Roll Front to Yellowcake:

Innovations in Uranium Mining;

Recollections of the Highland Uranium Operations

By Morris T. Worley

Much has been made of the ill-fated forays into mining by the oil industry, but we can thank those people for their willingness to break out of the traditional "box" and introduce innovative ideas to an industry long portrayed as being resistant to change. The Highland uranium operation is just one such example.

My first encounter with a mining "boom" occurred in 1958, when, as a young mining engineer, I worked one summer in the sandstone uranium mines that dotted the cliff faces west of Grants, New Mexico. Uranium ore had been discovered a few years earlier at Haystack Butte by a Navajo sheepherder, Paddy Martinez. That discovery set off a frenzy of exploration activity and led to the development of the world-class deposits of Ambrosia Lake.

Ambrosia Lake was an old dry playa on the surface, but saturated underneath. The porous sandstone that hosted the uranium deposits yielded its water in vast quantities. The water flows were not predictable by known hydraulic models, a fact that I tucked away in a corner of my mind, thinking it might come in handy somewhere down the line. Sure enough, it did. Also, I witnessed the miserable failure of mechanized coal-mining equipment in the wet, gritty muck of the newly developed mines. Another fact to store away for later use.

I began my stint in the Wyoming uranium patch with Humble Oil (later part of Exxon) in early 1969. This started with an indoctrination trip to Houston. While there, I visited Esso Production Research Co. (EPRCo) to discuss the concept of solution mining of uranium. They were experts in reservoir engineering, and the translation of reservoir technology to uranium mining seemed to them to be a logical extension. It turned out to be like a lot of technology; behavior in the field often did not replicate the results in the lab. But they were a persistent bunch and eventually worked out a viable operating program. (Some thirty years after the Highland ore body was discovered and developed conventionally, substantial production continues via solution mining.)

Humble had as many as nine rigs drilling on the Highland project, northeast of Casper, at any given time. Each rig was punching down rotary holes at the rate of about five holes per day, so the data was accumulating faster than it could be analyzed. We needed a computer! The radiation logging data was being sent to EPRCo. for processing by their maxi-computer, but we needed something that would give us results more quickly. Otherwise we would be wasting drill holes by drilling them in places where we really should not.

We ordered a desk top machine, an Olivetti, that used magnetic cards for data input and was programmable; at least it could be programmed to make rudimentary math calculations. I wrote a program we called PROFIT BLOCK, a crude ancestor of the "floating cone" concept. We held densities constant, along with mining cost parameters, and calculated the potential profit to be realized by mining a vertical block of ore represented by each drill hole. We had no way to calculate the overburden to be removed outside the vertical limit of the pit, so we resorted to hand methods when we got to that point. It was a far cry from the sophisticated models and the powerful computer systems available to today's mine planners, but it was a mighty step forward for us.

By mid-April 1969 we had delineated an ore body that contained around twelve million pounds of uranium in place, and it looked like we might be able to make a mine. Exploration in the district intensified, and by mid-summer there were more rigs working in the Powder River Basin than in any other uranium district. In addition to the Kerr–McGee discoveries to the west of us, Teton Exploration and Union Pacific had finds. We had to hire a security guard to insure that our claims were not jumped by some overzealous prospector. It was an exciting time to be in the uranium business!

By the time the snow began to fall, the Highland project was beginning to take shape. Jersey Nuclear Corp., another subsidiary in Richland, Washington, had sold the first one million pounds from the operation, with delivery scheduled to begin in July 1973. Several engineering and construction firms expressed interest in building the milling facilities, while all the dirt-moving companies in the free world (so it seemed) wanted to bid on the stripping.

We met with Humble's board in Denver on 14 October 1969, and presented the project. It was a very starchy affair; the individual board members were pleasant enough, but it was clear that, except for it being the first mining venture for the company, the project was "peanuts" in their world. The Humble icebreaking tanker *Manhattan* had just completed the first successful voyage through the Arctic ice pack in the Bering Straits to Prudhoe Bay on Alaska's North Slope, where a big new oil terminal was planned. The cost of outfitting the tanker was $25 million, greater than the cost of our entire project, so it was easy to see why the board was not overly excited about us.

