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Westinghouse Atomic Power Divisions

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FRACTURE MECHANICS EVALUATION OF REACTOR VESSEL STEELS TECHNICAL PROGRESS REPORT FOR THE PERIOD ENDING

SEPTEMBER 30, 1966

NOTICE
This report was received under the provisions of the Joint USAEC/Euratom R & D. arrangement and is subject to the terms thereof.

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PROGRAM DESCRIPTION

An experimental program will be performed directed towards further development and evaluation of a fracture mechanics approach to the problem of brittle fracture of reactor vessel materials, based upon the use of modified Wedge Opening Loading (WOL) specimens. Experimental testing of a group of reactor vessel steels will be performed to investigate the application of the fracture mechanics technique to these materials in both the unirradiated and irradiated conditions. Because of test reactor dimensional constraints, scaled-up specimens can only be used to obtain pre-irradiation data; therefore, irradiation effects will be determined on small specimens.

Testing in the unirradiated and irradiated conditions will be conducted to determine the variability in fracture toughness of various materials. Materials to be investigated will include base metal, weld and heat affected zone samples from two different heats of a nickel modified, manganese-molybdenum steel and a European forging grade material. Tensile, Charpy V-notch and drop weight specimens from those materials will also be included in the program in order to provide correlation data.

EUFM-100 - Program Management (Summary of Progress)

W. F. Eanes

This is the first technical progress report on a USAEC-Euratom joint program on fracture mechanics.

Program management is not discussed in this technical progress report, since separate reports emphasizing the administrative aspects of the project are published monthly for limited distribution.

Progress during the period ending September 30, 1966 may be summarized as follows:

1. Because the operating schedule for the Carolinas-Virginia Tube Reactor (CVTR) was not compatible with the irradiation program, another source for irradiation services was sought. After soliciting and receiving proposals from General Electric and Babcock and Wilcox, it was decided to utilize the latter's test reactor, BAWTR, on the program and a subcontract for such services was placed.

2. The specific materials for use in the manufacture of test specimens were selected and agreement was reached with the AEC on these selections. Procurement of the materials was initiated. Included are two different heats of SA533 Grade B Class I (12" and 8" thick), the nozzle cutouts from the NOK vessel and correlation monitor material. All but the 12" thick SA533 material has been received and fabrication of specimens initiated.

EUFM-200 - Irradiation and Analysis

W. S. Hazelton, T. R. Mager, R. E. Schreiber, S. E. Yanichko

This Task provides for the planning of the irradiation experiment, including the design, manufacture and assembly of the irradiation capsules. Technical direction shall be also provided during the capsule irradiation, capsule disassembly and the post-irradiation examination of specimens. Analysis and evaluation of the experimental results will be performed under this Task.

In the original proposal, the Carolinas Virginia Tube Reactor (CVTR) was discussed as a possible source for the irradiation of test specimens, assuming compatibility of the experiment with the reactor's schedule. Early in the work under this Task, it was determined that CVTR could not be used for the irradiation because the experiment would interfere with the planned fuel cycle schedule. Several locations in the core were considered in an effort to avoid this conflict, but were rejected when it was determined that the access ports were too small to accommodate the irradiation capsules.

In view of the above, other possible irradiation sources were considered and negotiations conducted for the required irradiation. Requests for quotations were submitted to General Electric (GETR) and Babcock and Wilcox (BAWTR) for the design, fabrication, and irradiation of the capsule assemblies. BAWTR submitted the lower bid, which was deemed to be reasonable on the basis of a cost analysis. In addition, discussions were held with the New York and Idaho Operations Offices of the AEC with respect to the feasibility of using an AEC facility for the irradiation. The AEC New York Operations Office subsequently approved the proposal to perform the irradiation at BAWTR, and a contract was awarded.

Work has been initiated at BAWTR on the preliminary design of capsules, and preparation of a dummy capsule to check out temperatures, neutron flux, and instrumentation has been started. A tentative work schedule is given in Figure 1.

Present plans are that each capsule or assembly irradiated will contain:

a) Three (3) 1T WOL specimens
b) Six (6) 1X WOL specimens
c) Four (4) .252 diameter tensile specimens
d) Sixteen (16) Charpy V-notch impact specimens

The capsules will also contain steel filler blocks to eliminate void spaces. Each capsule will be separately canned, in the shape of rectangular blocks approximately 3.3" x 1.0" x 14.7". Electric heating will be provided in a manner to maintain a constant and uniform temperature of $550^{\circ}F\ ^{+0^{\circ}}_{-10^{\circ}}$. Thermocouples and flux monitors will be embedded in the capsules to monitor and record temperature and neutron flux levels during the irradiation.

