Steel Image Inc., Failure Analysis and Metallography
7 Innovation Drive, Suite 155, Flamborough
Ontario, Canada, L9H 7H9, (289) 895-8363

DAMAGE SURVEY OF A FAILED STEAM BOILER

EXAMPLE REPORT

Modified from Original Report

OVERVIEW & OUTCOME

Verbal results were provided immediately on-site, allowing for decisions to be implemented during the repair. Report provided within 24 hours.

Boiler tube rupture resulted in an unplanned outage. In-situ metallography of the surrounding area found that (a) the failed boiler tube had suffered from long-term overheating and (b) the neighbouring tubes were in good condition, having operated at lower temperatures. This prompted boroscope inspection which found a partial blockage at the bottom of the tube.

- Electronic Copy -

Shane Turcott, *P.Eng. M.A.Sc.*
Principal Metallurgist

DAMAGE SURVEY OF FAILED STEAM BOILER

SUMMARY

A steam boiler experienced failure of its Wall Tube #69 forcing the boiler to shut down. In-situ metallography was used to survey the neighbouring regions to assess the conditions of the failed tube and neighbouring tubes. At the time of arriving on-site, the failed region of the tube had already been cut-out from the boiler. The tubes comprised of ASTM A192 plain carbon steel and had been in service for approximately thirty years.

Each site selected for evaluation was prepared for in-situ metallography by grinding and then polishing to a 1µm finish. Replications were made in the as-polished and after final etching. Optical examination was completed on-site and verbal results provided in real-time to assist with the on-going repairs.

Table 1 summarizes the results from the survey. Optical examination of the replications found Ruptured Tube #69 to exhibit severe spheroidization immediately beneath the cut-out (**Figure 3c,d**). The degree of spheroidization beneath the cut-out rupture site was rated as Level F (rating chart in **Appendix A**). This damage had been caused by days, weeks or even years of overheating. No creep voids was observed at this site yet, based upon the degree of sensitization, rupture was suspected to have occurred by creep damage from prolonged overheating.

Note that once damaged material on Tube #69 was found, it was clear that the intended repair plan had not removed all the damaged material. In-situ was used to survey how far above and below the microstructural damage continued (**Figure 3**). Based upon these findings, an additional foot was removed above the cut-out and another three feet cut out below. This ensured no thermally damaged pipe remained in the boiler.

In-situ metallography of the neighbouring Tubes #66, #67, #68, #70 and #73 found them to be in relatively good condition considering their thirty years of service (**Figure 5**). No creep voids were observed and each tube exhibited only minor spheroidization (Level C). These tubes had not experienced the same elevated temperatures as Ruptured Tube #69. This suggested that Tube #69 had experienced reduced flow/cooling resulting in increased wall temperatures.

CONCLUSIONS

Advanced, Level F spheroidization beneath the cut-out rupture site was consistent with overheating. Although analysis of the rupture itself would be required for a conclusive diagnosis, the advanced spheroidization made it likely that tube rupture had been caused by prolonged overheating and creep failure.

None of the neighbouring tubes exhibited indications of overheating. The increased operating temperature of Ruptured Tube #69 alone suggested a blockage restricting water flow. The neighbouring tubes had experienced adequate flow and were not at risk of having a similar creep failure.

In-situ metallography was used to ensure that all the thermally damaged Tube #69 material was removed during the repair.

Table 1: Summary of Tube Condition

Tube	Location Evaluated	Figure	Microstructural Condition	Spheriodization
#66	Failure Height	Figure 5a,b	Minor Damage	Level C
#67	Failure Height	Figure 2, 5c,d	Minimal Damage	Level A-B
#68	Bottom of Boiler	Figure 5e,f	Minor Damage	Level C
	Failure Height	Figure 5g,h	Minor Damage	Level C
#69 (Failed Tube)	~4 inches above cut-out	Figure 3a,b	Minor Damage	Level D
	~6 inches below cut-out	Figure 3c,d	Severe Damage	Level F
	~18 inches below cut-out	Figure 3e,f	Moderate Damage	Level D
	~36 inches below cut-out	Figure 3g,h	Minor Damage	Level C
	Bottom of Boiler	Figure 3j,k	Minimal Damage	Level B
#70	Failure Height	Figure 5i,j	Minor Damage	Level C
#73	Failure Height	Figure 5k,l	Minor Damage	Level C

