Ingenuity Can Often Negate Murphy's Law.

By Jack Titus

A FEW DECADES AGO, MY INVOLVEMENT WITH depleted uranium (DU) began in the metallurgical R&D department, developing program logic to heat treat DU in a two-chamber vacuum furnace with a water quench. (DU is a byproduct of the production of enriched uranium for fuel in nuclear reactors and in the manufacture of nuclear weapons. It's the primary penetrator material for armor piercing anti-tank projectiles.)

The furnace system that existed employed an oil quench. In 1974, the 1968 vintage 24" x 36" x 24" (600 mm x 900 mm x 600 mm) furnace hot zone was insulated with ceramic fiber and moly (molybdenum) sheet hot face, and it had graphite tube friction fit heating elements. The as-built hearth (load transfer system) was made from U-shaped moly structural members. At that time, moly was a relatively new vacuum furnace material, except for hot face sheathing and heating elements, so the hearth was purchased from Austria where moly usage was much more advanced. Likewise, graphite, except for heating elements, was not yet used in any significant quantity as a structural component. Maximum furnace load was about 800 pounds (363 kilograms), and the quench tank held approximately 800 gallons (3,028 liters) of oil (water).

This DU heat-treat process consisted of evacuation, heat and soak, backfill with nitrogen, transfer, and water quench. In addition, the load of DU bars had to descend slowly into the water quench, easily achieved with the hydraulically driven elevator, as was the inner door separating the hot zone from the vestibule.

Several months after the furnace was commissioned in R&D, there were a few relay logic and limit switch issues that continued to give us intermittent problems. While running a test load of, I believe, high speed steel, probably M2, the inner door began closing as the moly hearth was returning to the 2,200°F (1,204°C) hot zone from the quench chamber. Holding our breath, our worst fears were realized as we opened the furnace maintenance door after cooling the hot zone: the moly hearth was bent directly in the center across the three longitudinal support beams. Purchasing another moly hearth from Austria was out of the question. We made a two-prong decision: attempt to straighten the hearth and begin development of a graphite hearth. Straightening the complex eight-part moly hearth looked like an impossible task.

Moly — at that time in its development — became brittle (not doped to improve ductility) at room temperature after being heated above about 1,500°F (815°C). We knew in order to straighten the moly, we'd have to heat the entire assembly to at least 1,200°F (648°C) and probably as high as 1,500°F (815°C). The problem became how to do it.

Fortunately, another R&D department was working on automobile tire pyrolyzing and had a high-temperature low-profile horizontal hot chamber we could use. After that, the next issue became: How do we remove the hot assembly from the furnace and apply force to straighten the beams without the moly, which has high thermal conductivity, losing too much heat and cracking? Excess oxidation of the moly was also a concern, but we felt the moly would not be exposed to air in the furnace long enough to affect its strength. We wrapped the entire eight-member hearth in 2 inches of ceramic fiber to retain as much heat as possible. My cohort JGC and I donned fires suits so we could get as close as possible and manhandle the assembly hanging from a jib crane. Using a portable gantry-mounted hydraulic cylinder attached to a horizontal beam, we successfully straightened the hearth. It wasn't pretty, but it was reinstalled in the vacuum furnace and ran successfully for several months until the graphite hearth was developed.

Several months after installing the new graphite hearth, the DU arrived at our lab in the afternoon several hours later than expected. By then, we had removed the quench oil, cleaned the quench tank, added water, and were ready for the DU tests. Before unloading the DU from the truck, we were given radiation badges and gloves to handle the DU bars. DU is very dense. A cubic foot of steel weighs 490 pounds; DU weighs 1,192 pounds per cubic foot. Each 1.5-inch-diameter x 20-inch-long DU bar weighed about 24 pounds.