TENTATIVE SCHEDULE FOR FRACTURE MECHANICS SPECIMEN IRRADIATIONS

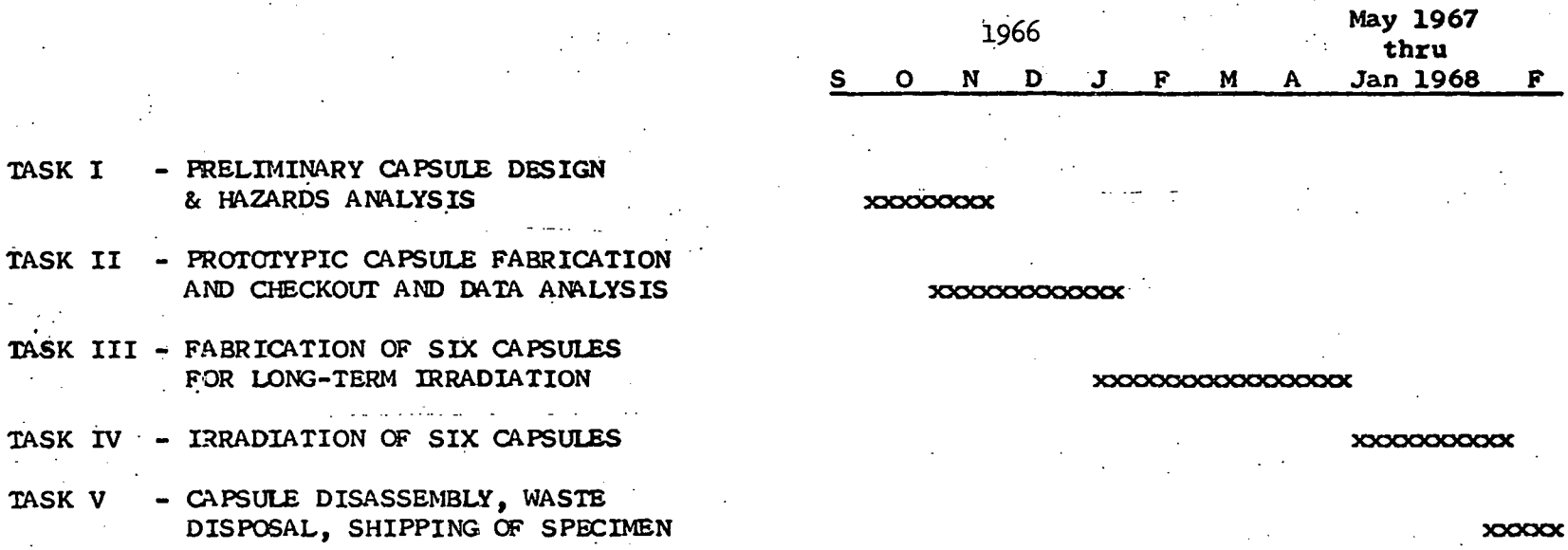


Figure 1 Tentative Work Schedule

EUFM-300 - Pre-Irradiation Testing

W. S. Hazelton, T. R. Mager, S. E. Yanichko

Under this Task, the material required for the test specimens will be procured and the pre- and post-irradiation specimens will be manufactured. The testing of the pre-irradiation specimens will be carried out and the results developed for analysis and evaluation under Task EUFM-200.

The procurement of materials proceeded as planned. The following materials were selected as suitable for the program, and were accepted by the AEC.

1. SA533 Grade B Class I (MnMo with Ni, quenched and tempered). Twelve (12) inch thick plate being procured by ORNL for the AEC from Lukens Steel Company, and to be heat treated by Combustion Engineering according to present commercial practice. This plate will be used to determine the variations in properties through the thickness, and effects of such variations on irradiation behavior.
2. SA533 Grade B Class I. Eight (8) inch thick plate produced by Lukens Steel Company and well documented with respect to manufacturing practice and mechanical properties.
3. European Steel 1.2 Mo 7 (similar to SA508 Class II) forging. This is a part of a nozzle cut-out from the NOK reactor vessel, so represents material currently being produced in Europe by Schneider Creusot.
4. Weld Metal to be supplied by welding pieces of the 12" plate described in 1 above.
5. SA302 Grade B correlation monitor material as provided by ASTM E10 Sub. 11. Charpy V-notch specimens of this 6" plate are on hand and will be used as controls in this program.

The chemical composition of all materials selected for this program are given in Table 1.

Table 1

Chemical Analysis of Experiment Heats

(Weight Percent)

	C	P	Mn	Ni	Mo	Si	Cr	Cu	S	Al
SA533 Grade B Class I* - 12" Plate (Check Analysis)	.22	.012	1.48	.68	.52	.25	.10	.18	.018	.033
SA533 Grade B Class I - 8" Plate	.19	.012	1.37	.52	.45	.25	-	.15	.016	.048
A302B Correlation Monitor Material	.24	.011	1.34	.18	.51	.23	.11	.20	.023	.042
Schneider Creusot 1.2 MDO 7 A, (Similar to A508 Class II Forging. (Nozzle Cut out from NOK Vessel)	.18	.009	1.16	.72	.51	.24	.28	-	.010	-

*This is a new designation for what has been known as A302B modified with Ni per Code Case 1339-1.

Selection of specimen location and orientation with respect to the rolling direction has been determined for the 12" and 8" SA533 Grade B Class I plate, and the nozzle cut-out from the NOK reactor vessel. Layout drawings have been prepared (Figures 2 through 8).

Requests for quotations for machining the specimens were submitted to several machine shops in the Pittsburgh area. Two submitted reasonable bids, and their capabilities are now being evaluated.

The test equipment at WAPD is being checked out very carefully before testing on this program. Further, results of testing will be correlated with tests on identical material made at the Westinghouse Research and Development Center, to make certain that the results will be accurate, before actual material testing begins. Machining of the correlation specimens in 1T and 2T sizes has been initiated.

The specimen type originally proposed for fracture toughness testing in this program was the design initially developed by Westinghouse, now referred to as the "X" type. It is extremely compact, and will yield valid data at K_{IC}/YS ratios of about .5. Above this toughness-strength ratio, slight bending of the loading arms reduces the accuracy of the value of fracture toughness determined. To improve the measurement capacity of the specimen, a new design was developed. This improved design, known as the "T" series, will provide valid K_{IC} values at higher K_{IC}/YS ratios, and is of particular value in the determination of the fracture toughness of non-irradiated pressure vessel steel.

Both specimen types will be used in this program, with emphasis on the "T" series for the pre-irradiation studies, and the "X" series for the irradiated material, where the greater measuring capacity of the "T" series is not required.

The dimensions of the "X" series of WOL specimens and the newer "T" series are shown in Figures 9 and 10.

Figure 2 LAYOUT OF SA 533 GRADE B CLASS I (Mn Mo WITH Ni) 12" THICK PLATE.

