FINAL INSPECTION REPORT

OF

PRIMARY REFERMER FURNACE 101-B

RISER AND CATALYST TUBES

NORTH COMPANY FOR FERTILIZERS (NCF)-BAIJI

1. INTRODUCTION

On 20th May 2006 North Company for Fertilizers (NCF) requested has AL-ROOKAL Co. to visit NCF processing plant in Baiji for the purpose of preliminary inspection to the Primary reformer furnace 101B which has riser tube "A" ruptured during operation. On 23rd May 2006 ourpresentative visited the site and a mutual side visit was carried out to the said facility to decide the required inspection and NDT/NDE program to be performed upon. From 28th April to 8th May 2006 our technical team were in site to perform Inspection and NDT/NDE of the primary reformer 101-B and to determine the real cause of failure and its mechanism and give recommendation regarding the safe use of the remaining riser tubes. we decided with the approval of NCF to carry out laboratory testing and examination on samples taken from the failed tube.

It is concluded that the failure was caused by sharp reduction in the ductility due to micro-structural changes in the tubes material. IT is recommended that all the riser tubes are not suitable for further use and the replacement is a necessity for the safe operation of the reformer.

2. FURNACE SPECIFICATIONS (taken from Kellogg Engineering Drawings)

ITEM	CATALYST TUBES	RISER TUBES	MIXED FEED	STEAM AIR
Design press.	34.8 Kg/cm seq.	32.25 Kg/cm seq.	41.50 Kg/cm seq.	38 Kg/cm seq.
Design fluid temp.	-	-	538 deg. c	524 deg.c
Working medium	Natural gas	Natural gas		
Number of passes	312	6	17	5
Over all tube length	10900 mm	10900 mm	13340 mm	13340 mm
Effective tube length	10290 mm	10290 mm	12858 mm	12858 mm
Total exposed surface	1114.9 m seq.	28.7 m seq.	279.1 m seq.	138.6 m seq.
Max. Tube wall design temp.	902 deg. c	922 deg. C	629 deg. c	582 deg. c
Max. Tube wall calculated temp.	872 deg. C	921 deg. C	601 deg. C	570 deg. c
Material specification (ASTM)	HP 50 MOD. 25%Cr, 35%Ni, 1.3%Nb, 0.4%C	HP 50 MOD. 25%Cr, 35%Ni, 1.3%Nb,0.4%C	A 213 T22	A 335 P22
Tube size	86.5mm ID x 12mm thk.	119mm ID x 15mm thk.	101.6mm O.D	112mm O.D
Design basis	MW Kellogg co.	MW Kellogg co.	API RP 530	API RP 530

3. PROPOSED INSPECTION PROGRAM BY NCF

During AL-Rook Co. representative visit to the site NCF inspection department proposed the following inspection program:

- UT examination to twelve (12) randomly selected welds on the riser tubes.
- Micro-examination to the riser tubes outside surfaces by replication 25 areas.

4. PROPOSED INSPECTION PROGRAM

After the preliminary inspection performed by our representative to the site the following inspection program was proposed to have a comprehensive picture about the reformer condition after the rupture especially the rest riser tubes “B” to “F” in addition to the catalyst tubes condition:

- Visual inspections to the ruptured riser tube “A” and the rest tubes.
- Micro-examination by replicas to the ruptured tube outside surface and through section In addition to the rest riser tubes for investigation of phase transformation or micro-structure changes due to high temperatures. Replication agreed to be at the tubes surfaces close to the burner flame dome, 2.5 m from the furnace top section.
- UT examination using attenuation technique to the riser tubes walls for investigation of tubes metal failure.
- UT thickness measurements for investigation of internal condition.
- Hardness measurements to the tubes outside surfaces and through section on the ruptured tube.
- Diametrical growth measurements to the tubes for the investigation of creep along the tubes length. **This activity was performed by NCF inspection staff.**
- Mechanical testing (bending and tensile) to the ruptured tube at the vicinity of rupture for investigation of the tubes strength and possibility of brittleness occurrence.

5. INSPECTION FINDINGS

From 28th May to 8th June 2006 the above mentioned inspection activities were performed by technical team. The following findings were observed:

➢ Visual inspection

Visual inspection to the ruptured tube and the rest riser tubes (see the attached photos No. 1, 2, 3& 4) revealed the following:

- No indication of tubes over heating.
- No indication of flame impingement.
- No indication of bulging especially in the ruptured area.
- Riser tube "F" showed an indication of crack on the external surface.
- No indication of necking and thinning in the tube wall at the ruptured area.
- Riser tubes seemed to be subjected to some extent of deflection from the longitudinal axis of the tube may be due to excessive stresses.
- Riser tube "A" (the ruptured one) inside surface showed a thin layer of carburization.
- No indication of corrosion in the tube "A" inside surface.
- The failure occurred due to a longitudinal crack of 1.25 m long.
- The appearance of the crack section is vitreous similar to the brittle failure.
- Increase in diameter as revealed by the diametrical measurements.

➢ Replication

A. Micro-examination by replicas to the riser tubes 6 no.s revealed the following:

- **Tube "A" new tube operation period 0.0 hours.**

  Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains. See photo no. 5 and report no. 03/2006.

- **Tube "A" ruptured tube** (on the surface & through section)

  Replica on the tube outside surface revealed the following:

1. Inter-granular carbides precipitation (agglomeration) on the grain boundaries associated with micro -cracks.
2. Some degree of grain growth due to ageing. See photos no. 6 &7 and report no. 04/2006.
3. Formation of sigma phase (σ- phase) which is brittle in nature.

