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January 8, 1982

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Mr. James P. O'Reilly, Regional Administrator
U. S. Nuclear Regulatory Commission
Region II
101 Marietta Street, Suite 3100
Atlanta, Georgia 30303

Reference: Oconee Nuclear Station
Docket Number 50-269
RO-269/81-11, Supplement 3

Dear Mr. O'Reilly:

My letter of July 24, 1981, as supplemented on August 5 and October 5, 1981, provided Reportable Occurrence Report RO-269/81-11 concerning broken lower thermal shield bolts. This letter and attachment supplement these initial submittals and provide information regarding the completion of repair and examination efforts for Unit 1.

It is concluded that the mechanism of failure of the lower thermal shield bolts was intergranular stress corrosion cracking in a region of pronounced microstructure transition at the head-to-shank fillet. This microstructure transition resulted from the hot forging of heavily cold reduced bar stock used in the manufacture of the lower thermal shield bolts.

All repairs to the reactor vessel internals have been completed. The lower thermal shield bolts have been replaced with stud and nut assemblies. The upper thermal shield restraints will be left as is. The reactor vessel internals, in the repaired configuration, have been reanalyzed for stresses and found to conform to the ASME Code, Section III, Subsection NG for core support structures.

It has been concluded that the failure of other joints with A286 bolts is not of concern since thorough examinations have revealed no evidence of distress in these bolts. Also, these bolts were <u>not</u> manufactured from heavily reduced bar stock which caused the pronounced microstructure transition in the lower thermal shield bolts.

This supplement 3 will be the final supplement to RO-269/81-11.

Very truly yours,

William O. Parker, Jr.

NAR/php
Attachment

cc: B&W Regulatory Response Group:

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Attachment

Thermal Shield Lower Restraint Repair Task Information

Introduction and Summary

The purpose of this report is to summarize and supplement previous submittals regarding the Oconee 1 thermal shield bolt problem. The cause of the lower thermal shield bolt failure has been defined. Repairs have been completed and all other bolted joints using A286 bolts have been found to be satisfactory. It has been concluded that a significant safety concern did not exist.

The sections listed below present more detailed information regarding the cause of the thermal shield bolt failures and the repair status. Information is also presented regarding site and laboratory examinations and other engineering investigations.

I. Cause of Failure

II. Supporting Investigations

- a. Bolt Manufacturing History
- b. Site Inspections
- c. Laboratory Examinations

III. Repair Status

- a. Thermal Shield
- b. Guide Blocks
- c. Other A286 Joints

I. Cause of Failure

The Oconee I lower thermal shield bolt fractures were caused by intergranular stress corrosion cracking (IGSCC) in the bolt head to shank fillet region. IGSCC is classically produced by an unfavorable interaction of material condition, stress and environment. In the case of the lower thermal shield bolts, a unique processing condition has reduced the resistance of the bolt material to IGSCC in the fracture zone. Unlike processing of bolts used in other bolt circles, the lower thermal shield bolts were made by hot heading heavily cold reduced (40-50%) bar stock. The result of this processing was a pronounced microstructural transition which was coincident with the bolt head to shank fillet. The other A286 bolted joints have not been susceptible to this failure mechanism since thorough examinations have revealed no evidence of distress in these bolts. Also, these bolts were not manufactured from heavily reduced bar stock which caused the pronounced microstructure transition in the lower thermal shield bolts. Since higher stressed areas of the bolts were not initiation sites, stress is not considered to be a principal cause of the fractures. All fractures initiated in the microstructure transition zone are described above.

II. Supporting Investigations

The following provides a summary of other supporting investigations.

a. Bolt Manufacturing History

The report of October 5, 1981, noted that the larger grain sizes characteristic of the archive lower thermal shield bolts were not seen in one of two examined unbroken bolts taken from the Oconee Unit 1 lower thermal shield. Further examination of that bolt has shown that while the actual grain size appears finer than the archive bolt, it is still considered to be within the distribution of grain structure expected from a heat of that nature.

An examination of a failed lower thermal shield bolt shows a similar transition in grain structure to that of the archive bolt and shows the fracture tending to follow this transition region over a portion of the bolt diameter. The mechanism of failure is considered more sensitive to microstructure transition than to actual grain size since the initial failure area is intergranular. This microstructure transition in the fillet region where the fractures occurred is considered to be the major contributing factor. This is also supported by the fact that the stress concentration factor is higher in the threads than in the fillet region where the fractures occurred.

b. Site Inspections

Site inspections included measurements at selected locations of the thermal shield bolt threaded holes for perpendicularity with the lower grid flange. The angle from perpendicular varies from 0 degrees up to almost 1 degree. This deviation from perpendicular has been evaluated for its contribution to the bolt stresses.

