

EXHIBIT 3

5170

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|---|---|-----------------|---|
| CENTRAL LABORATORIES SERVICES TECHNICAL REPORT | | Report No. | 95-1021 |
| | | Sheet No.: | 1 of 2 |
| | | Date of Report: | 6/2/95 |
| Plant/Project: | Watts Bar Nuclear Plant | | |
| Subject: | ICE CONDENSER BASKET SCREWS | | |
| Standards Used: | 904694, 901387 | | |
| Copies Sent to: | Vonda Sisson, IOB 1M-WBN (4); RIMS; Lab Files | | |
| Prepared by: | Daryl A. Smith / LAB | Approved by: | <i>Delsa L. Frazier</i> Delsa L. Frazier |

Eight sets of zinc plated, self-tapping, plain carbon steel screws were received by Central Laboratories Services (CLS) with a request to determine the cause of failure in some of the screws. The customer indicated that the screws were made from AISI 1022 plain carbon steel. The eight sets of screws received by CLS were labeled as follows:

- Set "A": Ten fractured screw heads, seen in the upper left view of Figure 1, and one new screw (not shown).
- Set "B": Twelve new screws, seen in the upper right view of Figure 1.
- Set "C": Two screws removed from service, labeled "Bay '24' Top Ring D-6".
- Set "D": Two screws removed from service, labeled "Bay '24' Bottom Ring D-6".
- Set "E": Two screws removed from service, labeled "Bay '12' Top Ring A-6".
- Set "F": Two screws removed from service, labeled "Bay '12' Bottom Ring A-6".
- Set "G": Two screws removed from service, labeled "Bay '1' Top Ring A-6".
- Set "H": Two screws removed from service, labeled "Bay '1' Bottom Ring A-6".

All screws removed from service had varying amounts of corrosion products on them, mostly in the threaded region. The lower view of Figure 1 shows a typical set of screws that were removed from service. The customer indicated that the screws were cyclically cooled and warmed between 15°F and room temperature. The customer also indicated that the screws were probably over-torqued when installed.

The chemical composition of the screws was checked with Energy Dispersive X-ray (EDX) analyses, and all screws examined had chemistries similar to that of plain carbon steel (see typical results in Table I). Carbon and sulfur amounts were measured using Induction Furnace Combustion Techniques on all sets of screws, and the results are presented in Table II. Note that the screws appeared to be case-hardened by carburization; therefore, the carbon amounts detected are averages of the core and case carbon contents of each screw that was examined. This may explain why some screws had carbon contents that were higher than would normally be expected for AISI 1022 steel.

Microhardness values were obtained from a fractured screw (set "A"), a new screw (set "B"), and a typical screw removed from service (set "G"). The average results are presented in Table III. Note that all fractured screws that were tested had higher hardness values than the new screws that were tested.

All of the fractured screws received in set "A" were examined in a Scanning Electron Microscope (SEM) in order to determine the mode of failure. Figures 2 and 3 show that the screws fractured in a brittle manner as indicated by the intergranular failure mode seen on all screws examined. There was usually a small final-fracture area on the fracture surface near the center of the shank that failed in a ductile manner.

An arbitrarily selected fractured screw from set "A" was cut so that a longitudinal cross-section through the fracture surface could be examined (as seen in Figure 4). Note that a secondary crack was noticed above the fracture surface. Closer examination of this crack revealed that it traveled in an intergranular manner. A screw that was removed from service (set "G") was similarly sectioned as seen in Figure 5. Note that two cracks were found in adjacent tooth roots. Similar cracks were discovered in the new screw received in set "A" and in the transverse section of a new screw sample examined from set "B" (see Figure 7). EDX analysis

of the crack revealed the presence of zinc (see Table I) indicating that the crack may have been present prior to plating (possibly formed when quenched during the manufacturer's heat treatment).

All screws examined had lapping from the thread-rolling process in the pitch, face, and root vicinities (see upper view of Figure 6). Lapping at the roots of the threads would be undesirable due to the fact that this is usually an area of high stress, and the lapping may initiate a fatigue crack. The lower view of Figure 6 shows a crack at a tooth root of one screw that was removed from service (set "G") that may have propagated by intergranular fatigue. Note that similar cracks were found both in the new and used screws (see Figure 7).

Two screws, one new and one used, were intentionally fractured with a hammer in order to determine the failure mechanism. SEM photography shows in Figures 8 and 9 that the used screw failed by intergranular fracture in the case and mixed-mode fracture (cleavage and void coalescence) in the core, while the new screw failed by quasi-cleavage in the case and void coalescence in the core. Three conclusions were drawn after this test was performed: 1) The fact that the new screw failed in a manner that was more ductile than the used screw corresponds to the lower hardness values of the new screws compared to those of the used screws. 2) Since both the new and used screw had ductile features on their fracture surfaces, hydrogen embrittlement from the plating process and Tempered Martensitic Embrittlement (TME) from the heat treatment were probably not factors in the failure of the screws in service. 3) The fact that the in-service screws were more brittle than the new screws can also be attributed to the used screws having a higher carbon content as compared to the new screws (see Table II).

The general microstructure of all screws was determined to be tempered martensite (see Figures 10 and 11). Note that the hardness of martensite is determined by carbon content, thus the used screws with higher carbon contents (except set "H") were harder than the new screws with lower carbon contents (the hardness values of screws in set "H" were not obtained due to lack of time).

In conclusion, the screws probably failed due to a combination of several factors:

- (1) Low temperatures when the screws are in service (lowering the ductility of the screws),
- (2) Stresses higher than design limits, specifically at the thread roots (due to possible over-torquing),
- (3) The presence of stress concentrators present at the thread roots (lapping from rolling process),
- (4) A corrosive environment that breaks down the zinc plating and initiates rust around the threads,
- (5) Elevated carbon content, thus higher hardness values (again lowering the screw's ductility),
- (6) The presence of quench cracks in the screws upon receipt from the manufacturer, and
- (7) Thermal cycling which may have initiated micro-cracking or propagation of pre-existent cracks.

The mode of failure in the screws was intergranular separation, and the mechanism was stress overload.

