5.2 Reducing the Cost of S-65C Grade Beryllium for ITER First Wall Applications

D. Kaczynski Brush Wellman, USA
K. Sato Brush Wellman, Japan
V.V. Savchuk ULBA Metallurgical Plant, Kazakhstan
V.P. Shestakov Institute of Experimental & Theoretical Physics Kazakh State Univ., Kazakhstan

Abstract
Beryllium is the current material of choice for plasma-facing components in ITER. The present design is for 10mm thick beryllium tiles bonded to an actively cooled copper substrate. Brush Wellman grade S65C beryllium is the preferred grade of beryllium for these tiles. S65C has the best resistance to low-cycle thermal fatigue than any other beryllium grade in the world. S65C grade beryllium has been successfully deployed in fusion reactors for more than two decades, most recently in the JET reactor.

This paper will detail a supply chain to produce the most cost-effective S65C plasma facing components for ITER. This paper will also propose some future work to demonstrate the best technology for bonding beryllium to copper.

Choosing S65C Beryllium for the First Wall
Beryllium was originally chosen for the First Wall because of its oxygen gettering ability, its low atomic number, and its ability to make plasma disruptions two orders of magnitude less severe. The ability to getter oxygen decreases the vessel conditioning time from the 2-3 weeks used for tokamaks with carbon walls to a few days. Less severe plasma distributions mean less damage to the machine and greater chance of recovery from the disruptions. The low atomic number means that accidental impingement of plasma on the First Wall does not dramatically cool down the plasma by radiation cooling. Since tungsten has a much higher atomic number, only one-millionth as much is needed to cool the plasma.

Beryllium has additional advantages over carbon in the ITER environment. One of these is much lower tritium retention in redeposition. Inevitably, the plasma scrapes off some amount of wall material when it goes out of control. The material will redeposit on some interior surfaces away from the point of plasma impingement. The settling and coalescing solid traps some of the gas in the reactor beneath it. Minimal amounts are trapped by redeposited beryllium. Recent measurements have shown that over 50% of a carbon redeposit is trapped tritium.

Another advantage beryllium has over carbon is resistance to chemical erosion. Under conditions of high heat flux and a hydrogen source (the plasma), carbon tiles can be significantly eroded.

Beryllium use has been criticized based on beryllium safety issues. However, for ITER beryllium safety issues are completely satisfied by the safety procedures required for the use of tritium.

S65C is the best grade of beryllium because it exhibits the best resistance to low-grade cycle fatigue than any other grade of beryllium in the World. This rating of S65C is based on a series of tests conducted by Sandia National Laboratories using the High Heat Flux Test Facility. These results are shown in Figure 1.