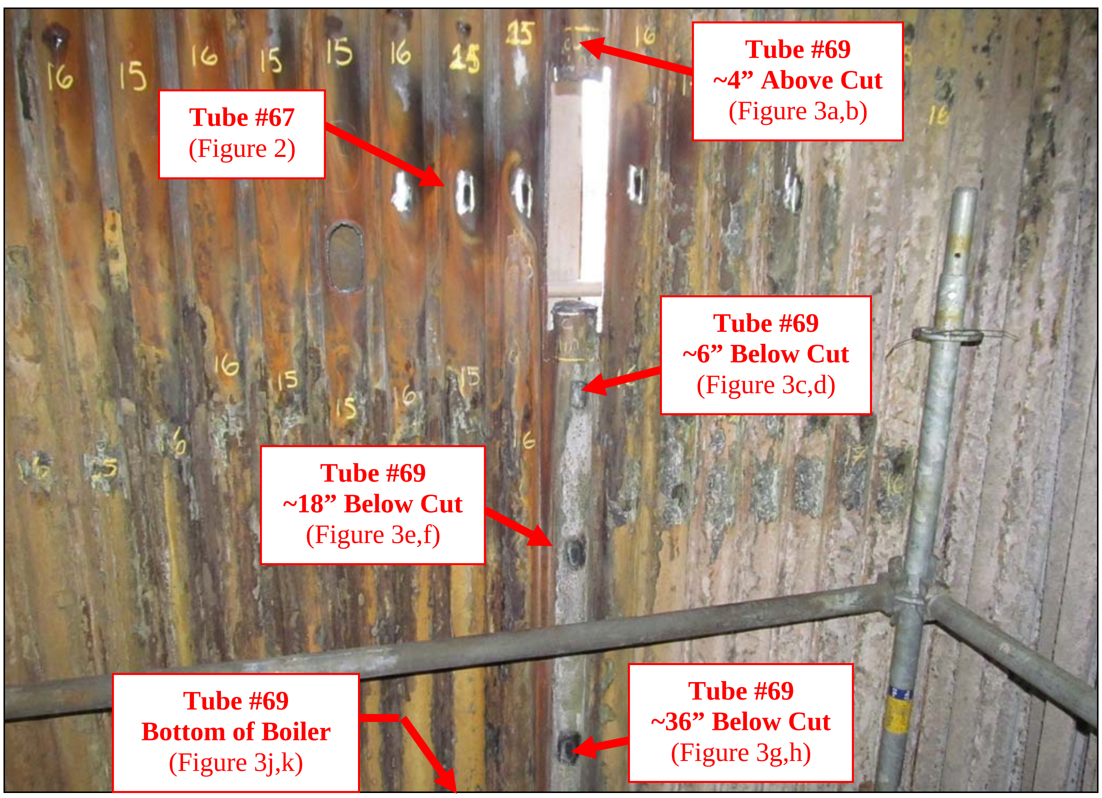


Figure 1: Photograph displaying the locations evaluated on the Failed Tube #69.

