United Nations Environment Programme

Distr.
GENERAL

UNEP/GC/61/Add.1
2 January 1976

Original: ENGLISH

Governing Council
Fourth session
Nairobi, 30 March-14 April 1976
Item 7(b) of the provisional agenda

REVIEW OF THE IMPACT OF PRODUCTION AND USE OF ENERGY ON THE ENVIRONMENT

REPORT OF THE EXECUTIVE DIRECTOR

CONTENTS

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PREFACE

The field of energy is an extensive one involving a variety of activities of different specialists - economists, politicians, physical scientists and engineers, among others. The United Nations system has been involved in nearly every aspect of energy development: the activities of the various organizations of the United Nations working in this field include exploration and assessment of energy resources, energy conversion, utilization and conservation, energy supply and demand, energy policy and legislation, etc. 1/. Apart from conventional fuels and technologies, attempts have been made for many years to foster interest in less conventional forms of energy such as geothermal, solar, wind and tidal energy. The activities of the United Nations Development Programme (UNDP), the Centre for Natural Resources, Energy and Transport and the United Nations Educational, Scientific and Cultural Organization (UNESCO) in these fields are well documented. In the field of nuclear energy, the International Atomic Energy Agency (IAEA) has undertaken extensive studies of the peaceful uses of nuclear energy in different fields, besides the formulation of measures for safety control and protection of the environment against radioactive hazards.

The United Nations Environment Programme (UNEP) has the primary role of supporting and initiating studies to define the impact on the local, regional and global environment of the extraction, processing, transportation, conversion, transmission and use of various forms of energy. To this end, UNEP emphasizes the role of the Global Environmental Monitoring System (GEMS) in the monitoring of global pollutants arising from the production and use of energy. Furthermore, UNEP is co-operating with other international organizations, for example with the World Meteorological Organization (WMO) and the World Health Organization (WHO) on the impact of energy production and use on climate and human health respectively and with IAEA on the environmental impact of nuclear energy production and use. UNEP is also supporting research and development efforts within and outside the United Nations system for the harnessing of renewable sources of energy which promise to have environmentally advantageous characteristics 2/.

At its first session, the Governing Council of UNEP requested the Executive Director to collect for presentation to the Governing Council detailed information on the problem of the world's energy crisis. At its second session it specified that the results of the sixth special session of the General Assembly should be taken into account in this task, and in the development of programme proposals for the environment programme, which should concentrate on the environmental consequences of alternative

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1/ See document E/C.7/47/Add.3 (1975) for a general account of the activities of the United Nations system in the field of energy.

2/ See document UNEP/GC/31/Add.1 (1975) for the role of UNEP in the field of energy.

patterns of energy generation and use and be carried on in close co-operation with the United Nations bodies concerned and with IAEA. In response to these two decisions the Executive Director has undertaken, with the assistance of a consultant, the preparation of a "Review of the impact of energy production and use on the environment and the role of the United Nations Environment Programme".

The first draft of this review was submitted for scrutiny to an international panel of experts which met in New York from 24 to 26 February 1975. The panel considered that since the issues dealt with in the review were complex and controversial and there were a number of gaps which needed to be filled, the document required exhaustive revision.

At its third session, the Governing Council of UNEP requested the revision of the review and its finalization by an expanded international panel of experts. The present report 3/ represents the rewritten review which was examined and finalized by an international panel of experts which met in Nairobi from 10 to 14 November 1975. In this report, emphasis is placed on the environmental impact of the production and use of various energy resources. A system analysis approach has been more or less used so that the environmental impact of each step in the energy production-utilization system is assessed.

3/ This report was written by Professor Essam El-Hinnawi, Natural Resources and Energy Consultant, UNEP. Chapter III, on nuclear energy, was written in co-operation with IAEA. The report does not deal specifically [illegible] UNEP in this respect, see footnote 2/.

CHAPTER I: INTRODUCTION

1. Energy is one of the most important prerequisites of life. Without energy our entire civilization - transportation, industrial manufacturing, commercial activity and food production - would come to a standstill. Since prehistoric times, human society has been consuming a constantly increasing amount of energy. A rapid increase in energy consumption started in the middle of this century; statistical analysis of data for the period between 1925 and 1950 shows that the average annual percentage rate of change in total energy consumption was 2.2 per cent. In the following ten years, from 1950 to 1960, the figure was 4.9 per cent and, in the following decade, it reached 5.6 per cent. The total energy consumption of the world in recent years is given in Table 1., together with the calculated per capita consumption. This shows that world consumption has increased by about 50 per cent in less than 10 years. The same is nearly true for per capita consumption. This increase is a natural result of growing socio-economic activities and the rising standard of living. 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.

2. Despite the enhanced standard of living which has made possible the greater use of energy, man has become increasingly aware that he is required to pay an associated price in the form of deterioration of the environment in which he is forced to live. At local and in some cases regional levels 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 examination 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. This study is an attempt to assess the order of magnitude of the various issues involved and to indicate in broad terms those aspects of energy development which deserve special attention if the global environment is not to be further degraded.

Table 1. WORLD ENERGY CONSUMPTION

Year	World consumption in million metric tons of coal equivalent	Per capita consumption (in kilogrammes)
1965	5213	1588
1966	5512	1648
1967	5605	1645
1968	6015	1733
1969	5399	1809
1970	6820	1892
1971	7084	1932
1972	7410	1984
1973	7797	2050

Source: After "United Nations Statistical Yearbook, 1974" (United Nations publication, Sales No.: E.75 XVII. 1).

3. The expansion of energy consumption has been an important factor in reducing poverty through the broadening of economic opportunity and growth. Although there are anomalies in the amounts of energy required in different countries to achieve a given level of gross national product (GNP), there is nevertheless a rather consistent relationship between GNP and energy consumption (Fig. 1). This close relationship has been valid historically, and analysis indicates that the correlation coefficients are uniformly and consistently high. Thus, as a country's GNP in real terms rises over time, its energy consumption goes up as well. However, the correlation between the two parametres should be interpreted with some caution. For example, the structure of the economy will affect the correlation between GNP and energy consumption; the rate of increase of GNP and energy use is somewhat similar for energy-intensive exports, but for non-energy intensive exports, GNP increases at a much faster rate than energy use. Furthermore, the variations in the relationships between GNP and energy consumption for different countries are due to numerous factors. Climate, for example, plays a direct part in the primary energy requirements of a country. For the same income levels, a colder region will consume more energy due to heating requirements than a more temperate region. The types of industry dominant in a country also have a significant impact on energy requirements. Furthermore, the mode of generating electricity is also of prime importance. Some countries using lignite, which because of its poor combustion properties is thermally a rather inefficient material for electricity production, have high primary energy consumption in relation to their GNP. It should be noted that, although for the last two decades the consumption weight of the less developed countries in the world energy balance has increased markedly, the disparity between the developed countries and the developing countries in terms of energy consumption is still very large.

4. This increase in world energy consumption has been accompanied by an increase in the production of primary energy resources, made possible through extensive advances in prospection and production technology. Table 2 gives the annual production of primary energy resources since 1965, and shows that total primary energy production has increased by about 50 per cent in less than 10 years (i.e. at nearly the same rate as energy consumption). It should be also noted that oil and gas production has appreciably increased (by about 50-60 per cent), while coal production has remained nearly constant. Recent estimates of the proven recoverable amounts of primary energy resources of the world are given in Table 3. It should be noted that accurate estimates are difficult to obtain, since the economics of recovery must also be considered, the estimates given in Table 3 must therefore be taken as only tentative. Recent exploration efforts have revealed the presence of extensive resources of oil and gas offshore and on the outer continental shelves of many countries. Furthermore, extensive oil deposits are known to exist in rock shales and tar sands, awaiting the proper technologies for their extraction. The same is true for the renewable sources of energy (solar, geothermal, tidal, sea-thermal, etc.), which have a tremendous potential.

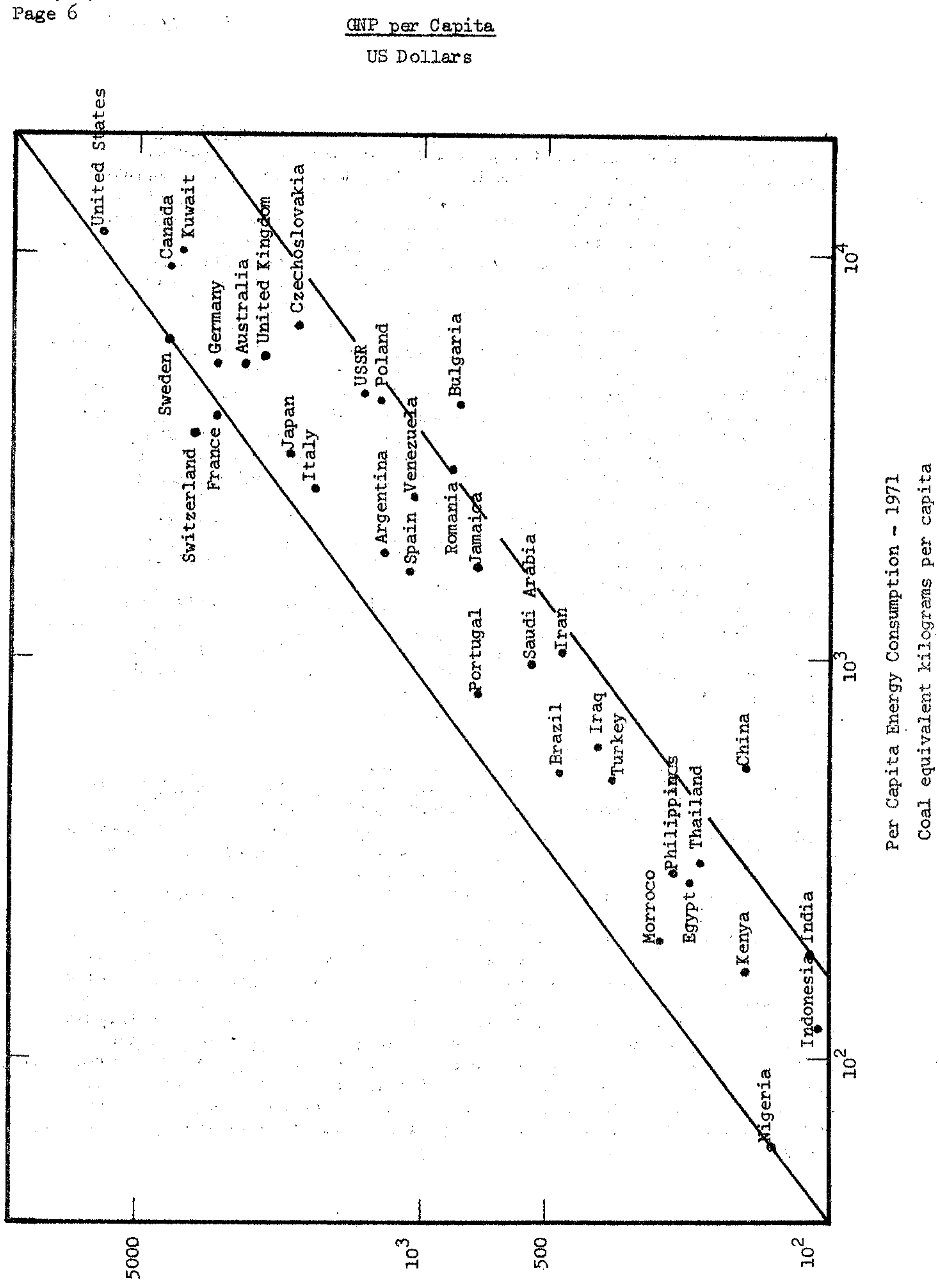
GNP per Capita
US Dollars
5000
10^3
500
10^2
10^2
10^3
10^4
Per Capita Energy Consumption - 1971
Coal equivalent kilograms per capita
United States
Canada
Kuwait
Sweden
Germany
Australia
United Kingdom
Czechoslovakia
Switzerland
France
Japan
Italy
USSR
Poland
Bulgaria
Argentina
Spain
Venezuela
Romania
Jamaica
Saudi Arabia
Portugal
Iran
Brazil
Iraq
Turkey
China
Morroco
Philippines
Egypt
Thailand
Kenya
India
Indonesia
Nigeria

Figure 1.

Table 2. PRODUCTION OF PRIMARY ENERGY RESOURCES

(quantities in million metric tons of coal equivalent)

Year	Total energy	Coal	Oil	Gas	Hydro- and Nuclear
1965	5318	2268	2001	931	117
1966	5623	2310	2172	1014	128
1967	5759	2207	2329	1092	132
1968	6144	2274	2543	1189	138
1969	6512	2326	2736	1302	148
1970	6989	2394	3002	1436	157
1971	7257	2392	3169	1529	167
1972	7566	2430	3340	1616	179
1973	8027	2486	3657	1695	189

Source: After "United Nations Statistical Yearbook, 1974".

5. The most important questions to be asked in any energy study are: will it be possible to ensure an adequate supply of energy over the long-term? and what are the limits of the environmental problems occasioned by the ever-increasing production and consumption of energy?. The Ford Foundation, in its 1974 study of energy policy in the United States (156), 4/ identified three main scenarios for energy growth, namely, the historical growth scenario, the technical fix scenario and the zero growth scenario. The first assumes that energy consumption will continue to grow till the end of this century at about 3.4 per cent annually. It assumes that no deliberate effort will be made to alter our habitual patterns of energy use, but that instead, a vigorous national effort will be directed toward enlarging energy supply to keep up with rising demand. The technical fix scenario reflects a conscious national effort to use energy more efficiently through engineering know-how, by putting to use the practical, economical, energy-saving technology that is either available now or soon will be. The zero energy growth scenario includes all the energy-saving devices of the technical fix scenario, with extra emphasis on efficiency. Its main difference lies in a small but distinct redirection of economic growth, away from energy-intensive industries toward economic activities that require less energy. An energy excise tax, by making energy more expensive, would encourage this shift. It is assumed that after 1985 this scenario could permit the use of clean renewable sources of energy (e.g. solar energy, wind energy, etc.).

4/ This and subsequent parenthetical figures in the text refer to the attached bibliography.

Table 3. PRIMARY ENERGY RESOURCES OF THE WORLD

	FOSSIL FUELS						HYDRO RESOURCES		NUCLEAR FUELS	
	Coal		Oil		Gas					
	$\times 10^6$ tons	per cent of world	$\times 10^6$ tons	Per cent of world	$\times 10^9 m^3$	Per cent of world	Capacity MW	Per cent of world	Uranium tons	Per cent of world
Asia	97,557	16.5	53,972	59.0	12,241	23.3	140,538	25.3	3,813	0.4
Africa	15,628	2.6	12,848	14.0	5,709	10.9	145,218	26.2	272,280	27.6
Western Europe	65,260	11.0	1,020	1.1	4,058	7.7	50,043	9.0	56,684	5.8
Eastern Europe	198,115	33.5	8,512	9.3	17,591	33.5	52,918	9.2	-	-
North America	187,319	31.7	6,644	7.3	10,132	19.3	57,728	10.6	515,066	52.3
South America	2,802	0.5	8,300	9.1	2,108	4.0	95,628	17.4	15,682	1.6
Oceania	24,518	4.2	229	0.2	693	1.3	12,987	2.3	120,949	12.3
World	591,199	100.0	91,525	100.0	52,532	100.0	555,060	100.0	984,474	100.0

Source: After "Survey of energy resources", World Energy Conference, 1974.

Table 4. WORLD ENERGY SITUATION IN 1970 AND 30 YEARS LATER

Region or Country	1970			2000		
	Consumption of energy a/	Per cent of the market	kW per capita	Consumption of energy a/	Per cent of the market	kW per capita
Africa	109	1.6	0.29	564	1.6	0.63
Asia	1,043	15.3	0.46	13,378	37.8	3.23
Central America	142	2.1	1.94	1,216	3.4	6.17
North America	2,472	36.3	9.90	7,934	22.4	21.76
South America	112	1.6	0.47	710	2.0	1.37
Western Europe	1,350	19.8	3.44	4,367	12.4	9.04
Eastern Europe	460	6.7	4.04	1,625	4.6	11.69
Oceania	78	1.1	3.67	364	1.0	9.44
Soviet Union	1,055	15.5	3.97	5,242	14.8	14.51
World	6,821	(100)	1.71	35,400	(100)	4.96

Source: After document ECE/Env./R.31 (Economic Commission for Europe, 1975).

a/ Millions of tons of coal equivalent (etc).