All test equipment and instrumentation used in the performance of this evaluation are calibrated in accordance with applicable TVA standards and Quality Assurance (QA) Procedures and conform to applicable portions of ANSI N45.2, 10 CFR 50/Appendix B, and 10 CFR 21. Standards used are traceable to the National Institute of Standards Technology (NIST), natural physical constants, or commercially accepted practices. All personnel, procedures, and instructions used comply with the requirements of the Central Laboratories Services (CLS) QA Program.

In the event that additional information or subsequent testing regarding this sample should be required, please refer to Report No. 95-1021.

DAS:

Attachments: Tables I-III
Figures 1-11

TABLE I
 REPORT OF CHEMICAL COMPOSITION BY
 ENERGY DISPERSIVE X-RAY ANALYSIS (EDX)*

REPORT NO. 95-1021

Elemental Weight Percent (Wt%)

| Element | Base Metal | Plating | Material in crack of screw removed from service (set "G") |
|------------|------------|---------|---|
| Aluminum | - | 0.4 | 3.4 |
| Silicon | 0.6 | 0.9 | 3.2 |
| Phosphorus | - | 24.8 | 0.5 |
| Calcium | - | 0.3 | 1.2 |
| Manganese | 1.0 | 0.6 | 0.7 |
| Iron | Bal. | Bal. | Bal. |
| Zinc | - | 28.5 | 2.8 |
| Copper | - | 0.4 | - |
| Potassium | - | 0.6 | - |
| Chlorine | - | 0.3 | - |

*EDX analysis is a semi-quantitative technique which uses no standards. TVA No. 453855

Analyzed By: Daryl Smith

Date: 5/31/95

TABLE II
REPORT OF CHEMICAL COMPOSITION ANALYSIS (WEIGHT PERCENT)
BY INDUCTION FURNACE COMBUSTION TECHNIQUES

REPORT NO. 95-1021

STANDARDS: 904694 (NBS 19h)

| Sample | Carbon | Sulfur |
|-----------------------------|--------|--------|
| Fractured Screws (Set "A") | 0.24 | 0.023 |
| New Screws (Set "B") | 0.22 | 0.021 |
| In-service Screws (Set "C") | 0.26 | 0.029 |
| In-service Screws (Set "D") | 0.27 | 0.31 |
| In-service Screws (Set "E") | 0.27 | 0.027 |
| In-service Screws (Set "F") | 0.27 | 0.023 |
| In-service Screws (Set "G") | 0.25 | 0.027 |
| In-service Screws (Set "H") | 0.21 | 0.028 |

Analyzed by: Phillip Gass

Date of analysis: 5/22/95

TABLE III
REPORT OF MATERIAL HARDNESS

REPORT NO. 95-1021

STANDARD(s): 901387 (62GM)

| <u>Sample No.</u> | <u>Average Hardness*</u> |
|---|--------------------------|
| Fractured Screw, Shank Case | 54.6 HRC (625.6 HK) |
| Fractured Screw, Shank Core | 44.6 HRC (460.6 HK) |
| Fractured Screw, Head Case | 61.6 HRC (768.2 HK) |
| Fractured Screw, Head Core | 44.9 HRC (465.7 HK) |
| New Screw (set "A"), Transverse Section, Case | 52.1 HRC (579.3 HK) |
| New Screw (set "A"), Transverse Section, Core | 43.6 HRC (447.7 HK) |
| New Screw (set "A"), Longitudinal Section, Head Core | 44.1 HRC (454.8 HK) |
| New Screw (set "A"), Longitudinal Section, Shank Core | 44.2 HRC (455.3 HK) |
| In-service Screw (from set "G"), Shank Case | 59.5 HRC (723 HK) |
| In-service Screw (from set "G"), Shank Core | 42.5 HRC (432.3 HK) |

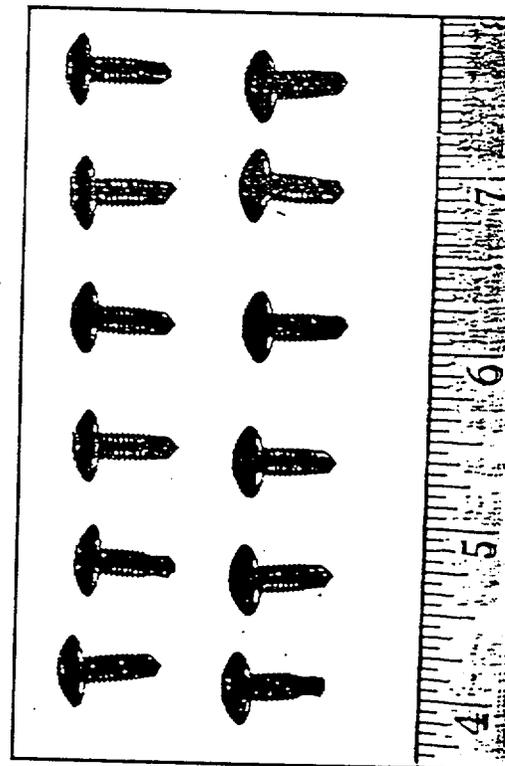
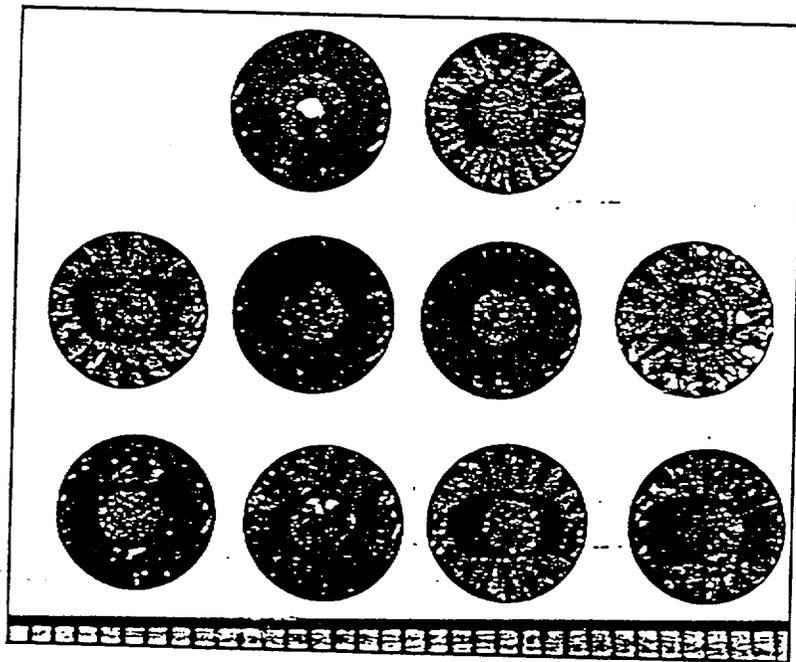
LABORATORY STANDARD TEST BLOCK SET TVA No. 901387

