Review of the Environmental Impact of Nuclear Energy

by Essam E. El-Hinnawi

Energy has long been viewed as an essential ingredient in meeting man's basic needs and in stimulating and supporting economic growth and the standard of living, so much so that often a nation identifies its wellbeing with its gargantuan and growing need for energy. Statistical data on energy consumption of the world in recent years [1] show that world consumption has increased by about 50% in less than ten years. It has been estimated that the per capita use of energy has more or less doubled during the past 30 years, and current trends indicate that consumption will grow at a faster rate in the future. This increase is a natural result of growing socio-economic activities and the rising standard of living.

The increasing global demand for energy has hitherto been met to an increasing extent by the use of fossil fuels and hydro power. Nuclear energy has been developed and used commercially for about two decades to meet a fraction of the electrical energy needs. The total installed nuclear generating capacity in the world in 1976 was 79.9 GWe from 187 power reactors operating in 19 countries [2].

Table I summarizes that most recent estimates of possible nuclear generating capacity at the turn of the century. The estimates demonstrate the wide range of possibilities, which is wider after 1985, because of possible changes in rates of growth of economic activity and a variety of other considerations that may affect the rate of commissioning of nuclear power stations. Using the IAEA estimates, nuclear energy will contribute about 11–13% of the total electricity generating capacity in the world in 1985 and about 17–20% in the year 2000.

At the local and in some cases regional level, the environmental aspects of energy production and use have become of paramount importance and have served as warnings of what could be in store on a wider scale if serious consideration is not given to the environmental implications of man's demands for energy. From recent examinations of the impact of energy on the environment, it has become apparent that individual nations are not isolated in this respect and that the actions of one country may well result in environmental damage in a neighbouring State. Against this background, an awakened public awareness of the issues has demanded that an attempt be made to examine rationally the environmental aspects of the energy-related society. Although nuclear power stations do not emit fly-ash or noxious gases into the atmosphere as fossil-fuel-operated plants do, the radioactivity released from the products of nuclear fission has been the main focus of public concern about the expansion in the use of nuclear power despite the stringent control measures and precautions taken There have been many attempts to set up acceptable levels for radioactivity in the environment or in man, and although the ICRP recommendations are generally accepted in evaluating occupational hazards, their extension to large populations and the environment as a whole has been subjected to extensive criticism.

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ENVIRONMENTAL IMPACTS OF THE NUCLEAR FUEL CYCLE

Today, the dominant reactor type uses enriched uranium-oxide fuel, and is moderated and cooled by water. The water may generate steam directly in the reactor (BWR) or may transfer its heat to an external steam generator (PWR). Besides these light-water reactors (LWR), other types based mostly on the use of graphite of D_2O as moderator have been developed. Experimental or prototype systems include the plutonium recycle reactor, where plutonium makes up part or all of the fuel, and the fast breeder reactor (e g LMFBR), where the fuel is a mixture of plutonium oxide and natural or depleted uranium oxide The latter type of reactor is designed to produce more fissile material, usable as reactor fuel, than it consumes

The 'nuclear fuel cycle' refers to the entire programme from the mining and milling of uranium, through the manufacture of fuel elements for the reactor, transport and reprocessing of irradiated fuel, to the management of wastes produced in all steps of the cycle The environmental impacts associated with all these steps are reviewed in this paper.

Uranium mining and milling

The uranium production in 1975 was about 26 000 tonnes and will, it is estimated, reach 40 000 tonnes in 1980 [4, 6–8] Current projections show that demand for low-cost uranium fuel will surpass uranium production capacity by 1985. The cumulative uranium requirements are estimated to be about 0 8–1 million tonnes in 1990 and 2–3 million tonnes by the year 2000 [6, 8] There is at present no consensus as to whether low-cost uranium to this amount actually physically exists in the uppermost part of the earth's crust from which it could be economically produced. In any case accelerated efforts for the exploration and exploitation of new resources to meet the projected increasing demands of the nuclear industry seem inevitable [6, 9].[1]

Uranium ores are mined by underground, surface or solution mining depending on the geological setting of the ore. For a 1000-MWe nuclear plant (LWR), about 50 000–80 000 tonnes of uranium ore (0 2% U content) are required. Over the lifetime of a plant, about 30 years, the figure will be about 1 5 million tonnes This corresponds to the need for mining about 1000 acre-feet of uranium ore as compared to about 50 000 acre-feet of coal for a coal-fired plant of the same capacity [10] [2]

