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SILO PROJECT INDEPENDENT REVIEW TEAM DOCUMENTATION - FEBRUARY 25-28, 1997 MEETING NOTES - PATH FORWARD DECISION

03/12/97

MN:WMTSP(SP):97-0070
IRT IRT
38
MINUTES

FEMP Silos Project
Path Forward Decision
Distribution List

Independent Review Team w/ Attachments
Gail E. Bingham, consultant
Gilles Chevrier, NUMATEC
Robert Cook, consultant
Jim Edmondson, consultant
Bob Lawrence, WVNS
Todd Martin, HEAL
Earl McDaniel, consultant
John Plodinec, WSRC
Bob Roal, consultant
Della Roy, consultant
Ben Smith, consultant

Decision Analysis Support Contractor
Lee Merkhofer, Applied Decision Analysis, Inc.
w/ Attachment

Fluor Daniel Fernald
John Bradburne w/o Attachments
Mike Connors w/o Attachments
Doug Daniels w/o Attachments
Yvonne Gale w/o Attachments
Terry Hagen w/o Attachments
Bob Heck w/ Attachments
Renee Holmes w/ Attachments
Richard L. Maurer w/o Attachments
Dennis Nixon w/o Attachments
Don Paine w/ Attachments
Tisha Patton w/ Attachments
Harry Robertson* w/ Attachments
Dennis Sizemore w/o Attachments
Jeff Stone w/o Attachments
Tricia Thompson w/o Attachments

Jeannie Foster w/ Attachments
Jill Oligee w/ Attachments

DOE-FN
Nina Akgunduz w/ Attachments
Jack Craig w/o Attachments
Glenn Griffiths w/o Attachments
Johnny Reising w/o Attachments
Gary Stegner w/o Attachments
David Yockman w/ Attachments

FRESH w/ Attachments
Lisa Crawford
Vicky Dastillung
Pam Dunn

Citizens Task Force
w/ Attachments
Gloria McKinley
Doug Sarno
Gene Willeke

FATLAC w/ Attachments
Robert Tabor
Rick Wilson

Building Trades w/ Attachments
Lou Doll

U.S. EPA-V
Gene Jablonowski
w/ Attachments
Jim Saric w/o Attachments

Ohio EPA
Kelly Kaletsky w/ Attachments
Tom Schneider w/o Attachments

Others w/ Attachments
Marc Fioravanti, IEER
Ben Rusche, MTR Inc.
Silos Project File 40000 -
Independent Assessment Team
Fernald Public Reading Room

*Author

2/21/97

MEETING NOTES MN:WMTSP(SP):97-0070

SUBJECT: Silos Project Path Forward Decision

MEETING DATE: February 25, 26, 27 and 28, 1997

LOCATION: Fluor Daniel Fernald Office
Project File 40000 - Independent Assessment Team

ISSUE DATE: March 12, 1997 File Record Storage Copy 104.(35).5

DISTRIBUTION: Please refer to the attached Distribution List

1.0 PURPOSE

The meeting was the fifth in a series of working sessions to review and evaluate the path forward alternatives for the FEMP Silos Project. This was anticipated to be the last meeting of the Team.

With the exception of three relatively brief presentations to the IRT, the majority of the four-day session was spent establishing the basis and methods of documenting the Team's recommendations. On Wednesday evening the Team was available to the public and gave a briefing of their recommendation status at that point in time to those who attended. This was followed by a question and answer period.

2.0 DISCUSSION

Tuesday, February 25

After brief opening remarks by Bob Heck, Harry Robertson followed with a suggested outline for the path forward report.

Lee Merkhofer presented the results of the decision analysis that incorporated data and probabilities that had been generated at the earlier February meeting. The decision tree performance measures (cost, schedule and accident scenarios) together with conclusions and some recommendations for reducing uncertainties are given in the attachments.

Wednesday, February 26

At 7 p.m. Bob Lawrence of the Independent Review Team (IRT), on behalf of the group, gave a status briefing on their recommendations to those who attended the public meeting. Following the briefing there was a question and answer period that continued

MEETING NOTES - Continued

until 9 p.m. The IRT's briefing notes as well as the public's summary notes and their questions are attached.

Thursday, February 27

At the request of the IRT, Rod Gimpel provided data and answered questions regarding various aspects of glass chemistry, glass formulations and redox control. His material is attached.

Friday, February 28

The IRT completed various portions of the draft report throughout the day and departed with instructions to Fluor Daniel Fernald to distribute the draft to all members when it had been completely compiled.

HLR:kjc
Attachments

MEETING NOTES - Continued

LIST OF ATTACHMENTS

- Agenda
- Suggested Outline of Independent Review Team Report
- Decision Analysis Results
- Silos Project Independent Review Team Status Report, February 26, 1997
- Summary of Independent Review Team (IRT) Public Briefing, February 26, 1997, 7:00 p.m., Alpha Building
- data supplied by Rod Gimpel

MEETING AGENDA

SUBJECT: FEMP Silos Project, Path Forward Decision
DATE: February 25, 26, 27 and 28, 1997
LOCATION: FEMP Alpha Bldg., Fernald, OH

Tuesday, February 25

8:00	Opening	R Heck
8:15	Path Forward Report Outline	H Robertson
8:30	Decision Analysis Results	L Merkhofer
9:00	Independent Review Team - Status of Draft Recommendations - Status of Review Team Assignments	IRT

Wednesday, February 26

	Development of Recommendations/Position Papers	IRT

7:00 p.m. Briefing of Stakeholder

Thursday, February 27

	Continuation of Wednesday's Activities	IRT

Friday, February 28

	Continuation of Summary Recommendations	IRT

SUGGESTED OUTLINE OF INDEPENDENT REVIEW TEAM REPORT

Volume 1

• Executive Summary	IRT
• History of the IRT	FDF
• Recommendations	IRT
• Decision Analysis Report	ADA

Volume 2

• Meeting Minutes, etc.	FDF

Decision Analysis Results

February 27, 1997

Applied Decision Analysis, Inc.
2710 Sand Hill Road
Menlo Park, CA 94025-7065

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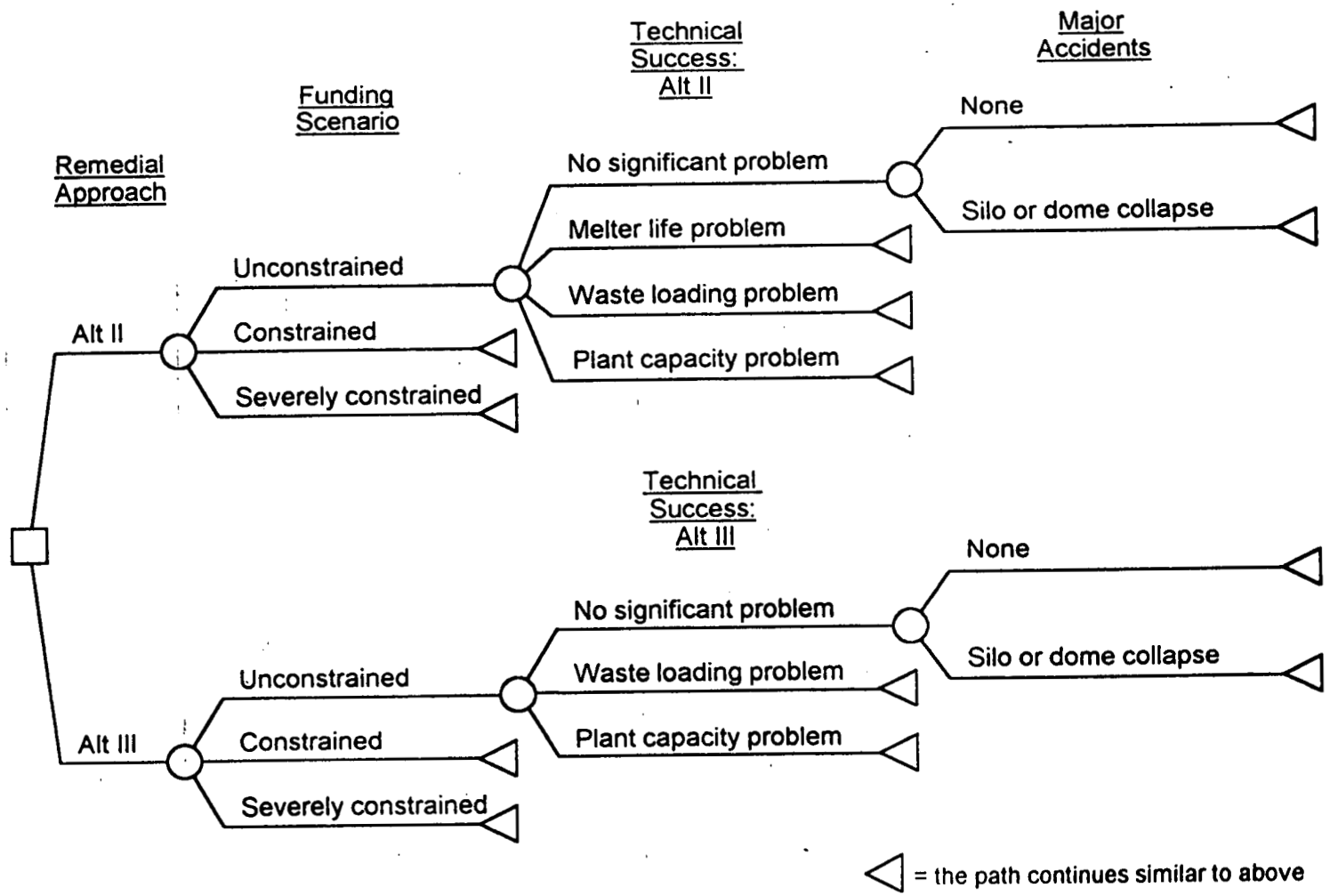
The final decision tree contains forty-two paths