- **Tube "B"**

  Replica on the tube outside surface revealed the following:
  1. Carbides precipitation (agglomeration) on the grain boundaries.
  2. Some degree of grain growth due to ageing. See photos no. 8 &9 and report no. 05/2006.

- **Tube "C"**

  Replica on the tube outside surface revealed the following:
  1. Carbides precipitation (agglomeration) on the grain boundaries.
  2. Some degree of grain growth due to ageing. See photos no. 10 &11 and report no. 06/2006.

- **Tube "D"**

  Replica on the tube outside surface revealed the following:
  1. Carbides precipitation (agglomeration) on the grain boundaries.
  2. Some degree of grain growth due to ageing. See photos no. 12 &13 and report no. 07/2006.

- **Tube "E"**

  Replica on the tube outside surface revealed the following:
  1. Carbides precipitation (agglomeration) on the grain boundaries associated with micro -cracks.
  2. Some degree of grain growth due to ageing. See photos no. 14 &15 and report no. 08/2006.

- **Tube "F"**

  Replica on the tube outside surface revealed the following:
  1. Carbides precipitation (agglomeration) on the grain boundaries (with micro –cracks)
  2. Some degree of grain growth due to ageing. See photos no. 16 &17 and report no. 09/2006.

B. Micro-examination by replicas to the catalyst tubes 5 no.s revealed the following:

- **Tube N0.26 row "A"**

  Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains with some degree or grain growth due to ageing. See photo no. 18 and report no. 10/2006.

- **Tube No.27 row "A"**

  Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains with some degree or grain growth due to ageing. See photo no. 19 and report no. 11/2006.

- **Tube No.26 row "F"**

Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains with some degree or grain growth due to ageing. See photo no. 20 and report no. 12/2006.

- **Tube No.27 row "F"**

  Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains with some degree or grain growth due to ageing. See photo no. 21 and report no. 13/2006.

- **Tube No.41 row "B"**

  Replica on the tube outside surface revealed a net work of primary eutectic carbides between the austenite grains with some degree or grain growth due to ageing. See photo no. 22 and report no. 14/2006.

➢ **UT examination**

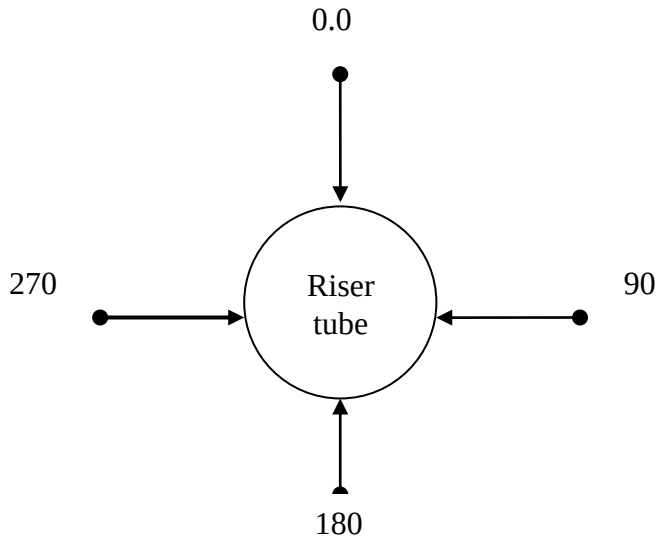
In accordance to UT examination using straight beam probe for attenuation technique the tubes were graded to the following grades:

- Grade "A" no failure in the tube metal.
- Grade "B" small failure in the tube metal.
- Grade "C" moderate failure in the tube metal.
- Grade "D" large failure in the tube metal.

Attenuation technique procedure required the following:

- ❖ UT flaw detector pulse-echo USK 7S Krautkramer Branson type.
- ❖ Single crystal probe 4.0 MHz, 15 mm diameter.
- ❖ Smoothening of the examined areas by removing the surface peaks only.

Examination was performed by scanning of four right angled areas (50 mm width X 500 mm long) on each riser tube as shown below. These areas located on the tubes surfaces at the vicinity of the flame dome (furnace top section) especially the tube section subjected to the largest diametrical growth.



UT examination results were as follows:

- **Riser tube "A". New tube 0.0 hours operation period.**

  UT echoes revealed that the tube metal is of grade "A". See photo no.23 and report no. 25/2006.

- **Riser tube "A". Ruptured tube**

  UT echoes revealed that the tube metal is of grade "D". See photo no.24 and report no. 26/2006.

- **Riser tube "B"**

  UT echoes revealed that the tube metal is of grade "C". See photo no.25 and report no. 27/2006.

- **Riser tube "C"**

  UT echoes revealed that the tube metal is of grade "C". See photo no.26 and report no. 28/2006.

- **Riser tube "D"**

  UT echoes revealed that the tube metal is of grade "D". See photo no.27 and report no. 29/2006.

- **Riser tube "E"**

  UT echoes revealed that the tube metal is of grade "D". See photo no.28 and report no. 30/2006.

- **Riser tube "F"**

  UT echoes revealed that the tube metal is of grade "D". See photo no.29 and report no. 31/2006.

- **UT thickness measurements.**

Thickness measurements procedure required the following:

- ❖ UT thickness meter pulse-echo DM4 Krautkramer Branson type.
- ❖ Single crystal probe 2.5 MHz, 10 mm diameter.
- ❖ Smoothening of the examined areas by removing the surface peaks only.

