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ENVIRONMENTAL CONCERNS OF ELECTRICAL POWER PRODUCTION IN ONTARIO FROM NUCLEAR ENERGY

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PREFACE

This paper was prepared in support of the DFE submission to the Royal Commission on Electric Power Production in Ontario, 'Electric Power Production and Transmission in Ontario from an Environmental Perspective, May 10, 1977'. It was modified before incorporation into the submission in order to reduce the overall length of the submission and reflect Departmental policy. The paper is a review of environmental impacts of nuclear power production currently observed and those envisaged from future development of Canada's nuclear program. The opinions expressed are the author's own and do not necessarily reflect Department nuclear policy.

1. REVIEW OF IMPACTS

There is widespread public concern over the environmental impacts of all phases of the nuclear fuel cycle. In chronological order the steps in this cycle are:

1. Uranium Mining and Milling
2. Uranium Refining and Fuel Fabrication
3. D_2O Production
4. Power Generation
5. Fuel Reprocessing
6. Radioactive Waste Management

These impacts arise from the releases of radioactivity and other contaminants to the environment during operation of each of these stages, and from the release of waste heat to the aquatic environment during power generation. The critical impact is that of radioactivity release on terrestial and aquatic ecosystems. Individual radionuclides move through the environment at different rates and by different pathways ultimately reaching the human population. Their ionizing radiations damage living cells which can result in both somatic and genetic effects to the organism depending on the intensity of the radiological dose received.

2. URANIUM MINING AND MILLING

In the process of extracting the raw material for nuclear fuel from the ground, uranium miners are inevitably exposed to the risk of lung cancer from inhalation of ^{222}Rn decay products. A detailed assessment of this risk is given in the report of the James M. Ham

Commission on the Health and Safety of Workers in Mines (1).

It is clear from the Commission's report that the risk of lung cancer increases with exposure and that no threshold of exposure exists below which the risk is zero. Although the regulatory exposure limit has been decreased in recent years, epidemiological research on uranium miners should be enhanced to provide a basis for reviewing the current exposure limit of 4 working level months (WLM) per annum.

The uranium mine tailings and mill wastes containing isotopes of radium and thorium are discharged to surface disposal areas where they are exposed to the leaching action of low pH surface water arising from bacterial oxidation of sulphides in the tailings. Although most of the radium leaching from active milling operations is precipitated by barium chloride treatment in holding ponds, there is a constant leakage of radium to local fresh water sources. The Serpent River, which drains the Elliot Lake uranium mining area, is contaminated with ^{226}Ra. Even at the mouth on the North Channel of Lake Huron where the water is used as a potable supply, the Ontario Ministry of the Environment reports levels of ^{226}Ra higher than the Province's criterion (2). There is an urgent need to develop much more efficient treatment processes for uranium mine and mill wastes to fix the radium and thorium in the discharged tailings so that they are impervious to leaching by surface runoff. Even though ore grades are declining, the uranium mining industry can still afford the added costs of permanent fixation of radioactivity in their wastes since the value of their product has escalated with the price of oil.

Research efforts on fixation of uranium mine and mill wastes by federal and provincial agencies should be increased so that treatment systems can be designed to diminish substantially the release of radionuclides to surface waters.

3. URANIUM REFINING AND FUEL FABRICATION

Since the bulk of the long-lived radioactive contaminants associated with natural uranium are removed at the mine site, the refining process which produces reactor-grade uranium does not discharge a great deal of radioactive waste. On the other hand, quantities of nitrates, ammonia and fluorides have to be disposed of which can contaminate ground water supplies.

Detailed studies of the hydrogeological characteristics of all proposed sites for waste disposal from refining and fabrication plants must be carried out to ensure that leachate from these wastes has no chance of reaching aquifer recharge areas.

4. D_2O PRODUCTION

The potential hazard from heavy water production is that of H_2S release to both the atmosphere and the aquatic environment. Waste H_2S discharged to the atmosphere is first oxidized to SO_2 and therefore adds to the global problem of long-range transport of sulphur oxides. The daily releases of H_2S from the Bruce Heavy Water Plant to Lake Huron are regulated by Ontario Ministry of the Environment to 154 kg per day. After dilution by the circulating cooling water the discharge to Lake Huron must not exceed 82 ppb. No changes to aquatic life in the vicinity of the site have been detected which could be attributed to

H_2S releases since operations started in 1974. However, toxicological studies on the effects of H_2S on fish eggs and larvae should be continued to ascertain that detrimental effects will not occur from chronic exposure to the maximum permissible 82 ppb concentration.