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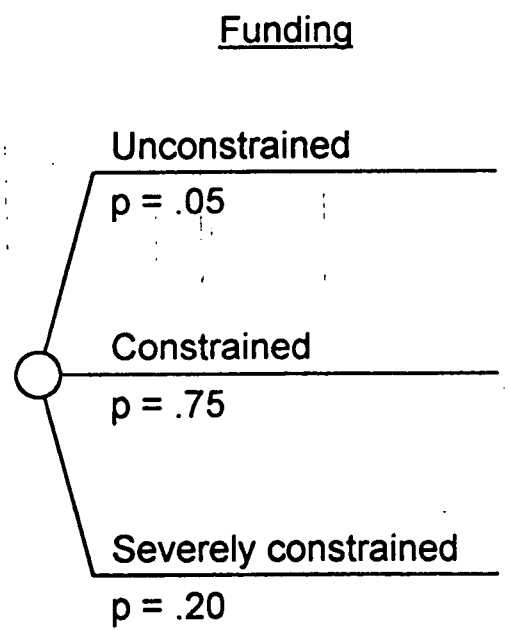
The funding node accounts for uncertainty over available funding level



- **Unconstrained.** Annual funding is at the level desired for efficient implementation of the selected strategy.
- **Constrained.** Annual funding is $25M from 1997 through 2001, $50M from 2002 through 2005, and unconstrained thereafter.
- **Severely constrained.** Funding is at the level of the current FY97 replan.

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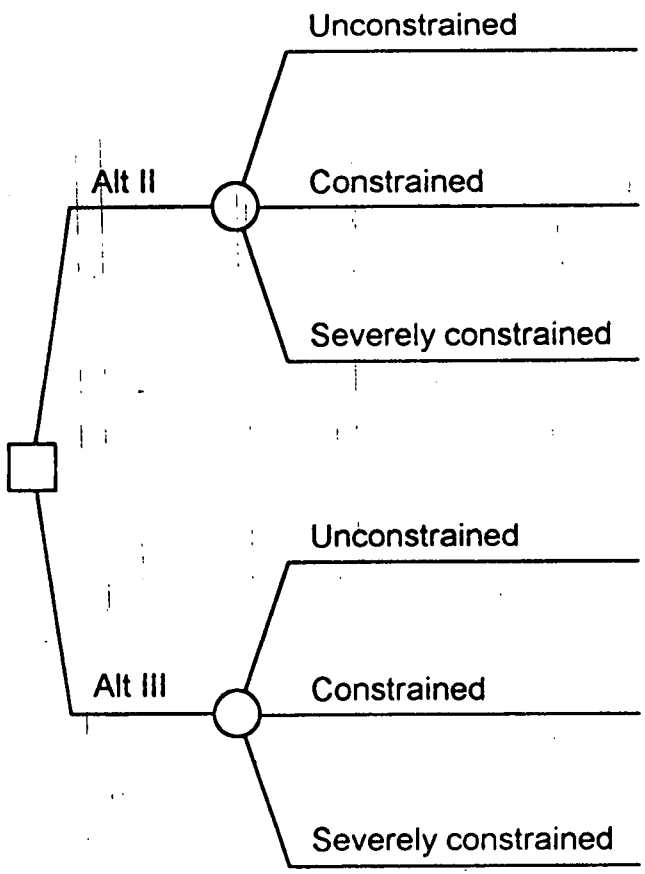
Cost and schedule inputs were estimated for each funding scenario



	Total Direct Cost ($M)	Total Escalated Cost ($M)	Uncertainty Range on Cost	Schedule Duration
Alt II – Unconstrained	485	846	–30%, +50%	14
Alt II – Constrained	496	943	–30%, +50%	16
Alt II – Severely constrained	537	1062	–30%, +50%	19
Alt III – Unconstrained	440	702	–50%, +50%	11
Alt III – Constrained	475	823	–50%, +50%	12.5
Alt III – Severely constrained	500	908	–50%, +50%	16

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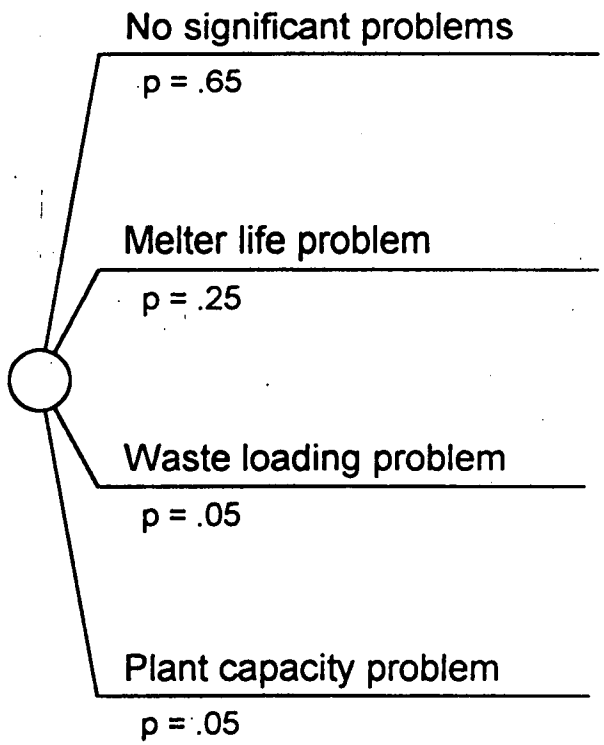
Technical success: Alt II

Accounts for unanticipated technical outcomes that may cause significant schedule or cost impacts for the vitrification of silos 1 & 2.

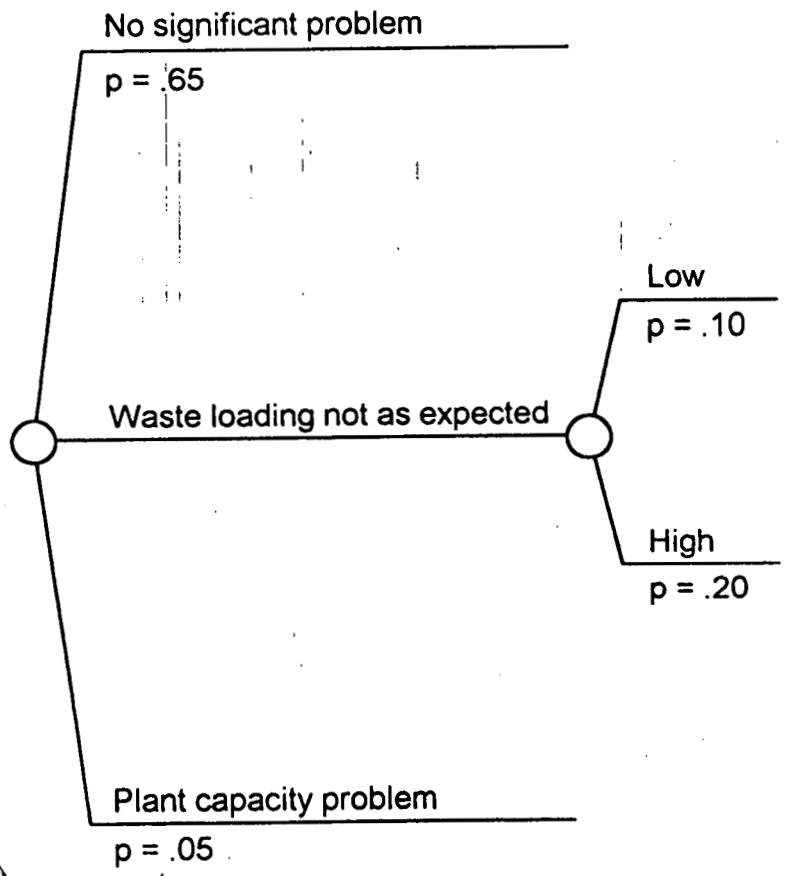


- **No significant problems.** There are no technical problems that cause significant delays or cost increases beyond those accounted for in the base case cost ranges.
- **Melter life problem.** Melter life does not meet design basis resulting in an increase in direct costs of $32M ($60M total*) and a schedule extension of 1 year.
- **Waste loading problem.** Waste loading varies significantly from design basis resulting in an increase in direct costs of $86M ($148M total) and a schedule extension of 2 years.
- **Plant capacity problem.** Plant capacity does not meet design basis resulting in an increase in direct costs of $74M ($167M total) and a schedule extension of 3 years.