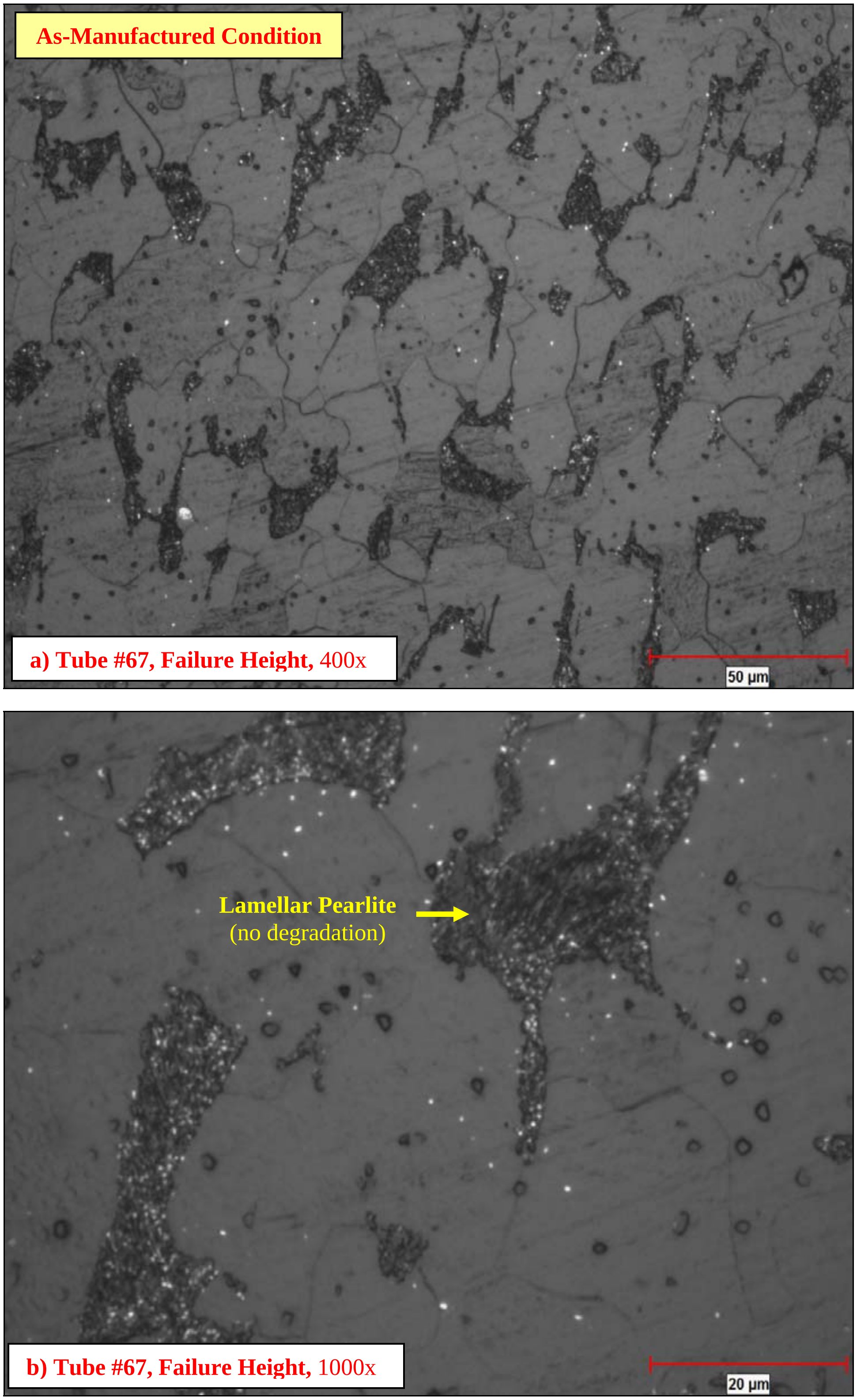


Figure 2: Micrographs taken from replicas of Tube #67 at the same height as failure of Tube #69. The microstructure comprised of ferrite and lamellar pearlite, typical for the as-manufactured ASTM A192 tube (ie. as-new structure, Level A-B spheroidization). This