Table I: Estimates of nuclear generating capacity (GWe) for the years 1985 and 2000

Year	OECD [3]	OECD – NEA/IAEA [4]	USERDA [5]	IAEA [6]
1985	538–700	479–530	390–488	350–400
2000	2800–4100	2005–2480	1695–2250	1500–1800

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[1] The situation is similar in the case of other metals used in the nuclear industry (e g zirconium, boron, cadmium, graphite) Appropriate management of these resources is needed to satisfy the increasing needs of the nuclear and other industries

[2] *An acre-foot is the volume of liquid or solid required to cover one acre to a depth of one foot*
One acre = 4 047 X $10^3 m^2$, one foot = 3 048 X 10^{-1}m

The environmental impacts associated with uranium mining can be classified into impact on land and water (through spoil and waste water arising from mine drainage and/or from water used in drilling) and occupational health hazards Radon produced by the radioactive decay of ^{226}Ra found in the ores has been considered a major factor in increasing the cancer incidence amoung uranium miners [11–14] Exposure is normally controlled by either natural or artificial ventilation and is kept within the permissible limits of radon concentration Control of dust generated in the mining processes is also necessary to prevent exposure to hazardous levels of silica as well as radiation

It should be noted that the environmental impacts and occupational hazards associated with coal mining (to operate a 1000 MWe plant), tend to be more significant than those associated with uranium mining (to operate a plant with the same capacity). Accidental mining fatalities per coal plant exceed those from nuclear plant by a factor of three [15]. The number of 'environmental deaths' among coal miners (from pneumoconiosis) is much higher than in the case of miners in the uranium industry

In the milling process, about 70% of the total radioactivity contained in the ore fed to the mills remains undissolved in the solid mill tailings [16]. The environmental effects of tailings piles include: wind erosion to unrestricted areas, river pollution from piles located near river banks, or from water level rising during flood conditions to the base of the piles causing leaching of radium from the material and percolation of water through piles into groundwater [17]. Studies [17–22] have shown that the tailings piles must be stabilized against wind and water erosion for very long periods (dictated by the radioactive half-life of 1620 years for ^{226}Ra). Because of the radon emanations from the radium in the mill tailings, this material should not be used either in structural materials or in backfill material in connection with buildings intended for human occupation, and equally such buildings should not be constructed in the proximity of mill tailings piles

Fuel fabrication

The main potential hazard in the fuel fabrication process arises from the toxicity of hydrogen fluoride and fluorine used in the production of uranium hexafluoride. Safe methods of handling these chemicals are, however, well-established in the fluorochemical industry. The UF_6 produced is a highly corrosive gas as passed through enrichment plants, but a solid at room temperature, and can be safely packaged in steel cylinders. It is at the point of discharge from the conversion operation as UF_6 that material in the fuel cycle passes into the Non-Proliferation Treaty safeguards system set up by the IAEA. Under these safeguards, nuclear material in all subsequent operations of the cycle must be physically accounted for with great precision.

As the level of uranium enrichment increases, so too does the risk of accidental agglomeration of sufficient quantities of ^{235}U to set off a chain reaction. Although criticality accidents are very unlikely to occur, great care is needed to ensure that such events never occur. The depleted uranium residue from enrichment plants is normally stockpiled for possible future use as a fertile component of reactor fuel. This material is mildly radioactive, and gradually produces the much more hazardous nuclides ^{226}Ra and ^{222}Rn Production of these nuclides is, however, very slow and any radiation hazard from the stockpiles is controlled by limiting access to the area.

The production of uranium dioxide fuel elements is now a well-established procedure which seems to be free of appreciable hazards. Manufacture of mixed-oxide fuel is, however, much more complicated. Hazards arise from the toxicity of plutonium and from the fact that the 'critical mass' of plutonium dioxide in which chain fission reactions can start up is only a few kilograms. However, normal operational hazards of mixed-oxide fuel production are not difficult to manage.

Reactor operation

During the normal operation of a nuclear reactor, radioactive fission and activation products are produced. These radioactive materials are for the most part retained within the fuel elements. Radionuclides which diffuse into or are formed within the cooland are removed by the gaseous and liquid waste-processing systems Low-level releases, which occur during normal operation, are closely regulated to ensure that authorized release limits are not exceeded.

