IAEA-SM-362/28

TECHNOLOGY AND THE URANIUM INDUSTRY

XA0055923

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Abstract

Continuing economic and regulatory pressures on the uranium industry can be countered only through advances in technology. Low prices, the "ALARA" principle, and concerns about "sustainability" require the industry to continually improve upon its already impressive record of performance. Technological improvement in the uranium industry is necessary in order to:

1) Maintain our resource base through the discovery of ever deeper deposits;
2) Improve the efficiency with which we may exploit - a) very high-grade deposits by remote underground mining methods - b) very low-grade deposits with environmentally-benign, in situ leaching methods - and c) moderate-grade, near-surface deposits by open-pit mining methods;
3) Meet increasingly stringent and, in many cases, arbitrary and unrealistic environmental and safety requirements; and
4) Cope with increasing competition from an expanding number of sources of secondary supply.

Manifestations of the uranium industry's ability to improve its performance through technology can be seen in many ways including: a continuing reduction in production costs; large gains in productivity; and a truly superior record of employee safety. Maintenance of these trends requires both innovation and the open sharing of information.

1. INTRODUCTION

Few industries have been subjected to more stress than the uranium industry. Prices for our product have fallen by an order of magnitude in the last two decades (Figure 1). This decline has rendered a large portion of known resources to be uneconomic. Production and production capacity have decreased by almost 50 percent. Increasingly stringent regulations require greater expenditures of time, effort and money to produce the same quantity of the same product. Non-governmental organizations are gaining a presence and a strength which threaten to dominate the licensing/permitting process. New uranium projects may now require ten years or more to complete this process. How can the industry cope with these pressures? Only through advances in technology.

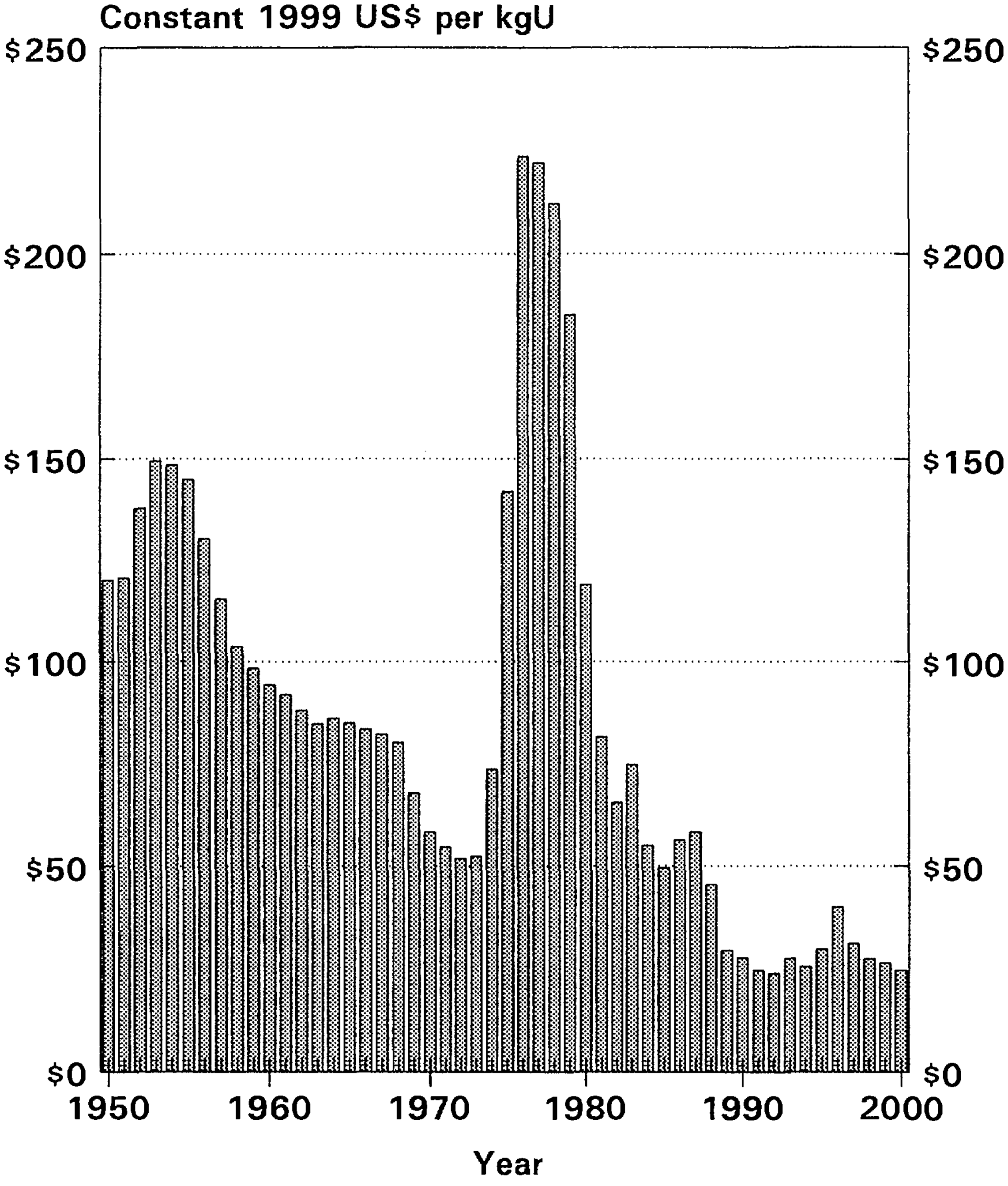
Let us recognize, however, that technology cannot be considered in isolation within the uranium industry. Technology is driven by needs which may be economic, environmental, social or a combination thereof. Most uranium projects already operate under the "**ALARA**" principle: the environmental impact must be **A**s **L**ow **A**s **R**easonably **A**chievable. Now we must also address the issue of sustainability. Sustainability has been recently defined as: "A balanced integration of high quality economic, environmental and social performance". Definitions of "reasonable" and "sustainable" are likely to be quite different between regulators, stakeholders and operators. The difference is almost entirely in cost. It is only through technology that we can maintain an acceptable balance among the three cornerstones of sustainability: economics, environment and social responsibility.