5. POWER GENERATION

The Great Lakes have been considered an excellent heat sink for thermal generating stations and a number of nuclear stations are operating on their shoreline with plans for many more. As radionuclides are continually released during plant operation, the levels of long-lived radionuclides in the lakes will gradually increase producing an increasing radiological dose to the individual drinking the water and eating fish caught in the lakes. This dose has been selected as the basis for defining a refined objective for radioactivity water quality in the Great Lakes for the Canada/USA Agreement (4).

The recommendation of the Canadian and United States Advisory Groups is that the radioactivity water quality objective for the Great Lakes should be a maximum annual radiological dose commitment of 1 millirem. This dose is not much higher than that obtained by drinking water from Lake Ontario with present day levels of weapons fallout contamination.

In the case of CANDU type reactors, the major contribution to these releases is from tritium, ^{3}H, which is discharged as tritiated water both to the atmosphere and to the cooling water. As it is isotopic with ordinary water, it rapidly equilibrates with biological systems.

The quantity of tritium released annually from a typical CANDU nuclear generating station is about 40,000 curies (5) compared to the 2 to 3 curies in total of other long-lived fission products. Two-thirds of this tritiated water is released to the atmosphere where it rapidly exchanges with atmospheric moisture and precipitates in the neighbourhood of the source. Obviously, it does not contribute to the long-range atmospheric transport of pollutants problem but it constantly contaminates the local environment. The remainder of the tritiated water discharged from the station is diluted by the condenser cooling water and dispersed into the lake. An estimate of the build up of tritium in the Great Lakes from Ontario Hydro's future nuclear operations predicts Lake Ontario ^{3}H levels to increase from the current 400 pCi/l to about 2000 pCi/l by 2000 (6). Even though the radiological dose to the individual drinking the water will only increase 0.3 mrem, this will be a major increase in concentration. In addition, stagnant pools of tritium could collect near discharge areas on a calm day (such pools have been observed off Pickering) and be carried by lake currents to public water supply intakes, thus adding a higher, short term dose to the public.

Tritium releases will involve the transboundary movement of a pollutant from Canadian to US waters. As US reactor systems discharge only minor quantities of ^{3}H, their effect on lake ^{3}H levels will be negligible so that a future concern may develop in the USA over pollution of US waters by Canadian nuclear generating stations.

Next in order of magnitude in aqueous discharges after ^{3}H are the radioisotopes of cesium, ^{134}Cs and ^{137}Cs. Although this element is bioaccumulated by plankton which in turn provide food for species at higher trophic levels, it is scavenged fairly rapidly from the water column to the sediment. It has been reported that about 93% of the ^{137}Cs in Lake Superior has been immobilized in the sediments (5). All of this ^{137}Cs was produced by weapons' testing with the major inputs to the lake being in 1963 and 1964. The levels of ^{137}Cs in Lake Superior lake trout are such that an individual would have to eat 50 kg annually to reach the 1 mrem objective. It has been calculated that ^{137}Cs inputs to the Great Lakes from Canadian and US nuclear stations through the year 2050 will result in levels in the water similar to current levels produced by fallout (7).

With the exception of localized areas near cooling water discharges, the radionuclides emitted from nuclear stations predicted through 2000 should not have a major effect on the water quality of the Great Lakes. Local effects will be monitored by provincial and state environmental and health authorities and coordinated by the IJC through its surveillance plan for measuring compliance with the objectives of the Canada/US Agreement.

The probability of an accident occurring at a CANDU nuclear generating station is very low in which there is both loss of coolant and failure of the emergency core cooling system (8). Nevertheless, the consequence of such an accident would be the release to the atmosphere of a large fraction of the 10^7 curies of ^{131}I contained in the fuel. Depending on climatic conditions and location of the generating station, the ^{131}I cloud could affect a very few or a very large number of people. This type of unexpected accident that releases large quantities of extremely toxic substances to the environment is becoming increasingly widespread. The Arrow incident in Chedabucto Bay, the releases of methyl mercury at Minamata and dioxin at Seveso are examples.