T = THICKNESS

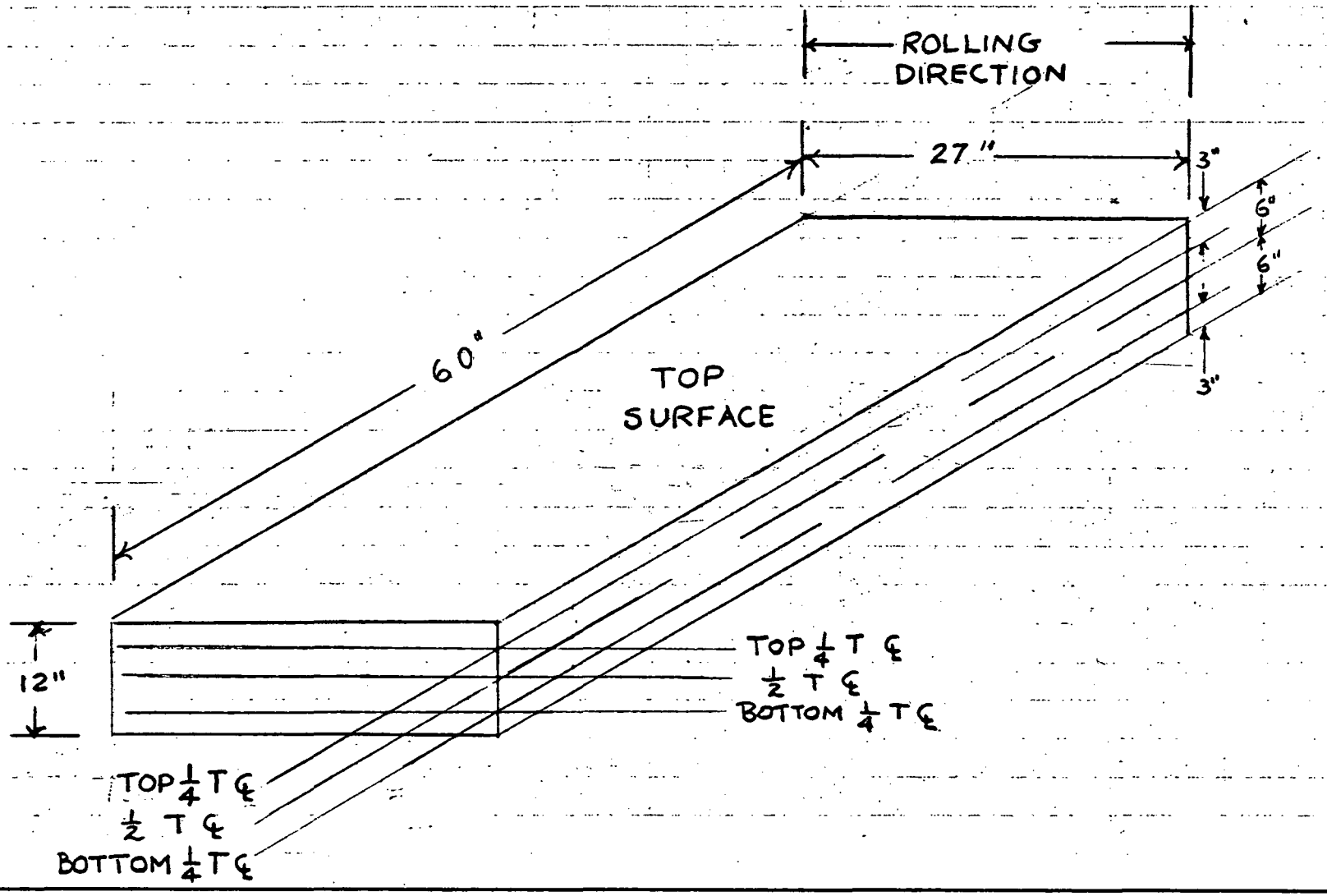


Figure 3 SPECIMEN LOCATION AND ORIENTATION IN 12" THICK PLATE

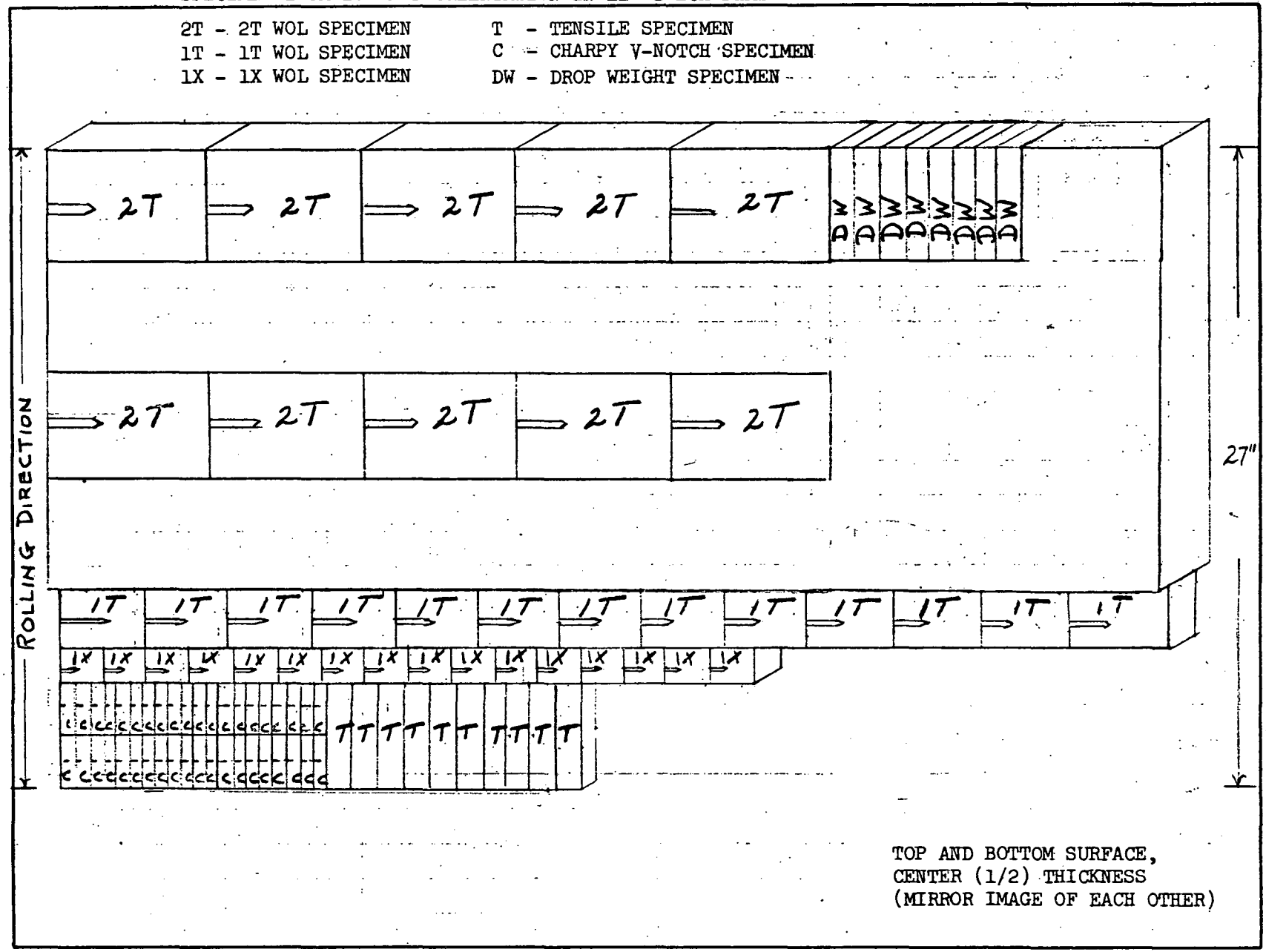


Figure 4 SPECIMEN LOCATION AND ORIENTATION IN 12" THICK PLATE.

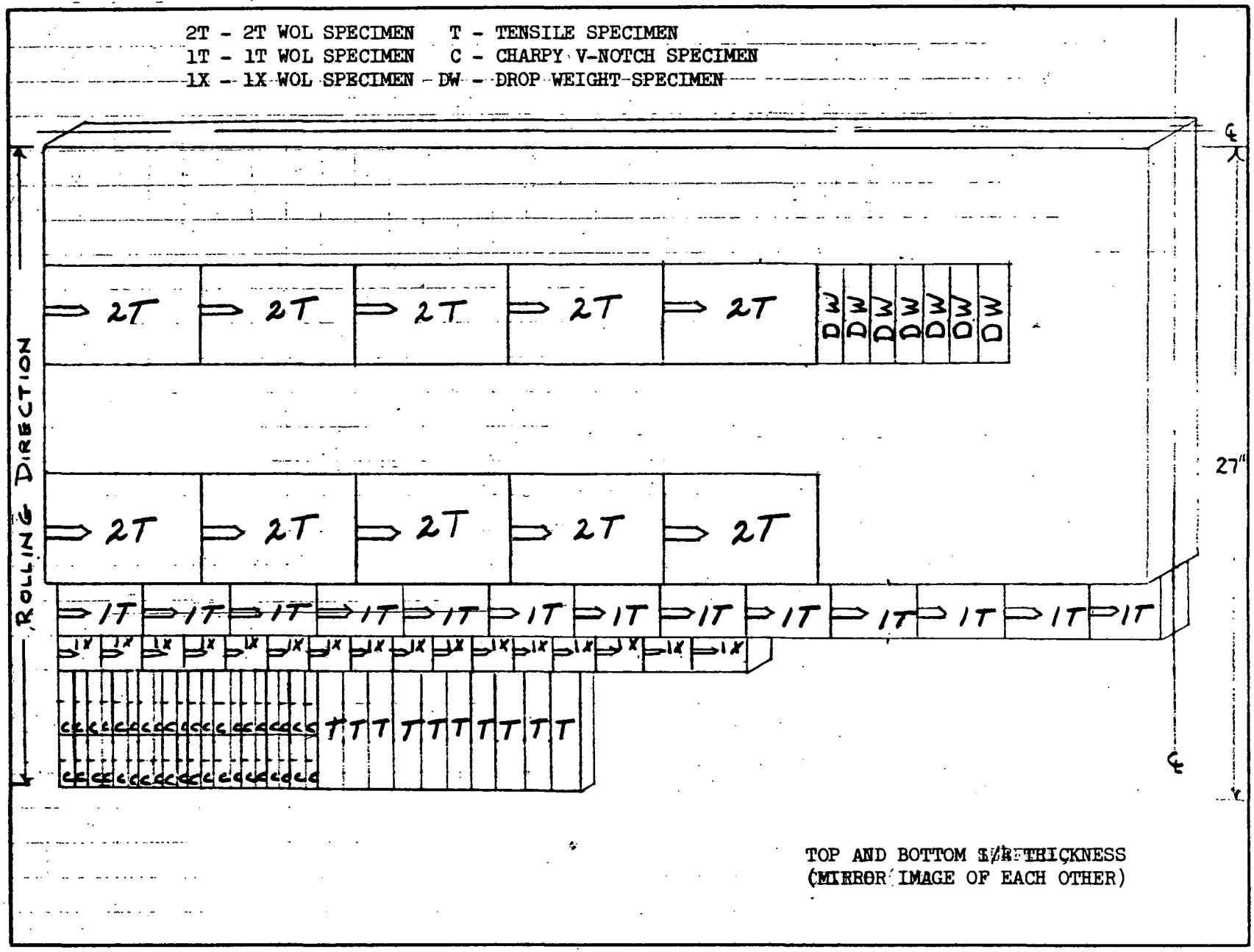


Figure 5 LUKENS STEEL - 8" PLATE - SA 533 GRADE B CLASS I
SPECIMEN ORIENTATION - NOTCH PERPENDICULAR TO ROLLING DIRECTION