The outer fiber stress state may be increased due to this angularity. However, the angularity is not considered to be a dominant factor in the failure mechanism of the bolts or a concern for the studs for two reasons:

1. 94 of 96 bolts failed even though direct measurements of 12 locations would indicate that most were perpendicular (within 1/3 degree).

2. Angularity was random and therefore the stress component caused by angularity was also randomly oriented; thus, this stress component would be expected to subtract at some locations from the bolt stresses caused by uniform circumferential moments at the bolted joint.

c. <u>Laboratory Examinations</u>

Laboratory examinations have been completed at the Babcock & Wilcox Lynchburg Research Center which have helped define the failure mode of the lower thermal shield bolts and confirmed the integrity of the other A286 bolts. These final examinations are summarized below.

1. <u>Scanning Electron Microscope (SEM) Surface Examination</u>

Four intact Oconee 1 bolts (upper restraint bolt, upper core barrel bolts, lower thermal shield bolts and flow distributor bolt) were examined using the SEM. Each bolt surface (fillet area and upper thread area) was carefully examined for surface flaws at a magnification of 230X. Higher magnifications were used in areas containing surface imperfections. No cracks were found within the fillet or thread root regions. A small intergranular crack (shown in attached Figure 2) was observed on the crest of one thread of an upper restraint bolt. The defect is isolated in the top portion of the thread where residual tensile stresses, formed during fabrication, may have led to the intergranular crack. The only other surface imperfections observed were two linear indications located on the thread crown of an upper core barrel bolt and lower thermal shield bolt. These linear indications were formed during bolt thread rolling operations.

2. <u>Metallography</u>

A comparison metallographic examination was performed on three lower thermal shield bolts (fractured bolt #9[illegible], whole bolt #94, and an archive bolt). Metallography was performed near the fillet area in the hot heading, heat affected zone (HAZ). All etching was performed with equivalent etching times and solutions so that differences in metallographic appearances (grain size, etc.) would be readily seen. The following observations applicable to all three bolts were made:

a. The grain size appears to be a maximum of ASTM-7 in the HAZ with the shank region generally much smaller.

b. Other than small differences in grain size, the samples appeared similar metallographically in the fillet region.

c. The cracking observed in the failed bolts initiates in the HAZ.

This metallographic examination confirmed the microstructure transition in the HAZ of the lower thermal shield bolts, and showed this HAZ to be the initiation site of intergranular cracking.

3. Examination of Bolt Surface Contaminants

A replication technique was used to extract loosely adhering surface contaminants. The replicas were placed on each bolt shank, stripped off and analyzed. The loosely adhering deposits on the replica were analyzed using an energy dispersive x-ray analysis technique. The composition of the loosely adhering material included the following elements:

Iron, nickel, chromium, titanium, silicon, and traces of potassium, aluminum, and chlorine.

The only questionable contaminant found was chlorine. Three of the eight bolts sampled contained trace amounts of chlorine. The source of chlorine is speculative (i.e., during service handling, shipment, etc.).

III. Repair Status

The following is a summary of the various repairs which have been completed.

a. Thermal Shield

All 96 bolts and locking clips on the lower thermal shield have been replaced with stud and nut assemblies in accordance with the plans described in the report of October 5, 1981. The thermal shield was pulled down on the lower grid shell forging flange during the installation and tensioning of the new lower thermal shield studs. This closed the gap between the lower thermal shield and the lower grid shell forging flange. The affected areas of the reactor vessel internals have been reanalyzed for stresses and these have been found to be within the limits of the ASME Code, Section III, Subsection NG for core support structures.

Contrary to the report of October 5, 1981, one thermal shield bolt head remains missing and the loose parts summary in the report of August 5, 1981, remains valid.

The integrity of the lower thermal shield attachment studs without upper thermal shield restraint has been evaluated as part of the above reanalysis. All sources of stud stresses were combined including:

1. Dynamic pressures from reactor coolant pump operation
2. Random turbulence
3. Gamma heating
4. Pre-load
5. Bolt hole angularity.

This analysis employed both an analytical approach and experimental results from previous hot functional testing. The effects of fluid-structure interaction was accounted for by using the "hydrodynamic mass method for weakly coupled systems."

This analysis showed that the absence of the upper restraint would result in slightly reduced response frequencies of the thermal shield in the shell modes and slightly increased amplitudes. The stresses in the lower thermal shield attachment studs were not increased significantly. The calculated stresses were all within allowable values and are in compliance with ASME Code Section III, Subsection NG for core support structures.

Calculations have also shown that this noted change in the thermal shield response will slightly increase the stresses in the core barrel to lower grid shell forging bolts while slightly lowering the stresses in the core barrel to core support shield bolts. These changes are not considered to be significant in either case.