*Includes escalation and hotel costs.

Technical success: Alt III

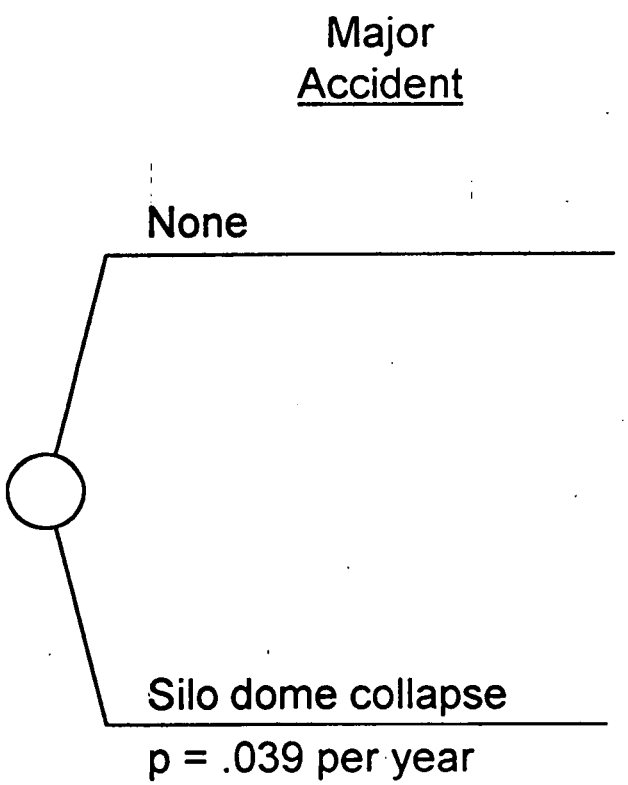
Accounts for unanticipated technical outcomes that may cause significant schedule or cost impacts for the cementation of silos 1 & 2.



- **No significant problems.** There are no technical problems that cause significant delays or cost increases beyond those accounted for in the base case cost ranges.
- **Low.** Only 10% waste loading can be achieved for steady operations resulting in an increase in direct costs of $229M ($340M total*) and an increase in schedule of 3 years.
- **High.** 30% of waste loading can be achieved resulting in a reduction in direct costs of $64M ($67M total) and a decrease in schedule of Y years.
- **Plant capacity problem.** Plant capacity does not meet design basis resulting in an increase in direct costs of $21M ($22M total), but no change in schedule.

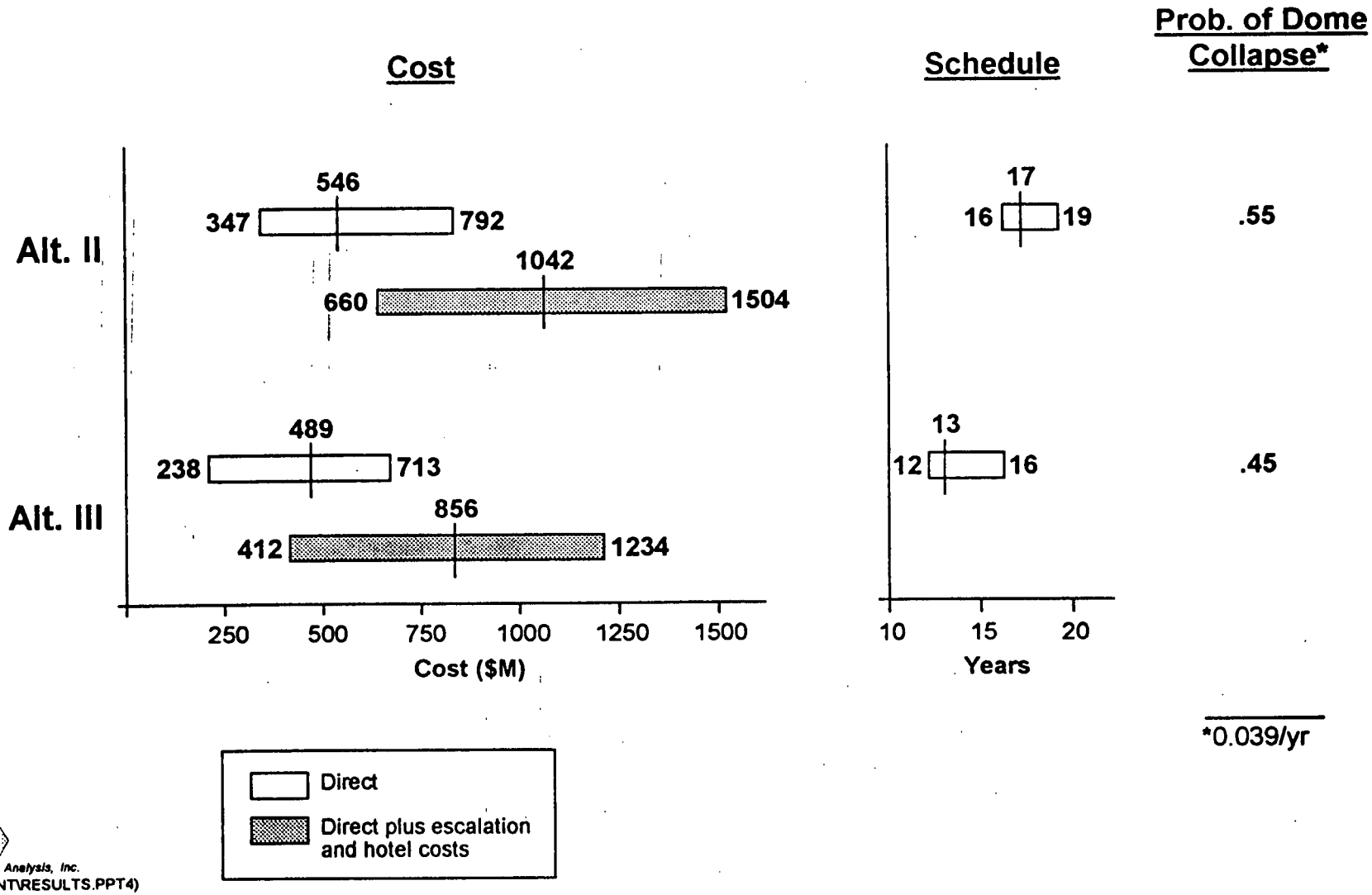
*Includes escalation and hotel costs.

