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The Smith Ranch Project: a 1990s In Situ Uranium Mine

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The Smith Ranch uranium mine is the newest and largest uranium production centre in the United States, and today is producing at a rate of 580 tU (1.5 million lbs U_3O_8) per year using mild alkaline in situ leach technology. This paper provides a review of property history; a brief discussion of the geology of the deposit; the regulatory framework for uranium mining in the United States; the project design, construction and startup experience; and production history to date.

Property History

The Smith Ranch Project is located in east central Wyoming in the western United States in an area commonly referred to in geological terms as the South Powder River Basin (Figure 1). The area is characterised as a semi-arid, rolling grassland with very few trees except along the rivers. Deer and antelope thrive in this environment and are the main big game animals hunted in the area. The primary business in the area is cattle and sheep ranching. With a limited growing season and relatively harsh winters, the number of animals that can be supported in a given area is restricted and the ranches are therefore relatively large and stay in a family for generations. For example, the ranch on which Rio Algom's mine is located, which was started in 1897 and has been in the Smith family for over 100 years, is a combination cattle and sheep operation that maintains a livestock count which includes about 1000 cows and 5000 sheep. To support an operation of this size, the Smith family ranch owns and/or controls over 30 000 hectares (75 000 acres) of grazing land.

The interest in uranium in the area goes back to the mid to late 1950s when two of the local ranch families formed a small mining company to mine mineralised outcrops at a site 20 miles north of our plant. This operation was relatively short lived because of high unit costs due to the size of the operation and uranium disequilibrium problems in the outcrops.

As the US electricity utilities expanded their interests in nuclear power in the mid 1960s, US oil, gas and mining companies became very interested in the uranium mineralisation in the South Powder River Basin and a number of large exploration programmes were initiated. Most of the mineral land positions (mining rights) that exist today were put together in that timeframe. Kerr-McGee Corporation was one of those companies with a large exploration programme, and it put together a land block of mineral rights that includes what is now the Smith Ranch Project.

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Kerr-McGee sank a 286 m (940 ft) shaft on the Smith Ranch Property in the mid 1970s and did a limited amount of underground mining in the late 1970s. However, the high cost of maintaining the mine working due to unstable ground conditions (swelling shale formations) and the costs of treating the 95 to 125 litre/second (l/s) (1500 to 2000 gallon per minute (gpm)) of water that had to be produced to keep the mine from flooding, resulted in the mine being placed on standby; it was never re-opened.

Kerr-McGee also began stripping operations (overburden removal) in 1977 for open pit mines at two uranium deposits about 15 miles north of the underground mine. Shortly after these mines began production in 1978 and 1979, the rapid decline in uranium prices caused them to be put on standby. The south pit was at a maximum depth of 80 m (265 ft) when the operation was suspended. Rio Algom subsequently reclaimed this pit and today it blends in with the natural countryside.

During the 1970s and early 1980s, many of the companies working in the South Powder River Basin, including Kerr-McGee, were also conducting research programmes and/or field tests with in situ uranium mining. Kerr-McGee conducted two very successful pilot tests in the Smith Ranch area in the 1981–86 period.

The pilots were conducted to obtain process and wellfield performance information for economic evaluation and to demonstrate to Wyoming regulatory agencies that the leaching fluids could be contained and the groundwater restored. To the extent possible, pilot operations simulated projected commercial operations. The first pilot test was conducted in a deposit at a depth of 152 m (500 ft) and was located only 450 m (1500 ft) south of the underground mine shaft. The 6.3 l/s (100 gpm) test operated from October 1981 through November 1984, with restoration continuing to May 1986. Aquifer stability and restoration of this test was accepted by the State of Wyoming in August 1987. The second test began operation in August 1984 and continued through 1990. It was conducted in a different formation at a depth of 230 m (750 ft) and covered a 0.73 hectare (1.8 acre) area.

The first test was in one of the thinner ore-bearing units in the Smith Ranch area, which ranged from 3 to 15 m (10 to 45 ft) in thickness in the test area. The second test was conducted in one of the thickest mineralised formations within Smith Ranch. In the test area, it was 75 to 90 m (250 to 300 ft) thick, however, only a portion of this thicker zone was leached during the pilot programme.

