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EXAMINATION OF A BOLT WITH BORIC ACID ATTACK FROM THREE MILE ISLAND NUCLEAR GENERATING STATION

by

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Examination of a Bolt with Boric Acid Attack
From Three Mile Island Nuclear Generating Station

1. Introduction

The U.S. Nuclear Regulatory Commission (NRC) contracted with Brookhaven National Laboratory (BNL) to confirm the root cause analysis of a failed bolt at Three Mile Island Nuclear Generating Station (TMI). The root cause analysis was conducted by TMI. Supplementary documentation supplied by NRC indicated that the bolt was removed from a valve in the pressurizer at TMI. The bolt was stated to be 5/8 inch diameter, A-193, B7 material.

BNL testing and analysis was to consist of:

* measuring the hardness of the bolt,
* determining dimensional characteristics according to System 21 and System 22 of ASME B1.3M (Ref. 1), and
* SEM examination of the bolt for its failure mode.

2. Description of Stud Pieces

Two pieces of the "bolt" to be examined were received at BNL, accompanied by the paperwork shown as Figure 1. According to this document, the pieces were stated to be item #2 in the drawing having 46,000 disintegrations per minute (dpm) smearable contamination and a contact reading of 4 millirem/hour (mrem/hr). The "bolt" was actually a threaded stud, and was covered with rust-colored corrosion. A BNL drawing of the stud pieces "as received" is shown in Figure 2. This figure also indicates the section cuts for the tests described below.

The tests for dimensional characteristics require clean materials, so the stud pieces were decontaminated in preparation for thread gaging tests by washing with an alkaline detergent solution (Quick Off, The Quick Chemical Co.) and hand scrubbing with a wire brush. Following this they were soaked in a solution containing ammonium hydroxide, EDTA, and Alconox and wiped off. These activities reduced smearable contamination to less than 100 dpm Dose rate at contact with both pieces was less than 0.7 mrem/hr.

The bolts were photographed following decontamination, as shown in Figures 3, 4 and 5. In spite of the cleaning for decontamination purpose, the surfaces of the nut and stud pieces exhibited significant corrosion. Stud piece A (no nut) showed visual evidence of having been stretched, with the threads deformed, as if they had been stripped. The threads on the stud piece B with the nut in place were deformed (possibly due to galling) on the side of the nut with the fracture face present. (The ASM [Ref. 2] defines galling as "developing a condition on the rubbing surface ... where excessive friction between high spots results in

localized welding with subsequent spalling and a further roughening of the surface.") The threads on the opposing side of the nut appeared to be undamaged, except for the surface corrosion.

3. Dimensional Characteristics

The two pieces of threaded stud were inspected according to System 21 and System 22, of ANSI/ASME B1.3M (Ref. 1).

System 21 Test

System 21 requires testing for GO maximum material, NOT GO functional diameter, and minor diameter. GO and NOT GO threaded ring gages, respectively, can be used for the first two parameters, while an optical comparator can be used for the minor diameter.

GO and NOT GO gages are functional tests, in which a bolt or threaded stud is threaded into the gage, which resembles a threaded nut. The GO gage, which determines that maximum material is not exceeded, is passed when the bolt of interest can be threaded through the gage and beyond. The NOT GO gage is passed when the bolt of interest can not be threaded into the gage for three turns. The NOT GO gage measures functional diameter.

A threaded ring gage, size 5/8-11-UNC(2A) (TG-7, BNL# 1T462, calibration expiration 2/15/95) was used for the GO and NOT GO tests. Stud piece B (with the nut present) was tested on both sides of the nut. On the longer threaded side with the fracture face, the stud failed the GO test. The short threaded side easily fit the GO gage, but had insufficient thread to pass all the way through the gage, which constitutes a failure. Stud piece A failed the GO gage test, since it could not be threaded all the way through the gage.

According to the ANSI standard, the "screw thread of a threaded product shall be acceptable when each of the thread characteristics specified in the designated gaging system is found acceptable." The failure to fulfill one characteristic thus constitutes an unacceptable product. Further tests under System 21 were stopped.

System 22 Test

System 22 calls for measuring GO maximum material, minimum material, and minor diameter. The test for GO maximum material already failed both stud pieces under System 21 above, so there was no need to pursue the test further. However, the optical comparator was used to measure major and minor diameters, and thread depth. These results and the specified values and tolerances for 5/8-11 UNC external threads are shown in Table 1.

The measurements indicate that the only undisturbed threads (starter side of stud piece B, with the nut) are too big for the specified minimum diameter. This could explain the

galling observed on the fracture side of the nut, if the nut had been run up the stud and then backed off.

Following this test, the stud pieces were sectioned for scanning electron microscopy (SEM) and hardness testing.

