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Subject : Slurry Fed Ceramic Melter Disassembly Report

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The following report covers the disassembly and examination of the West Valley Slurry Fed Ceramic Melter. It had been used during five years of testing at West Valley Demonstration Project to process glass from a simulated slurry waste composition. This work was done to document the condition of the melter and identify any improvements for current melter design.

If you have any questions, please feel free to contact the undersigned on Ext. 4512.

R. B. Brooks, Senior Engineer

RBB:KMG

Attachment: Slurry Fed Ceramic Melter Disassembly Report

1289KMG

SLURRY FED CERAMIC MELTER
DISASSEMBLY REPORT

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CMH032493

TABLE OF CONTENTS

LIST OF DIAGRAMS

LIST OF ILLUSTRATIONS

INTRODUCTION

The Slurry Fed Ceramic Melter, SFCM, was built and operated to process various slurry compositions into glass. These compositions were combinations of simulated radioactive waste and nonradioactive additives that would result in a chosen glass product. This melter along with supporting hardware was tested at West Valley Nuclear Services, WVNS, during a five year period. Upon completion of testing, the melter was disassembled and examined to determine the resultant effects of glass processing on its internal components such as refractory bricks and electrodes. All refractory and internal parts including cooling lines and embedded thermocouples were removed and examined for wear and deterioration that occurred during the five years of operations and testing. The various refractories were measured for wear and examined for glass penetration within joints between blocks. Information from disassembly has been and will be used to improve the SFCM design and assembly and also document the condition of the melter. The following items were of particular interest for the design of the new melter:

(1) The condition of the melter lid, nozzles, and flanges.

(2) The condition of lid refractory including refractory anchors and clips and effects of corrosion/erosion.

(3) The condition of the electrodes
- evidence of erosion, galvanic corrosion, and damage due to localized high temperatures,
- amount of wear and type of deterioration at the electrodes

(4) The amount of wear on Monofrax-E riser blocks at their exterior and within glass airlift passages.

(5) Confirmation that there was no electrical conduction path between the glass pool and melter shell which would have caused an electrical ground.

(6) Determine amount of glass penetration into refractory joints and around the electrodes and any resulting damage.

MELTER DESCRIPTION

The SFCM was constructed with five different refractory types: Alfrax, Monofrax-H, Monofrax K-3, Monofrax-E, and Zirmul. Each type was placed in a specific melter area based on the function of the location. For example, the most glass corrosion resistance refractory was placed in areas of high wear while refractory which was most resistant to vapor attack was placed above the glass pool where glass vapors were expected.

The melter was divided into two chambers, the melting chamber and the discharge chamber. Slurry was fed into the melting chamber where it was heated and processed into molten glass then moved into the discharge chamber and poured into canisters beneath the melter. Glass contact areas in the melting chamber were lined with Monofrax K-3 and Monofrax-E refractories. Monofrax K-3 refractory was arranged to form an open chamber shaped in an inverted pyramid with the electrodes aligned parallel to each other lengthwise. Glass was channeled through a passage in an Monofrax-E riser block into the discharge chamber. It was called a riser block because its exit sits higher than the entrance and glass has to <u>rise</u> a level to pass through the block. This area was expected to have the greatest corrosion because of glass velocity in the passage and therefore Monofrax-E, the most corrosive resistant refractory, was used. Behind or backing up the Monofrax K-3 refractory was Zirmul, a less corrosion resistive refractory but a better insulator. A layer of Alfrax castable refractory and a layer of fiberboard which sat against the melter shell backed up the Zirmul refractory. The melting chamber formed by the refractory was 50 inches wide by 68 inches long at its top and narrowed to the dimensions of the bottom electrode, 14 inches wide by 25 inches long, on the floor. Figure 1 shows locations of refractories and their arrangement in the melter. There were three horizontally mounted inconel electrodes in the melting chamber placed in a triangular arrangement with one of

the electrodes in the floor and two electrodes in the sidewalls. An electrical current travelled between electrodes through the glass which resulted in joule effect heating for glass melting.

Monofrax-H refractory lined the plenum area above the melting chamber between the lid and glass pool. These refractory blocks formed a rectangular shaped air space that vapors and volatiles occupied until they either condensed or were swept out of the area for off-gas treatment.

The melter discharge chamber was divided into two discharge cavities, east and west, either of which could be used to remove glass from the melter and direct it into a canister. The discharge cavities were separated from the melting chamber by a refractory wall that included the riser blocks. Both cavities were identical in size and shape and were lined with Alfrax or a equivalent castable refractory. Both were heated by a series of electrically powered radiant heaters but only the cavity in use, normally the west cavity, had radiant heaters installed. Inconel plates called dams were casted into the Alfrax wall separating the melting chamber from the discharge chamber to prevent the possibility of glass seepage through the wall. A refractory wall and dam also separated the two discharge cavities into east and west. Refer to Figure 1.

MELTER LID

The melter lid shell was built from Inconel 690 and filled with Alfrax or an equivalent castable refractory. Melter disassembly began by removing the melter lid and inverting it such that the lid refractory sat on the top inconel plate of the shell. Various sizes of pipes with flanges, called nozzles, were welded to the top of the shell with pipes extending twelve inches below the top inconel plate. These nozzles were built using various diameter Inconel 690 pipes and allowed various types of probes such as thermowells or level detection devices to enter the melting chamber and glass pool from above. The lid was lined with two grades of Alfrax castable ceramic refractory with one inch thick ceramic fiberboard between the castable refractory and the top of the lid's inconel

shell. Ceramic fiberboard functioned as high grade thermal insulation between the inconel shell and castable refractory as well as a material that will absorb thermal growth of castable during heat up. See Figure 2 for the layout of the melter lid.

Castable was prepared and poured into the lid during melter construction. At the perimeter of the lid, castable was sixteen inches in depth. This portion of lid castable sat above and adjacent to melter refractory walls surrounding the glass pool. Castable in the center of the lid directly over the glass pool was only eleven inches in depth. Inconel brackets were welded to the bottom of the lid shell as a support for ceramic anchors. These anchors were eleven inches long, built from alumina ceramic, and had a square wave pattern along their faces to grip and support castable refractory lining the lid. Anchors along with their brackets were distributed over the lid with castable refractory poured around them. Once the castable cured and hardened, the lid was flipped over and welded to the top of the melter. There were fifteen nozzles on the melter lid: nine nozzles above the glass pool, four nozzles above the discharge chamber, one nozzle above the refractory wall, and one nozzle connected to an air cooling line. All nozzles functioned as entry locations for instrumentation, and utilities or process connections.