provided a benchmark to which the degradation of Tube #69 was compared against. Images taken from replication, tube etched with 3% nital.

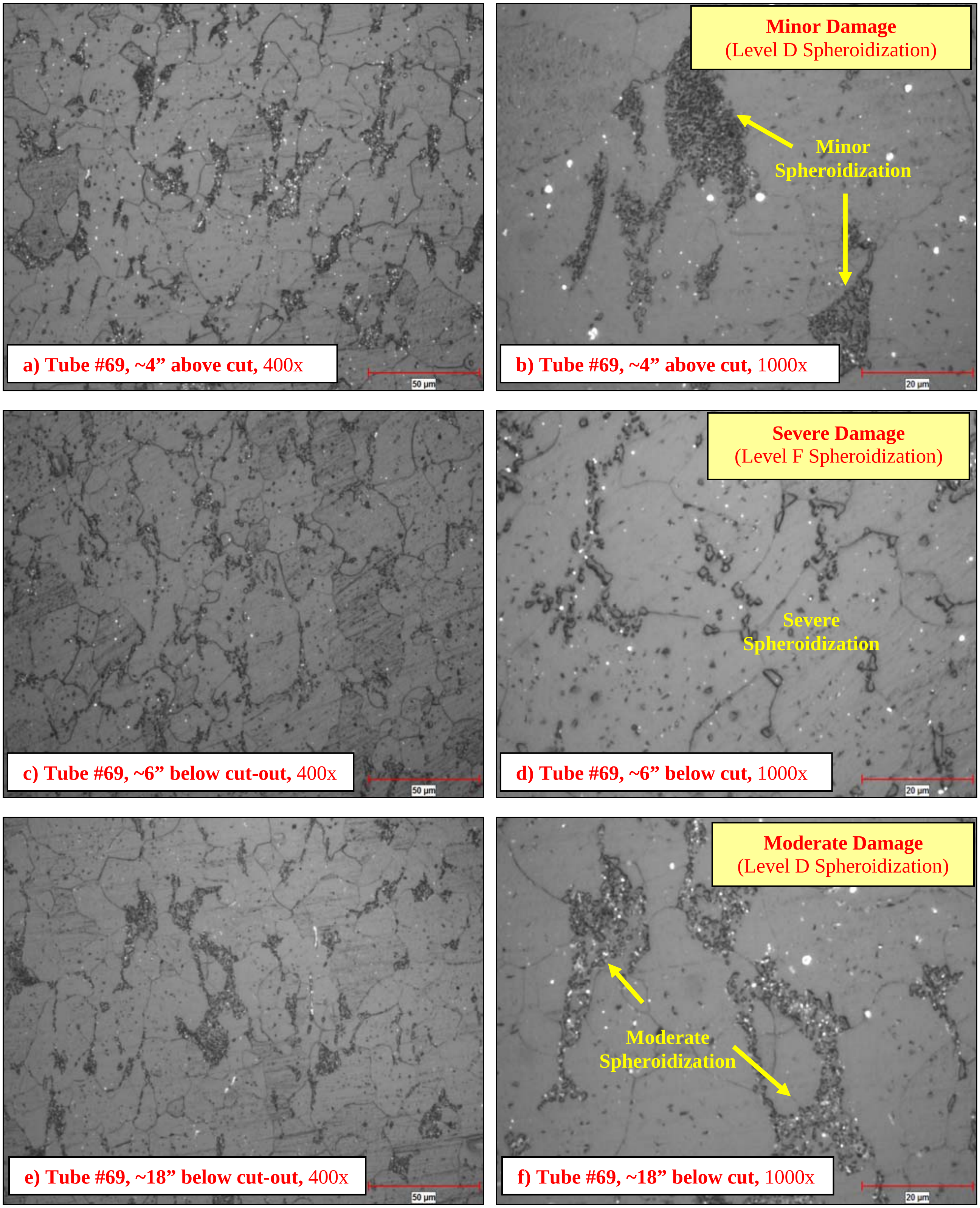
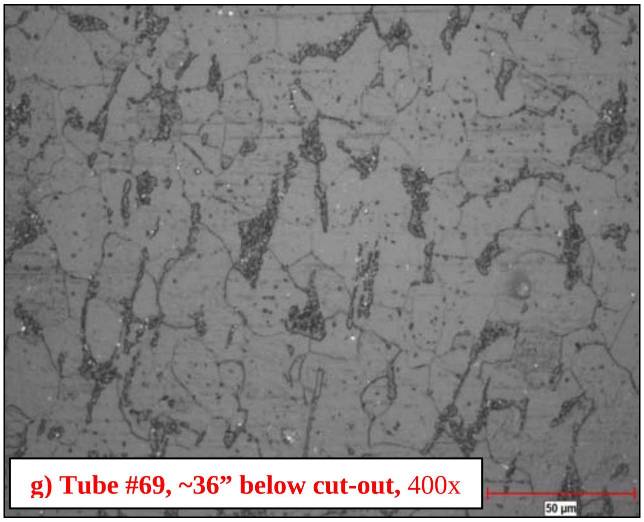
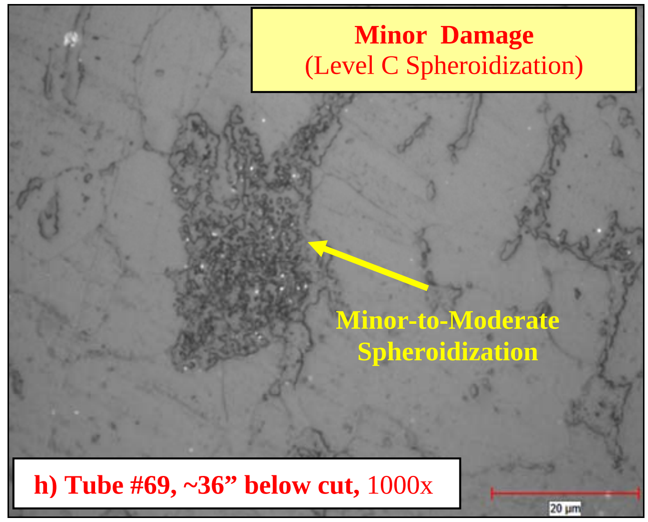
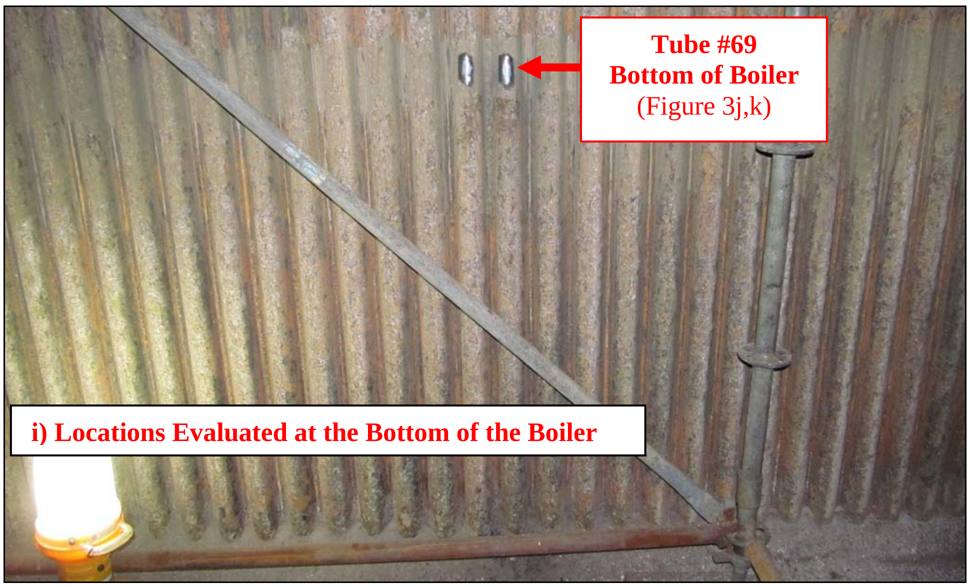