The regulatory environment was considerably different than that you find today. Wyoming had no reclamation law. In fact, the state used our internally developed plan as a model for the legislation enacted in the next session. The milling facility was regulated by the Nuclear Regulatory Commission, successor to the Atomic Energy Commission. The plant was to be a conventional acid-leach, solvent-extraction circuit, with precipitation, drying, and packaging of yellowcake on the back end. The tailings were to be transported by slurry pipeline to a small canyon east of the mill, where they would be discharged at the face of a manmade dam.

There was nothing out of the ordinary in the circuit or impoundment that would cause issuance of a federal license to be controversial and, allowing for the usual bureaucratic pathway through which it had to pass, the license was issued without comment or conditions. The state permits, likewise, were processed at snail's pace, but without controversy.

We proposed to build the tailings dam with a compacted clay core tied into the underlying bedrock. The down slope side was at a 3:1 slope and was topsoiled and seeded as soon as construction was complete. The discharge of tailings along the face of the dam built a delta that prevented hydraulic pressure at the toe of the dam from becoming excessive and creating a potential for leakage.

The reclamation plan called for excavation of pits in a sequence that permitted backfilling of all but the final pit. We began concurrent reclamation as soon as the initial stripping of the starter pit was completed. The overburden areas were sloped to replicate as closely as possible the preexisting topography, so the areas would blend into the landscape. We were ahead of our time in reclamation practices, but Humble wanted this mine to be their showcase and spared no expense to make sure that it was.

The contractor began stripping in mid-August 1970 using a fleet of Cat 666s. This fleet was brand new and at the time was the highest capacity fleet in operation in the uranium industry. While we were developing the conventional surface mine, we were also in the process of developing an experimental solution-mining project.

The experimental solution mine was located in an area of the ore body that would eventually be mined by surface methods, so the effectiveness of the process could be determined by observation. A five spot pattern was used, in two different operational modes. First, the center well was used to inject the leaching solution and the four corner wells to pump the pregnant solution. After about six months or so, the process was reversed, with barren solution injected into each of the corner wells and pregnant solution removed through the center well.

The leaching solution we used was softened water and air. Previous experiments with in-situ extraction had used either sulfuric acid or ammonium hydroxide, but both of these extractants had environmental liabilities. The acid could contaminate the groundwater and the ammonium ions tended to attach to clay particles, making cleanup of the aquifer after mining virtually impossible.

Outside of the possibility of contaminating the groundwater aquifer, the chief operational concern was the ability to control solution flow so as not to lose uranium values to an uncontrolled environment. A ring of observation wells at varying distances from the well pattern was monitored to assure that proper control was being exercised. The field installation was well insulated against the extreme cold of a Wyoming winter. All lines were buried below the frost line and the well head piping was wrapped and heat taped. The reagent and recovery building was insulated and heated. Yellowcake was precipitated from the pregnant liquor and eventually transported to the mill, in a small tank trailer pulled by a pickup, for drying and packaging.

Early spring 1973 found us ready to begin thinking about the mining operation, as contrasted with the contract stripping. We needed to begin equipment selection and more detailed mine planning. The Highland Project became a high-profile project for a number of reasons: Humble Oil & Refining Co. was by far the largest oil company to enter the uranium industry, thus everyone assumed the "deep pockets" had arrived; we wanted to be viewed as environmental leaders, not as being pushed into reclamation by outside interests; and we had some unconventional ideas about what we wanted from a workforce.

Humble had an oil refinery at Benicia, California, in the San Francisco area, that operated union-free with an all-salaried workforce. We were asked to come up with a similar type of an organization for Highland. It would be a radical departure from any mining organization I had known, but we agreed to give it a try.