Table 1
Measurements and ANSI/ASME Specifications* for 5/8-11 Threads
(inches)

	Major Diameter	Minor Diameter	Thread Depth
Stud w/o Nut	0.5993	0.5109	0.0468
Stud with Nut: Starter Side	0.6220	0.5210	0.0490
Stud with Nut: Fracture Side	0.5962**	0.5116**	0.0363**
ANSI Specification Maximum Minimum	 0.6234 0.6113	 0.5152	 .05413

* Ref. 3.
** Average of two measurements.

4. Hardness testing

Hardness tests were conducted on the two stud piece ends cut as shown in Figure 2, such that the cut piece was as long as the thickness (5/8 in). Test results are shown in Table 2.

The initial set of test readings for Section C (stud piece A) were inconsistent, and microhardness measurements were conducted on two separate instruments, after mounting and polishing the samples. After the microhardness measurements, the Rockwell hardness tests were repeated on section C using the polished stud specimen after it was removed from the mounting material.

The Rockwell C values for stud section C are lower as measured using the hardness tester and more scattered. Microhardness values for section C are more consistent and approximately equal to the values found for Section D (stud piece E). The lower values for the Rockwell C tests reflect the fact that the bulk hardness for piece C is lower. Microhardness tests measure the hardness of much smaller areas of material, and the results

can be affected by precipitates or harder phases. Rockwell C tests use larger indenters that measure more material; thus, they can be considered as approaching a bulk measurement.

The consistent microhardness values for stud piece C and Rockwell C values for Section D (stud piece B) fall within the range of 33 to 36 on the Rockwell C scale. The corresponding approximate tensile strengths for these values are 150 to 164 ksi (Ref. 4). The lower average value on the Rockwell C tester was 25.5, which corresponds to approximately 124 ksi. The TMI stud material is stated to be ASTM A193 Class B7. While ASTM A193 does not specify maximum hardness values for Class B7, it does specify a minimum tensile strength of 125 ksi for threaded fasteners less than 2.5 inches diameter (Ref. 5). The tensile strength values estimated from hardness measurements indicate that the bolting material was within specification.

Table 2
Hardness Test Results

Rockwell C Hardness	Rockwell C Hardness (Knoop)*	Rockwell C Hardness (Vickers**)	Rockwell C Hardness
Stud Section C			
22 29 29 22	36.3 (363.3) 35.5 (356.1) 34.9 (350.1) 36.2 (362.7)	32 (313.8)	24 22 30 28
Avg. 25.5	Avg. 35.7		Avg. 26
Stud Section D			
33 33 34 33	36.9 (369.3) 36.8 (368.1) 36.6 (366.0) 35.9 (359.4)	35.5 (347.7)	Not tested
Avg. 33.3	Avg. 36.6		

* First microhardness measurement calibrated as Knoop hardness in parentheses. Rockwell C values calculated from these.

** Second microhardness measurement calibrated on Vickers scale is in parentheses. Rockwell C value calculated from this.

5. Scanning Electron Microscopy and Visual Inspection of Fracture Faces

Stud pieces A and B were sectioned as shown in Figure 2, to remove the fracture faces for scanning electron microscopy (SEM). Figure 3 is a side view of the two pieces before sectioning, and after decontamination.

The visual appearance of the fracture faces (Figures 4 and 5) indicate that the stud pieces were from two separate failed studs. Fracture face B (Figure 4, from the stud piece with the nut) was heavily corroded around the threads, but the fracture face appeared as the tip of a relatively intact central core. Fracture face B is relatively flat compared to face A (Figure 5) on the other piece. Face A is pointed, being much smaller in area, and is surrounded by a larger area of general corrosion. The general corrosion seen in these and the SEM photomicrographs below is consistent with the wastage corrosion seen in other cases of component failures due to boric acid attack (Ref. 6).

SEM photomicrographs of the fracture faces are shown in Figures 6 and 7 (both at 22X magnification). Fracture face B (Figure 6) has two areas with ripple marks which suggest a fatigue-assisted failure. The non-corroded portions of both faces A and B indicate ductile rupture. The SEM micrographs of both fracture faces confirm that they are from two separate studs.

Visual and SEM examination of the two fractures confirm the presence of general corrosion in both pieces which contributed to the failure of the studs. Face A appears to have undergone more corrosion and some wear before failure, which seems to have been induced by tensile stress. In Face A, the wear before failure is evidenced by the stretched and missing threads on the stud. Face B, in addition to the possible fatigue marks in two locations, has indications of a torsional stress in its overall appearance. It may have failed when the stud was removed.