Figure 3: Micrographs of Failed Tube #69 (a,b) above the cut-out, (c-h) at various locations below the cut-out and (j,k) at the bottom of the boiler. The degradation was most severe immediately below the cut-out. Tube #69 was in good condition at the base of the boiler. No creep voids were observed at any of the sites evaluated.

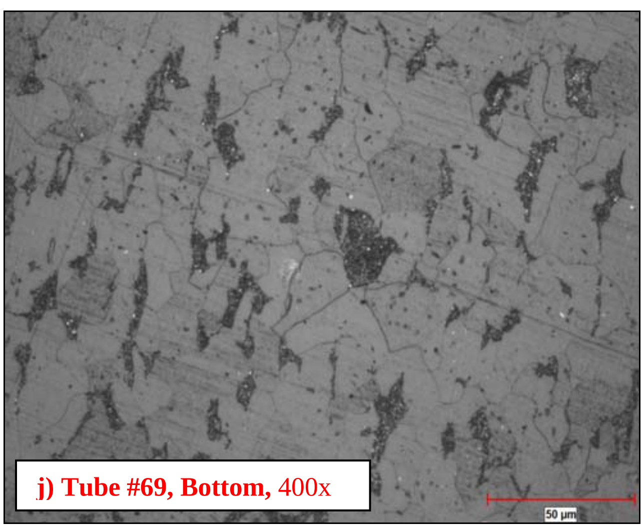

g) Tube #69, ~36" below cut-out, 400x

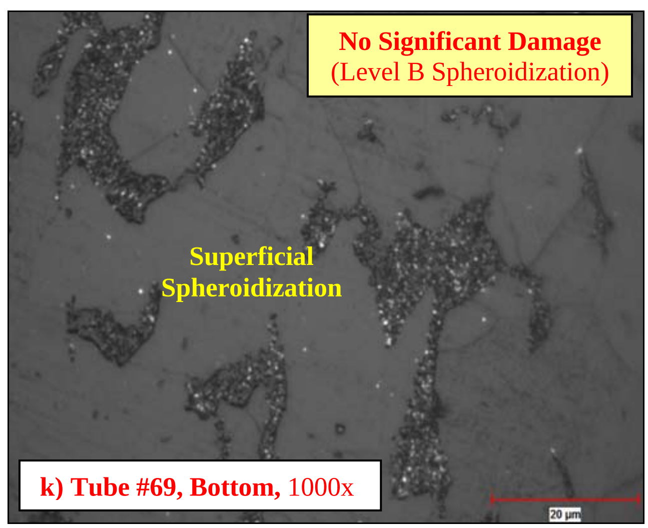


h) Tube #69, ~36" below cut, 1000x



i) Locations Evaluated at the Bottom of the Boiler


j) Tube #69, Bottom, 400x



k) Tube #69, Bottom, 1000x

Figure 3 Continued.

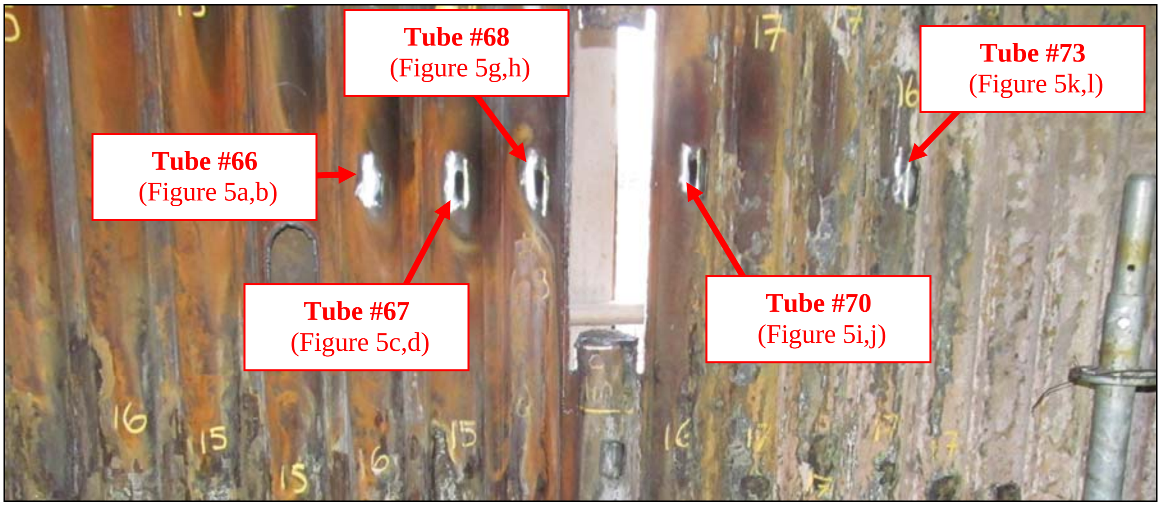


Figure 4: Photograph displaying the locations evaluated on the neighbouring tubes adjacent to the failure. These tubes were evaluated at the same height as failure, plus Tube #68 was evaluated at the boiler bottom.