Examination of the nine nozzles over the glass pool revealed that they all had gone through visible deterioration or corrosion. This occurred inside the nozzles just below where they were welded to the top of the lid's shell and in some nozzles corrosion extended above the weld. Vapors produced while heating glass condensed inside these nozzles and corroded metal. The larger diameter nozzles were most susceptible to corrosion but even one small diameter nozzle had been completely corroded away from its lower twelve inch long pipe section. Larger diameter nozzles had the thinnest wall thicknesses. Lower sections of some nozzles had been completely corroded apart from the nozzle section above the shell but did not fall into the glass because they were held in place by the surrounding castable. Nozzles B, C, E, and R1 had completely corroded into lower and upper pipe sections with the upper section remaining attached to the melter lid (Refer to Figure 3). Nozzle C had corroded apart and was repaired during

melter operations but had continued to corrode at the repaired area. It was reported by Pacific Northwest Laboratory, PNL, based on their analyses from old slurry fed melters that corrosion was due to sulfidation, molten sulfur salts attack. Samples of corroded nozzles were given to vitrification process personnel for analytical confirmation. Sulfidation occurs in regions where metal temperature is between 600 and 900 centigrade which would have been below where the nozzles were welded to the lid.

Of the four nozzles over the discharge chamber, two contained permanently installed inconel pipes enclosed with castable and two were above a passage in the discharge riser blocks for installation of removable probes. The inconel pipes permanently installed inside nozzles bubbled air into the riser blocks discharge passage to lift and overflow glass into the discharge chamber. This was called airlifting. These pipes eventually plugged with cold devitrified glass and could not be used. The remaining two nozzles had removable inconel pipes which also airlifted glass into the discharge chamber and were used once the permanent pipes plugged. G1 and G2, the removable or temporary airlift nozzles, were exposed to vapors from glass moving into the discharge chamber. An examination of G1 found a glass coating at the lower section of the inconel nozzle but significantly less corrosion as seen in nozzles over the glass pool. G2, which was only used once during testing, was slightly discolored but did not have visible corrosion. Neither G1 or G2 had corrosion to the degree of the inconel nozzles over the glass pool.

Small amounts of castable from the lid above the melter chamber would at times break or spall off and fall into the glass pool. During disassembly, the lid was divided into one foot squares using a string grid and the depth of refractory below the grid was measured to determine the amount of spalling. (Refer to Figure 2) Refractory had spalled off or broken away from the lid in a somewhat random pattern. Refractory depth measurements found a maximum loss of only two inches of castable in some areas of the lid. Within one foot square grid areas across the lid refractory, there were differences of from one to one and one half inches in refractory depth. Since the ceramic anchors did not spall, they held adjacent

castable material in place resulting in only small variations in spalling depths over short distances. A diagram of refractory depths measurements across the lid is included (Diagram 1). The distance from the intersection of grid strings to refractory below it is written on the diagram. The large mass of lid castable, even with spalling, was securely held in place by anchors and brackets.

If a nozzle had corroded to the point where vapors from the glass pool could reach the fiberboard at the top of the lid, the fiberboard adjacent to the corroded portion of the nozzle had also corroded. Nozzle welds at the bottom side of the lid as well as the parent metal plate were also corroded around these nozzles. Fiberboard is an excellent insulating material but is poor for corrosion resistance; therefore, corrosion progressed through the fiberboard onto brackets supporting ceramic anchors. Brackets over the refractory wall were not corroded but some over the glass pool had corroded.

When the lid was placed over the melter, a one inch layer of fiberboard was placed into the joint between the lid refractory and the melter plenum refractory. Glass or slurry from the melting chamber had penetrated one inch into this joint except around nozzles G1 and G2. There was a noticeable glass stain around G1 and G2 at the joint that extended into the melting chamber. Fiberboard around the nozzles had corroded creating a path for glass and air to move between the discharge and melting chambers as indicated by this discoloration along the joint. (Refer to Figures 4 and 5)

MELTER PLENUM

Monofrax-H refractory blocks were used above the glass line because of their resistance to thermal shock and vapor attack from condensates from the glass pool. The plenum went through dramatic temperature changes going from a red hot radiating surface at 1100°C to a 400°C surface with a dried slurry insulating cap over the glass pool. These temperature variations of approximately 600°C occurred in relatively short periods of time but did not crack blocks in the plenum. Vapors and gases resulting from the processing of slurry and the heating

of molten glass are extremely corrosive to certain metals and refractories. Any refractory lining the plenum area of the melter was coated with condensed vapors and slurry spewed from the glass pool. Contact with these substances did not result in visible areas of extreme corrosion on the plenum blocks.

Measurements of Monofrax-H blocks removed from the melter found essentially no wear. The blocks were initially six inches in width and lost a maximum of one quarter inch during testing. The block face inside the plenum was stained brown and had a typical mosaic pattern at its surface. (Refer to Figure 6) Slurry and vapors from the glass pool coated the surface of the lid and plenum refractories and flowed down into the glass pool once the plenum area was heated. Slurry penetrated into joints between Monofrax-H blocks from one-half to one and one quarter inches. (Refer to Figure 7) There was no evidence of slurry penetrating past the joints to the refractory behind the Monofrax-H.

A passage was cut down plenum refractory blocks beneath the temporary airlift nozzles, G1 and G2, to the top of the riser blocks discharge passage. The nozzles built from inconel extended twelve inches down each passage but the remaining length was just bare refractory blocks. The passage was cut along two types of refractory, Monofrax-H and Zirmul, which sat over each riser block passage. A view down the passage is shown in Figure 10. Glass stained the passage top to bottom and penetrated into the joint between the two types of refractory blocks. The blocks at worst were only slightly worn along the passage with no glass penetration past their joints.

Two plenum blocks in the north wall were pushed out of alignment; a possible indication of buckling due to thermal expansion. Measurements that checked the dimensions and alignment of the other refractory walls which had no indications of buckling confirmed that the buckling occurred because of the removal of a thermowell imbedded in the north refractory wall.