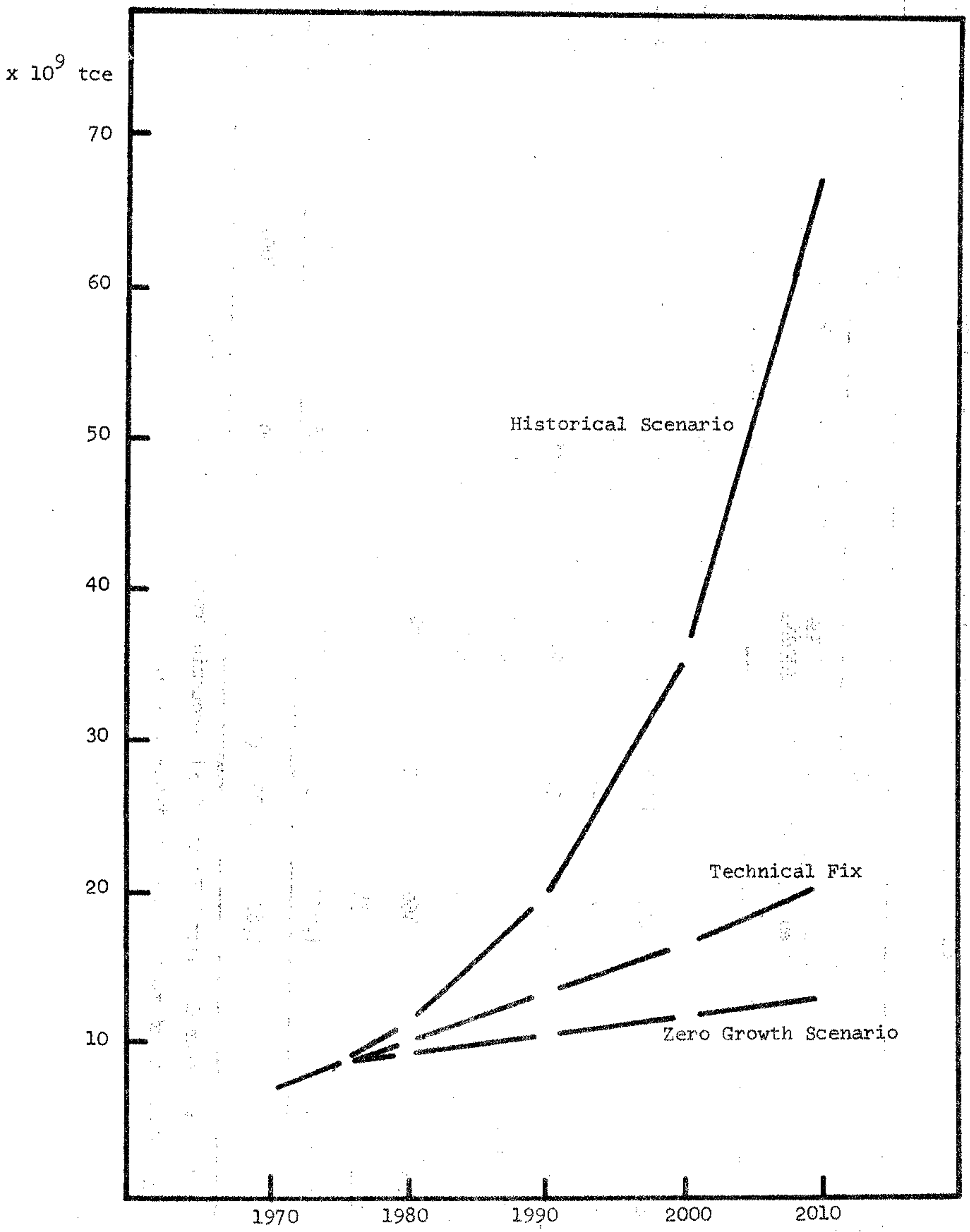
x 10^9 tce
70
60
50
40
30
20
10
Historical Scenario
Technical Fix
Zero Growth Scenario
1970
1980
1990
2000
2010

Figure 2.

6. Table 4 giving the world energy situation in 1970 and in the year 2000 (projected historical growth), predicts that the world consumption of energy in the year 2000 will be about five times that of 1970. One can imagine the excessive demand for energy resources and the excessive burden implied on the environment due to this historical growth. However, if a policy of energy saving based on a technical fix scenario or a policy aimed at zero energy growth by the year 2000 is adopted, a great decrease in energy consumption, compared to the historical growth trend, will be achieved. Table 5 gives the calculated projections of world energy consumption for the three scenarios (see also Figure 2). The average annual energy consumption growth rate for historical growth, technical fix and zero growth is 5.0 per cent, 2.8 per cent and 1.3 per cent respectively.

Table 5. PROJECTIONS OF WORLD ENERGY CONSUMPTION
(in million tons coal equivalent)

Year	Historical growth	Technical fix scenario	Zero energy growth
1970	6,821	6,821	6,821
1980	11,247	10,181	9,236
1990	19,606	13,163	10,642
2000	35,672	16,656	12,040
2010	67,967	20,600	13,328

Source: Compiled from document ECE/Env./R.31 (1975).

7. It is desirable, technically feasible and economical to reduce the rate of energy growth in the years ahead, at least to the level of the technical fix scenario. Such a conservation-oriented energy policy would provide benefits in every major area of concern - avoiding shortages, protecting the environment and keeping real social costs as low as possible. The future rate of growth in GNP is independent of this energy conservation policy, GNP could grow at essentially historical rates, while energy consumption grew at the technical fix scenario level. The great bulk of the savings over historical growth in energy consumption could be achieved by technical fix scenarios in three key areas: construction of buildings to reduce energy needed for heating and cooling, better mileage for automobiles and increasing energy efficiency in industrial plants. To reach the zero energy growth level would necessitate an intensive programme for developing renewable energy sources, such as solar energy and synthetic fuels from organic wastes, which could contribute to these sources taking over a substantial share of energy requirements in the next century. Furthermore, environmental problems, particularly air pollution, would be more easily controlled with slower growth in fossil fuel consumption.

CHAPTER II: FOSSIL FUELS

A. COAL

8. Coal has long been used as an energy source. Although the total energy demand met by coal has declined in some countries (peaks were recorded in the period 1920-1940), coal is regaining its position as an important source of energy. The current energy crisis is fostering a conversion to coal of oil-fired electric power plants, some of which has only recently been converted to oil in order to meet environmental protection standards.

9. The recoverable amounts of coal, together with the calculated tons per capita in the different regions of the world, are given in Table 6. This table gives the actual proven amounts of coal, and it should be noted that future exploration might reveal quite different figures. However, it is expected that, because of its large population, the per capita resources in Asia will remain lower than those in Europe or North America.

10. The coal-energy system consists of several steps: extraction, processing and use in power plants. The extraction of coal is carried out either by surface or underground mining. The next step is the wet or dry processing of coal to remove some of the impurities before the coal is transported to the power plant. Here the heat released by combustion of the coal in a boiler produces high-pressure steam to drive a turbine, which is linked to a generator that converts the rotary mechanical energy into electricity. The latter is then distributed, usually by overhead power lines, to load centres such as homes, offices, etc. Each step in the coal-energy system has some environmental impacts. These are discussed below.

1. Coal extraction and processing

11. Coal can be mined, according to its geological setting, by a variety of methods: open pit mining, strip mining (area or contour) and underground mining. The most common methods are underground mining and strip mining.

12. Underground coal mining has been considered in many countries to be one of the most hazardous occupations. Besides fire and explosion hazards, land subsidence is common. This can damage surface structures and disrupt ground-water hydrology, and if sudden, could cause localized earth tremors. In deep mining, workers are also exposed to several respiratory diseases (for example, bronchitis, dyspnoea and black lung - known as coal-worker's pneumoconiosis, CWP). In the United States it has been estimated that the incidence rates of simple and acute CWP are approximately 3.47 and 1.60 cases per thousand man-years respectively. In the United Kingdom, the rate is about 2 acute cases per thousand man-years. CWP is a non-curable fatal disease (estimated deaths in the United States are 3 to 4 thousand per year). In addition to these impacts on land and human health, acid mine drainage (which contains high amounts of sulphuric acid leached from exposed coal seams) constitutes a potential pollution hazard by contaminating ground-waters.

13. Surface coal mining (strip mining) is more common than underground mining. It may have serious consequences on land, and hence food production in some countries. It has been estimated that in the United States, for example, more than 2 million hectares will be disturbed by surface-mining operations by 1980 (coal accounts for about 45 per cent of these operations). Where surface mining is carried out in densely populated areas (for example, in the Rhineland, Federal Republic of Germany), it has a direct effect on human settlements and the total infrastructure in the area. Construction of new settlements, roads, etc., is necessary if mining operations are to move towards older inhabited areas. Reclamation of strip-mined areas has been successfully achieved in some countries. In the Rhine area, for example, huge wheel excavators selectively strip off and save the top layer of loess (an extremely fertile type of loam), and remove the remaining sand, gravel and clay overburden to expose the coal beds. Simultaneously, mammoth spreader machines fill the overburden back into mined-out pits while bulldozers level it out in preparation for applying the top layer of loess. Fields of grain and hay are already thriving on land that was restored less than five years ago. In some other areas, for example in Appalachia, United States, the above reclamation method cannot be applied, since mining in Appalachia is conducted in hilly terrain where reclamation is difficult, if not impossible. With the future increase in strip-mining operations, several technological and engineering problems have to be solved to render the reclamation of strip-mined areas economically feasible. Improved methods for eliminating acid and sediment pollution from spoil-bank materials, forming and stabilizing soil, and adopting plant species that will flourish in mined areas are still needed to supplement the findings of the limited research efforts of the past.

14. Strip-mining also has a potential environmental impact on water resources. The sulphur-bearing minerals associated with coal oxidize readily on exposure to air and water leading to the formation of sulphuric acid. This acid can contaminate ground waters and can pollute streams after being leached from the spoil surfaces during periods of surface runoff. Indirect concomitants of acid drainage are the undesirable slimy red or yellow iron precipitates in streams that drain sulphide-bearing coal. Acid drainage affects fish and wildlife in several ways. Although the concentration may not be lethal, it may bring about changes in their physical condition and rate of growth. The United States Bureau of Sport Fisheries and Wildlife has reported that in the United States some 9,000 kilometres of streams and 11,500 hectares of impoundments and reservoirs are seriously affected by surface coal-mining operations.

15. From the point of view of environmental health, the incidence of CWP among surface miners is clearly lower than that among deep miners working in confined spaces, but the rate has apparently not yet been quantitatively determined.

16. The extracted coal is usually processed, to reduce the impurities, before it is used in power plants. A large coal processing plant may clean a million tons of raw coal per year and produce about 1.5 tons of waste water per ton of coal processed. During cleaning of the raw mine product, about 24 per cent of the feed is discarded, and about half of this amount is coal. Coal-dust arises almost entirely from thermal drying of wet-processed coal. However, by adding wet scrubbers and air recirculation to the cyclone separators in common use, dust emissions can be reduced.

Table 6. COAL RESERVES IN THE WORLD

	Proven recoverable coal x 10^6 tonnes	%	Per capita resources (tonnes)
Asia	97,557	16.5	47.7
Africa	15,628	2.6	43.8
Western Europe	65,260	11.0	165.1
Eastern Europe	198,115	33.5	565.4
North America	187,319	31.7	819.4
South America	2,802	0.5	9.7
Oceania	24,518	4.2	1213.8
Total	591,199	100.0	160.5

Source: After "Survey of energy resources", World Energy Conference, 1974.

2. Use of coal for power production

17. Huge amounts of coal are consumed annually for power production. The first stage of producing electricity in conventional power stations involves the combustion of coal (or other fossil fuel), and the conversion of its energy content into heat in the form of steam at high temperature and pressure. Although this energy conversion step is of high efficiency, the effects of burning fuel are one of the main sources of interaction between the industry and the environment. These effects arise from the handling and storage of fuel before combustion, and the disposal of the flue gases and particulates after combustion. The second stage in the production of electricity involves the transformation of the heat generated into mechanical energy. Steam turbines extract the heat from high-pressure steam and convert it into mechanical energy of rotation. For maximum efficiency the steam is expanded down to a low vacuum and is then condensed for re-use in the boiler. The condensation process requires a large flow of cooling water at ambient temperatures, and almost half of the total heat energy available in the steam is lost to the environment in this way.

18. The environmental impacts of the use of coal in electricity production can therefore, be summarized in the following stages: pre-combustion stage, combustion stage and mechanical energy production stage.

19. The environmental problems encountered in the pre-combustion stage include the handling and storage of coal at the power-plant site. The prevention of dust nuisance from coal handling and storage is mainly a matter of enclosing as much as possible of the plant to exclude the wind. The coal stock itself may cover several hectares and is therefore too large for a roof, but windblown dust is minimized by careful layering and compaction of the coal.

20. In the combustion stage, significant quantities of particulates and noxious gases such as sulphur oxides, nitrogen oxides, carbon monoxide and hydrocarbons are emitted. Table 7 gives an estimate of the annual emission rates of various pollutants resulting from the operating of a typical modern 1,000 MWe coal-fired steam power plant of conventional design. The characteristics of the different pollutants emitted from power plants, together with their impact on the atmosphere and different ecosystems, are discussed below.

Table 7. POLLUTANTS EMITTED FROM A 1000 MWe COAL-FIRED POWER PLANT

	Annual release (10^6 kg) a/
Particulates	4.49
Sulphur oxides	139.00
Nitrogen oxides	20.88
Carbon monoxide	0.21
Hydrocarbons	0.52

Source: Committee on Power Plant Siting, National Academy of Engineering, Washington, DC 1972.

a/ These figures assume that the plant burns 2.3 x 10^6 tons of coal per year and that the sulphur content is 3.5 per cent of which 15 per cent remains in the ash. The ash content of the coal is assumed to be 9 per cent and the fly ash removal efficiency 97.5 per cent.

21. The amounts of ash and slag produced by burning coal in power plants vary widely depending on the quality of the coal. Attempts are being made to use this waste for productive purposes. Ash has been used for producing building materials, but there are dangers in using these for residential buildings because of their radioactivy. Ash can also be used as an aggregate in road construction. At present, there seems to be no prospect of substantially reducing the need to store the produced ash and slag on land, which is scarce, especially in densely populated areas.

22. Although supplies of peat are not particularly abundant or widespread throughout the world, they can nevertheless constitute a valuable energy resource in some parts of the world, such as Scotland and Ireland. Peat is used as a domestic fuel and for the production of electricity. It is found in a variety of locations, sometimes on dry land where an operation equivalent to shallow open-cast mining is undertaken and sometimes under-water in marsh conditions. Before undertaking any project related to the large-scale gathering of this fuel a careful study of the probable ecological results must be carried out, with particular reference to the resulting top soil and surface-water conditions.

E. OIL

23. Oil is the most important fossil fuel hitherto discovered. The versatility of petroleum provides a range of useful products which no other fuel can match - from the lightest gaseous hydrocarbons to the heavy residual fuel oils. There is so far no practical alternative to oil as a propellant for motor cars, aircraft and ships, industry and agriculture are heavily dependent on petroleum fuels. Indeed, no other fuel than petroleum currently has an important impact on the socio-economic structure of the world.

24. The estimated recoverable amounts of oil, together with the calculated tons per capita in the different regions of the world are given in Table 8. Again, it should be noted that these figures are only the present known estimates and do not represent the potential of oil reserves in the world. Exploration activities, particularly in the offshore and outer continental shelf areas, will probably lead to the discovery of huge oil reserves, hitherto unknown (see below). The reserves in Asia constitute 59 per cent of world reserves, a considerable portion of which comes from the oil-producing countries of the Middle East.

25. As in the case of coal, the oil-energy system consists of several steps: extraction, transportation, processing, use in power plants and automative devices, etc. The soaring growth in oil demand has brought certain environmental problems in every step of the oil-energy system. By the nature of its activities the oil industry operates very large plants whose emissions and effluents are capable of polluting air, soil and water. Crude oil is transported across the oceans by tanker fleets which include the largest ships afloat. Storage and distribution of the products to the consumer should be carried out with great care to ensure safety and to minimize pollution risks. The burning of gases associated with oil may also have an appreciable impact on the environment. The environmental impacts of each step in the oil-energy system are discussed below.

Table 8. OIL RESERVES IN THE WORLD

	Proven recoverable oil x 10^6 tons	Percentage	Per capita resources (tons)
Asia	53,972	59.0	26.4
Africa	12,848	14.0	36.0
Western Europe	1,020	1.1	2.6
Eastern Europe	8,512	9.3	24.2
North America	6,644	7.3	29.1
South America	8,300	9.1	28.8
Oceania	229	0.2	11.3
Total	91,525	100.0	24.8

Source: After "Survey of energy resources", World Energy Conference, 1974.

1. Exploration and production of oil

26. Exploration and production operations, whether carried out on land or offshore, involve a number of environmental impacts. Accidents and operational and equipment failures can result in serious harm to both personnel and the environment through explosions, fire, or oil pollution. Different safety systems have been proposed with the principal objective of preventing accidents and/or containing them and minimizing their effects. Land-based operations have, generally, less environmental impacts than offshore ones.

27. The average growth rate of offshore petroleum production has been 13 per cent in the last decade, which is nearly double that of land-based production. The share of offshore petroleum in worldwide production is estimated to reach 25 to 30 per cent in 1980 and probably 35 to 40 per cent in 1990 (275). Table 9 shows the rapid increase in oil production from offshore wells.

Table 9. OFFSHORE OIL PRODUCTION
(TONS/DAY)

	1970	1974
United States	225,511	164,156
Middle East	295,152	559,855
Venezuela	349,063	296,186
Others	170,982	304,414
Total	1,040,708	1,324,611

Source: After (322)

28. The direct impact of offshore oil development may result from accidental oil spills or the chronic discharges of normal operations, from disposal of drilling muds and cuttings into the ocean, and from disturbance of the ocean bottom and of wetlands by platform and pipeline construction. Daily operational discharges of the above materials may result in sublethal or long-term ecological damage to an area. Several recent studies have found significant concentrations of heavy metals near platforms. These enter the food chain and could pose problems for human health (356). Nearshore spills are particularly damaging to estuarine and coastal marine life. Tidal marshes, coastal wetlands, river swamps, and sheltered bays support a variety of organisms at all stages of development. If an oil spill reaches shore within 1 or 2 days, extensive mortality is to be expected initially in all exposed habitats and they may require years to recover.

29. Although accidents during offshore operations account for only a small portion of oil discharges in comparison to oil spilled from tankers, locally they can be significant. Table 10 summarizes the major accidents on the outer continental shelf of the United States during the period 1953 to 1972. The 1969 Santa Barbara blowout, which released between 2650 and 11,000 tons of oil, raised serious questions concerning the adequacy of outer continental shelf operations. Figure 3 illustrating worldwide offshore operations, shows that most of these are carried out in "restricted" waters, where the impact of such operations will have serious regional effects. It is, therefore, important that daily operations in such regions be carefully monitored and that stringent standards for discharge of oil, muds, and cuttings be enforced.