The major accident node accounts for the possibility of a silo dome collapse



- There are no accidents producing significant impacts to cost, schedule, or health & safety.
- Accident occurs (Note: Possible cost & schedule impacts not reflected in results)

Results indicate that Alt III (cem.) outperforms Alt II (vit.) with respect to the mathematical expectation of cost, schedule, and probability of dome collapse



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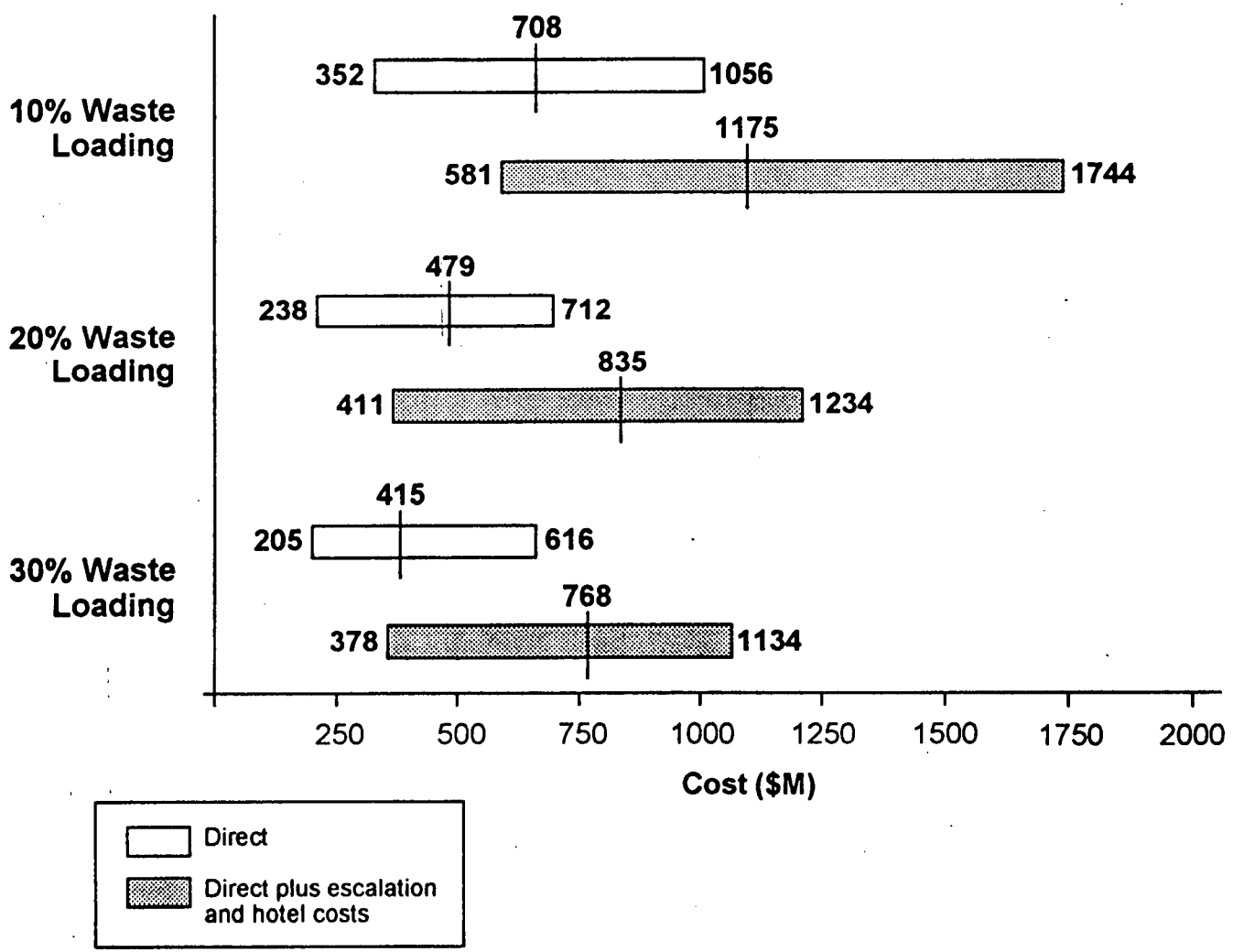
The cost range for Alt III is highly sensitive to the waste loading



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There is significant value only to resolving uncertainties in the cost of Alt II & III and the waste loading achieved with Alt III

Factor	Alt II	Alt III	Both Alt II & III
Melter Life	~0	N/A	N/A
Waste Loading	~0	16M	16M
Plant Capacity	~0	~0	~0
All Tech Success Factors	~0	16M	16M
Residual Cost Uncertainty	31M	47M	66M
All Tech & Cost Uncertainty	31M	55M	72M

Note: analysis done using direct cost

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The ranking of the alternatives is not sensitive to the funding uncertainty

	Direct Cost ($M)	
	Alternative II	Alternative III
Unconstrained	526	451
Constrained	538	486
Severely constrained	581	511

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Conclusions

- Either alternative appears capable of technical success--the differences are primarily cost and schedule.
- Although uncertainties are considerable, results favor Alt III. Alt III is expected:
  - to be less costly (roughly $60M less in direct costs, $190M counting escalation and hotel costs)
  - to be completed sooner (4 years sooner).
- When similar probability distributions are obtained in the world of commercial R&D, they are generally regarded as sufficient for decision making.
- Unlike commercial R&D, additional considerations may be important (e.g., impact of decision on public trust).

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Conclusions (continued)

- Although not analyzed, an alternative of parallel development may be superior to either Alt II or Alt III.
- There may be value to using the decision framework to evaluate one or more parallel development alternatives
- Current VOI results suggest considering strategies that
  - retain vitrification as a fallback, while
  - resolving uncertainties regarding waste loading and other cost and technical uncertainties associated with cementation.
- Dome collapse prior to waste retrieval may be a serious risk. More analysis of the issue is needed.

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SILOS PROJECT

INDEPENDENT REVIEW TEAM

STATUS REPORT

February 26, 1997

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Where are we in the process?

- Recommendation report drafted
  --Alternative II presently preferred
- Further discussion required to finalize
- Technical and institutional factors being considered
- Fernald vitrification experience is considered important
- Compelling reason to change from vitrification for Silo 1 and 2 wastes not clearly evident
- No additional Fernald supporting data expected to be required for Team conclusion
- Fluor Daniel Fernald has been responsive to Team requests for amplifying data

Points of Team Agreement

- Silo 3 wastes should be immobilized separately from Silo 1 and 2 wastes
- Both vitrification and cementation of Silo 1 and 2 wastes are technically feasible
- Cost and schedule risk for cement appear to be less than for vitrification
- Both waste forms would require a tailored recipe
- Both waste forms are capable of satisfying Nevada Test Site waste acceptance criteria
- Both waste forms are capable of satisfying 10CFR61 criteria

Significant Success Factors

- Effective project management system
- Subcontract turnkey program
- Confirmation of
  - --waste characteristics
  - --waste acceptance criteria approval
  - --disposal site performance assessment approval
- Silo waste retrieval and heel removal

SUMMARY OF INDEPENDENT REVIEW TEAM (IRT)
PUBLIC BRIEFING
February 26, 1997; 7:00 p.m. Alpha Building

The Independent Review Team held their February 25 & 26 meetings without DOE, Fluor Daniel Fernald or stakeholders and prepared a status report that was given to stakeholders Wednesday evening. Attending the meeting included reps from U.S. EPA, OEPA, FRESH, Fernald Citizens Task Force, GCBCTC, FAT&LC, Ohio Field Office, DOE and Fluor Daniel Fernald.

Gary Stegner opened the meeting and asked the nine-member panel (Jim Edmondson and Della Roy were absent) to briefly introduce themselves. Bob Lawrence, West Valley Nuclear Services, gave a brief presentation:

WHERE ARE WE IN THE PROCESS?

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POINTS OF TEAM AGREEMENT

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SIGNIFICANT SUCCESS FACTORS

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- Subcontract turnkey program
- Confirmation of:
  --waste characteristics
  --waste acceptance criteria approval
  --disposal site performance assessment approval
- Silo waste retrieval and heel removal

Following are questions/concerns from stakeholders directed to the panel:

Interested to know some factors that the panel views differently with regards to vitrification or cementation. When you prepare your report, please include your differences of opinion

as well as your consensus.

If Silo 3 is eliminated from vitrification, how much re-engineering of the pilot plant will be required?

Is there a compelling reason to move away from vit? Concern about enormous amounts of money being taken away from other cleanup projects. Can you comment on a worse case scenario involving costs? We have good lessons learned from the pilot plant but they have been very expensive.

Where does the Performance Assessment with NTS stand? (a PA for glass has been done -- it took almost two years and is still a draft; we have not done a PA for cement.)

If the IRT was provided data showing that cementation will cut six years off schedule -- need to get same info to stakeholders.

Everything presented so far hasn't convinced some that vitrification, as a technology, won't work for Silos 1 and 2.

Are the results back from the Silo 3 samples sent to Miami University? Make it a priority and notify FRESH as soon as you get them.

To your knowledge, any vitrification anywhere on material similar to Silos 1 & 2?

How many vit facilities are there around the country?

If you cement Silo 3, will you gain enough experience in cementation in case vit fails on Silos 1 & 2 you can switch to cementation? Could you use the same equipment on Silos 1 & 2 as 3?

The community around Niagara Falls is very unhappy with the way the waste (same as K-65) was retrieved and disposed of there. The OU4 ROD says vit and we need to move forward in that direction.

