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FEB 11 1980

Dr. David V. Bates,
Chairman,
Royal Commission of Inquiry
Into Uranium Mining,
3724 West Broadway,
Vancouver, B.C.
V6R 2C1

Dear Dr. Bates:

We are pleased to forward to you, on behalf of the Departments of the Environment and Fisheries and Oceans, a contribution to the hearings of the Royal Commission of Inquiry into Uranium Mining.

The submission discusses, in general terms the environmental concerns related to uranium mining, particularly from the perspective of the responsibilities and expertise of the two federal departments. Where possible, we have attempted to provide a sense of perspective by relating to experience and information acquired through involvement in other inquiries or through involvement with investigative and regulatory aspects of other uranium mining developments. A brief summary on the organizational and legislative features of the two departments as they pertain to the subject will also be presented at a later date.

We see our primary involvement in the hearings coinciding with phases V and VI and trust our submission and participation will be useful.

Yours sincerely,

for D.D. Tansley
Deputy Minister
Department of Fisheries & Oceans

Yours sincerely,

for J.B. Seaborn
Deputy Minister
Department of Environment

# BRIEF PRESENTED

# TO

# THE BRITISH COLUMBIA

# ROYAL COMMISSION OF INQUIRY

# HEALTH AND ENVIRONMENTAL PROTECTION

# URANIUM MINING

PHASE VI

by

Department of Environment

Department of Fisheries and Oceans

Environmental Protection Service

Department of Environment

Pacific Region

Report EPS 7-PR-79-1

March, 1979

# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

## 1.0 INTRODUCTION

This summary report has been prepared by the Department of Environment and the Department of Fisheries and Oceans to provide an overview of environmental problems associated with uranium mining and milling in British Columbia. Detailed information on sources of pollution, pollution control technology, and environmental impact concerns can be found in Appendices I and II respectively.

Two considerations related to uranium mining in British Columbia dominate our concerns: one is the increased or accelerated release of radioactivity, particularly Radium-226 and Radon-222 and of nitrogen compounds to the environment; the other, the geographical setting within which mining will take place. The former distinguishes uranium mining from other forms of metal mining in British Columbia, the latter from uranium mining in other parts of Canada.

It is the local setting - the topography, the amount and chemistry of available water, the fluctuations of supply, the climate, biological species, etc. which set constraints on mining operations, their layout and processes, that influence to some degree the scale of environmental concern. The conditions under which uranium mining would be carried out in British Columbia, relating to topography, climate and biological species, are such that the consequences of radium, radon, nitrate and ammonia release could be of greater significance in British Columbia than elsewhere.

An increase in radionuclide concentrations in B.C. waters could result in a corresponding increased radiation doses to Pacific salmon through the various life stages of members of that species. The significance of this increased dose is not well understood but the important point is that it does constitute a unique concern not yet encountered with uranium mining in Canada.

The climate, in particular as related to the semi-arid regions of the Okanagan and Kettle Valleys, poses unique problems of water quality managements as increased retention times for discharged pollutants could lead to elevated concentrations of radium and other contaminants. The release of radon is also a potential problem because the topography and demography of potential mining regions may result in enhanced exposure of the general population to the radon and its radioactive decay products.

Whatever the factors, the significance of radioactive releases to the environment are related to the amounts released and to the effects of the radiation on living systems. These effects, to a large degree, will depend on the pathways governing the movement of the key radionuclides of concern (these include thorium, lead, radium and radon). These pathways are likely all highly site-specific and consequently pathway analyses must be performed thoroughly for each mine site in order to understand the environmental significance of mining activities.

In the following pages we will address those factors relating to the natural setting and to the process of uranium mining that are, in our opinion, of major importance in assessing the potential impact of uranium mining in British Columbia. These factors must be considered as early in the planning stages of development as possible. In the development of mining it is the pre-operational stages, prospecting, exploration and development where the majority of capital expenditures are committed and the decisions made that will define the type of mining operation to be established. It is also here where the major environmental decisions and commitments must be made.

In reading the following pages and appendices, it should be borne in mind that much of the information on pathways and levels relates to areas substantially different from British Columbia. Similarly, the impact ascribed to these levels and therefore the levels of releases deemed acceptable are based upon dispersions and pathways that may differ significantly from the B.C. situation.

# 2.0 THE GEOGRAPHICAL SETTING

## 2.1 Land Use Characteristics

Restrictions due to topographical characteristics are probably the most important factors that characterize land use in British Columbia. It is estimated that over 90% of the province is mountainous and non-arable. It is in the remaining 10%, particularly the lower elevations and the valley bottoms, that the majority of land use activities take place. These areas are important habitats for wildlife, provide outdoor recreation opportunities, and are the location of human settlements and agricultural activities. It is also in these valleys, specifically in the Okanagan area, that potential uranium reserves have been found. This proximity to human settlements requires care in assessing and controlling the impact of uranium mining activities in British Columbia.

Although the land requirements for mining are relatively small compared, for example, to the requirements for timber harvesting; the construction of ancilliary facilities such as roads, railroads and possibly new towns, will undoubtedly add to the total land requirements. Since only a small proportion of the total land area of British Columbia is available for meeting future land use needs, it is therefore vital that the relationship of the various mining proposals to special status lands in the province be considered. For example, a proposed mining development's encroachment or impact upon prime agricultural lands, ecological reserves, prime recreational areas, and critical wildlife areas should be evaluated prior to a decision being made to initiate mining. It is particulary important that, given the limited amount of land available for the various land use activities, effects over the long-term be carefully assessed so that future options are not foreclosed.

## 2.2 Atmospheric Considerations

The topography of British Columbia results in atmospheric situations quite unlike those found in most other parts of Canada. Small-scale air circulations that develop in British Columbia's mountainous terrain can confine and concentrate airborne pollutants to localized areas and stagnation conditions can lead to a gradual increase in levels of pollutant. A well-accepted methodology for predicting ambient air pollution concentrations in regions of complex terrain has not yet been developed, although if details of the wind flow are known, considerable information can be obtained from the application of relatively simple models.

In British Columbia, wind records are, however, available from only a relatively small number of locations. Most of these locations are major airports located in well exposed areas. The data, therefore, do not in general relate to mining sites which may be located many miles away in mountainous terrain. In fact, because the wind flow and structure are so highly dependent on the topography, the wind records from one observation site are usually of doubtful value in determining dispersion characteristics at even nearby stations. Thus, because of the extreme spatial variability of the wind over the complex terrain found in British Columbia, it would be necessary to obtain wind statistics from a number of observation sites in representative topographical situations in order to determine the air quality impact from a particular source. This can best be illustrated by the following example (Fig. 1). Swift Current and Moose Jaw are located in the generally open landscape of the Saskatchewan prairie. Although the two stations are 160 km apart, the wind roses (Fig. 1.1 and 1.2) for the two stations are similar and vary through all quadrants of the compass. This is to be expected as it is well known that in mid latitudes the weather is variable and the resulting climatology is the integrated sum of many different kinds of meterological systems. In the absence of topographic controls the wind roses reflect the large scale weather features that traverse the country from west to east.