Table 10. MAJOR ACCIDENTS ON THE OUTER CONTINENTAL SHELF OF THE UNITED STATES 1953 TO 1972

	Number of accidents
Oil wells	11
Oil and gas	9
Gas	19
Others	4
Total	43
Number of oil spills	20
Oil volume (in 1,000 barrels)	290 - 1100
Deaths (total)	56
Injuries	108
Fires	20
Major rig damage	15

Source: After (356).

30. A main pollutant during the extraction phase is the brine which is brought to the surface along with the crude oil. Reinjection into subsurface strata could seriously contaminate ground water. For example, 100 kg. of brine containing 1,000 ppm of sodium chloride will render approximately 40 tons of fresh water unpotable.

2. Transportation of oil

31. The transport of huge volumes of oil each year is not without environmental impacts. Marine transportation is the most important means of transporting oil from oil-producing to oil-consuming countries (in 1972, 1,225 million tons of crude oil and 275 million tons of refined products were transported by sea). The world's oil tanker fleet has grown from less than 10 million DWT in 1950 to over 200 million DWT now, and is comprised of some 3,700 ships (Table 11). More than one quarter of the world's total oil-carrying capacity in service at the end of 1971 consisted of very large crude carriers (VLCC) of 175,000 DWT and over (up to 484,000 DWT). It is assumed that the introduction of VLCCs and ULCCs (ultra-large crude carriers; above 350,000 DWT) will not only reduce the cost of oil transportation, but will also reduce the number of small tankers. This reduction could be expected to decrease the number of accidents, but this will be offset to a certain extent by the inferior manoeuvrability characteristics of the larger tankers. In addition the large cargoes carried by the VLCCs and ULCCs will tend to increase the environmental impact of each accident. The VLCC systems will have a profound impact on landside oil distribution systems and port development (adequate harbours, channels and/or VLCC mooring facilities) of receiving user countries.

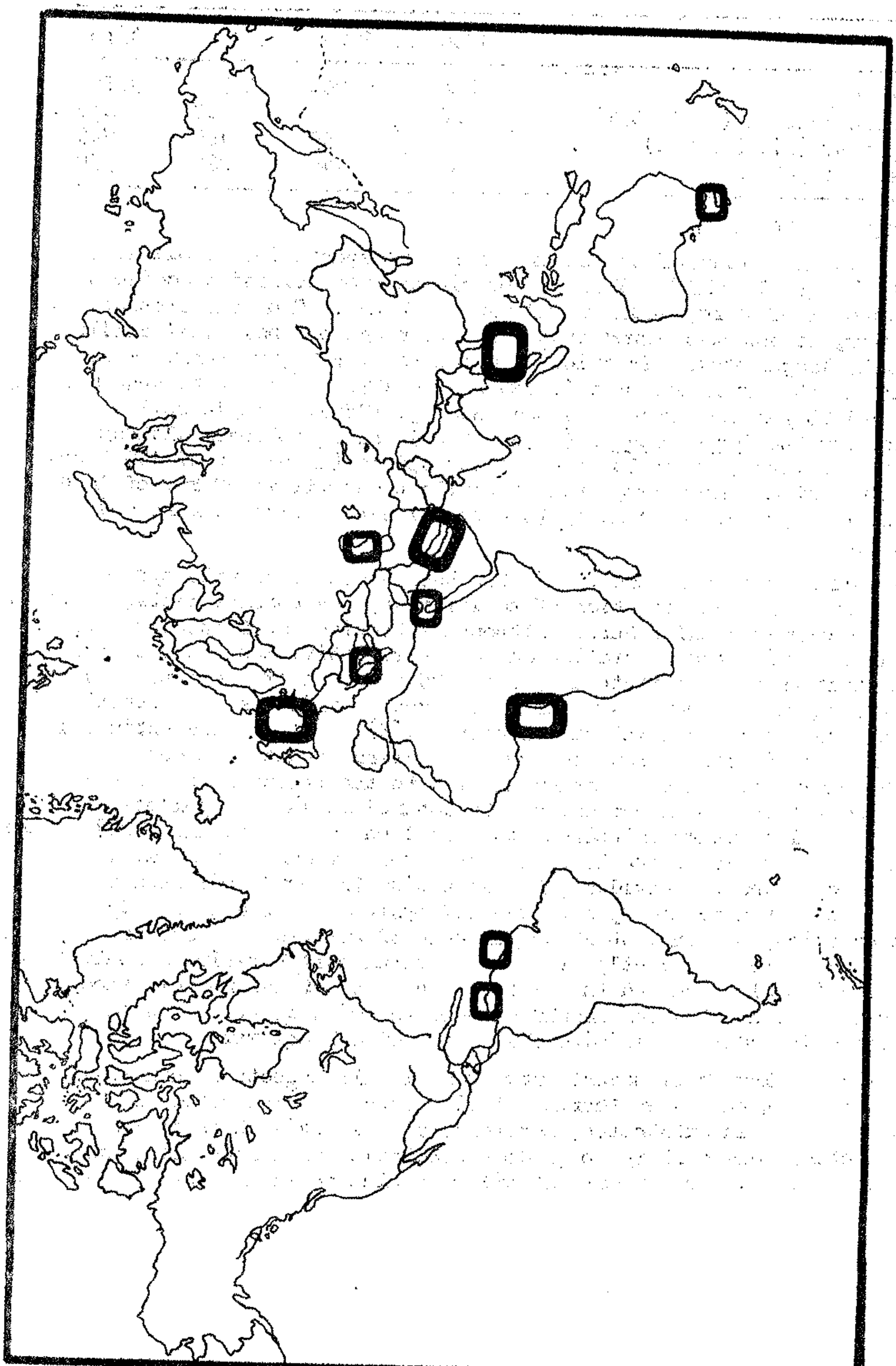

Figure 3.

Table 11. SIZE OF OIL TANKERS

	1950	1960	1970	1973
Number of ships	400	2,000	3,500	3,760
Average size ordered (1,000 DWT)	20	40	200	275
Fleet capacity (million DWT)	8	55	160	225
Maximum size (1,000 DWT)	47	140	225	530

Source: After (387).

32. The main environmental impact of marine transportation of oil is oil pollution (oil spill). This can originate from collision accidents and/or disposal of dirty ballast and tank washings. From the statistical poin of view, it has been found that the size range of individual spills is extremely large, from a fraction of a ton to over 20,000 tons. Most spills are at the lower end of this range; in 1972, 96 per cent were less than 3.4 tons and 85 per cent were less than 300 kg. (356). Single spills like that from the Torrey Canyon (50,000 tons) are exceptional although in the past 20 years, about 50 major tanker spills (in excess of 150 tons) have been reported. Most large tanker spills occur within 80 km. of land and result from grounding, ramming (the vessel hits a fixed structure) or collision.

33. The pollution of the seas by oil has been a matter of wide spread concern, attracting the attention of politicians, environmentalists, physical and social scientists and others. Although attention has focused on oil spills due to marine transportation and offshore activities, it has been estimated that these constitute only about 35 per cent of the total oil finding its way to the world's waters. The rest originates from normal ship operations, refineries and industrial wastes (63). It has been estimated that the direct oil losses into the world's waters amount to about 2,000,000 tons/year. This situation has led to the creation of several regional and international conventions to control marine oil pollution. In 1964, the oil industry introduced the "Load on Top" principle (LOT) by means of which the oil residues are kept on board, the new cargo of crude is loaded "on Top", and the residue put ashore with the crude oil when the tanker reaches her discharge port. The LOT system is now a generally accepted practice, but only about 80 per cent of existing tankers are capable of using this system. Recently, the Intergovernmental Maritime Consultative Organization (IMCO) discussed the different aspects of marine pollution and proposed that new tankers should be equipped with segregated water ballast tanks in order to minimize the mixing of oil and water.

34. Significant levels of uncertainty exist in all aspects of oil-spill impacts: composition and weathering of oil, processes and rates of degradation of oil in substrates, sensitivity of individual organisms to various fractions and ability to predict population/community-level initial impact and recovery. The effects of oil on marine organisms are categorized as:

(a) Direct lethal toxicity due to soluble aromatic hydrocarbons;

(b) Sub-lethal disruption of physiological-behavioural activities;

(c) Coating of birds, mammals and inter- and sub-tidal species with oil;

(d) Alteration of substrates by oil, which makes habitats uninhabitable for normally found species, and

(e) Incorporation of hydrocarbons into organism tissues causing the accumulation of potential carcinogens. From the theoretical point of view, exposure of adult marine organisms to 1-100 ppm soluble aromatics for a few hours can be lethal. Concentrations as low as 0.1 ppm may be lethal to larval stages.

35. When an oil spill occurs, decision-makers face an identifiable variety of options for dealing with it. Present technology offers the following choices:

(a) Leave it;

(b) Burn it;

(c) Sink it;

(d) Contain and remove it; and

(e) Disperse it. Each of these approaches presents its peculiar problems, and none of them is likely to be the best choice in all cases. One of the promising new possibilities is the breakdown of oil into harmless substances by certain strains of bacteria. This, however, has so far been successfully accomplished only under laboratory conditions: extensive field trials have yet to be conducted. It is felt that special effort should be directed to solving many of the problems associated with these approaches to dealing with oil spills (356). For example, recent studies show that Baltic herring larvae are 50-100 times more sensitive to an oil dispersion that is obtained by adding a dispersant to the oil than to a "natural" oil dispersion without a dispersant (282). It is also shown that the acute toxicity of a self-dispersed crude oil decreases considerably in 24 to 72 hours, but if the oil is dispersed by a dispersant, the high toxicity remains almost unchanged over the same period.

36. The importance of ocean pollution and its impact on marine ecosystems has initiated several activities, both on the regional and global scale. The activities of IMCO and other United Nations agencies are well documented. One of the important activities of UNEP in this field is that of the GEMS programme, one of the goals of which is "an assessment of the state of ocean pollution and its impact on marine ecosystems". The Marine Pollution Monitoring Workshop sponsored by Intergovernmental Oceanographic Commission of UNESCO (IOC) recommended that all marine pollution data and information, whether or not suitable for centralized archiving and routine exchange, should be inventoried and fully documented, and incorporated into a centralized international referral system such as that being developed by the International Oceanographic Data Exchange <u>ad hoc</u> Group on Marine Pollution Data Exchange and the Joint Task Team made up of representatives of IOC, IAEA, the Food and Agriculture Organization of the United Nations (FAO), the International Labour Organization (ILO), WMO, WHO, the Intergovernmental Maritime Consultative Organization (IMCO) and UNEP.

37. Oil spills can also occur during the transportation of oil by pipelines. Most of those spills are due to breakage in the pipelines, and are generally less important than those occurring in oceans. However, pipelines may in some regions have potential environmental impacts. For example, the Trans-Alaskan Pipeline has been criticized for its potential impact on permafrost, wildlife, climate and glacial activity, seismic activity, etc., and several alternative routes have been proposed with less impact on the environment (89).

3. Oil processing (refining)

38. Effluent control is perhaps the most important problem with which refineries have to deal, especially in densely populated inland areas. The waste disposal problem is similar to the general marine problem of oil pollution. Waste requiring disposal includes: accidental spills from oil tankers servicing refineries, leakage from damaged pipelines, spills from overflowing tanks, and discharges from tank washings. Besides oil, other substances may escape in the waste from oil refineries: these may be natural constituents of petroleum, or substances added in the purification and separation processes. Sulphur and vanadium compounds from the crude petroleum, phenols formed during cracking and fractionation, and catalysts used in refining are some of the non-oil constituents. Most organic substances are lipophilic (have an affinity for oil) and may be present in the oil film; they include phenols from refinery effluent, frequently found in oil slicks near a refinery, and chlorinated hydrocarbons entering from other sources. The inorganic constituents are often water-soluble, and are usually found in the aqueous fraction of refinery effluent, which becomes rapidly diluted and dispersed in receiving waters. To a large extent, the toxic constituents are in the oil fraction discharged from a refinery. They may have their most serious effects on the intertidal fauna. Several methods of treatment are in practice, ranging from physical methods (gravity separation of oil) to biological treatment with bacteria, depending on the effluent characteristics and the nature of receiving water (into which the treated water will be discharged).

39. Different types of emissions are also encountered in oil-processing operations, the most important of which are sulphur oxides, hydrocarbons, nitrogen oxides and carbon monoxide. Table 12 gives an estimate of the emissions from a refinery treating about 29,000 tons/day.

Table 12. EMISSIONS FROM OIL REFINERY

	Particulates	SO_x	HC	NO_x	CO
Total (tons/day)	4.82	11.30	34.57	13.22	1.00
Total (tons/year) a/	1591	3739	11403	4363	330

Source: After (356).

a/ Assuming 90 per cent efficiency.

40. Odour is also a potential nuisance in oil refineries. The principal malodorous compounds existing in crude oil or formed during its processing into products are hydrogen sulphide and mercaptans. Should any of these escape from a refinery there is a risk of smells in the neighbourhood. Ethyl mercaptan has a perceptible smell when present in a concentration of only one part per thousand million; thus even a very small loss can create an unpleasant smell over an area several square kilometres in certain meteorological conditions. The control of odours remains, as a matter of fact, one of the most intractable of refinery air pollution problems.

41. Spills of refined products can occur during storage and transport operations. However, most oil companies follow regid codes of good practice in protection against failure of storage tanks and standards of transportation for oil products.

4. Use of oil products

42. Oil is commonly used as a fuel in power plants. Similar to coal, the combustion stage produces a number of pollutants. Table 13 gives an estimate of the amounts of pollutants emitted from a 1000 MWe oil-fired conventional power plant.

Table 13. EMISSIONS FROM A 1000 MWe OIL-FIRED POWER PLANT

	Annual release (10^6) kg a/
Particulates	0.73
Sulphur oxides	52.66
Nitrogen oxides	21.70
Carbon monoxide	0.008
Hydrocarbons	0.67

Source: Committee on Power Plant Siting, National Academy of Engineering, Washington, DC 1972.

a/ Assuming that the power plant burns 1.57 x 10^6 tons of oil per year, which has 1.6 per cent sulphur and 0.05 per cent ash.

43. The most important product that has a potential impact on the environment is gasoline in the motor car. Car exhaust emissions are a subject of major public concern. Ideal and complete combustion of gasoline produces carbon dioxide and water. However, this is never achieved by the motor car engine. In consequence, appreciable amounts of unburned hydrocarbons and cabon monoxide are discharged from the exhaust. The amount of emissions varies considerably from one car to another (according to type of engine, car model, speed ... etc.), but generally the amount of emissions from mobile sources exceeds those from stationary sources, especially in urban areas (Table 14). In addition to these gases, particulates are also common in auto exhaust. Lead, an anti-knock additive, has been most widely discussed, but it is not the only gasoline additive. There are also manganese and nickel anti-knock additives. Scavengers such as ethylene

dichloride are added to remove lead oxide deposits from valves and spark plugs; phosphorus and boron compounds alter the character of combustion chamber deposits; etc. Many of these additives contribute to the particles in automobile emissions, with the metallic ones, such as lead, boron and nickel, being especially suspect in terms of impairing visibility and contributing to effects on health and weather. Regulations are now in force, and technical efforts being made, in many countries to reduce the impact of automotive emissions. It is assumed that by 1985 the emissions of carbon monoxide and hydrocarbons will be reduced by about 75 per cent of the 1972 level. However, the total input into the atmosphere may not be changed, since by 1985 the number of running cars will be nearly double, or perhaps even triple that of 1972.

Table 14. EMISSION SOURCES IN URBAN AREAS

	Pollutant per cent of total		
	HC	CO	NO_x
Automobiles	50-65	77-87	40-50
Trucks, buses ... etc.	5-10	8-10	8-13
Stationary sources	25-45	3-15	37-52

Source: After (214)

C. NATURAL GAS

44. Natural gas is becoming more and more attractive as an energy source, especially from the environmental point of view. The production of natural gas has greatly increased during the last 10 years, the actual proven recoverable amounts are given in Table 15, together with the calculated *per capita* resources in the different regions of the world. These figures are, again, approximate figures and do not represent the true gas potential of the world. Recent exploration operations have led to the discovery of huge fields of natural gas, and the proven reserves in Asia have been estimated as amounting to 37 per cent of world reserves (322).

Table 15. PROVEN RECOVERABLE AMOUNTS OF NATURAL GAS

	Natural gas $x\ 10^9\ m^3$	Per cent	Per capita resources $x\ 10^3\ m^3$
Asia	12,241	23.3	6.0
Africa	5,709	10.9	16.0
Western Europe	4,058	7.7	10.3
Eastern Europe	17,591	33.5	50.1
North America	10,132	19.3	44.3
South America	2,108	4.0	7.3
Oceania	693	1.3	34.3
Total	52,532	100.0	14.3

Source: After "Survey of energy resources", World Energy Conference, 1974.

45. The operations involved in the production of gas (whether from land-based or offshore wells) are identical with those for oil; hence most of the environmental impacts are similar. After being produced from the well, natural gas is generally liquified, transported and then subjected to re-gasification at the consumption terminal. The liquefaction plant uses power from either a steam turbine or a gas turbine, which represents the major source of pollution by the plant. The liquified natural gas (LNG) is then transported by LNG tankers which burn some vapourized LNG (normal boil-off) and some fuel oil. Aside from the atmospheric pollution caused by the fuel oil, an LNG tanker has little effect on the environment. No noxious oily ballast is discharged, and LNG tankers discharge no sewage while in port. The capacity of LNG tankers has greatly increased in the last 15 years as a result of the ever-increasing production and consumption of LNG (Table 16). It should be noted, however, that strict safety precautions should be excercized in handling LNG. Besides fire hazards, LNG produces frostbite on short exposures. A massive marine spill of LNG due to accident would coat the water surface in the vicinity of the spill with a boiling cryogenic liquid endangering any near-surface water fauna which had not already fled the area of collision. Any large quantity of LNG will spread across the water, vapourizing rapidly and creating a large cloud of condensed water vapour. The LNG vapours, predominantly methane, are lighter than air and would thus rise and diffuse in the atmosphere.