6. Summary

Two stud pieces were tested for physical characteristics and examined for evidence of boric acid attack. Both pieces failed ANSI/ASME gaging tests for dimensional characteristics, indicating that the stud piece did not meet ANSI specifications. Because the gaging tests were conducted on failed stud pieces with obvious corrosion attack, no statement can be made about stud thread acceptability before the studs were put in service. Tensile strength values estimated from Rockwell C hardness measurements indicate that the stud pieces were within the tensile specification for A-193, B7 materials. The corroded state of the stud pieces was consistent with boric acid attack, and SEM examination of the stud fracture faces showed that they failed by ductile rupture.

References

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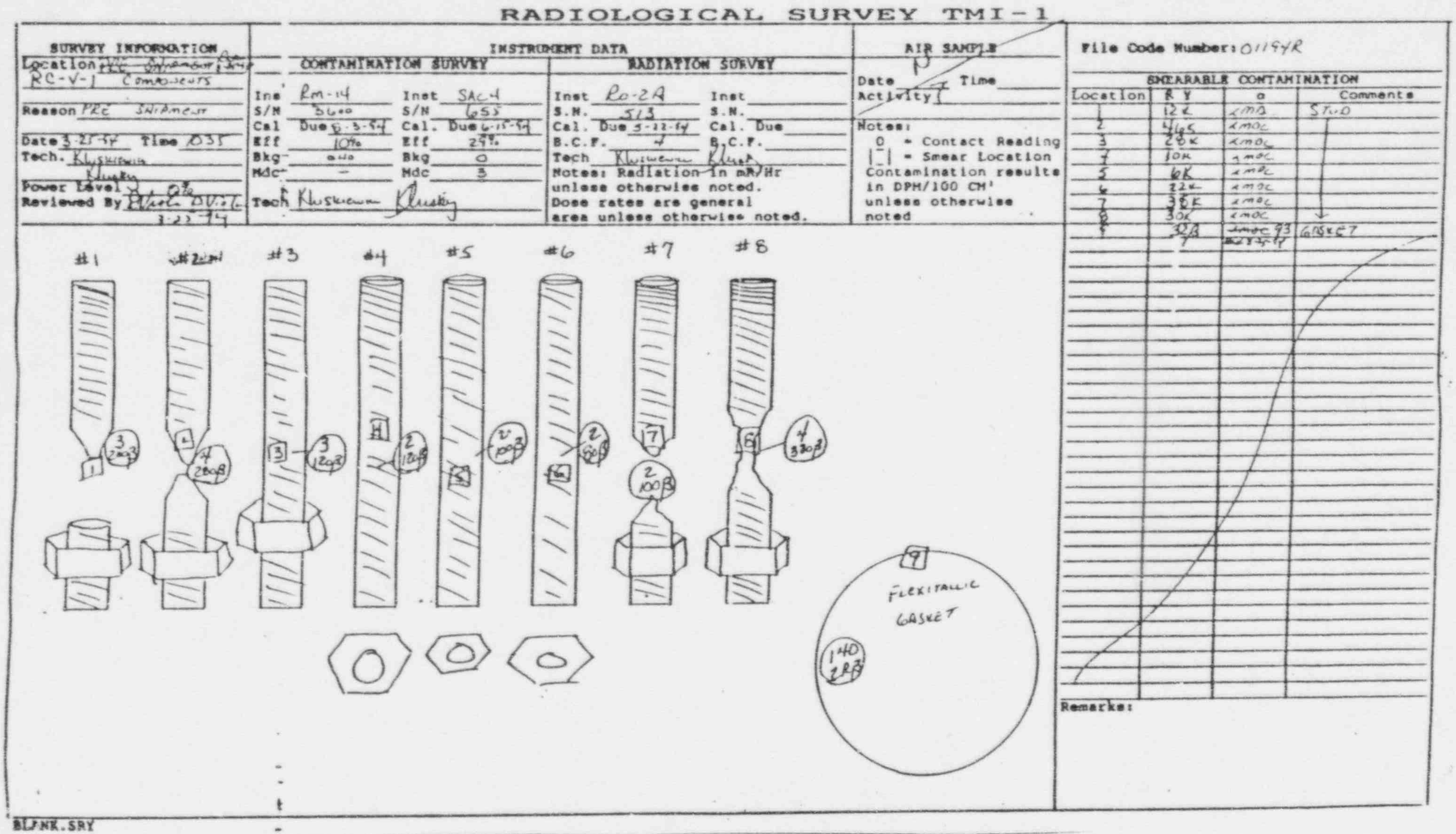

Figure 1. Documentation received with stud pieces.