In complete contrast to this, Fig. 1.3 and 1.4 show the wind roses from Castlegar Airport and the Castlegar BCHPA Dam station which are less that 12 km apart but located in mountainous terrain. Channelling of the wind by the Valley appears to be the dominant factor in this case.

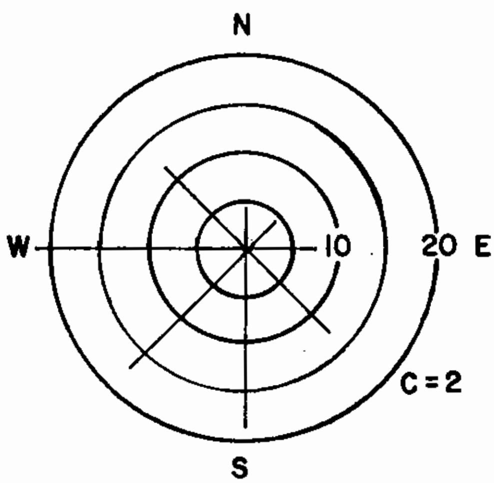


FIG. 1.1 SWIFT CURRENT (A), SASKATCHEWAN

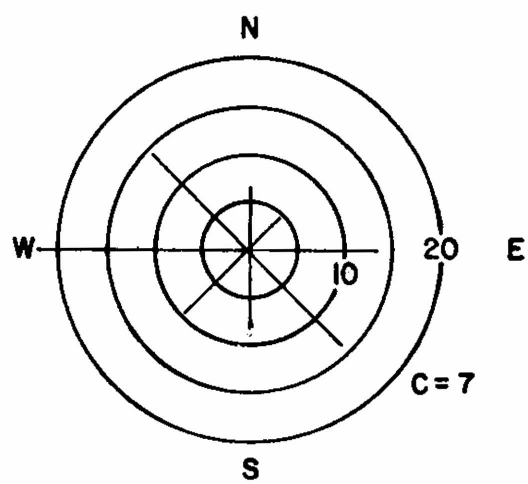


FIG. 1.2 MOOSE JAW (A), SASKATCHEWAN

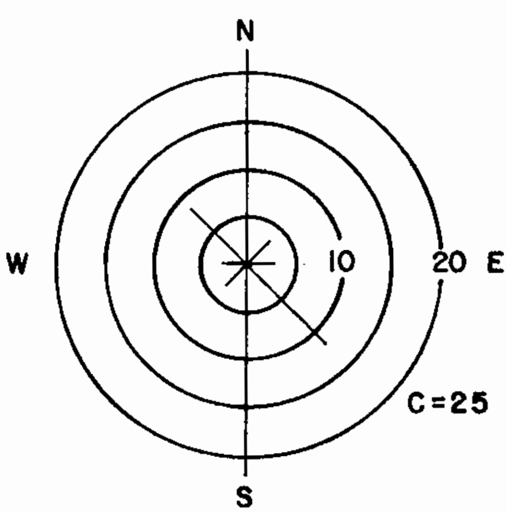


FIG. 1.3 CASTLEGAR (A), BRITISH COLUMBIA

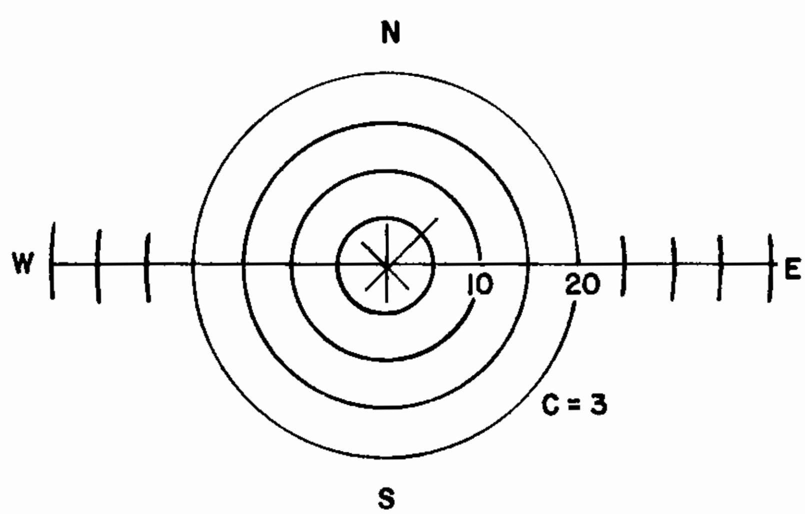


FIG. 1.4 CASTLEGAR BCHPA DAM, BRITISH COLUMBIA

NOTE: Circular lines are drawn at 5% intervals. The bars indicate the percent frequency that the wind blows from each direction. The percentage of calms are shown by "C".

An additional factor that contributes to the difficulty in assessing the air quality implications of uranium mining and milling in particular results from the fact that emission sources are located near ground level. Lower level wind flow is difficult to estimate although of importance, since the wind not only affects the dispersion of pollutants but, in some instances, it is also an important factor in determining the strength of the emission source. For example, the speed of the wind has a pronounced effect on the erosion of material from ore stockpiles and tailings areas and therefore is directly related to the emission rate.

Another factor of significance in British Columbia is the occurrence of periods of severe air stagnation that persist for long periods of time. This is particularly critical in valleys and other areas sheltered from the main air flow. There are two meterological conditions commonly associated with this phenomenon. In the summer and fall months, poor ventilation occurs when large high pressure systems stall and remain stationary over the province. Winds are generally light and strong inversions develop in the subsiding air mass. In the winter season poor ventilation occurs when a shallow layer of cold air becomes trapped in an interior valley. If successive storms pass overhead with insufficient strength to scour the cold air from the valley bottom, then a build-up of pollutants could occur in the cold air near the earth's surface.

## 2.3 Surface and Groundwater Considerations

In terms of water quality and hydrology the general setting of potential mine sites in British Columbia differs in two ways from those established elsewhere in Canada: 1) in water utilization, 2) hydrological conditions.

An examination of water use in a number of regions in British Columbia where deposits of uranium have been found shows an intensity of multiple uses (domestic, recreational, irrigation) not found in uranium mining areas in other parts of Canada. The combination of uranium bearing deposits, intensive water use, and extensive sub-surface drainage may pose difficult questions in such semi-arid regions as the Okanagan and Kettle Valleys where good quality and supplies of water are needed for irrigation.

The agricultural and industrial based economies of the Columbia and Thompson river systems, also semi-arid regions, are also dependent on a good supply of quality water for irrigation. Indeed the potential conflict for use of surface and groundwater for assimilating seepage and decant from tailings ponds and the continued irrigation of orchards, vineyards and pastures is substantial. Potential conflict in Northern areas, such as Atlin, while not as extensively settled or intensively used also have distinctive hydrological systems whose characteristics must also be considered so as not to foreclose future development options.