Both pilot wellfields were arranged as five-spot patterns, that is four injection wells arranged in a square with the recovery or extraction well in the centre. For the first pilot, the square was a nominal 30 m by 30 m (100 ft by 100 ft) (Figure 2). For the second pilot, the nominal spacing was 36 m by 36 m (120 ft by 120 ft) (Figure 2). All wells, including monitor wells, were connected via buried pipelines to a wellfield “headerhouse” where injection and recovery well flow meters, pressure gauges, flow controls, oxygen mixers, and sample ports were located. Each monitor well was equipped with a pump for ease of sampling at the headerhouse. The pilot recovery plant was a standard anionic resin ion-exchange system. Since both tests operated simultaneously for a period, two ion exchange systems were installed and both upflow and downflow ion exchange vessels were used.

The first pilot had an average uranium concentration of 90 mg/l from inception until its average dropped to 20 mg/l (a generally accepted cut-off point to begin restoration) in a flow of 5.0 to 6.3 l/s (75 to 100 gpm).

The second pilot, which was in the thicker formation and had a greater spacing between wells, averaged about 70 mg/l in a flow of about 9.5 l/s (150 gpm). The difference in total flow rate was due to design considerations and differing licence conditions for each test. Aquifer drawdown was not a problem. The performances of the pilots are summarised in Table 1. Even though the pilot operations were successful, Kerr-McGee decided to exit the uranium mining business in 1988. In 1989, Rio Algom acquired Kerr-McGee's uranium interests in the South Powder River Basin.

A number of the mining and energy companies associated with uranium mining in the United States have or have had uranium interests in Wyoming's South Powder River Basin, including Exxon, Tennessee Valley Authority, Cameco, Cogema, Pathfinder, United Nuclear, CEGB, Everest Minerals, and Power Resources. To date, approximately 20 000 tU (50 million lbs U_3O_8) has been produced in the South Powder River Basin area.

Geology

The Powder River Basin located in eastern Wyoming and southern Montana is a structural basin that is bounded on the south by the Laramie mountain range, by the Big Horn mountains on the west, and on the east by the Black Hills mountains (Figure 3). The basin is open on the north. The basin has an area of approximately 3.1 million hectares (7.7 million acres). The Smith Ranch permit area, which is located in the very southern portion of the basin, comprises 6600 hectares (16 300 acres) of the 22 000 hectares (54 000 acres) of mineral rights controlled by Rio Algom in that area (Figure 4). The topography in the permit area is characterised by generally rolling upland areas, broad stream valleys, steep-sided draws, and rounded ridge crests. Current surface elevations within the permit area range from 1610 to 1780 m (5300 to 5800 ft) above mean sea level, with elevation changes of up to 60 m (200 ft) occurring in a wellfield development area.

The significant uranium deposits in the South Powder River Basin are in tertiary strata, that is, the Paleocene Fort Union formation and Eocene Wasatch formation. At the end of Cretaceous time, structural uplifts had developed and continental deposition began during Paleocene time. Most of the basal Paleocene Fort Union formation rocks were derived from erosion of Cretaceous shales and sandstones and hence are mostly fine-grained clastic. By late Paleocene time, erosion had cut into the crystalline core of the ancestral Laramie Mountains and intermittent loads of arkosic sediments poured into the southern end of the present Powder River Basin.

In late Paleocene to early Eocene time, the Powder River Basin underwent further subsidence with corresponding uplifts of the surrounding mountain blocks. Deposition during this period was primarily by large, sluggish streams with associated coal swamps. In early Eocene time, large amounts of coarse clastic eroded from the highlands forming large fans and braided stream deposits. Deposition of the Wasatch formation in the Powder River Basin was to a degree cyclic with periods of quiescence followed by periods of uplift and rejuvenation of the coarse clastic cycle. Sedimentary studies show the Granite Mountains to be the main source of clastic material, with minor clastic provided from the ancestral Laramie Mountains and Hartville uplift.

Following deposition of the Wasatch formation, subsidence of the Powder River Basin resulted in a northerly regional dip of approximately 1.5 degrees in the Eocene and earlier rocks. Degradation of the area continued from middle to late Eocene with the development of a mature topography which later was buried by Oligocene deposits. During the Oligocene, Miocene, and Pliocene times large deposits of sandstones and tufaceous sediments collected in the Powder River Basin. Vulcanism was incessant during this period and the area was covered with thick layers of volcanic ash.

A major regional uplift took place near the close of Pliocene time and rejuvenated streams began erosion and down-cutting of the existing sediments. This erosion continued and brought about the present topography.