Advances in technology are important to the uranium industry because they provide the means by which:

1) Our resource base is sustainable through: a) discovery of new orebodies; b) exploitation of both "difficult" orebodies and lower-grade resources; and c) application of new technology to known, undeveloped resources.
2) Economic exploitation is sustainable through a continuing reduction in production costs.
3) Our environment is sustainable through the decrease or elimination of adverse impacts.
4) Our ability to meet social obligations is sustainable through increasing safety and well-being for both employees and stakeholders.

Figure 1

Historical Uranium Prices



This presentation sets forth a brief survey of current technology in the uranium industry, relates that technology to economic, environmental and social concerns, and attempts to provide a projection of current trends into the future.

2. EXPLORATION

Exploration is the means by which the industry maintains a viable resource base to provide for future production. It is also the first segment of the industry to react to changes in price (Figure 2).

With today's low prices, less incentive to explore exists and only a few exploration projects are being pursued. Those few projects are located mainly in areas where a potential exists to discover large, high-grade deposits. Saskatchewan's Athabasca Basin is the focus of most of these activities, although Australia is seeing some exploration as a result of a change in government which removed the restrictive "three mines" policy of the Australian Labor Party.

Most of the early discoveries in the Athabasca Basin were in relatively shallow areas of the basin where surface indications of mineralization, glacial boulder trains for example, provided clear evidence of nearby deposits. Extensive and intensive exploration of these shallow areas has now exhausted much of the near-surface potential and exploration is moving into deeper and deeper parts of the basin. This process is illustrated in the following table which sets forth the year of discovery and depth for most of the major Athabascan orebodies.