While not causing enough concern to consider halting the nuclear power program, which in Canada has an enviable safety record, the consequences of a major accident such as long-term environmental contamination and human somatic and genetic effects cannot be ignored and must be fully evaluated. Also, the industry must be constantly alert to possible safety system interactions that could propogate failures such as occurred in the Brown's Ferry nuclear station fire in 1975.

6. RADIOACTIVE WASTE MANAGEMENT

Radioactive wastes arising from nuclear power stations are in solid, liquid and gaseous forms. The liquid and gaseous wastes from reactor leakage and station housekeeping generally contain low levels of radioactivity and are discharged to the environment after dilution with the cooling water or ventilation air. The impacts of releases of these wastes were described in section 5.

The solid wastes consist of spent fuel bundles with very high levels of radioactivity and lower-level disposables such as spent ion-exchange resin columns and contaminated equipment. The low-level material from Ontario Hydro's reactors is stored in covered concrete-lined trenches at the Bruce site. Control of surface water which could leach radioactive material and a thorough knowledge of hydraulic and hydrogeologic characteristics of the soil are necessary to prevent contamination of ground water.

CANDU reactors currently operate on a once-through natural uranium fuel cycle with the high level wastes (i.e. spent fuel) being stored under water at the nuclear station. It is planned to have a central storage facility in operation by 1985 (9) to store indefinitely spent fuel from all Canadian nuclear stations. While the fuel sheath is intact, the mode of storage, either under water or in convection cooled canisters, will not cause radioactivity to be lost from the irradiated UO_2. If the reprocessing option is taken up sometime in the near future then this will be interim storage only. If not, then spent fuel must be stored in perpetuity because of the 24,390 year half-life of ^{239}Pu. Readily accessible storage under these circumstances is too heavy a burden to lay on future generations and permanent disposal such as in isolated geologic strata is imperative.

Criteria and standards for environmental protection against high level wastes must be developed starting now, to assure negligible risk to the health of present and future generations. These criteria and standards should be in effect before a disposal site is chosen in order that they can serve as criteria for site selection.

7. DECOMMISSIONING OF NUCLEAR INSTALLATIONS

At this early stage in the history of Canada's nuclear power program, decommissioning of nuclear reactors is a rare event. Even at the termination of a station's predicted thirty year life span, it is unlikely that a nuclear generating site will be abandoned unless it was a bad choice environmentally in the first place. What is more likely to happen is that upgrading of the nuclear component will take place as thermal efficiency of reactors is improved through continuing engineering research and development. Disposal of large sections of highly radioactive reactor structures presents an engineering problem but experience at AECL in this area can be called upon to minimize radiation exposure to personnel during such operations. Transportation of large reactor components to a central disposal site is not feasible because of the large mass of shielding required. Long-term on-site shielded storage will be needed until radioactivity levels have decayed sufficiently to allow off-site disposal. Storage could be required for a decade or so for neutron activation contaminants such as ^{60}Co.

8. FUTURE DEVELOPMENTS

8.1 Fuel Reprocessing

The current once-through fuel cycle of CANDU reactors does not require reprocessing of spent fuel for its low fuelling cost. However, the spent fuel is still a valuable commodity from the standpoint of further fission energy content as it contains about 0.3% fissile plutonium. In order to burn this plutonium, the irradiated fuel has to be reprocessed to extract the plutonium for incorporation into fresh fuel.

The extraction process involves mechanically decladding the fuel, dissolving the irradiated UO_2 in nitric acid, separating the plutonium by solvent extraction and then recovering it by backwashing the solvent. The bulk of the fission products remain in the nitric acid solution which is evaporated to high solids content and stored in stainless steel tank farms. Radioactive waste streams are generated at each step of the process with levels of radioactivity ranging from high to low. Liquid wastes discharged to the Irish Sea from the United Kingdom's Windscale plant during 1973-4 included 1800 curies of plutonium and 44,000 curies of ^{137}Cs (10). Gaseous fission products with long half lives liberated during dissolution of the fuel are ^{85}Kr, ^{129}I and ^{3}H. The ^{85}Kr and ^{129}I can be trapped and stored although no satisfactory method for disposal of ^{129}I with a half-life of 1.6×10^{7} years has yet been found (11).