Radioactive releases from reactors depend on the reactor type and on the specific waste-processing systems utilized. Radionuclides which diffuse into or are formed within the coolant are removed by the gaseous and liquid waste-processing systems Low-level releases, which occur during normal operation, are closely regulated to ensure that authorized release limits are not exceeded.

Radioactive releases from reactors depend on the reactor type and on the specific waste-processing systems utilized Radionuclides released in the airborne effluents consist essentially of: noble gases (^{133}Xe), activation gases (^{41}Ar, ^{14}C, ^{16}N and ^{35}S), tritium vapour and gas, halogens and particulates The dose rates associated with the releases of ^{14}C are very low, yet with its long half-life (5730 years) it makes a significant contribution to the collective dose [23–26] Similarly, the increasing release of tritium (mainly as tritiated water HTO) to the atmosphere calls for detailed studies and periodic assessment of the environmental impacts of these releases, involving chronic exposures at very low exposure levels [27] Discharges in the liquid effluents include tritium, ^{137}Cs, ^{134}Cs, ^{131}I, ^{133}I, ^{58}Co and ^{60}Co besides a number of activated corrosion products such as ^{51}Ch and ^{51}Mn, which are quite prevalent in liquid effluents from LWRs

Compared to the risks from gaseous emissions produced by fossil-fuel-operated power plants, the risks from discharges from nuclear power plants during normal operation are negligibly small However, thermal pollution is considered to be more pronounced with nuclear plants than with fossil-fuel plants. The former reject essentially all their reject heat to the cooling water, while in the latter about 15% of the heat is rejected up the smoke stack along with combustion products [28] In other words, a nuclear power plant will discharge about 50% more waste heat to the receiving waters than a fossil-fuel plant producing the same amount of electricity.

Public concern about reactor operation has concentrated on the possibility of the occurrence of an accident leading to the release of a considerable amount of radioactivity to the surrounding environment. Although various types of accidents are possible during the operation of a nuclear reactor, many safety devices are incorporated into reactor design and operating procedures that will automatically close the reactor down in case of any serious malfunction In addition, most power reactors are placed inside a containment building, the purpose of which is to contain essentially all the radioactivity that might be released in the case of a serious accident However, the efficiency of these safety measures (particularly the emergency core-cooling systems) has met with some criticism [13, 29–31].

Several studies have been made to determine the probability of a major nuclear reactor accident, using information on the failure rate of the various engineering components of the reactor. The most recent of these studies [32], generally referred to as the Rasmussen report, estimates that a core-melting accident in LWRs has a probability of about 1 in 20 000 per reactor-year, and that 99 out of 100 core-melting accidents would cause no early fatalities. About 1 in 170 core-melting accidents are predicted to cause more than 10 early fatalities, and only one core-melting accident out of 500 is predicted to cause more than 100 early fatalities. The arguments over the adequacy of this study are extensive and complex. Critics questioned the validity of the methods used, the estimation of the risks of accidents and the factor of human error (see, for example, [33–35]). Other critics concentrated on the inadequacy of consideration given by the study to the risks of natural hazards (e g. hurricanes, earthquakes), deliberate sabotage, or war.

Accidents with fast breeder reactors may have more serious consequences than with LWRs. The major concern arises from the theoretical possibility that an FBR core could form a critical configuration if it is melted. Other factors suggested as possibly making them more dangerous are the use of sodium as coolant, the higher energy density, the greater neutron flux and the higher working temperature.

In any case, the consequences of a major accident would depend not only on the amount of radioactivity released to the environment, but upon many other factors: for example, the average age of the fission products, the relative quantity of actinide elements present, the kind of release (e.g. into the atmosphere or to a river), the meteorological conditions and population density in the area, and the rapidity with which remedial measures are taken. Apart from these considerations, the fact that so far there has been no serious reactor accident, and that the estimated probabilities for such an occurrence are very low, make it rather difficult to quantify the environmental impact of possible major reactor accidents.

Complete dismantling of a nuclear power station after its write-off period (usually fixed at 20–30 years) will be difficult and hazardous, because of radioactivity induced in the reactor structure during its operating life. Bombardment by neutrons of the materials used to build a reactor produces a range of radioactive nuclides Some of these emit highly penetrating gamma radiation, and have half-lives of several years. However, the experience gained in decommissioning small power reactors gives some optimism about the possibility of totally disposing of power reactors after their write-off. The environmental consequences of this operation are far from being sufficiently understood

Fuel reprocessing

The spent fuel elements removed from reactors at refuelling are the most intensely radioactive material in the fuel cycle. The main hazard is the enormous amount of gamma radiation emitted by decay of radioactive fission products. The spent elements are removed to deep tanks of water known as cooling ponds, and left there for some time. It is necessary to store them in the ponds in a way that prevents the considerable amount of fissile material present – ^{235}U and Pu – from forming a critical configuration. After the short-lived fission products have decayed to low levels of activity – which takes a few months – the fuel can be reprocessed.