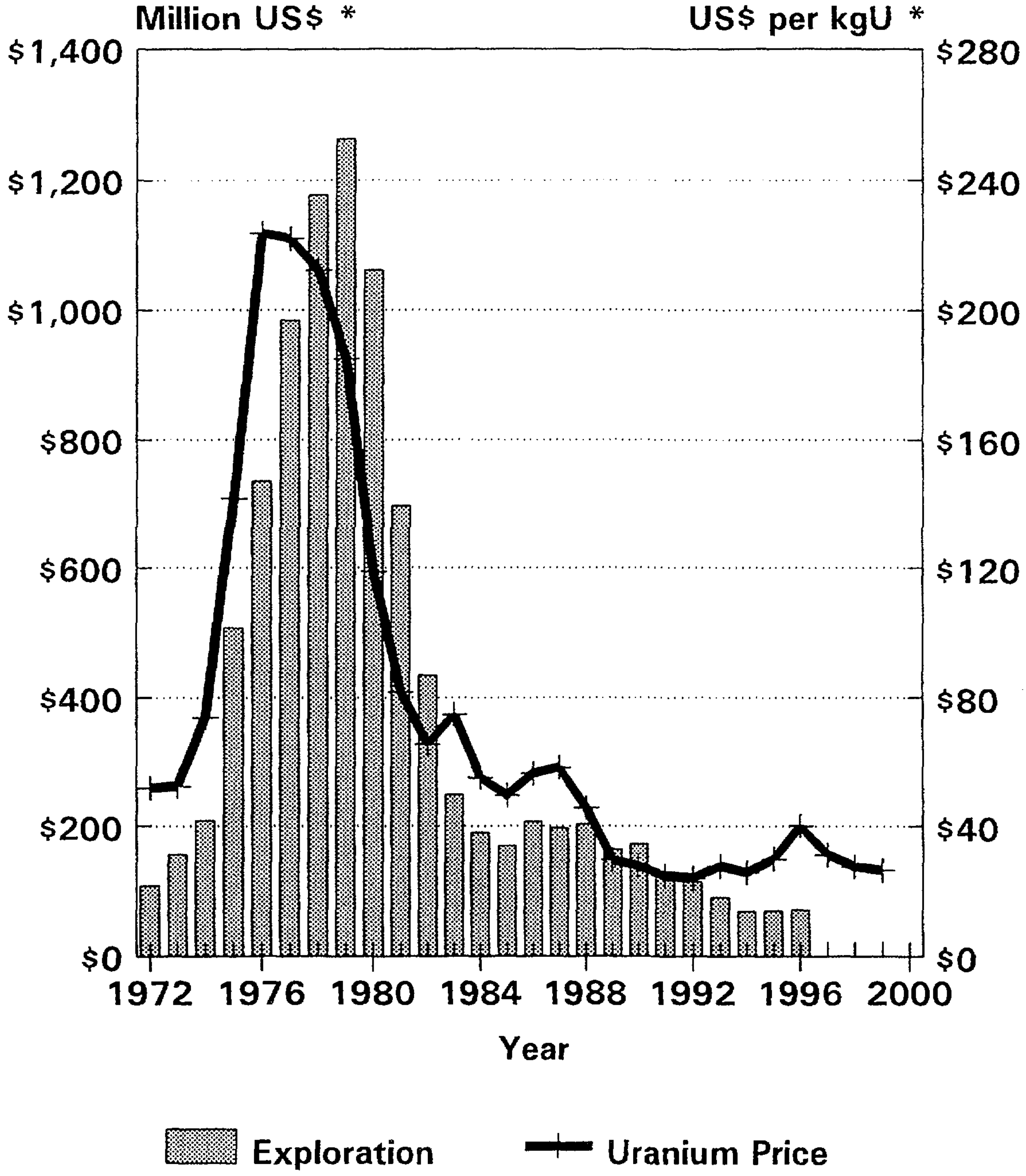
TABLE I: DEPTH-DATE OF DISCOVERY RELATIONSHIP ATHABASCA BASIN URANIUM DEPOSITS

Deposit	Year of Discovery	Depth (m)
Rabbit Lake	1968	150
Cluff Lake	1975	200
Key Lake	1975	200
Collins Bay	1976-1979	100
Dawn Lake	1978	200
Midwest	1978	200
Eagle Point	1980	400
McClean Lake	1980	200
Cigar Lake	1981	450
McArthur River	1988	550
La Roche Lake	1999	280

Discovery of progressively deeper orebodies with progressively less surface expression requires increasingly sophisticated methods and equipment. Much of the recent exploration work in Saskatchewan has utilized **large-loop ground electromagnetic surveys** to search for graphitic conductors at depth. To date, the deepest success for geophysics in the Athabasca Basin has been the

Figure 2

Exploration Expenditures and Prices



* Constant 1999 US$

discovery of a mineralized zone at a depth of 700 meters on Cogema's Shea Creek project. **Infrared spectroscopy** has been used in several instances to assess subtle variations in clay mineralogy which might be indicative of an alteration halo surrounding an unconformity uranium deposit.

While exploration is expected to continue in a few of the most prospective areas and higher prices will encourage a resumption of limited exploration in other areas, much of the future for our industry lies in applying new technology to known, but as yet undeveloped, deposits. This process applies especially to sandstone deposits which may be amenable to in situ leaching (ISL) and to high-grade deposits which may require some type of remote, bore-hole mining method.

3. MINING

Mining in the twenty-first century presents at least two major challenges: production of very high-grade ore under difficult ground and water conditions, and production of lower-grade ores under difficult economic conditions. Technological advances will be needed in both cases.