Table 16. CAPACITY OF WORLD LNG TANKERS

	1960	1970	1975
Number of ships	1	14	36
Fleet capacity (1,000 m^3)	5	1500	5000

Source: After (387).

46. In its use for power generation, natural gas produces much less emissions than other fossil fuels. Table 17 gives an estimate of the emissions produced by a 1000 MWe gas-fired power plant. Moreover, LNG as an engine fuel has the advantage over other fuels of being smokeless and contributing far less to air pollution. LNG therefore has great potential as a fuel for automotive vehicles. Its use in aircraft, though problematic, also holds significant advantages in terms of environmental impacts.

Table 17. EMISSIONS FROM A 1000 MWe GAS-FIRED POWER PLANT

	Annual release (10^6) kg a/
Particulates	0.46
Sulphur oxides	0.012
Nitrogen oxides	12.08
Carbon monoxide	negligible
Hydrocarbons	negligible

Source: After Committee on Power Plant Siting, National Academy of Engineering, Washington, DC 1972.

a/ Assuming that the plant burns 1.9 x 10^9 m^3/year.

D. OIL SHALES AND TAR SANDS

47. Oil shales exist in many parts of the world, and the technology for processing them to produce oil is well established, extending back to the last century. This energy resource can be utilized in two ways. First the shale can be pulverized and burnt in a specially-designed power station boiler to produce electricity. From an environmental standpoint the use of oil shale in this manner is subject to the restrictions which apply to power stations operating on pulverized coal. However, since oil shale is a inferior fuel to coal, a greater amount is needed for a given electrical output and problems with the emission of particulates are therefore important. The second method of utilizing oil shale is to mine the rock and crush it before extracting the oil by a chemical process. Environmentally this procedure involves the disadvantages associated with any open-cast mining operation, and land reclamation is essential to restore the land. Unfortunately, after processing the shale has a larger volume than before and this presents difficulties for its disposal in any reclamation scheme. Moreover, the present technology for producing oil from oil shales involves the use of large quantities of water, and in some locations such as the arid regions of the western United States this condition has imposed a severe environmental barrier to development of the resource.

48. In some parts of the world there exist vast deposits of sand saturated with a low-grade bituminous tar. After open-cast mining of these sand deposits, the oil can be extracted by heating. A project of this nature is in operation on the Athabasca Tar Sand Site in Canada where valuable experience is being gained in the operation, although it is economically only marginal. The environmental problems of developing this energy resource are those associated with the reclamation of land after open-cast mining.

E. CHARACTERISTICS AND ENVIRONMENTAL IMPACTS OF POLLUTANTS FROM FOSSIL-FUEL POWER PLANTS

1. Sulphur oxides

49. Sulphur is an impurity in most coals and oils, and is oxidized during the combustion of these fuels in power stations. Unless control systems are employed to remove the oxides of sulphur from the combustion gases, essentially all of these oxides (primarily SO_2 plus small quantities of SO_3) pass into the atmosphere. Various estimates of the total emission of sulphur oxides due to man's activities are available. SCEP calculated a global figure of 93 million tons per year SO_2 (about 70 per cent of which coming from fossil-fueled power stations). The Organization for Economic Co-operation and Development (OECD) estimates that European emissions will rise to 27.4 million tons per year by 1980.

50. There is no evidence that sulphur oxides are accumulating in the atmosphere. Because of the ease with which sulphur dioxide is converted into sulphates and sulphuric acid in the air, its lifetime there is short.

The rate of oxidation of sulphur dioxide to sulphuric acid depends on the sunlight available, the concentration of moisture, catalysts, hydrocarbons and the quantity of directly reactive material in the air. Although more quantitative data on dose-response relationships are needed, sufficient evidence exists to conclude that atmospheres polluted with oxides of sulphur directly and indirectly attack and damage a wide range of materials. Much of this damage is due to the conversion of sulphur oxides to highly reactive sulphuric acid. It has been noticed that in many parts of the world, there is a trend towards increasing acidity of rain (pH values of 4.0 have been reported for Liverpool and 2.8 has been reported in Scandinavia).

51. Atmosphere containing sulphur oxides can corrode several materials (for example, overhead powerline hardware, steel structures, etc.). It attacks and damages a variety of building materials - limestone, marble, mortar - as well as statuary and similar works, causing their physical deterioration.

52. Sulphur dioxide also has an appreciable impact on plants. Plant species and varieties vary in sensitivity to sulphur dioxide as a result of the interaction of environmental and genetic factors that influence plant response. Temperature, humidity, light, other pollutants and the stage of plant growth all interact in affecting this sensitivity. Sulphur dioxide absorbed by plants may produce two types of visible leaf injury, acute and chronic. Acute injury, which is associated with high concentrations over relatively short intervals, usually results in drying of the injured tissues to a dark brown colour. Chronic injury, which results from lower concentrations over a number of days or weeks, leads to a gradual yellowing (i.e. chlorosis, in which the chlorophyll-making mechanism is impeded). Different varieties of plants vary in their susceptibility to sulphur dioxide injury. For example, the threshold response of alfalfa to acute injury is 3.4 mg/m^3 over one hour, while some trees have shown injury at exposures of 1.4 mg/m^3 for seven hours. Some species are tolerant and some can benefit from absorption of SO_2 if they are growing on sulphur-deficient soils.

53. Acid rains may increase the acidity of soils and may reduce populations of micro-organisms. Furthermore, they may also contribute to the leaching of nutrients from plant leaves. Sulphuric acid mist, which may occur in polluted fogs and mists, causes a spotted injury to leaves at concentrations of 0.1 mg/m^3. There is increasing evidence that low levels of sulphur dioxide can cause reductions in growth without visual symptoms. Such growth reduction can be confused with effects due to other causes, such as soil poverty or exposure to soot. However, there is great need for extensive research work in this area because of the serious long-term implications. There is also some evidence that two pollutants together can combine to have greater effects than each separately, and this question also needs further examination.

54. One of the primary problems in determining the health effects of sulphur dioxide continues to be the development of an understanding of the manner in which this gas interacts with other substances in the atmosphere. Laboratory studies have demonstrated that the levels of sulphur dioxide found in the ambient air are innocuous until combined with other substances.

The available data on comparative toxicity of the sulphur oxides indicate that sulphur dioxide is only a mild respiratory irritant, whereas specific sulphate and sulphuric acid aerosols are more potent. Particle size and mass concentration are of paramount importance in the toxicity of sulphur dioxide mist. Over the years, a number of acute air-pollution episodes have been reported. Both oxides of sulphur and the total suspended particles (TSP) have contributed significantly to the health effects associated with these episodes. In London in 1952, a rise in the daily death rate was reported when the concentration of sulphur dioxide rose abruptly to levels at or about 0.715 mg/m^3. Daily concentrations of sulphur dioxide in excess of 1.5 mg/m^3 for 1 day in conjunction with levels of TSP exceeding 2 mg/m^3 have resulted in an increase in the death rate of 20 per cent or more over baseline levels. In New York City, sulphur dioxide concentrations of 1.5 mg/m^3 in combination with a similar TSP level have led to increased mortality and morbidity. Similar observations have been made in Rotterdam and other industrial cities.

55. More detailed studies are therefore necessary on the effects of sulphur dioxide (alone or in combination with TSP and other pollutants) on human health. A WHO report (469) indicates that "There have been some reports of studies that can be used to establish dose-response relationships or associations for sulphur dioxide and suspended particulates. These studies are limited in number, however, and at present there is little information available concerning the effect of varying one of these pollutants while the other is kept constant ... In view of the above, it is imperative that, until cause-effect relationships become established, sulphur dioxide and locally associated smoke and suspended particulates be considered as indices rather than as necessarily the specific pollutants causing the effects".

56. It should be noted that there is a natural sulphur cycle in nature, in which H_2S is released to the atmosphere by decay of organic matter and from geological sources, and absorbed, after oxidation to sulphate, by land and sea surfaces, partly after solution in rain and snow. Such natural circulation of sulphur oxides has been calculated to be much greater than the amounts added by fuel combustion. It follows, therefore that environmental damage by sulphur oxides from fuel combustion can only be local or regional in character.

57. Sulphur oxides emitted in combustion gases from domestic chimneys and small factories are more serious pollutants than those emitted from large power stations and industrial plants with tall chimneys capable of dispersing and diluting them effectively. In a number of countries, in fact, the adoption by environmental control authorities of a madatory system of tall stack heights for large plants, for example 200 to 300 m for large power stations, has had the effect of reducing ground-level concentrations of sulphur oxides attributable to these sources to levels which are undetectable against the background of low-level emissions over wide areas. Consequently, in considering local effects of sulphur oxide emissions, domestic and small-industry use of fuel merits more stringent control than heavy industry emitting combustion gases at high levels.

58. However, although tall stacks have proved very efficacious as a means of preventing local and regional effects of sulphur oxide emissions (except in some unfavourable topographical situations), it is not at present certain whether or not SO_2 emitted at a high level can produce harmful effects at ground level at distances of several hundred kilometres from its source. It has been claimed that high-level emissions from western Europe contribute to increased acidity of rain in Scandinavia, and a number of large continental countries (United States, Soviet Union) also regard high-level dispersion as possibly inadequate to prevent ground-level effects at considerable distances.

59. To reduce sulphur oxide concentrations from low-level (domestic and small industry) sources, and from heavy industry in cases where dispersion is ineffective, four types of strategy are available:

(a) Use of low-sulphur fuels such as natural gas or desulphurized liquid and solid fuels. Since naturally low-sulphur fuels are of limited availability and desulphurization is not possible with all fuels and in any event involves an economic penalty, this strategy is best applied on a selective basis, i.e. over restricted sensitive areas and at times when weather conditions favour build-up of ground-level concentrations;

(b) Desulphurization of fuels before use. This can be effected at modest cost for distillate petroleum fuels, but only at very heavy cost and incompletely in the case of heavy fuel oils. In the case of solid fuels, reduction of sulphur content to around 1.5 per cent is possible in many cases by normal washing processes, but to attain lower levels would be prohibitively expensive. For coals of very high sulphur content (e.g. 3-4 per cent) which are not amenable to such treatment, conversion to gaseous or liquid fuels which can be readily desulphurized is being considered in some countries;

(c) Removal of sulphur oxides from combustion gases before they are released to the atmosphere. Several technologies are available for the removal of sulphur oxides from flue gases. These are generally divided into two main processes: wet and dry (see (471) for example). The removal efficiency of these processes varies between 80 and 95 per cent, the sulphur being converted to sulphuric acid or some other sulphate. Of the large number of these sulphur dioxide removal systems, none is yet in routine full-scale operation on large boilers burning high-sulphur coal (448). It is anticipated that the present techno-economic difficulties will be overcome by continued development and that successful regenerative units will be installed by 1980;

(d) Removal of sulphur during combustion. A promising line of development for the future is combustion of high-sulphur solid or liquid fuels in fluidized beds of particles containing alkaline earth oxides (lime or dolomite); under these conditions the sulphur remains in the solid residues rejected from the combustion chamber, and the use of this technique also confers a number of other technological advantages.

2. Nitrogen oxides

60. Nitrogen oxides, primarily NO plus smaller quantities of NO_2, arise from a different source than other pollutants. Basically, nitrogen in the combustion air (plus, possibly, small quantities of nitrogen chemically contained in fossil fuels) combines with the oxygen in the air during the combustion process to produce NO. Later, most of the NO oxidizes further to form NO_2. Most NO_2 is formed outside the boiler, often at a considerable distance downwind from the plant stack. The nitrogen oxide concentrations in flue gases vary from 100 to 1460 ppm, depending on the type of boiler and the combustion conditions. The emission of nitrogen oxides varies greatly from one country to another, the world total has been estimated as 14.8 million tons in 1968, while double this amount is expected to be emitted in 1980 (see Table 18). It should be noted that an approximately equal amount of nitrogen oxides (NO_x) is also emitted from transportation devices (motor vehicles, etc.). However, the major source of world-wide atmospheric NO_x is biologically produced NO. Natural sources produce about 450 million metric tons of NO per year. Man's contribution is nevertheless a cause for concern because the emissions are concentrated in urban areas (NO_x concentrations in urban atmospheres are 10 to 100 times higher than those in rural atmospheres).

61. Nitrogen oxide emissions are of particular concern because they are "starting" materials for atmospheric reactions which lead to the production of photochemical oxidants (photochemical smog). Their presence also enhances the oxidation of sulphur dioxide into sulphuric acid. Several studies have shown that the emission of NO_x from supersonic transport may reduce the amount of stratospheric ozone. The ozone is important in protecting the biosphere from exposure to ultra-violet radiation, an increase in which can cause skin cancer and other damage.

Table 18. ESTIMATED TOTAL EMISSION OF NITROGEN OXIDES FROM STATIONARY SOURCES, 1968 AND 1980 (NO SPECIAL ABATEMENT MEASURES IN 1980)

Country	NO_x, 10^6 metric tons	
	1968	1980
Austria	0.078	0.098
Belgium	0.177	0.232
Canada	0.31	0.59
Denmark	0.088	0.148
Finland	0.119	0.208
France	0.494	0.588
Germany, Federal Republic of	1.26	1.94
Greece	0.035	0.116
Italy	0.418	1.124
Japan	0.97	3.36
Netherlands	0.220	0.374
Norway	0.027	0.038
Spain	0.210	0.518

Country	NO_x, 10^6 metric tons	
	1968	1980
Sweden	0.103	0.224
Switzerland	0.035	0.054
Turkey	0.137	0.317
United Kingdom	1.065	1.19
United States	9.02	16.01
Grand total	14.8	27.1

Source: (339).

62. Nitrogen oxides have a severe impact on plants. Many kinds of plants develop acute leaf injury (lesions) when exposed to concentrations of NO_2 greater than 25 ppm for 1 hour. Recent studies suggest that 0.25 ppm or less of NO_2 supplied continuously for 8 months increases leaf-drop and reduced yield of some oranges. A four-month exposure to 0.25 ppm NO_2 resulted in a 22 per cent reduced yielf of tomatoes. The degree of injury from lower atmospheric concentrations of NO_2 remains to be determined. Smog compounds (produced by the reaction of NO_x, sunlight and hydrocarbons of which ozone and peroxyacetyl nitrate are the most important) can have detrimental effects on vegetation and materials. However, at the moment not enough information is available concerning the toxic effects of smog compounds in ambient air to give quantitative dose-response relationships. Moreover, the photochemical reactions in ambient air are highly complex and only partially and insufficiently understood (132).

63. Nitrogen dioxide is well known as a toxic gas in industrial environments. It can, if inhaled in high enough concentrations, produce pulmonary oedema which occurs only after a latent period. The concentrations found in polluted air are rarely more than 0.1 to 0.2 ppm and could not produce pulmonary oedema, but there is evidence from animal experiments that concentrations not much higher than those occasionally found in outside air can produce cellular alterations and structural changes resembling those seen in some human lung disease. On the other hand, very little work has been done on the toxic effects of NO mainly because it used to be thought that it was oxidized immediately to NO_2. However, NO is a very active molecule, capable of forming addition compounds with haemoglobin as does carbon monoxide (see below), and more work is needed to study its true effects (see also (469).

64. Methods of controlling nitrogen oxide emissions have been directed at both combustion sources and chemical processes, since no proven process is currently available for substantial removal of NO_x from stack gases. For stationary sources, the control principle has been based on reducing either the flame temperature or the availability of oxygen, both of which prevent NO formation. Similar principles of control are applicable to motor vehicles. Catalytic principles, which have been applied to reduce NO_x from chemical processes, may also be applicable to the control of NO_x in motor vehicle exhaust.

3. Carbon monoxide

65. Carbon monoxide is formed by the incomplete combustion of fuels, and is a sign of inefficiency. Petrol-engined motor vehicles are the principal source. The carbon monoxide background concentration of clean air has been found to be 0.13-0.14 ppm in the northern hemisphere and 0.06 ppm in the southern hemisphere (341). The worldwide emissions of CO have been estimated to be more than 200 million tons annually, which would increase the background level of CO by 0.03 ppm per year. However, this level is more or less constant. Several removal processes are known that explain this fact. The oxidation of CO by OH radicals seems to be the most important sink. Additionally, carbon monoxide is removed by such natural processes as the metabolic conversion of CO to CO_2 and methane by soil micro-organisms.

66. Table 19 indicates carbon monoxide emissions from different sources in the United States, and illustrates that transportation devices account for about 75 per cent of the carbon monoxide emitted. Distinct seasonal patterns of variation in carbon monoxide emissions are known; these are primarily the result of both traffic and meteorological variables.

67. There is no evidence that the carbon monoxide discharged as a result of man's activities is of any global significance. The only adverse effects known occur in urban areas (especially road tunnels and confined spaces with heavy traffic) where levels can rise sufficiently to block a small proportion of the oxygen-carrying capacity of the blood.