Were the Niagara materials characterized? There was no bentonite. (Comment: Stakeholders were assured when bentonite was added to Silos 1 & 2 that it would not be a problem for vitrification).

When you say "turnkey" do you mean total privatization of OU4? DOE gets another contractor, money comes in for subcontractor. Shouldn't sub report directly to DOE and get another level of management out of the way?

Cementation of Silo 3 will meet the NTS WAC; however, calculating cementing Silos 1 & 2 to meet the NTS WAC is more difficult and complex.

How many years will it take to vit Silos 1 & 2? Looking at six years is being very optimistic.

If we can't afford to vit 1 & 2 and cement 3 in parallel, which would you do first?

Concern about using the turnkey concept which would bring in their own workers and cause layoffs of current staff. (Mr. Hamric ~~said he did~~ not see that happening; sub would oversee our workforce).

In the IRT Final Report, include recommendations, path forward, and all correspondence to date from team members. Suggest DOE get independent experts to review at critical points as we move forward with remediation of silos.

Will the IRT be back? (Hope to be finished when we leave this time).

Make sure the info coming from Miami University gets to Earl (stabilization expert).

Are there issues which would preclude us from finding a need complex-wide and building a facility and shipping the silo materials there?

How about a mobile melter that would come to the location of the waste?

Can you do a side-by-side cost comparison of the two treatments?

Looking forward to: IRT Final Report and FDF cost estimates (ADA report).

At the close of the meeting, the Chair of the Task Force said the briefing was tremendously helpful, thanked the panel, and said he even appreciated the varying opinions and differences because it shows the true independence of the group.

Table 2-2
Silo Compositions According To PNL Analysis

Rank	SILO 1			SILO 2			SILO 3		
	Component	Measured	Normalized	Component	Measured	Normalized	Component	Measured	Normalized
1	SiO_2	50.00	58.06	SiO_2	51.00	60.23	SO_3	15.00	17.26
2	PbO	12.00	13.93	PbO	6.20	7.32	SiO_2	14.00	16.11
3	BaO	6.30	7.32	Fe_2O_3	6.10	7.20	MgO	10.00	11.51
4	CO_2	3.20	3.72	Al_2O_3	3.40	4.02	P_2O_5	9.30	10.70
5	Al_2O_3	2.60	3.02	CO_2	3.40	4.02	Fe_2O_3	8.00	9.21
6	Fe_2O_3	2.50	2.90	BaO	3.00	3.54	N_2O_5	6.10	7.02
7	Na_2O	1.80	2.09	CaO	2.50	2.95	Na_2O	5.90	6.79
8	SO_3	1.80	2.09	MgO	1.70	2.01	Al_2O_3	5.30	6.10
9	MgO	1.20	1.39	SO_3	1.70	2.01	CaO	4.70	5.41
10	K_2O	0.68	0.79	Na_2O	0.88	1.04	CO_2	1.90	2.19
11	P_2O_5	0.62	0.72	K_2O	0.68	0.80	K_2O	1.80	2.07
12	MoO_2	0.43	0.50	P_2O_5	0.68	0.80	MnO_2	0.67	0.77
13	La_2O_3	0.42	0.49	N_2O_5	0.62	0.73	NiO	0.52	0.60
14	NiO	0.42	0.49	UO_2	0.47	0.56	V_2O_3	0.50	0.58
15	Ce_2O_3	0.41	0.48	NiO	0.36	0.43	Li_2O	0.47	0.54
16	CaO	0.37	0.43	Ce_2O_3	0.33	0.39	CuO	0.41	0.47
17	N_2O_5	0.29	0.34	TiO_2	0.33	0.39	CoO	0.36	0.41
18	TiO_2	0.28	0.33	La_2O_3	0.29	0.34	UO_2	0.34	0.39
19	CoO	0.19	0.22	CoO	0.21	0.25	ThO_2	0.31	0.36
20	Nd_2O_3	0.19	0.22	Nd_2O_3	0.16	0.19	As_2O_3	0.29	0.33
21	SrO	0.08	0.10	ZrO_2	0.14	0.17	TiO_2	0.22	0.25
22	Cl	0.08	0.09	CuO	0.08	0.10	PbO	0.19	0.22
23	V_2O_3	0.06	0.07	Cr_2O_3	0.08	0.10	MoO_2	0.18	0.21
24	CuO	0.06	0.07	V_2O_3	0.08	0.10	Cr_2O_3	0.08	0.10
25	ZrO_2	0.05	0.06	MoO_2	0.08	0.09	F	0.07	0.08
26	SeO_2	0.05	0.05	SrO	0.06	0.07	ZnO	0.07	0.08
27	Cr_2O_3	0.02	0.02	As_2O_3	0.05	0.06	Y_2O_3	0.04	0.04
28	MnO_2	0.01	0.02	SeO_2	0.04	0.05	BaO	0.03	0.04
29	BeO	0.01	0.01	MnO_2	0.03	0.04	SeO_2	0.03	0.03
30	F	0.00	0.01	ZnO	0.01	0.01	SrO	0.03	0.03
31	As_2O_3			Cl	0.00	0.01	Ce_2O_3	0.02	0.02
32	CdO			F	0.00	0.01	ZrO_2	0.02	0.02
33	Li_2O			BeO			Cl	0.02	0.02
34	ThO_2			CdO			Nd_2O_3	0.01	0.01
35	UO_2			Li_2O			La_2O_3	0.01	0.01
36	Y_2O_5			ThO_2			BeO	0.01	0.01
37	ZnO			Y_2O_3			CdO	0.00	0.01
	Totals	86.12	100.00		84.68	100.00		86.89	100.00

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Table 2-11
Silo 1 Residue Composition
as Measured by FD Fernald 11/22/96

a Element as oxide	b Analyzed wt%	c Normalized wt%	d Stoichio. mol. %	e PNL Anal. wt%	f c - e wt%
Al2O3	2.63	2.91	2.04	3.02	-0.11
B2O3	0.36	0.40	0.41	0.00	0.40
BaO	5.81	6.44	3.00	7.32	-0.88
CO2	3.36	***3.72***	6.05	3.72	0.00
CaO	0.24	0.27	0.34	0.43	-0.16
Fe2O3	2.10	2.33	1.04	2.90	-0.57
K2O	0.12	0.13	0.10	0.79	-0.66
Li2O	0.19	0.21	0.50	0.00	0.21
MgO	0.29	0.32	0.57	1.39	-1.07
MnO2	0.01	0.01	0.01	0.01	0.00
N2O5	0.31	***0.34***	0.23	0.34	0.00
Na2O	1.73	1.92	2.21	2.09	-0.17
NiO	0.44	0.49	0.47	0.49	-0.00
P2O5	0.65	***0.72***	0.36	0.72	0.00
PbO	12.69	14.06	4.51	13.93	0.13
SO3	3.40	3.77	3.37	2.09	1.68
SiO2	53.49	59.26	70.56	58.06	1.20
V2O5	0.08	0.09	0.03	0.07	0.02
Others	2.37	***2.63***	4.20	2.63	-0.00
	90.27	100.00	100.00	100.00	-0.00

Sample No.: 200222611

Numbers in bold were not analyzed by FD Fernald. They are taken from the PNL Analysis.
The "others" are other elements in the residue that are less than 0.5 wt% each, but total collectively to the amount shown.

Table 2-12
Silo 2 Residue Composition
as Measured by FD Fernald 11/22/96

a Element as oxide	b Analyzed wt%	c Normalized wt%	d Stoichio. mol. %	e PNL Anal. wt%	f c - e wt%
Al2O3	3.01	3.47	2.37	4.02	-0.55
B2O3	0.00	0.00	0.00	0.00	0.00
BaO	4.47	5.15	2.34	3.54	1.61
CO2	3.49	***4.02***	6.36	4.02	0.00
CaO	2.81	3.24	4.02	2.95	0.29
Fe2O3	4.82	5.56	2.42	7.20	-1.64
K2O	0.25	0.29	0.21	0.80	-0.51
Li2O	0.00	0.00	0.00	0.00	0.00
MgO	0.39	0.45	0.78	2.01	-1.56
MnO2	0.00	0.00	0.00	0.04	-0.04
N2O5	0.63	***0.73***	0.47	0.73	-0.00
Na2O	0.74	0.85	0.96	1.04	-0.19
NiO	0.38	0.44	0.41	0.43	0.01
P2O5	0.69	***0.80***	0.39	0.80	-0.00
PbO	7.59	8.75	2.73	7.32	1.43
SO3	3.50	4.03	3.51	2.01	2.02
SiO2	51.58	59.46	68.85	60.23	-0.77
V2O5	0.01	0.01	0.00	0.10	-0.09
Others	2.39	***2.76***	4.20	2.76	-0.00
	86.75	100.00	100.00	100.00	0.00

Sample No.: 200222612

Numbers in bold were not analyzed by FD Fernald. They are taken from the PNL Analysis.
The "others" are other elements in the residue that are less than 0.5 wt% each, but total collectively to the amount shown.