We decided to make all of our operating employees Operations Technicians, and our maintenance employees Maintenance Technicians. Each classification was to be salaried and eligible for all of the perks available to traditional salaried employees. Wyoming was then and remains a right-to-work state, and we felt that if we could give all our employees the same salary structure and employee benefits, we stood a good chance of being able to operate without a union. Humble was a non-union company on the oil side, and did not relish the idea of organized labor making inroads through the mining side.

Meanwhile, development drilling on the ore body continued to extend the ore to the northwest, to a point beyond which it was no longer economical to strip the overburden to expose the ore in a pit. We would have to go underground, and that possibility brought with it a whole new menu of choices. At that time we were uncertain of the outcome of in-situ extraction, so we began to plan for a shaft mine. All our drill holes made water, and the reason that the uranium had remained in place was because the ore lay below the water table, so we knew it would be wet.

Our choice of a ventilation system was tied to our decision to dewater by the use of wells drilled at the periphery of the ore body. If we could get enough wells pumping at a given time, we could create a pressure sink outside the ore and any radon gas associated with the ore would tend to migrate toward the wells. If the mine were to be over-pressured as it was developed, it would steepen the gradient even more and reduce the hazard of radon gas to miners. The most common and usually the most economical way to ventilate an underground mine is to place it under negative pressure by putting the main fans on exhaust and pulling the air through the mine. We, however, chose to put the fans on the intake and push the air through the mine; it was less efficient, used more power, but kept the migration of radon from the unbroken ore to a minimum.

As the pit neared the top of the ore zone, we began to encounter groundwater and began plans to dewater the pit as stripping progressed downward. We purchased a Poclain 300 backhoe for excavating a drainage ditch around the periphery of the pit. The Poclain had the capability of digging in excess of twenty-four feet below the pit bottom. The collection ditch would intercept water flowing into the pit, and by maintaining a sump below the pit bottom the water trapped in the interior of the pit would also drain.

We elected to do the dewatering ourselves, rather than have the contractor do it. However, this meant that we would have to be able to keep the pit floor dry or else be willing to pay the contractor for handling wet muck. The sandstone formation had great transmissivity and the water drained readily, as long as we kept the ditch low enough and the sump pumped down. There were isolated instances, such as when we lost electric power and couldn't keep the sump low enough, that we would have water in the pit, but it never caused a contractor problem and it allowed us to begin to get used to the equipment we would use to mine the ore.

A portion of the initial overburden area had been contoured and re-seeded in the spring, and by the time snow fell in the fall, we had a beautiful stand of crested wheat, western wheat, and rye over the hillside. It was difficult to see where the disturbed area met the undisturbed, which is what reclamation is all about. We were able to keep up the concurrent reclamation throughout the life of the surface mining and produced a landscape that truly blended in with the original.

As the snow flew in earnest, we began to see why the topographic features were named as they were. There was a ridge called Blizzard Heights to the west of us where Kerr–McGee had their discovery. The Highland Flats, immediately west of the mine, was an extension of the ridge, with nothing to keep the wind and snow from blowing. Once the snow began, access to the mine became critical. We used our contractor's grader, dozer, and front end loader, and called on the county for help when we could not keep up. We erected snow fences at critical places along the road to keep the snow from drifting the road shut. Some times it worked and some times it did not. There was no question that mining in Wyoming winters would pose challenges.

We received approval to purchase a mining fleet in late December 1972. This fleet consisted of three Poclain HC300 hydraulic shovels, five Cat 769B haul trucks, two Cat 633C self-loading scrapers, two Cat 980B front end loaders, an International Harvester TD25 bulldozer, and a Galion T-500 motor grader. The mix was a nightmare for operating and maintenance, but the corporate purchasing group was *so* pleased with their purchases. We would not be dependent upon any one service provider, they proudly explained. But we had to stock parts from four manufacturers instead of one or two. It was the usual battle between those of us who favored Caterpillar equipment for its reliability and productivity and those who looked only at the bottom line. It was one of a number of battles we lost to the bureaucracy in Houston, but you can't win 'em all.