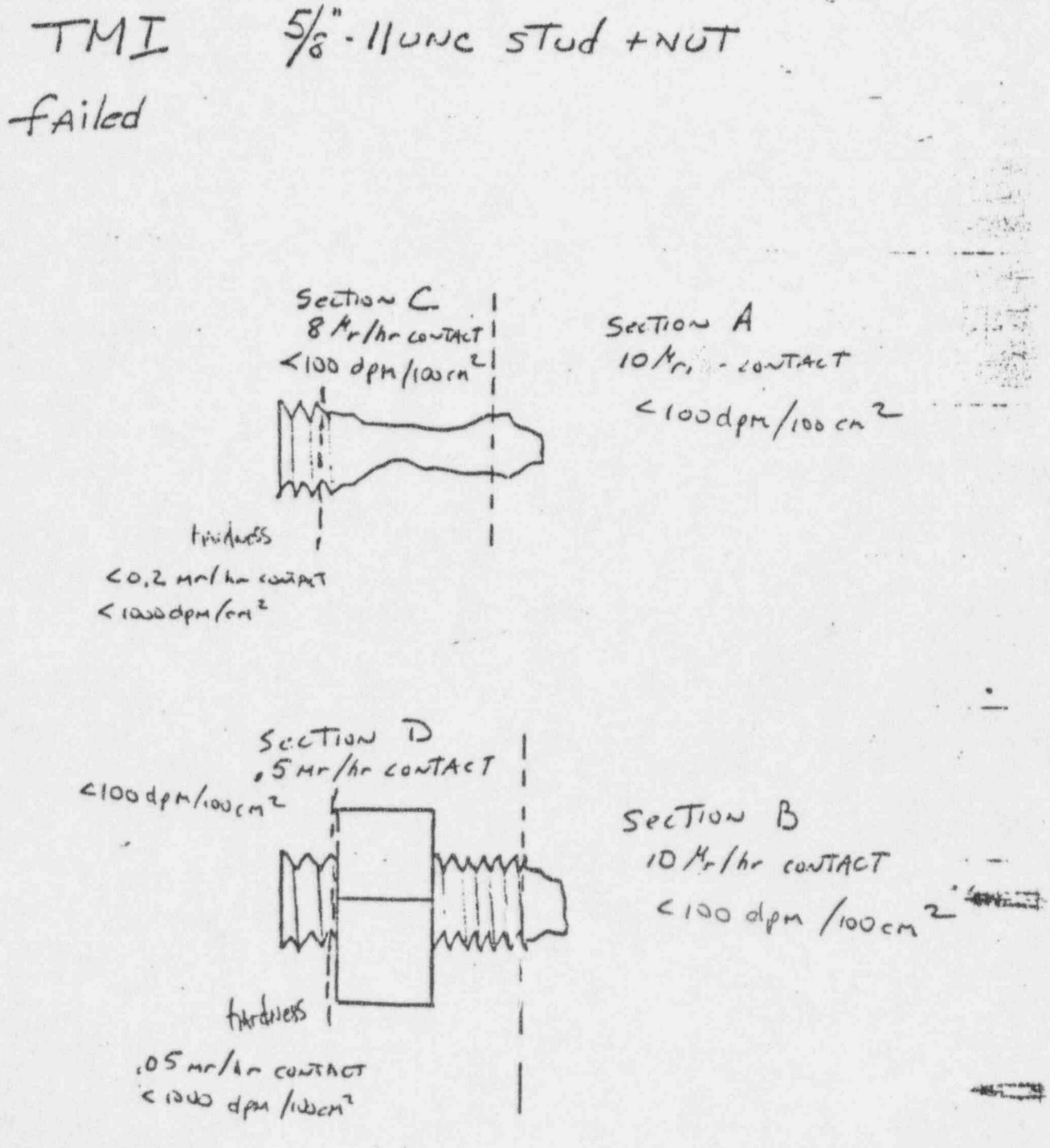

Figure 2. BNL Drawing of TMI Stud pieces showing cuts for hardness test and SEM samples.

