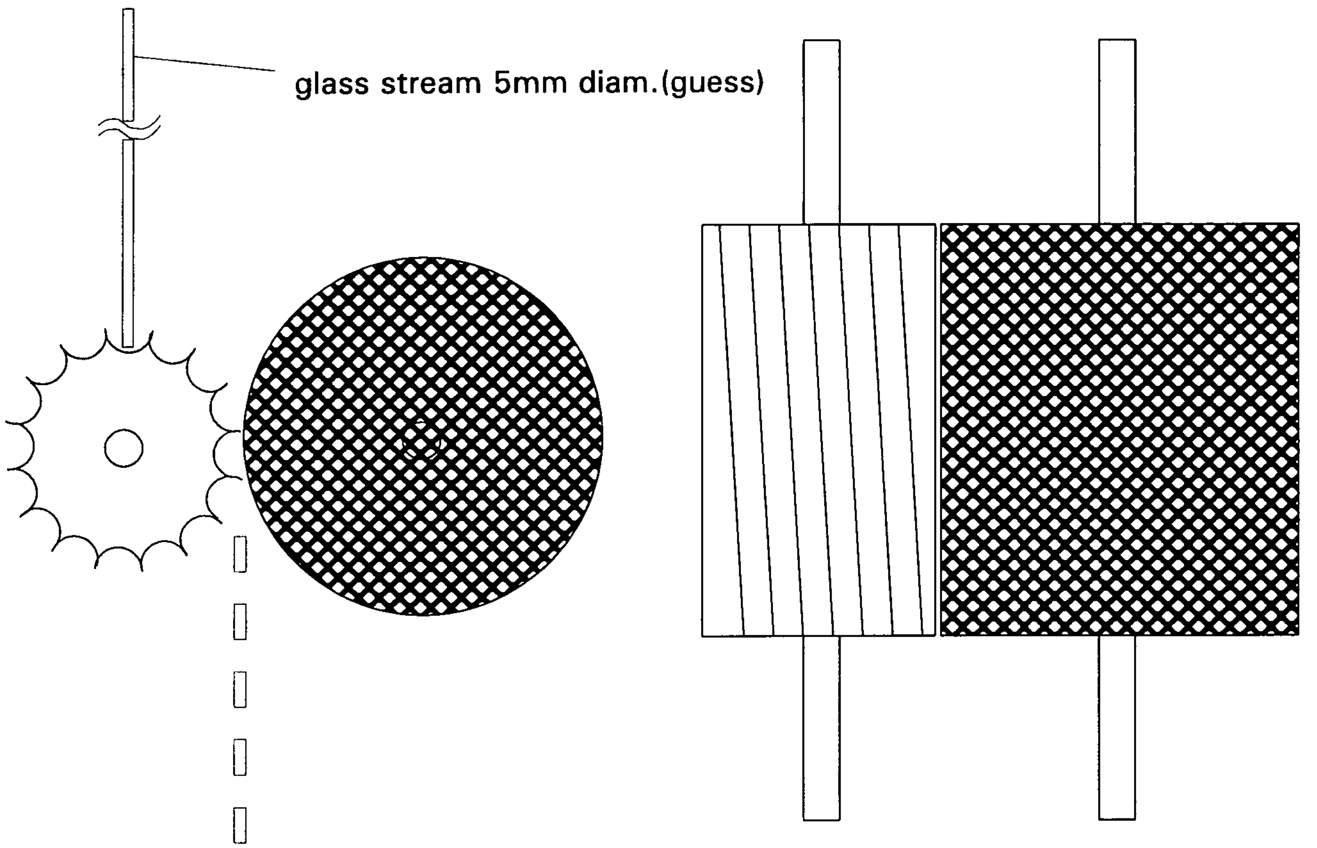


Fig.2

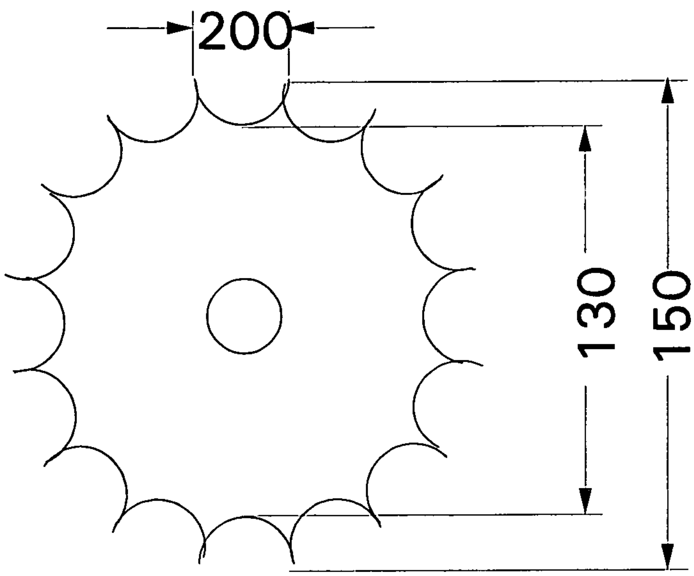
melter6.drw

2. Heat Transfer Glass Gob-Cutter Environment

Fig.3 shows sketch of the gob cutter/graphite roller and its dimensions.