| <u>Serial No.</u> | <u>Standard Value</u> | <u>Measured Results and Average</u> | | | | |
|-------------------|-----------------------|-------------------------------------|-------|-------|-----------|----------|
| 62GM | 556 ± 15 HK | 557.1 | 553.2 | 555.1 | \bar{X} | 555.1 HK |

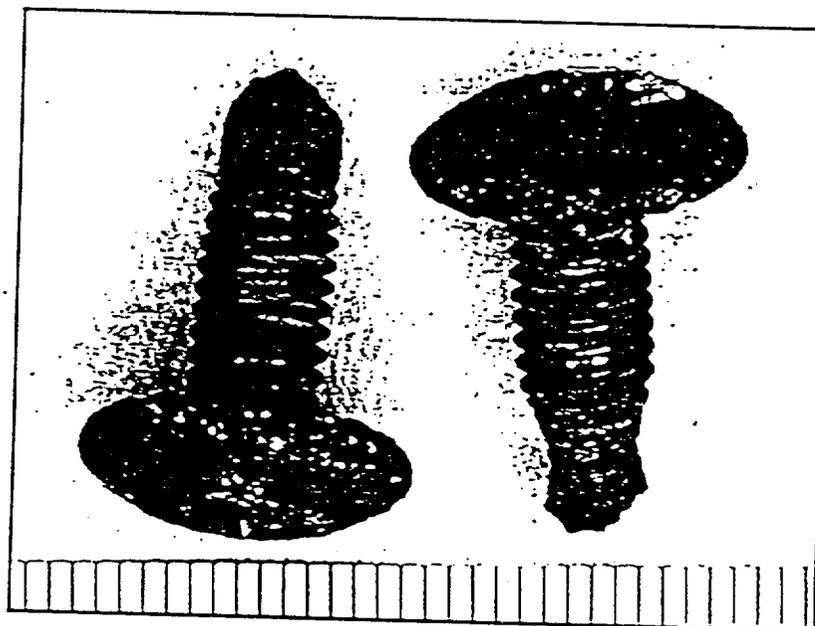
Measured By: Daryl Smith

Date: 5/26/95

* The value reported is an average of three readings. Measured values are shown in parenthesis following converted values. Source of conversion is the Wilson Digital Microhardness Tester, which is based on ASTM A370.



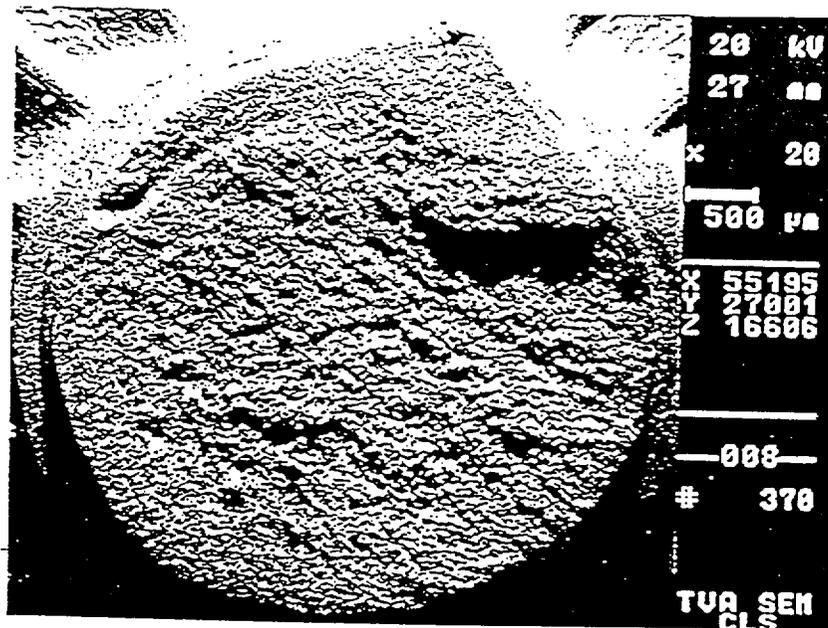
Left: As-received photograph of the fractured screws (set "A"). Note that the unfractured screw from this set is not shown. Right: As-received photograph of the new screws (set "B").



As-received photograph of a typical pair of used screws. Note that each set of used screws (set "C" through set "H") varied in degree of corrosion.

Figure 1:

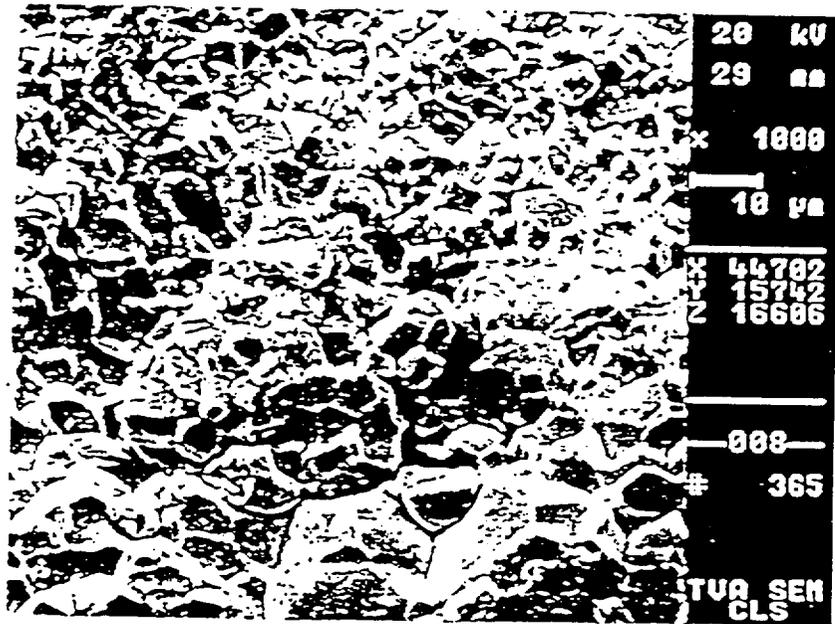
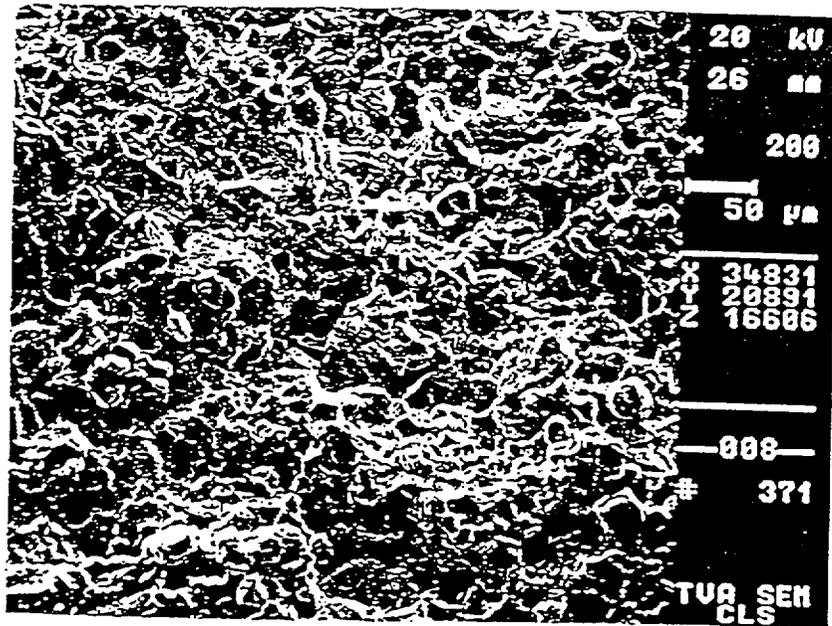
Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Laboratory Report No. 95-1021.



SEM photographs of typical fracture surfaces taken from fractures screws (set "A"). Note that all fractured screws received in set "A" failed in a brittle manner (except for the small final fracture area near the center which failed in a ductile manner). 20X.

Figure 2:

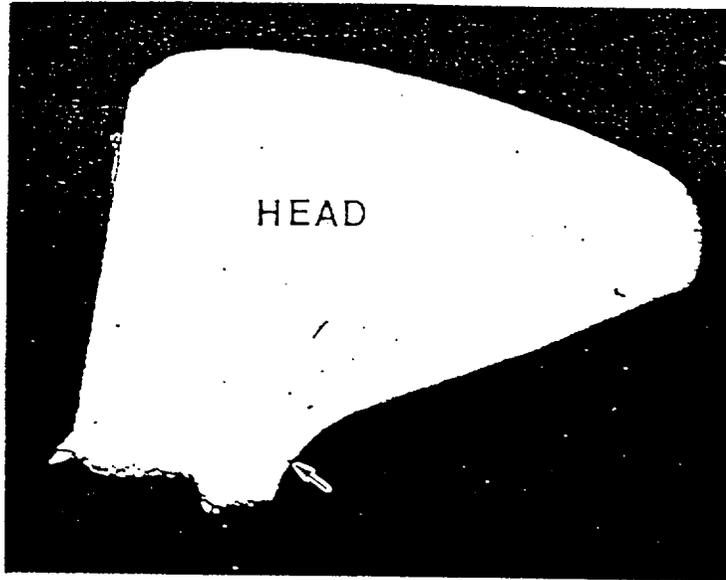
Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.



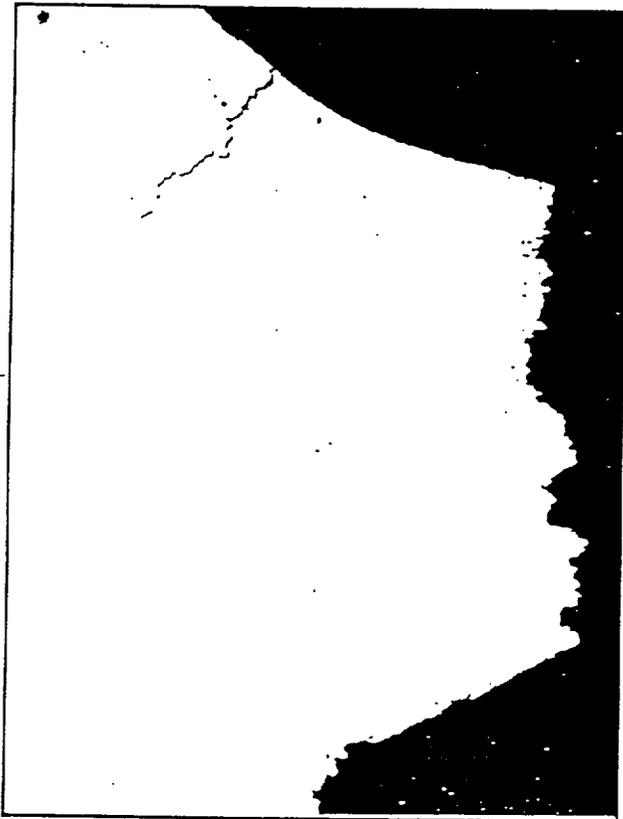
SEM photographs of typical fracture topography seen on failed screws in set "A." The "rock-candy" appearance indicates that these screws failed in a brittle, intergranular manner. Top: 200X; Bottom: 1000X.

