8.1 Design of the Low Temperature DCT Experiment — M. A. Sokolov, J. McDuffee, D. Heatherly, (Oak Ridge National Laboratory)

OBJECTIVE

The low-temperature DCT experiment will provide F82H fracture toughness data in the high irradiation hardening regime. These data will be compared to data on specimens with other geometries, to calibrate effect of specimen size and geometry on fracture toughness parameters in material with a high level of irradiation hardening.

SUMMARY

An experiment has been designed, fabricated and assembled to irradiate disk compact tension (DCT) specimens of F82H in the flux trap of the High Flux Isotope Reactor (HFIR). Twelve DCT specimens with an outer diameter of 12.5 mm are exposed directly to HFIR coolant flow. The specimens are separated by perforated spacers to ensure cooling flow to the upper and lower surfaces of the specimens. Another experiment will use a perforated capsule to irradiate bend bar and tensile specimens to supplement this irradiation experiment, and provide the other specimen geometries for comparison with the DCT specimen data.

PROGRESS AND STATUS

Introduction

The fracture toughness response to high dose irradiation is a key factor in selecting ferritic-martensitic steel for fusion application. A large number of 3-point bend and DC(T) specimens of F82H RAFM steel were irradiated at 250-500°C in capsules RB11, RB12, JP26 and JP-27 to doses from 3.5 to 22 dpa. These specimens were tested in the hot cell and results are summarized in [1]. These irradiation studies rely on the ability of small specimens to adequately measure irradiation-induced shift in transition fracture toughness. Disk-shaped specimens with diameter 12.5 mm remain the largest fracture toughness specimen that can be irradiated in HFIR experiments. In capsules RB11 and RB12, both DC(T) and bend bars were irradiated up to 5 dpa. Results of these experiments indicated that for irradiation up to 5 dpa, shifts of transition fracture toughness temperature, T_o, are comparable for the two specimen types [1]. However, as goals and interests of the program evolve toward high-dose irradiation, the irradiation experiments are shifting to use of target capsules like JP26 and JP27 and rabbit capsules. Current target and rabbit capsule designs cannot accommodate DC(T) specimens. Thus, we have to rely on use of small 3-point bend specimens for post-irradiation fracture toughness measurement. Because of their small size, data from these specimens are evaluated using statistical, weakest-link, based size adjustments as well as constraint based adjustments. The statistical size adjustment is derived from the Weibul distribution function based on crack length and the widely used Master Curve methodology. The constraint corrections are volume based adjustments. The most commonly applied constraint adjustment for F82H data is the model developed by UCSB. However, the latest development of the UCSB model raises concerns about the validity of applying the constraint adjustment to materials with a high degree of hardening caused by irradiation [2]. That may make the small 3-point bend fracture toughness specimens unusable in high doses experiments.

The goal of this and the companion experiment is to irradiate large DC(T) and small 3-point bend specimens for one cycle (~1.6 dpa) at HFIR coolant temperature. This low-temperature irradiation will insure a high degree of hardening even at relatively low dose thus providing experimental data on the validity of using small bend bars to measure the fracture toughness

shift as large specimens after high irradiation-induced hardening. The data can be used for any needed potential tuning of the UCSB constraint model.

Specimen Design and Preparation

Figure 1 shows the DCT specimen design. The specimen has an outer diameter of 12.5 mm (0.492 in) and a 4.62 mm thickness (0.182 in). Fracture toughness and tensile specimens were machined out of broken halves of previously tested 1T C(T) specimens. Figure 2 provides the schematic layout of specimens that were machined for this and the companion experiment.