Incidentally, the total delivered cost of the equipment was $1.2 million. (See what you can buy for that price nowadays!) The Poclains had been purchased for use on the Aleyska pipeline, but never were, so we got them at a nice discount. They had high-pressure hydraulic systems, much greater than their U.S. competitors, and were capable of exerting enough breakout force to allow us to mine with only ripping of the ore. They were metric machines with all the inherent disadvantages that went along with the need for special tools. However, we wanted to have a machine that could dig without substantial prior disturbance to the ore in place—and the price was right!

We continued to develop our concept of a multi-skilled workforce by contacting Casper College and cooperating with them in developing a curriculum. The college agreed to give academic credit for the course work, so each technician graduating from the program received a Certificate of Completion from the Mining Technology program. For the time, it was an innovative approach to vocational training, but one that Humble supported enthusiastically.

We began interviewing candidates for the operating crews in May. Once the word spread that we were hiring, we were deluged with applications. We had over six hundred applicants for fifty-five jobs. We tried to get a mixture of age and experience in the initial contingent, but the majority were young farm or ranch hands from eastern Wyoming or western Nebraska. Their farm backgrounds had exposed them to machinery and their upbringing had instilled in them a good work ethic. We found that they adapted to our multi-skill system better than construction or mining hands. And they did exceptionally well in the formal training program we instituted at Casper College.

That program consisted of basic mathematics, basic electricity, English, hydraulics, welding, and diesel engines. The workforce was divided into three groups: one in class at Casper College, a second training on the mining equipment at the mine, and a third training in the mill. The crews rotated every two weeks. By rotating frequently, the men were constantly being exposed to new learning, but were kept from becoming discouraged by any one aspect of the training.

By summer's end, the initial crews had completed the training program and were beginning to produce ore from the pit that was stockpiled at the mill crusher for processing once the mill became operational. Mine production increased as more of the orebody was exposed. A daily rate exceeding 4,000 tons was reached in November, with a sustained rate of 3,300tpd by year's end.

Pre-stripping extended down from the surface to the top of the ore body, where the 666s could no longer operate efficiently because of the random nature of the ore pods. A local contractor with a fleet of self-loading 633s carefully removed the waste from around the ore pods, then ripped the ore zone with a D-9 dozer and double-tooth ripper. Finally, our crew moved in with their Poclain shovels and mined the ore, under the direction of a grade-control technician.

Ore-grade control was first established by the ore controller, using a hand-held gamma ray probe. Each row ripped by the dozer was probed, and the edges of the ore flagged. As mining progressed, each bucket-load of material was again probed prior to loading into the 769 haul trucks. Each truck-load of ore was checked one last time at the sampling tower, located on the haul road to the mill. Here, a representative sample was augered and run through a radiation analyzer. The tower operator then communicated with the truck driver and directed him to the proper stockpile. It was a far cry from today's mobile dispatching system, but it was state-of-the-art for its time. By the time the mill was ready for shakedown, it had an ore stockpile of around fifty thousand tons.

Mill construction progressed fairly well. There were the usual trade union jurisdictional fights, and a couple of walk offs when non-union subcontractors were used, but, all in all, construction went well. We began to check the crushing circuit in late October 1972, and had worked most of the mechanical bugs out of the front end of the circuit by the middle of November. Our most serious problems were with chute designs. The ore was stickier than anticipated and tended to plug chutes as the tonnage through the mill increased. Once the ore was in the leach tanks, however, the remainder of the circuit worked like a charm—until we got to the tailings disposal system.

The tailings were pumped from the thickener circuit over fifteen thousand feet through a PVC pipeline to the face of the tailings dam. The PVC line was laid on a roadway twenty-five feet wide to allow it to expand and contract with changes of temperature. The roadway was at a negative one degree gradient, so that if power was lost and the pumps stopped, the line would drain by gravity. The only problem was that the slurry would segregate—the liquid flowing on out of the line, but the solids settling to the bottom and plugging the pipe.