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Table 2-15
Decomposition Temperatures of Sulfates

Compound	Melting Point, °C	Decomposition Temperature, °C	Behavior
$Al_2(SO_4)_3$	--	770	Low temperature decomposition.
$BaSO_4$	1580	>1580	Melts without decomposition.
$CaSO_4$	1450	Graduated	Some decomposition before melting, but slow.
$Fe_2(SO_4)_3$	--	480	Low temperature decomposition.
Li_2SO_4	860	860	Decomposition is not far above melting temperature.
$MgSO_4$	--	<1124	Decomposes before melting.
Na_2SO_4	884	Graduated	Volatilization and decomposition both take place, however, both are slow at lower molten glass temperatures. Increases with temperature.
$PbSO_4$	1170	< 1170	Decomposes noticeably below the melting point.

Information from:

The Chemical Rubber Company (CRC) Handbook of Chemistry and Physics, 51st Edition, and

High Temperature Properties and Decomposition of Inorganic Salts, "Part 1. Sulfates," October 1, 1966, K. H. Stern and E. L. Weise, Institute for Basic Standards, National Bureau of Standards, Washington, D.C.

Table 2-5
Silo 1 Surrogate

Silo 1 Surrogate Compound	mo. wt.	Silo wt%	Silo, n wt%	mols X100	Metal	Nonmetal
Al2O3	101.96	2.60	3.14	3.08	3.08	
B2O3	69.62					
H3BO3	61.83					
BaO	153.34	6.30	7.62	4.97	4.97	
BaCO3	197.35					
BaSO4	233.40					
CO2	44.01	3.20	3.87	8.79		8.79
CaO	56.08					
CaCO3	100.09					
CaSO4	136.14					
Ca3(PO4)2	310.18					
Fe2O3	159.69	2.50	3.02	1.89	1.89	
K2O	94.20	0.68	0.82	0.87	0.87	
K2CO3	138.21					
KNO3	101.11					
Li2O	29.88					
Li2CO3	73.89					
MgO	40.31	1.20	1.45	3.60	3.60	
MgCO3	84.32					
MgSO4	120.37					
Mg3(PO4)2	262.88					
MnO2	70.94					
N2O5	108.01					
Na2O	61.98	1.80	2.18	3.51	3.51	
Na2B4O7	201.22					
Na2SO4	142.04					
Na2CO3	105.99					
NaNO3	84.99					
NiO	74.71					
P2O5	141.94	0.62	0.75	0.53		0.53
PbO	223.19	12.00	14.51	6.50	6.50	
SO3	80.06	1.80	2.18	2.72		2.72
SiO2	60.08	50.00	60.46	100.63	100.63	
TiO2	79.90					
V2O3	149.88					
Other						
Bentonite	na					
		82.70	100.00	137.10	125.06	12.04

Surrogate Compound	Oxide	CO2	N2O5	P2O5	SO3	as metal Oxide	Compound Mols%	Rod F. Gimpel V2.0 Compound wt%	Compound wt%, n	06/26/96 Compound wt%, c
Al2O3	3.08					3.08	3.08	3.14	3.15	3.02
BaCO3		2.25				2.25	2.25	4.44	4.44	4.27
BaSO4					2.72	2.72	2.72	6.35	6.35	6.10
Fe2O3	1.89					1.89	1.89	3.02	3.02	2.90
K2CO3		0.87				0.87	0.87	1.21	1.21	1.16
MgCO3		2.02				2.02	2.02	1.70	1.70	1.63
Mg3(PO4)2				0.53		1.58	0.53	1.39	1.39	1.33
Na2CO3		3.51				3.51	3.51	3.72	3.72	3.58
NaNO3										
PbO	6.50					6.50	6.50	14.51	14.52	13.94
SiO2	100.63					100.63	100.63	60.46	60.50	58.09
V2O3										3.97
	112.11	8.65		0.53	2.72	125.06	124.01	99.94	100.00	100.00
Difference:		-0.14								

Note: n = data normalized to 100 wt%
c = Corrected. The actual wastes contain other compounds that are less than 0.5 wt%, but total to the amount labeled "other" in this table.
Therefore, the compound concentrations are adjusted for the mass the "others" occupy in the real waste.

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Table 2-6
Silo 2 Surrogate

Silo 2 Surrogate

Compound	mol. wt.	Silo wt %	Silo, n wt %	mols x100	Metal	Nonmetal
Al2O3	101.96	3.40	4.15	4.07	4.07	
B2O3	69.62					
H3BO3	61.83					
BaO	153.34	3.00	3.66	2.39	2.39	
BaCO3	197.35					
BaSO4	233.40					
CO2	44.01	3.40	4.15	9.44		9.44
CaO	56.08	2.50	3.05	5.45	5.45	
CaCO3	100.09					
CaSO4	136.14					
Ca3(PO4)2	310.18					
Fe2O3	159.69	6.10	7.45	4.67	4.67	
K2O	94.20	0.68	0.83	0.88	0.88	
K2CO3	138.21					
KNO3	101.11					
Li2O	29.88					
Li2CO3	73.89					
MgO	40.31	1.70	2.06	5.15	5.15	
MgCO3	84.32					
MgSO4	120.37					
Mg3(PO4)2	262.88					
MnO2	70.94					
N2O5	108.01	0.62	0.76	0.70		0.70
Na2O	61.98	0.88	1.08	1.73	1.73	
Na2B4O7	201.22					
Na2SO4	142.04					
Na2CO3	105.99					
NaNO3	84.99					
NiO	74.71					
P2O5	141.94	0.68	0.83	0.59		0.59
PbO	223.19	6.20	7.57	3.39	3.39	
SO3	80.06	1.70	2.06	2.59		2.59
SiO2	60.08	61.00	62.30	103.70	103.70	
TiO2	79.90					
V2O3	149.88					
Other						
Bentonite	na					
		81.86	100.00	144.75	131.43	13.32

Surrogate Compound	Oxide	CO2	N2O5	P2O5	SO3	as metal Oxide	Compound mols	Rod F. Gimpel V2.0 Compound wt%	Compound wt%, n	05/25/95 Compound wt%, c
Al2O3	4.07					4.07	4.07	4.15	4.15	4.02
BaSO4					2.39	2.39	2.39	5.58	5.58	5.39
CaO	1.12					1.12	1.12	0.63	0.63	0.61
CaCO3		4.12				4.12	4.12	4.13	4.13	3.99
CaSO4					0.20	0.20	0.20	0.28	0.28	0.27
Fe2O3	4.67					4.67	4.67	7.45	7.45	7.20
K2CO3		0.88				0.88	0.88	1.22	1.22	1.18
MgCO3		3.40				3.40	3.40	2.66	2.66	2.77
Mg3(PO4)2				0.59		1.76	0.59	1.54	1.54	1.49
Na2CO3		1.03				1.03	1.03	1.10	1.10	1.06
NaNO3			0.70			0.70	1.40	1.19	1.19	1.15
PbO	3.39					3.39	3.39	7.57	7.57	7.32
SiO2	103.70					103.70	103.70	62.30	62.30	60.23
Other										3.33
	116.95	9.43	0.70	0.59	2.59	131.43	130.97	100.00	100.00	100.00
Difference:		-0.00				-0.00				

Note: n = data normalized to 100 wt%
c = Corrected. The actual wastes contain other compounds that are less than 0.5 wt%, but total to the amount labeled "other" in this table. Therefore, the compound concentrations are adjusted for the mass the "others" occupy in the real waste.