The ledge below the Monofrax-H refractory was made from Monofrax K-3 refractory. Melter glass level was normally just below this ledge and these blocks were considered the transition between the plenum and the glass pool. Slurry or partially melted slurry from the glass pool would have reached these blocks dependent on the glass level. K-3 refractory blocks in the ledge were cracked and broken but had little evidence of wear or corrosion. Cracks were most likely a result of thermal shock since plenum temperatures can cycle in relatively short periods of time. Monofrax K-3 is not as resistant to thermal shock as Monofrax-H. Some of these blocks most likely cracked or fractured during rapid cooling resulting from glass removal at melter shut down since glass nor slurry was visible in some fractures. (See Figures 8 and 9)

Behind Monofrax-H blocks was Zirmul refractory which has intermediate glass corrosion resistance and better thermal shock resistance than the glass contact blocks. All backup Zirmul refractory in the plenum area were in good condition. Glass and slurry at the plenum area did not come in contact with these blocks and hence there was no corrosion and the blocks were intact.

MELTING CHAMBER

Monofrax K-3 and Monofrax-E refractory blocks lined the glass contact areas inside the melter with multiple layers of Zirmul refractory behind them. Glass penetrated between joints of glass contact refractory blocks and in some areas reached the layer of Zirmul blocks behind and adjacent to the glass contact blocks. Since temperatures decreased moving away from the glass pool, glass solidified after it moved a certain distance into the joints. Only small amounts of glass penetrated refractory joints as indicated by glass stains on the face of Zirmul refractory blocks rather than bulk accumulations. The only areas in the melter chamber where glass had accumulated rather than staining the refractory was along the sidewall electrodes. Sidewall electrodes were enclosed on five of six faces by refractory and were bowed slightly along their length. Neither sidewall electrode sat flush against Zirmul blocks at its back face because of the bowing. This resulted in small gaps which glass puddles eventually filled.

The stem end of the electrodes went through circular holes in the melter shell and were connected to electrical power cables. A ceramic grout was packed around the stem where it passed through the circular hole in the melter shell for electrical isolation. All three electrode stems changed from rectangular to circular cross sections before they reached the melter shell. This area of the electrode did not sit flush against its surrounding refractory which created small gaps. Any gaps between electrodes and refractory blocks near the glass pool were filled with glass. Refractories adjacent to glass accumulations at the back face of the electrode and along its stem were not severely corroded; therefore, the glass in these gaps was relatively cold.

A layer of sludge approximately two inches in depth covered the bottom electrode. This sludge was apparently electrically conductive at high temperatures since this electrode was still in use at the shut down of the SFCM. Samples of the sludge are being analyzed but it is assumed to be a combination of glass precipitates and refractory corrosion products.

A visual examination of the three electrodes found no major problems. The sidewall and bottom electrodes had sharp corners along their faces indicating little wear or corrosion. There were small nick marks, approximately a half inch long, on the electrode face and the sidewall electrodes were bowed as previously mentioned. But the marks were made during disassembly and the bow was a result of fabrication. Electrodes were turned over to vitrification process personnel for further examination.

Dimensions of the melting chamber and glass contact refractory blocks were measured and compared to the their initial dimensions. Diagram 2 gives the distance from the top of a grid over the melting chamber to the refractory below it. This data confirmed that the melting chamber dimensions were essentially the same as they were before testing began and that there was a two inch build up of sludge over the bottom electrode. Monofrax K-3 blocks which lined the majority of the melting chamber had little wear, were intact and in place with no large fractures. Most K-3 blocks had worn at most one eighth of an inch. The only

significant refractory corrosion occurred in the north and south walls on blocks at the glass/slurry interface. This corrosion, characteristic of a glass line cut, did not occur at the east or west walls because sidewall electrodes not refractory were in these walls. A maximum of one half inch of refractory had been worn away at the center of these blocks resulting in a concave or "C" shape along the glass contact face. These blocks were originally six inches in width. (Refer to Figure 12)

The riser blocks which channeled glass into the discharge chamber and canisters were built from Monofrax-E refractory. There were two Monofrax-E blocks, the east and west discharge riser blocks. The east discharge block had only been used once during testing. Each riser block had a cylindrical passage drilled through it which glass would move to the discharge chamber. Measurements found that dimensions of each Monofrax-E block including the passage were unchanged after five years of operation. Also, there was no measurable wear at the surface of these blocks where a glass line cut would have occurred as it did with adjacent Monofrax K-3 blocks. Inside the passage there was an accumulation of glass or a sludge which rounded any corners. Figure 13 shows one riser block cut in half with accumulations of this material at corners and at the entrance of the passage. Samples of this material have been collected for analyses. Both riser blocks were intact at the start of removal but later broke into three sections. No glass was found on the surfaces between the broken sections which indicated that these fractures occurred during disassembly but both blocks fractured with the same pattern indicating a preference for this block to break in this configuration. (Refer to Figure 14)

During the removal of refractory blocks from the melting chamber, each block was visually examined for glass penetration between joints. A glass path between the glass pool and the melter shell would have caused an electrical short. As previously mentioned, glass did not migrate past the first layer of Zirmul refractory adjacent to the glass contact refractory; therefore, no path for an electrical short was found. Ceramic grout used as the electrical isolation material between the electrode stem and the melter shell was also examined for

indications of an electrical short. There were no indications of an electrical short in or around the area between the electrode stem and melter shell.

MELTER DISCHARGE CHAMBER

The melter discharge chamber was built from Alfrax castable and was in excellent condition after melter shutdown. Refractory had not cracked, there was no noticeable corrosion, and no evidence of spalling. Electrically powered radiant heaters rested in the top of the discharge cavities and during operations kept this area above 1150°C. The west discharge cavity was used primarily during testing for glass removal. The refractory wall separating melting chamber from discharge chamber had an inconel dam cast into it and the trough which channelled glass from the exit of the riser block into the discharge cavity was welded to the dam. The west discharge trough was built from Inconel 690 while the east discharge trough was built from Monofrax-E refractory. A major concern in the design of the discharge area was the prevention of glass leaks around the dams and troughs. A visual examination of the area found no glass leaks around or through the troughs or dams.

High temperatures in the west discharge cavity had partially melted the inconel trough, but it was still used after being damaged. Except for the obvious damage from melting, there was no indication of a problem with the trough. The east discharge trough which was built from refractory was intact with no indications of wear but it had been used only once during testing. There were air cooling lines around the perimeter of the dams and beneath the east refractory trough to cool and solidify any glass that may have flowed around them. Both cooling lines were imbedded in castable refractory and were in good condition showing no corrosion. It is important to note that glass had not come into contact with the cooling lines since there was no glass penetration into or around the castable.

CONCLUSIONS

The following conclusions can be made about the condition of the SFCM after five years of operation.