Current uranium production methods include conventional open pit and underground mining, in situ leaching and by-product recovery. Since 1982, the relative output of these four methods has changed substantially (Figure 3). Output from underground mines has declined from almost 50 percent of the total to less than 30 percent. Open pit mining now accounts for just under one-half of total output, up from about one-third in 1982. By-product output has remained at somewhat over ten percent, but in situ leaching has shown a substantial increase up to 17.5 percent in 1999.

For the future, underground output is expected to regain its former share as McArthur River and Cigar Lake add almost 7,000 mtU each to the total. No major changes are expected in open pit or by-product output. Modest price increases could stimulate a significant increase in ISL production since there are many projects on the drawing board which would likely be economic if prices rise to the $35 to $40 per kgU level.

3.1. Underground

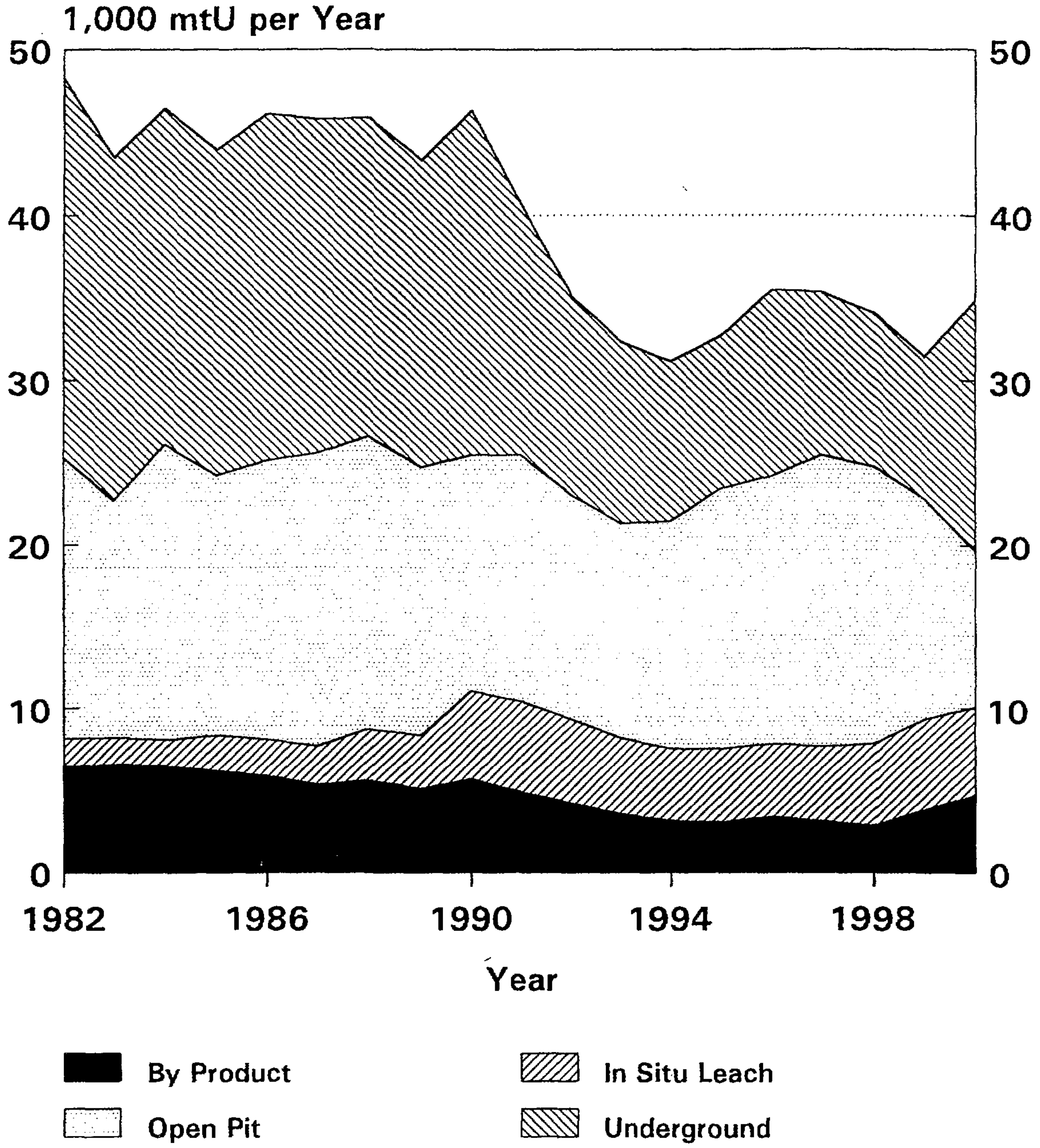
It will be very interesting to follow the course of production at McArthur River, the first of a series new high-grade mines in the Athabasca Basin, to see if new production methods can achieve the cost and output levels desired. **Remote mining** of frozen ore, underground crushing and grinding, and pumping slurry to the surface are new to the uranium industry. Costs per metric ton of ore produced are projected to be quite high but, with a uranium content of 10 percent or more, costs per kgU of output should be very competitive.