Local Geology

Within the permit boundary the host sandstones targeted for uranium production are the arkosic sandstone units of the upper Paleocene Fort Union formation and lower sandstone units of the Eocene Wasatch formation.

The Wasatch formation is the youngest bedrock unit present throughout the permit area with thickness ranging from 60 to 90 m (200 to 300 ft) in the northern and southern portions of the permit area to 150 m (500 ft) in the central area. The Fort Union formation, which below lies the Wasatch, is over 300 m (1000 ft) thick; however, only the upper 180 to 210 m (600 to 700 ft) contains the sandstone units with uranium mineralisation of interest. The contact between the Fort Union and Wasatch formation is defined as the base of the School Coal seam which is a correlatable lignite zone present throughout permit area.

Uranium resources in the permit area are primarily concentrated in six sandstone units. Thickness in these sandstone units ranges from 3 to 60 m (10 to 200 ft). The ore occurs as a typical oxidation reduction roll front and the fronts are generally north-facing, C-shaped features. A sandstone unit, depending upon its thickness, can contain a number of small mineral fronts within the unit with those individual mineral fronts occurring as sub-features of the overall mineral deposit.

The generally accepted theory on the deposition of the uranium in this area is that uranium contained in the volcanic ash that covered the area was mobilised by oxygenated rainwater and the dissolved uranium was carried down into the sandstone outcrops with the rainwater and continued down dip in the permeable formations until it reached a reducing environment where it precipitated. Over geological time, that depositional process resulted in today's commercially viable uranium deposits.

Design Criteria

The basic design objective for the Smith Ranch Mine was to have a facility that could achieve and maintain a production rate of 770 tU (2 million lbs U_3O_8) per year. All process design and equipment selection was done by our in-house engineering staff. Contractors were used to prepare the final design on items such as piping detail and structural steel. The plant concept included a central processing facility (elution, precipitating, and drying) with an adjacent 380 tU (1 million lbs U_3O_8) per year ion exchange recovery system. An additional ion exchange recovery unit with the same capacity would be built as a satellite facility to keep pumping and pipeline costs to a minimum. Individual wellfields, each containing 380 to 770 tU (1 to 2 million lbs U_3O_8) of recoverable reserves, would be developed and connected to one of the ion exchange recovery facilities using high density polypropylene pipelines buried at a depth of 1.5 m (5 ft) to get below the frost line and avoid freezing, even during shutdown conditions.

The mechanics of uranium in situ mining are relatively straightforward. A leaching solution (lixiviate), formed by adding gaseous carbon dioxide and oxygen to native groundwater, is injected into a uranium ore-bearing sandstone through a series of injection wells. As the lixiviate moves through the aquifer contacting the ore, the oxygen reacts and oxidises the uranium to the +6 valence state. The oxidised uranium then complexes with the carbon dioxide and water to form a soluble uranyl dicarbonate ion $[UO_2(CO_3)_2]^{-2}$. The uranium-rich lixiviate flows through the formation to a recovery well where it is pumped to the surface by submersible pumps and transported through a piping system to a surface recovery plant. At the recovery plant, the uranium is removed from the fluid by ion exchange. The barren fluid is then re-fortified with carbon dioxide and oxygen and re-injected to extract additional uranium.

A simplified flow process schematic is shown in Figure 5. The wellfields and ion exchange recovery plant are shown under "Uranium Extraction" and the central processing plant is under the heading "Yellowcake Recovery". During production operations, about 99% of the produced water is re-fortified with oxygen and carbon dioxide gas and re-injected into the wellfield. A bleed of 0.5–1.5% is taken to maintain a hydrological cone of depression to ensure the leach solutions are contained within the wellfield.

The major equipment items in the recovery plant are the ion exchange vessels, ion exchange resin, the process tanks, the instrument and control system, and the pumping system. The ion exchange vessels are 3.5 m (11.5 ft) in diameter pressure vessels constructed to Rio Algom's specifications and are loaded with 14.2 m^3 (500 cubic feet) of Dow 21XLT resin. Two columns operate in series and are designed for a flow of 63 l/s (1000 gpm). There are three pairs of ion exchange columns at each facility for a total design flow capacity of 380 l/s (6000 gpm).