(1) Corrosion of melter lid nozzles was the major problem that resulted from five years of melter operation. This occurred inside nozzles just below where they were welded to the top of the lid and was found in every nozzle above the glass pool. Lower sections of nozzles that had corroded in half were securely held in place by the lid castable.

(2) All three electrodes were in good condition and had no visual indications of major wear or corrosion. Both sidewall electrodes bowed slightly along their length as a result of fabrication not melter operation. The bottom electrode was covered by a two inch layer of an electrically conductive sludge and there were accumulations of glass in areas where the sidewall electrodes did not sit snugly against its surrounding refractory.

(3) Both Monofrax-E riser blocks were in excellent condition. Neither had measurable wear either inside their airlift passage or at their exterior.

(4) Small amounts of lid refractory had spalled away and fallen into the glass pool but ceramic anchors securely held the bulk of the refractory in the lid. These anchors were not fractured or corroded nor did they show any evidence of spalling. Brackets holding the anchors in place over the glass pool were in some cases corroded by vapors and condensate from the glass pool.

(5) There was no glass path through refractory blocks causing a electrical short to the melter shell. Glass solidified in refractory joints as it moved away from the glass pool before reaching the melter shell.

(6) The discharge chamber including dams, troughs, and cooling coils were in excellent condition. Refractory in the discharge chamber was not cracked and had not spalled from walls. The west discharge trough had been damaged during testing but was still used until shutdown. The east trough, the two dams, and the cooling coils were not damaged and were used until the end of testing.

(7) The fiberboard seal between the melter plenum and lid refractories around nozzles G1 and G2 had corroded away creating a path for air to move between the discharge and melting chambers.

(8) There was minimal corrosion on glass contact refractories inside the melter. Most wear occurred with glass contact Monofrax K-3 blocks at the sidewall electrodes depth in the north/south walls. This was a glass line cut which corroded away a maximum of one half inch of refractory resulting in a "C" shaped face on the blocks.

DIAGRAM 1

MELTER GRID SPALLING DEPTH MEASUREMENTS

2.81	2.44		2.88	2.63	2.88		2.75
2.88	6.75	8.25	6.94	8.33	7.81	7.50	5.56
2.88	7.00	9.13	9.75	9.50	7.88	7.44	4.94
2.88	6.00	9.50	8.75	8.50	9.69	8.44	4.88
2.81	6.25	8.38	8.19	9.06	8.94	7.25	5.88
2.88	6.88	7.06	6.94	7.88	7.75	6.88	5.44
2.91	2.75	2.81	2.75	2.63	2.81	2.81	2.94

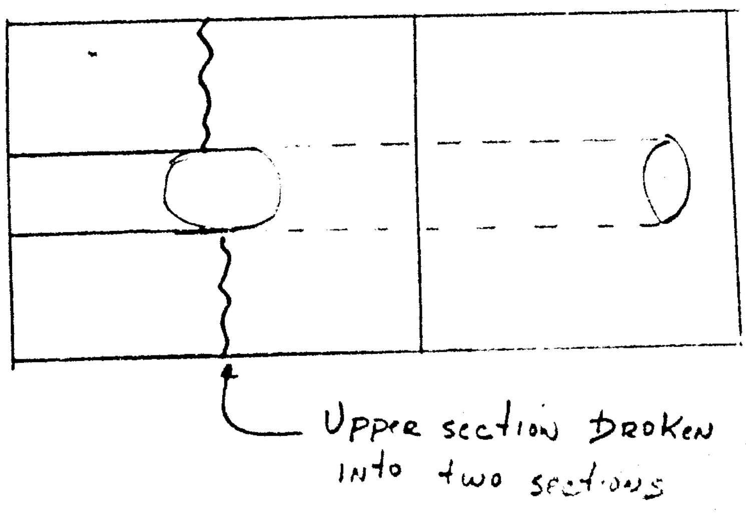
Values represent depth of refractory in inches below the grid.

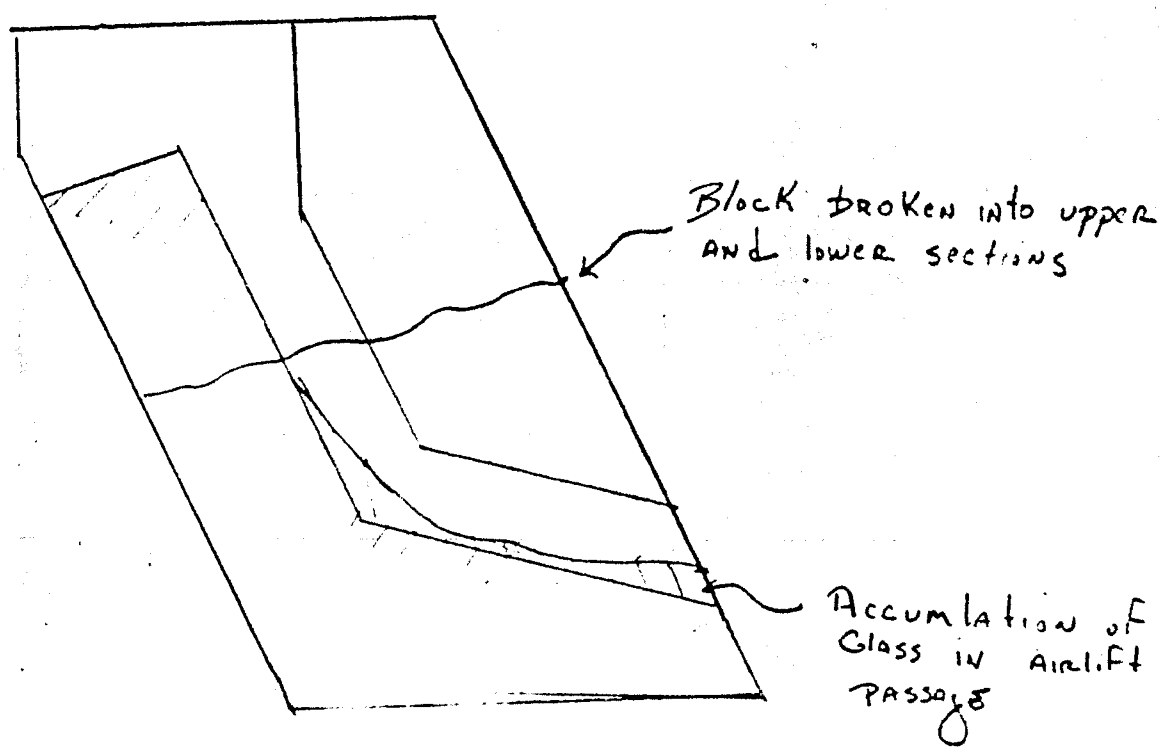
DIAGRAM 2

MELTER CHAMBER DEPTH MEASUREMENTS

24.8	23.50	23.75	23.75	23.75	23.75	24.0
24.0	48.0	52.75	54.50	55.50	49.50	24.0
24.0	48.0	54.50	55.50	55.25	37.50	23.75
23.75	47.75	53.50	55.0	55.0	48.50	23.75
24.5	39.0	30.75	39.13	39.50	39.38	24.0