This production technology is dictated by both ground conditions and regulations. Weak, water-saturated ground must be frozen in order to stabilize underground openings. Advanced drilling systems which allow freeze holes to be cased as drilling progresses were developed to cope with high pressure water and squeezing ground. Concrete backfill is required to prevent subsidence. A special **cold-temperature concrete** has been developed for this application. Very high-grade ore, up to 20 percent U or more, presents a radiation hazard to miners and must be mined by remote means. McArthur River will utilize a high-pressure water,**bore-hole mining** method for much of its production.

Many underground mining operations are already using remote ore removal methods. Cameco, at its Eagle Point mine, has utilized **remote-controlled**, rubber-tired, diesel, load-haul-dump equipment for several years. Tests have been conducted using raise boring and bore-hole methods at Midwest and Cigar Lake, respectively, to produce high-grade ore. Blast-hole, box-hole and slot mining methods also limit miners exposure to radiation. Drilling from outside the ore zone is a primary characteristic of these methods.

Figure 3

Historical Uranium Production by Method



It is expected that the development of the underground bore-hole mining method for high-grade deposits in Canada will lead, ultimately, to further development of the method for application to progressively lower-grade deposits. Bore-hole hydraulic mining from the surface was tested in the U.S. in the 1970s for mining of uranium-bearing sandstone ores, but has yet to be applied commercially.

Underground uranium mining has also benefited from the development of **small equipment for use in narrow-vein mining** as at Cluff Lake.

3.2. Open Pit

Despite its moderate ore grade, 0.25% U, the Ranger mine in Australia consistently ranks as one of the world's most productive uranium mines. In 1999, for example, the company employed a total of 272 people who mined 7.8 million metric tons of ore and waste, milled 1.8 million metric tons of ore, and produced 3,710 metric tons of uranium. This productivity of 13.6 mtU per employee was the world's highest in 1999. Only the Key Lake and Rabbit Lake mines in Saskatchewan can compete with Ranger in terms of productivity and the ore grades at those mines have been much higher; about 1.7 and 1.2% U, respectively.

What makes the Ranger mine so productive? Part of the answer is **large equipment**: a 14 m^3 backhoe loading 125-metric ton haul trucks. Key Lake was using an 8 m^3 loader and 50-ton trucks.

Rössing is another success story in open pit mining. As the world's lowest grade, 0.025% U, conventional uranium mine, Rössing continues to increase its productivity and to evaluate new means for further increases. Past implementations include: larger excavating equipment (34 m^3) and an **electric trolley assist** for haul trucks (180 metric ton capacity). Future improvements now under consideration include **in-pit crushing and conveyor haulage**. Rössing's productivity is now 2.3 mtU per employee-year, a very creditable output considering the grade of ore being mined, and double its production at full capacity in 1980.