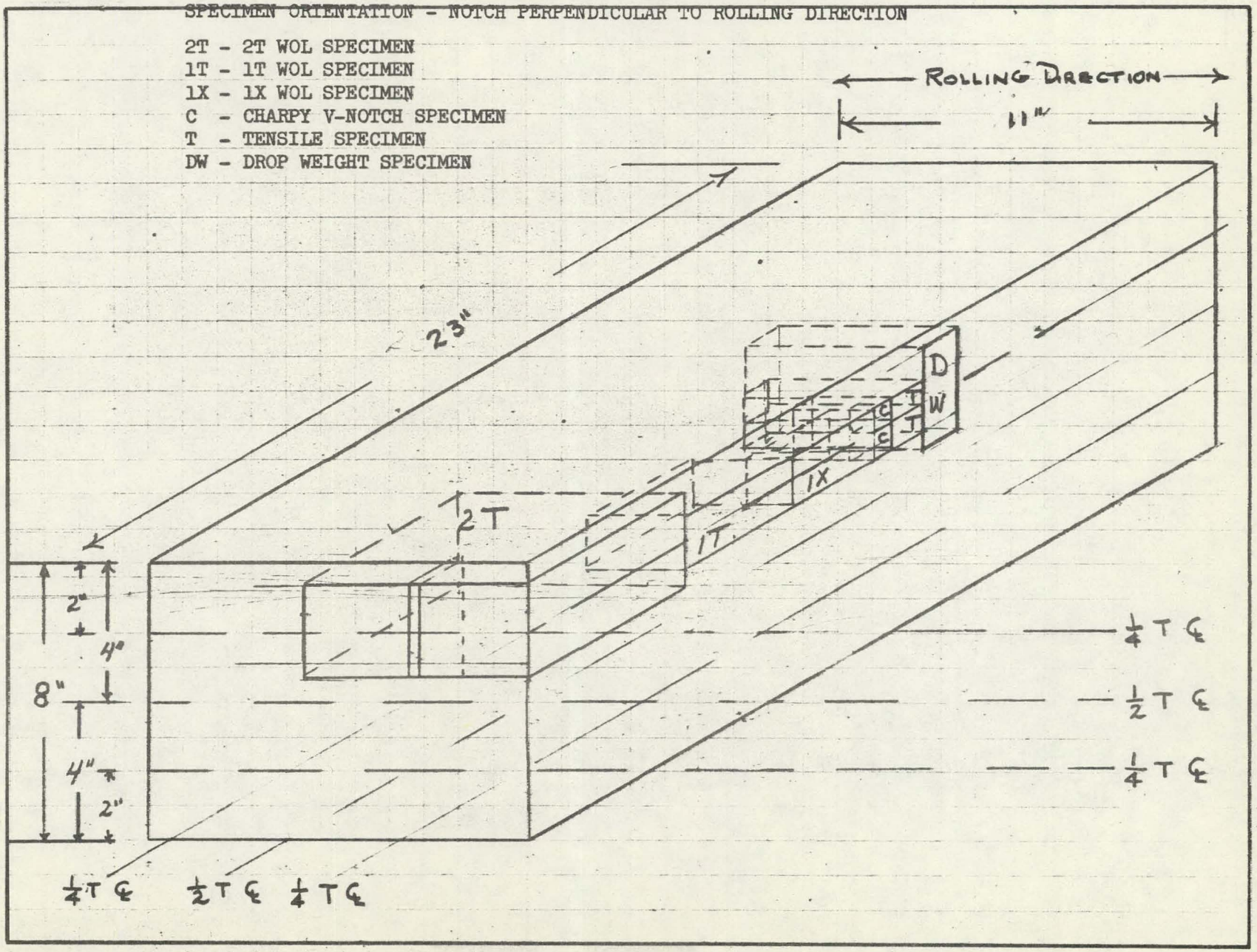


Figure 6 SPECIMEN LOCATION AND ORIENTATION 8" THICK PLATE

TOP AND BOTTOM 1/4 THICKNESS (MIRROR IMAGE OF EACH OTHER)