Naturally, we began to use this system in the winter, when temperatures were routinely subzero. Until the system became fully operational—with redundant pumps and a spare line—we spent a lot of time cutting the line, pulling it into the mill building in five-hundred-foot sections, thawing it out, flushing the solids to the sump, and then relaying and re-welding the segments.

We began to produce and stockpile yellowcake in late November, in preparation for our first shipment to a customer in July 1973. An outside storage pad was constructed adjacent to the yellowcake packaging area. As barrels were filled with yellowcake, they were weighed and labeled with all the identifying marks required by the NRC, then placed on the outside pad and covered with a tarpaulin. We made our first shipment of yellowcake to Exxon Nuclear on 21 March 1973 from the stockpile we had accumulated. Now we were in a position to provide Exxon with positive cash flow. The capital expenditure to get us to this point had been slightly less than $32 million.

Our reclamation efforts were also really beginning to bear fruit; well, not literally. But the wet spring had nourished the grass on the re-seeded overburden area, and the western wheat and crested wheat were almost waist high. The area had become a haven for wildlife. A large deer herd had taken up residence, and antelope and rabbits freely roamed the site. We had given a tour to a couple of Audubon Society staffers the previous year, so it was no great surprise when we received a request from the society to include a visit to Highland as a field trip tacked on to the end of its annual meeting in Denver.

Two reporters, one from the *New York Times* and the other from the *Washington Post*, accompanied the visit, as did a staff photographer from *Audubon*, the society's magazine. The tour went well, with thirty-five guests, plus the two reporters and the photographer. We received very positive press from the papers and a nice color spread in the magazine. I doubt that we changed many minds about mined-land reclamation, but they could see that not only were we making an effort to restore the land, but that we were succeeding.

Work continued on the design of underground facilities. By then the dewatering wells ringed the ore body and had been producing groundwater for use in the milling operation for almost a year. The shaft was collared and sinking suspended while the headframe and hoist were installed. It was decided that a completely covered headframe would be needed to withstand the cold Wyoming winters. This proved to be a good decision; we never lost any production time due to weather. An eight-foot-diameter shaft was excavated for ventilation and as a second escape way. It, too, was completely enclosed. Mine offices and a warehouse completed the surface installation. The enclosure was in our familiar teal and yellow color scheme.

During the initial stripping of the first pit, we left some overburden in the east side because the stripping ratio would not support the economics of mining. The low-grade ore remained exposed in the pit wall, untouched. I guess I just could not get the idea of using continuous miners for uranium ore out of my head. I did not get to try it earlier at Grants, but there was no one in Exxon who pooh-poohed the idea. We located a used Alpine miner, an F5 or 7, I believe. We decided to build a skid-mounted portal of corrugated metal, move it into position where the ore was exposed, and try to mine a drift into the ore.

The continuous mining worked like a charm, but excavation was limited to drifting. As we advanced into the wall, the ore thickened and widened to the point where we could not efficiently extract all of it. We then established square-set stoping to remove the remaining ore. The experiment did not produce the desired economics, but we were sufficiently encouraged to attempt to use the Alpine in our shaft mine.

Shaft sinking at the underground mine progressed routinely. The groundwater encountered was minimal, thanks to the ring of dewatering wells we had drilled. By the time the shaft station was completed in mid-September, both the shaft and station were essentially dry.

We solicited bids for stripping the second pit in the mining sequence, but, as often happens, when the bids were compared with purchasing our own equipment and doing the job ourselves, it looked like we should bite the bullet, invest in a mining fleet, and get rid of the contractor. It was a scenario I have since replayed many times. We placed orders for two P&H 2100 BL cable shovels and a fleet of seven Unit Rig M-100 haul trucks, and terminated the contractor.

We began to receive the new mining fleet and assemble it for use in stripping the second pit. The equipment arrived by rail and was offloaded at Douglas. The haul trucks were assembled there and driven to the mine. The two shovels were off-loaded at Douglas also, and their components transported to the mine site by lowboy. We assembled the shovels near the mine shop, close to where they would be put into service.