As the uranium-rich lixiviate enters the recovery facility, booster pumps pressurise the fluid to 790 to 1000 kPa (100 to 130 psig). The lixiviate is then routed through the ion exchange columns and dissolved uranium in the lixiviate is chemically adsorbed on to ion exchange resin. Any sand or silt entrained in the lixiviate is trapped by the resin bed which acts like a traditional sand filter. The barren lixiviate exiting the second ion exchange column will normally contain less than 2 mg/l of uranium. This fluid is again pressurised to 790 to 1000 kPa (100 to 130 psig) by booster pumps and returned to the wellfield for re-injection.

When the resin in a column reaches a predetermined loading, the column is isolated from the production flow and the resin is physically removed and transported to the central recovery plant. For the ion exchange unit adjacent to the recovery plant, all transfers are done by pipeline; however, resin trailers are used to transport the material between the satellite and the central plant.

In the recovery plant the resin first passes over vibrating screens with wash water to remove entrained sand particles and any other debris. The resin is then fed into downflow elution vessels for uranium recovery and resin regeneration. In the elution vessel, the resin is contacted with an eluate containing about 90 g/l sodium chloride and 20 g/l sodium carbonate (soda ash), which regenerates the resin.

Using a three stage elution circuit, 170 m^3 (45 000 gallons) of eluate contact 14.2 m^3 (500 cubic feet) of resin. The first stage elution results in 57 m^3 (15 000 gallons) of rich eluate containing 10 to 20 g/l U_3O_8. The fresh eluate, 57 m^3 (15 000 gallons) per elution, is prepared by mixing quantities of saturated sodium chloride (salt) solution, saturated sodium carbonate (soda ash) solution, and water. The salt solution is generated in salt saturators (brine generators). Saturated soda ash solution is prepared by passing warm water at >40°C (>105°F), through a bed of soda ash. In the final stage, the eluted resin is rinsed with fresh water and then is ready to be returned to an ion exchange column for reuse.

The eluate containing the high concentration of uranium is treated with sulphuric acid, ammonia and hydrogen peroxide to begin the precipitation process. Sulphuric acid is added to break down the uranyl carbonate complex, which liberates carbon dioxide and frees uranyl ions. The acidic, uranium-rich fluid is pumped to agitated tanks where hydrogen peroxide is added (0.2 kg H_2O_2/kg U_3O_8) in a continuous circuit to form a uranyl peroxide compound. Ammonia is then added to raise the pH to a level where the uranyl peroxide becomes insoluble and initiates the digestion and precipitation process. The treated solution is then routed to a 11.6 m (38 ft) diameter cone-bottomed thickener to allow the uranium crystals to settle and concentrate.

The settled slurry is pumped to a plate and frame filter press where it is washed to remove the excess chlorides and is then pumped to one of two low temperature vacuum dryers. The vacuum dryers are totally enclosed during the drying cycle and the off-gases generated during the drying cycle are filtered and scrubbed to remove entrained particulates. The water sealed vacuum pumps are also used to provide positive ventilation while unloading the dryer. The vacuum dryers are unloaded through a sealed chute directly into 208 litre

(55 gallon) steel drums, which after cooling, are sealed, weighed, and prepared for shipment.

Operations in the central processing facility are primarily batch operations that are monitored or controlled through a computer system. Pressures, temperatures, tank levels, flow rates, and other similar data are collected, alarmed, displayed, and trended as appropriate to aid the plant operators. Local displays and control panels are also installed to provide the operator the data needed for complete manual control if required.

Wellfields

The other key part of the process is the wellfield. The wellfield areas have been divided into mining units for scheduling development and to establish baseline data, monitoring requirements and restoration criteria. Each mining unit consists of a reserve block in the range of 8 to 24 hectares (20 to 60 acres) and represents an area that will be developed, produced and restored as a unit. Approximately fifteen such units will be required to develop the total project area. Two to three mining units will be in production at any one time with additional units in various stages of development and/or restoration. A mining unit will typically have a flow rate in the 126 to 189 l/s (2000 to 3000 gpm) range. The size and location of the mining units are defined based on final delineation of the ore deposits, the expected performance of the area, and development requirements.

Injection and recovery wells are cased and cemented to isolate the open hole or screened ore bearing interval from all other aquifers. Production zone monitor wells are located in a pattern around the mining unit or units with the completion interval open to the production zone. Production zone monitor wells are located approximately 150 m (500 ft) from the mining zone and from each other. One overlying and one underlying monitor well are completed in the aquifers immediately above and below the production zone for each 1.6 hectares (4 acres) of wellfield area. The outer ring of production zone monitor wells are completed in the formation being mined to ensure leach fluids are not moving horizontally out of the controlled areas. Monitor wells completed in the next overlying and underlying aquifers ensure there is no vertical movement of leach fluids.