3.3. In Situ Leaching

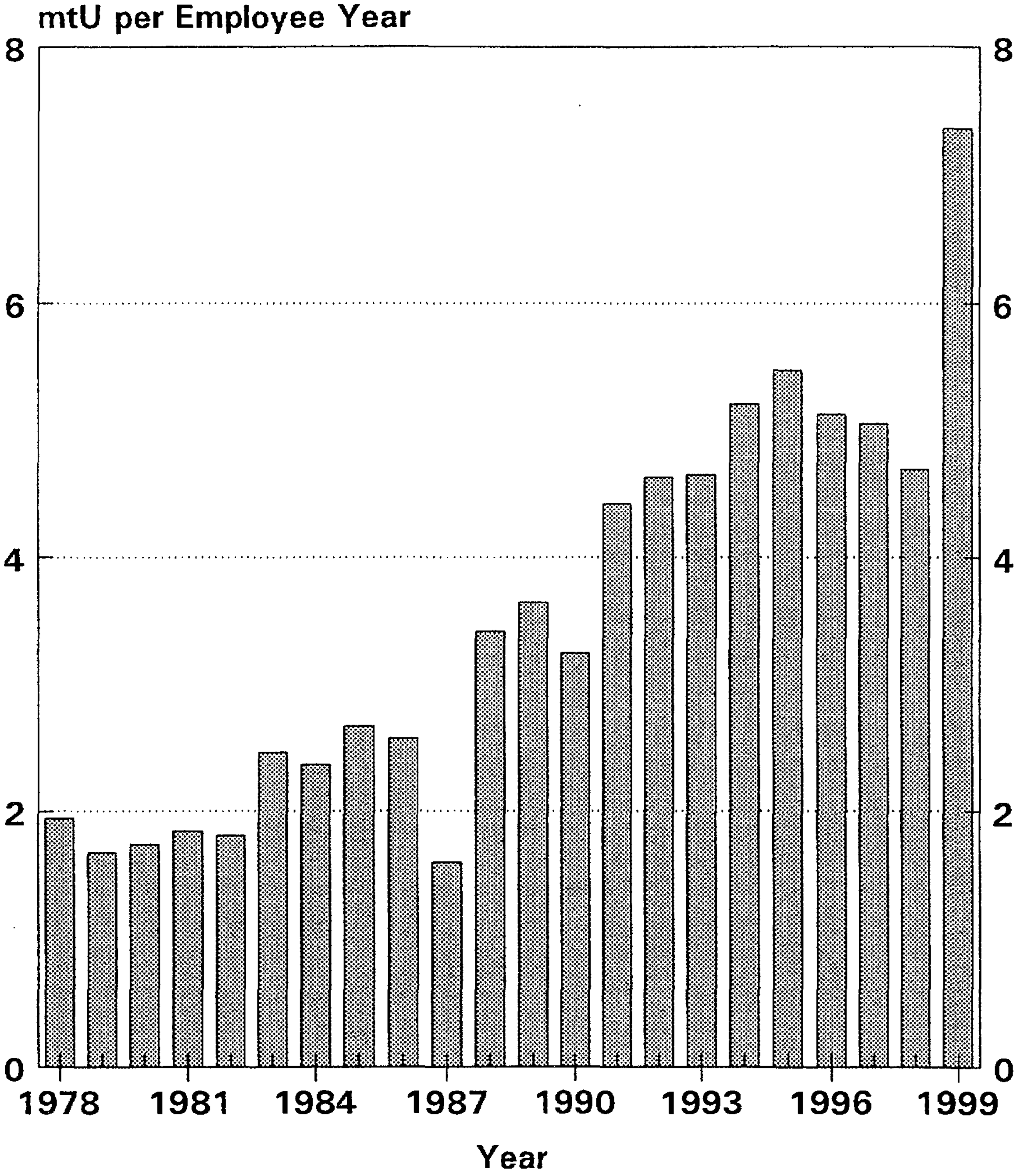
In situ leaching (ISL) has gained an increasing share of world uranium production. This increase can be attributed to a combination of economics, technology, and low environmental impact.

ISL production offers a more flexible cost structure which has the capacity to react more readily to changes in market price than conventional methods. As a methodology of moving chemical solutions through a system of pumps, pipes and valves, ISL offers great opportunities for increased automation. ISL producers in the U.S., such as Smith Ranch, Crow Butte and Highland, rank quite high among uranium producers, in general, with productivity in the range of 6 to 8 mtU per employee-year. Much of this ranking can be attributed to **advanced instrumentation and computerization**. Figure 4 illustrates the advances made in ISL productivity in the U.S. ISL industry. Uranium production by ISL methods has a relatively low impact on the environment; the only major concern being degradation of the groundwater regime. This combination of attributes provides ISL with somewhat greater "staying power" than other methods.

Opportunities for technological improvements in the ISL method are many, but perhaps the most intriguing are those dealing with the wellfield which is typically the most costly part of an ISL operation. Optimization of flow patterns and leaching chemistry holds the key to increased spacing between wells. **Directional drilling** offers the opportunity for multiple completions from a single drill site and may be employed in the future as an economic means of accessing deep orebodies. Horizontal wells are also possible through directional drilling.

Figure 4

US In Situ Leaching Productivity



3.4. Uranium as a By-Product

Uranium has been produced as a by-product mainly from gold, copper, and phosphate. Uranium production from South Africa's gold mines has decreased as a result of both low prices and declining ore grades. In the past, some South African gold ores were sorted radiometrically to provide a higher-grade feed, in both gold and uranium, for the milling process. A "reverse" leaching process where sulfuric acid leaching of gold-uranium ore for uranium enhances subsequent gold recovery is used in the only two remaining uranium-from-gold by-product operations in South Africa. Substantial quantities of tailings were also reprocessed for the uranium and gold content. Low prices for uranium and depletion of the higher-grade tailings have caused such projects to be abandoned.