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Table 2-17
Minimelter Melter Glass Formulas

Series - Run	A		C-1		C-2	
Melt Number	C4A-03		C4C-03		C4C-08	
Comp. (Wt%)	Calc.	Analy.	Calc.	Analy.	Calc.	Analy.
Al_2O_3	5.89	6.08	12.35	11.98	14.43	13.75
B_2O_3	12.89	11.84	12.23	11.77	6.00	5.79
BaO	4.47	4.11	0.03	0.04	0.03	0.04
CaO	5.08	5.49	9.43	9.08	8.61	8.09
Fe_2O_3	3.98	3.60	5.72	5.47	7.70	7.02
K_2O	0.61	0.55	1.35	1.38	1.74	1.63
La_2O_3	0.34	0.02	-	-	-	-
Li_2O	1.52	1.44	2.13	1.97	1.88	1.82
MgO	1.32	1.20	7.18	6.74	9.63	9.07
MnO_2	-	-	0.48	0.53	0.64	0.64
Na_2O	5.68	4.66	7.86	6.91	5.27	4.88
NiO	0.38	0.33	0.37	0.35	0.50	0.43
P_2O_5	0.63	0.65	6.73	6.67	8.95	6.41
PbO	8.63	7.87	0.20	0.24	0.20	0.25
SO_3	1.62	1.44	0.00	na	0.00	na
SiO_2	46.90	40.70	33.56	33.68	33.93	33.33
V2O5	-	-	0.36	na	0.48	na
ZrO_2	0.09	0.11	-	na	na	na
Total	100.00	90.81	100.00	96.81	100.00	93.36
Appearance upon cooling	Dark brown glass		Opaque on top black on bottom		Dark brown	
Liquidus	<1100°C		<1000°C		about 1050°C	
Density, g/cm³	2.76		2.49		2.7	
Temp., °C						
1150	234.0	0.06-0.08	40.07	0.11	53.47	0.055
1200	123.1	--	25.21	0.15	34.96	0.084
1250	76.2	0.07-0.09	16.96	0.21	23.51	0.125
1300	52.6		12.03	0.28	16.21	0.180
1350	39.1	--	8.91	0.38	11.44	0.255
1400		--	--	--	--	--
TCLP, ppm						
Pb	2.6		0.05		0.07	
Ba	2.06		0.24		0.88	
Ni	0.10		0.47		0.71	
Waste Loading:						
g dry waste/g glass	79.08 %		68.00 %		81.60 %	
as oxides in glass (100% - additives)	74.00% (74.50% w/SO_3)		50.00% (~52% w/SO_3)		60.00% (~62.00% w/SO_3)	

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Table 2-18
Minimelter Melter Glass Formulas

Series, Run	D-1		D-2		D-3	
Glass Number	C4D-04		C4D-15		C4D-01	
Comp. (Wt%)	Calc.	Anal.	Calc.	Anal.	Calc.	Anal.
Al_2O_3	9.63	9.34	15.13	12.69	13.98	13.37
B_2O_3	14.96	13.98	10.06	7.87	10.04	9.60
BaO	2.46	2.11	2.45	2.30	2.66	2.32
CaO	6.97	6.78	7.70	6.91	13.88	13.18
Fe_2O_3	5.33	5.01	5.58	5.01	4.33	4.15
K_2O	1.13	1.04	1.10	1.06	0.79	0.67
La_2O_3	-	-	-	-	-	-
Li_2O	0.2	0.25	0.18	0.24	1.08	1.22
MgO	4.51	3.64	5.03	4.28	2.76	2.41
MnO	-	-	-	-	-	-
Na_2O	6.66	5.93	7.01	5.92	7.09	6.12
NiO	0.41	0.40	0.40	0.36	0.10	0.10
P_2O_5	3.48	3.20	3.87	3.42	2.46	2.33
PbO	5.53	5.02	4.85	4.61	5.22	5.41
SO_3	2.05	na	-	-	1.97	1.56
SiO_2	36.58	34.38	36.56	33.59	33.66	34.27
ZrO_2	0.10	0.11	0.06	0.07	0.00	0.00
Total	100.00	91.33	100.00	88.33	100.00	96.71
Appearance upon cooling	bottom black; top opaque blue/green		black glass		dark brown homogeneous	
Liquidus	<1100°C		<1050°C		<1050°C	
Density, g/cm³	2.71		na		2.79	
Temp., °C						
1100	205.15	0.017	314.1*	0.02	87.45	0.046
1150	114.92	0.026	161.3	0.032	53.16	0.067
1200	69.73	0.038	92.6	0.051	34.52	0.095
1250	45.13	0.055	57.9	0.078	23.64	0.133
1300	30.79	0.077	38.8	0.116	16.92	0.181
1350	21.94	0.106	27.4	0.169	12.57*	0.243
1400	--	--	*extrapolated	--	*extrapolated	--
TCLP, ppm						
Pb		2.43		1.4		3.15
Ba		1.56		1.2		1.88
Ni		0.32		0.12		0.10
Waste Loading:						
g dry waste/g glass		79.82%		78.68%		71.84%
as oxides in glass (100% - additives)	70.00% (70.50% w/SO_3)		69.00% (69.5% w/SO_3)		63.00% (63.5% w/SO_3)	

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Table 2-19
Modified Series A Glass Formula

Series - Run	Ax	
Melt Number	S12-04 (C4A-03 mod.)	
Comp. (Wt%)	Calc.	Analy.
Al_2O_3	6.15	na
B_2O_3	10.51	na
BaO	4.09	na
CaO	13.31	na
Fe_2O_3	3.60	na
K_2O	0.58	na
Li_2O	1.28	na
MgO	1.23	na
Na_2O	7.33	na
NiO	0.56	na
P_2O_5	0.56	na
PbO	7.98	na
SiO_2	43.38	na
Total	100.00	na
Appearance upon cooling	brown clear transparent glass	
Liquidus	<na°C	
Density, g/cm³	na	
Temp., °C		
1100	258	na
1150	140	na
1200	84	na
1250	53	na
1300	35	na
1350	23	na
1400	17	na
TCLP, ppm		
Pb		na
Ba		na
Ni		na
Waste Loading:		
g dry waste/g glass		71.60 %
as oxides in glass (100% - additives)		0.67

Table 2-16

Rick Frost & Rod Gimpel R2 4/24/96

Robustness of Series D Glass AG-10/C4D-01

Changed Component	Original AG-10/C4D-01 g/100g glass	Silo 3 Portions g/100g glass	Changed Amount g/100g glass	Change in Silo 3 wt%	Density g/cc	Visual Viscosity 1 thru 10 *a	Viscosity at 1250^C	Good Glass at 1250^C	Melt No.	Appearance
Control - no change					2.87	3	57	yes	AG-10a-26	Transparent, dark-amber glass, no bubbles
Al2O3	14.21	1.18	-5.00	425	2.84	3	66	yes	AG-11-26	Same as control w/slight glaze -- disappears w/> time or temp.
	"	"	-10.00	849	2.78	3		yes	AG-19a-31	looks better than control -- melts good at 1150^C (AG-19b-57)
B2O3	10.24	0.00	-5.00	na	2.87	3	70	yes	AG-12-26	Same as control but a little less fluid.
	"	"	-10.24	na	2.82	7		yes	AG-20-31	Translucent, dark-amber glass w/small air bubbles
BaO	2.89	0.01	nd	nd						
CaO	14.06	1.04	-5.00	479	2.79	3	34	yes	AG-13-26	Same as control w/small bubbles -- disappear w/> time or temp.
	"	"	-10.00	958	2.71	4			AG-21-32	Same as control w/small bubbles -- disappear w/> time or temp.
Fe2O3	4.28	1.78	nd	nd						
K2O	0.81	0.40	nd	nd						
Li2O	1.13	0.10	-1.13	1084	2.78	4		yes	AG-26-34	Same as control w/small bubbles -- disappear w/> time or temp.
MgO	3.27	2.22	nd	nd						
MnO2	0.15	0.14	nd	nd						
Na2O	7.06	1.31	-2.50	191	2.87	3	63	yes	AG-14-27	Same as control w/small bubbles -- disappear w/> time or temp.
	"	"	-5.00	382	2.83	5		yes	AG-22-32	Transparent, very dark-amber glass, w/small air bubbles
NiO	0.12	0.12	nd	nd						
P2O5	2.43	2.06	5.00	242		3		yes-b	AG-30-35	Bottom 1 mm same as control; rest opaque greenish-gray (PO4)
PbO	5.25	0.04	nd	nd						
SiO2	34.14	3.11	5.00	161	2.78	3	47	yes	AG-16-26	Same as control w/small bubbles -- disappear w/> time or temp.
V2O5	0.12	0.11	1.00	893		4			AG-32-37	Same as control w/small bubbles -- disappear w/> time or temp.
	100.00	13.62								
Special Cases:										
-5% Al2O3 + =mole% SiO2					2.86	3		yes	AG-15-27	Same as control w/small bubbles -- disappear w/> time or temp.
-10% Al2O3 + =mole% SiO2					2.79	3		yes	AG-23-32	Same as control w/small bubbles -- disappear w/> time or temp.
-2.5% NaO2 + 3.75%CaO					2.80	3		yes	AG-24-33	Same as control w/small bubbles -- disappear w/> time or temp.
SO3 Saturated			Saturated	na	2.74	3	26	yes	AG-17-26	Same as control w/small bubbles -- disappear w/> time or temp.
-25% Additives					2.79	4		yes	AG-28-35	Same as control w/small bubbles -- disappear w/> time or temp.
+25% Additives					2.78	4		yes	AG-29-35	Best looking glass in series

*a Visual Viscosity was determined by looking at a glass while it was poured and giving it a number between 1 and 10.
1 appears to pour like water. 10 it is solid like and cannot be racked out of the crucible. The startup glass was given a 3 as a standard.