All production area wells are constructed to serve as either injection or recovery wells. This permits flow directions to easily be changed to maximise uranium recovery and to optimise groundwater restoration. A typical wellfield will contain 300 to 400 injection and production wells and 40 to 60 monitor wells. The wells will generally be located in a pattern similar to that shown in Figure 6.

Wells are drilled to the top of the target completion interval with a truck-mounted, rotary drilling unit using native mud and a small amount of commercial viscosity control additive. The well is then cased and cemented to isolate the target completion interval from all overlying aquifers. The cement is pumped down the casing and is forced out of the bottom of the casing and back up the casing-drill hole annulus. The cement volume for each well is calculated to fill the annulus and return cement to the surface. Occasionally the drilling may result in a larger annulus volume than anticipated and cement may not return to the surface. In this situation the upper portion of the annulus will be cemented from the surface.

After the cement has cured, the plug is drilled out and the well completed by under-reaming the zone below the casing. If sand production or hole stability problems are anticipated, a wire-wrapped screen or a similar device is installed across the completion interval. The well is then air-lifted to remove any remaining drilling mud and cuttings. A typical well completion is shown in Figure 7. Typical casing for a 150 m (500 ft) well will be 127 mm (5 inches) nominal diameter with a minimum wall thickness of 6.55 mm (0.258 inches) and a minimum pressure rating of 1480 kPa (200 psig).

Regulatory Reviews and Licensing

In the United States, conventional open pit or underground mining of uranium is regulated by the individual states in much the same manner as any other mineral. However, any milling process or process that extracts the uranium from natural ore is closely regulated by the federal government. In some cases, a state will enter into an agreement with the federal government giving it the authority to regulate the extraction of the uranium from ore following federal regulations, which is referred to as “Agreement State” status.

Wyoming is not an “Agreement State”.

In situ mining of uranium by its very nature results in the extraction of uranium from the ore in place, and the federal government has thereby concluded that all phases of uranium in situ mining are subject to its regulations and must be licensed by the federal government. This federal licensing authority is administered by the US Nuclear Regulatory Commission (NRC). State statutes require the Wyoming Department of Environmental Quality (Wyoming DEQ) to oversee all mining activities in the state. Therefore, uranium recovery operations in Wyoming are under the supervision of both federal and state regulatory agencies.

There also are a number of other state and federal agencies charged with the protection of the health and safety of the public and employees and with the protection of the environment. In total, Smith Ranch was required to get approvals, licences, or permits from the fifteen different state and federal agencies shown in Table 2 prior to beginning operation. A number of the approval processes are drawn out and time consuming, but the two critical and controlling approvals are those from the NRC and from the Wyoming DEQ.

The Smith Ranch licence applications, which included over two years of baseline hydrological and environmental data, were initially submitted to the NRC and the Wyoming DEQ on 31 March 1988. Approval of the mining plan was received from the Wyoming DEQ on 18 June 1991. The NRC approval was received on 12 March 1992. This was an uncontested licence application; that is, there was no public or private group opposing the granting of the licence.

In addition to the mining plan permits, both agencies require the operator to submit additional applications and obtain approval for each wellfield placed into production. In Wyoming, the wellfield approval process typically takes nine to twelve months. This would include two to three months of drilling for installing and developing 60 to 80 baseline wells, two months of baseline sampling and analyses, one to two months of hydrological testing, one month for the final report preparation, and three to four months for regulatory agency approval.

The approved licences contain very specific environmental sampling and monitoring programmes that must be conducted during operations. At Smith Ranch, all injection well pressures and flow rates must be recorded daily and all monitor wells must be sampled every two weeks and analysed for key indicator parameters, including chlorides, carbonates and water levels. Plant operations must be inspected daily and air samples are collected weekly and analysed for airborne contaminants. All required activities must be documented and the records are subject to inspection by the regulatory agencies at any time.

Over two years of operations sampling has been completed at Smith Ranch and to date none of the samples have contained elevated parameters that would indicate an excursion of leach solution or that any other threat to the environment exists or is likely to exist. During 1998, the Smith Ranch facility was inspected on ten different occasions by state and/or federal agencies and received only two minor regulatory violations related to topsoil handling and protection.