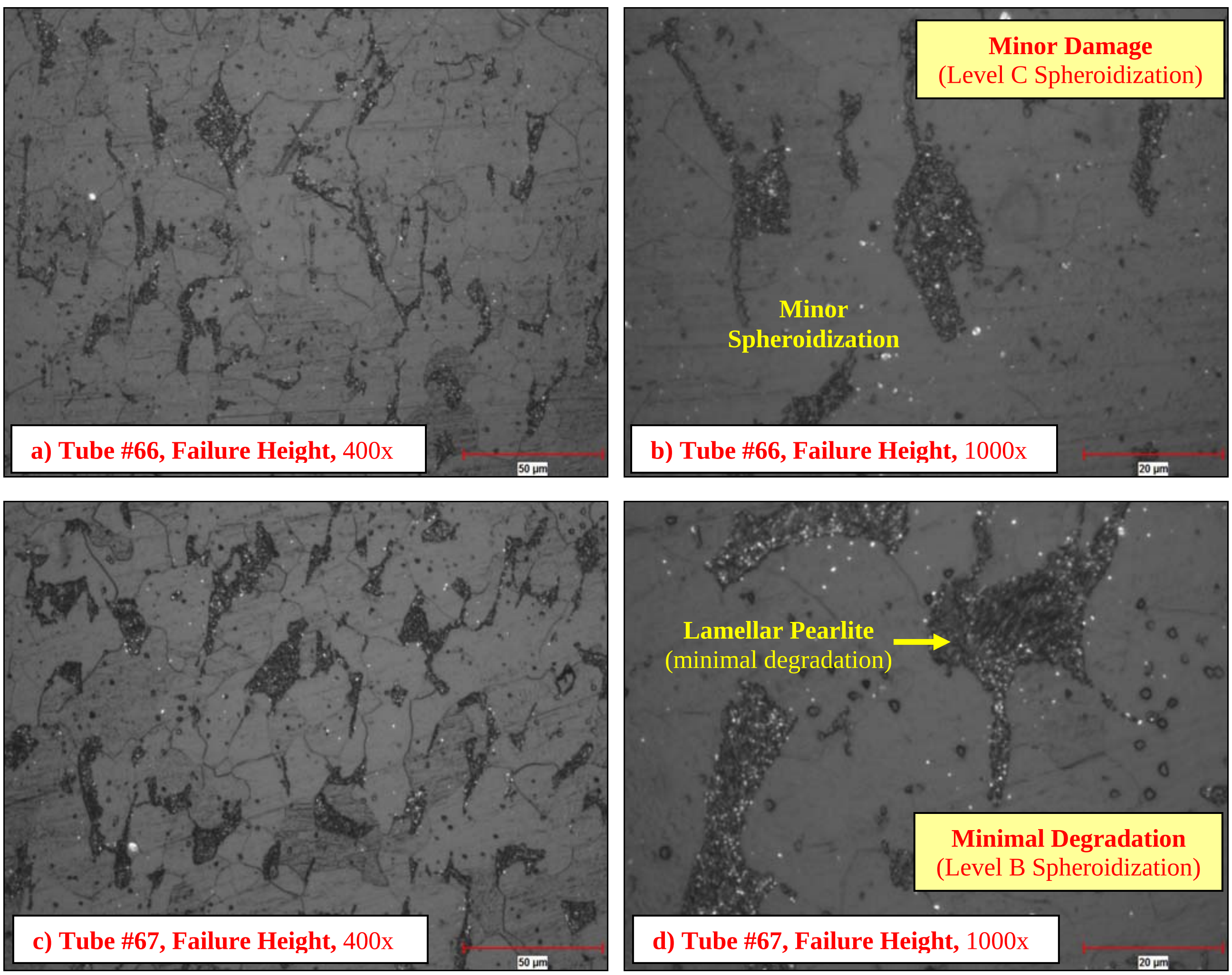
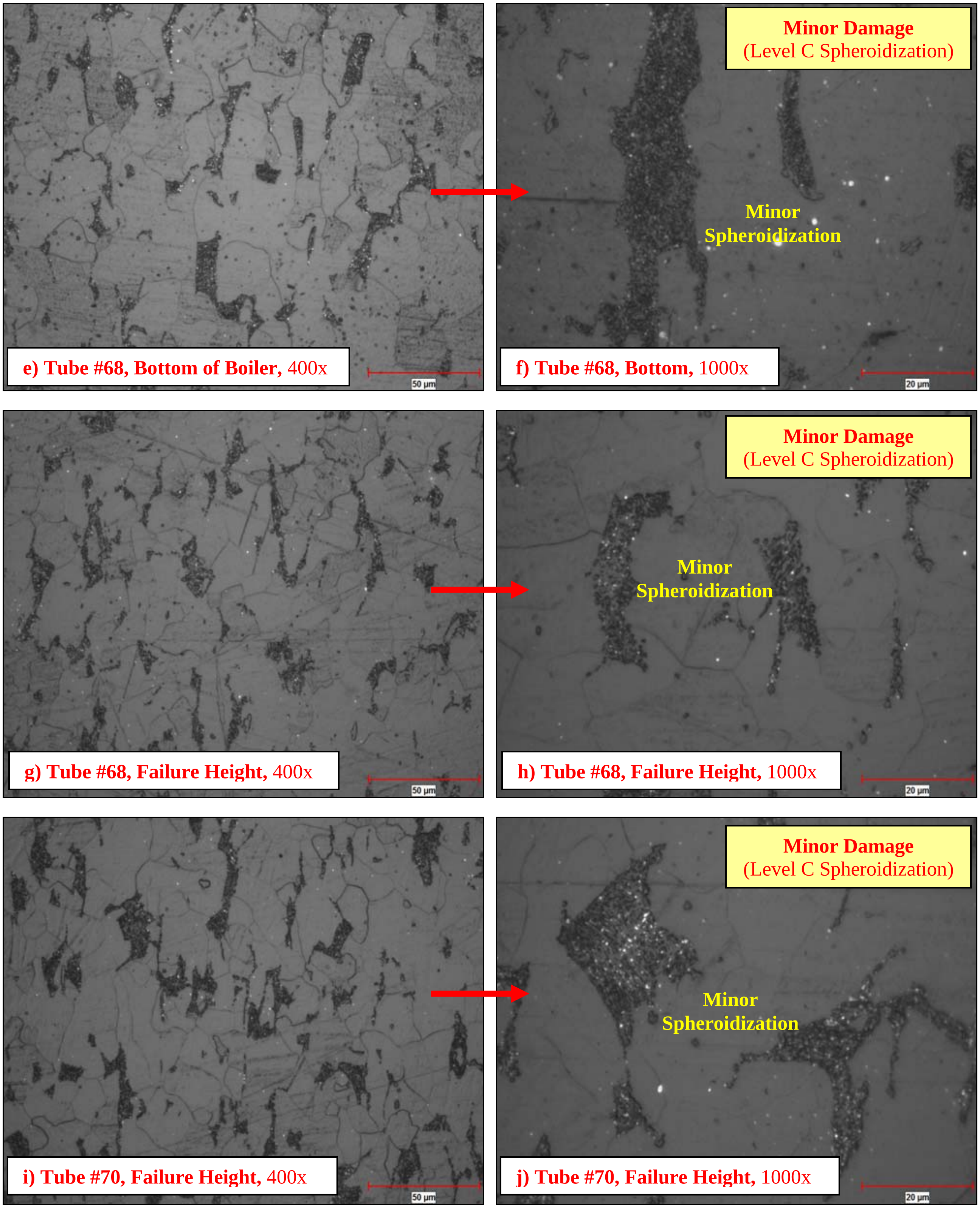