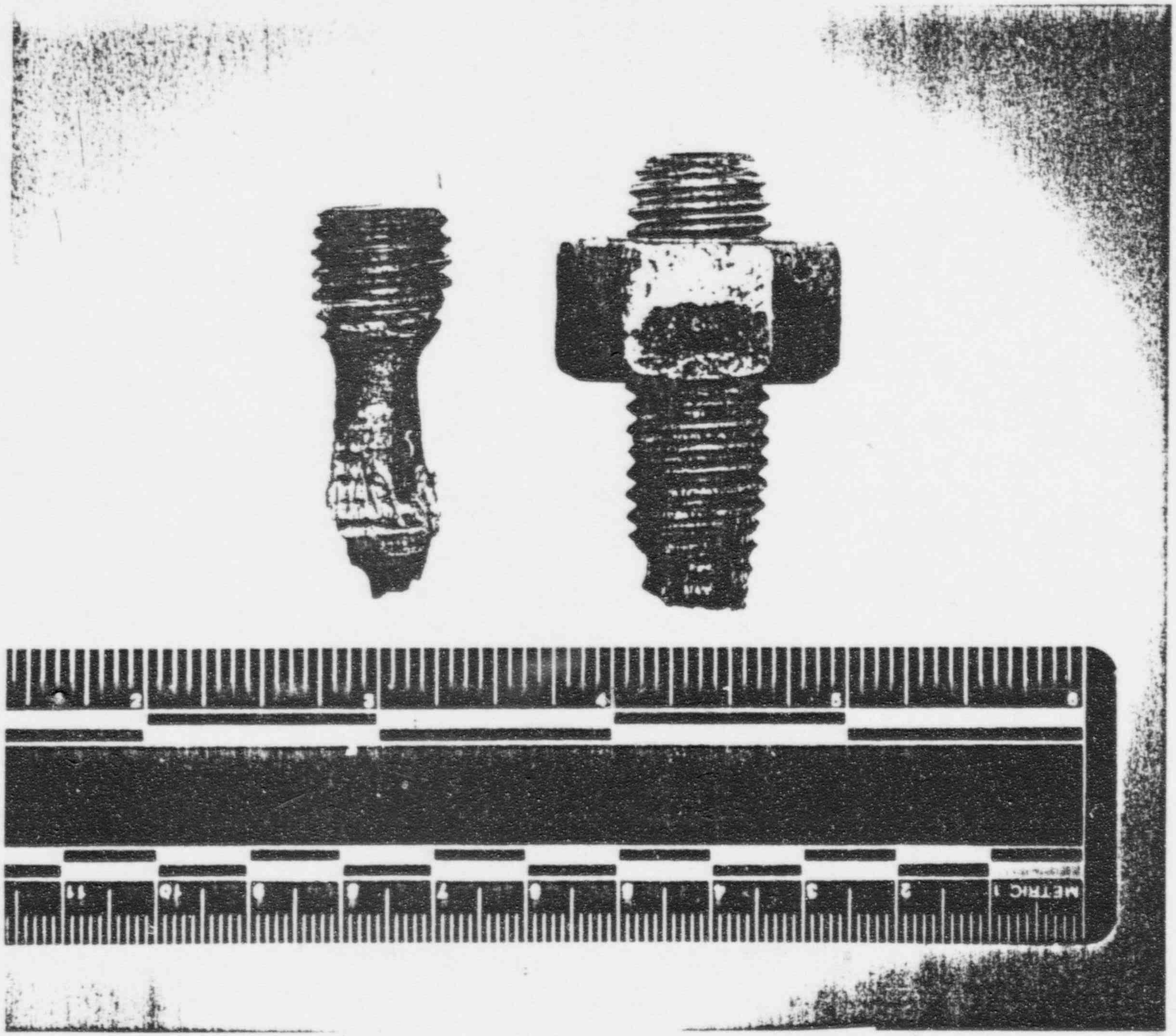

Figure 3. Side view of TMI stud pieces.