Thickness measurements results were as follows:

- **Riser tubes "A". New tube 0.0 hours operation period.**

  Thickness measurements values were 15.2-15.4 mm in average against **15 mm** original.

- **Riser tube "A". Ruptured tube.**

  Thickness measurements values (as attached in the table) on the tube rupture vicinity revealed some degree of thickness reduction due to diametrical enlargement only not due to internal corrosion as visual inspection revealed.

Points from the tube top section	Thickness value mm	remarks
1	14.7	
2	14.3	
3	13.8	
4	13.6	
5	13.3	
6	13.2	**2.5 m from the top section. Area of max. Increase in diameter**.
7	13.4	
8	14.1	
9	14.3	
10	14.4	
11	14.8	

- **Riser tube "B"**

  Thickness measurements values (as attached in the table) revealed some degree of thickness reduction due to diametrical enlargement.

Points from the tube top section	Thickness value mm	remarks
1 ▪	13.9	
2 ▪	13.9	
3 ▪ ▪	13.4	**2.5 m from the top section. Area of max. Increase in diameter.**
4 ▪	13.9	
5 ▪	13.9	
6	13.8	▪
7	14.1	▪
8	14.3	▪
9	14.7	▪
10	14.7	▪
11	14.8	▪

- **Riser tube "C"**

  Thickness measurements values (as attached in the table) revealed some degree of thickness reduction due to diametrical enlargement.

Points from the tube top section	Thickness value mm	remarks
1	14.1	
2	14.0	**2.5 m from the top section. Area of max. Increase in diameter.**
3	13.9	
4	14.3	
5	14.4	
6	14.7	
7	14.7	
8	14.4	
9	15.6	
10	15.5	
11	-	

- **Riser tube "D"**

  Thickness measurements values (as attached in the table) revealed some degree of thickness reduction due to diametrical enlargement.

Points from the tube top section	Thickness value mm	remarks
1	14.1	
2	14.1	**2.5 m from the top section. Area of max. Increase in diameter.**
3	14.1	
4	14.8	
5	14.6	
6	14.9	
7	15.2	
8	15.3	
9	15.1	
10	15.0	
11	-	

- **Riser tube "E"**

  Thickness measurements values (as attached in the table) revealed some degree of thickness reduction due to diametrical enlargement.

Points from the tube top section	Thickness value mm	remarks
1	14.4	
2	14.3	**2.5 m from the top section. Area of max. Increase in diameter.**
3	14.3	
4	14.5	
5	14.5	
6	15.1	
7	14.7	
8	15.1	
9	14.7	
10	15.4	
11	-	

- **Riser tube "F"**
  Thickness measurements values (as attached in the table) revealed some degree of thickness reduction due to diametrical enlargement.

Points from the tube top section to the bottom	Thickness value mm	remarks
1	14.2	
2	13.8	**2.5 m from the top section. Area of max. Increase in diameter.**
3	14.2	
4	14.2	
5	14.6	
6	14.6	
7	15.2	
8	15.0	
9	14.9	
10	14.9	
11	-	

- **Hardness measurements**

Hardness measurements procedure required the following:

- ❖ Hardness values are average of five measurements.
- ❖ Measurements have been taken on smooth ground surfaces.
- ❖ Eqoutip II hardness tester used for this purpose.

Tube No.	Location	Hardness value HB	Remarks
A / new	Outside surface	224-238	Unreachable cross Section
A / ruptured	Outside surface	167- 175	
A / ruptured	Inside surface	139-144	
A / ruptured	Through section	159-162	
B	Outside surface	170	Unreachable cross Section
C	Outside surface	167	Unreachable cross Section
D	Outside surface	165	Unreachable cross Section
E	Outside surface	162	Unreachable cross Section
F	Outside surface	160	Unreachable cross Section

It is concluded that no sharp increase or decrease in the hardness indicating no formation of martensite this confirmed by the micro-structure. Hardness of the new material is much higher indicating that the sample is not a genuine sample.

➢ Diametrical Growth Measurements

This activity have been done by NCF inspection staff and confirmed by AL-ROOKAL co. technical team. Diametrical values were as follows:

- **Riser tube "A". ruptured**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical increment %
1	149.84	0.5
2	151.91	1.9
3	153.06	2.7
4	153.98	3.3
5	155.3	4.2
6	155.96	4.6
7	153.78	3.2
8	152.85	2.5
9	150.98	1.3
10	149.85	0.5
11	149.56	0,43

- **Riser tube "B"**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical increment %
1	150.85	1.2
2	151.01	1.3
3	152.02	2.02
4	152.18	2.13
5	152.25	2.18
6	151.72	1.81
7	151.27	1.52
8	150.57	1.05
9	150.38	0.92
10	149.73	0.24
11	150.08	0.72

- **Riser tube "C"**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical increment %
1	150.68	1.12
2	151.07	1.38
3	151.25	1.51
4	150.47	1.0
5	150.15	0.77
6	149.85	0.5
7	149.80	0.5
8	149.69	0.46
9	149.58	0.38
10	149.38	0.25
11	-	-

- **Riser tube "D"**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical increment %
1	150.47	0.98
2	151.77	1.85
3	151.16	1.44
4	150.30	0.87
5	150.32	0.87
6	149.68	0.45
7	150.17	0.78
8	149.73	0.48
9	149.68	0.45
10	-	-
11	-	-

- **Riser tube E"**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical increment %
1	149.95	0.63
2	151.16	1.44
3	151.29	1.53
4	150.92	1.28
5	150.53	1.02
6	150.24	0.83
7	150.30	0.87
8	150.73	1.16
9	149.89	0.59
10	150.17	0.78
11	-	-

- **Riser tube "F"**

Points from the tube top section to the bottom	Actual O.D mm 149mm original O.D	Diametrical enlargement increment %
1	151.43	0.95
2	153.53	3.04
3	152.46	2.32
4	151.12	1.42
5	150.47	0.98
6	150.14	0.76
7	150.33	0.89
8	150.27	0.85
9	150.10	0.73
10	149.90	0.60
11	-	-

It is concluded that that the tubes were subjected to a creep of various degrees in different locations.