The activity at the spur track in Douglas generated a lot of interest on the part of the locals. Most of them had never seen such gigantic trucks, and as the trucks began to take shape their size became even more impressive. The shovel assembly, because it took place at the mine, did not create the same level of interest as had the trucks, but for those of us at the mine who watched daily as the superstructures took on their distinctive form, it was a beautiful sight. We could hardly wait to put the shovels in the dirt.

Teton Exploration, which by that time had been acquired by United Nuclear, discovered a new uranium deposit west of Highland, about midway between our mine and Kerr–McGee's. This opened up a very large block of additional acreage for us to explore. We put first two, then three rigs to work, and soon came up with a substantial new reserve we called West Highland. Its mineralization was too deep for surface mining and too scattered for effective underground mining, but proved to be ideal for in-situ extraction.

Since we had plenty of minable ore already developed, we were able to maintain a slow but steady pace in drilling and evaluating the new reserves. We took the claims to patent, the first and only claims patented at Highland. The application process was slow, but Exxon received the patents without any bureaucratic opposition. It was a far cry from the continuously swirling controversy that later engulfed the patenting process and led to today's moratorium on the issuance of new mineral patents.

Along with the increased activity associated with preparations for stripping Pit 2, we contracted out a small underground development and mining program at the bottom of Pit 1. Once we completed mining in the initial pit, we wanted to begin backfilling, but there was a roll front—a uranium concentration in an ancient river channel—extending out from the pit bottom that could not justify the stripping necessary to reach it.

U. S. Energy Co., of Riverton, Wyoming, essentially made its livelihood by contract mining these small roll fronts. They opened two portals and drove their development headings in ore, much like the hard rock vein miners of yesteryear. When the roll front pinched out or they lost it in the face, they would begin to retreat, taking all the ore they had previously exposed that could be safely mined. They used roof bolts and an occasional stull for ground support, but the secret to their success was their ability to get in and get out quickly. We paid them by the cubic yard, so the onus for grade control was on us. The contract mining of the pit wall was completed at about the same time as our own pit–wall mining with the Alpine concluded.

Our initial experiments with the Alpine miner in the pit wall and the underground incline were sufficiently encouraging to cause us to look further into mechanized development. We put the Alpine miner to work driving an incline from the haulage level to the ore level as soon as the shaft and station were completed at the underground mine. And we began to look at tunneling machines, even making a trip to Milwaukee to see a soft-rock machine at work on a storm sewer project underneath the city streets.

We eventually signed a contract with MEMCO of Milwaukee to construct and operate a soft-rock machine for underground haulage drift development. The machine was about eight feet in diameter, and consisted of a circular shield held in place by hydraulic jacks that thrust outward to engage the wall rock. The jacks advanced the shield by thrusting it forward, much like a pushing a cookie cutter through dough. It had a set of cutting teeth around the circumference of its leading edge, and a small hydraulic rock pick within to break rock fragments from the face. Broken rock was picked up by a chain conveyer, then transported from the shield to the ore cars by an overhead belt conveyor. The newly excavated ground was supported by vertical steel rings placed on three-foot centers and lagged between rings with hardwood beams. The machine was laser guided for drift alignment.

Once the machine was up and running, the contract crew was able to drift through the soft sandstone and shale with incredible speed. Eventually, the machine drove about ten thousand linear feet of drift. When the job was done, the machine was left in place in the drift, a lasting monument to the first successful mechanized development in the uranium industry. United Nuclear used a similar machine to develop their mine west of Highland, the only two applications of this tunneling technique in uranium, as far as I know.

One thing I must say about Exxon's people: when they grabbed hold of a concept, they went "whole hog." The Alpine and the shield were both proven machines, but Houston decided that they did not offer sufficient flexibility for mining, so we once again contracted with MEMCO to build us a customized mechanical miner. The staff engineers in Houston worked with MEMCO to produce a hybrid machine that was a cross between the two proven machines. But there was little, if any, communication between Houston and Highland concerning the machine's design, a guaranteed prescription for failure.