DIAGRAM 3
MONOFRAX-E BLOCK FRACTURE PATTERN





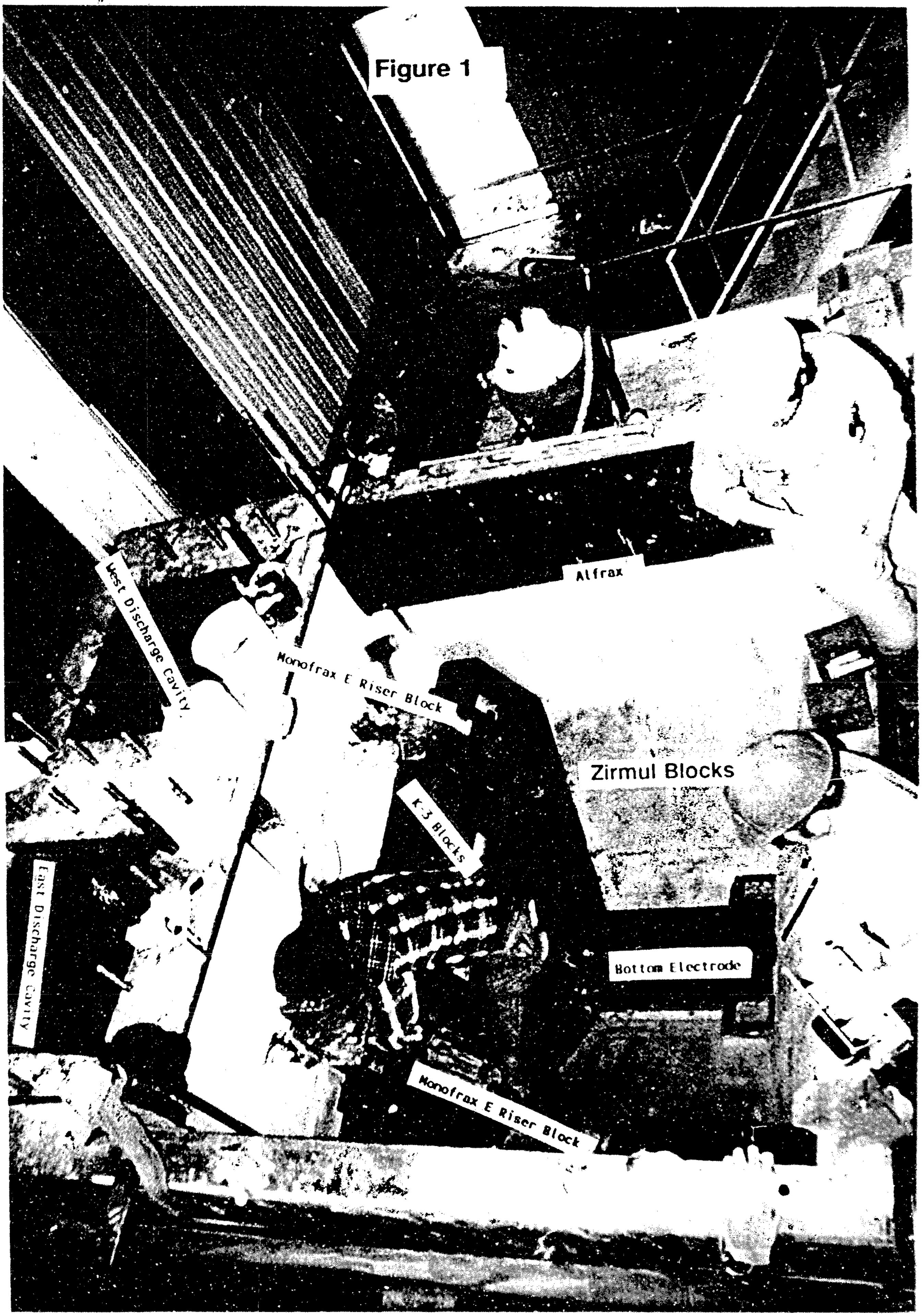


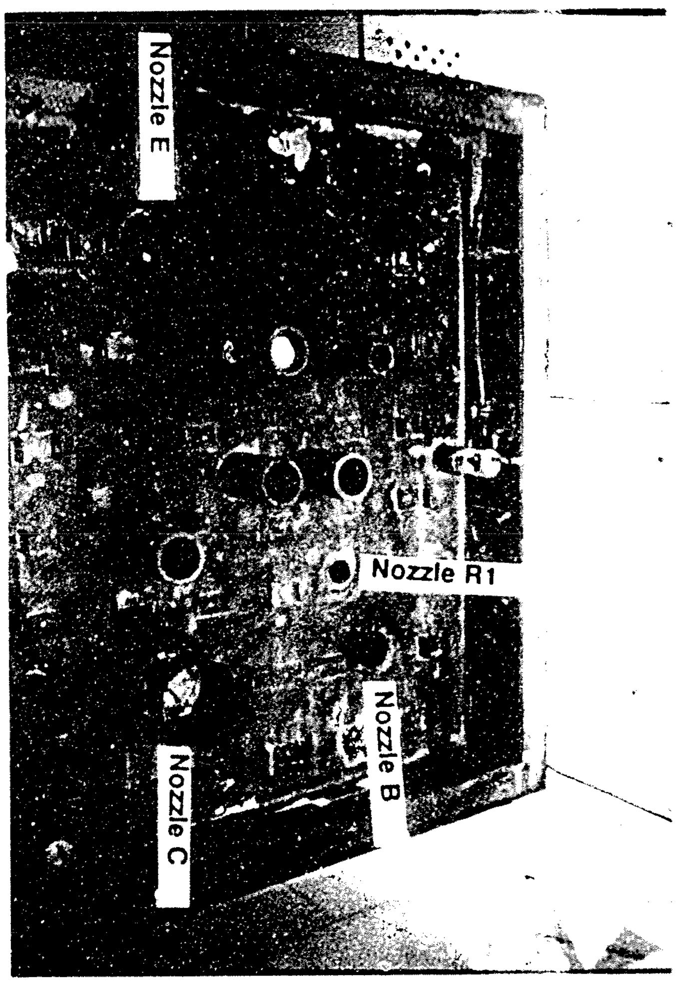
Figure 1
Alfrax
West Discharge Cavity
Monofrax E Riser Block
Zirmul Blocks
K-3 Blocks
East Discharge Cavity
Bottom Electrode
Monofrax E Riser Block