➢ PMI INSPECTION

PMI inspection was carried out to check the chemical composition of the ruptured tube and it appears that the chemical composition is different from Kellogg specification.

➢ Mechanical testing

To determine the micro-structure changes influence on the riser tubes mechanical properties AL-Rook Co. recommend to perform the following mechanical testing to the ruptured tube:

- Tensile test to the area opposite to fracture. One test specimen.
  Tensile test specimen was broken during the machining showing brittle nature fracture. See photo no. 30. the tube was abandoned
- Bending test to the area at vicinity of the fracture. Tow test specimens.
  Bending test specimens have failed in the test showing brittle nature fracture. See photo no. 31.

6. RESULTS ANALYSIS AND CONCLUSIONS

Results of the destructive and non-destructive testing (DT &NDT) performed gave us the following conclusions:

- Riser tube "A" failure occurred due to micro-structure changes caused by long time exposure of the tube metal to the sever operation condition in addition to the repeated emergency shut downs(cyclic thermal shocks) which accelerated the micro-structure changes mentioned earlier.
- Micro-structure changes characteristics were as follows:
  - Grain growth compared to the new metal grain size.
  - Carbides precipitation on the grain boundaries.
  - Formation of sigma phase (σ – phase) which is brittle in nature.
  - Creep damage in form of diametrical enlargement.

- The micro-structure changes were accompanied with remarkable changes in the metal mechanical properties in form of acute reduction rate in the elasticity and transformation of the alloy nature from ductility to brittleness.

7. RECOMMENDATION

A. **All the riser tubes exposed to the same operation conditions might be subjected to the same type of failure in the future operation period, therefore AL-Rook Co. recommend replacing the riser tubes all by new ones of the same specifications.**

B. **Measures should be taken to avoid occurrence of emergency shut downs in the future.**

C. **Reformer catalyst tubes should be observed closely during the coming operation period for hot spots and over heating occurrence.**

D. **The new tubes should be inspected after a specific operation period or in accordance to the designer recommendations for investigation of the metal micro-structure changes and creep phenomenon to avoid explosion of riser tubes in the future.**

PHOTO No. 1 RUPTURED TUBE "A"

PHOTO No. 2 RUPTURED TUBE "A"