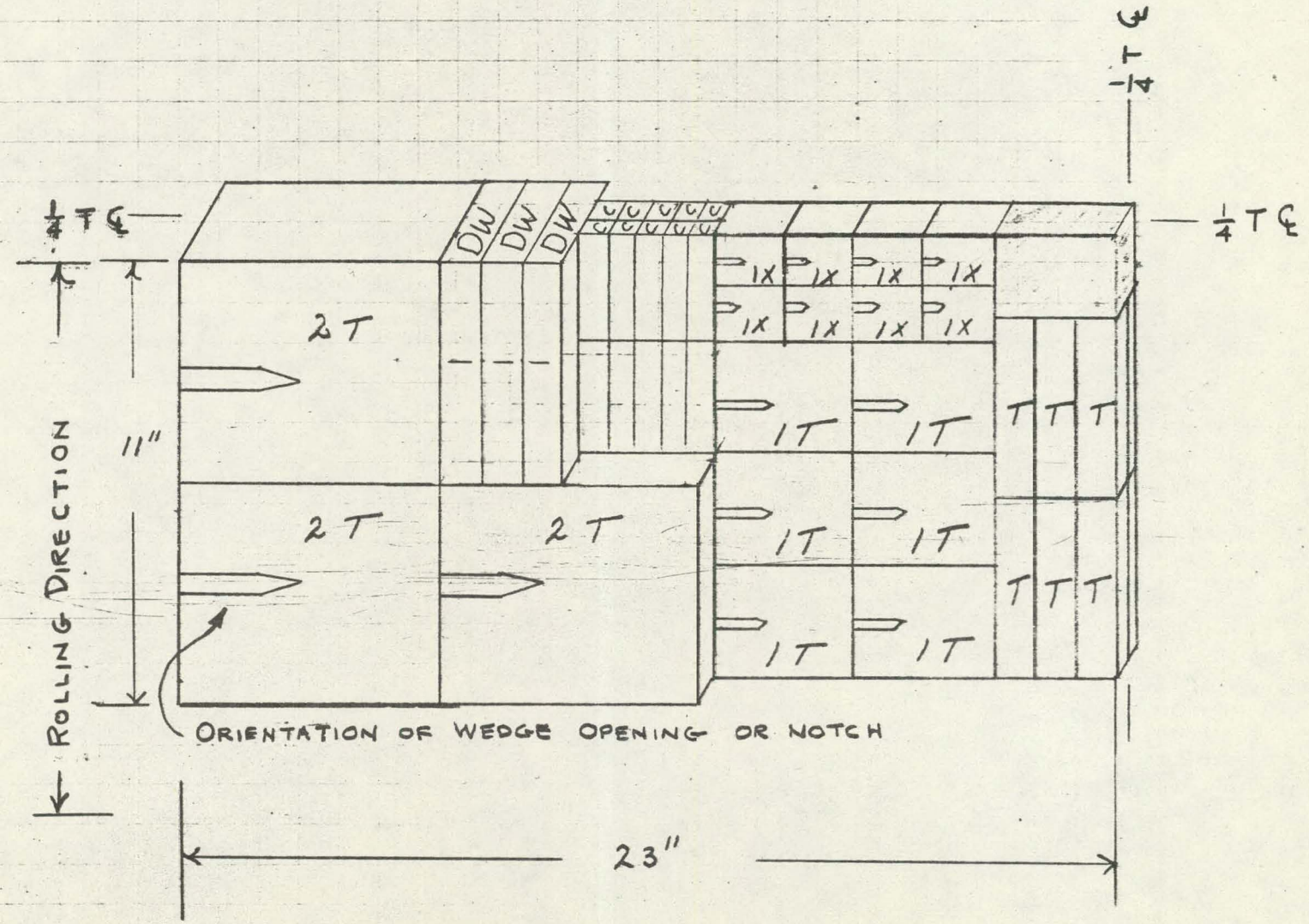


Figure 7. NOZZLE CUTOUT FROM VESSEL RING FORGING
SA 508 CLASS II - EUROPEAN STEEL
SPECIMEN ORIENTATION - NOTCH PERPENDICULAR
TO ROLLING DIRECTION