Diameter cutter = 15cm(6")
Diameter graphite roller = 20cm(8")
width = 45cm(18")



Dimensions in mm

2.1 Calculation of Basic Data (Surface Areas, Weights)

The following numbers were used for the calculations:

Gob cutter circumference:	$C=\pi*d=\pi*15$ cm=47.1cm
Amount of flutes:	47.1/2cm[1]=23.5 flutes
Half circumference of one flute:	3.14cm
Total circumference of all flutes:	3.14*23.5=73.8cm
Total surface of the gob cutter:	$73.8*45+\pi*d^2/2 = 0.33+0.026= 0.36m^2$
Weight of the gob cutter:	≈ 47 kg
Energy to heat up the cutter from 30°C to 500°C:	2.8 KW
Total surface of the graphite roller:	$0.35m^2$
Weight of the graphite roller:	≈ 23 kg
Energy to heat up the graphite roller from 30°C to 500°C:	2.1 KW
Throughput of glass:	1 Mg/day = 41.7 kg/h
Temperature of glass stream:	1350°C
Temperature of glass stream after gob cutter:	1000°C (assumption)
Heat content of glass (ΔT 350°C):	4.4 KW

1 Assumption

Calculation of Heat Transfer from Gob Cutter and Graphite Roller to the Environment

This procedure describes how to estimate the amount of heat which is transferred by the molten glass stream to the gob cutter and graphite roller. The heat removal from the gob cutter and graphite roller to the environment takes place through heat transfer by radiation and heat transfer by convection and is based on the following assumptions:

a) The temperature of the glass stream after passing the gob cutter/roller *is decreased to 350 °C* . For 1 Mg glass throughput /day the ***corresponding energy is 4.4 KW***. In the steady state this energy has to be removed from the gob cutter/roller.

b) The temperature of the gob cutter at the temperature equilibrium (steady state) *is about 400 °C* (There is a temperature limit for the gob cutter. When the temperature becomes too high, the glass will stick on the surface of the cutter).

c) The temperature distribution in the gob cutter and graphite roller *is homogenous*.

d) The emissivity coefficient for stainless steel at this temperature *is 0.3*

e) The emissivity coefficient for the inside wall of the Gem-Making machine *is 0.5*

f) The heat transfer coefficient for convection *is 60 W/ m^2 °C* and ΔT for the cooling air *is 50 °C*

Under these provisions the heat transfer by radiation from the gob cutter is about 0.8 KW and from the graphite roller about 1.5 KW (see Fig. 4).

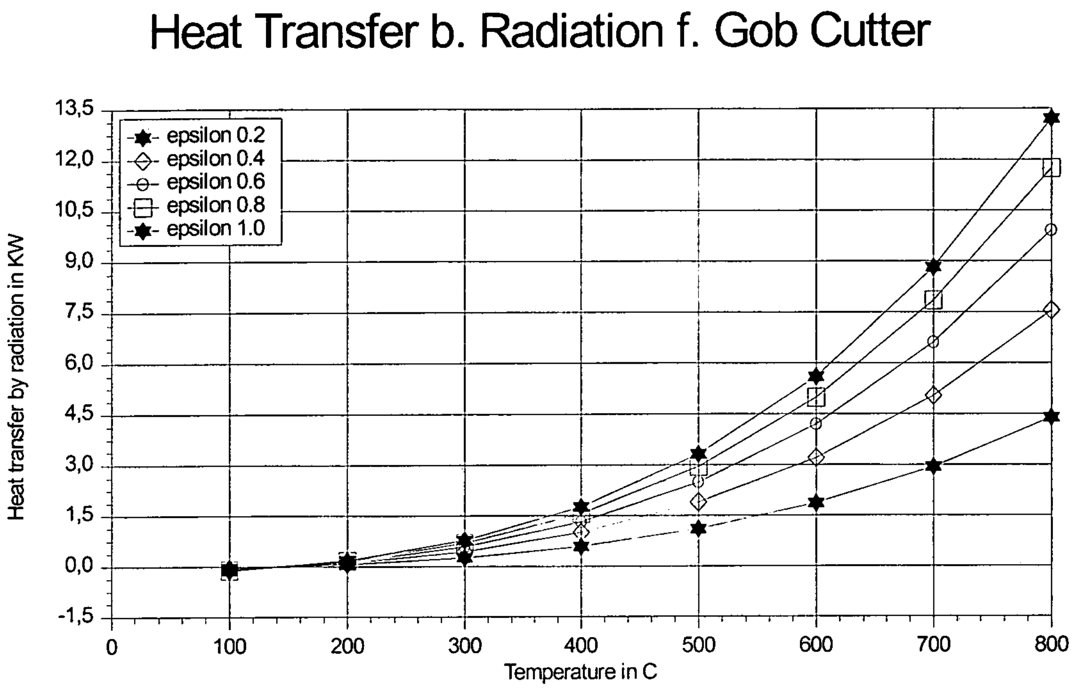
Heat transfer by convection from the gob cutter at 400°C is about:

$H = \alpha * S * (\Delta T) = 60 \text{ W/m}^2 \text{ °C} * 0.36 \text{ m}^2 * (90-30) = 1.26 \text{ KW}$

and from the graphite roller at 400°C about: 1.2 K W

The total heat removal is then:

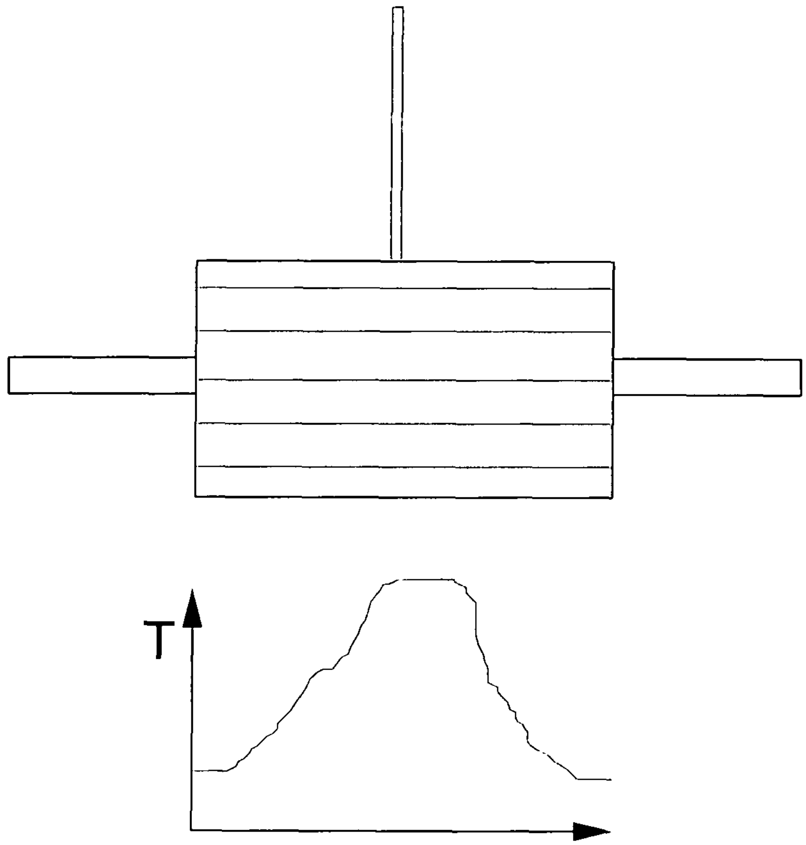
0.8 + 1.5 + 1.26 + 1.2 = 4.76 KW



Gob cutter epsilon 0.2 - 1.0
S = 0.36 m2
Epsilon wall = 0.5 T wall = 150 C

Fig. 4

This calculation based on a homogenous temperature distribution along the axle of the gob cutter and graphite roller. But because of the worse heat transfer coefficient for stainless steel and graphite (compared to other metals like Al and Cu) an inhomogeneous temperature distribution in the cutter and roller will occur (see Fig. 5). The temperature of that part of the gob cutter which is touched by the glass therefore will be much higher than the rest of the cutter. Therefore, the 6.3 KW heat removal is calculated under very conservative assumptions. For this 350°C temperature drop of the glass while passing the gob cutter 4.4 KW energy is transferred to the gob cutter/graphite roller and the environment.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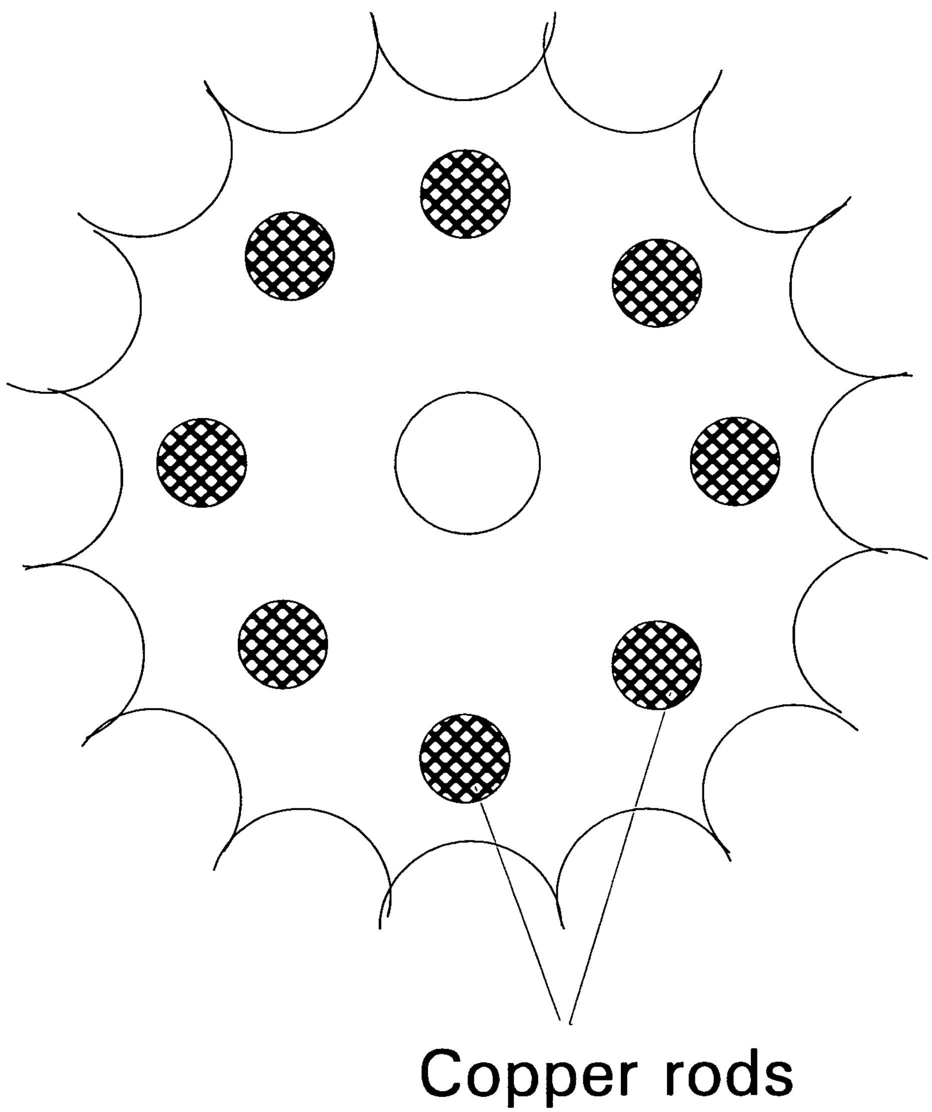
To improve the emissivity coefficient and the heat transfer along the gob cutter it should be made of carbon steel[2] with copper rods which are pressed into drill holes along the cutter (see Fig. 6).