PHOTO No. 3 RUPTURED TUBE "A" SECTION

PHOTO No. 3 RUPTURED TUBE "A" SECTION

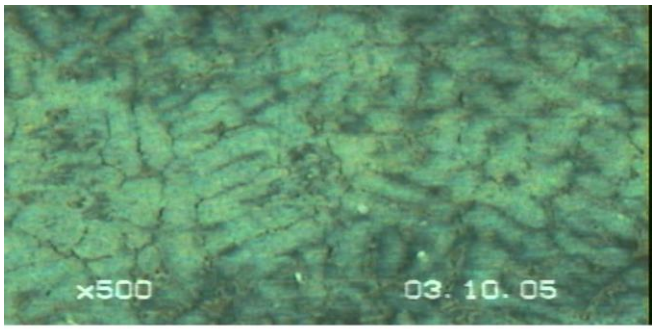


PHOTO No. 5 NEW RISER TUBE "A" MICRO-STRUCTURE

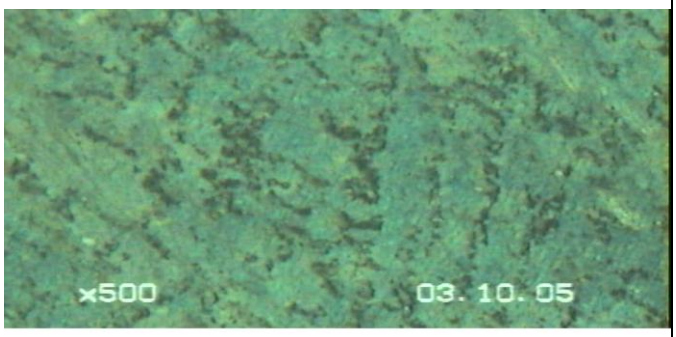


PHOTO No. 6 RUPTURED RISER TUBE "A" MICRO-STRUCTURE

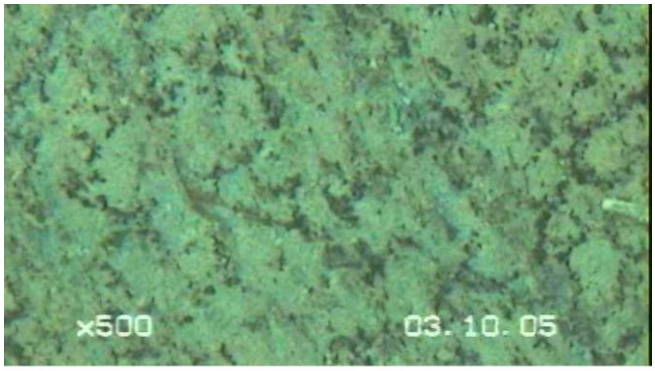


PHOTO No. 7 RUPTURED RISER TUBE "A" MICRO-STRUCTURE

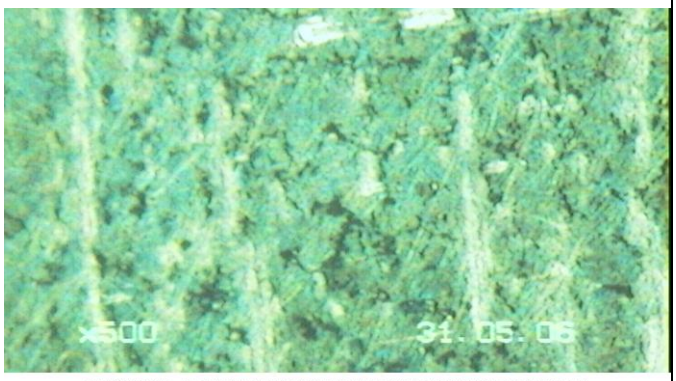


PHOTO No. 8 RUPTURED RISER TUBE "B" MICRO-STRUCTURE

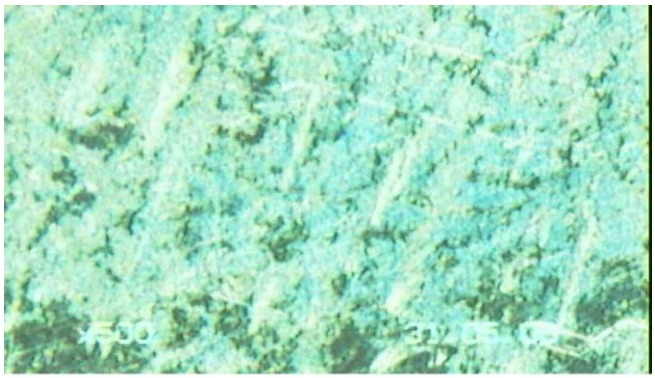


PHOTO No. 9 RUPTURED RISER TUBE "B" MICRO-STRUCTURE

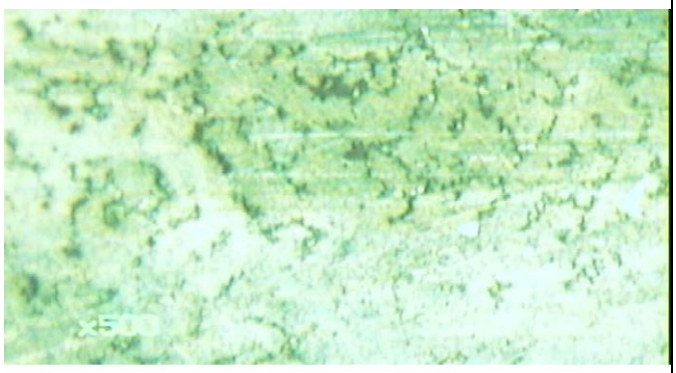


PHOTO No. 10 RUPTURED RISER TUBE "C" MICRO-STRUCTURE

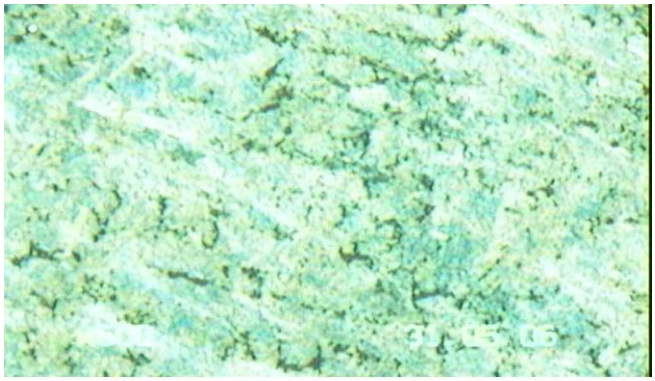