In summary, the above evaluation confirmed that the upper end of the thermal shield can be left as is (see Figure 1) even though inspections indicate loss of the original interference fit condition.

b. Guide Blocks

In addition to the missing guide block (W7R) as reported in the letter of October 5, 1981, a second guide block (W7L) along with its dowel and bolt was removed in accordance with the plan as explained in the October 5 letter. Ultrasonic tests of the bolt for this guide block had resulted in an indication requiring further evaluation. Extensive dye penetrant (PT) testing on the bolt following removal failed to show any surface defect. As a result, the W8L guide block (whose bolt had also shown a lesser UT indication) was not removed.

A portion of the shank of the missing guide block bolt is still in place. Attempts to remove it failed and the bolt portion was left in place.

c. Other A286 Joints

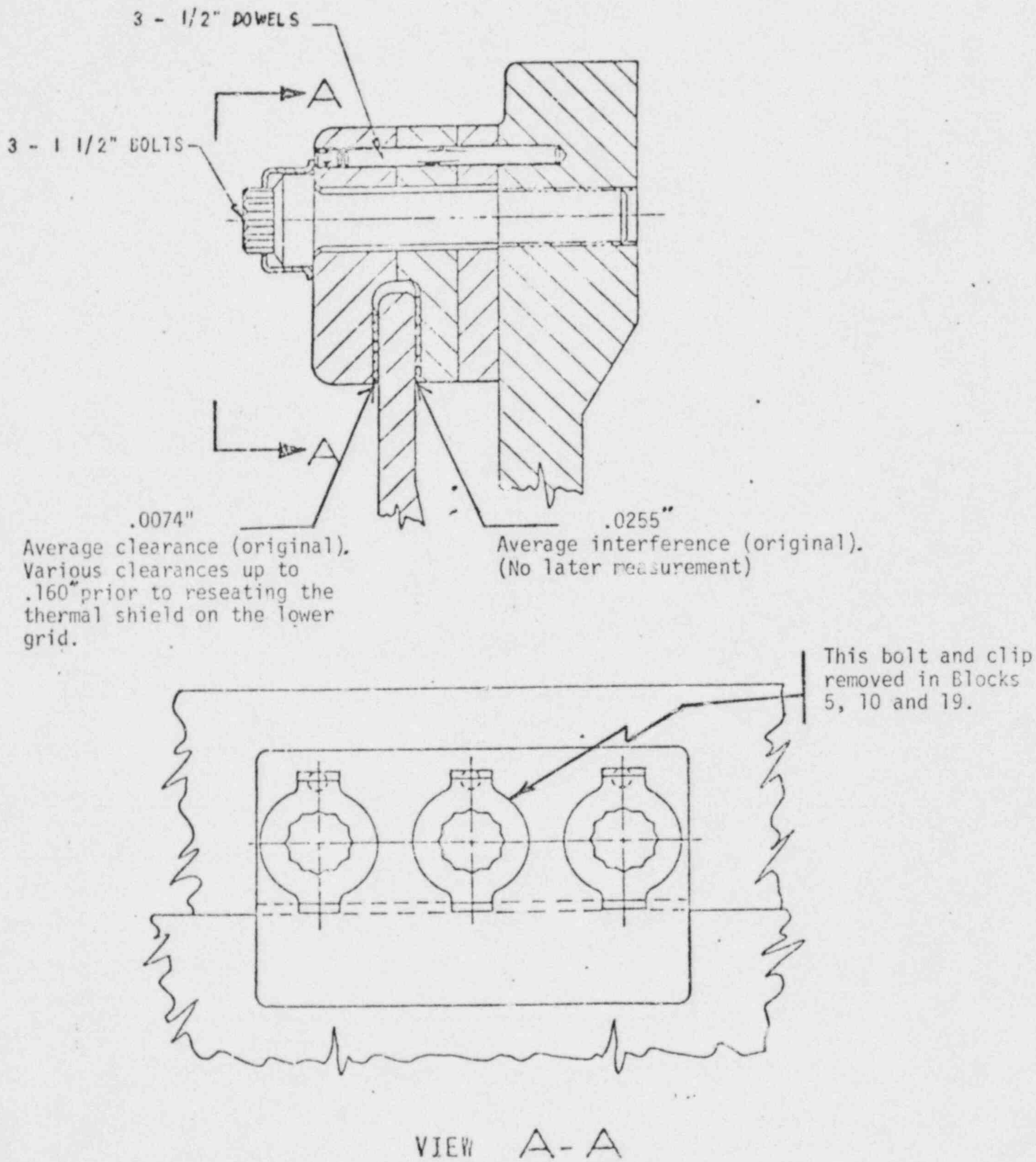
The following bolts have been removed as part of the sampling program:

Joint	Bolts
Upper thermal shield restraint (MK 375)	1 center bolt from the number 5, 10, and 19 assemblies (20 assemblies total). These three holes have been permanently plugged to prevent flow through them.
Core barrel to core support shield (MK 256)	Numbers 1 and 60 (120 total)
Flow distributor to lower grid assembly (MK 390)	Number 2 (96 total), number 47 locking device also removed in preparation for removal of bolt 47. Bolt 47, however, would not turn under high torque, and could not be removed.