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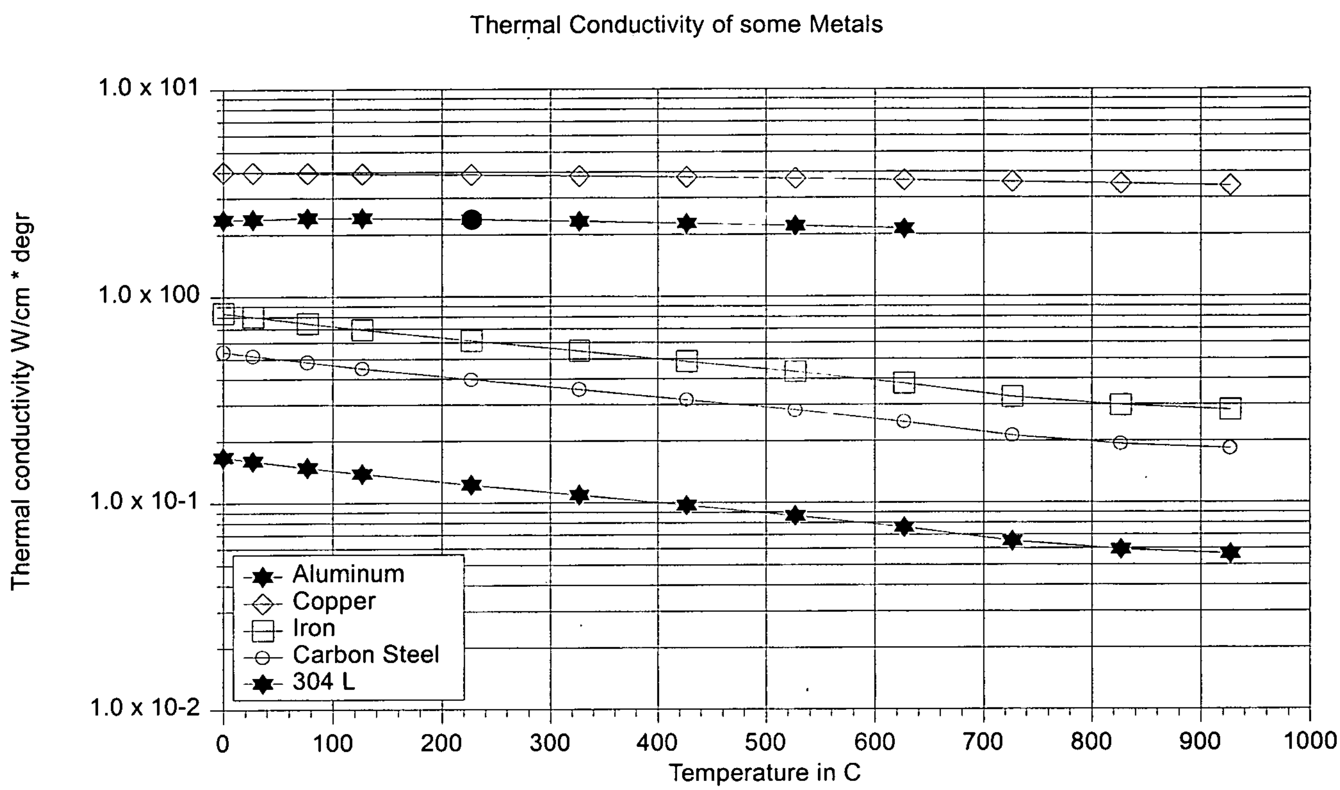
[2] Oxidized carbon steel has a much better emissivity coefficient than stainless steel (≈ 0.7 compared to 0.3-0.4 for stainless steel)



Purity of the metals Al, Cu, Fe 99.9%
Data: Handbook of Chemstry and Physics
Carbon st. and 304L extrap.from iron

From Fig. 7 it can be seen that the thermal conductivity for carbon steel is about three times and for copper about 40 times better than stainless steel.

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APPENDIX K

Comments on the Phase I Pilot Plant Test Plan

This appendix contains selected portions of the Phase I Test Plan, 18-SU-0003. Comments are provided to this plan in the form of footnotes.

1.2 Scope

1.2.1 General

Phase I Testing is scheduled for approximately 91[1] calendar days (including 21 days for bakeout) and is estimated to consume approximately 91 metric tons of surrogate material, additives and Bentonite. The assumptions are:

- 7 formula Campaigns (based on 7 formulas).
- 1 run per Campaign (assuming that the glass from the first run meets the acceptance criteria).
- 8 batches (approximately one metric ton each) per run for Campaigns #1, #2 (Part #1), #3, #4, #5, #6, and #7 (assuming that three melter volumes of the new formula are needed to displace the previous melter contents before representative glass of the current formula is realized).
- 21 batches (approximately one metric ton each) for Campaign #2 (Part #2).
- One metric ton (approximately) per batch per day (except for Campaign #2, Part #2).
- Three operating shifts per day, seven days a week.
- No down time due to process or equipment problems or off-normal conditions.

After completing all of the Campaign Testing, the Melter will be placed in a stable, hot standby mode of operation while awaiting the beginning of Phase II Testing. More furnace data will be collected and become part of the final report. If possible, (based on specific Melter conditions such as temperature, working conditions, etc.), photographs, physical dimensions, and sediment accumulation; basically all data that could not be obtained during vitrification operations will be recorded and evaluated for the melter and Gem Machine and any other equipment deemed necessary.

1.2.2 Campaign Sequence and Description

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[1] Melter volume = 0.84 m^3 = 840 L, glass throughput ≈16 L/hr. 3 melter volumes @ 840 L each = 2520 L to flush between each campaign. 2520/16 = 158 hr = 6.58 days for each flush. 7 campaigns @ 6.58 days each = 46 days just for flushing! Total 91 days less 21days for bakeout less 46 days for flushing leaves only 24 days to run all 7 campaigns. This seems to be a very ambitious time frame!

The benign glass formula (Campaign #1) will have three scheduled runs: (1) to establish Melter control, (2) to synchronize the operation of the Melter and Gem Machine, and (3) to attempt to increase the glass output of the Melter to three[2] Metric Tons per day.

The Melter acceptance target formula (Campaign #2) will initially be run to perform the vendor acceptance test of the Melter and the Gem Machine and then will perform testing of the first of four target formulas.

The remaining three target formulas will be tested by the performance of the final five campaigns (Campaign #3 through #7) of Phase I Testing.

A series of seven Campaigns, which test the 4 target formulas, are planned to be run during Phase I Testing. Campaigns #1 and #2 are multiple part Campaigns containing three and two runs respectively. Each of the remaining Campaigns will have a minimum of one run conforming to procedural test sequence to achieve glass acceptance criteria. For Campaigns #3 through #7, if the first run of any Campaign results in meeting the acceptance criteria, the process will then be prepared for the next Campaign. If the results from the completed run do not meet the acceptance criteria, another run within that same Campaign will be performed. A Campaign will continue until the surrogate glass is acceptable under stable operating conditions or until all flexibility within the procedures, equipment and formula range has been exhausted while considering practicality of time invested and the relative information gained.

The following Campaign descriptions and estimated glass tonnages are based on one Run (eight Batches) per Campaign. Unsuccessful Runs may justify additional Runs to be completed for the related Campaign depending on performance data evaluation results.