In the USA no commercial fuel reprocessing plants are currently operating. Nuclear Fuel Services ceased operation in 1971 to upgrade its waste treatment facilities and increase capacity but a recent decision has been taken by Getty Oil, the parent company, to close it down. The G.E. Midwest plant constructed near Chicago had problems of such a magnitude during the testing phase that it would be uneconomic to proceed further. The site is being used for spent fuel storage. The Allied Gulf plant at Barnwell, S.C. has applied for an operating license and NRC is planning public hearings.

AECL has proposed to the Commission that reprocessing of CANDU fuel and disposal of highly radioactive waste can be incorporated into one site (12). The wastes would be fixed in glass by the nepheline syenite process (13) and buried in a deep disposal well on site. This procedure carries with it inherent difficulties as a result of the volatility of some of the radionuclides in the dissolution of the spent fuel. Although those wastes that are concentrated in the glass would probably be as safe as burying unprocessed fuel, this would not be the case for volatile radionuclides such as ^{3}H, ^{129}I, ^{137}Cs, ^{106}Ru and ^{85}Kr which are released during the reprocessing. This disposal problem faces every country with a nuclear program and no practical solution has yet been found.

Fuel reprocessing should not be instituted in Canada until it has been demonstrated elsewhere that technology is available to ensure releases of radionuclides to the environment are as low as from power generation. Furthermore, the demonstration of safe disposal of the vitrified high-level wastes in geological formations must be undertaken. The stability of the geological formations under consideration, with particular emphasis on the hydrogeological characteristics of the rocks, are key factors to be studied.

8.2 Thorium Cycle

One of the added advantages of the high neutron economy of the CANDU reactor is the possibility of absorbing excess neutrons in the fertile element thorium to produce fissile ^{233}U. Once a sufficient ^{233}U inventory has been produced for a given electrical installation capacity the thorium cycle is self-sufficient. This is an attractive fuel cycle because it decreases dependence on security of uranium supply without having to go to fast breeder technology. It does, however, require fuel reprocessing to remove fission products which build up and reduce reactivity by parasitic neutron capture. The use of thorium as a fuel, therefore, should not be instigated until the environmental effects of fuel reprocessing have been minimized.

8.3 Fusion Power

The development of electrical power from nuclear fusion processes will create fewer environmental problems than from fission. The reaction under investigation exclusively at present in world fusion research centres is that of deuterium and tritium nuclei interacting to produce helium-4 and a neutron, and releasing energy. This reaction will proceed at the lowest temperature of any fusion reaction but is still very high at about $4x10^7$ degrees Kelvin. Two approaches are being taken to raise the materials to this temperature. One is by magnetic constriction of a gaseous toroidal plasma in a "Tokamak" and the other is by inertial constriction using a laser beam to irradiate pellets containing tritium and deuterium. In both cases the tritium feed is produced in situ from lithium which releases tritium through reaction with the neutrons emitted during fusion.

The recent announcement (March, 1977) from USERDA that their Los Alamos Laboratory had achieved D-T fusion with a high energy CO_2 laser implies that fusion generating stations could be available by the year 2000.

The direct environmental impacts of electrical generation from fusion power are fewer than from fission power. There would be less impact from mining lithium ore than uranium as there are no radiological effects, however, D_2O production would still be required to provide deuterium feed. Like the CANDU reactor, there would be a high inventory of tritium in a fusion reactor, leading to the reasonable assumption that releases of this radionuclide to the environment would also be high. The primary coolant of this type of reactor would probably be a liquid metal because of the high power density. Impurities in the metal would become radioactive due to activation in the intense neutron flux and would require periodic processing of the coolant and disposal of the radioactive wastes. The advantage that the fusion system has over the fission is that the quantities of higher level wastes for ultimate disposal are much lower and their radioactive half lives are much shorter.

It is unlikely, however, that the intense neutron flux in the fusion reactor will be wasted but in order to make fusion power competitive will be moderated by deuterium and absorbed by a fertile blanket of thorium to provide ^{233}U for fission reactor fuel. Thus, the indirect effects of fusion power could be the reprocessing of irradiated thorium and the production of further fission product wastes arising from use of the ^{233}U in the CANDU thorium cycle.