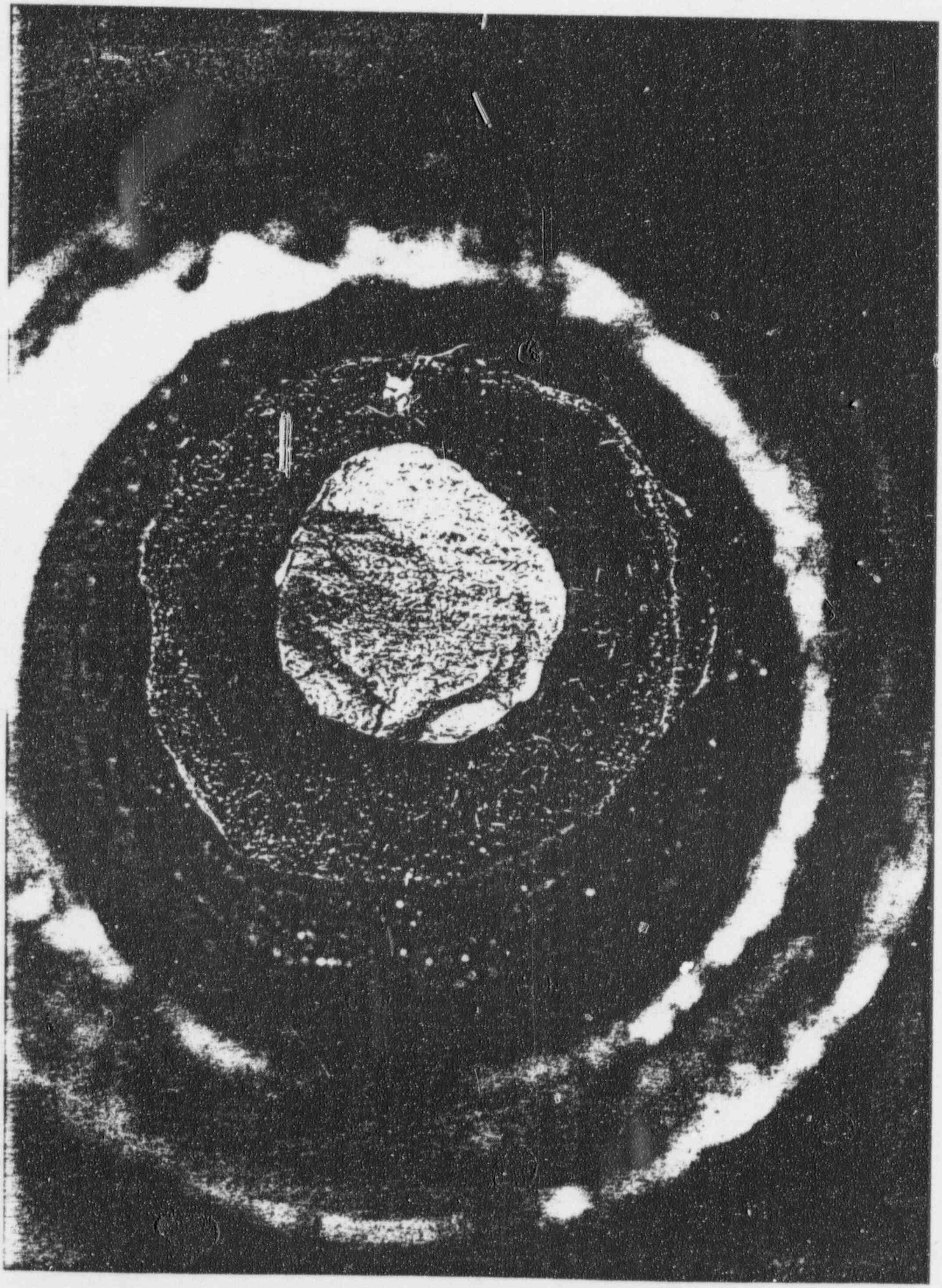

Figure 4. Fracture face of TMI stud piece B.