CAMPAIGN #1

Campaign #1, Benign Glass Formula, will be completed over an estimated 21-day duration. This Campaign will be completed in three parts, each part satisfying a particular Melter operation or performance function.

Part 1 of Campaign #1 will process seven metric tons of material over a seven-day duration and will aid in establishing Melter control philosophy. The melter and glass parameters will be monitored and measured and a means of melter control will be developed.

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[2] Because of the small off-gas pipe between film cooler and quench tower, glass throughput is limited to about 1 Mg/day, see Appendix I.

The most preferred parameter of control for the Melter is the viscosity of the glass. Viscosity of the glass is important because it can affect the success of gem forming in the Gem Machine. Viscosity of the glass can be affected by temperature and the batch chemistry. Because there is no direct production monitoring device to provide an indication of viscosity, visual monitoring is the only real time method to subjectively determine viscosity. Although visual monitoring of the glass stream can be important to the Melter evaluation and operation, this method is not a very accurate or practical method for Melter control. The viscosity of the glass can more closely be determined by viscometer measurements of crucible melts of samples collected from the current batch. The results of this type of test will not be available in time to be considered a viable real-time Melter control function. The only practical, real-time parameter that can be monitored and provide control is the Melter glass temperature. Temperature and glass formulation will be relied upon heavily to control the Melter.

During the first part of Campaign #1, thermocouples will be placed directly into the molten glass and the indications from the thermocouples will be correlated to the permanent temperature monitoring instrumentation for the Melter[3]. These thermocouples will be place in the glass during this Campaign because, with the formula makeup, they have the best chance to operate and provide data without damage. When surrogates for Silo #1 and Silo #3 are fed to the Melter, the thermocouples are expected to be damaged by the glass chemistry. The early Melter crossectional temperature correlation will be monitored and tracked during the one metric ton per day batch throughput.

The information gained from this part of Campaign #1 will be used to support Melter control for the remainder of Phase I Testing and for Phase II Testing.

Part 2 of Campaign #1 will be the first time that the Gem Machine[4] is operated and tested while making glass gems. Part 2 of Campaign #1 will

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[3] These thermocouples, which can be influenced by the electric field between the electrodes, should be calibrated by a redundant temperature measurement, I. e. a pyrometric measurement?

[4] Because of the complexity of the melter, off-gas treatment system, and the gem-making machine, it is recommended that the gem machine not be used during the melter and off-gas system tests. It is expected that proper operation of the gem- making machine will take more time than planned. For the gem-making machine test, it is recommended that the melter be fed with dry feed (glass frit or cullet) to get a continuous glass flow at the overflow pour spout. In this case there is no dependency on feed system, cold-cap formation and stabilization, and the off-gas treatment system.

process seven metric tons of material over a seven day period. This part will include sampling, analysis, Melter operation, and Gem Machine operation as well as other Pilot Plant functions such as Off-Gas System, Recycle Water System and Process Cooling Water System[5]. This will be the first time that the Pilot Plant is tested under full production conditions (except for Thickener operation). The main objective of this part is to synchronize the operation of the Melter and the Gem Machine with all of the auxiliary support systems at a one metric ton per day batch throughput of the Melter.

Part 3 of Campaign #1 involves the determination of the Melter maximum capacity throughput over a 24-hour period. The test will attempt to achieve a target throughput rate of three[6] metric tons of glass per day. This part will provide data that is important for scale-up to the full size remedial melter design. This three metric tons of batch per day rate (or the maximum attainable rate) will be maintained for a duration of seven days for an approximate tonnage of 21 metric tons. During this time, the factors that may limit this rate will be observed and documented. The major limiting factor for Pilot Plant operation is suspected to be the Off-Gas System capacity. Other possible limiting factors include the sample and analysis turn-around time and batch preparation time.

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<u>CAMPAIGN #4</u> (Continued)

For this Campaign, Inconel and platinum wire coupons will be placed in the Melter main chamber simulate the electrodes[7] and thermocouples of a low temperature melter. The coupons will be retrieved and analyzed determine the effect of the glass formulation on these materials. The major concern with this formula is that the destruction of sulfates at 1150°C may not be possible, therefore the status of the sulfates will be

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5 The availability and operability of the cooling water system should be verified before heating up the melter. Water cooling is essential for the Mo electrode sealing and bottom drain freeze valves and responsible for heat removal from the glass in the gem machine!

6 See footnote No.2

7 Using Inconel 690 as an electrode material, the corrosion rate in this molten glass is also a function of the electrical current surface density. Checking this material without electrical current stress results in a lower corrosion rate.

monitored closely during this Campaign. If the sulfates are destroyed and the coupons survive with little or no erosion or deterioration, then a low-temperature melter may be considered for the remedial design melter. A low-temperature melter implies a better scale-up, a fewer number of melters, and a considerable savings in capital and operating costs.

CAMPAIGN #5

Campaign #5, Silo 1 - High Temperature formula, will be completed over an estimated seven day duration and may process as much as eight metric tons of material. This Campaign introduces the high temperature (between 1250°C and 1350°C) Silo 1 Surrogate formula.

For this Campaign, Silo 1 Surrogate material will be placed into the Thickener Tank for preparation of slurry feed the Slurry Tanks and on the Melter. This is the first time that the Thickener is used for feed preparation. A pre-mixed sand (silica) slurry will be purchased at the approximate particle size of the Silo 1 waste. Lead and barium will be introduced into the batch material at the Slurry Tanks using the pneumatic Additives System. Additional glass additives will be transferred the Slurry tanks complete the formula blending. Silo 1 and Silo 2 material appear have similar waste constituents, but the Silo 1 Surrogate formula was chosen due some extreme component concentrations that can increase the difficulty of glass making.

CAMPAIGN #6

Campaign #6, Silo 1 - with 50 wt% Bentonite formula, will be completed over an estimated seven day duration and may process as much as eight metric tons of material. This campaign may impose the highest degree of difficulty with respect making an acceptable glass product. This is observed as a problem formula for two major reasons, both of which relate the Bentonite component in the formula.