Olympic Dam, a copper producer in Australia, has recently increased its uranium output to almost 4,000 mtU per year as the result of a major expansion project.

IMC has recently demolished its uranium-from-phosphoric-acid production facilities in the U.S. due to low uranium prices. Uranium from phosphoric acid technology is old solvent extraction technology from the mid-1970s. Failure to improve that technology is probably responsible for its demise. Opportunities for potential improvements are seen to exist through both **ion exchange and membrane technologies**. It is interesting to consider that uranium removal from phosphoric acid may, some day, be a requirement for environmental reasons. That situation will then promote a new range of uranium recovery technology.

4. PROCESSING

Uranium ores have been processed, mainly, by: crushing and grinding, sulfuric acid leaching, and either ion exchange or solvent extraction concentration. Little change has occurred in these unit processes for decades. What is changing, however, is an increasing trend toward optimization of the recovery process.

Optimization is occurring in several ways.

Energy usage and chemical consumption are being balanced against recovery through increasing application of the **heap leach process**. Lagoa Real in Brazil is the world's newest uranium processing facility and treats all ore by heap leaching. Technology transfer from the gold industry where heap leaching accounts for a substantial percentage of production can be expected to contribute to the future of heap leaching for uranium. Several new heap leach projects in Australia, Portugal and the U.S. have been proposed by Anaconda Uranium. China is shifting its production focus from conventional milling to heap and in situ leaching.

By-passing fines around the grinding circuit not only reduces energy consumption, but also reduces the generation of difficult-to-handle slimes. ENUSA's Quercus mill in Spain was designed and built on this principle. Rössing is considering implementation of a similar system.

For most of its history, the uranium industry of the Soviet Union/CIS has focused on maximum recovery of not only the identified primary resource, but also on recovery of minuscule amounts of by-products such as molybdenum, vanadium and scandium. Economics of the recovery process were not a major concern and, consequently, most of the Soviet/CIS producers consumed large amounts of energy and chemicals in comparison to their western counterparts. As market economy concerns become more widespread, we can expect to see increasing efficiencies in CIS processing facilities. This transition can be classified as the application of **economic technology**.

Radiometric sorting is an underused technology in the uranium industry even though it has proved its usefulness in Canada, South Africa and the U.S. A particular problem is the general softness of many uranium ores which results in a wide range of particle sizes and consequent difficulties in sorting.

Nevertheless, the proposed Kintyre project in Australia has been designed to incorporate sorting and, as a result, the proposed plant milling rate will be less than one-fourth as large as would otherwise be the case. Kintyre is also notable for the proposed use of **heavy media** separation of fines in the crushing and sorting process.

5. TAILINGS DISPOSAL

Uranium tailings did not present a disposal problem during the first few decades of our industry; they were simply pumped to the nearest topographic low and discharged. Increasing concerns relative to groundwater contamination and windblown dispersion have now raised tailings disposal to one of the most important considerations for any uranium project. This elevation of concern has increased the cost of producing uranium, but several technologies have the potential to minimize that increase as well as to satisfy most of the concerns of NGOs and regulating authorities.

In-pit disposal of tailings is seen as a major advance in containment. Developed at Rabbit Lake as the "pervious surround" method, in-pit disposal has now been applied at Key Lake for tailings from McArthur River ore, at the McClean Lake project, and at Ranger. Several underground mines use the coarser portion of tailings for backfill.

It is clear that finely-ground tailings carried in a slurry pipeline to an above-grade disposal site present substantial opportunities for contamination of the surrounding area. **Paste disposal** is a technology which addresses most of the concerns of such a system. Paste disposal, in essence, provides for elimination of most of the water from the tailings prior to disposal. Advantages are many, including: a reduction in volume, a reduction in geotechnical hazards associated with containment structures, a reduction in both short- and long-term environmental liability, an increase in siting and operational flexibility of storage facilities, and significant water conservation potential. Paste disposal technology will be used for Cigar Lake tailings disposal at the McClean Lake project where a portion of Cigar Lake ore will be milled.

Paste disposal is not new. It has been applied in at least one other instance: the Zirovski Vrh uranium project in Slovenia. At Zirovski Vrh, **belt filters** dewatered the tailings which were then loaded into trucks for transport to a nearby disposal area.

6. RECLAMATION

As more and more uranium facilities are forced to close because of low prices, a greater focus on reclamation activity is apparent throughout the industry. Within this activity, one key element emerges time after time: Reclamation is less expensive when designed into the initial project plan and when carried out **concurrently with production**. This principle is not always applied since reclamation is seen as non-productive and operators are inclined to defer non-productive expenses. This deferral can cause severe problems, particularly when an operator loses the financial ability to meet its reclamation obligations.