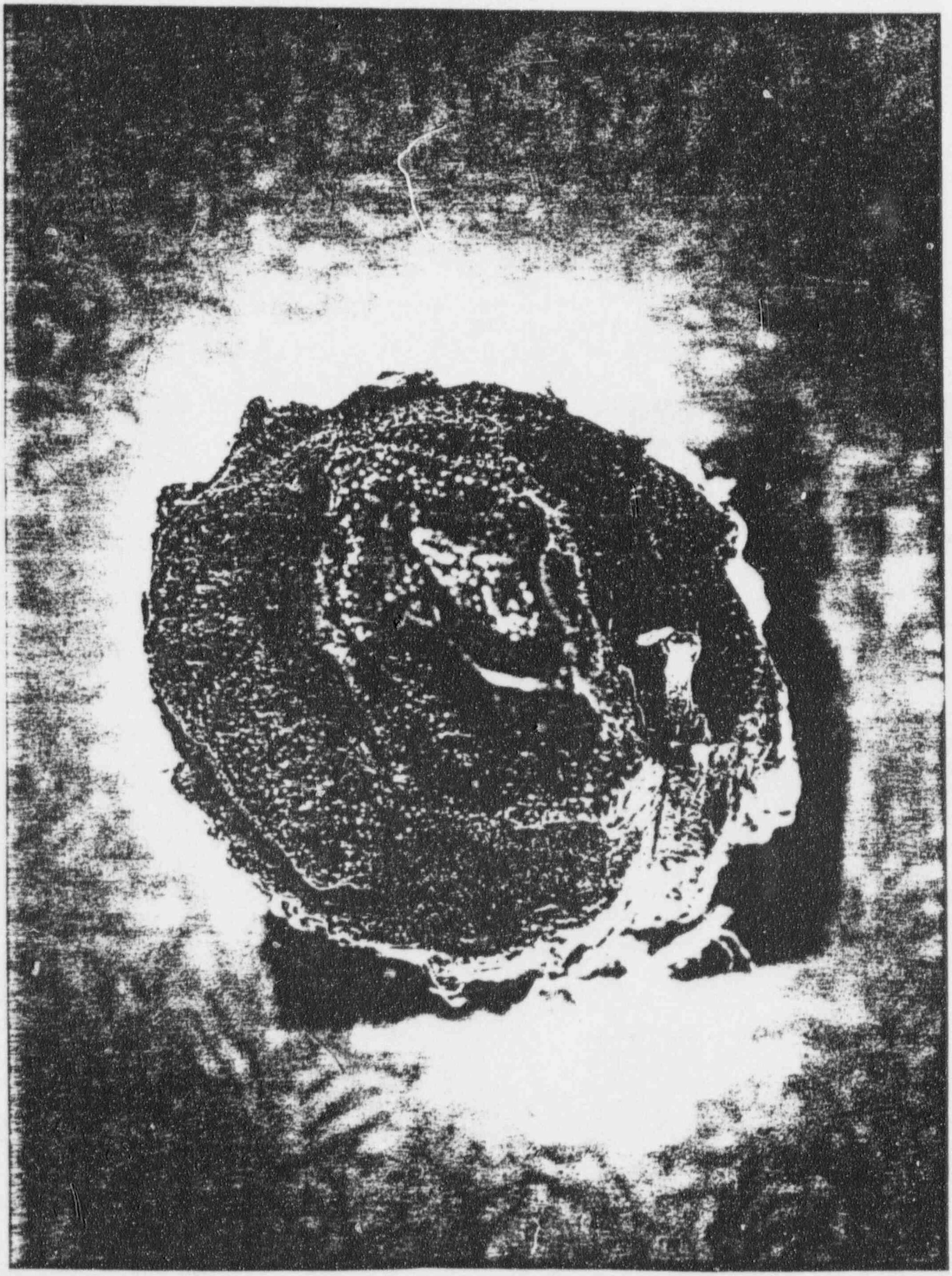

Figure 5. Fracture face of TMI stud piece A.