Cursory data is available for natural levels of uranium in surface and groundwaters for many of the areas so far explored, however, detailed studies of uranium, radium and radon levels in water used for irrigation and domestic consumption are not available. Of concern is that the drainage of much of southeastern B.C. flows into the United States where much of the water use is agricultural and recreational. Canada's obligations under the Boundary Waters Treaty and the United Nations Charter on the Human Environment as well as her responsibilities as a good neighbour must be considered in any development likely to alter the quality of these waters.

In the semi-arid regions of British Columbia, particularly the Okanagan Basin, low surface runoff from tributaries and the presence of flood control structures (e.g. retention basins) minimize transport of sediment-associated wastes out of the region. In addition, dissolved wastes in such surface waters are not subject to the rapid dilution that occurs in uncontrolled rivers during freshet. Some of these streams presently contain uranium which is probably contributed by leaching from sediments or aquifers. In this respect it is important to note the recent lowering of the maximum permissible uranium concentration in drinking water to 20 ugm/l is occasionally exceeded in some of these waters.

The low level of precipitation in the semi-arid regions will likely provide little water to the mine by direct precipitation.

Because of the low rainfall during the summer, much of the tributary flow in the Okanagan region is provided by groundwater rather than surface runoff. In the Okanagan where permeable sediments overlie bedrock, movement of groundwater is substantially affected by the alteration of geohydrological conditions. This subsurface drainage is subject to fluctuations associated with recharge from controlled and impounded surface flows, and with high pumping rates from wells when irrigation is intensive. Dispersion and dilution of material in groundwater is also complex and may be restricted in this confined basin. The potential for transport by flowing groundwater of contaminants produced by mining, and the difficulties of monitoring such transport suggests that each site should be subjected to a hydrological study.

## 2.4 Fisheries Considerations

The fishery of British Columbia is unique from the rest of Canada in that it contains five species of Pacific salmon (pink, chum, coho, chinook and sockeye) as well as several other species of anadromous fish (e.g. steelhead trout), which depend to a high degree on both the freshwater and marine environment for survival. Mature adult salmon migrate from the sea into freshwater streams where eggs are deposited and fertilized in redds (nests) due in the gravel substrate. The eggs are covered with gravel and left to incubate for several months, during which time they develop into fry and emerge from the gravel. During the incubation period the survival of the eggs and juvenile forms depend heavily on the quality and quantity of water flowing through the gravel substrate. Salmon are particularly sensitive to degraded water quality during the developmental stages of their life history. Following emergence juvenile salmon rely on freshwater stream habitats for up to two years prior to migration to the sea.

Nearly all the major rivers which enter into the Pacific Ocean along the coastline of British Columbia support one or more species of Pacific salmon (Figure 2).

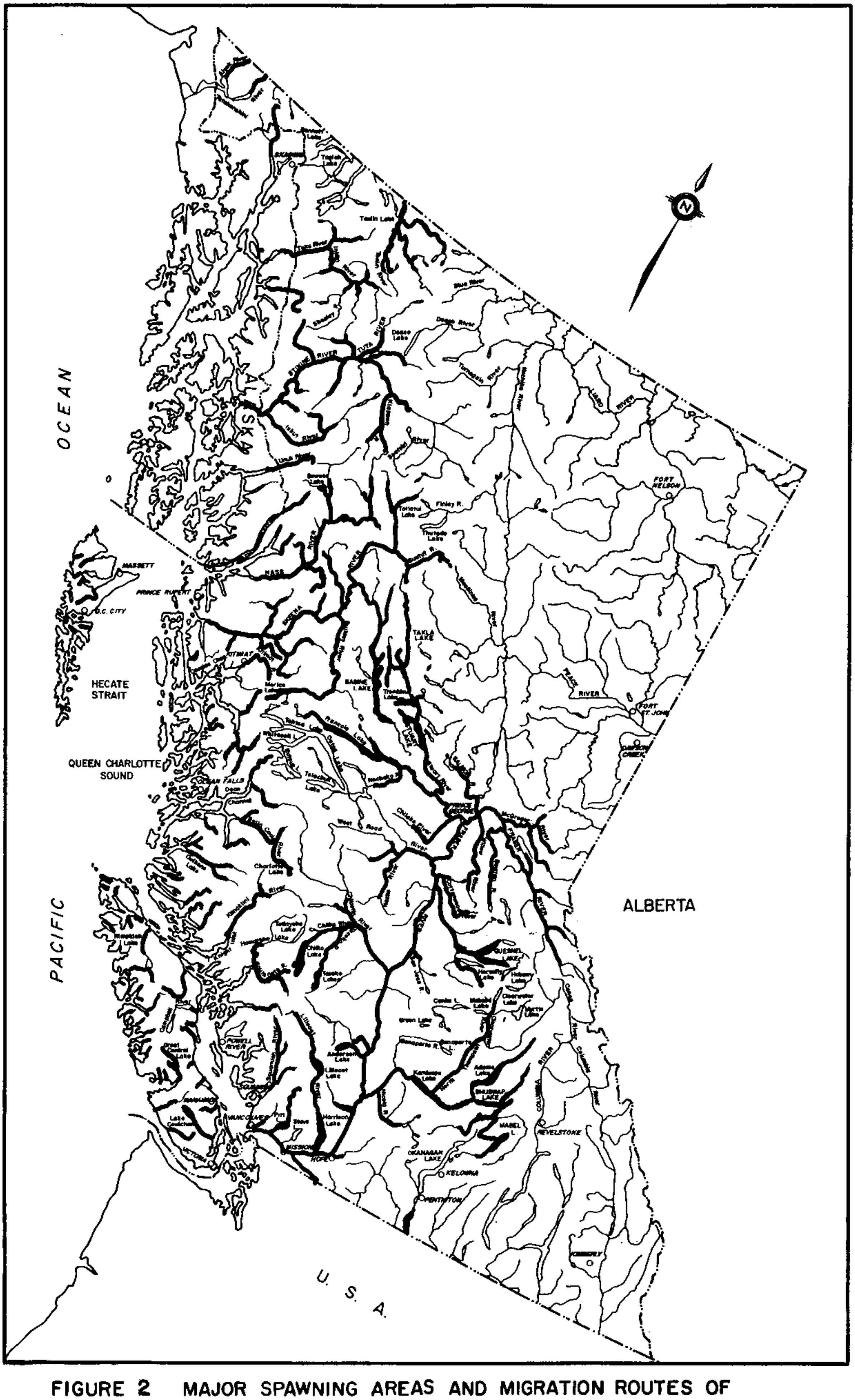


FIGURE 2 MAJOR SPAWNING AREAS AND MIGRATION ROUTES OF PACIFIC SALMON IN BRITISH COLUMBIA, CANADA.

In 1978 the process value of the fishing industry output in British Columbia was approximately $470 million; the salmon fishing industry accounts for 57% ($267 million) of this processed value. The British Columbia fishing industry revenues, in turn, generated a national income of about $900 million.