The number of spent fuel elements in storage is growing rapidly and evidently will continue to do so for some time Cooling ponds are satisfactory for short-term storage, but clearly they cannot be a permanent resting place for spent fuel The ponds require continual surveillance and, despite the reduction in radioactivity during storage, the actinides in the spent elements will remain dangerously radioactive for hundreds of thousands of years At a fuel reprocessing plant the spent fuel is chemically dissolved and the residual fuel material recovered. During this process the major portion of the fission products, in addition to induced radioactive products present in the fuel cladding, is converted into solid and liquid waste material. Up to the present time, fuel reprocessing plants have been the major source of radioactive environmental contamination from the nuclear industry

The gaseous fission products contained in the fuel elements, notably ^{85}Kr and ^{129}I, are released from the fuel pellets during reprocessing. Tritium and volatile compounds of ^{14}C are also released. Much of the radioactive material is removed from the effluent gases, but ^{85}Kr (half-life 10.8 years) and tritium (half-life 12 3 years) are vented into the atmosphere from existing plants. Most of the output of these two gases will almost certainly have to be removed from stack emissions if radiation standards are to be maintained when large-scale oxide fuel reprocessing begins

Low-level liquid waste, eventually discharged to the environment, also arises in reprocessing. Generally, most of the small quantity of tritium is discharged with this waste. Improved methods of storage or disposal of this waste have to be developed Reprocessing plants also produce intermediate and low-level solid wastes Reprocessing the fuel used in one year by a 1000 MWe LWR would produce some 20–60 m^3 of such wastes. The main component of the intermediate-level solids is fuel cladding material, radioactive to a degree depending on its composition and irradiation history It is contaminated with small amounts of spent fuel. Up to now, most waste of this kind has been buried on land or placed in canisters and dumped in the ocean. The OECD/NEA is currently supervising the disposal of 7000 t/a at a depth of 4500 m in the Atlantic Ocean [36, 37]. Other methods of disposal include deep burial in abandoned mines or in suitable geological formations [38, 39]

The high-activity wastes arising from the reprocessing of spent fuel are estimated to reach 20 000 m^3 by 1990 [22]. These wastes contain over 99% of the fission products present in the fuel together with smaller quantities of actinides. High-level wastes are at present stored mainly in liquid form, and some constituents will remain dangerously radioactive for

Table II: Number of shipments in the nuclear fuel cycle projected to the year 2000 [40]

	Shipments/year in		
	1980	1990	2000
Fuel	670	2500	5 400
Spent fuel	2000	6400	12 000
Plutonium	20	143	438
Wastes and fission products	630	2450	5 500

several hundreds of thousands of years. There is at present no generally accepted means by which high-level waste can be permanently isolated from the environment and remain safe for very long periods. Processes for the conversion of high-level waste to a relatively inert solid have been developed [22] Permanent disposal of high-level solid wastes in stable geological formations is regarded as the most likely solution, but has yet to be demonstrated as feasible. It is not certain that such methods and disposal sites will entirely prevent radioactive releases following disturbances caused by natural processes or human activity.

Marine disposal of high-level radioactive wastes has been extensively restricted by international and regional conventions which are binding on many countries with nuclear power industries. Disposal in Antarctica is prohibited by treaty.

Transport of radioactive material

One important side of the nuclear industry is the safe transport of radioactive materials. The facilities involved in the nuclear fuel cycle are generally geographically dispersed even within one country, and radioactive materials in various forms have to be transported to and from such facilities. The volume of transport of radioactive materials has grown and will continue to grow in step with the growth of the nuclear power industry Radioactive materials arising in the nuclear fuel cycle are generally transported by surface either by truck or rail and sea. Transport by air is commonly used for small quantities required for medical and research purposes. The estimated number of shipments in the nuclear fuel cycle in the United States of America is given in Table II (for LWRs, HTGRs and LMFBRs).