FIGURE 2
MELTER LID PRIOR TO REFRACTORY REMOVAL

Figure 2

Melter Lid flipped over
refractory side-up

FIGURE 3
MELTER LID AFTER REFRACTORY REMOVAL



Melter Lid

Figure 3

FIGURE 4
MELTER LID NOZZLES C, D, AND G1

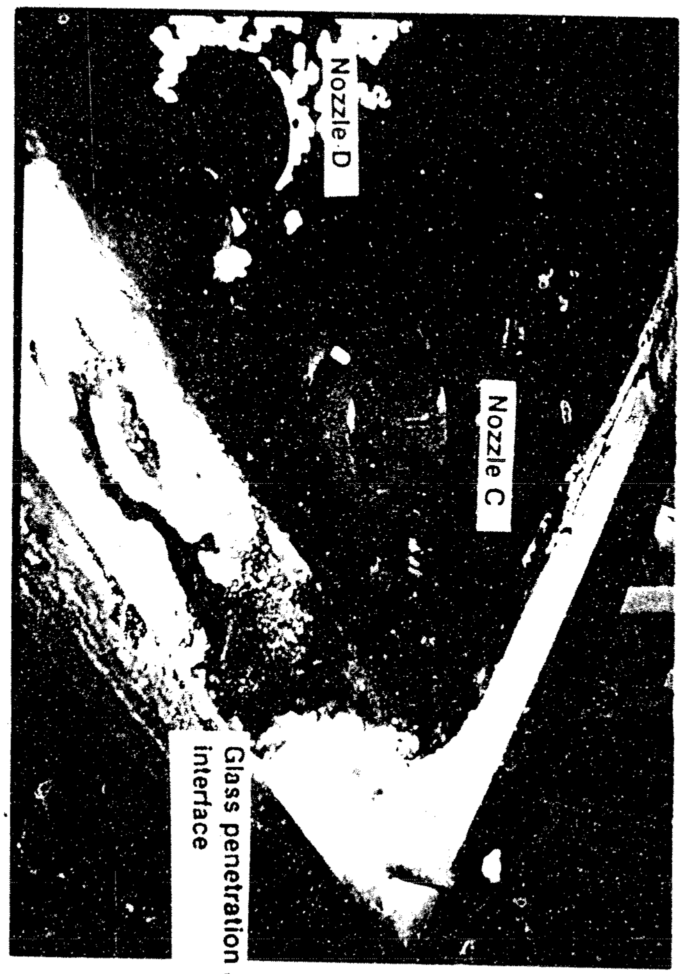


FIGURE 5
MELTER LID WITH GRID FOR DEPTH MEASUREMENTS

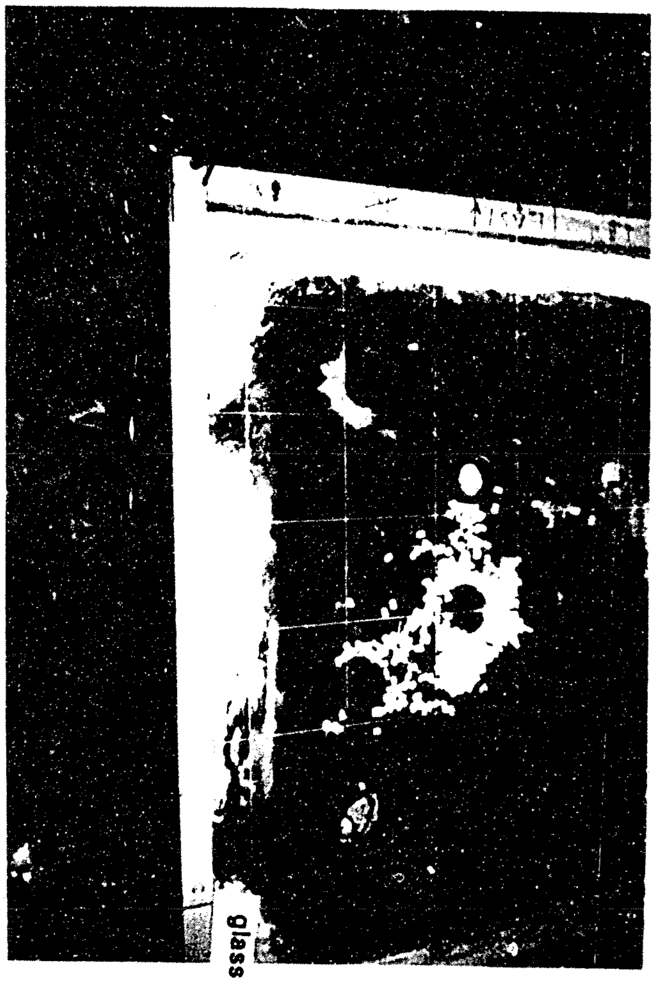