Future design of fusion power reactors should not be such that the fission power era is extended through utilization of the neutron flux for fissile nuclide production.

9. GENERAL ENVIRONMENTAL CONCERNS OF NUCLEAR POWER

The primary concern of the people of Canada regarding the development of nuclear power is the risk to human health from the release of radioactivity to the environment. Quantification of this risk cannot be made very accurately although it can be approached more precisely than for any other toxic substance. ICRP has recommended a maximum permissible whole body dose of 5 rem per year for an employee of the nuclear industry and one tenth of that for the general public. This dose limit has been incorporated into the Atomic Energy Control Act, although guidelines for nuclear facility releases have been issued by the Atomic Energy Control Board which require the licensee to limit these to 1% of the maximum dose at the site boundary. Recent epidemiologic studies of human populations have shown excess leukaemia in Hiroshima survivors exposed to 20-49 rads, increased risk of thyroid cancer to children from a thyroid dose of 6.5 rads and increased risk of leukaemia to children exposed in utero to 0.5 - 2 rads (14). These studies of low-level radiation effects suggest that the current annual maximum exposure limits in the Atomic Energy Control Act are too high and require lowering to diminish the population health risk.

A Federal-Provincial Task Force of radiological protection experts should review current epidemiological studies of individuals receiving doses of less than 50 rem with a view to refining the annual maximum permissible exposure.

The possibility of a proliferation of plutonium weapons from the overseas sales of CANDU reactors and fuel reprocessing plants from other countries has been shown to be real by India's underground explosion of such a device. There is a high probability of this occurring in Pakistan also. If these exports are to continue then safeguard techniques must be developed and international control and inspection through IAEA must be strengthened. Without this control, testing of nuclear weapons will continue with the resulting radiocontamination of the atmosphere ad infinitum.

10. SUMMARY OF CONCERN PRIORITIES

The environmental concerns outlined above arising from the implementation of Ontario Hydro's nuclear power program have different levels of immediacy. Some are critical to the future development of nuclear power and are summarized here in order of priority.

10.1 Fuel Reprocessing

Experience with fuel reprocessing by other nations with nuclear programs has shown that both aqueous and atmospheric radioactive discharges from such plants are invariably high and frequently exceed regulatory criteria. Advanced fuel cycles requiring fuel reprocessing should not be instituted until technology is available to keep radioactive discharges in line with those from the power generation phase of the nuclear fuel cycle.

10.2 High Level Waste Disposal

The problem of disposal of spent fuel from the once-through uranium fuel cycle must be solved before commitment to a large scale nuclear power program is made. Criteria for environmental protection from radioactive releases from the disposed wastes must be developed and the stability of the geological formations used for such disposals against fracture from thermal and mechanical shock demonstrated.

10.3 Uranium Mining and Milling Wastes

The leaching of radioisotopes of radium and thorium from uranium mine tailings by surface runoff made acid by biological oxidation of sulphides in the tailings has contaminated surface water supplies in the Elliot Lake area. Immediate action is required to develop better methods to treat the mill waste streams for radium and thorium removal and fix these radionuclides in the tailings so that they are impervious to leaching by low pH drainage.

10.4 Radioactive Discharges from CANDU Reactors

The continuous discharge of high curie amounts of tritium during normal operation of CANDU reactors will cause locally high levels from rainout and a steady build up in the Great Lakes, especially in Lake Ontario. Atmospheric releases of ^{131}I could contaminate forage, resulting in contaminated milk. Other radionuclides emitted with the condenser cooling water will be concentrated by sediments and biota in the vicinity of the discharge. Programs of environmental agencies for regular monitoring of the environment near nuclear generating stations must be provided with sufficient resources to ensure the continuous evaluation of the effects of the releases.

A realistic evaluation of the consequences of a major accident at a nuclear generating station should be made by involving scientists from the environmental and health agencies along with Ontario Hydro personnel in a joint task force. Such a task force could also design a contingency plan to minimize the environmental effects of a major accident.

10.5 Maximum Radiation Exposure Limits

Recent epidemiological studies of uranium mine workers and nuclear weapon survivors have shown induction of excess cancer cases at integrated dose levels appreciably lower than those that lead to the 1965 ICRP recommendations on annual dose limits. These limits may be too high to give adequate health protection to workers in the nuclear industry and the public at large.

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