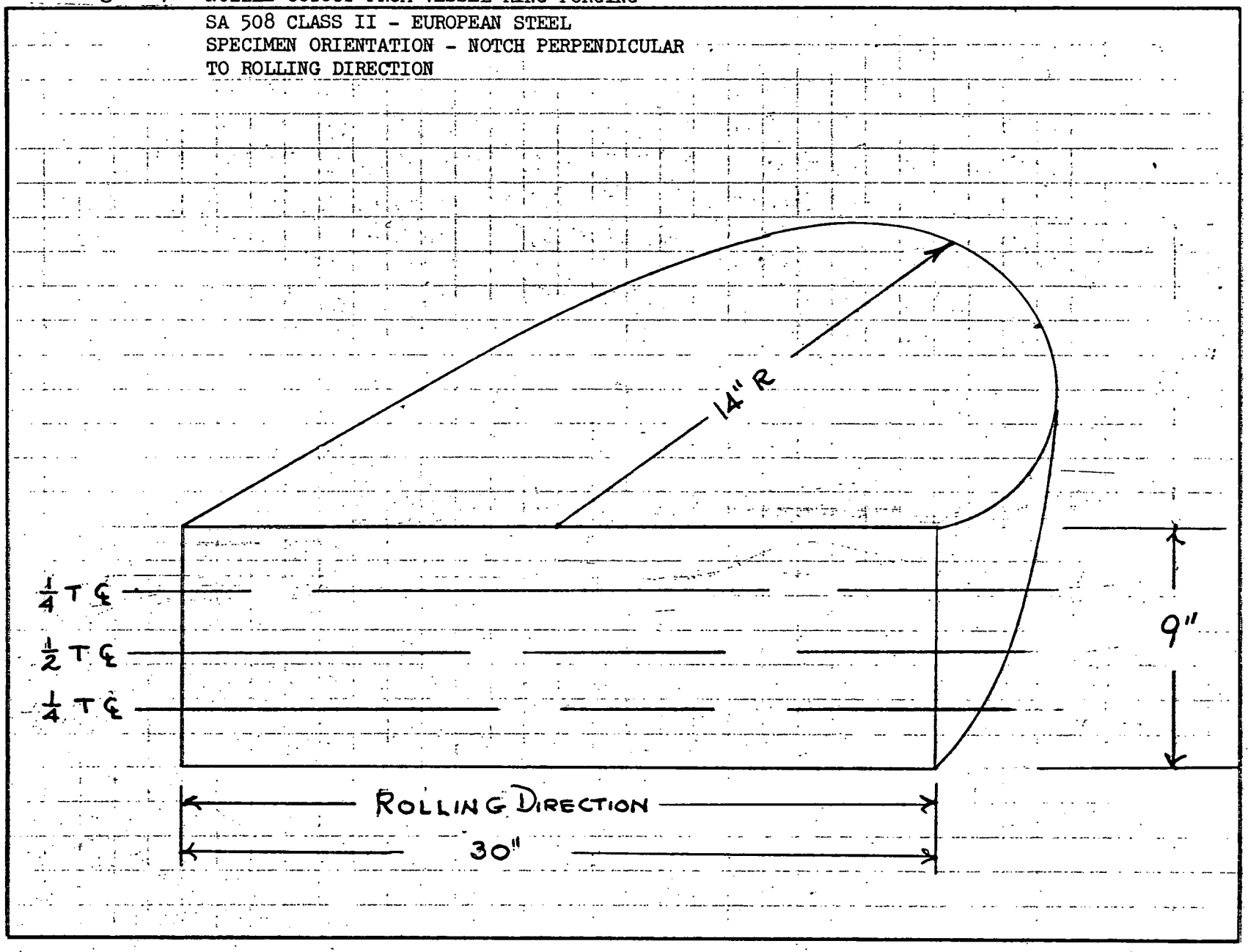
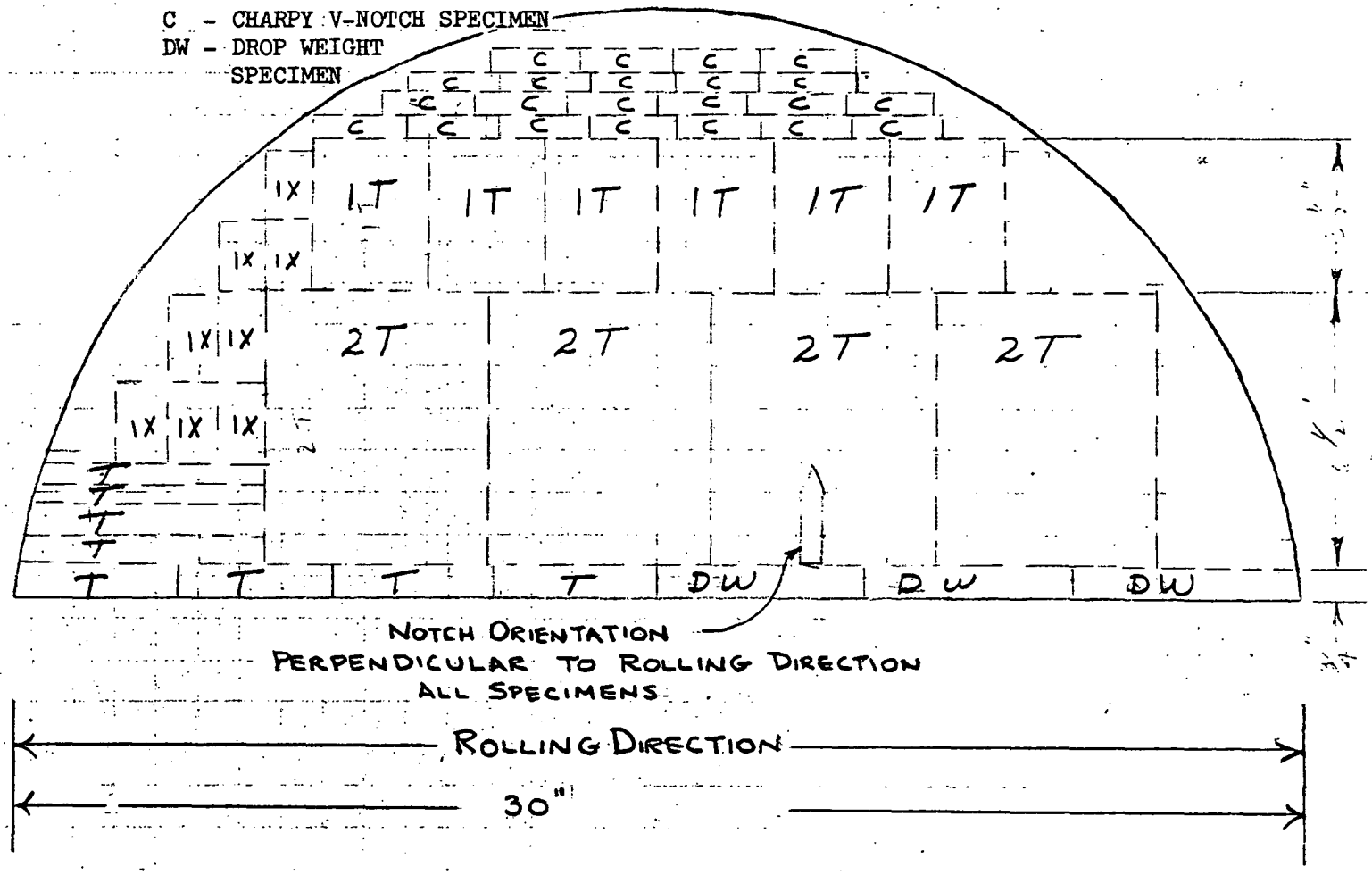
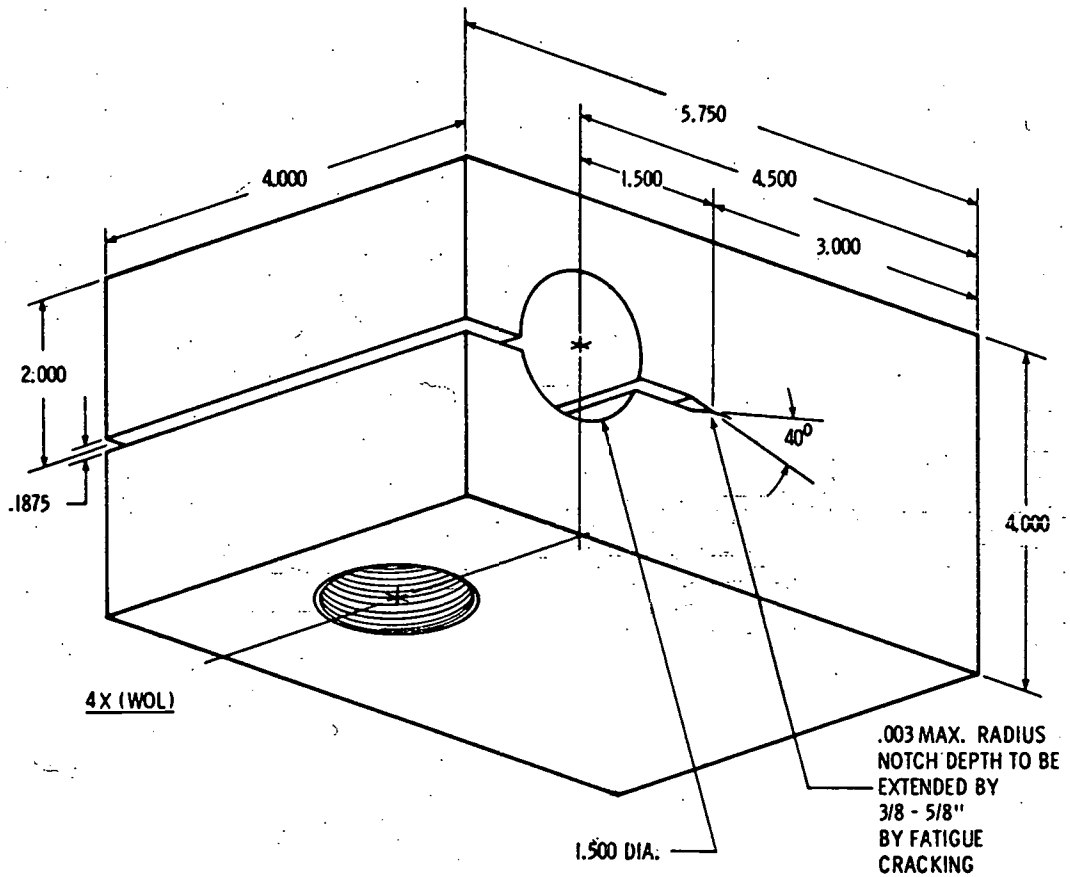