Direct employment in the fishing industry includes 17,500 fishermen and 6,000 shoreworkers. In addition, the equivalent of 10,000 full-time Canadian jobs (of which approximately 50% are outside of British Columbia) depend on the British Columbia fishing industry.

The fishery resources of British Columbia also provide recreational opportunities for both residents and non-residents. Participation in British Columbia's recreational fishery (1975) totalled 670,000 people, 450,000 British Columbia sport fishermen, 70,000 other Canadians and 150,000 non-Canadians.

The total value of the fresh and salt water recreational fishery is approximately $70 million annually. In addition to the direct satisfaction and values enjoyed by the recreational opportunities provided by the lakes, rivers, and tidal areas, there are significant business opportunities associated with fishery based recreational activities. It is estimated that the total annual expenditures directly related to the recreational fishery amounts to approximately $75 million (1975).

The federal government, in cooperation with the province of British Columbia has recently embarked on phase I of the Salmonid Enhancement Program. This involves a federal investment of $150 million and a provincial investment of $8 million over the next 7 years and is projected to increase salmonid fish production by 50 million pounds annually, Phase II, if approved will mean further investment of $30 million annually with the final objective of doubling salmonid populations.

The salmon resources are important to British Columbia's 194 native bands. Although no proper methodological approach has been developed to value the subsistence fishery, salmon play an integral role in the native lifestyle and culture.

## 3.0 THE PROBLEM OF RADIOACTIVITY

As mentioned previously the major difference between uranium mining and other base metal mining is the accelerated release of radioactivity to the environment associated with the mining and milling of uranium bearing ore.

The source of the radioactivity of concern consists of materials that were present in the parent ore body and whose mobility in the environment has been enhanced by the mining and milling process. The rate of release of these materials will of course vary with ore grade, ore type, and the mining, milling and waste management practices carried out. Radionuclides of most concern are Ra-226, Pb-210, Po-210, Rn-222 and the thorium isotopes. These radionuclides are generally released in liquid effluents either dissolved or suspended to the aquatic environment or in gaseous or particulate form to the atmosphere.

### 3.1 Environmental Pathways

Once these radioactive materials are released to the aquatic or atmospheric environment their dispersion and distribution will be dependent upon a host of factors related to the characteristics of the materials themselves (chemical, physical and biological properties) and to those of the environment around them (atmospheric conditions, dispersal of dissolved and suspended matter, sorption by natural materials, interaction with sediment or dust particles, accumulation in biological organisms etc.). These characteristcs determine the pathways by which radionuclides will migrate and sometimes attain a final resting place or "sink". It is essential that these pathways be well understood prior to establishing a mining operation.

3.1.1 Aquatic Pathways. Sediments are generally considered to be the major sink or resting place for radionuclides in the aquatic environment. Certain aquatic biota (particularly algae) have been shown to take up and accumulate specific radionuclides from water and/or sediments. This transfer of radionuclides from water or sediments to biota is an important pathway in the movement of radionulides within the aquatic environment as it reveals the potential for accumulation and resuspension of radioactive material. Aquatic plants and benthic invertebrates have frequently been found to contain higher concentrations of Ra-226 and uranium than sediments while fish and water have been found to contain lower concentrations. Although the actual concentrations of radionuclides in different environmental compartments will vary from area to area, it suggests the possibility of using algae or invertebrates as key indicators in the movement of radionuclides in the aquatic environment.

In semi-arid areas, such as the Okanagan basin, low surface runoff, flood control structures and retention basins will likely minimize transport of sediment associated contaminants out of the region, resulting in a build-up over time of radioactive contaminated sediment and increased possiblities of resuspension. In addition, dissolved contaminants will not be subject to the rapid dilution that occurs in wetter areas. Thus semi-arid conditions such as those found in certain parts of the Thompson, Columbia, Okanagan and Kettle watersheds will generally result in increased retention times and potentially higher concentrations of radionuclides released from uranium mining areas.

The potential for transport of radioactive contaminants in groundwater rather than surface drainage presents a particular problem in the semi-arid Okanagan region where groundwater supplies the major reservoir of water for use in irrigation, agriculture and domestic consumption. Dispersion of materials in an aquifer can be variable and hard to predict, for example, in the Okanagan where permeable sediments overlie bedrock, movement of groundwater can be substantially affected by varying hydrological conditions such as the fluctuations associated with recharge from controlled and impounded surface flows and by high pumping rates from wells during irrigation. A careful examination of groundwater flow patterns should therefore precede any decision to establish a tailings disposal site. Should it be decided to mine by the in-situ leaching of ores, it is of course essential to have detailed knowledge of groundwater characteristics and movements through all likely climatic and hydrological conditions.

3.1.2 Atmospheric Pathways. The main airborne radiological hazard associated with uranium mining is the release of radon-222 and its daughter products with fugitive dust during the mining and milling process, and from dry tailings areas. Radioactivity released to the atmosphere is normally dispersed and diluted such that its concentration in air generally decreases as the distance from the source increases. Studies have shown that the maximum concentration of radon daughters at a "model" mill would occur just beyond the edge of the tailings impoundment in the direction of the prevailing wind. Data obtained in the southwest U.S.A. show that radon concentration falls off rapidly with distance and that the concentrations are virtually indistinguishable from the background levels beyond 1 or 2 km. The resultant dose due to inhalation is therefore strongly dependent on distance. These results (in particular those from the "model" study) are based on areas with good ventilation consistent with flat terrain and light to moderate winds. These results may not, however, be applicable to the B.C. situation where air may become stagnant in valleys under stable atmospheric conditions and unidirectional wind flows result in substantially different conditions.

The major impact associated with the release of radon is the inhalation and retention of its daughter products in the lung. Under stagnant air conditions, such as sometimes found in B.C., short-lived daughter products have time to approach secular equilibrium with the radon released. For example, if the tailings disposal area was in a deep valley, these factors would be aggravated since the source emissions remain about the same but reduced ventilation could result in concentrations of radon daughters well above the usual background. Consequently, even though the radon concentration may be reduced, the daughters still constitute a potential health hazard.

Tailings areas can become quite dry in summer in semi-arid regions such as the Okanagan, and radon concentrations at that time could reach levels which may restrict human habitation in the immediate area. In the U.S., where many mine/mill sites are located in dry areas, the dose from radon in the tailings is considered to be the largest contributor to radiation exposure to the public from the entire nuclear fuel cycle. These considerations make it essential that tailings be carefully sited and designed, and proper management be undertaken both during the operation of the mine and after abandonment.

Another potential health hazard is the ingestion of food products or water contaminated by long-lived radon daughter products (Pb-210, Bi-210, Po-210). These radionuclides as well as Th-230 and Ra-226 from airborne dust materials settle on the ground and foliage as a result of dry deposition and washout. With the prevailing unidirectional wind conditions in valleys, this may be of concern in areas downwind from tailings sites.