1. Industrial process experience indicates that Bentonite is considered be the hardest constituent in the silo wastes for thickeners handle. Settling of the Bentonite in the Thickener is be aided by a flocculent[8] that is added the Thickener slurry. The degree of success of this process will be monitored and documented during this Campaign.

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8 How much does it influence the feed composition?

2. Bentonite has a high alumina content. Experience with glass making formula chemistry indicates that having an alumina constituent included in the formula will increase the melting point. Because of the Melter maximum operating temperature of 1350°C, the melting characteristics of this formula will be closely monitored and documented during this Campaign.

Due to the bentonite content, adjustments will be made the formula by way of additive component selection in order lower the glass melting temperature and viscosity[9]. The formula may have be adjusted establish the desired or workable glass conductivity remain compatible with the Melter operation.

CAMPAIGN #7

Campaign #7, Silo 1 - Low Temperature formula, will be completed over an estimated seven day duration and may process as much as eight metric tons of material. This Campaign introduces the low temperature ($\geq$ 1150°C) Silo 1 Surrogate formula.

For this Campaign Inconel and platinum wire coupons will be placed in the Melter main chamber simulate the electrodes and thermocouples of a low temperature melter. The coupons will be retrieved and analyzed determine the effect of the glass formulation on these materials. The major concern with this formula is that the destruction of sulfates at 1150°C may not be possible, therefore the status of the sulfates will be monitored closely during this Campaign. If the sulfates are destroyed and the coupons survived with little or no erosion or deterioration, then a low temperature melter may be considered for the remedial design melter allowing for better scale-up with fewer melters for a considerable savings in capital and operating costs.

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2.0 OBJECTIVES

PILOT PLANT

1. Determine process parameters for Phase II Testing while processing surrogate material. By using surrogate materials, the process parameters

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9 Is this planned in a Lab-scale or in the pilot melter?

should be applicable Phase II operation.

2. Validate the performance and integration of the SOPs with the Pilot Plant operation and the performance with this Test Plan. This will enhance the stable operation of the Pilot plant in preparation for Phase II Testing.

FEED PREPARATION

1. Target ≥50 wt% solids content, with K-65 Surrogate and Bentonite, in the underflow from the Thickener using a flocculent additive as necessary. (A decrease of solids content (<50 wt%) will result in an increased off-gas volume from the excess water and a reduced glass output, both undesirable from an efficiency standpoint[10].) This can be directly related Phase II operation.

2. Achieve low enough solids content (≤ 1 wt%), with K-65 Surrogate and Bentonite, in the overflow from the Thickener for satisfactory reuse at the Thickener and the Quench Tower. The performance of the Thickener and Flocculent System is critical the Recycled Water System for off-gas cooling, batch blending, and mining.

3. Demonstrate consistent flow rates, density, %wt solids, and chemistry for the transfer of the thickened solids slurry the two Slurry Tanks. This can be directly related Phase II processes.

4. Demonstrate pneumatic transfer of glass batch materials and additive materials the two Slurry Tanks. Validate the weight balance characteristics of the Slurry Tanks. This can be directly related Phase II processes.

5. Demonstrate homogenous slurry mixing and formula matching in the two Slurry Tanks. This can be directly related Phase II process chemistry consistency within +/- 0.25 % by weight.

6. Demonstrate recirculation of slurry in the Slurry Tank primary and secondary recirculate modes. This can be directly related Phase II processes.

MELTER OPERATION

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[10] But it may be necessary to find out the best relationship between water/solid to form a satisfactory cold cap.

1. Successfully regulate the transfer of blended slurry the Melter for vitrification. This can be directly related Phase II processes.

2. Ensure that the Melter operation is controlled, monitored, and documented as required in order consider the following related items:

   a. Investigate the redox state in the Melter.
   b. Determine Melter retention time for each formula campaign.
   c. Determine glass resistivity/conductivity.
   d. Investigate and record glass behavior during glass forming operation.
   e. Determine electrode consumption rate and cause of any erosion[11].
   f. Document the Melter maximum performance up a three metric tons per day production rate if possible. Document limiting factors of systems or components as they relate Melter performance

   The above items will be considered during Phase II Testing. Therefore, Phase I Testing results will provide a basis for the control of the Melter in Phase II.

3. Determine optimum glass formulation for surrogate material loading[12]. (Lowest possible temperature with workable viscosity and maximum surrogate material loading.) This will provide relative waste loading information for the Phase II operation with respect the glass formulation.

4. Demonstrate control of Melter operation include temperature control, electrode current/voltage/cooling control, slurry feed control, glass level control, glass airlift control, and off-gas control. This can be directly related Phase II processes.

5. Demonstrate Melter ability produce one metric ton of glass per 24-hour day for a continuous 36-hour period. This is required satisfy the Melter acceptance test performed in this Test Plan.

OFF-GAS SYSTEM OPERATION

1. Obtain design performance data of the Off-Gas system and maintain air

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11 Which electrodes? Only the Mo electrodes or also the Monofrax E electrodes, if yes, how?

12 This should be known before and not tested in the melter. Only the best composition should be used in the melter.

flow balance. This can be directly related to Phase II processes.

2. Achieve temperature[13] that is within design limits of the off-gas from the Quench Tower and for the Quench Tower bottoms from the Heat Exchanger during slurry feed the Melter. This can be directly related Phase II processes.

3. Maintain a pH of approximately 11.0 for Scrubber operation using caustic solution[14] and the caustic metering system. Ensure that the net pressure drop for the off-gas through the Scrubber is within design limits. This can be directly related Phase II processes.

RECYCLE WATER SYSTEM OPERATION

1. Demonstrate Waste Water Filter operation, include filtration of discharge water, transfer of water the Building Sump and transfer of the water the High Nitrate Tank, Waste Water Filter backflush operation, and reseating of Waste Water Filter filtration material. Ensure that during this operation the Melter glass production is not interrupted. This can be directly related Phase II processes.

2. Demonstrate a balance of Recycle Water System operation as a function of thickener water overflow balance, Quench Tower water supply, and slurry line flushing operations. This can be directly related Phase II processes.