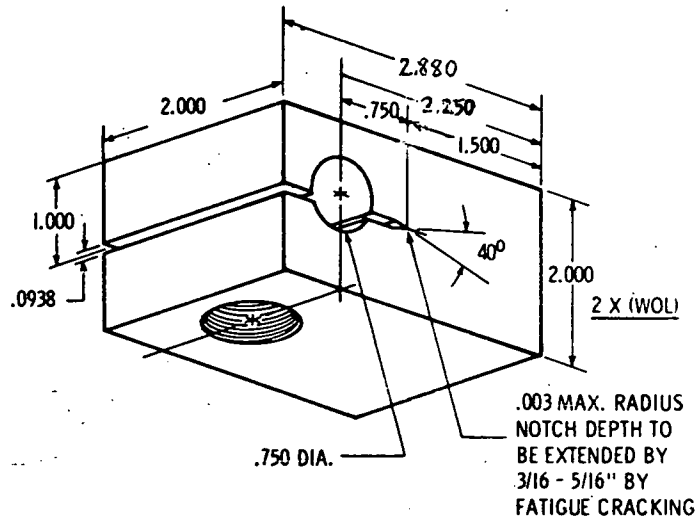
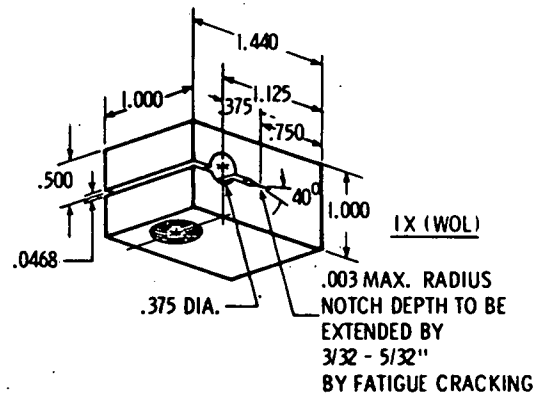