Table 19. CARBON MONOXIDE EMISSION ESTIMATES BY SOURCE CATEGORY FOR THE UNITED STATES

Source	CO x 10^9 kg/year	Percentage
Transportation	101.0	73.7
Fuel combustion in stationary sources	1.6	1.2
Industrial processes	10.8	7.9
Miscellaneous	23.7	17.2

68. When inhaled, carbon monoxide combines with haemoglobin, whose vital function is to transport oxygen. Since carbon monoxide has an affinity for haemoglobin some 240 times that of oxygen, the prime result of this reversible combination is to decrease the capacity of the blood to transport oxygen from the lung to the tissues. It should be noted that carbon monoxide is naturally present in the blood, the normal "background" concentration of blood carboxyhaemoglobin (COHb) is about 0.5 per cent, and this is attributed to endogenous sources such as catabolic processes. Exposure to carbon monoxide in the air does not necessarily raise the level in the blood. For example, continuous exposure to 25 ppm of carbon monoxide will eventually result in 4 per cent saturation, irrespective of the initial concentration in the blood (a person with an initial

saturation of less than 4 per cent will absorb the gas, while a smoker with an initial saturation greater than 4 per cent will exhale carbon monoxide until the COHb concentration falls to 4 per cent. The saturation level of 4 per cent has been selected since higher levels appear to increase the risk for patients with cardiovascular disease.

69. Studies have shown that long-term exposure of animals to carbon monoxide may produce morphological changes in the heart and brain: short-term exposure to low levels of carbon monoxide produces effects on the central nervous system. No long-term exposure studies have been carried out on human beings, although there are some data on occupational exposures. Brief exposures to high levels of carbon monoxide have produced effects on the central nervous, vascular and respiratory systems.

4. Carbon dioxide

70. Carbon dioxide is the final oxidation product of carbonaceous fuels; it is also an abundant compound, intimately involved in the natural cycle and essential to the maintenance of life. It exists in the ambient air at a concentration of around 300 ppm, and it is only if man's activities increase this value so as to interfere adversely with natural processes that carbon dioxide can be considered a pollutant.

71. Carbon dioxide is involved in continuous cycles of interchange between atmosphere and oceans, soil and rock layers, and the biosphere. Both land and marine plants withdraw and use carbon dioxide to create carbohydrate compounds. Animals consume plants, releasing carbon dioxide back to the atmosphere in the process of biological oxidation (respiration). Although the geochemical equilibrium keeps the atmospheric content of carbon dioxide fixed at a level of around 300 ppm, it has been reported that during the past 110 years there has been an increase in atmospheric carbon dioxide from about 295 ppm to 320 ppm (1970 value), i.e. an increase of about 10 per cent. It is estimated that with continued increase of consumption of fossil fuels, the concentration of carbon dioxide in the atmosphere will reach about 375 to 400 ppm in the year 2000, assuming that 35-45 per cent of carbon dioxide released remains in the atmosphere (the rest is removed in the geochemical cycle).

72. This increase in carbon dioxide content in the atmosphere is viewed by some as a possible long-range problem, since it could modify the heat balance of the atmosphere, resulting in possible climatic changes (see below). On the other hand, recent agricultural studies (472) show that huge amounts of carbon dioxide are needed to promote the growth of some plants. Research work is, therefore, needed to establish the exact geochemical cycle of carbon dioxide in order to decide whether it should be considered as a pollutant or not.

5. Particulates

73. With respect to coal-fired boilers, the source of particulates (fly ash) emitted into the atmosphere is the ash content of the fuel burned. Boiler design and method of operation determine to some small degree the extent to which portion of ash in the fuel may drop out in the boiler as "bottom ash" and not appear as particulates in the combustion gases

emitted from the boiler. In the case of oil, the particulates originate from two sources - the ash content of the oil burned and chemical reactions occurring in the combustion process.

74. Different technologies are now available for the removal of particulates from flue gases (wet collection devices, electrostatic separators, etc.), and it is estimated that wider use and further improvement of these technologies may reduce particulates to about one-third of their present level by the year 2000. Unfortunately, however, the present removal devices remove particles down to one micron in diameter only. Finer particles remain suspended and are apt to be carried far from the source and even into the upper layers of the atmosphere. These fine particles contribute relatively little to the total weight of particulate emissions; it takes one thousand particles of 0.5 micron diameter to equal in weight one particle 5 microns in diameter. Yet one ton of fine particles in the air is 25 times as effective in reducing visibility as the same weight of larger particles. There is growing evidence that these fine particles, which can lodge in the deep recesses of the lung, are the ones most responsible for adverse health effects. Small particles can interact with sulphur dioxide in the air to create a much worse health hazard than can SO_2 or particulate pollution independently. There is also growing evidence that small particles tend to worsen the impact of other pollutants on the environment. Another potential impact is that harmful metallic trace elements released in burning fossil fuels are found in the highest concentrations with these small particles.

6. Hydrocarbons

75. Hydrocarbons are formed during the combustion process as a result of incomplete combustion or the occurrence of other chemical reactions. The quantities produced by the combustion of natural gas in conventional steam boilers are considered negligible. The quantity of hydrocarbons produced by the combustion of coal and oil is of possible significance, but can be minimized by good combustion control. However, the bulk of hydrocarbons emitted (about 60 per cent) is produced by motor vehicles. Concentrations of different hydrocarbons vary greatly among urban areas, and accurate monitoring of the different hydrocarbons (especially of polycyclic hydrocarbons, which are considered carcinogenic) are needed to assess their impact on human health. Hydrocarbons are also reported to have an adverse impact on plants.

7. Other pollutants

76. Various metals (for example, mercury, lead, cadmium, beryllium, etc.) are known to occur as trace constituents in coal and oil. Such metals are released in a varying degree by combustion (some constitute volatile compounds, for example arsenic, mercury, etc.). As measurement techniques for determining the concentration of some of these metals in the atmosphere are both difficult and subject to considerable error, there is a lack of sound knowledge in respect to their possible role as significant air pollutants. It has recently been pointed out (284) that coal combustion alone releases into the atmosphere about 3,000 tons of mercury annually

(90 per cent of the mercury in coal is released in stack gases). Many of the trace elements in coal (for example, Sb, Cd, Tl, Se, and Pb) have been found adsorbed on emitted fine particles (345).

77. Gasoline additives (particularly lead) have received special attention, since most of them are emitted with the exhaust products from motor vehicles. Approximately 70 per cent of the lead is emitted from the exhaust pipe as an aerosol, mostly in combination with bromine, chlorine or phosphorus. Although the medical significance of the emission of lead from motor vehicles may be in question, its presence throughout the environment is not in doubt: the dust in most urban streets carrying a reasonable burden of traffic contains lead in concentrations of 1,000 to 3,000 ppm.

78. Power plants burning coal discharge some radioactivity. In the case of coal containing 2.0 ppm of thorium and 1.1 ppm of uranium (typical concentrations as trace elements), the fly ash released annually from a hypothetical 1000 MWe power plant burning 2.3 x 10^6 tons per year and having a 97.5 per cent efficient fly ash removal system would contain 17.2 mCi of ^{226}Ra and 10.8 mCi of ^{228}Ra, which are the daughter products of ^{235}U and ^{232}Th. It has been stated (130) that this total of 28 mCi per year of mixed radium isotopes is approximately equivalent to 10^4 Ci of ^{85}Kr or 10Ci of ^{131}I.

F. OTHER ENVIRONMENTAL IMPACTS OF POWER PRODUCTION FROM FOSSIL FUELS

1. Thermal pollution

79. In thermal power stations, the heat rejected from steam turbine condensers is discharged to the environment in one of two ways. Where there is plentiful cooling water available it is used only once in a "straight through" system, and the warmed water is then returned to its source. Alternatively, where the cooling water supply is limited the warmed water is recirculated through cooling towers and the heat is rejected to the atmosphere in the form of warm air and evaporated water. The recooled circulating water is returned to the steam condensers, thus limiting the demand for fresh water to a small fraction of that required for direct cooling.

80. With direct-cooled systems the major concern for the environment centres on the possible effects of a large and usually continuous discharge of water heated some 9-12°C above the natural temperature of the surrounding water body. Much has been written about the effects of such discharges on the chemical and biological processes that take place in natural waters. However, the establishment of temperature criteria for regulating the ecological consequences of thermal discharges has been one of the most confused, if not controversial, issues in pollution control legislation in many developed countries. There are, certainly, many potential ecological effects of varying significance at all trophic levels, from changes in the mud or in detritus-feeding bacteria to subtle changes in the habits of fish-eating birds. The confusion is attributed to the lack of basic *in situ* biological research into and, especially of long-term

data on, the role of temperature in fresh-water ecology. There is also a tendency to extrapolate laboratory data to cover field situations, using temperature as the single variable (and not current velocity and chemistry, for example). It is therefore felt that long-term studies are essential to determine the real impact of thermal discharges on the ecosystem (265).

81. On the other hand, thermal discharges may have useful applications. They may keep waters in some countries ice-free during at least a part of the winter, which offers advantages for shipping and run-off of rivers. Thermal discharges may also be used in fish farms (aquaculture) and for the accelerated growth of shrimps and lobsters. The use of cooling water for agricultural applications has also been considered (101). There are, however, two basic problems with the possible use of thermal discharges. Firstly, the volume of heated water discharged is generally significantly larger than can be beneficially used. Secondly, the utility of thermal discharges is strongly constrained by climatic conditions, including seasonal changes.

82. With a cooling-tower system, about one third of the heat contained in the cooling water is transferred to the air passing up the tower, and the remaining two thirds is absorbed as latent heat in evaporating about 1 per cent of the water flow. This water vapour also passes up the tower and is discharged to the atmosphere. Two main effects on the environment are associated with cooling towers, the physical effect of the warm air and water vapour discharged and the impact on visual amenity of the large tower structures and their associated plumes. The warm air and water vapour might be expected to have some effect on the local climate (see below).

2. Impact on climate

83. Several theories have been introduced concerning the impact of emissions from fossil-fuel power plants (and transportation devices) on climate. On the local scale, significant climate changes have been found. Urban areas, for example, are noticeably warmer than their rural surroundings. Occasionally urban-rural temperature differences reach 10°C, but on the average cities are 1-2°C warmer. Cooling towers produce fog and drizzle, initiate clouds and increase rainfall. These potential hazards can be lessened through research, by locating towers away from highways, and by thorough examination of a chosen site's local meteorological conditions. Similar climatic changes may occur on the regional scale, with continued growth of fossil fuel consumption, and this may become important by the turn of the present century.

84. On the global scale, there is uncertainty concerning the possible effects of pollutants on global climate. WMO has pointed out that "A fully satisfactory model of atmospheric motions and dynamics needed to forecast the consequences of changing atmospheric composition is not yet available. Hence, estimates of the climatic consequences of increasing atmospheric carbon dioxide are very uncertain" (474). As was noted above, the best available data indicate that the carbon dioxide content in the atmosphere will reach 375-400 ppm in the year 2000; this would warm the lower atmosphere by about 0.5°C. On the other hand, the increase in particulates

in the atmosphere is expected to reduce the amount of incoming solar radiation reaching the earth's surface, thereby tending to decrease the air temperature. However, it is not possible at present to calculate with any accuracy what will be the combined effect of such changes, because the refraction indexes for different types of particles are unsufficiently known. It is postulated that the decrease in temperature due to the effect of particulate matter may lead to the extension of the Arctic ice to a limit 8-10° of latitude south of the present position. The opposite may happen if the temperature increases, due to increasing amounts of carbon dioxide. This could trigger a process by which the Arctic ice might disappear completely.

85. In view of these uncertainties, WMO has initiated the World Weather Watch Programme which includes around the world about 9,000 land observation stations and 5,500 ships for the collection of meteorological data. WMO decided in 1970 to launch a project aiming at the establishment of a global network of observation stations for monitoring atmospheric pollution at background level. The network comprised in 1973 some 90 stations in 43 countries and is now considered a part of the GEMS.

CHAPTER III: NUCLEAR ENERGY

A. INTRODUCTION

86. Nuclear power is one of the alternative sources for meeting world requirements for energy production. Present reasonably assured uranium ore reserves at low price in the OECD countries are adequate for about 5000 GWe years of reactor operation with present reactors. Since estimated additional resources in those same countries are of the same magnitude, the total will be exhausted within a limited period of time unless additional ore becomes available or other reactor types (breeder reactor, plutonium recycle reactor) come into use. This amount of energy is considered significant enough, however, to keep reactors with present technology as an alternative source of energy production.

87. The present nuclear power reactors generate heat by fission, where a uranium atom splits into lighter atoms and gives up energy in the process. In a reactor the rate of fission is controlled to produce the designed power level. The heat is used to produce steam which drives a turbine and a generator to give electrical power. Reactor operation must be distinguished from nuclear weapons, where uncontrolled fission takes place so rapidly that an explosion occurs. Loss of control in a reactor could conceivably destroy the reactor, but would not result in a nuclear explosion.

88. Nuclear reactors are best suited to electricity production, and the most efficient operation is obtained from large base-load power plants. They are also used for ship propulsion (mostly naval vessels) and can be used for industrial applications, district heating and desalination of water. At the present time, most power reactors operate on the fission of uranium. Experimental or prototype systems include the plutonium recycle reactor where plutonium makes up part or all of the fuel, the breeder reactor where a fission reactor is surrounded by uranium which is converted to plutonium - thus generating new fuel slightly faster than the reactor uses it up. Development of the fusion process, where two very light elements combine with release of energy, has not yet reached a stage where fusion can be maintained. A fission reactor produce three types of radioactive material, fission products, activation products from reactor components, and the actinides, typified by plutonium. These materials all constitute radioactive hazards and the success and safety of the nuclear industry depends on controlling them and preventing significant releases into the environment.

89. The present nuclear industry is based on light water reactors which require that the uranium fuel be enriched in the uranium-235 and on isotope, heavy water and graphite reactors, both using natural uranium. The present size of the industry and its projected growth are shown in Table 20. The projections were made in 1974 and now appear optimistic, due to changed economic conditions and environmental objections, and further possible changes. Although the first power reactor began operation only a little over 20 years ago, about 1000 reactor years of experience have been accumulated. This experience indicates that nuclear plants are comparable in reliability to conventional power plants of the same size.

Table 20. PROJECTED WORLD INSTALLED TOTAL ELECTRICAL AND NUCLEAR CAPACITY

	1975	1985	2000
Total electrical	1600 GWe	3200 GWe	8900 GWe
Nuclear	69.8 GWe	620 GWe	3300 GWe
Percentage share of nuclear	5	19	39
Number of nuclear power plants	174 as of 1 November 1975	730 a/	3410 a/

a/ Estimated needs based on additional 1 GWe capacity reactors.

90. Environmental concern has tended to centre on nuclear power, at least partly because it is seen in connexion with the production of nuclear weapons. The success of the nuclear industry depends on the control of the radioactive fission products, activation products and actinides at all stages of operation. A second problem is the requirement for cooling the reactor, with consequent transfer of heat to the environment. The radioactive materials will be covered in some detail in succeeding sections of this chapter, and it should be noted here that they can affect man by external irradiation or by entry into the body through inhalation or ingestion with water or food. Since it is not possible to maintain zero release from a complex system, there have been many attempts to set up acceptable levels for radioactivity in the environment or in man. The acceptable levels are those which result in radiation doses, in addition to natural background radiation, which are kept as far below the dose limits as can reasonably be achieved taking economic and social factors into account. The prime body for developing recommended standards is the International Commission on Radiological Protection (ICRP). Its recommendations have no legal standing, but are the basis of regulations set up by the International Atomic Energy Agency (IAEA) and national bodies. Such standards are generally accepted in evaluating occupational hazards, but their extension to large populations and the environment as a whole has been subjected to extensive criticism and is being reviewed. The standard-setting bodies believe that their recommendations are conservative, but their views are not accepted by some critics. It is not possible to settle this disagreement by any conceivable direct experiment, although long-term studies may allow better approximations to the conditions which would exist following unintended or permissible release of small amount of radioactivity. Present data are more adequate for assessing higher exposures that might occur in a serious accident.

B. THE NUCLEAR FUEL CYCLE

91. The term "nuclear fuel cycle" is used to describe the entire programme from mining of uranium ore through the management of wastes produced in all steps of the cycle. These steps, together with the associated environmental impacts, are discussed below. An important factor in the

nuclear industry is the safeguards system, designed to prevent diversion of nuclear material to the manufacture of nuclear weapons and to prevent any damage to the environment. The International Programme comes under IAEA, while national bodies are responsible for their own programmes.

1. Mining and milling

92. The first stages in the fuel cycle are the extraction of uranium ore and the production of a concentrated uranium oxide suitable for further processing. The uranium concentration in most of the world's ores is very low and the concentration process requires very large quantities of ore and large quantities of water and chemical agents. Uranium ores are mined by either underground, surface or solution mining, depending on the geological setting of the ore. The typical requirements for a 1 GWe reactor would be 200 tons of uranium oxide per year. About 3 x 10^6 tons of overburden would be removed, which might then be replaced after mining was finished. These values are based on an ore containing 0.2 per cent uranium oxide. Mine wastes also include water which arises from mine drainage or from water used in drilling. The occupational exposure of miners to radon and its daughter products would be much higher in underground mines than in open pit mines. The inhalation of radioactive daughter products of radon has produced increased statistical evidence of lung cancer in badly ventilated underground mines where radon concentration was higher than the ICRP concentration limits (226).