The DU bars were loaded vertically in fixtures and placed on the elevator in the two-chamber vestibule. We opened the inner door via pushbutton and enabled the hearth to drive from the cold hot zone into the vestibule where the elevator forks lowered the DU onto the hearth, then enabled the hearth to drive back into the hot zone. When moving back to the hot zone, we noticed that the hearth sounded different. We moved the hearth back to the vestibule for inspection and discovered a cracked graphite cross beam. We unloaded the DU and proceeded to replace the cross beam. After an hour or two, the hearth was again ready. After the DU technicians left that late evening, the hearth was moved several times back-and-forth from vestibule to hot zone to confirm that all worked as expected for tests the following day.

Then it happened — for reasons I cannot explain to this day, I manually enabled the elevator to lower into the quench (without limit switch stops via the elevator hydraulic valve over-ride), not realizing that the hearth was in the vestibule. The elevator forks lowered right through four of the five graphite cross beams. After all these years, I can still hear that sound of graphite beams being crushed. Luckily, the one intact beam kept the broken beams from falling into the water quench. Needless to say, that was a long night cutting new hearth beams with a DoAll vertical band saw from a slab of graphite. But the next morning, we did successfully conduct the tests. And upon leaving, the DU technicians asked for our radiation badges, explaining that they were for our own peace of mind as gamma ray badges would not detect the weaker alpha radiation from the primary emitter from DU.

Next is an incident that won't be soon forgotten by the engineers associated with it, even though it happened a few decades ago involving the solution portion of a solution-and-age pusher system for 7000 series aluminum ogive portions of an artillery round.

The 6-inch-diameter by 2-inch-thick parts were loaded on edge in rod frame alloy baskets located on 30-square-inch alloy trays in a single-row pusher furnace about 30 feet long. There were maybe 56 parts in a basket. During startup, temperature uniformity tests revealed non-uniformity in portions of the furnace. After cooling the furnace, an engineer proceeded to work his way through the furnace, adjusting directional baffles to redirect air to the cold areas of the zones. Startup and dry-out again continued without any problems. Production commenced after proving that the temperature uniformity had improved.

As time passed, no one at first realized that the rod frame baskets exiting the solution furnace were empty. Then, as more attention was payed to the push schedule, it was discovered that parts should have been coming out of the furnace long ago, but no parts were coming out. The baskets were empty. Again, after cooling the furnace, inspection revealed that all of the production parts entering the furnace were lying in puddles on the furnace floor. So what happened? As the engineer was adjusting baffles inside the solution furnace, he would hit his head on thermocouples protruding from the refractory walls, pushing them all in so he wouldn't break the protection tubes, but he forgot to reposition them when he finished with the adjustments. Since the thermocouples were now positioned in the refractory wall, they could not sense the true zone temperature and caused the controllers to overheat and melt the aluminum as they passed through the furnace.

Lastly, this episode involves an atmosphere box carburizing furnace. Commissioning had been proceeding successfully until it was time for refractory dry-out. The startup engineer began the normal step-up heating procedure. Periodically, he would open the furnace door to visually check for any abnormalities. During an inspection after lunch, he noticed that the horizontally mounted radiant tubes had mysteriously grown, pushing the burners away from the furnace case so much so that he could see red heat where the tubes entered the sidewalls. This was not normal. Opening the furnace door, he was blasted with white heat way above the 1,750°F (954°C) he expected. There were no electrical or high-limit failures since the high limit was set to 50°F (10°C) above the set point at 1,800°F (982°C) and the controller did indicate 1,750°F.

After an exhaustive investigation, it was discovered that the control and high-limit thermocouples were type K as required, but the temperature controller and high-limit instruments were configured for type J. When the type K furnace thermocouple reached 1,750°F equaling 39.5 millivolts, the type J controller set for 1,750°F only indicated 1,303°F. The type J controller continued calling for heat to reach the 55.2 millivolts corresponding to 1,750°F. When the type J controller finally reached 1,750°F, the furnace was over 2,500°F (1,371°C), well above the melting point of the radiant tubes, roof fan, and alloy work support.

ABOUT THE AUTHOR: Jack Titus can be reached at (248) 668-4040 or jtitus@afc-holcroft.com. Go to www.afc-holcroft.com.