The transport of radioactive ore from mine to mill under normal or accident conditions is unlikely to result in environmental effects of any consequence. Similarly the transport of the mill product, i e. the 'yellowcake', or the subsequent transport of UF_6 and UO_2 contained in suitable transport containers are not likely to result in any environmental effects.

The fuel elements are shipped in packages designed to prevent accidental criticality even under severe accident conditions. The radioactivity of the new unirradiated fuel can have essentially no impact on the environment, and very little on individual transport workers under normal conditions. Even in an accident the physical properties and the low specific activity of the fuel would limit radiation effects to very small levels. Theoretically, accidental criticality may lead to significant adverse environmental effects. Dose equivalents in excess of 500 rem to individuals in the immediate vicinity might result, and the immediate area would require a thorough and perhaps costly decontamination. However, by means of strict controls and authoritative standards for container design and construction, the possibility of reaching criticality during transport is practically eliminated.

Spent fuel elements are transported in shielded air- or water-cooled casks weighing 20 tonnes or more. The heavy shielding of the casks must reduce the radiation from the spent fuel elements inside to pre-established levels of the IAEA regulations or else the casks must be sent under special arrangements. Under normal transport conditions the radiation dose exposures to transport workers should be kept within permissible values by the limitation of the radiation around the containers. If the workers are handling substantial numbers of shipments it may be necessary to make surveys and introduce additional control measures such as job rotation. A severe accident in which the cask walls are ruptured, resulting in a loss of content, might have severe impacts on the public and the environment, but the possibility of such rupture is minimized by strict adherence to the regulatory requirements regarding design, construction testing and approval of the casks.

Low-level radioactive wastes are packaged in sealed containers such as 55-gallon steel drums and are shipped by common carrier to burial grounds. Solidified high-level radioactive wastes will be shipped to retrievable storage sites, such as geological formations, salt mines or surface storage facilities, in containers resembling the casks utilized in shipments of spent fuel.

Packaging and transport of radioactive materials are regulated by international as well as national transport regulations. The IAEA has published regulations for the safe transport of radioactive materials, and these have been adopted by virtually all international transport authorities and taken by most Member States as the basis of their own regulations Substantial continuing effort is being made by the IAEA to keep its regulations for the safe transport of radioactive materials technically up to date and to encourage their adoption and implementation

The plutonium issue

Plutonium-239 (which is not separable from the other Pu isotopes) is the isotope of greatest concern, it is the type used in atom bombs and constitutes at least 70% of the total amount of plutonium produced in power reactors. It has a half-life of 24 400 years Much evidence points to the relatively great quantities of plutonium which would be generated and processed in a major world nuclear power programme, particularly if fast breeder reactors are widely adopted. At present, about 20 tonnes are produced each year, most of which remains in unprocessed form in spent fuel rods By the year 2000, the annual production could be several hundred tonnes.

Only about 6 kg of ^{239}Pu is needed in metal form to produce a chain reaction, perhaps 9 kg as PuO_2, and slightly larger amounts of reactor-grade plutonium containing various plutonium isotopes The danger exists that if sufficient plutonium of reactor grade came together inadvertently, possibly during reprocessing of fuel fabrication, a chain reaction could occur with consequent emission of a powerful pulse of lethal radiation, and dispersion, possibly violently, of the plutonium. Strict control measures are routinely applied and have so far proved effective

Regarding the toxicity and carcinogenic effects of plutonium, there have been a number of contradictory views (see, for example, [41–43]). Plutonium is highly toxic, its absolute toxicity is comparable to that of biological toxins [43] However, the latter are unstable like most proteins, boiled in solution they lose their activity in a few minutes Plutonium, on the other hand, remains a hazard for periods up to some 20 times its half-life, or nearly half a million years Unlike toxins, plutonium acts slowly, small carcinogenic doses in the lungs may not produce cancer for 10, 20 or 40 years (Some pollutants have also long latency periods and do not easily decay) Several authors have therefore called for a revision of the ICRP maximum permissible dose of 40 nCi of ^{239}Pu

NUCLEAR SAFEGUARDS AND ENVIRONMENTAL PROTECTION

During the entire fuel cycle, including transport of nuclear material, strict vigilance and care must be ensured, both on national and international levels, so that nuclear material does not fall into unauthorized hands which may use it for uncontrolled activities leading to damaging effects either on general population or the environment An enormous effort is therefore required, both nationally and internationally, to prevent any diversion of nuclear material or sabotage of nuclear installations.