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Figure 3: Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.



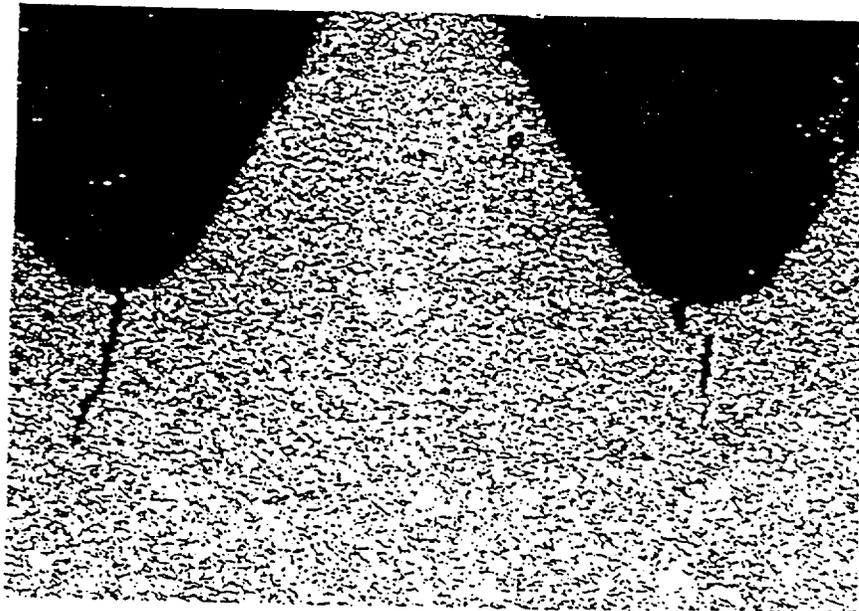
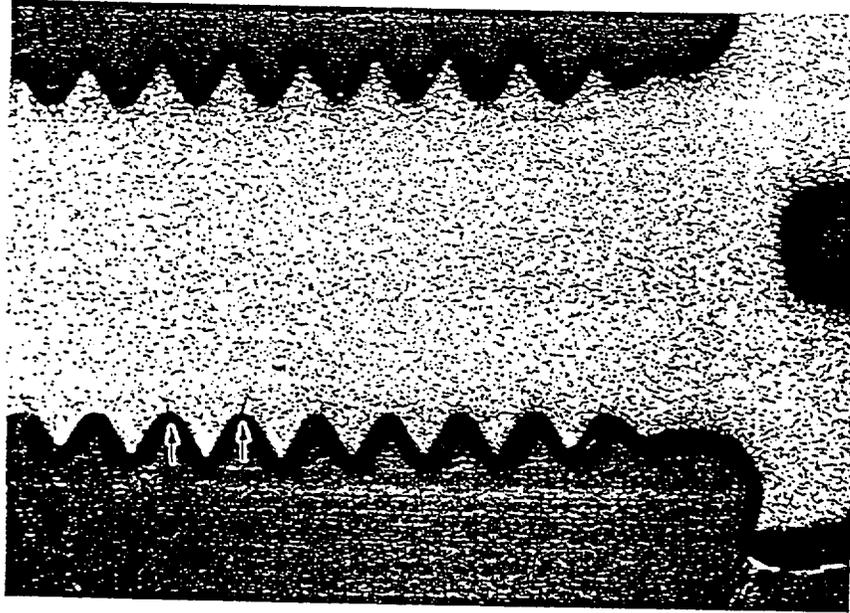
Longitudinal cross section through a fractured screw. The arrow points to a secondary crack above the fracture surface. 20X. As-polished.



Close-up views of secondary crack seen in the upper view of this Figure. Left: As-polished, 125X; Right: Vilella's etch, 400X.

Figure 4:

Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.



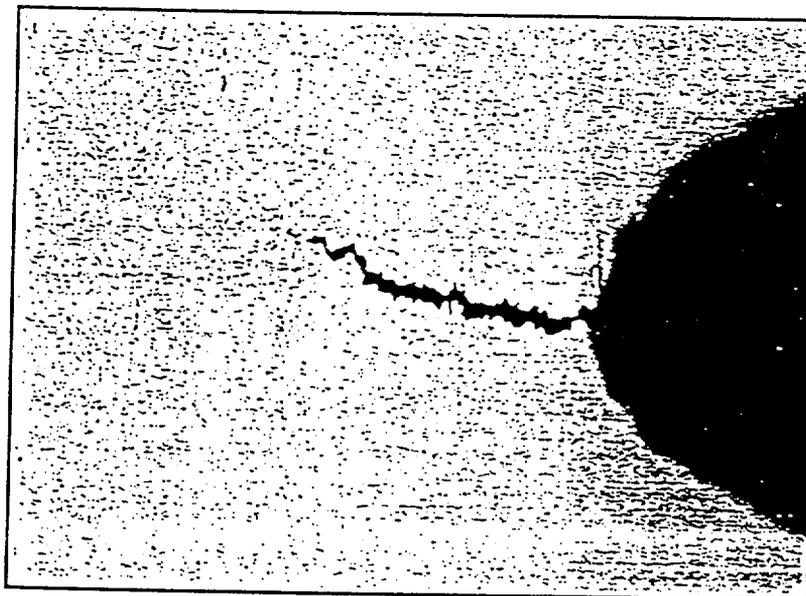
Longitudinal view of cracks present in one of the screws that were removed from service in set "G". Top: 12X; Bottom: 100X.

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Figure 5: Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.