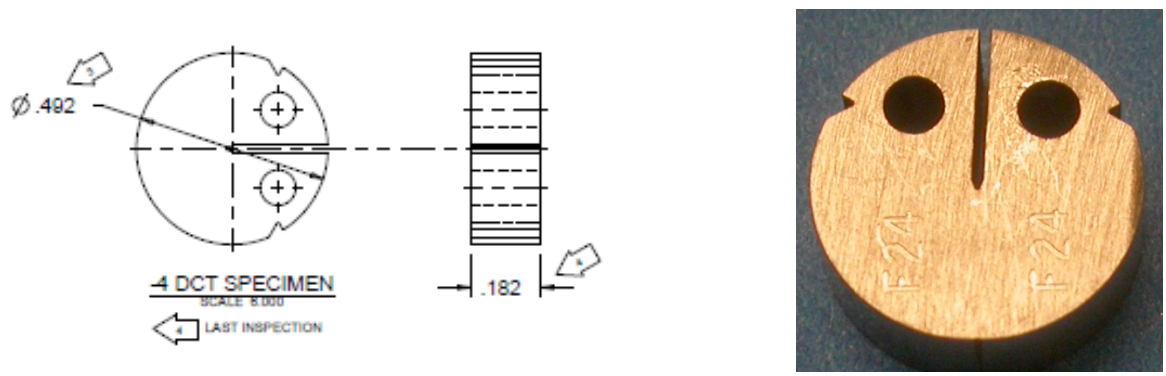

Figure 1. DCT specimen design.

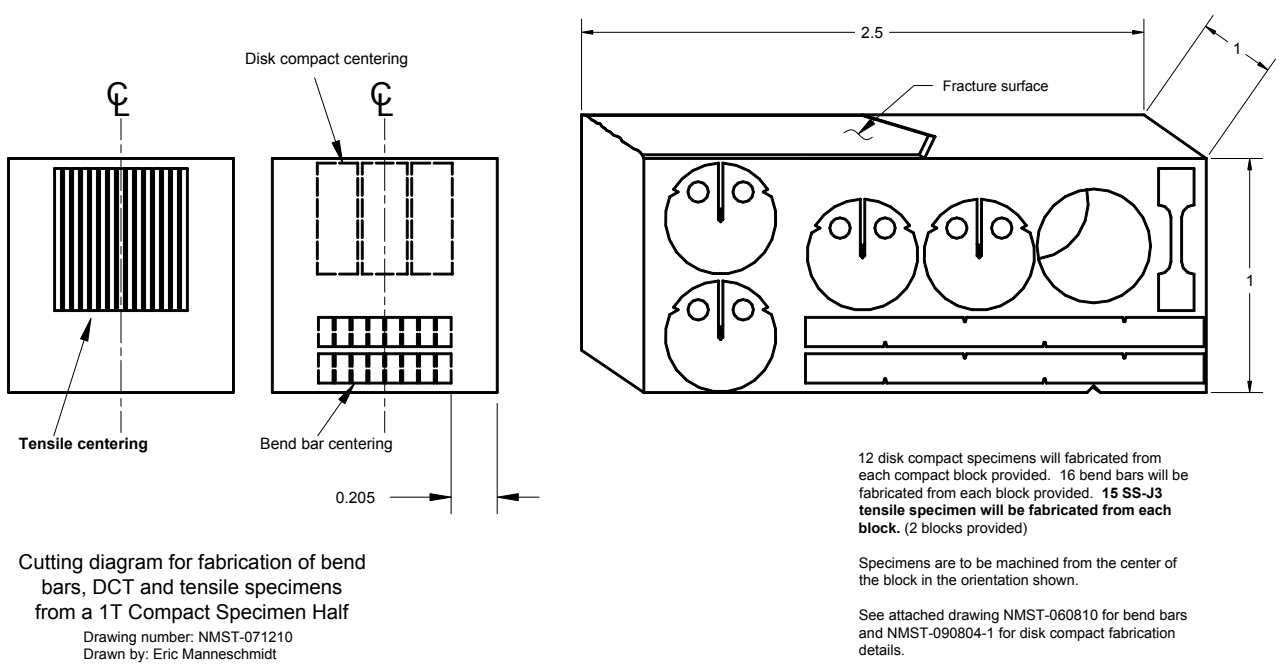

Figure 2. Cutting diagram for fabrication of bend bars, DCT and tensile specimens. (Dimensions in inches)

Design Drawings

Table 1 lists design drawings and titles that were developed for the DCT experiment. The experiment consists of a stack of 12 DCT specimens with perforated spacers located between each specimen. Figure 3 shows the inner assembly in the specimen region.

Table 1. Low-temperature DCT experiment design drawings.