FIGURE 6
SFCM PLENUM

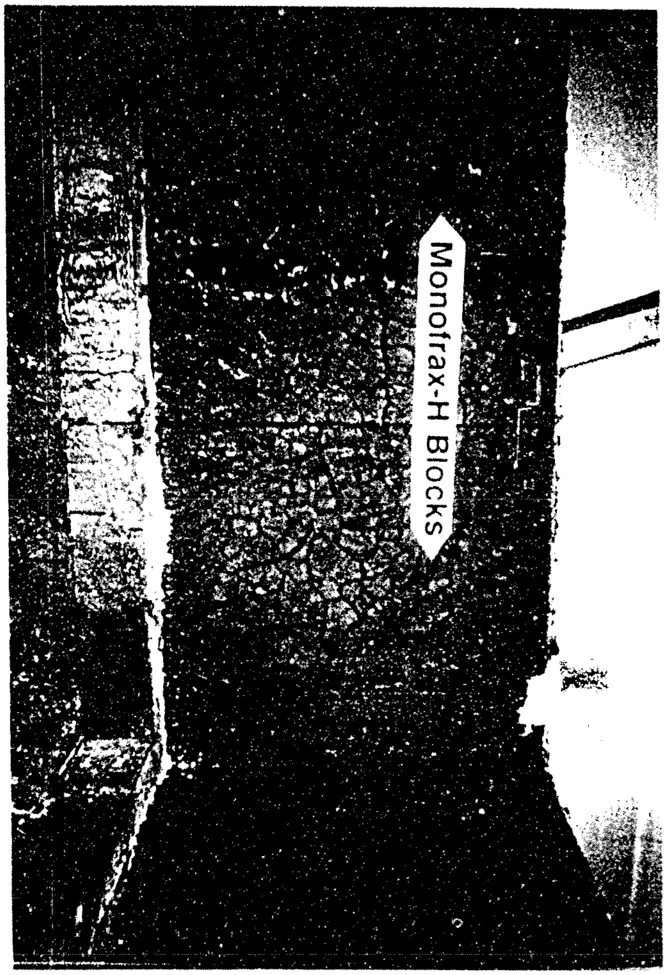


Figure 6

FIGURE 7
MONOFRAX-H BLOCK AFTER REMOVAL

Figure 7

Glass and slurry penetration in
joints of Monofrax-H blocks

FIGURE 8
MONOFRAX K-3 BLOCKS IN THE LEDGE

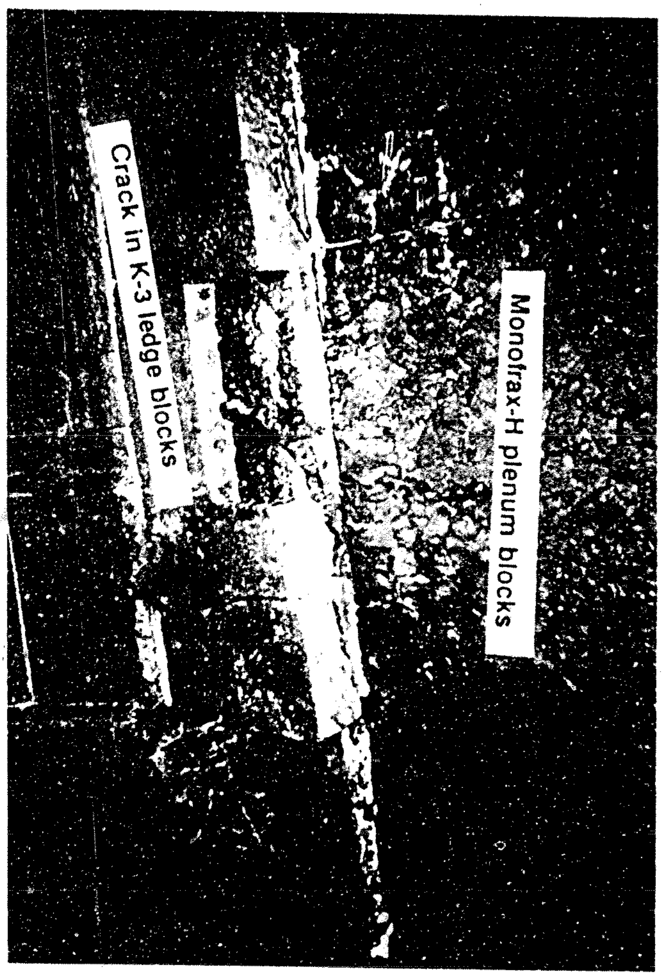
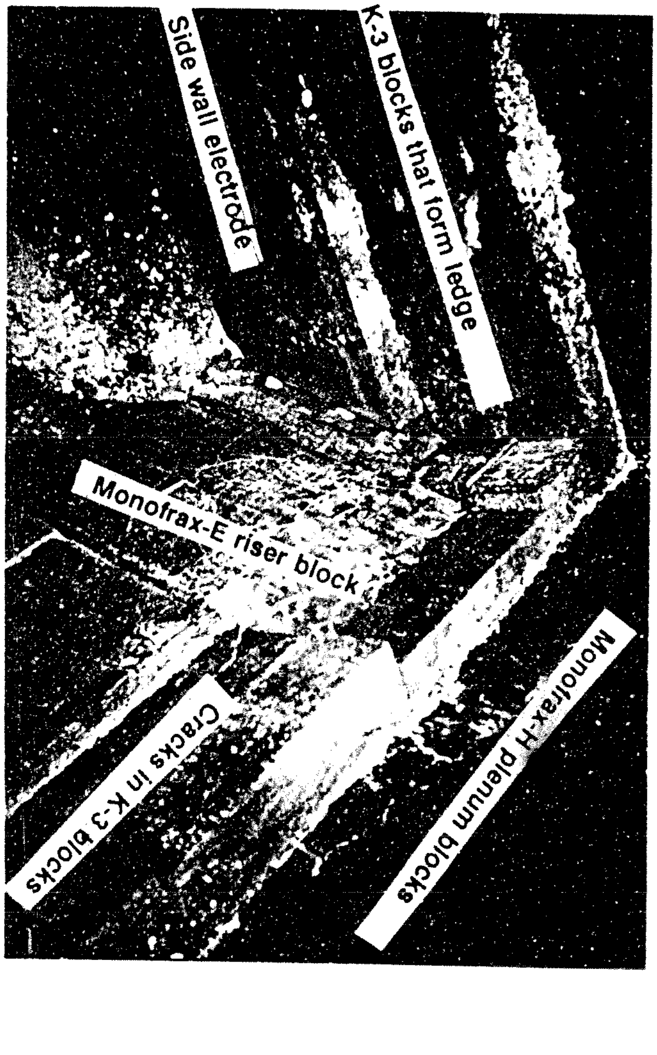