Figure 5: Micrographs of the neighbouring tubes to the failure. These tubes had not experienced the same, elevated temperatures during service as Tube #69 and were in good condition given their years of service.



e) Tube #68, Bottom of Boiler, 400x

f) Tube #68, Bottom, 1000x

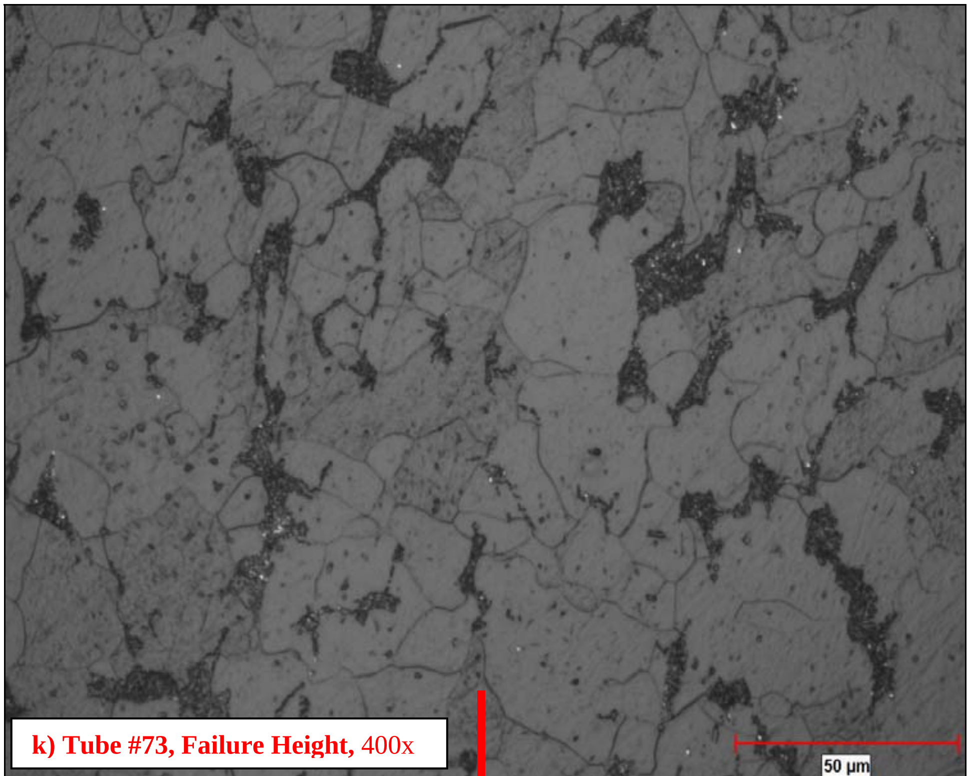
g) Tube #68, Failure Height, 400x

h) Tube #68, Failure Height, 1000x

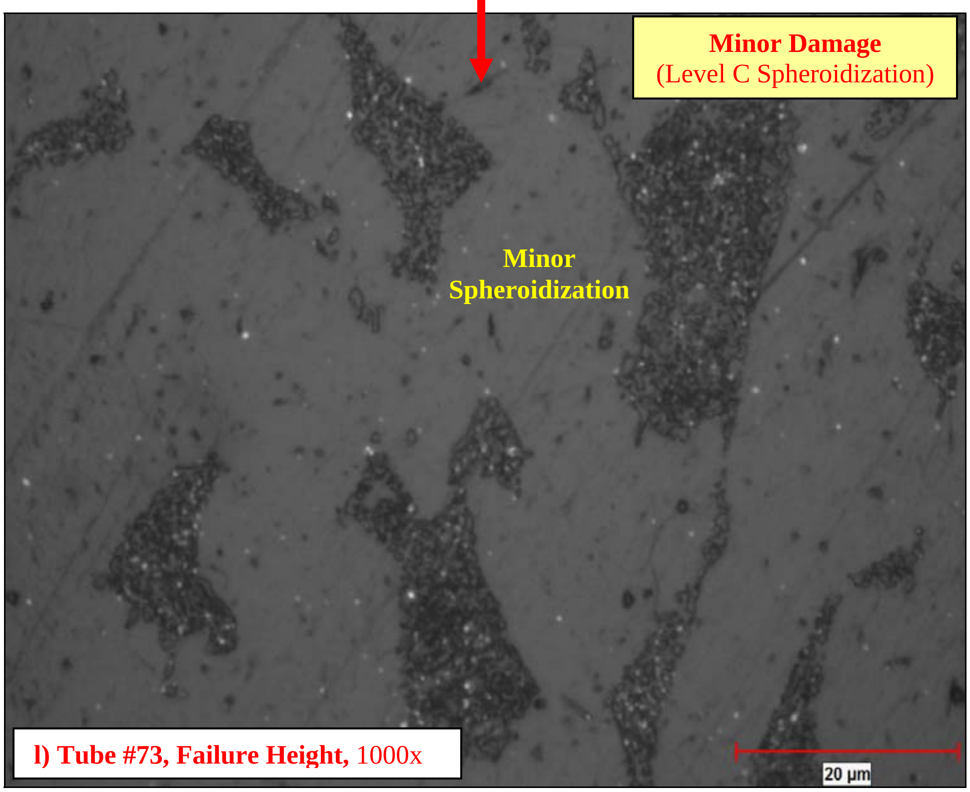
i) Tube #70, Failure Height, 400x

j) Tube #70, Failure Height, 1000x

Figure 5 Continued.



k) Tube #73, Failure Height, 400x

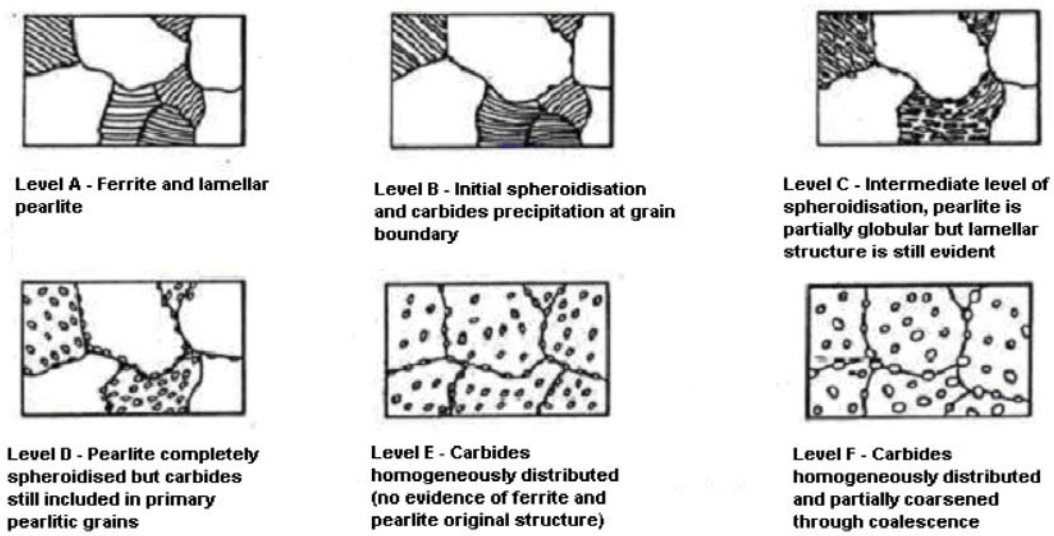


l) Tube #73, Failure Height, 1000x

Figure 5 Continued.

APPENDIX A: LEVEL CLASSIFICATIONS OF SPHERIODIZATION