Rio Algom believes that in our current regulatory environment, the approval of a new green field uranium in situ leach project in a US non-agreement state such as Wyoming would require a minimum of three to four years after the decision was made to initiate the baseline data collection. A projected timeline for the baseline data collection, application preparation, regulatory approval and construction is shown in Figure 8. If the application is actively opposed by a landowner or local interest group, it could add several months or even years to the approval process.

Smith Ranch Development

With the increasing uranium prices in 1995, a decision was made to proceed with development of Smith Ranch as a 770 tU (2 million lbs U_3O_8) per year facility, and funding for the US$44 million project was approved in January 1996. The plan was to construct the central process plant, the adjacent ion exchange recovery plant, and the first wellfield as Phase I, and then construct the satellite ion exchange recovery plant and a second wellfield in Phase II.

The central processing plant was located at the old underground mine site to take advantage of the infrastructure that was already in place, including access roads, utilities, and some buildings. Equipment with long lead times had already been specified and orders were placed almost immediately after project approval. Physical construction on the Phase I plant facilities began in April 1996 and was completed in May 1997. Leaching operations in the first wellfield were initiated on 20 June 1997. The facilities were ready and operations could have begun earlier, but the wellfield regulatory approvals delayed operation until June.

The on-site contractor workforce at the central plant/ion exchange recovery facility peaked at about 100 employees. Contract drill rigs were used for all well drilling and well casing programmes, and in Phase I peaked with 20 drill rigs operating in the wellfield development and evaluation programmes. Each drill rig was staffed with an experienced driller and two helpers. During this same period, Rio Algom was also organising its staff and increasing its on-site workforce from 7 to 75 employees. All project management; geology; engineering planning, scheduling, and evaluations; purchasing; and wellfield construction, including the pipeline and headerhouse installation, was done by company employees.

As soon as the Phase I work was completed, work began on the satellite ion exchange recovery facility and the second wellfield. Leaching operations at the satellite and second wellfield began on 11 August 1998. The startup of this wellfield was also delayed for over a month waiting for final regulatory approval for the wellfield. With both wellfields operating, production continued to increase, and in January 1999 Smith Ranch achieved its design production rate by producing at a 770 tU (2 million lbs U_3O_8) per year rate for the entire month. A total wellfield-ion exchange recovery flow capacity in excess of 378 l/s (6000 gpm) has also been demonstrated.

Since January, production has been allowed to decline to our target production for 1999 of 580 tU (1.5 million lbs U_3O_8). The Smith Ranch weekly production history is shown in Figure 9. As can be seen on the graph, the first wellfield is nearing the end of its economic life and groundwater restoration will be initiated next year. The third Smith Ranch wellfield has been approved by the NRC, and Wyoming DEQ approval was expected in early August 1999.

Smith Ranch is currently operating with an on-site staff of 85 employees, with engineering and accounting support provided by the staff in Oklahoma City. With in situ mining, wellfield planning and development is an ongoing process and about 25% of the total on-site workforce is dedicated to that effort.

Expenditures on the US$44 million Smith Ranch Project, except for a few deferred items, were completed in August 1999 with the total project coming in about 4% under budget. A summary of the major cost categories for the project are provided in Table 3.

Smith Ranch, like any new project, has encountered startup problems over the past two years that were not anticipated or fully provided for. One of the initial difficulties encountered was that a number of wells produced more fine silts and clays than expected, which settled in the trunklines and/or carried through the system and plugged the injection wells. This has been addressed by installing an additional level of filtering for all injection waters in the headerhouses and by gravel packing all well completions in areas where the production of fines is expected to be a problem.

A problem also quickly became apparent in unloading the vacuum dryers used to dry the yellowcake slurry. The original unloading doors proved to be difficult to operate and the sealing mechanism would fail frequently, causing a loss of vacuum. After working with the manufacturer supplied doors for several months, Rio Algom re-designed the sealing system and the shape of the door assembly to allow increased clearances to be used. This modification has eliminated nearly all the problems in this area.

Another problem experienced with the dryers was excessive corrosion inside the filter housings mounted above the dryers. The pre-formed, stainless steel assemblies to which the fabric filter socks were attached experienced rapid corrosion and failure after only a few months of operation. It was concluded that the corrosion resulted from a combination of the residual stresses in the metal from a stamping process during manufacture, the elevated temperature of 204°C (400°F) maintained in the filter assembly to prevent condensation, and a normally mildly corrosive atmosphere. The prefabricated adapters were eliminated and replaced by heavier welded adapters and the operating temperature of the filter assembly was reduced to about 150°C (300°F). These changes have eliminated the corrosion problem with the filter assembly adapters.