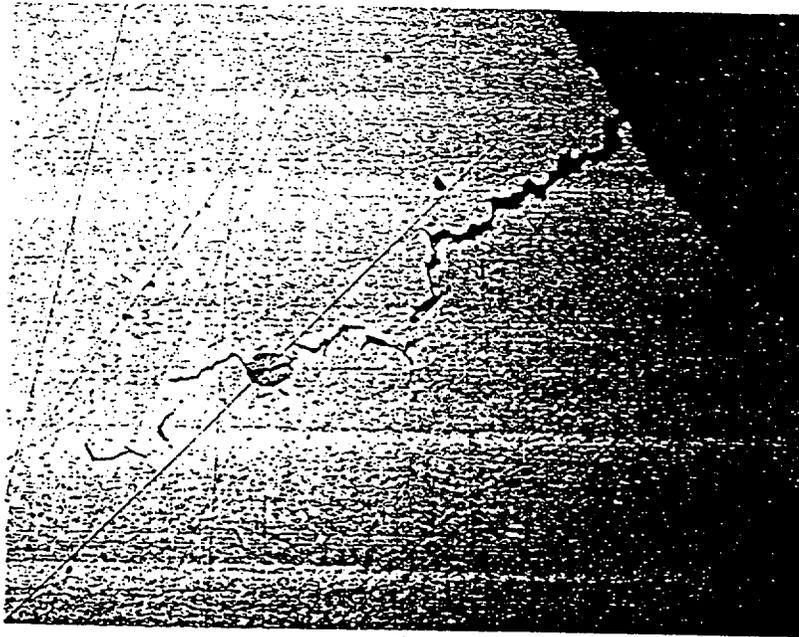


As-polished, longitudinal view of lapping present at tooth root of a screw that was removed from service in set "G". 200X.

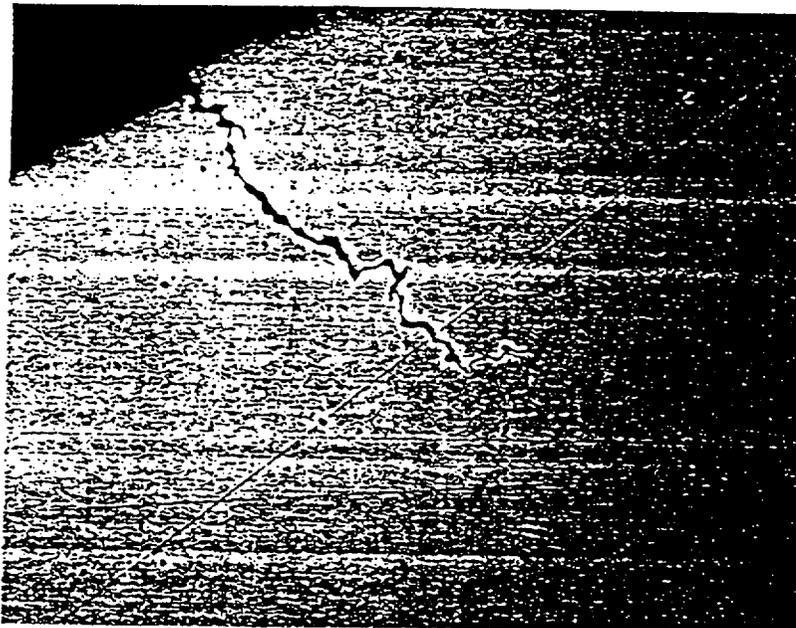


As-polished, longitudinal view of crack present at tooth root of a screw that was removed from service in set "G". 200X.

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As-polished, longitudinal view of crack present in shank, near head of a screw that was fractured in set "A" (see Figure 4). 400X.

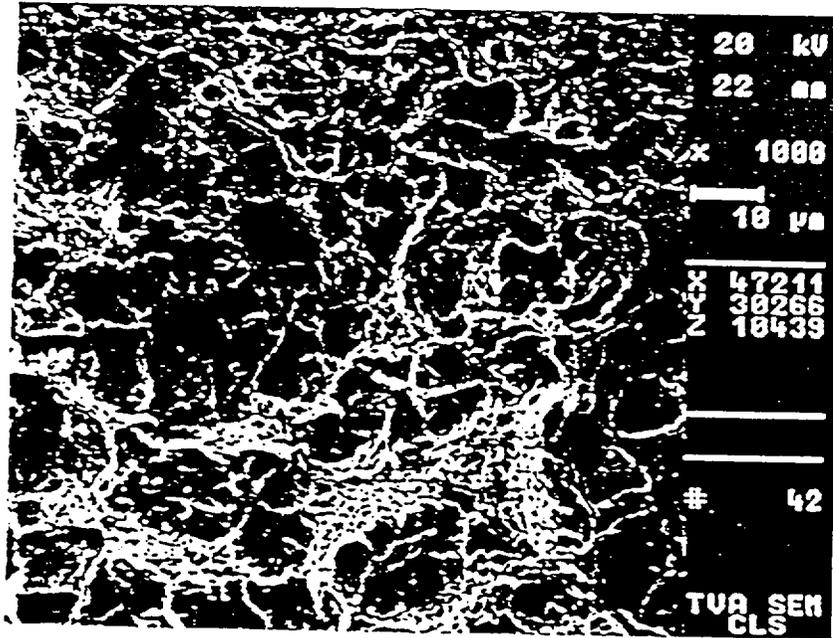


As-polished, transverse view of crack present in a new screw that was received in set "B". 400X.

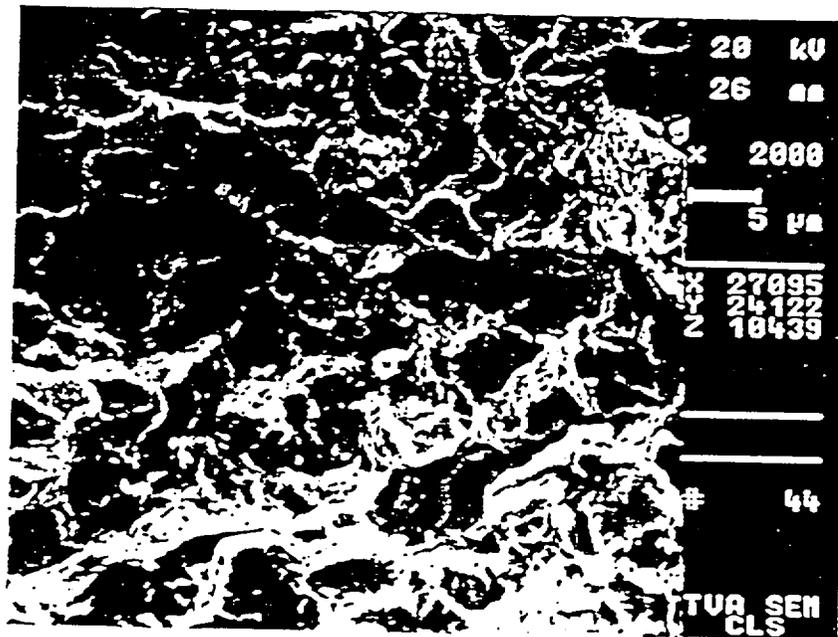
Figure 7:

Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.