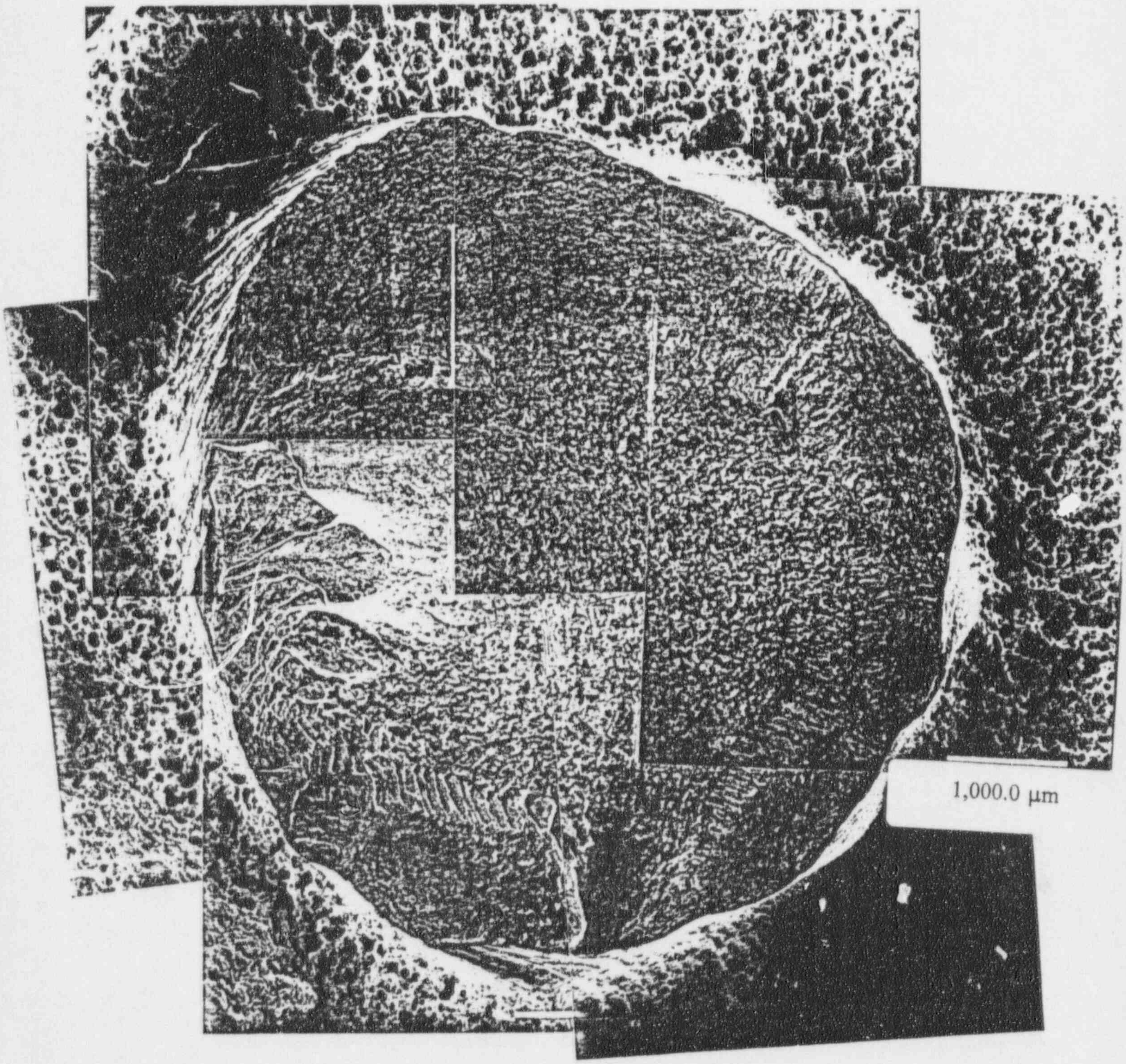

Figure 6. SEM photomicrograph of stud fracture face B (25 kV, 22 x magnification)

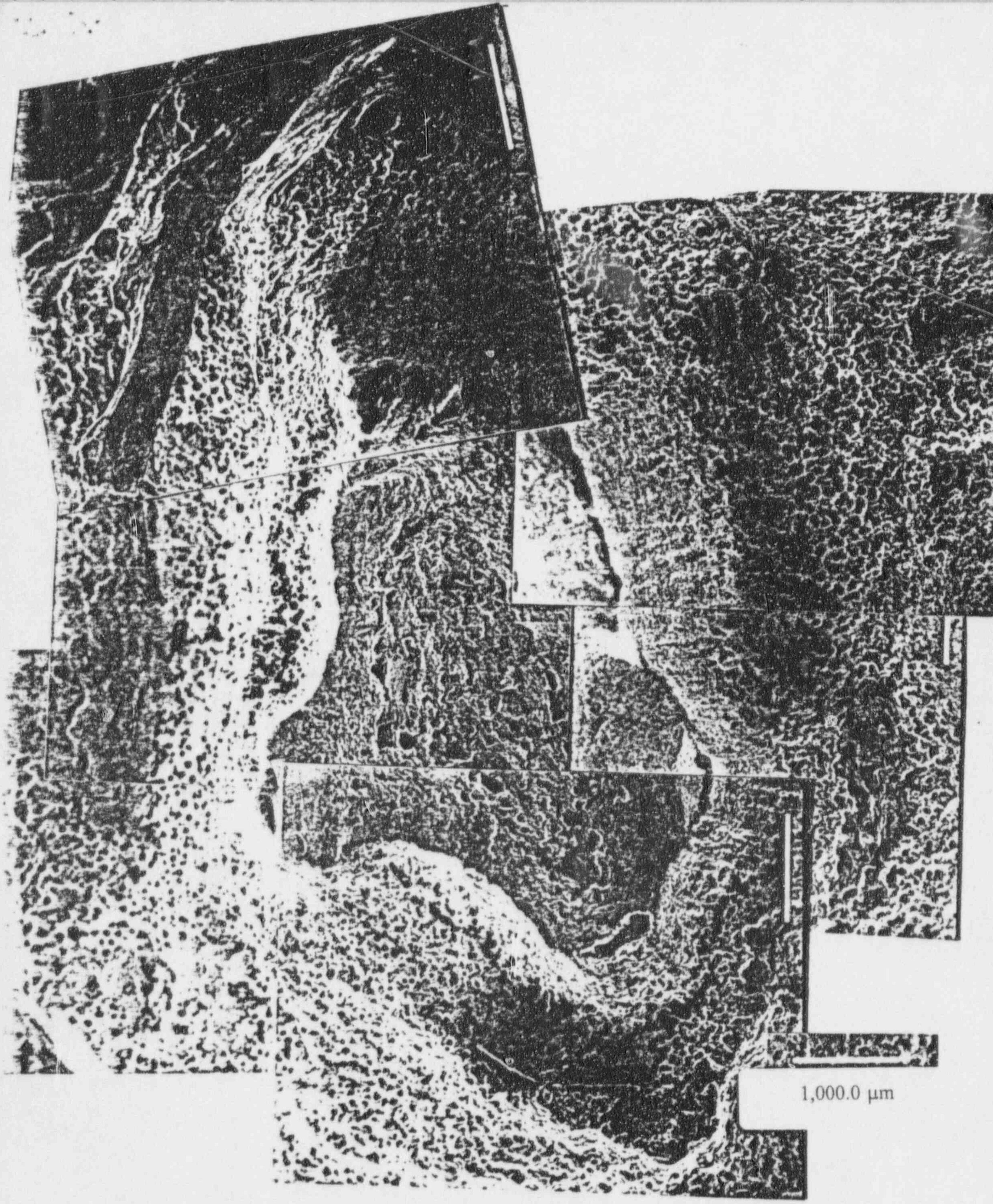

Figure 7. SEM photomicrograph of stud fracture face A (25 kV, 22 x magnification)