Drawing No.	Title
X3E020977A575	SHROUDED TARGET CAPSULE SHROUD TUBE
X3E020977A578	12-DCT LOW TEMPERATURE TARGET CAPSULE
X3E020977A579	12-DCT LOW TEMPERATURE TARGET CAPSULE DCT TOP CAP
X3E020977A580	12-DCT LOW TEMPERATURE TARGET CAPSULE DCT GUIDE PIN
X3E020977A581	12-DCT LOW TEMPERATURE TARGET CAPSULE SPECIMEN ASSEMBLY

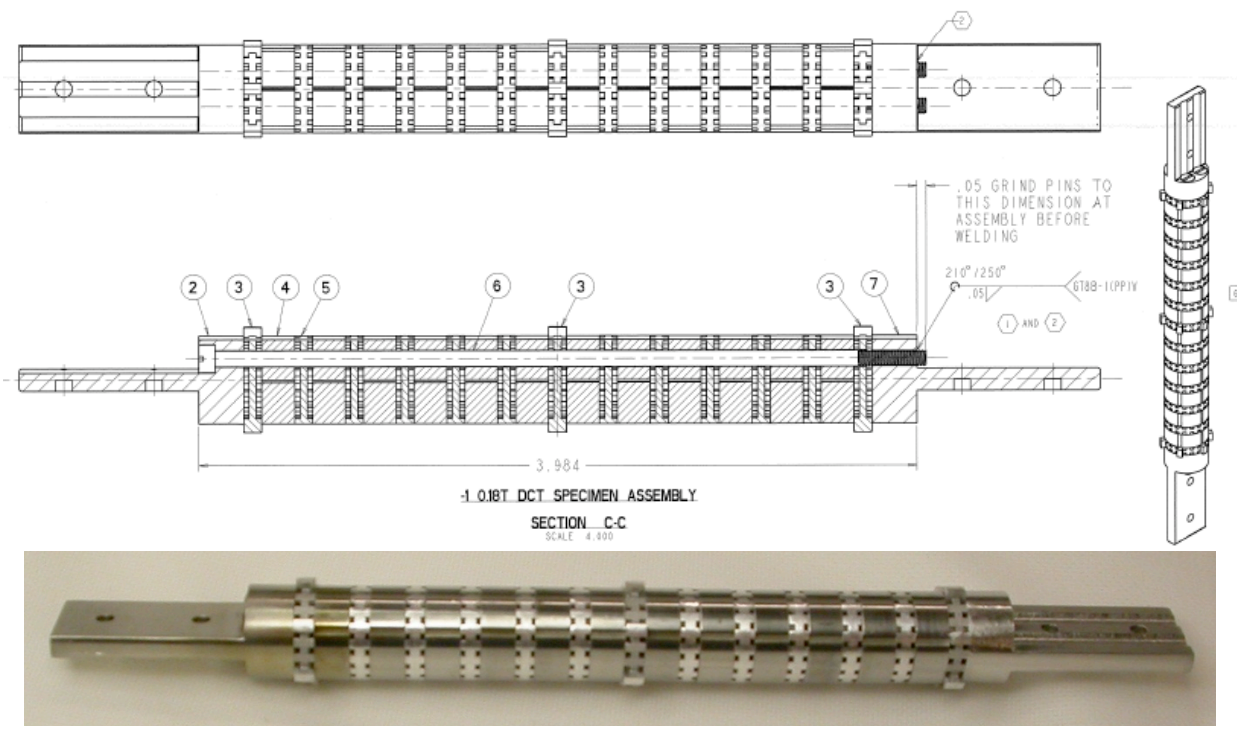

Figure 3. Specimen layout for the DCT experiment.

As shown in Figure 4, there are two types of spacers used in the experiment. The purpose of the primary spacer (right) is to ensure coolant flow to the upper and lower surfaces of the DCT specimens. The secondary spacer (left) has the added function of centering the assembly inside the coolant channel.

Figure 4. Specimen spacers for the DCT experiment.

The assembly is held together by two stainless steel rods that protrude through the matching holes in the DCT specimens and spacers. The connecting rod is sealed to retainers on either end of the specimen stack, and the inner assembly is then pinned to the upper and lower top cap and guide pin. The entire assembly is located inside a shroud tube, which directs coolant flow into the experiment region. Figure 5 demonstrates a partial assembly with just the retainers and connecting rods. Figure 6 shows a similar assembly with the first spacer and specimen installed. Figure 7 shows the entire completed target assembly.