Radioactive particulate matter may become suspended in the atmosphere as a result of crushing and grinding operations, drying and packaging of yellowcake and wind erosion of tailing ponds. Of these sources, tailings erosion is considered the most serious. The quantity of the suspended materials is affected by the topography and physical properties of the tailings surface, the extent of surface contamination and the local micrometerology. Covering with earth or otherwise stabilizing the tailings serves to prevent resuspension of tailings particulates and decreases the radiation to individuals living close to tailings impoundments.

These atmospheric releases may result in direct exposure of man and animals through inhalation of radon progeny and particulates and/or their indirect exposure through ingestion of contaminated vegetation resulting from deposition on foliage or uptake of radioactivity from soils.

## 3.2 Effects of Radioactive Releases

A thorough and comprehensive review of the effects of radioactivity on biological systems would entail the discussion of matters beyond the scope and purpose of this brief. It is assumed that the reader is familiar, or can become familiar with the basic concepts of radiation and of the interaction of radiation with matter. A major point to note is that radiation effects are of two major types: acute effects, or effects that the evident shortly after exposure to moderate or high levels of irradiation (50 rem/year or more), and chronic or late effects that become evident only after a period of "latency" following exposure to low-level radiation. Because radioactivity from uranium mining results in low levels of radiation, only late effects will be discussed.

The late effects of radiation manifest themselves some time after the dose has been received and result from radiation interference with the biological information that the cells transmit during the natural process of cell (mitotic or meiotic) division. When this interference affects the cells of a tissue then the effect is termed "somatic". Somatic effects include cancers and leukemias. When this interference occurs among the cells responsible for sperm or egg production, then the effect is usually manifested in future generations and the phenomenon is called "genetic" effect.

The somatic and genetic effects of radiation are not specific to radiation and may be induced by other environmental factors. Most members of a population exposed to low levels of radiation will not suffer any effect, but a small fraction of that population might develop cancer or might pass on genetic damage to their offspring. It is not possible to predict which individuals of a population will be affected and therefore the late effects of radiation are termed "stochastic" in order to reflect this statistical nature of possible effects.

Risk estimates have been derived for the stochastic effects of radiation in human populations. For somatic effects, these risk estimates are based, to a large extent, on epidemiological studies of groups exposed to reasonably quantifiable levels of radiation (e.g., personnel in nuclear facilities). While data on the natural incidence of genetic diseases in humans are of some use, the genetic risk estimates are not based on the epidemiological studies of irradiated human populations. Instead these genetic risk estimates are based mainly on the observation of radiation effects in laboratory animals such as mice.

Risk estimates for stochastic effects in biological systems other than man have not been as well quantified, partly because little is known of the natural incidence of malignancies in key species of the ecosystem, but mainly because the study of stochastic effects has been of more importance in public health considerations than in ecological protection. It is often suggested that man is one of the most radiosensitive species, however, this is difficult to substantiate because of the lack of data on stochastic effects for other species. It is also often claimed that radiation standards set to protect man will also ensure protection of the environment. This is so only if secondary or derived release standards take into account the complexities of the ecosystem, the potential for bioaccumulation, possible radiosensitive species and/or radiosensitive stages of certain species, and the combined impact of all radionuclides of concern. This factor is of particular concern in the British Columbia context for the reasons indicated earlier relating to the location of potential mining sites in proximity to human settlements and the unique biological resources of the province.

There is a good deal of disagreement over the seriousness of late effects at low doses, especially when the low doses are received by large populations over longer periods of time. Much of the disagreement is focused on two alternative possibilities with respect to the dose-effect relationship for the delayed consequences of low level exposure: threshold and linearity. Most scientists will agree with the notion that all radiation has the potential of resulting in an adverse effect no matter how little the dose. They therefore reject the idea that, for late effects, there is a threshold of dose below which no effect will result even though no experiment can be devised which is sensitive enough to demonstrate the presence or absence of an effect at the very lowest doses. Consequently, it is believed that rejection of the threshold concept is a prudent step. The concept of linearity suggests that the observed effects of measurably larger doses provides a first indication of the effects that might be expected at smaller doses.

The release of radioactive materials from uranium mining and milling results in exposure of living systems to levels of radiation additional to that from "background" or "natural" sources. These sources include cosmic rays, naturally occurring (and relatively undisturbed by human activity) radionuclides such as

H-3, C-14, K-40, Th-232. There is also irradiation from radionuclides in fallout from nuclear weapons testing. Estimated dose rates to humans from these "background" sources vary from 0.12 to 1.5 rem/year and for aquatic organisms up to 0.7 rad/y.

Evaluation of exposure pathways suggest that incorporated radionuclides are the most important source of radioactivity for plankton and pelagic fish, that beta- and gamma-radiation from radionuclides in the sediment is equally important as incorporated radionuclides for benthos and dimersal fish, and that the dose from radionuclides in water is less important. Of particular concern in British Columbia is the exposure pathway from radionuclides in the sediment since the eggs and alevins of Pacific salmon are associated closely with the bottoms of streams and lakes for up to half a year.

The presence of radionuclides within an organism will result in exposure to radiation from within the body and consequently in internal radiation dose. Radionuclide uptake by organisms can occur by inhalation of air and by ingestion of water and food containing radionculides. The magnitude of the internal dose rate depends on the quantity of the radionuclide internally deposited and its distribution within an organism.

Internal radiation doses have been calculated for aquatic organisms exposed to liquid effluents from an average USA uranium mine and mill. At the average USA uranium mine, the estimated internal dose was 63 rad/y to aquatic plants, 100 rad/y to invertebrates and 1.1 rad/y to fish, and at the average USA uranium mill the estimated dose was 1 200 rad/y to aquatic plants, 350 rad/y to invertebrates and 22 rad/y to fish. Th-230, Ra-226 and Po-210 contributed most of these doses. However these calculations may not reflect the dose rates to be expected at proposed British Columbia uranium mines and mills since the average USA uranium mine and mill may not have the same characteristics as British Columbia uranium mines and mills, and the calculations did not consider external dose rates or radionuclide distribution at specific localities and the subsequent exposure of aquatic organisms.

Laboratory studies have shown that single doses of 1,100 rad and above may be lethal to adult fish, the most sensitive group of aquatic organisms, and single doses of about 16 rad may be lethal to the most sensitive stage of development of coho salmon (O. kisutch), and that dose rates of 1 rad/day and above may cause sublethal somatic and genetic effects in aquatic organisms. However significant effects on natural populations of aquatic organisms have been observed only at dose rates of 10 rad/day and above, although some effects on individuals have been observed at dose rates of 0.5 rad/day and above. For instance, dose rates of about 10 rad/day and above resulted in increased mortality and reduced growth of fingerling chinook salmon (O. tshawytscha), and in retarded gonadal development, reduced growth and increased age of return of adults, abnormalities in young fish increased at dose rates of 0.5 rad/day and above.