Figure 8 NOZZLE CUTOUT FROM VESSEL RING FORGING
SA 508 CLASS II - EUROPEAN STEEL
BOTTOM 1/4 THICKNESS CUTOUT IS MIRROR IMAGE
OF TOP 1/4 THICKNESS.
2T - 2T WOL SPECIMEN
1T - 1T WOL SPECIMEN
1X - 1X WOL SPECIMEN
C - CHARPY V-NOTCH SPECIMEN
DW - DROP WEIGHT
SPECIMEN



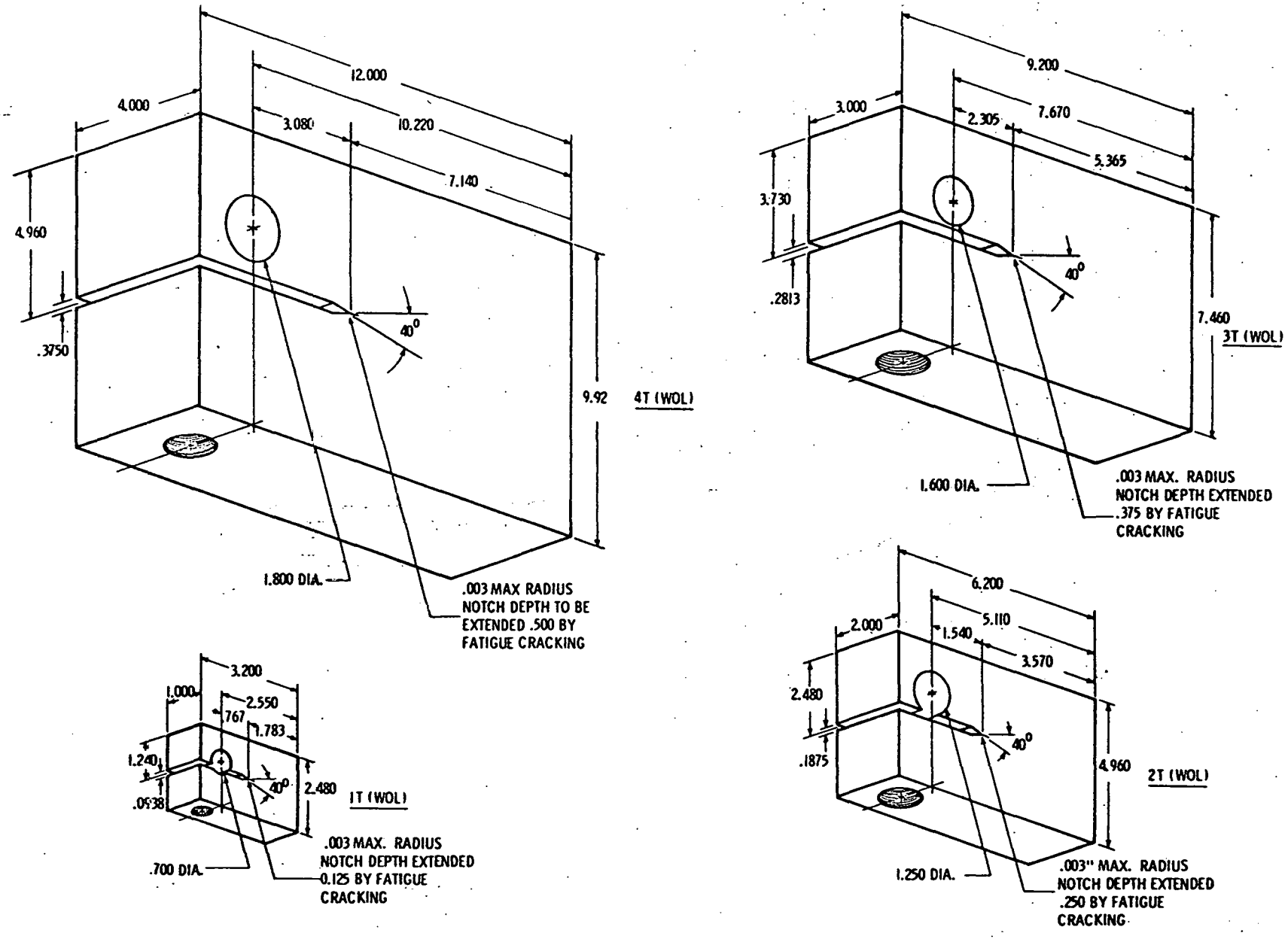






WEDGE OPENING LOADING (WOL) SPECIMENS ("X" TYPE)

Figure 9



WEDGE OPENING LOADING (WOL) SPECIMENS ("T" TYPE)

Figure 10