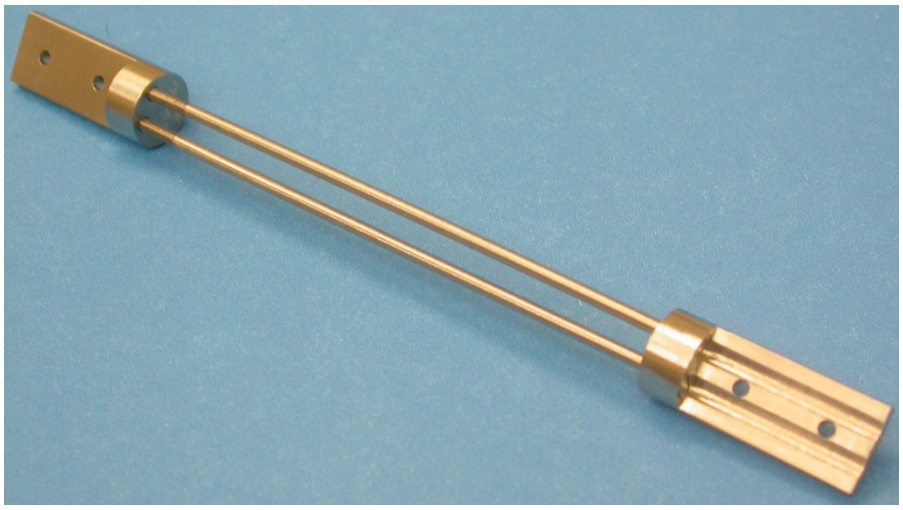

Figure 5. Partial assembly of the retainers and connecting rods.

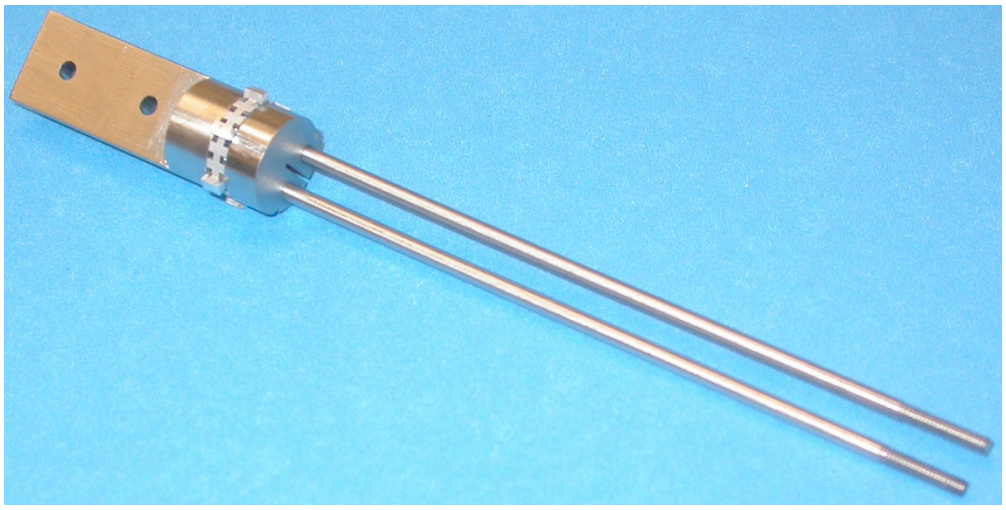

Figure 6. Partial assembly showing the first spacer and specimen.

Figure 7. Completed target assembly before loading into shroud tube.

Materials of Construction

The top cap, guide pin, spacers, and outer shroud are fabricated from aluminum alloy Al6061. Specimens are all F82H or variations of this steel alloy. The end retainers and guide pins are fabricated from 304L stainless steel.

Irradiation Environment

The reactor core, illustrated in Figure 8, consists of two concentric annular fuel regions, each approximately 61 cm in height. The flux trap is ~12.7 cm in diameter and is located inside the inner fuel annulus.