PHOTO No. 11 RUPTURED RISER TUBE "C" MICRO-STRUCTURE

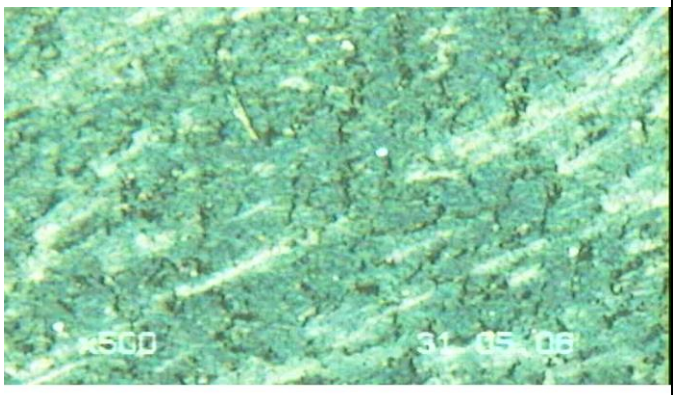


PHOTO No. 12 RUPTURED RISER TUBE "D" MICRO-STRUCTURE

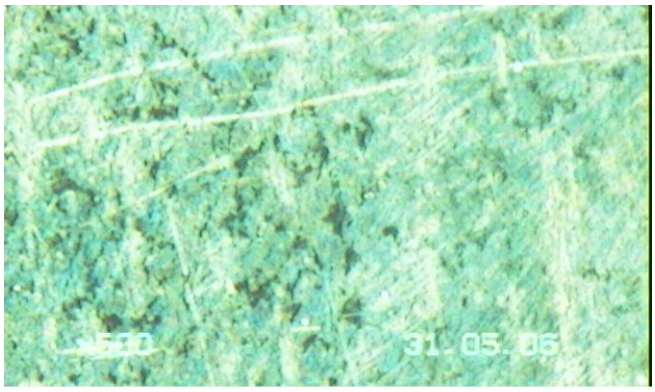


PHOTO No. 13 RUPTURED RISER TUBE "D" MICRO-STRUCTURE

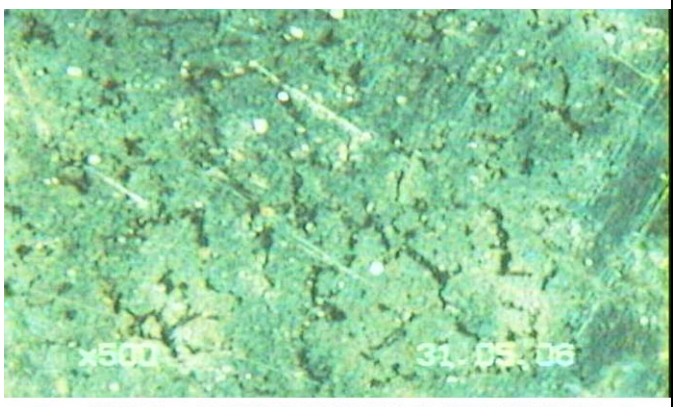


PHOTO No. 14 RUPTURED RISER TUBE "E" MICRO-STRUCTURE

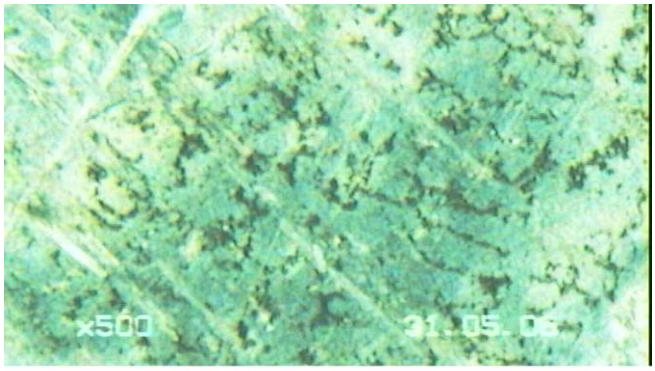


PHOTO No. 15 RUPTURED RISER TUBE "E" MICRO-STRUCTURE

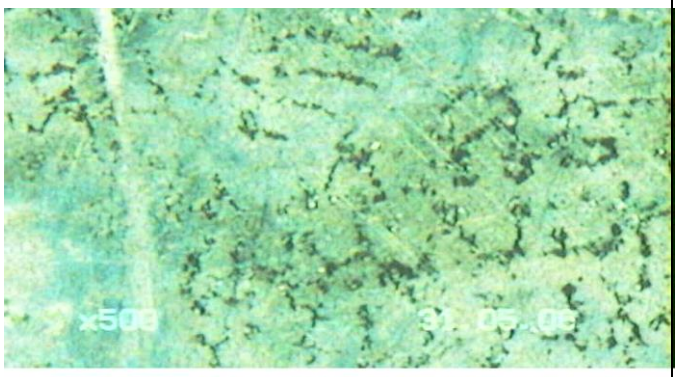


PHOTO No. 16 RUPTURED RISER TUBE "F" MICRO-STRUCTURE

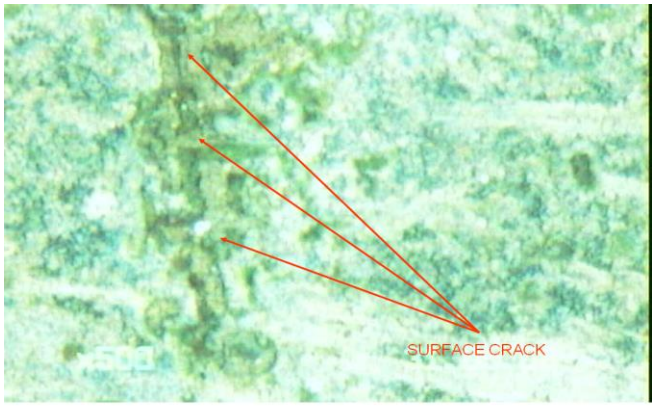


PHOTO No. 17 RUPTURED RISER TUBE "F" MICRO-STRUCTURE

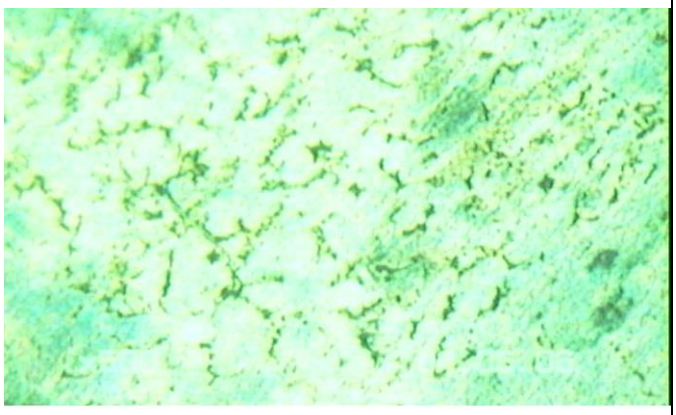


PHOTO No. 18 CATALYST TUBE No. 26 ROW "A"