3. Collect data document and anticipate the buildup rates of dissolved solids in the Recycle Water System during Melter operation. This can be directly related Phase II processes.

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[13] Are only temperatures measured? It is recommended to place taps before and after each off-gas equipment to measure the pressure difference for different flow rates. This is very useful information for design of off-gas equipment. It is also recommended to measure the off-gas flow during the SOT after the film cooler to get data about in-leakage air and verify this data with calculations (estimations).

[14] The liquid from the quench tower and venturi scrubber is recycled into the thickener. This increases the Na content in the feed!

9.2 TEST PROCEDURE

9.2.1 TEST APPROACH

A minimum of 7 campaigns are presently planned that will test the basic vitrification combinations expected. They are as follows:

Campaign 1 --	Benign Glass Formula (Sec. 9.2.4)
Campaign 2 --	Melter Acceptance Test Formula (Sec. 9.2.5)
Campaign 3 --	Silo #3 - High Temperature Formula (Sec. 9.2.6)
Campaign 4 --	Silo #3 - Low Temperature Formula (Sec. 9.2.7)
Campaign 5 --	Silo #1 - High Temperature Formula (Sec. 9.2.8)
Campaign 6 --	Silo #1 - With 50 wt% Bentonite Formula (Sec. 9.2.9)
Campaign 7 --	Silo #1 - Low Temperature Formula (Sec. 9.2.10)

The initial Phase I tests will be preformed with a Benign Glass Formula. The Benign Glass Formula provides a more standard glass that is of known workability with respect to the Melter operation. It provides glass with a compatible viscosity range and conductivity range to allow for the establishment of initial Melter control. It will provide an optimum glass that can be used to test the initial operation of the Gem Machine. This glass will also allow for the attempt to achieve a 3 Metric Tons per day Melter throughput[15].

Next, the Melter Acceptance Test Formula will be processed through the Melter. During this testing the Melter 36 Hour Acceptance test will be performed.

The remainder of the Phase I Tests involves the testing of the Melter and Gem Machine operation with formulas of high and low temperature glass melting characteristics that represent Silo #3 Surrogate and Silo #1 Surrogate (with and without bentonite).

Each campaign presently consists of one run. However, if the glass formulation or conditions of the Run do not meet the Acceptance Criteria or test objectives, then another Run will be performed with a modified formula and/or operating parameters--for Example: Campaign 1, Run 2. Pending results of each run, subsequent runs within that campaign may be scheduled as required to meet the glass acceptance criteria.

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[15] One Mg throughput per day for this melter means a specific throughput rate of 50 $kg/m^2/hr$. For a throughput of three Mg per day the specific throughput rate would be 150 $kg/m^2/hr$. The specific throughput rate for the PAMELA process was about 38 $kg/m^2/hr$, and the Savannah River Plant was about 40 $kg/m^2/hr$. PNL (Richland) predicted 80 $kg/m^2/hr$ for their high temperature lab scale melter using LLW waste surrogate, but only reached 52 $kg/m^2/hr$ in performance tests.

<-- BREAK -->

During the Phase I Campaigns, multiple runs are not anticipated but may be required. If the glass formula for a Campaign requires an adjustment and a new Run is prepared, the following optimization criteria will be considered:

1. Easiest to process

   The easiest to process are probably those glass formulations that have:

   - Lower viscosity/lower temperature melting
   - No secondary phases
   - Medium to lower conductances
   - Little or no foaming
   - High processing rate

2. Easiest to form into glass gems

   - Glass that forms a molten stream that is easy to cut.
   - Glass that remains soft/fluid over a workable and practical temperature range while remaining within the Melter range. This allows the glass gobs more time to pull themselves together as well-formed gems on the conveyor below the Gem Machine.

3. Least corrosiveness/erosiveness to equipment

   Those glasses that are the least corrosive to the Melter refractories and Melter parts are preferred. They are mandatory if the alternative glass formulations have aggressive erosion properties[16]. Even though the Pilot Plant Melter does not have exposed in-bed electrodes[17] and is, therefore, not an erosion problem, a low erosive glass is still desired. This is because the construction and operation of a full-scale Melter with in-bed electrodes would be less costly to construct and could be less expensive to operate. This will not be evaluated until all Campaign Runs are complete and the Melter is drained.

4. Highest waste loading

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[16] All important data, i.e. corrosion rates of the K3, Monofrax E material and the physical properties about the glass, should be known before this glass is used in the melter.

[17] Mo-electrodes

Glasses with the high waste loading (concentrations of K-65 and Silo 3 Surrogates) would give the greatest volume reduction and the less amount of glass produced. Higher waste loading would mean (1) less disposal volumes and costs and (2) a smaller Melter size and/or shorter operational schedules.

<-- BREAK --
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9.2.5.1 Test Run

k. **IF** it is determined that the applicable Run Formula can **NOT** be obtained **AND** it is has been determined that a transfer of the slurry to the Spare Storage Tank is required, **THEN**

DIRECT the transfer of slurry to the Spare Storage Tank in accordance with the following as applicable:

- 9.7.5.3, Transfer From 5-TK-29A, Slurry Tank A to 5-TK-56, Spare Storage Tank. ____/____

  OR

- 9.7.5.4, Transfer From 5-TK-29B, Slurry Tank B to 5-TK-56, Spare Storage Tank. ____/____

AND

GO TO Step 9.2.5.1.a. ____/____

NOTE: Steps 9.2.5.1.l, 9.2.5.1.m, and 9.2.5.1.n should be performed in conjunction with one another to coordinate the transfer of slurry to the Melter, collect samples, and to control the vitrification process.

l. **ENSURE** that Slurry is transferred from the appropriate Slurry Tank to the Melter[18] in accordance with the following:

- 9.4.2.5, Transfer of Slurry From Slurry Tank A to the Melter. ____/____

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[18] At this time the melter is filled with benign glass (surrogate glass in the main chamber) and at operating temperature.