A lesson in the cost of deferral is evident in the "Title I" tailings remediation program conducted by the U.S. Department of Energy on a number of old U.S. uranium processing sites for which no "responsible party" could be found to fund the cleanup. In this case, U.S. DOE funded and managed the clean-up at a cost of approximately $53 per metric ton of tailings, or $30 per kgU produced. By contrast, company reclamation, albeit not necessarily contemporaneous with production, has cost about $2.50 per metric ton of tailings, or $2.00 per kgU produced.

New technologies are being developed and applied to uranium reclamation. Most deal with groundwater restoration since that is the most difficult problem facing the industry today. Because in situ leaching of uranium is a groundwater technology in and of itself, it can be expected that a substantial portion of groundwater restoration technology has its roots in the ISL process.

1) Uranerz has demonstrated at its Ruth ISL pilot plant in Wyoming that the introduction of a **reductant such as hydrogen sulfide** into the depleted wellfield regime can precipitate and immobilize a variety of metal ions.
2) **Reverse osmosis** technology is applied to most ISL restoration projects in the U.S. Membrane and electrochemical water treatment methodologies are finding increasing application in a variety of clean-up situations.
3) **Reactive chemical barriers** are now in use as a means of reducing groundwater contamination. Cotter Corporation recently installed a reactive barrier containing zero valant iron at its Cañon City, Colorado, U.S. uranium mill to intercept molybdenum-contaminated groundwater.
4) **Bioremediation** of uranium contaminated groundwater has been addressed by several researchers.
5) A three-stage process of **ion exchange**, lime neutralization and filtration is being used to clean-up groundwater contamination from an underground acid-leach uranium mine in the former East Germany.

All of the above references relate to active means of combating groundwater contamination and are likely to find application to a large number of specific clean-up situations. Still, the most interesting approach to groundwater clean-up of which I am aware is that taken at ore body No. 10 of the South Bukinai deposit in Kazakhstan: **natural attenuation**. Natural attenuation of contaminated groundwater has been studied in some detail at this location with a conclusion that background levels of contaminants were likely to have been reached within a period of 26 to 31 years. After an 11-year period of natural attenuation, however, this process was accelerated by pumping and reinjection of fresh groundwater from just outside of the mined area and was completed in just an additional 20 months. The significance of natural attenuation is that it may provide assistance in the restoration process and that it may place very real limits on the amount of restoration work required. A thorough understanding of the potential for natural attenuation prior to licensing or even commencement of restoration could provide substantial economic benefits. Even the U.S. Environmental Protection Agency, one of the world's most conservative environmental regulators, has adopted this approach at a number of abandoned uranium millsites in the U.S. where contaminated groundwater is unlikely to pose an active threat to the environment.

Uranium is also being produced from so-called "**alternate feed**" materials, mainly uranium-contaminated soils from clean-up of nuclear weapons facilities. Existing tailings ponds at uranium processing facilities provide an economical means of disposing of this material even though the uranium content may be quite low. The current trend toward increasing protection of the public and the environment can be expected to generate additional opportunities for uranium recovery. These opportunities are likely to include an increasing variety of uranium-containing materials which will be produced from both water and mineral treatment facilities.

7. HEALTH AND SAFETY

Social concerns in the uranium industry are centered upon the health and safety of 1) employees of uranium production facilities; and 2) people living in the vicinity of those facilities. Because the hazards of radiation are well known, most uranium production facilities are extremely safe from a radiological standpoint. This emphasis on radiological safety carries over into other areas of health and safety such that uranium production facilities are among the safest industrial facilities in the world.

In this regard, I want to specifically recognize the following operations: Rössing in Namibia, Ranger in Australia, and Highland in the US. Rössing receives continual recognition as one of the safest mines in southern Africa. Ranger ranks in the top five percent of industrial health and safety performance in Australia. Highland has produced over 10 million pounds U_3O_8 without a lost-time accident. These achievements occur at least partially because of the generally high level of technology within the uranium industry. I noted previously that Rössing, Ranger and Highland are among the most productive mines in the world. I will ask again: Is it a coincidence that some of the most productive mines in the world are also the safest? Is it also a coincidence that these mines are technologically advanced?

8. CONCLUSION

A high level of technology is currently incorporated into most uranium production facilities. Continuing technological advancement is required in order to maintain a "sustainable" industry. These advances may be driven by a variety of concerns: economic, environmental or social. Let us continue to share these advances in forums such as this for the benefit of all.

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