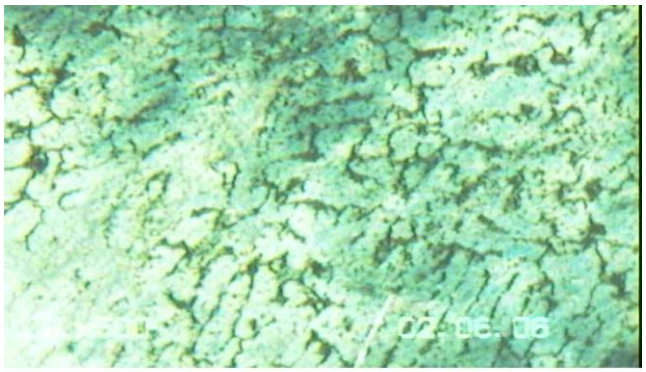


PHOTO No. 19 CATALYST TUBE No. 27 ROW "A"

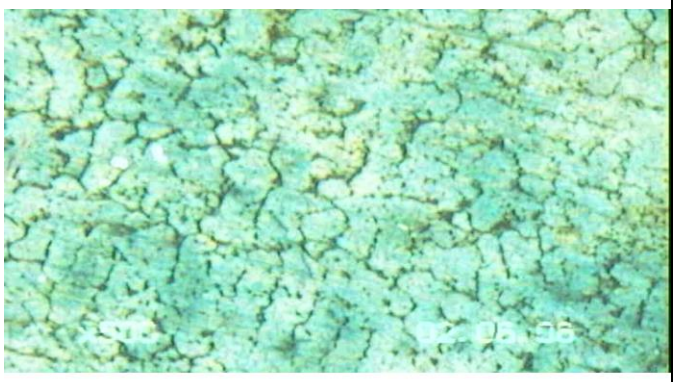


PHOTO No. 20 CATALYST TUBE No. 26 ROW "F"

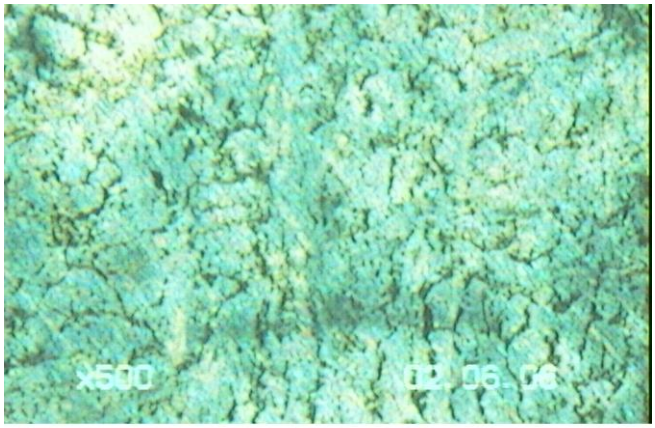


PHOTO No. 21CATALYST TUBE No. 27 ROW "F"

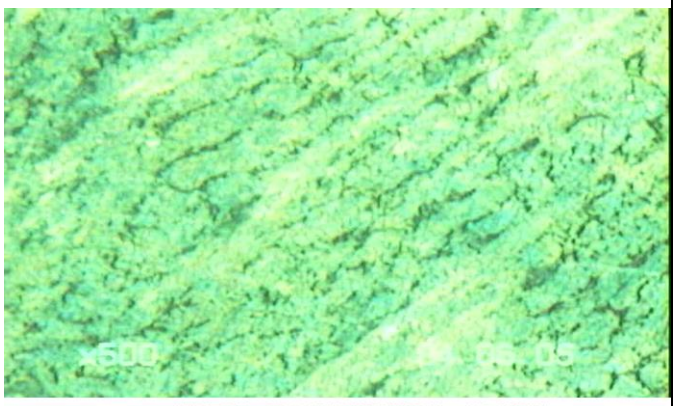


PHOTO No. 22 CATALYST TUBE No. 41ROW "B"