The machine's components were too large to be taken underground, so the machine had to be disassembled more than intended in order to get it down the shaft and through the drifts. Assembly had to be done at the face, where there was insufficient headroom for the mechanics to work efficiently. Once assembled, the machine was too heavy for the ground to support. The crawler pads sank into the shale bottom until the machine was literally high centered. Attempts to widen the crawler tracks to reduce bearing pressure were not very successful because there was not enough clearance under the frame for wider tracks.

I do not know what finally became of the MEMCO miner, but I imagine it remains entombed in the mine, a relic to pique the curiosity of future miners, if its tomb is ever reopened. From that experience, I learned that you never want to push technology on an operator without his wholehearted endorsement. It will never work. I also learned that evolutionary or incremental technology is usually to be preferred over the revolutionary, particularly if one has to respond to the pressures of the bottom line.

The underground drifts and stopes, while not as wet as they might have been without the peripheral dewatering wells, were wet enough to cause some swelling and heaving of the haulage track. We had a track repair crew at work almost full time. The moisture also contributed to weak and unstable ground conditions. We had to spile through much of the Alpine's incline, drilling back holes at twenty to thirty degrees upward, into which we inserted one-inch rebar. The rebar would hold the brow long enough to excavate six feet with the Alpine and install the posts and caps of the timber set. Conventional roof bolting did not provide adequate protection, even when used in conjunction with wire mesh, and grouted bolts were too expensive and time consuming to be of help.

I had worked with Dr. Jim Scott a number of times over the years on ground control problems. I called him at his office at the University of Missouri-Rolla, where he was teaching and doing research. Our conversation had not been going on for more than a couple of minutes when he exclaimed: "Have I got a deal for you!" He had been working on a new kind of roof bolt that was continuously anchored in the hole and held in place by the friction between the bolt and the rock. He had successfully tested his bolts in several coal mines, but had not yet found a place to try them out in a non-coal environment. I invited him to bring some of his bolts to Highland, with the assurance that if they worked and the price was right, we would give them a thorough test.

Jim showed up at the mine with what looked to be a pallet loaded with exhaust pipes. His bolt was nothing more than a slotted tube of sheet metal, sized to fit snugly in a 2" inch drill hole. It had a regular square rock-bolt plate that fit over the tube and rested against a welded washer on one end of the tube, the other end of which was tapered to easily enter the hole. The bolt was driven into the hole by a jackleg drill, allowing the tube slot to contract as required to maintain continuous skin contact throughout the length of the hole.

Jim had several of the bolts placed, then hooked up a hydraulic puller for conventional pull tests. We were unable to pull any of the bolts from the holes. The system had a great deal of potential, if it worked. There was no separate shell required for anchorage, and so one less component to worry about. The installation technique was simple; there was no application of torque required and no possibility of shearing the bolt and ruining the hole. This was the type of incremental improvement that was likely to work. We decided to try the bolts on a larger scale, so we ordered a truckload.

In the years following that initial application at Highland, the Split Set friction bolt became the hard rock industry standard, largely supplanting the bolt-shell combination as the preferred method of ground control. Jim went on to develop a number of other ground control devices for more difficult rock conditions. He founded his own company, learned to fly, and died when he crashed his light plane returning to Rolla from a business trip. He will be remembered as one of the true innovators of ground support devices and a major contributor to improved safety in underground mining.

The development of the Highland uranium mine is a study in innovation—from the introduction of desktop computing to continuous mining machines and Split Set rock bolts; from multi-skilled salaried workers to formal classroom training; from pro-active reclamation practices to environmentally friendly in-situ mining. It was a real "hoot" to be a part of it!

Morris Worley, mine manager on the Highland project, is a graduate mining engineer with fifty years of experience in all phases of the mining industry. He began his career as a surveyor's helper and retired as COO of a mid-sized mining company. Since retiring he has served with an international relief and development company in Central Asia, directed the vocational programs at a local community college, and established a consulting business that serves a variety of industrial minerals clients.