Spheroidization of carbon and alloy steels is a long-term degradation mode that occurs gradually over years and decades of service (depending upon the temperature of operation). Eventually spheroidization will result in strength reduction of the steel. Advanced Levels E-F spheroidization damage often precedes creep void/crack formation. The schematics below illustrate the six stages of spheroidization.



APPENDIX B: SUMMARY OF CREEP STAGES

Table B1: Creep Damage Stages

Stage	Description	Recommended Boiler Remedial Actions
1	No creep voids	No action
2	Intermittent creep voids	Re-inspect 3-5 years
3	Oriented, creep void strings	Re-inspect 1-3 years
4	Microcracks	Replace in 6 months
5	Macrocracks	Replace immediately

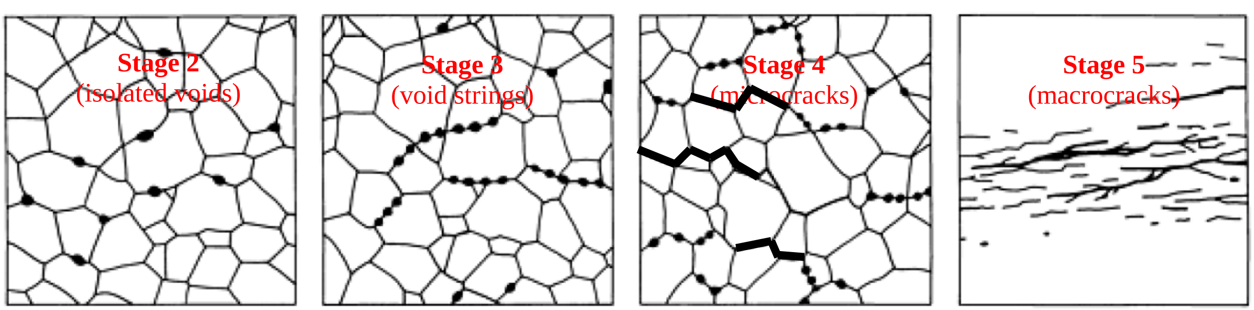


Figure B1: Schematics displaying the different stages of creep void damage.