Pathway studies have tended to focus exclusively on critical paths leading to exposure of human populations. While the importance of these studies is unquestionable, they do fail to take note of the exposure to the other organisms themselves and, more importantly, to the potential adverse effects on key species or key development stages of some species. As mentioned before, the Pacific salmon is of such importance to B.C. that it cannot be treated simply as a compartment in the environment leading to exposure of humans. It is therefore essential that pathway studies consider the radiation doses that would be absorbed by salmon and also provide a scientifically-based estimate of the effects at the population level. These estimates will remain somewhat uncertain for reasons already discussed.

## 4.0 THE PROBLEM OF NITROGEN

The mining and milling operations can also result in the discharge of substantial quantities of nitrogen compounds. At concentrations greater than 0.2 mg/l, un-ionized ammonia is highly toxic to aquatic organisms. Concentrations of un-ionized ammonia in the final settling pond overflow at Elliot Lake uranium mills have been calculated to range from 0.0036 mg/l to 7.7 mg/l. The discharge of nitrogen in the form of ammonia, nitrate and nitrite can also lead to problems of eutrophication where nitrogen is a limiting nutrient in receiving waters.

In order to protect the fisheries resource, consideration should be given to establishing a maximum allowable level of un-ionized and total ammonia (as N) in effluent discharge in the order of 0.02 and 0.5 mg/l respectively.

The difficulty in removing nitrogen compounds from effluent streams would suggest the most practical means to minimize their effects is to avoid their use wherever possible. This can be partially achieved by using alternate reagents in the milling operation, e.g. the LAMIX process. Utilization of reagents other than ammonia based compounds has the added advantage of allowing the recycling of water from tailings ponds to the milling process - a practice recommended for uranium mining operations in British Columbia. Nitrogen compounds in the mine water can be minimized by careful blasting and explosive handling practices in the mines.

## 5.0 URANIUM MINING AND MILLING/ENVIRONMENTAL CONTROLS

The major difference between uranium mining operations and base-metal mining activities is the nature of the wastes generated. Uranium mining and milling operations produce large quantities of radioactive and non-radioactive wastes. Our main concerns are with: (i) the potential environmental effects of radioactive wastes requiring disposal, (ii) the substantial quantities of nitrogen as ammonia or nitrate released in aqueous discharges. Varying quantities of these materials are associated with the various stages of the uranium production cycle, including: prospecting, exploration, development, mining, milling, waste disposal and shutdown. The degree of environmental concern and therefore control required for each of these operations will, of course, vary considerably with both the nature of the operation and the site.

While available technology appears to be able to effectively control most emissions and effluents from uranium mining and milling activities during the operating life of the mine/mill facility, it must be pointed out that this view is based upon tests and experience elsewhere and may not accurately represent the situation in British Columbia for reasons of topography, climate, etc., outlined earlier. It must also be recognized that environmentally acceptable methods of long-term mill tailings disposal which would not be dependent on continued human management, have yet to be developed.

Measures aimed at minimizing the release of radioactive materials and nitrogen based compounds should be incorporated into all phases of uranium mining operations save prospecting which generally does not result in increased release of radioactive materials to the natural environment, and therefore requires no special considerations. Exploration and development activities have the potential for significant releases of radioactive materials and therefore environmental controls should be incorporated into exploration permits and the control technology employed to protect the environment during the development phase should be the same as that practiced during the operation of the mine.

The mining stage of a uranium operation produces liquid effluents and gaseous and particulate emissions. Depending on the mineralogy and hydrogeology of an ore body and the mining technique employed, mine water is known to vary considerably in both volume and concentration of suspended solids, radionuclides, heavy metals, sulphates, ammonia and nitrates (the latter two from explosives). Generally, mine water is of a quality that precludes its untreated release to the environment (Appendix I, Tables 1 and 2). The general practice in Canada for uranium mines with mills on site is to route the mine water to the mill for use as process water and for recovery of its contained uranium. These waters are then discharged to the tailings pond. At open pit mines, efforts must be made to reduce the volumes of water entering the pit by diverting uncontaminated surface water flows away from the pit. To avoid excessive groundwater entering the pit, aquifers in the immediate vicinity should be drawn down by a series of external wells.

Mine faces, ore stockpiles and waste dumps can all be sources of radon gas and radioactive and non-radioactive particulate emissions. The importance of the environmental problems associated with these emissions and the selection of suitable control measures are dependent on a number of site specific factors, such as geology, ore grade, mining method and weather conditions. (See Appendix I for more details.) Particulate emissions from open pit mines can be controlled by employing dust collectors on blast hole drills, wet drilling, limiting blast size, spraying water on haulage roads, orefaces, and stockpiles, by proper siting and design of stockpiles and storage yards and by covering ore trucks.

The milling process in which uranium is concentrated in the form of yellowcake produces the bulk of the waste associated with uranium mining. Typically, liquid mill wastes (tailings) are pumped as a slurry of 25-40% solids to a tailings impoundment area for treatment and confinement. Eighty-five percent of the radioactivity originally in the ore is discharged with the mill tailings slurry, 1-2% in solution and the remainder as solids. All the chemicals that are used in the milling process, with the exception of some reagents contained in the yellowcake, are ultimately discharged to the tailings area.

The milling process is also a source of particulate and gaseous radioactive emissions. The main source of particulate releases are the ore crushing circuits and the yellowcake drying and packaging operations. These particulates, containing uranium and its daughter products, have been reported to be released at rates ranging from 0.05-0.25 gm/sec at Elliot Lake mills to 0.1-0.5 gm/sec for U.S. mills with a capacity of 7000 tonnes. Radon gas is emitted from the ore crushing and grinding operation and the leach tanks. Radon emissions from the Denison and Quirke mills have been reported to range from 5-10 pCi/sec.

## 5.1 Waste Management

It is however from the waste management site that the major aqueous and atmospheric emissions result. This facility generally consists of two sections, a tailings pond contained by a dam or other structure, and a radium precipitation pond.

Effluent discharges include treated tailings pond effluents, mine water or seepage (surface or underground). It should be noted here that underground seepage has not been well documented in Canada but could be a significant source of radioactive materials if the soil or rock underlying the tailings ponds are relatively porous, sandy or fractured. Aqueous releases may result from other phases of the operation but are considered to be minor when standard control procedures are implemented (See Appendix I, Sections 5 and 6).

A major concern with respect to liquid emissions is of course the volume of the releases. These can be reduced by recycling of water from the waste management facility to the the milling process.

While over 98% of the radium and essentially all of the thorium in the original mill feed are retained in the tailings impoundment area, effluents from tailings impoundments still contain sufficient dissolved Ra-226 to be of concern and require additional Ra-226 removal. This is accomplished by the addition of $BaCl_2$ to coprecipitate the radium as a barium-radium-sulphate ($BaRaSO_4$) precipitate which is settled and retained in the precipitation pond.