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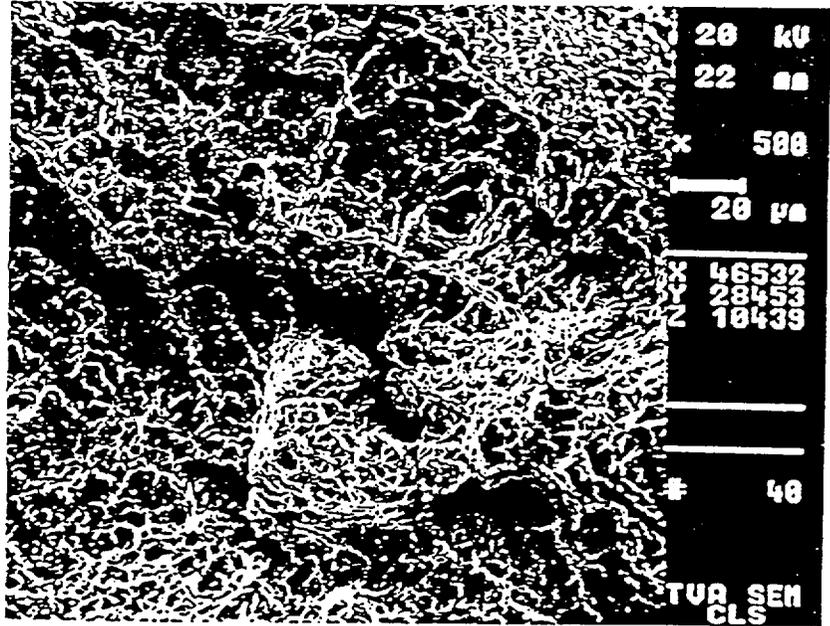


SEM photograph of fresh fracture surface showing quasi-cleavage in the case of a new screw. 1000X.

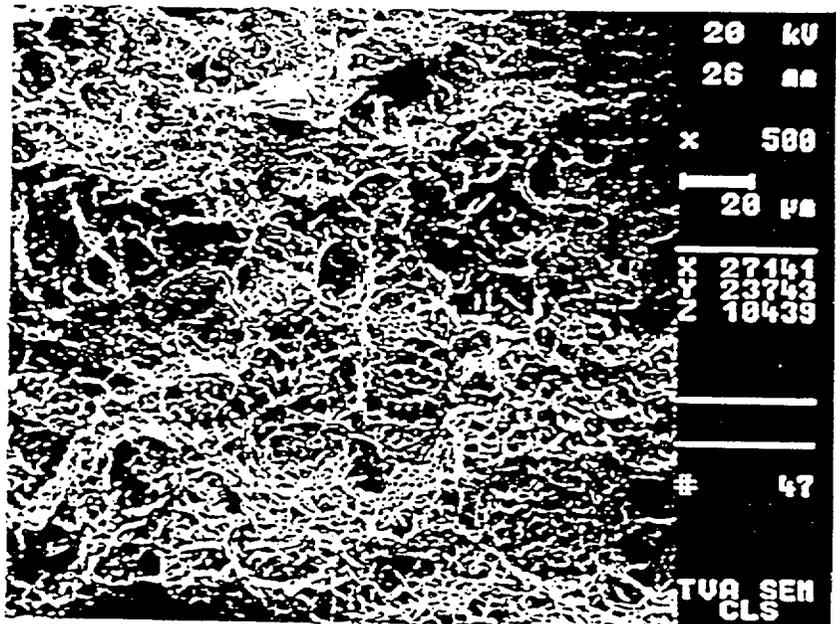


SEM photograph of fresh fracture surface showing intergranular separation (with some void coalescence) in the case of a screw that was removed from service in set "D". 2000X.

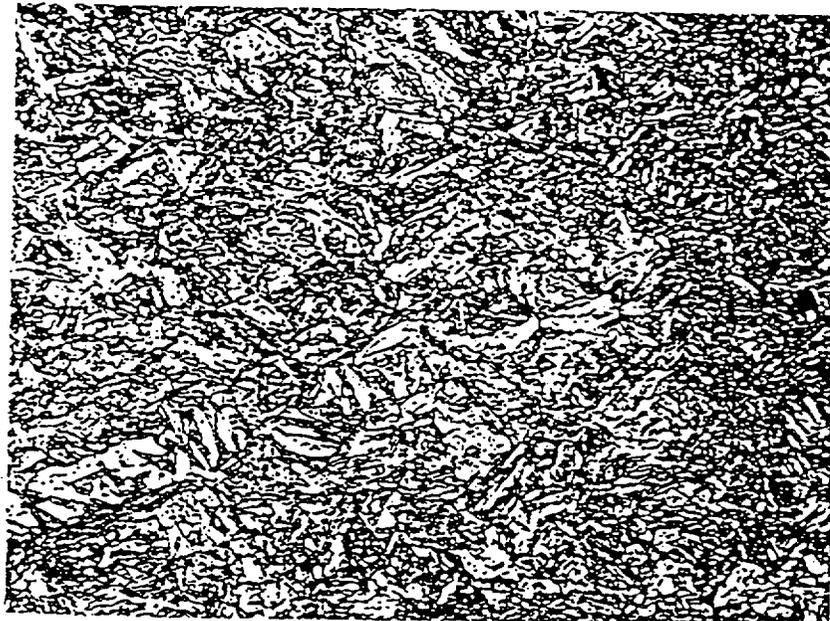
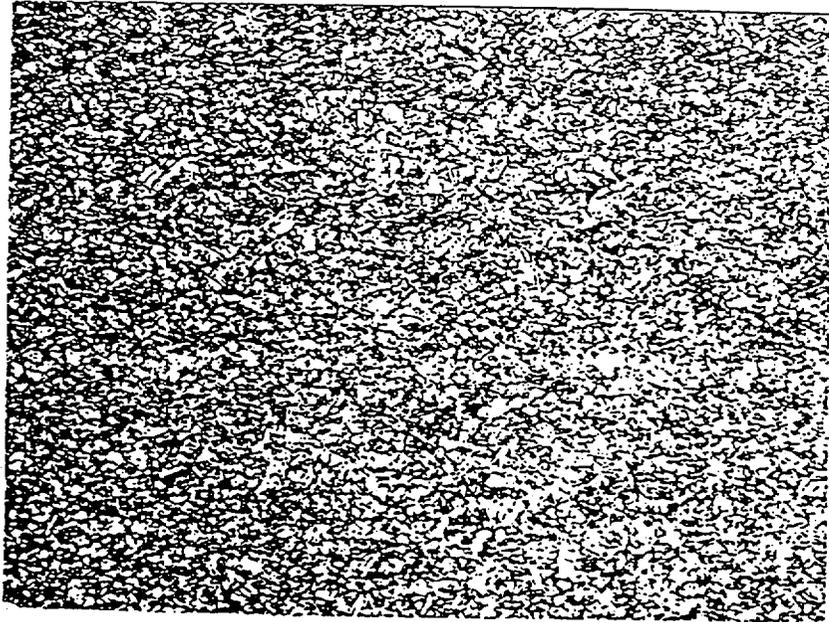
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SEM photograph of fresh fracture surface showing void coalescence in the core of a new screw. 500X