93. Milling includes the crushing of the ore, chemical extraction of the uranium with acid or alkaline reagents and preparation of a uranium oxide concentrate. The extraction of the 200 tons of uranium oxide required for a 1 GWe reactor requires handling about 100,000 tons of ore and 250,000 tons of water, most of which would be evaporated into the atmosphere from tailings ponds. The residue after extraction would be over 90 per cent of the original ore. These mill tailings are placed on tailings piles near the mill, giving a volume of about 40,000 m^3 per year. The liquid tailings are held in tailings ponds for evaporation of the water. The liquid tailings would contain small amounts of uranium and some of the radium from the ore. A basic uranium extraction process is also used which requires less water. Both processes give liquid tailings with high chemical content. Radon and finely ground ore residue particules are the prime problems of the milling and concentration processes, the gas escaping from tailings dumps and wind eroding and resuspending radioactive fine particles. The solid tailings contain most of the radium from the ore. This decays to gaseous radon, which is also radioactive. A fraction of the gas escapes from the tailings, but this radon cannot be distinguished from natural atmospheric levels a few km downwind. This is therefore a local problem of radiation exposure. The liquid wastes cannot be disposed of to streams or other bodies of water unless suitably treated. Some of the liquid certainly seeps into the ground but chemical contamination of ground water has not been reported. The most likely accident with environmental consequences is a break in the tailings pile dam, which would increase the chances of ground and surface water contamination. This of course would be a local effect.

2. Enrichment and fuel fabrication

94. The uranium fuel is loaded into a reactor in the form of oxide pellets or metal pins enclosed in a metallic sheath of stainless steel or zirconium alloy (cladding). To maintain efficiency, the fuel must contain a minimum of impurities, so a number of purification steps are included in the milling process, or later in a refining step. For natural uranium fuel, the purified material is converted to metal or oxide, canned in the metallic sheath and assembled into fuel elements. Where enriched uranium is required, the material is converted to uranium hexafluoride and the uranium-235 content raised to about 4 times the natural content by diffusion or centrifugation. The product is then converted to metal or oxide as above. The residual material is depleted in uranium-235, and current practice is to store it for possible use.

95. If sufficient quantities of enriched uranium are brought together, a nuclear fission reaction (criticality) can occur. In such accidents, the heat produced has always dispersed the material sufficiently so that the reaction stops, but a short intense burst of radiation occurs which has caused the death of several workers. The contamination problems have been confined to the buildings concerned. Releases to the environment under normal operations or accident conditions consist of uranium oxide or salts. For inhalation, the main hazard is the radioactivity, while for ingestion it is the chemical toxicity (of the same order as lead). Any releases should be local in nature, the greatest spread coming from an accidental release of large quantities of uranium hexafluoride. No estimate of health effects is available, but they are certainly much smaller than in later steps of the fuel cycle.

3. Reactor operation

96. At the present time virtually all nuclear power production uses so-called thermal reactors. In these reactors, the fission process is induced by neutrons reduced to low energy (thermal energy) by the presence of a moderator in the reactor core. Thermal reactors at present in extensive use employ light water, heavy water or graphite as neutron moderators. The different types of thermal power reactor will release somewhat different amounts of each radionuclide to the environment. In addition a number of reactors that do not contain a neutron moderator, called fast reactors are under development. The importance of the fast reactor lies in its potential ability to utilize essentially all the uranium-238, in addition to the 0.7 per cent of uranium-235 present in natural uranium. However, present fast reactors require fuel that is highly enriched in uranium-235 or plutonium-239. A forecast of growth in nuclear generating capacity in different regions of the world is shown in Table 21. The only experience presently available on the environmental impact of power reactors is for thermal reactors. However the possible extensive use of fast breeder reactors in the future poses the added problems of safety and security, in handling large quantities of plutonium. This problem is discussed in (449).

97. Under normal operation most of the radioactive materials produced in a reactor are fission products formed in the nuclear fuel. Under normal operation, essentially all this radioactivity is contained within the fuel cladding. However, small quantities of some fission products, particularly the more volatile ones (essentially tritium), do diffuse through the fuel cladding, and the quantity depends to some extent on the material and design of the cladding. In addition, fission products can leak out of small cracks that may develop in the cladding. Other radionuclides can be produced by neutron activation of chemical impurities present in the coolant fluid. These are called activation products, and their type and quantity depend to a large extent on the reacter type. Radioactivity can be present in both the liquid and gaseous effluents discharged from reactors.

98. Radioactivity releases from power reactors can give rise to radiation doses to the personnel operating the stations, people living in the neighbourhood of the reactor, and the world populations of man and other biota. Radiation dose rates to the operating staff, which in general are the highest are required to be less than certain standards set by national authorities. The maximum annual radiation dose to people living close to the reactor is also set by similar authorities. Table 22 shows local radiation doses from noble gas releases, received by persons residing in the regions surrounding reactors in the United States in 1969. New information up to the year 1972 is available (448). There are a few radionuclides, the most significant being krypton-85, tritium and possibly carbon-14, which when released to the environment tend to mix somewhat uniformly within the atmosphere and/or the circulating waters of the world. These radionuclides are released from both reactors and nuclear fuel reprocessing plants, so the radiation doses from them will be considered in the section on fuel reprocessing.

99. Various types of accidents are possible during the operation of a nuclear power reactor. The potential danger resides in the fact that, after some time of operation, a huge quantity of fission product activity is present in the fuel elements. For this activity to be released a major rupture or melt-down of the fuel rods would be necessary. To reduce the risk of the accidental release of radioactivity, many safety features are incorporated into reactor design and operating procedures. All reactors incorporate safety systems 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. It is also usual to site the reactor in a locality where there are not large populations in the immediate vicinity so that even in the event of a large release of radioactivity, that population could be quickly evacuated. Up to the present time there has not been a major release of activity from a nuclear power reactor. In spite of these precautions the inherent safety of certain types of reactor has met with some criticism.

Table 21. FORECAST CUMULATED NUCLEAR CAPACITY (GWe) AND ANNUAL FUEL REPROCESSING LOAD ON A GEOGRAPHICAL BASIS FROM 1974 TO 1990

	Regional Nuclear Capacity GWe						Typical Fuel Reprocessing Load, Tons U/y					
Year	North America	Western Europe	Eastern Europe and USSR	Japan	Others	World Total	North America	Western Europe	Eastern Europe and USSR	Japan	Others	World Total
1974	44.8	22.8	4.3	5.2	1.2	78.3	200	262	49	60	25	596
1978	91.5	53.6	14.9	20.6	6.6	187.2	1890	760	212	292	316	3470
1980	138.5	81.3	19.5	32.0	12.0	283.3	2400	1500	365	600	535	5400
1985	295	184	56	60	28.0	623	5600	3800	1150	1250	1200	13000
1990	539	373	146	100	56	1214	10200	7200	2800	1900	2000	24100

Source: (363).

Table 22. CALCULATED DOSES TO UNSHIELDED INDIVIDUALS AND POPULATIONS IN THE VICINITY OF UNITED STATES NUCLEAR POWER PLANTS, FROM NOBLE GASES DISCHARGED IN 1969

Reactor Site	Power produced in MWe/y	Years of production (to December 1970)	Dose at boundary (millirad)	Annual doses for 1969 — Within circle of 80 km radius	
				Population (thousands)	Average dose (millirad)
Dresden - I	100	11	18	5,715	0.063
Big Rock	48	8	3.2	100	0.036
Humboldt Bay	44	8	150	101	1.1
La Crosse	9	3	0.5	328	0.00092
Nine Mile Point	8	1	0.005	533	0.000023
Oyster Creek	40	1	0.37	1,158	0.00052
Yankee Rowe	138	10	0.11	1,209	0.00058
Indian Point 1	206	8	0.055	13,324	0.00015
Conn. Yankee	438	3	5	2,682	0.0058
San Onofre	314	3	0.23	2,696	0.00038
Ginna	17	1	0.005	953	0.0000081

Note: Natural background radiation has a mean value of about 100 millirad/y.

Source: (444).

100. 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 estimated probability of such an accident, obtained in a recent study (450) was of the order of one core melt-down accident for 17,000 reactor years. 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 also on the rapidity with which remedial measures are taken. Apart from these factors, the facts that so far there has been no serious reactor accident, and that the estimated probabilities for such an occurrence are very low, make it impossible to quantify the environmental impact of possible major reactor accidents.

101. A nuclear plant, whether a reactor or a processing plant has a finite economic life, variously estimated at 20 to 40 years, at the end of which the plant can be merely locked up and guarded to prevent access, or more likely disassembled and prepared for other uses. The equipment that has not been contaminated with radioactivity can be handled as in conventional plants. This might include controls, turbines and accessory equipment. Reactor vessels, chemical processing equipment and the like would require treating as solid wastes, with the possibility that a few items could be decontaminated for normal use or re-used in other nuclear plants. The hazards of decommissioning are occupational and the local environmental radioactivity remaining would represent releases during the working lifetime of the plant. If extensive decontamination is carried out, additional liquid wastes will be generated. These should be handled as described in the section on waste management and should not be released to the environment. A survey of the area would be required in order to decide on possible future uses of land and/or buildings. There has been some experience in the decommissioning of small plants. The eventual disposal of the plant must be kept in mind during its design, construction and operation. This should include not only the physical plant but the residues such as tailings. Unless all radioactive material (including high level storage tanks) can be removed from the site, decommissioning would require containing restricted site access and continued monitoring to prevent escapes to the environment.

4. Fuel reprocessing

102. After spent fuel is removed from a reactor, it is stored for a period to allow the decay of short-lived fission products, then transported to a fuel reprocessing plant where it 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. In practice there is a release into the environment, to both the atmosphere and the waterways. Indeed, up to the present time fuel reprocessing plants have been the major source of radioactive environmental contamination from the nuclear industry. Projected requirements for the nuclear fuel reprocessing industry in various regions are shown in Table 21.

103. The environment surrounding nuclear fuel reprocessing plants is monitored for possible radioactive releases. There are several radionuclides which may become a problem in the first half of the next century if their release is not reduced. These are iodine-129, tritium, krypton-85 and possibly carbon-14. At present these are essentially all released to the earth's atmosphere and/or hydrosphere, thereby contributing radiation doses to the world's population. Table 23 gives some information on typical annual releases of tritium, carbon-14 and krypton-85 from a nuclear fuel reprocessing plant per gigawatt of nuclear plant being serviced. Other radionuclides are released in small quantities but their impact is more local, and may effect small numbers of people consuming certain foodstuffs. Estimates of radiation dose rates to large populations resulting from the release of krypton-85, tritium and iodine-129 from the nuclear power industry are shown in Table 24.

104. It is possible, by making a number of assumptions, to estimate what the numbers of health effects, largely some form of cancer, caused by the release of radionuclides from the nuclear industry, would be. Estimates of cancer risks per unit radiation dose have been published by the United Nations Scientific Committee on the Effects of Atomic Radiation, based largely upon studies of the incidence in atom bomb survivors at Hiroshima and Nagasaki as well as in medical patients who received high doses of radiation for therapeutic purposes. Assuming that these risk estimates can be extrapolated down to low doses and dose rates, the projected health effects from the release of iodine-129, tritium-85 and the actinides are shown in Table 25. The assumption here is that all these radionuclides will continue to be completely released into the environment.

<u>Table 23</u>. REPRESENTATIVE RELEASE RATES OF RADIOACTIVE ELEMENTS IN GASEOUS EFFLUENTS FROM RE-PROCESSING PLANTS
(curies/gigawatt - year)

Tritium	16,000
Carbon-14	40
Krypton-85	350,000

105. The figures in Table 25 are likely to represent an upper estimate of risk, the actual being anything between this upper limit and zero, depending on the shape of the dose-effect-relationship curve at low doses and at low dose rates. In the case of the actinides, use of more pessimistic values for the release fraction and resuspension factor gives an increase in the estimated health effects by a factor of 1,000. Prediction of future releases is therefore subject to considerable uncertainty, and estimates of health effects should thus be revised as additional information becomes available. There has been no experience of a major accident, such as fire, at a nuclear fuel reprocessing plant that has caused the release of large amounts of radioactivity.

Table 24. ESTIMATED RADIATION EXPOSURE FROM KRYPTON-85, TRITIUM AND IODINE-129

Population, Group and critical organ	Average dose rate (millirad/yr) Year 1972	2000
Krypton-85		
Local, skin	8.5×10^{-2}	40
$30^{\circ} - 60^{\circ}$, N.gonads	7×10^{-4}	8×10^{-2}
Tritium		
World, gonads	1×10^{-5}	4×10^{-3}
Iodine		
Local, thyroids	1×10^{-3}	4×10^{-2}
World, thyroids	3×10^{-5}	1×10^{-2}

Source: (363).

5. Waste management problems

106. Wastes are produced at all stages of the nuclear fuel cycle, but waste management problems associated with reprocessing of spent fuel seem to be the most severe. Problems relating to nuclear wastes will be reviewed according to waste type, rather than the stage at which it is produced. The philosophy of waste management should be to maintain control over waste products, rather than simply to dispose of them. Currently, wastes are generally handled by:

(a) Dilution and dispersion of low-level liquid and gaseous wastes;

(b) Delay in processing intermediate and high-level wastes until short-lived nuclides have decayed;

(c) Concentration and containment of intermediate and high-level solid liquid and gaseous wastes.

107. Gaseous wastes occur at all stages of the fuel cycle. Radon is released in mining and milling operations where it is accompanied by airborne dusts containing uranium, and radium. The dusts and gases are controlled through the mine ventilation system, particulates being filtered out and handled as solids. During normal operation of nuclear power reactors, tritium, krypton, xenon and two radioactive isotopes of iodine are produced, but most of these are retained within the fuel rods until released during fuel reprocessing. In both heavy and light-water moderated reactors, the small quantities of gases that escape from the fuel rods dissolve in the coolant and very little actually escapes from the system during operation. Reprocessing to extract plutonium and recover uranium in fuel involves cooling and storage to allow short-lived nuclides to decay. The fuel

dissolution operation releases gaseous radionuclides; gas cleaning equipment involving scrubbers and filters has therefore to be used. Release of the gases to the atmosphere is ultimately through high stacks fitted with monitoring equipment, and the area around the plant is also monitored. Some of the physiologically active iodine has been reported escaping, and concern has been expressed regarding the escape and build-up of carbon-14 in the atmosphere. Tritium, the radioactive hydrogen isotope, may also become a problem in the future as it can exchange with normal hydrogen in water. Krypton-85 is a noble gas and being chemically unreactive it is distributed more or less globally, as dictated by meteorological conditions. Systems to remove it are now being planned. In the event of an accident, these same gases might be able to escape from the plant, together with some particulate material. Their distribution in the external environment would depend on meteorological conditions.

108. Mining, milling and refining processes produce some slimes and ore residues which are normally concentrated. Because of its value, as little as possible of the oxide is lost at this stage. Radioactive liquid effluents produced during normal reactor operations include small quantities of fission products that escape to the coolant due to faulty cladding, irradiation products of the coolant, coolant impurities and soluble corrosion products. After ion-exchange removal, the processed effluents are claimed to be of sufficiently low radiation level to be within radiation protection standards for routine operations. Reprocessing plants produce several cubic metres of low-level aqueous wastes each day, primarily fuel storage pond water, evaporator condensates, and some plant effluents. Depending on the radioactive materials present, these may be held for decay of radioactive nuclides, or chemically treated to precipitate them before releasing the liquid under controlled conditions. Tritium is a significant waste product, and tritiated water is released to the environment where it is diluted and dispersed. Medium-activity wastes come mainly from chemical operations, but do include some plant effluents. They usually contain significant quantities of dissolved salts, and are treated by a selection or combination of evaporation, ion exchange, and chemical precipitation, the final products being low-level liquid waste, high-level concentrates and solids. The low-level liquids are discharged. High-level liquid wastes contain the bulk of the fission products generated in power reactors. The first treatment is concentration by evaporation, and the intensely active liquid is stored in multi-shell thick-walled steel tanks. These are usually underground and cooled, and the gaseous effluents are cleaned as described above. Depending on the concentrations of transuranic elements in these tanks, required isolation times may be several hundred thousand years. While temporary storage in modern multishell tanks is considered to be safe, spare capacity is installed to accept the contents of a tank in case of leakage. Older tanks in the United States have indeed leaked; such leakages could contaminate the groundwater, and radioactive materials might then travel through the aquifers. Current research is oriented towards conversion of such liquid wastes to solids.

Table 25. PROJECTED NUMBERS OF HEALTH EFFECTS ATTRIBUTABLE TO RELEASE OF CERTAIN LONG-LIVED RADIONUCLIDES BY NORMAL OPERATION OF THE NUCLEAR POWER INDUSTRY (ESTIMATED FOR ANTICIPATED MINIMUM PERFORMANCE BY INDUSTRY ASSUMING CURRENT RELEASE PRACTICES)

	Cumulative number of health effects							
	Iodine - 129		Tritium		Krypton-85		Actinides	
	Past-present a/	Future b/	Past-present a/	Future b/	Past-present a/	Future b/	Past-present a/	Future b/
1975	0	0	2	0.5	0.3	5	0	0
1985	0	0	35	8	14	79	0	0.4
2000	0.1	0.3	360	81	230	760	0.4	4
2020	0.8	1.7	2,300	500	2,300	4,600	3	21
	ONE FOURTH FATAL		TWO THIRDS FATAL		TWO THIRDS FATAL		ALL FATAL	

Source: (453)

a/ The number of health effects committed from doses received through year (t).

b/ The number of health effects committed from doses delivered after year (t) by radionuclide releases up through year (t) only.

109. All steam-power electrical generating plants, whether fired by fossil or by nuclear fuel, have a common need to release unused heat to the environment. Nuclear reactor steam systems now being used operate at lower temperatures than conventional plants. This results in a lower thermal efficiency with consequent larger heat releases per GWe. The impact of thermal discharges on the environment and the possible beneficial use of these discharges have been discussed in some detail in Chapter II. Cooling towers, whether from conventional or nuclear power plants, add large amounts of water to the atmosphere and under appropriate conditions, this can result in fog, ice formation on trees, roads and transmission lines, or snow. Chemicals, including chlorine, zinc, chromium and phosphates are added to the water in cooling towers to inhibit the growth of organisms within them, corrosion, and the deposition of dissolved salts. These chemicals, transported in tower plumes (spray drift) and in tower blowdown, may have damaging effects on the environment. In addition, cooling towers can pose aesthetic problems, common to both nuclear and fossil fuel plants.