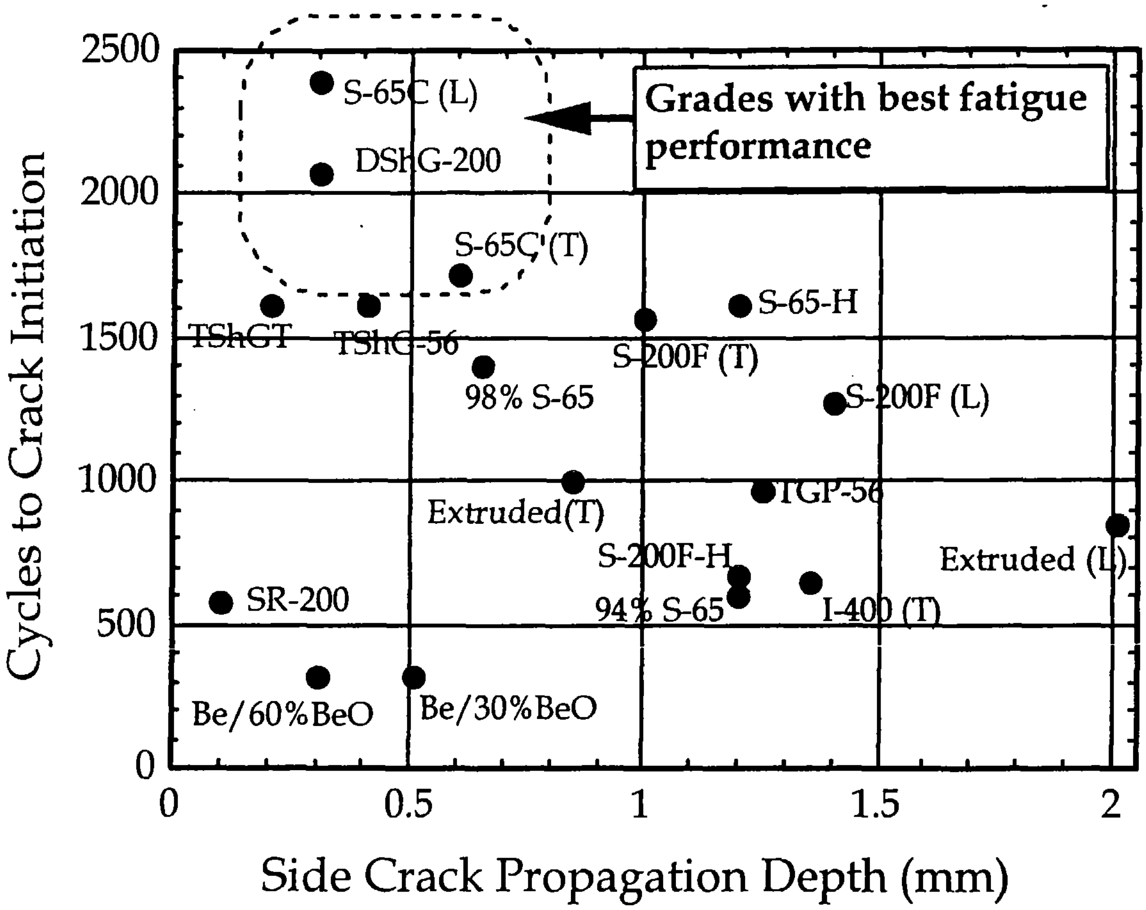

Figure 1 Results of Low Cycle Thermal Fatigue Tests for ITER Candidate Beryllium Grades Conducted by Sandia National Laboratories High Heat Flux Test Facility

Brush Wellman has a plant capable of producing over 100 tons per year of S65C grade beryllium. This entire capacity is essentially available for ITER applications, as current demands for S65 grade material are less than 5 tons per year.

The Supply Chain for ITER

The Supply Chain has been constructed to produce the most cost-effective delivery of high quality plasma facing components to ITER.

ULBA Metallurgical Works, Ust Kamenogorsk, Kazakhstan, supplies high quality vacuum cast ingot to Brush Wellman. Brush Wellman in its Elmore, Ohio plant will convert this ingot to fully qualified S65C grade near net shape beryllium tiles. The solid beryllium tiles will be returned to ULBA for machining and possibly also bonding to the copper alloy substrate. ULBA will finish machine the components. Brush Wellman will be responsible for final inspection and delivery of finished components to ITER

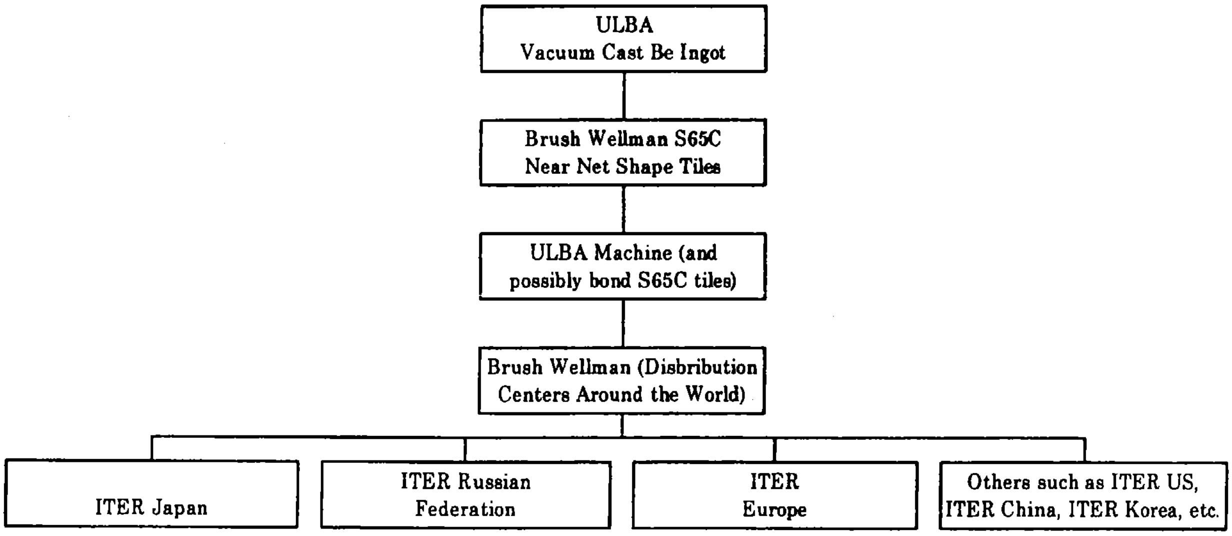

Figure 2
The Supply Chain for Delivery of Cost-Effective Beryllium Components to ITER

Why the Proposed Supply Chain is the Most Cost Effective

ULBA Metallurgical Works has been producing high-quality vacuum cast beryllium ingot for many decades. The ULBA ingot is the lowest cost ingot beryllium available in quantity in the World.