*b This glass appears that it would be a good glass in the melter, but upon cooling it degrades.

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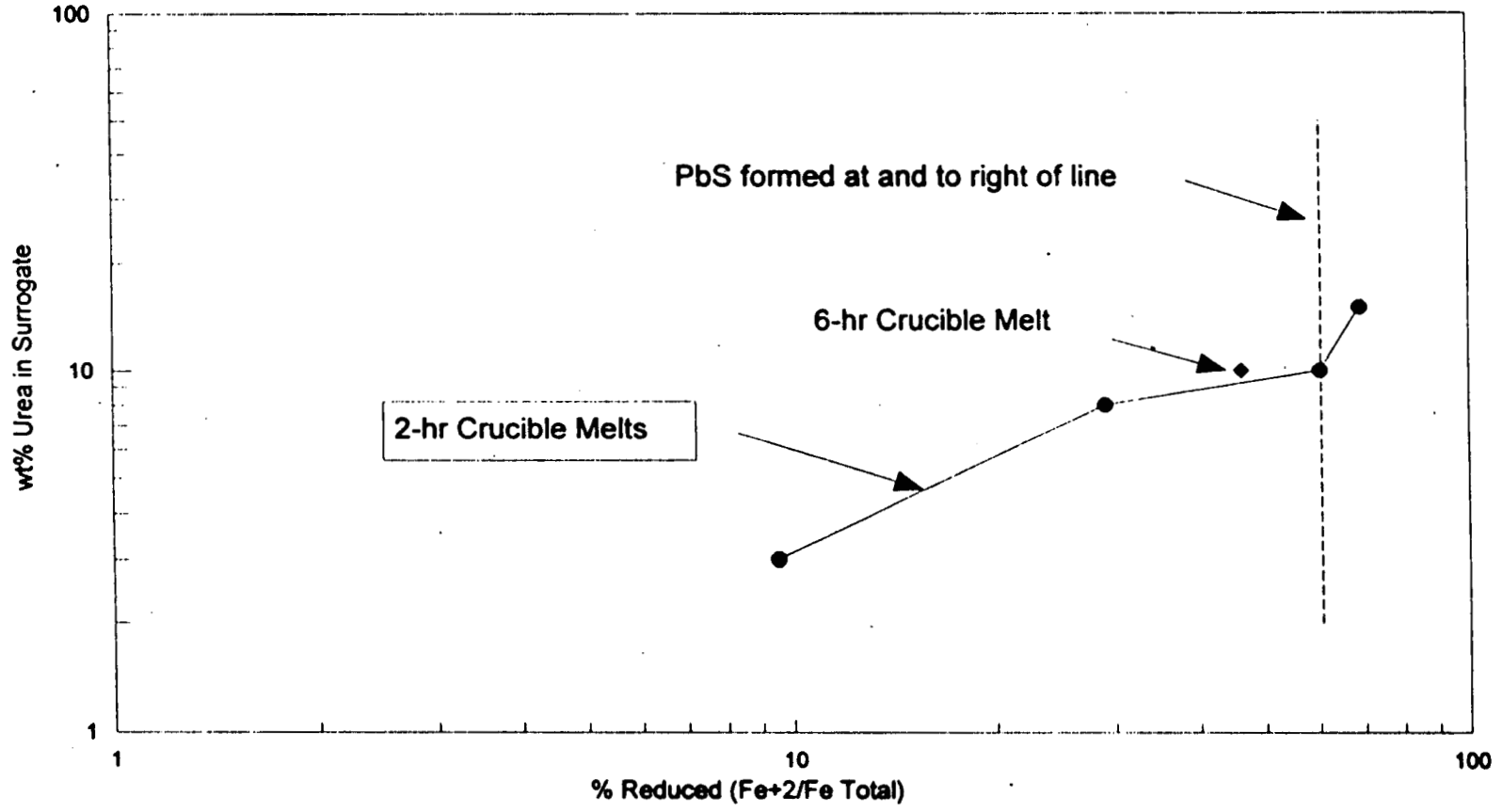
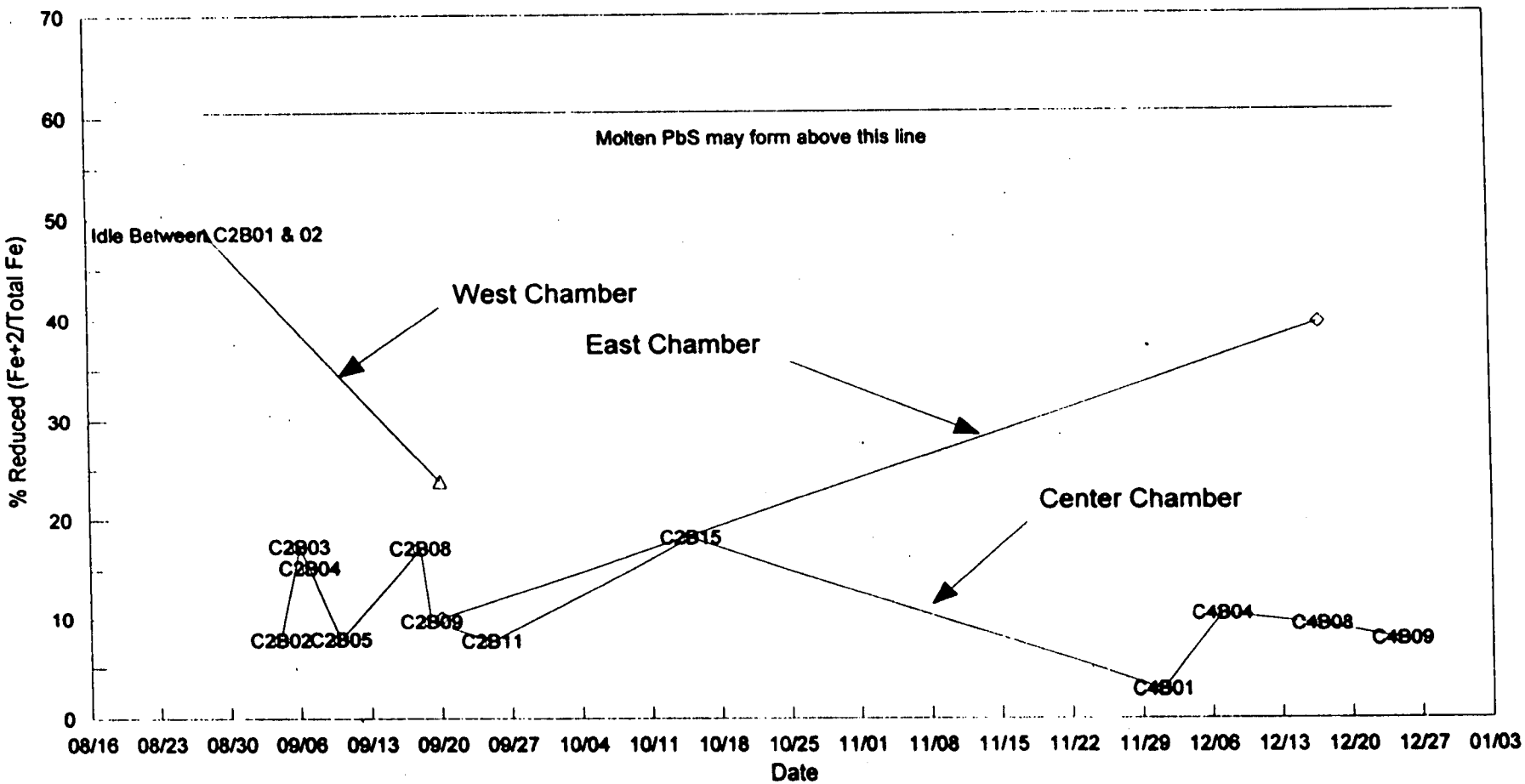
Redox of Surrogate Glass vs. Urea Crucible Melts

Figure XX



VitPP Redox During Phase I

Figure XX



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