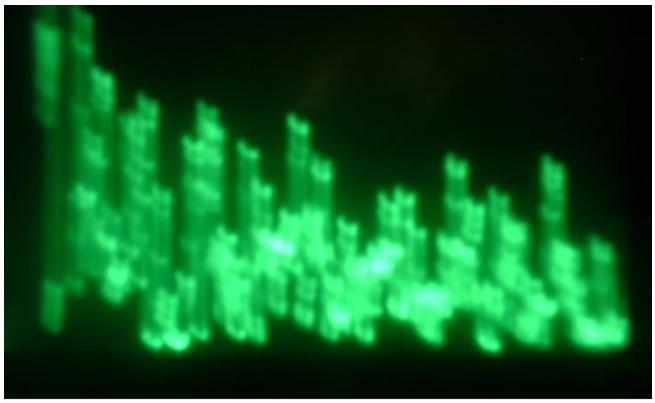


PHOTO No.23 NEW TUBE "A" ECHOES SHOWED NO FAILURE

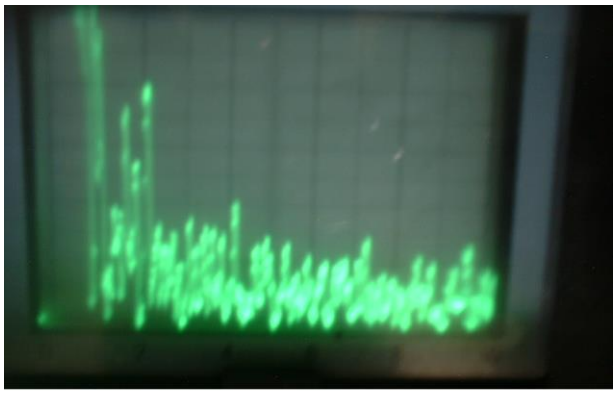


PHOTO No.24 RUPTUREDTUBE"A" ECHOES SHOWED LARGE FAILURE

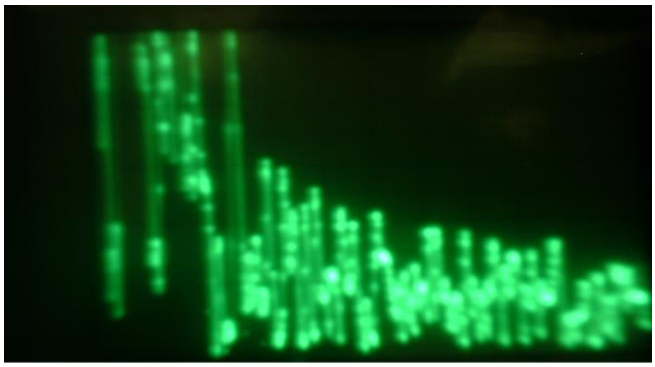


PHOTO No.25 TUBE "B" ECHOES SHOWED MODERATE FAILURE

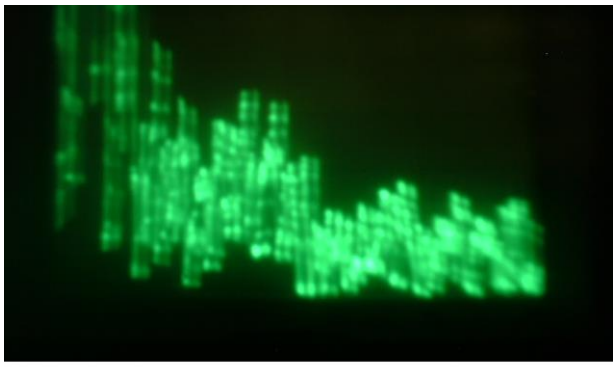


PHOTO No.26TUBE "C" ECHOES SHOWED MODERATE FAILURE

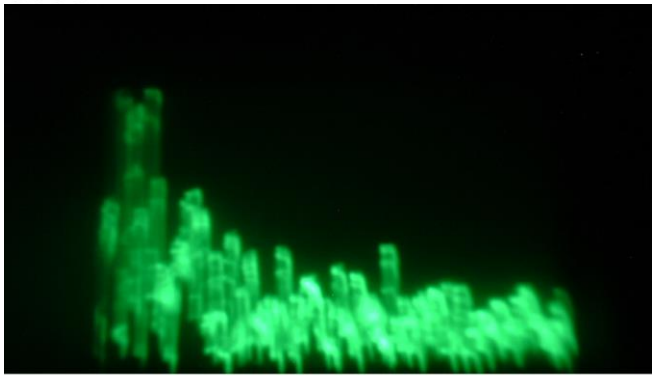


PHOTO No.27TUBE "D" ECHOES SHOWED MODERATE FAILURE

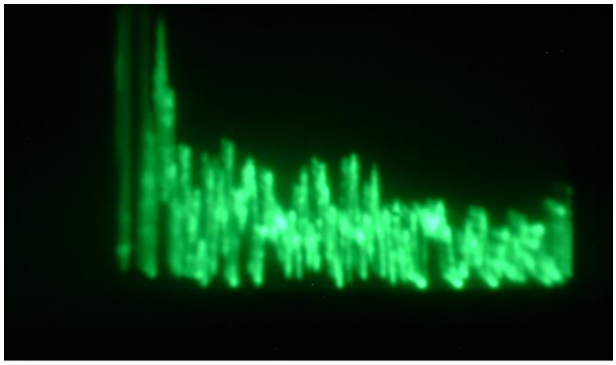


PHOTO No.28 TUBE"E" ECHOES SHOWED LARGE FAILURE

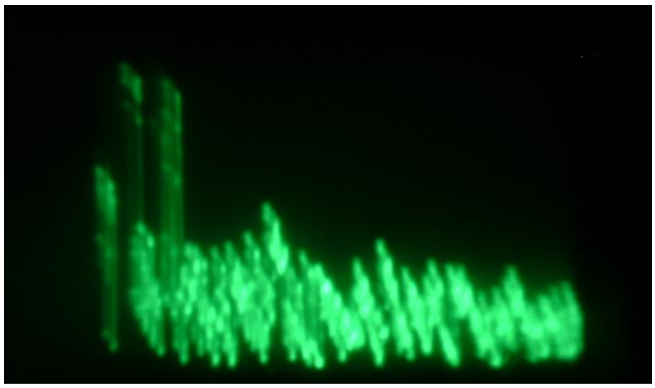


PHOTO No.29TUBE "F" ECHOES SHOWED LARGE FAILURE

PHOTO No. 30 TENSILE TEST SPECIMEN FAILED DURING MACHINING

BEND TEST SPECIMENS FAILED SHOWING BRITTLE NATURE FRACTURE

Written by	Check by	Approved by
Maher A. Ameri **NDT Level III** **Replica Specialist**	**Kassim A. Zalzala** **Director General**	**Rafik S. Ansari** **Consultant**