Figure 8

FIGURE 9
GLASS CONTACT MONOFRAX K-3 BLOCKS IN SOUTH WALL



Melter Cavity Northwest Corner

Figure 9

FIGURE 10
REFRACTORY AREA OF NOZZLE G1

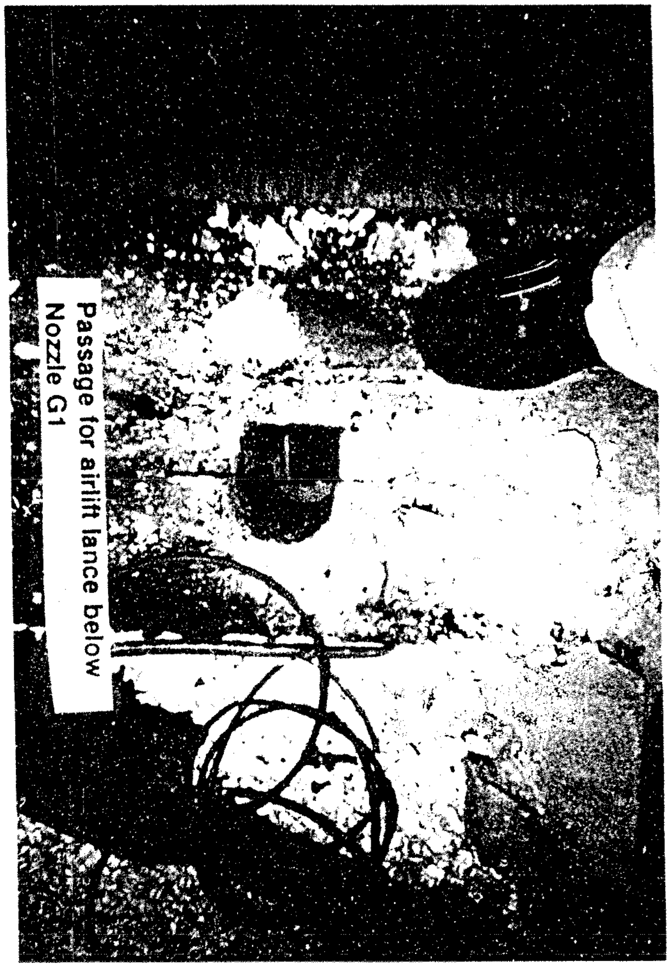
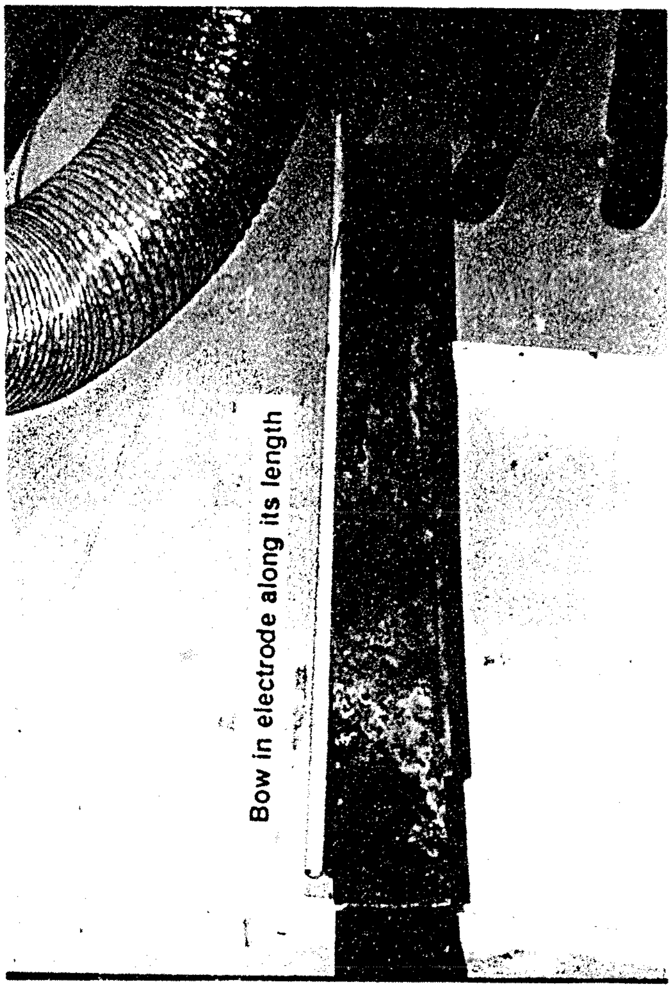


Figure 10

Figure 11

WEST SIDEWALL ELECTRODE



Side wall electrode

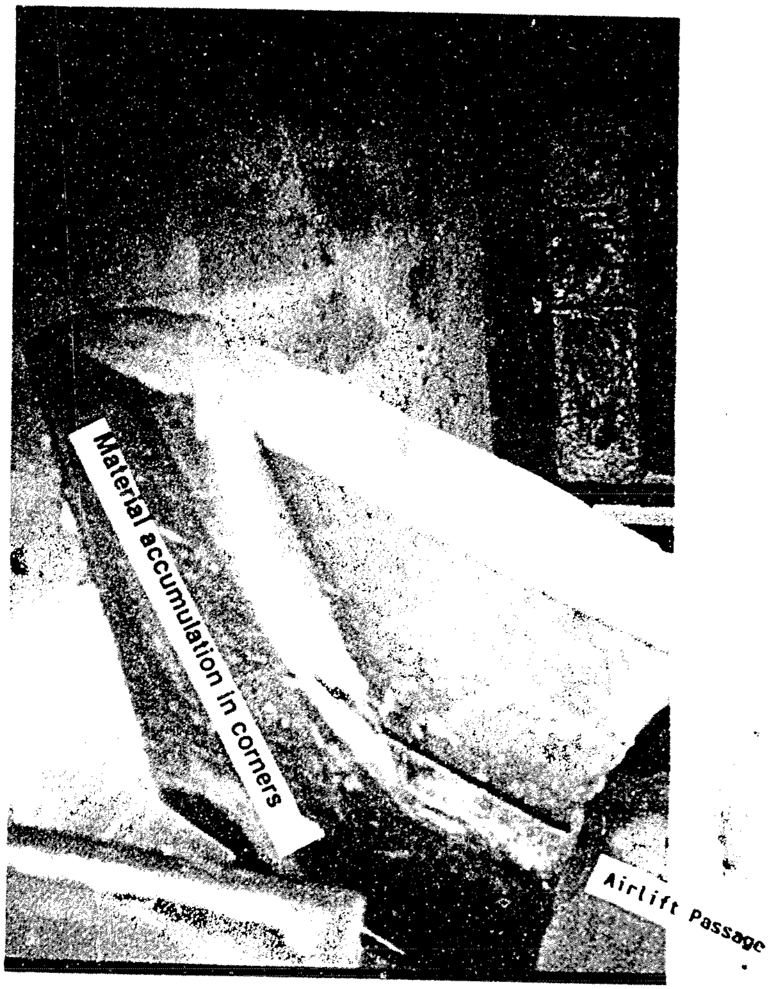
FIGURE 12
BOTTOM ELECTRODE AND NORTH WALL K-3 BLOCKS

Melter North wall

Figure 12

FIGURE 13
MONOFRAX-E BLOCK SECTIONED IN HALF

Figure 13



Monofrax-E Riser block split in half