Conclusion

In summary, Smith Ranch was brought into production under budget and on schedule, except for regulatory delays, and now has a demonstrated production capacity of 770 tU (2 million lbs U_3O_8) per year. It also has an experienced, top quality staff that is continuously seeking ways to improve the operation; and over the past two and a half years, the staff has done this without a single lost time accident. These factors, combined with an area resource base of nearly 23 000 tU (60 million lbs U_3O_8), give Rio Algom a project that can be competitive with other uranium mining operations and ensure our customers a reliable, secure source of supply. We invite and encourage our customers and potential customers to come to Wyoming and tour the Smith Ranch Facilities.

Table 1. Smith Ranch ISL pilot summary.

	"Q" sand	**"O" sand**
Leaching period	Oct. 1981–Nov. 1984	Aug. 1984–Jan. 1991
Restoration period	Nov. 1984–May 1986	–
Restoration certified	Aug. 1987	–
Pilot flow rate	378 l/m (100 gpm)	568 l/m (150 gpm)
5-Spot pattern size	30 m x 30 m (100 ft x 100 ft)	36 m x 36 m (120 ft x 120 ft)
Ore depth	152 m (500 ft)	230 m (750 ft)
In-place reserves (U_3O_8)	61 200 kg (135 000 lbs)	103 500 kg (228 000 lbs)
Production	35 400 kg (78 000 lbs)	96 600 kg (213 000 lbs)
Recovery	58%	93%
Fluid processed		
Pore volume	11 700 m^3	45 800 m^3
Pore volume — production	42	45
Pore volume — restoration	20	–
Days/pore volume	22	56

Table 2. Smith Ranch Project state and federal agency approval.

Federal agencies	**Approvals required**
US Nuclear Regulatory Agency	General mine plan licence Individual wellfield approvals Wastewater disposal system Radiation safety programme
US Mine Safety & Health Administration	Safety training plans & procedures
US Bureau of Land Management	Mine plan approval on federal lands
US Environmental Protection Agency	Groundwater protection (agreement state) Wastewater injection programme Water discharge plans (NPDES)
US Corps of Engineers	No impact to wetlands
US Department of Transportation	Hazardous material (U_3O_8) transport
State agencies	
WDEQ[1] – Land Quality Division	General mine plan Individual wellfield approval Evaporation/storage pond permits
WDEQ – Water Quality Division	Groundwater quality designations Wastewater disposal well design Water sampling & monitoring programme Permit to construct septic system
WDEQ – Air Quality Division	Construction permit
WDEQ – Solid Waste Division	Construction debris disposal permit
Wyoming State Engineer	Permit to appropriate water Disposal well permit Evaporation/storage pond design approval
State Historical Officer	Approval of archaeological studies
Wyoming Game & Fish	Approval of wildlife studies
Wyoming Farm & Land Board	State lands surface agreements
Converse County Commissioner	Construction permits Road right-of-way crossings Septic system design

[1] Wyoming Department of Environmental Quality.

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Table 3. Smith RanchProject costs.

	US$ million
Central processing plant	5.7
IX recovery plants	5.8
Water treatment & disposal	1.6[1]
Wellfield drilling & installation	12.1
Mobile equipment & administration facility	2.7
Pre-production technical expenses	4.0
Pre-production administration & overhead	5.2
Working capital	4.1
Total project cost to design production level	**41.2**[2]

[1] Does not include US$1.2 million of project expenditure deferred to 1999.
[2] Roads, utilities and some buildings were installed for the underground mine and their costs are not included.

Figure 1. Smith Ranch Project general location.

Figure 2. "Q" sand and "O" sand pilot well patterns.

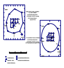

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Figure 3. Generalised geologic map of Powder River Basin post-Tertiary formations.

Figure 4. South Powder River Basin — Rio Algom Mining Corp. Smith Ranch area land position.

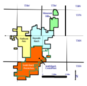


Figure 5. Flow process schematic.

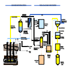


Figure 6. Typical wellfield development pattern.

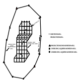


Figure 7. Well completion method.

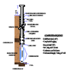


Figure 8. Projected time line for licensing an ISL facility in Wyoming.

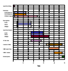
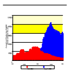


Figure 9. Smith Ranch weekly production history.



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