OR

9.4.2.6, Transfer of Slurry From Slurry Tank B to the melter. ____/____

<-- BREAK --->

9.2.5.1 (Continued)

s. **IF** it has been determined that the vitrified product physical, chemical, and processing characteristics are **NOT** as expected **AND** a new Run is required, **THEN**

ADJUST the Run Formula[19], **AND**

GO TO Step 9.2.5.1.a to begin a new Run. ____/____

t. **IF** it has been determined that Campaign 1 is complete, **THEN**

GO TO appropriate section. ____/____

<-- BREAK --->

9.5 VITRIFICATION

NOTE #1: Section 9.5.1 provides guidance for the first Melter operation and subsequent restarts of the Melter in Phase I. This section assumes that the Melter is filled with a molten heterogeneous glass, that it is at a stable temperature, and that is ready for the introduction of slurry material. During SOT, cullet was placed in the Melter and heated until molten using electric lid heaters. Once the glass was molten, the melting process was continued by the Joule Heating provided by the electrode heating system. The objective of this process was to seal the joints in the refractories and to verify proper operation of the Melter temperature control system[20]. This section

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[19] This is one of the most complicated means to find out the reason for that!

[20] Question: Are the thermocouples calibrated by a different temperature control system, I. e. using a micro-pyrometer, to avoid any influence from the electrical field in the Joule

identifies the Melter equipment and the support system equipment that is required to operate the Melter. The specific equipment conditions required to support vitrification are included.

NOTE #2: Section 9.5.2 provides for Melter operational guidance on an ongoing basis. The guidance provided should be followed on a continuing basis and operating conditions should be verified as a minimum on a once-per-shift and once-per-batch basis. Documentation of this is to be recorded in the Test Log.

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heated glass melt?

FINDINGS

from the

ENGINEERING SUPPORT SERVICES CONTRACT
for implementation of the
RECORD OF DECISION
for the
FERNALD ENVIRONMENTAL MANAGEMENT PROGRAM
OPERABLE UNIT 4

FERMCO Contract Number 95SP004785

APPENDIX L

Summary of Phase I Pilot Plant Testing Campaigns 1 - 7

The following table presents a summary of the proposed Phase I pilot plant testing program. There are some apparent arithmetic errors in calculating the total glass throughput during operating time. This is currently being investigated.

Cam-paign		Glass throughput [Mg/day]	Operating time	Total glass throughput during operating time [Mg]	Purpose
#1	Phase #1	1.00	7 days	7.00	• establishing melter control philosophy • monitoring melter and glass parameters
	Phase #2	1.00	7 days	7.00	• first time that Gem making machine is in operation • sampling, analysis, melter operation, gem making machine, off-gas system, recycle water system, process cooling water system • pilot plant test under full production conditions(except thickener operation)
	Phase #3	3.00 or max. attainable rate	7 days	21.00	• determination of melter maximum batch throughput • observation of the limiting factors for throughput

Cam-paign		Glass throughput [Mg/day]	Operating time	Total glass throughput during operating time [Mg]	Purpose
#2	Part #1			8.00	• demonstration that the melter vitrifies glass based on a representative average of silo material composites: 30% Silo1, 30% Silo 2, 30% Silo 3, 10% bentonite. • demonstration that the melter vitrifies material of the described formula • gem making machine can produce one metric ton per day continuously for 36 hours duration in accordance with the vendor acceptance test specifications
	Part #2	1.00	7 days	8.00	• only if required. This part will only be run if more time is required for a formula adjustment
# 3			7 days	8.00	• This Campaign introduces the high temperature (between 1250°C and 1350°C) Silo 3 Surrogate formula. • collect information relating to three areas of the glass formula, Melter, and Off-Gas System capabilities. • The effects of sulfate, nitrate, and phosphate on the melter and the glass formula • SO_X and NO_X handling capabilities of the Off-Gas System. • Devitrification potentials on the glass and glass pours.

Cam-paign		Glass throughput [Mg/day]	Operating time	Total glass throughput during operating time [Mg]	Purpose
# 4			7 days	8.00	• This Campaign introduces the low temperature (≥ 1150°C) Silo 3 Surrogate formula. • coupon testing (Inconel, Pt) • monitoring SO_4^{2-} destruction at 1150°C
# 5			7 days	8.00	• 1250-1350 Silo 1 surrogate formula • Silo 1 Surrogate material will be placed into the Thickener Tank for preparation of slurry feed to the Slurry Tanks and on to the Melter. This is the first time that the Thickener is used for feed preparation. • Lead and barium will be introduced into the batch material at the Slurry Tanks

Cam-paign		Glass throughput [Mg/day]	Operating time	Total glass throughput during operating time [Mg]	Purpose
# 6			7 days	8.00	• Silo 1 - with 50 wt% Bentonite formula • Bentonite is considered to be the hardest constituent in the silo wastes for thickeners to handle. Settling of the Bentonite in the Thickener is to be aided by a flocculent that is added to the Thickener slurry. The degree of success of this process will be monitored and documented Silo 1 - Low Temperature formula during this Campaign. • Bentonite has a high alumina content. Because of the Melter maximum operating temperature of 1350°C, the melting characteristics of this formula will be closely monitored and documented during this Campaign.
# 7			7 days	8.00	• the same as Campaign #4? • Silo 1 - Low Temperature formula
			63.00	91.00	

FINDINGS

from the

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OPERABLE UNIT 4

FERMCO Contract Number 95SP004785

APPENDIX N

Phase II Pilot Plant Testing Time Schedule

PROPOSED TIME SCHEDULE PHASE II

Schedule and glass formulation will be determined by results Phase I test results

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Activity																														
Preparation time before feeding radioactive material																														
Displace of non-radioactive glass (6 times of waste glass melter volume) 1 Mg/24hr throughput (60%TOE)			**One campaign with one glass formula**					**Each additional campaign with different glass formula extends the schedule by about 6 weeks**																						
Testing Radon removal from recycling water sparge tank																														
Carbon filter efficiency test																														

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Activity																														
Increasing waste oxide loading in the glass (equilibrium after 6 times of melter volumes)								**One campaign with one glass formula**																						
Displace of radioactive glass against surrogate glass(melter flush)																														
Preparation for melter draining+ melter draining																														

Detlef Stritzke September 18, 1995