Ultrasonic inspections, laboratory examinations, and a detailed reevaluation of the stresses in these bolted joints have rendered them acceptable for continued operation, including consideration that these sample bolts will not be replaced.

The above examinations indicated that intergranular cracking is limited to the lower thermal shield bolts.

Figure 1 Thermal Shield Upper Support



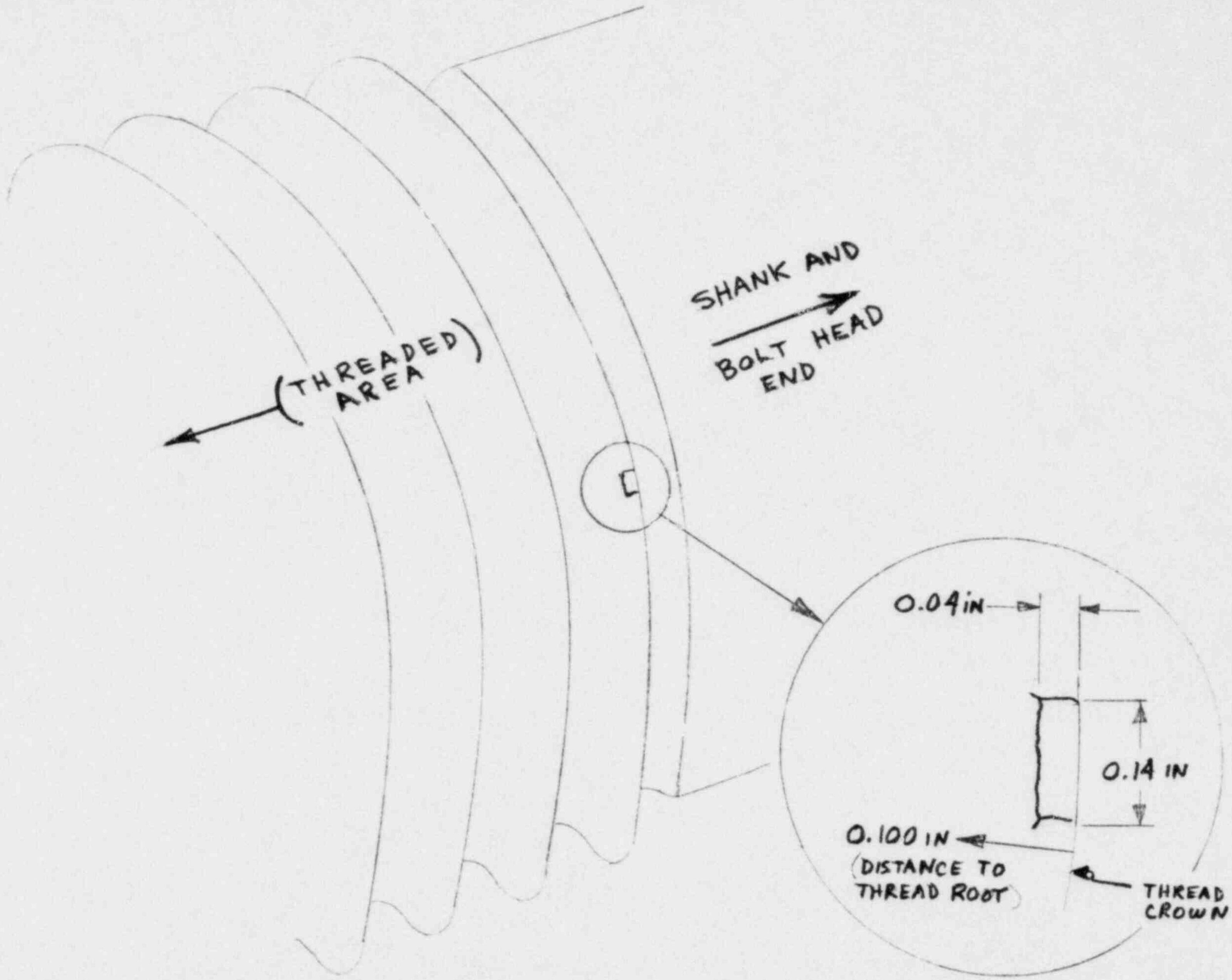


FIG. 2

UPPER RESTRAINT BOLT - SMALL INTERGRANULAR CRACK LOCATED IN TOP PORTION OF THREAD.