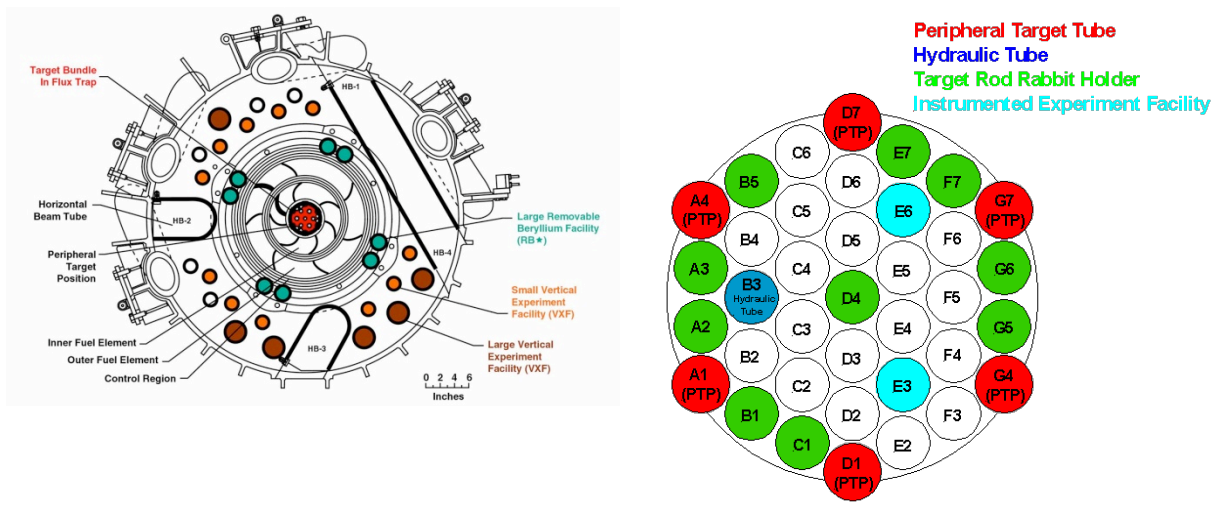

Figure 8. Cross section through HFIR illustrating the primary experimental sites in the reactor as a whole (left) and in the flux trap (right).

The DCT experiment will be located in one of the outer ring positions in the flux trap. Table 2 summarizes the neutron flux characteristics at these locations [3]. The fast fluence is based on a typical 24 day cycle and 7 cycles per year.

Table 2. Neutron Flux Characteristics of the Outer Ring Flux Trap Position

Parameter	**Outer Ring Flux Trap** (Greenwood, June 30, 1999)
Fast flux (10^{14} n/cm²·sec) [E > 1 MeV]	5.5
Fast flux (10^{14} n/cm²·sec) [E > 0.1 MeV]	10.8
Thermal flux (10^{14} n/cm²·sec) [E < 0.5 eV]	20.2
Fast fluence/cycle (10^{21} n/cm²) [E > 0.1 MeV]	2.24
Fast fluence/year (10^{21} n/cm²) [E > 0.1 MeV]	15.7
Axial peaking factor profile[1]	$1 - 1.06 \cdot 10^{-3} \cdot z^2$
dpa/cycle (iron)	1.6

1 peaking factor is the ratio of the local flux at a distance z from the reactor midplane (in cm) to the flux at the reactor midplane

The design places the 12 DCT specimens in an 8.8 cm region centered at the HFIR midplane. Using the profile from Table 2 gives a peaking factor of $1 - 1.06 \cdot 10^{-3} \cdot (4.4)^2 = 0.98$. Therefore, all specimens in this experiment should receive a relatively constant 1.6 dpa/cycle.

CONCLUSIONS

An experiment has been designed, fabricated and assembled to irradiate DCT specimens of F82H in the flux trap of the HFIR. There are 12 DCT specimens with an outer diameter of 12.5 mm that are exposed directly to HFIR coolant flow. The specimens are separated by perforated spacers to ensure cooling flow on the upper and lower surfaces of the specimens.

REFERENCES

[1] M. A. Sokolov, G. R. Odette, T. Yamamoto, H. Tanigawa and N. Okubo, "Dose Dependence of Fracture Toughness Of F82H Steel," in Fusion Reactor Materials Program, Semi-annual Progress Report, June 30, 2010. DOE/ER- 0313/48 - Volume 48.

[2] T. Yamamoto, G. R. Odette and M. A. Sokolov, "On the Fracture Toughness of Irradiated F82H: Effects of Loss of Constraint and Strain Hardening Capacity," in Fusion Reactor Materials Program, Semi-annual Progress Report, December 31, 2010. DOE/ER-0313/47 - Volume 47.

[3] Greenwood, L. R., "Neutron Dosimetry and Damage Calculations for the HFIR-CTR-62 and 63," Fusion Reactor Materials Program, Semi-annual Progress Report, June 30, 1999. DOE/ER-0313/26 - Volume 26.