"Typical" treated tailings effluent and seepage from the Elliot Lake area range from 1-7 pCi/l and 5-42 pCi/l dissolved and total Ra-226 respectively (see Tables 6 and 8, Appendix I for more details). Although radium removal methods currently in practice have proven successful in meeting the federal requirement of 10 pCi/l dissolved Ra-226, this technology has resulted in total Ra-226 levels greatly exceeding the dissolved values due to the presence of Ra-226 in the form of unsettled $BaRaSO_4$ precipitate. This difference is illustrated in Table 1.

TABLE 1 MEAN VALUES (pCi/l) FOR RADIUM-226 IN FINAL EFFLUENT (12 MONTH PERIOD)

| | | Eldorado Nuclear | Gulf Minerals | Rio Algom | Denison |
|---|---|---|---|---|---|
| Ra-226 | (Dissolved) | 5.2 | 3.4 | 7.3 | 2.1 |
| Ra-226 | (Total) | 16.5 | 29.9 | 83.0 | 23.0 |

The presence of $BaRaSO_4$ solids in the effluents is a matter of concern since these are soluble at the lower sulphate concentrations encountered in receiving waters and ultimately can result in the release of Ra-226 into the aquatic environment. It is noteworthy that over a recent ten month period, one company discharged an effluent containing less than 10 pCi/l total Ra-226. Also, although the government/industry pilot plant project (mechanical treatment system) at Elliot Lake is still in its demonstration stage, there is every indication that treated effluents containing less than 10 pCi/l total Ra-226 can be produced routinely. Accordingly, the Department of Environment and the Department of Fisheries and Oceans concur with the recommendation of the Radioactivity Sub-group to the federal Mining Effluent Task Force that there is a need to regulate total as well as dissolved Ra-226 in effluents to more fully safeguard the receiving environment.

Ammonia, nitrates, and sulphates are not specifically treated nor affected within the treatment system other than by dilution.

The tailings impoundment area is also the main source of atmospheric emissions. The rates at which radon and particulates are released from the tailing area vary considerably, as such factors as covering materials, snow cover, moisture content, humidity, temperature, grain size, as well as radium concentration can change the emanation rate of radon by an order of magnitude or more. In relatively dry areas of the United States, similar to those encountered in parts of B.C. where uranium mining is proposed, emanation rates of 650 pCi/sec have been estimated for unstabilized tailings areas. Revegetation of the tailings either directly or after soil covering is used to minimize dust releases. Radon gas emissions can be attenuated by a compacted soil cover on top of the tailings or by water cover.

## 5.2 Shutdown

Unquestionably the most significant environmental concerns pertaining to uranium mining and milling operations are directly related to the shutdown phase. Because each tonne of ore commonly contains only a few pounds of uranium, essentially all of the other constituents including the radionuclides radium-226, thorium and lead-210 are waste products which must be disposed of in a manner which is environmentally acceptable not only over the short-term, but more significantly over a period of several centuries.

Although current waste management practices pertaining to the storage of tailings during the operating life of a mine are acceptable as interim measures, environmentally acceptable tailings disposal methods for the long-term have still not been identified. In view of this, government agencies and the uranium industry are studying methods for the disposal of radioactive mine wastes which will safeguard the environment over the long-term. In the meantime, industry and government agencies must ensure that uranium mine/mill wastes are stored in a manner which affords the maximum protection of man and the environment until permanent disposal techniques are developed which do not require perpetual human intervention.

In order to achieve this goal, mine shutdown plans must have as their objective the elimination or reduction of sources of environmental degradation such as:

1) contamination of surface or groundwater systems through the release of acidic, radioactive and heavy metal laden seepage or leachate;
2) redissolution of radium from $BaRaSO_4$ sludges in the precipitation ponds;
3) tailings impoundment dam failures,
4) emissions of radon gas from moist and dry tailings pond surfaces;
5) contamination of soil and vegetation from wind blown particulates from dry tailings surfaces.

The potential environmental ramifications from these factors are briefly considered below:

1) Seepage from inactive tailings impoundments containing iron sulphide minerals but lacking natural buffering capacity may be highly acidic and carry elevated levels of radionuclides, particularly thorium and lead, and toxic heavy metals. Unless preventative measures are taken, seepage may persist long after mining operations cease. Table 2 indicates the nature of seepage from inactive tailings sites in the Elliot Lake area.

TABLE 2 SEEPAGE WATER CHARACTERISTICS

| Parameter | Measure Range | |
|---|---|---|
| pH | 1.8 - 3.8 | |
| Dissolved Ra-226 | 5 - 42 | pCi/l |
| Total Thorium | 1000 - 10000 | pCi/l |
| Dissolved Pb-210 | 30 - 1000 | pCi/l |
| Fe | 1.8 - 3760 | mg/l |
| Dissolved Solids | 630 - 21500 | mg/l |
| $SO_4$ | 360 - 11550 | mg/l |
| $NH_3$ | 0.12 - 35 | mg/l |
| $NO_3$ | 0.01 - 0.6 | mg/l |
| Ni | 0.32 - 5 | mg/l |
| Zn | 0.06 - 11.5 | mg/l |

2) Barium-radium-sulphate sludge ($BaRaSO_4$) remains stable under the high sulphate condition existing in an active treatment pond. Investigations have shown, however, that radium leaches from the sludge under low sulphate conditions as would occur in an inactive pond where natural precipitation or surface runoff would reduce the sulphate content of the water. Unless sludge storage sites are properly isolated from fresh water, redissolved radium could enter the environment at unacceptable rates.

3) Tailings dam failures have occurred at base metal mines in B.C. and the Yukon and at uranium mines in Elliot Lake. The structural integrity of tailings management facilities is of major importance during both the operative and post operative stages of a mine. This factor would be particularly significant in areas of B.C. which are seismically sensitive and/or are subject to high rainfall and runoff.

4) Radon gas and particulates can become a problem when inactive or dry tailings sites are exposed to the atmosphere. The rates of release are dependent upon the physical and mineralogical nature of the tailings, local topography and such climatic conditions as precipitation, wind speed and direction.

In order to prevent the occurrence of potential environmental damage during the period between mine shutdown and the implementation of effective long term disposal techniques, decommissioning plans must ensure that:

1) Sources of surface water or runoff are diverted away from tailings storage sites in order to reduce the volume of seepage or leachate emanating from the tailings.
2) Tailings pond surfaces are chemically fixed or otherwise stabilized and revegetated.
3) $BaRaSO_4$ sludges presently stored in the precipitation ponds are disposed of in a manner to delay the release of radium. Suitable disposal techniques are presently under study by both government and industry. One possibility which is receiving attention is underground storage of sludge in worked-out sections of mines. At Madawaska Mines, the precipitation pond is actually a concrete tank which will be capped upon cessation of operation with the $BaRaSO_4$ sludge remaining on the bottom.
4) The most appropriate preventative measures for the control of radon and particulates from tailings will depend upon the specific site. A water cover will prevent the escape of radon and particulates but may be difficult to maintain or prevent escape of contaminated seepage. Covering the tailings with earth and revegetating will eliminate most of the radon and dust problems but its long-term suitability, including the effect on the quality and quantity of seepage, has yet to be demonstrated.
5) The siting of tailings disposal facilities is an important consideration in the long-term management of the sites. Such facilities should be located, constructed and rehabilitated in a manner that will minimize the degrading effects of erosional processes.