110. Solid tailings from the mining, milling and refining operations can cause radiation exposure problems as they contain radium, which in turn emits radon gas. As the tailings dumps consist of finely ground particles, they are easily eroded by wind. Unless covered with earth to an approximate depth of 15m to retain the particles containing the radium-226, radon can still escape. As the radioactive half-life of radium-226, is 1626 years it will take some 8000 years to decay to about 3 per cent of its initial level, so such dumps will have to remain undisturbed for long periods of time. These dumps require an annual land storage commitment of 1-2 hectares per 1 GWe; it is hoped that in the future, increasing amounts of these tailings might be returned to worked-out mines. Depending on the location of these tailings dumps, rainwater leaching and ground-water recharge might result in aquifer contamination and mobility of radioactive waste.

111. The principal direct solid wastes from fuel reprocessing are metallic discards, cladding cuttings and leached sections of fuel cans; to these must be added the solidified wastes resulting from treatment of liquids and contaminated ion-exchange resins. Usually these metallics are too radioactive for disposal by simple burial, although this procedure has been selected at some facilities where suitably impervious geological strata exist. More often, they are stored in concrete silos on the site, designed and operated in such a way as not to preclude the possibility of ultimate removal and final disposal after a very long decay period. Other solid wastes are monitored and segregated into convenient types - combustible and non-combustible materials, and medium-and low-level activities. A variety of disposal techniques have been adopted for these wastes in different countries. For the lower levels of activity, burial in large trenches on the reprocessing site or on an adjacent site has been used; long-lived activity is limited in these disposals, so that the ultimate release of the site is feasible within a short period of time. Regular monitoring of water draining from such sites is essential.

112. Combustible waste has been incinerated at some sites. This requires cleaning of the gaseous combustion products by conventional scrubbing and filtering techniques, the ash being either subjected to chemical recovery treatment, or stored. It is technically possible that longer-lived active materials such as plutonium, could be extracted from ash to facilitate its ultimate safe disposal in the environment, even though the actual recovery of the plutonium may not be economic in itself. Medium-level solid wastes are generally placed in long-term storage to allow their activity to decay. Table 26 indicates the annual requirements for storage of solid wastes.

113. As seen from the foregoing paragraphs, gaseous radio nuclides that cannot be recovered ultimately find their way to the atmosphere, or, like tritium in water, are widely dispersed in the environment. Liquid wastes that cannot be directly discharged or solidified are stored in large tanks. Some countries, often as a combined international venture, have disposed of low-level solid wastes in the sea. Waste is packed in concrete-encased drums and dumped in selected ocean areas at least 4,000m in depth and well away from fishing grounds. The dumping of high-level wastes has been prohibited under the recently-signed Ocean Dumping Convention. At present there appear to be four general concepts for the storage or ultimate disposal of those high-level or other radioactive wastes which require many centuries or millenia of isolation. They are:

(a) Extraterrestrial (i.e. by disposal into space),

(b) Transmutation - by bombardment with atomic particles to form stable elements or short half-life radionuclides,

(c) On the surface of the earth, which includes using engineered facilities on ground surfaces;

(d) Geological formations on land, or under the sea bed.

114. Until the end of this century, only surface or subsurface storage of solid wastes appear to be viable options, but there may be significant difficulties associated with these techniques depending on the location. Although both are currently in use, such long-term storage is predicated on the stability and imperviousness of geological formations over at least hundreds of thousands of years, situations which geologists are at present unable to predict. Continuous monitoring and surveillance of a surface storage site over such long periods would be difficult, although the stored material would be more accessible if technologies for further reprocessing become available than using storage deep in suitable geological formations. On the other hand, the latter would provide better protection from catastrophic occurrences, and radioactive material would only move through contamination of the groundwater. However, presently, "dry and stable" formations could be changed by earthquakes either natural or man-induced) or by interaction between waste forms and formations, with ultimate corrosion of containers and mobilization of radioactive material.

Table 26. ESTIMATED ANNUAL RATE OF SOLID WASTE ACCUMULATION PER GWe YEAR AND CUMULATIVE QUANTITIES OF SOLID WASTES CONTAINING FISSION PRODUCTS AT REPROCESSING PLANTS
(World total)

	Annual rate	1975	1985	2000
High-Level vitrified wastes				
Cubic metres	2.5	110	6,100	51,100
Kilogrammes	5×10^3	1.1×10^6	1.2×10^7	1.0×10^8
Cladding hulls				
Cubic metres	1.7	374	4,100	35,000
Kilogrammes	7.6×10^3	1.7×10^6	1.8×10^7	1.6×10^8
Low-level solids				
Cubic metres	17 - 115	$3\text{-}25 \times 10^3$	$4\text{-}28 \times 10^4$	$3\text{-}23 \times 10^5$
Kilogrammes	$3\text{-}6.5 \times 10^4$	$6\text{-}14 \times 10^6$	$7\text{-}16 \times 10^7$	$6\text{-}13 \times 10^8$
Storage site area used hectares	9.3	2,000	20,000	200,000

Source: (363)

6. Transport

115. One important aspect of the nuclear industry is the safe transport of radioactive materials. The facilities involved in the nuclear fuel cycle are generally spread out in various locations, 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 with the growth of the nuclear power industry and the present trend indicates that such transport on both national and international scale will rise rapidly. 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. As an example, Table 27 shows the number of different types of shipments in the nuclear fuel cycle in the United States which were made in 1971 and were expected to be made in 1974.

116. 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 "yellow cake" or the subsequent transport of uranium hexafluoride and uranium oxide contained in suitable trasport containers are not likely to result in any environmental effects except for chemicals ores resulting from possible spills.

Table 27. SHIPMENT STATISTICS FOR THE FUEL CYCLE IN THE UNITED STATES a/

	Number of shipments 1971	1974
Mill ---> Converter (as U_3O_8)	704	1071
Converter ---> Enrichment Plant (as UF_6)	938	1438
Enrichment Plant Powder and Pellet Mfgrs. (as enriched UF_6)	781	1347
Powder and Pellet Mfgrs. ---> Fabricators (as enriched U_3O_8 powder or pellets)	136	223
Fuel Fabricators ↑ Reactors (as fuel elements)	272	360
Reactors ---> Spent Fuel Reprocessing (as spent fuel elements)	76	1417

a/ An undetermined number of air shipments were made.

117. A typical 1 GWe light water power reactor (LWR) needs a fuel charge of about 90-120 tons of slightly enriched uranium depending upon type of reactor. About one-third of the fuel is replaced annually. The fuel elements are shipped in packages designed to prevent accidental criticality even under severe accident conditions (tests include drops from a height of 9 metres, submersion in water and exposure to fire). The radio activity of the new, unirradiated fuel, about 3 curies per ton, 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. Radiation doses in excess of 500 roentgen equivalents (man) 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 including approval by the competent authority of container design and construction the possibility of reaching criticality during transport is practically eliminated. This is also evidenced by the experience of 30 years of nuclear industry during which no such criticality accident during transport of fissile material has been reported.

118. Spent fuel elements contain large amounts of radioactive fission products, and are therefore stored for a period of time to allow the short-lived radioactivity to decay before shipment is made. Spent fuel elements are transported in shielded air or water-cooled casks weighing 20 tons or more. The heavy shielding of the casks must reduce the radiation from the spent fuel elements inside to permissible levels, or else the casks must be sent under special arrangements. Under normal transport conditions the radiation doses exposure to transport workers, such as truck drivers, train brakemen, large operators etc. are (should be) kept within permissible values by the limitation of the radiation around the containers. If the workers are handling substantial numbers of shipment, 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. From Table 27 some appreciation can be gained of the quantity of fuel to be shipped between nuclear power plants and spent fuel reprocessing plants on a geographical basis.

119. 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.

120. Packaging and transport of radioactive materials are regulated by international as well as national transport regulations. 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.

C. NUCLEAR SAFEGUARDS AND ENVIRONMENTAL PROTECTION

121. 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. Therefore, an enormous effort is required, both nationally and internationally, in order to prevent any diversion of nuclear material or sabotage of nuclear installations.

122. The establishment and implementation of a physical protection system is the primary responsibility of a country and is closely connected to its national system of accounting and safeguards for 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, IAEA has initiated and implemented a nuclear safeguards system. Following the obligations that are assumed by IAEA Member States under international legal instruments such as the Non-Proliferation Treaty, the most existing nuclear power plants and auxiliary installations in the non-nuclear weapons States are presently under international safeguards.

123. The increase in the international transport of nuclear material has generated a growing interest on the part of many nations in establishing an international regime for the physical protection of this material during transportation. IAEA has prepared a set of procedures for physical security of handling nuclear materials and this was accepted by the IAEA General Conference in 1975. Plans are afoot to draw up an international convention to set standards for the protection of nuclear material in inter-State transport.

124. The possibilities of establishing regional centres for the enrichment, fabrication and reprocessing of nuclear material are at present being examined by IAEA. It is believed that locating such installations in centres could be economically attractive and would have great advantages from the point of view both of physical protection and of international safeguards.

1. Technical control measures and institutions

125. The inherent safety problems of the nuclear power industry have long been realized both by Governments and by the industry itself. While national Governments are responsible for the establishment and implementation of physical protection systems and the control of nuclear materials, these tend to be based on or at least strongly influenced by the recommendations of a number of international institutions. ICRP develops recommendations on radiation dose limits for individuals (and occupational groups) and the United Nations Scientific Committee on the Effects of Atomic Radiation evaluates global releases of radioactivity and assesses their impact on man. IAEA develops technical standards and guidelines concerning the safety of nuclear facilities and the handling of materials. These standards and guidelines are based on ICRP recommendations, and IAEA works very closely with WHO. It also co-operates with national and international regulatory agencies in the development of regulations that relate to nuclear matters in other spheres.

2. Land-use considerations

126. Land committed to the establishment of different nuclear facilities of the LWR and HTGR nuclear fuel cycle has been estimated by USAEC. Such data are drawn up on the basis of present United States nuclear power industry practices and may differ from experiences in other nations. Comparable data are not readily available for non-nuclear power stations. The total global land use based on LWR power plants may be estimated as given in Table 28.

Table 28. GLOBAL LAND USE - NUCLEAR POWER THROUGH THE YEAR 2000 (hect. x 10^4)

Base facilities	7.2	30	670
Land "usage" (cumulative)	0.15	1.7	14
Land committed	4.1	45	370

These figures would have to be considerably increased to include heavy-water and breeder reactors. They therefore highlight the need for careful consideration of alternate land uses before construction, particularly encroachment on prime quality agricultural land at a time when it is already under pressure from urban and industrial demand.

CHAPTER IV: RENEWABLE SOURCES OF ENERGY

A. INTRODUCTION

127. For the greater part of the last century the rising global demand for energy has been met to an increasing extent by the use of fossil fuels, chiefly in the form of oil and natural gas. This trend was encouraged by the comparatively low price of oil, which in many instances has not been used in the most efficient manner. With the ever-rising demand for fossil fuels there has been an accompanying realization that these energy resources are finite in extent and should therefore be regarded as wasting assets. It has been argued that fossil fuel resources which have accumulated over millions of years will be consumed in a twinkling of geological time. As shortages develop in various fossil fuels, the laws of supply and demand can be expected to increase their price levels. This in turn will encourage further exploration activity resulting in the probable location of additional supplies. In these circumstances, it is not possible to make any reliable estimate, at the present time, of when fossil fuel resources will be exhausted. However, whatever the future rate of depreciation will be it is generally acknowledged that exhaustion will take place at some time preceded by a period of shortage. The general realization of the finite nature of fossil fuel resources has caused a re-examination of the possibility of using those energy resources which are of a non-depleting nature and, therefore, considered renewable. These energy sources are increasingly important, particularly in developing countries.

B. GEOTHERMAL ENERGY

128. A great amount of heat is known to be stored in the earth's crust. The base of the crust, which is some 25-30 km beneath the surface of the earth, is estimated to be at temperatures ranging from 200 to 1,000°C. The amount of heat in the outer 10 kms, if available has been estimated to be 3×10^{26} calories, which is more than 2,000 times the heat represented by the total coal resources of the world (316). In some favourable zones of the earth's crust (called seismic-active zones, which are usually zones of young volcanism and mountain-building located along the margins of major crustal plates), volcanic activity may be frequent. This includes the outpouring of magma (molten mass of the earth's mantle) in the form of lava flows from volcanoes and/or the creation of intrusive bodies of high thermal value, hot springs, geysers and fumaroles along favourable fissure planes. Water convenction systems can also contribute effectively to the transfer of heat.

129. Water makes possible the extraction of heat from deep seated rocks. Water derived from geothermal activity was formerly considered to be of magmatic origin. However, recent geochemical studies indicate that most of this water is derived from surface precipitation seeping down into porous rocks heated by magma, and therefore, it is "meteoric" rather than typically "volcanic". The early history of geothermal development and exploitation saw the utilization of thermal springs as baths and health resorts, and the occasional use of thermal waters to heat buildings. Today geothermal energy is used for electricity production, heating purposes, greenhouses, etc. Geothermal resources (dry steam and wet steam) have been exploited to generate electricity in relatively limited areas at Larderello and Mount Amiata (Italy), Wairakei and Kawerau (New Zealand), the Geysers (United States), Cerro Prieto and Pathe (Mexico), Otake and Matsukawa (Japan), Pauzhetka and Paratunka

(Soviet Union) and Namafjall (Iceland). Electric power was first generated from geothermal sources in Italy in 1904, using a pilot-scale reciprocating engine. In 1913, a 250 kW turbo-alternator replaced the reciprocating engine; geothermal electric production on an industrial scale dates from this year.

130. Today the electrical generating capacity in the main geothermal fields amounts to more than 1,000 MW and is projected to reach about 2,500 MW by 1980 (Table 29). Conservative estimates are that 100,000 MW of generating capacity could be developed by the end of this century. Several exploration programmes for geothermal fields are taking place in many countries (especially in the developing countries) with the assistance of the United Nations (for example, projects are being carried out in Kenya, Ethiopia, Chile, India, ... etc.).

131. Hot water reservoirs are also now being exploited for heating in several countries. Greenhouse heating, for example, has been expanding in Iceland since 1920 (the total ground area covered by glass has been estimated to be more than 100,000 m^2). Heating on a commercial scale is also developed in Hungary, the Soviet Union, New Zealand and the United States. Small-scale heating for buildings and greenhouses is in operation in France, Czechoslovakia, Romania, and other countries. Other uses include animal breeding, drying of timber and diatomaceous earth, processing of cellulose (New Zealand, etc.).

132. From the techno-economic point of view, it has been found feasible to utilize the hot fluids directly at the location of geothermal wells. Accordingly, the power plants and/or greenhouses should be located near the steam-extraction area. Cost/benefit analysis has shown that geothermal power is at least competitive with the power produced by conventional thermal, hydraulic or nuclear sources. In suitable locations, the cost of producing a geothermal kWh is lower than that for conventional thermal generating plant.

<u>Table 29</u>. INSTALLED ELECTRICAL GENERATING CAPACITY OF GEOTHERMAL POWER STATIONS

Country	September 1975 (MW)	Projected 1980 (MW)
El Salvador	30	-
Iceland	3	-
Italy	417	450
Japan	35	60
Mexico	75	150
New Zealand	190	-
Soviet Union	5	25
United States	502	1180
Total	1,257	1,865

<u>Source</u>: After (285), (274), (80) and (326).

133. The impact of geothermal energy on the environment can be divided into four categories:

(a) Impact on land;

(b) Impact on air;

(c) Impact on water; and

(d) Noise.

134. Geothermal resources are tapped by drilling wells to various depths (generally 300-2,700 m). The wells, pipelines and associated facilities of the producing field modify the existing terrain (it has been estimated that about 15 km^2 are needed to drill the some 150 wells required to generate 1,000 MW). However, because the wells themselves and the pipelines occupy small patches and strips of the field, most of the land could be used for varied agricultural purposes. Land subsidence may be a potential effect, although no subsidence has so far been recorded in dry steam fields. Subsidence is more likely to occur in hot-water fields which behave like unconsolidated petroleum reservoirs. This probability can be minimized by injecting waste fluids into the reservoir. This process may, however, accelerate seismic effects in the area (although a re-injection experiment recently carried out in the Viterbo region, Italy involved no seismic or micro-seismic effects (Cameli et al., personal communication 1975), such effects have been detected in connexion with deep-well disposal of industrial wastes in some countries). The Los Alamos Scientific Laboratory proposes to use hydrofracturing techniques similar to those employed in petroleum recovery to create large cracks in a bed of hard rock (for example, granite) near an extinct volcanic area. The cracks would expose a large area of rock to a circulating flow of pressurized water pumped down one well and up another to extract the heat. At the top of the well, the heat would be transferred to a secondary fluid before being delivered to a turbine. The unknown geotechnical behaviour of the hard rocks at the temperatures and pressures in question and the associated earth-activities remain to be clarified. Stimulation of geothermal fields by using either large chemical or small nuclear explosive devices merits further examination.

135. Geothermal activity liberates noxious gases. Such gases include mainly carbon dioxide, hydrogen sulphide, hydrogen, methane, nitrogen and ammonia. Boric acid, hydrofluoric acid, hydro-chloric acid and minor amounts of mercury, selenium and arsenic compounds may also be released.