The establishment and implementation of a physical protection system at the national level is the primary responsibility of the Government and is closely connected to its national system of accounting for and safeguarding and control of nuclear material. This system has to cover the nuclear material in use, storage, and transport throughout the entire fuel cycle both nationally and internationally. At the international level, the IAEA has initiated and implemented a nuclear safeguards system.

The system established under the Non-Proliferation Treaty (NPT) is the most widely applied and, in most respects, appears to be the most effective. However, the main limitations and weaknesses of the present safeguards arrangements which give cause for environmental concern can be summarized as follows: the failure of many States to become parties to the NPT, the inability of safeguards to prevent the transfer of nuclear technology from nuclear power production to the acquisition of nuclear weapons competence; the fact that many nuclear facilities are covered by no safeguards; the existence of a number of loopholes in safeguards agreements regarding their application to peaceful nuclear explosions, to materials intended for non-explosive military uses, and to the re-transfer of materials to a third State, the absence, in practice, of safegaurds for source materials, the practical problems of maintaining effective checks on nuclear inventories, the ease with which States can withdraw from the NPT and from most non-NPT safeguards agreements, deficiencies in accounting and warning procedures, and the absence of reliable sanctions to deter division of safeguarded material.

The possibility should not be discounted of diversion of nuclear material through terrorist acts and the risk that the opportunity and the motive for nuclear blackmail will develop

Measures designed to prevent theft of nuclear materials and attacks on nuclear installations have been tightened in recent years. Welcome as those measures are, the evidence indicates that the risks are real and will tend to increase with the further spread of nuclear technology.

CONCLUSIONS

Table III makes a comparison between the environmental impacts of a 1000-MWe coal-fired power plant and three nuclear plants with the same capacity. The environmental advantages of the reactors are: (1) in the category of effluents, where the reactors are assigned 1200 to 1500 t/a as against the million tonnes of air pollutants coming from coal-fired plants, and (2) in land use, where the 300 to 400 acres of space which is needed for a coal-fired plant is compared with 70 to 140 acres for a nuclear plant and the 200 acres per year which must be stripped for the coal is compared with 13 acres of uranium strip-mining for the LWBR and much less than 1 acre for the LMFBR. The cooling-water needs are about even for the LMFBR and coal plants and 40 to 50% higher for the LWBR However, the effect of pollutants is not measurable by weight or volume. It is the interaction with the things vital to life that determine the extent of the damage. It is true that non-nuclear wastes and pollutants affect man and his environment and some may have genetic effects but in the case of radioactive wastes, the damage would be more potential and not easily reparable

Although some countries have slowed down their nuclear energy programmes, the abandonment of nuclear fission would, however, be neither wise nor justified [45] It is important at this stage of nuclear power development that increased efforts should be devoted to detailed in-depth studies of the different environmental impacts associated with all steps of the nuclear fuel cycle, to develop adequate measures for ensuring the protection of man and his environment.

Table III: Environmental effects of 1000-MWe generating plant [44]

Type	Coal-fired	LWBR	HTGR	LMFBR
THERMAL				
Btu/s[a]				
to be dissipated	1.49×10^6	1.93×10^6	1.43×10^6	1.31×10^6
EFFLUENT				
Radioactivity				
(10^3 Ci/a)	–	2253	2	2
AIR POLLUTION				
(t/a)				
SO_2	45 000	1500[b]	1200[b]	–
NO_x	26 000	900	700	–
CO	750	25	20	–
Particulates	3 500	120	95	–
HC	260	9	7	–
WASTES ($10^3 ft^3/a$)[c]				
Radioactive	–	12	10	8
Ashes	200	7[b]	5[b]	–
LAND				
Acres mined	200	13	9	0.05
Plant sites (acres)	300–400	◄———	70–140	———►

[a] 1 Btu = 1054×10^3 J

[b] The emissions charged to the reactors are computed from the electric energy used in enrichment

[c] 1 ft^3 = 2832×10^{-2} m^3

The United Nations Environment Programme has been concerned with studies on the environmental impacts of all sources of energy At its fourth session (1976), the Governing Council of UNEP requested the preparation of in-depth studies on the environmental impacts of fossil fuels, nuclear energy and renewable sources of energy. These studies, which are carried out in co-operation with UN bodies concerned and other organizations, will provide a comprehensive comparative assessment of these impacts with the main goal of identifying a priority list of inadequacies in knowledge for further research and development

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