## 6.0 CONCLUSION

Uranium is currently mined in Ontario and Saskatchewan as well as in many other parts of the world. In all mining locations, there have been risks to the environment that have necessitated mitigating measures to make this industrial activity socially acceptable. To a large extent, concern over these risks has focused on the radioactivity released during the mining and milling operation and also on the radioactivity remaining in the tailings. The radioactive material of greatest concern with respect to contamination of aquatic systems is radium-226, while the concern with respect to contamination of the air is radon-222. Both of these radionuclides have a potential for even greater impact in the British Columbia scene: radium because it can, and probably will, result in increased exposure to B.C. fisheries, especially the Pacific salmon and because it has the potential of accumulating in the semi-arid regions; and radon because the unique topography, microclimatology and demography of the potential mining areas in B.C. are such that the doses to populations can be higher than those experienced elsewhere.

Radiation standards have been well developed for human populations and, although interpretation of data differs, they have been based on a rather large data base on radiation effects. Standards for radiation levels in environmental media are mainly secondary human health standards that relate to the dose humans would receive from being "associated" with the particular medium. They are essentially derived standards. It would certainly be useful to identify a primary standard for key members of the ecosystem such as Pacific salmon to ensure that releases of radioactivity in both the short and the long-term do not result in unacceptable risks to populations of that species.

Mitigating measures have been directed at controlling the release of radium and radon, as well as that of non-radioactive pollutants such as ammonia. To a large extent, the technology exists to ensure compliance of operational mines and mills with all relevant environmental and health standards. Whether these standards are adequate to protect the environment in British Columbia will depend on the specific conditions within which the mine will operate. The major difficulty, however, lies in the post-operational phase. No acceptable institutional or technological mechanism has been developed to ensure that the "walk-away" situation will pose negligible risks to man and to the environment.

While it is true that this problem is real for all industries that create hazardous wastes, society must show increasing awareness of risks to future generations. One should recognize that the uranium mining industry as well as the regulatory agencies have been giving this matter serious consideration over the past several years, for it is one of the most important problems in radiation control. However, satisfactory solutions are yet to be developed.

In fact, it has not yet been possible to define or get general agreement on what would be the environmentally acceptable "walk-away" condition of the tailings. To arrive at such a definition more work is required on the dynamics of abandoned tailings, the pathways that radium and other key radionuclides take in the environment, and the cost effectiveness and feasability of removing radium and thorium either in the milling process or from the tailings themselves. The following recommendations are placed before the Commission in full cognizance of the difficulties attendant on the general lack of understanding of key pathways and processes and the uncertainty surrounding many of the effects of low level radiation on the ecosystem.

## RECOMMENDATIONS

It is recommended that:

(1) The environmental acceptability of each uranium mining proposal in British Columbia be based on site-specific environmental impact assessment and provisions or procedures be established that provide opportunity for public review and discussion of such an impact assessment.

(2) Mandatory environmental impact assessments be carried out by proponent companies under the guidance of regulatory authorities and should include:

(a) estimates of the total release and the release rate of the major radionuclides throughout the life of each mine and mill,

(b) predictions of the behaviour of these radionuclides in the aquatic and atmospheric environment,

(c) identification of sites where long-lived radionuclides may accumulate,

(d) identification of aquatic and atmospheric transport pathways and estimates of the resultant dose rates to aquatic organisms, especially Pacific salmon and human populations directly and indirectly,

(e) the potential effects of these dose rates on aquatic organisms, especially Pacific salmon,

(f) aquatic resource utilization and consequent intake of radionuclides by humans and its impact,

(g) the combined effects of all uranium mining/milling developments proposed for the watershed on aquatic and terrestrial organism.

(3) Exploration Permits specify that sound environmental protection measures be employed during the exploration phase to minimize (a) the damage to land surfaces and surface/groundwater systems and (b) present and future releases of radiological and non-radiological contaminants to the environment.

(4) Data be obtained to estimate radon and particulate distribution by atmospheric dispersion modelling techniques. This information is required for evaluating both short- and long-term impact on air quality.

(5) A pre-operational, operational and post-operational environmental monitoring program which includes the monitoring of the physical, chemical, biological and radiological aspects of the receiving environment based on the site-specific nature of each operation and its environs be implemented at each site.

(6) The control technologies normally utilized during the operating life of a uranium mine to protect the aquatic, terrestrial and atmospheric environment be initiated and employed as early as possible in the mine development phase.

(7) Mine operators be required to plan their waste management facilities such that whenever an environmentally acceptable permanent disposal method is developed, the $BaRaSO_4$ precipitates can be:
- (a) recovered from the treatment ponds in order to be disposed of in a more secure manner,
- (b) encapsulated within specially designed and constructed settlement/confinement facilities.

(8) Uranium mill tailings management facilities be designed, constructed and maintained in an environmentally acceptable manner during the active life of the mill. The design of a tailings facility must allow for the ongoing containment of tailings and the management of the tailings facility following the operation life of the uranium mill.

(9) Site-specific factors, eg. ore grade, mining method, weather conditions, be taken into account in determining the air pollution control facilities to be installed.

(10) Acceptable effluent concentrations of pollutants not specified in the Federal Metal Mining Liquid Effluent Regulations be determined on a site-specific basis.

(11) Effluent standards be prescribed in terms of both dissolved Ra-226 and total Ra-226 concentrations.

(12) Consideration should be given to establishing a maximum level of un-ionized and total ammonia as (N) in uranium mine wastewater discharges of 0.02 mg/l and 0.5 mg/l respectively in order to protect the fisheries resource.

(13) Uranium producers recycle treated effluent to the mill wherever possible in order to decrease both the volume of effluent discharged to the receiving environment and also the amount of freshwater make-up required in the milling process.

(14) At a particular site, if technically feasible alternatives exist, uranium mining and milling processes requiring the use of ammonia or ammonium compounds be avoided.

(15) Comprehensive effluent and emission monitoring programs be developed on a site-specific basis. The Federal Metal Mining Liquid Effluent Regulations are recommended as the minimum requirement for effluent monitoring and reporting.

(16) As part of a routine effluent monitoring program, each uranium mining and milling operation be required to monitor the concentrations of total Th-230, total Th-232 and total Pb-210 in their effluents during the life of the mine and until it has been established that these radionuclides are not present at levels of concern.

(17) Studies be undertaken on the stabilization of mill tailings with the objective of reducing emissions of radon and airborne particulates and the mobility of radium and other contaminants in ground or surface waters.

(18) Research in the areas of wastewater treatment, alternate milling practices and short- and long-term tailings and $BaRaSO_4$ sludge management be accelerated.