Brush Wellman is the World's only producer of S65C beryllium. The Brush Wellman plant is fully installed (no capital requirements) and capable of producing the quantity of material required for ITER in a short period of time. The Brush Wellman processes are very efficient in converting ingot to fully qualified solid S65C parts. The proprietary Brush Wellman conversion process is a high yield low energy operation relative to processes such as beryllium distillation. The cold press sintering operation, used for S65C, gives a very near to shape beryllium tile, resulting in minimal waste from final machining. This process was demonstrated in fulfilling the beryllium tile order for JET.

ULBA has substantial beryllium machining capacity, including qualified beryllium machinists. The attractive labor rate in the ULBA facility will be important in meeting ITER cost objectives. Brush Wellman will work closely with ULBA in developing all processes and procedures to deliver fully qualified parts through Brush Wellman's worldwide network of distribution centers.

Using ULBA for Bonding and Finishing Tiles

Bonding beryllium to copper has been a technical issue for ITER. This bonding must be done without silver or any element that will decompose under irradiation into low melting point, or radioactive elements. This bond must also pass the thermal fatigue test.

Brush Wellman has patented a bonding process (US Patent #5901336) where a gradient of compositions of copper and beryllium is used as the bond layer between beryllium and copper. Brush Wellman tested the strength of this bonding process. The results from this testing is shown in Table 1. The concept is to put a beryllium rich layer next to the beryllium, gradually grading to a copper rich layer next to the copper. This process will result in a compliant bond, without adding any new activating or low melting elements to the assemblies. Hot isostatic pressing was used by Brush Wellman to insure the bond was 100% across the entire bond surface. The high-pressure pressing insures there will be no voids to initiate failure in a thermal fatigue environment.

Table 1
Results of Testing S65 Beryllium Bonded to Copper using Brush Wellman's Proprietary Compositional Gradient CuBe Bond Layer

Conditions of Bonding

Test No.	Bonding Process	Bond Temperature	Bond Pressure
1468	Gradient Compositional Cu & Be	700°C	170 MPa
1470	Gradient Compositional Cu & Be	600°C	170 MPa

Tensile Strength of Bond

Test No.	Room Temperature	200°C	400°C
1468	142 Mpa	141 Mpa	96 MPa
1470	88 Mpa	112 Mpa	90 MPa

We are confident that hot "forming/forging" in a closed die will be as good or better in forming this bond. The hot forming will also control part shapes. In this forming process, the curative of the finish components will be controlled to the curvature of the forming die(s) used. It may also be possible to contour the back of the copper alloy, locating the machine tool path for the cooling passage in the copper.

ULBA is expert in this hot forming process. The ULBA facility contains a number of forming presses up to the largest with 9600 tons pressure. This would allow ULBA the capability to bond and contour parts nearly one meter square in plan area. ITER tiles could efficiently be machined from these large, bonded, and contoured panels.

Conclusions

The proposed supply chain is believed to be the most cost-effective route to supplying high-quality beryllium plasma facing components to ITER. This supply chain will:

1) Utilize the world's lowest cost, high quality vacuum cast beryllium ingot from ULBA Metallurgical Works, in Ust Kamenogorsk, Kazakhstan.
2) Produce fusion qualified Brush Wellman S65C grade beryllium using:
   - Existing facilities with excess capacity
   - Demonstrated, qualified high yield processes
   - Demonstrated high-yield, near-net shape consolidation
3) Produce bonded ITER ready parts in ULBA Metallurgical Works. Leveraging ULBA's:
   - Existing beryllium machining capacity
   - Extensive hot forming plant

Future Studies

A collaboration between ULBA, the Kazakhstan ITER Team, and Brush Wellman has been formed to demonstrate all steps in the proposed supply chain including ITER qualification of parts by the Kazakhstan ITER team. This process has already begun with a contract for ULBA to supply beryllium ingot to Brush Wellman and applications to the governments of Kazakhstan and the United States for the proper export and import licenses. Brush Wellman will supply some of the funding for this study. Funding is also being sought from the CRDF (US Civilian Research and Development Foundation) which supports industry programs between US industries and entities in the Former Soviet Union to exchange technology and develop business opportunities between the US and FSU.