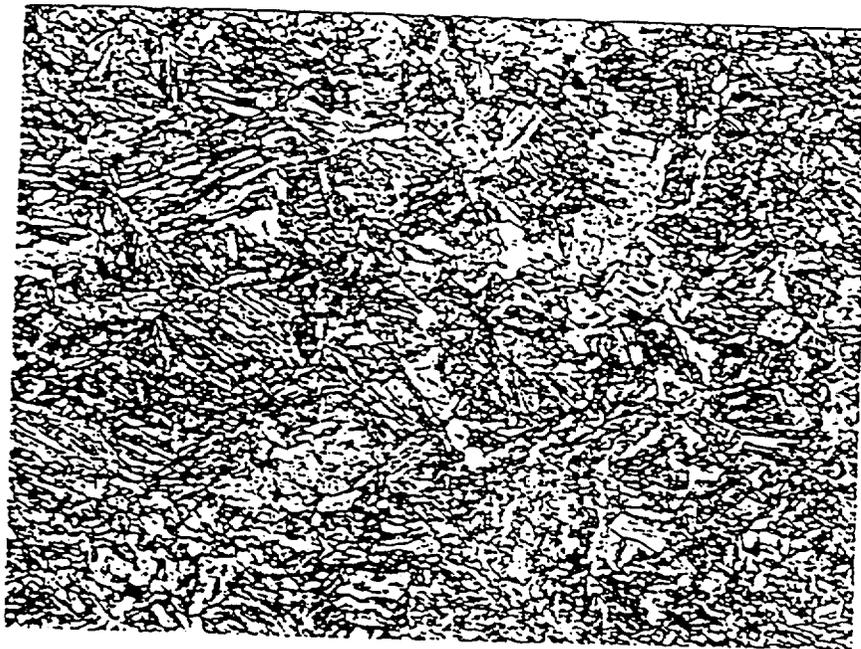
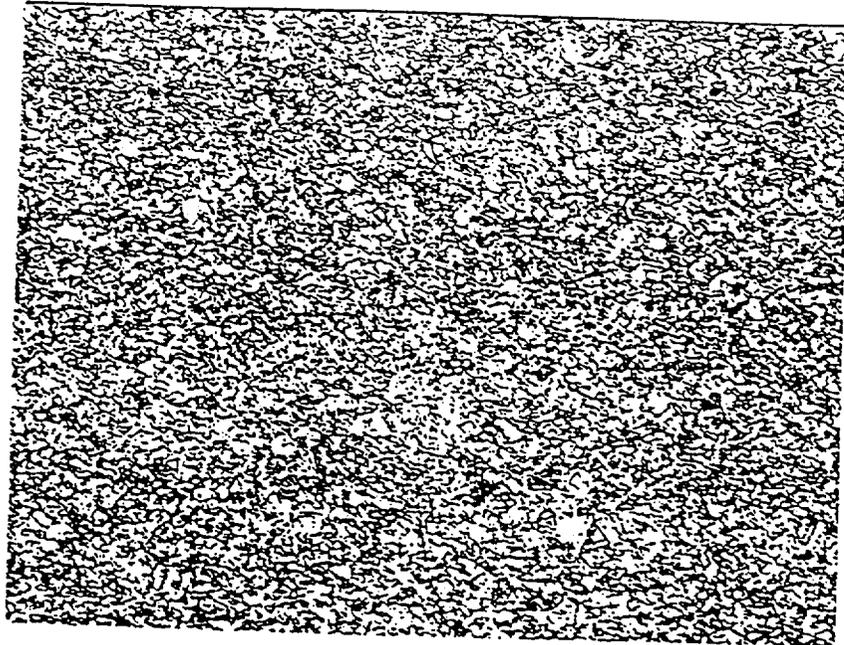
SEM photograph of fresh fracture surface showing mixed-mode separation (cleavage and void coalescence) in the core of a screw that was removed from service in set "D". 500X.



General microstructure of a typical new screw: tempered martensite. Top: 100X; Bottom: 500X.

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Figure 10: Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07. Laboratory Report No. 95-1021.



General microstructure of a typical screw that was removed from service in set "G": tempered martensite. Note microstructure was similar for screws in each set that was removed from service. Top: 100X; Bottom: 500X.

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Figure 11: Ice Condenser Basket Screws, Watts Bar Nuclear Plant, Unit No. 1. Customer Identification No. 95-07, Laboratory Report No. 95-1021.