136. Although many gases can be separated from the steam in geothermal plants, hydrogen sulphide dissolves readily in water and can escape into the atmosphere during the cooling process. Estimates indicate that the amount of sulphur escaping the Geysers (California) is equivalent to that emitted by a fossil-fuel plant of the same size burning low-sulphur oil, and that at the hot water plant at Cerro Prieto, the sulphur release might exceed that of comparable fossil-fuel plants burning high-sulphur fuel. Since hydrogen sulphide is heavier than air, it tends to settle towards the ground, particularly during conditions of temperature inversion. The smell of hydrogen sulphide in and around geothermal power stations is frequently strong. Although individual responses to hydrogen sulphide vary, the mean concentration

for human detection is only 0.002 ppm; irritation to the human eye occurs at 10 ppm and to human lungs at 20 ppm. Accurate data for hydrogen sulphide concentration in and around geothermal power plants are lacking, although it is estimated to be around the limit detectable by man.

137. Carbon dioxide also constitutes an appreciable portion of the non-condensable gases in geothermal fields (in the Geysers, for example, about 82 per cent while in Larderello it may constitute up to 94 per cent). The emission of carbon dioxide from a geothermal plant is, however, lower than that from a coal-fired plant of comparable electrical capacity. For example, a 1,000 MW geothermal plant emits about 860 tons of carbon dioxide per day, while a coal-fired plant of the same capacity emits about 20,000 tons of carbon dioxide per day. Whether carbon dioxide is to be considered as a pollutant or not depends, again, on our exact knowledge of its geochemical cycle.

138. Some mercury, selenium and arsenic compounds are associated with the volatile constituents in geothermal fields. Aerometric measurements carried out in Iceland show that mercury is greatly increased near fumarolic areas (1.3 - 37 micrograms per cubic metre as compared to 0.6 - 1.0 in non-thermal areas). In Hawaii, values up to 40.7 micrograms of mercury per cubic metre have been reported (415). Prolonged exposure to atmospheric levels in excess of 0.1 microgram/m^3 is harmful to human beings, and levels well in excess of this amount exist even at distances of 350 km or more from active sites in Hawaii.

139. Radioactive measurements of radon (428) at several geothermal reservoirs indicate that the environmental impact of radon release into the atmosphere appears to be small, and indistinguishable from that generated by natural emanations from the surrounding land mass.

140. Concerning the environmental impacts on water, it should be noted that dry steam geothermal fields offer the most economic and environmentally acceptable conditions, since the steam produced does not involve the handling of large quantities of hot brine requiring subsequent disposal. Wet steam fields, on the other hand, produce hot water which may be equal to three times the weight of the steam produced. All plants should, therefore, have centrifugal separators to separate the steam and water. The steam is then handled in the same way as that produced in dry steam fields and the water is taken by pipe or by channel to a disposal point. In New Zealand, where the salinity of the geothermal fluid is low (about one tenth that of sea water), the water is simply discharged into a large neighbouring river, with negligible environmental effects. In some other fields, the disposal of the waste waters could pose a substantial problem. For example, near the Salton Sea in California, the salt content of geothermal waters reaches 20 per cent compared to about 3.3 per cent in sea water. On the other hand, although the geothermal fluids in, for example, Cerro Prieto (Mexico) are less highly mineralized (about 2 per cent), a huge amount of salt water would be produced from a 1,000 MW plant containing an estimated 1,200 tons of salt per day. Deep well injection of these waste waters seems to be a promising solution, since in addition to disposing of the waste, the injection could help prevent land subsidence that may occur in some geothermal fields.

141. Geothermal plants release more water vapour and waste heat into the atmosphere than other types of plants. Being less efficient than a fossil-fuel or nuclear plant, a 1,000 MW geothermal plant evaporates 11-13 x 10^4 m^3 of water per day, as compared to 9-11 x 10^4 and 5-8 x 10^4 m^3 per day for nuclear and fossil-fuel plants of the same generating capacity. Table 30 illustrates the differences between the thermal effluents from Wairakei geothermal plants and those from fossil-fuel plants. Although the waste heat and water vapour from even large-scale geothermal developments would represent at most a few per cent of that produced by natural processes, the effect of this additional heat on the local weather is not known and would probably depend greatly on the prevailing meteorological conditions.

142. Noise may constitute a potential environmental hazard if the geothermal wells are allowed to discharge to the atmosphere for long periods, without installing some type of silencing device. Not only is the noise most unpleasant to those working or living in the vicinity, but it can also cause permanent damage to the hearing of people more or less continuously exposed to it at close quarters. Noise inside the power stations is, however, of the same magnitude as in conventional fossil-fuel power stations.

Table 30. COMPARISON OF THERMAL EFFLUENTS FROM THREE POWER PLANTS

	E a/	Electrical Output (MW)	Waste heat Thermal (MW)
Wairakei geothermal	8.3%	143	1575
Huntly, New Zealand (Fossil-fuel)	35%	1000	1860
United States (Fossil fuel)	42%	1000	1380

Source: After (21)

a/ E = net electrical efficiency = $\frac{\text{net electrical output}}{\text{total thermal input}}$

C. HYDRO-ELECTRIC POWER

143. Although water power has been used since prehistoric times to drive water mills, it came into major vogue only with the use of elctricity to transmit power over long distances. Hydro-electric power is a utilization of the kinetic energy of a fast-moving body of water, such as a river or rapids, and is developed through man-made dams.

144. Although in the developed countries most of the hydro-power resources have been exploited, only 8.6 per cent of this power potential in the developing world has been so far utilized. Many large rivers flow through the developing regions of the world, and offer sites where immense power stations could be constructed. However, in many cases the demand for power within economic transmission distance of these sites is not large enough to support such project. In these cases, local electricity demand must be stimulated through - intensive industries, in order to develop such hydro-electric projects.

145. The actual capacity of world hydro-resources is given in Table 31, together with the calculated watts per capita in the different regions. This table shows that despite the fact that the actual hydro-power capacity in Asia amounts to nearly 25 per cent of world capacity, its high population mean that the per capita capacity is only 68.8, the lowest in the world.

Table 31. ACTUAL INSTALLED CAPACITY OF WORLD HYDRO POWER

	Capacity (MW)	Percentage of world	Watts per capita
Asia	140,538	25.3	68.8
Africa	145,218	26.2	407.2
Western Europe	50,043	9.0	126.6
Eastern Europe	52,918	9.2	150.8
North America	57,728	10.6	252.5
South America	95,628	17.4	331.7
Oceania	12,987	2.3	642.9
World	555,060	100.0	150.7

Source: Survey of Energy Resources, World Energy Conference, 1974.

146. Although hydro-electric resources are generally considered to involve few constraints and little inconvenience to the socio-ecological environment, there are a number of environmental side-effects associated with dam construction that deserve serious consideration. No dam can be built and no lake can be created without environmental costs of some kind. A dam becomes a dominant factor in the hydrological regime, and sets in motion a series of impacts on physical, biological and socio-cultural systems. The construction of a dam and the filling of its reservoir cause substantial local change by introducing an immense structure into a natural setting. The flooding of the region could have immediate significant impact on the means of communication, historic sites, communities which are inundated, and the local flora and fauna. The dam itself presents an obstacle not only to the free running of water, but also to fish migration and navigation. Continued fish migration may be achieved by the construction of fish ladders, or by collecting fish and transporting them by road. In the case of some very high dams, artificial conditions favourable to spawning have been constructed below the dam, and eggs cultured under ideal conditions in hatcheries. While this is a costly process, it can ensure the survival of larger numbers of eggs and fingerlings than possible under natural conditions. Care must also be taken to assure migration during dam construction. Traditional navigation routes either have to be changed, or very costly canal and lock systems constructed if they are not to be abandoned.

147. The many consequences on the environment of the dam and the lake behind it appear to be factors in common regardless of the dam's geographical location. However, the environmental effects of reservoirs located in tropical areas occur more quickly than those located in temperate zones.

148. The environmental side-effects of dam construction are generally divided into three categories:

(a) The local effects and the reactions within the area of the reservoir;

(b) The downstream effects resulting from a change in the hydraulic regime;

(c) The regional effects in terms of the overall aspects of changes, with particular emphasis on sociological effects.

149. The environmental impacts of man-made lakes and the reactions within the area of the lake are summarized in the cyclic flow-sheet given in Figure 4. The physical impacts of man-made lakes include minor changes in local climate, especially in humidity, leading to a minor increase in fog in some cases. The hydrological cycle in the lake area is markedly affected. The variation of the level of groundwater up and downstream, water seepage and possible erosion downstream are the most important effects encountered. The load of water in the lake may also enhance seismic activity around the dam (micro-seismic activities have been recorded in the Kariba Dam area).

150. From the geochemical and bio-geochemical points of view, the filling of a reservoir produces marked modifications in the aquatic system which existed before its installation. Changes in water quality resulting from the new environment especially through the action of bacteria and eutrophication, are generally encountered. Strong variations in the nutrient contents (nitrogen and phosphorus compounds) and in the amount of some trace elements have been recorded. The increase in nutrients causes a more or less extensive development of bacteria and algae, which gives the water a disagreeable odour and taste and affects its oxygen concentration, which may be catastrophic for some species of fish; it may lead also to anaerobic conditions. In some cases, nitrogen supersaturation may be alarming (for example, it was estimated in 1970 that nearly 90 per cent of the downstream migrating salmon of the Snake River in the United States were killed largely because of nitrogen supersaturation).

151. In tropical regions, the enhanced development of aquatic vegetation (for example, water lettuce and water hyacinth) may give rise to serious problems_ in particular, it may hamper navigation and fishing, shelter disease-carrying insects, reduce the dissolved oxygen level in water or produce marked changes in the chemical composition of the water.

152. Although many vector-borne diseases occur in temperate region, they are generally more widespread and pose more serious health problems in the tropics. Among the most important of these are malaria, schistosomiasis and onchocerciasis, whose vectors pass all or part of their life-cycles in water. The blackfly which carries onchocerciasis prefers to breed in fast-flowing streams, while malarial mosquitoes breed in stagnant water. Impoundments resulting from dam construction have been responsible for shifts in the relative distribution of these two diseases and have provided ideal habitats for the water snails that carry schistosomiasis.

153. From the socio-economic point of view, the construction of dams and creation of lakes leads to a re-adjustment of the human settlements in the area of construction, which may be favourable or unfavourable according to the regional conditions and the dam site. In general, dams have a number of beneficial effects: they control floods and lead to a better development of irrigation systems, thereby increasing agricultural output. The production of power accelerates socio-economic development and the creation of a man-made lake promotes several activities in agriculture, fisheries, tourism and industry.

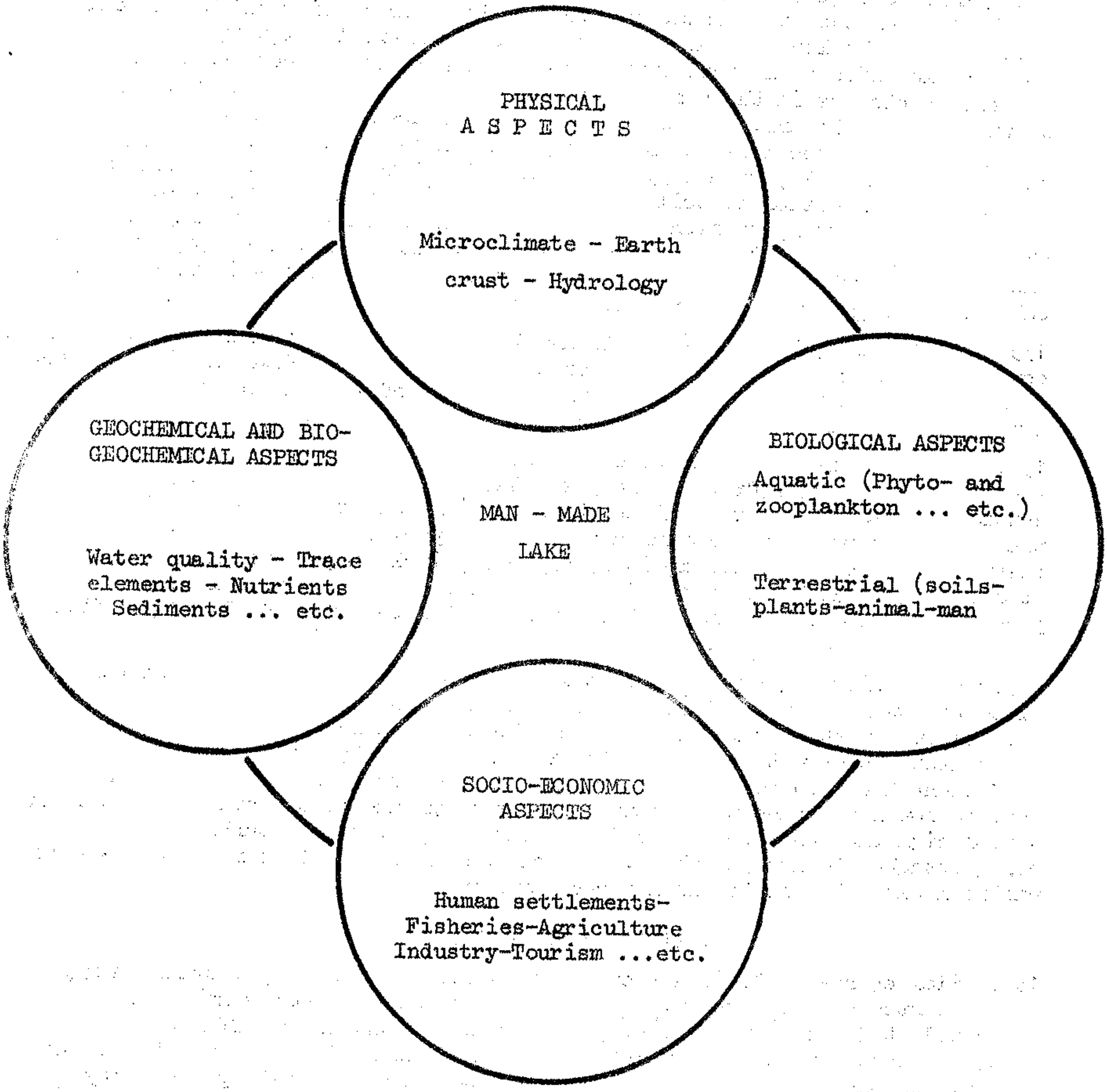
PHYSICAL
A S P E C T S
Microclimate - Earth
crust - Hydrology
GEOCHEMICAL AND BIO-
GEOCHEMICAL ASPECTS
Water quality - Trace
elements - Nutrients
Sediments ... etc.
MAN - MADE
LAKE
BIOLOGICAL ASPECTS
Aquatic (Phyto- and
zooplankton ... etc.)
Terrestrial (soils-
plants-animal-man
SOCIO-ECONOMIC
ASPECTS
Human settlements-
Fisheries-Agriculture
Industry-Tourism ...etc.

Figure 4.

154. With respect to downstream effects, the consequences of a change in the hydraulic regime result in the reduction in frequency and amplitude of floods. On the other hand, the changes in water quality and biological activity and the lowering of the silt content can create significant undesirable effects on agriculture. These effects can be compensated for in part by changes in the agricultural system and by the use of increased amounts of fertilizers. The change in the hydrological regime of the river has an effect on the irrigation system, and unless an efficient drainage network is available, waterlogging of irrigated lands may occur, leading to serious degradation of soils. The decrease in the silt content of the water leads to strong erosion of the river banks downstream, and may enhance the erosive effect of the sea on the delta shorelines near the outpourings of the river. Furthermore, the changes in water quality and nutrients may have substantial impacts on fishing industries.

155. Dam failures, both small-scale and large-scale, are well documented. Their consequences vary according to the size of the dam and include flooding of vast areas, destruction of property, death, spreading of several diseases, etc. Large-scale dam failures rank as major disasters.

156. The environmental side-effects associated with dam construction for the exploitation of hydroelectric power therefore deserve more serious consideration. Extensive studies should be carried out to find remedies for the effects created by existing dams. Future projects must be planned to ensure a broadly inter-disciplinary approach, including environmental impact studies. The construction of dams and the harnessing of hydroelectric power would then offer man improved quality of life, with the least possible impact on the environment.

157. With a view to supplying electric power to small communities located close to low-head hydro-electric power sites, considerable work has been carried out on the development of small bulb-type hydro power plants. These machines operate on a level differential of only a few feet, and a sufficient head can be obtained by the construction of a simple weir. A further low-head generating plant has been developed with a rim generator. In this design the generator rotor is an integral part of the turbine rotor, being attached to its periphery. The compact nature of this machine makes it particularly relevant to tidal power development.

D. TIDAL AND WAVE POWER

158. Tidal energy is derived from the combined kinetic and potential energy of the earth-moon-sun system. The energy from tidaly sources has been estimated at 3×10^{12} watts (426), and can be harnessed in different ways, the most important of which are the one-basin scheme and the two-basin scheme. In the first, tidal power is obtained from the filling and emptying of a bay or estuary that can be closed by a dam. The basin is allowed to fill and empty over brief periods at high and low tides in order to develop as much power as possible. This scheme has the disadvantage that the power available varies with the tide conditions. In the second scheme, two basins are separated by a dam containing the turbogenerator units. The higher basin is filled with the incoming tide and the water is allowed to flow through the turbines into the lower basin. The latter is permitted to empty itself at low tide. The basic objective of this scheme is to increase the versatility of the system by providing for power generation at any time . It is, however, more expensive than the single-basin scheme since an additional system of dams is required.

159. The possibility of harnessing tidal energy has been exploited in France and the Soviet Union. The world's first major tidal electric power plant (single-basin type with 24 generator units) was completed in 1966 at La Rance estuary, in France; its capacity is 240 MW. Some of the promising tidal power sites are given in Table 32. However, the world's tidal resources are small and are unlikely to ever provide more than 60,000 to 100,000 MW of power, a very small fraction of world demand.

Table 32. TIDAL POWER SITES

Site	Average tidal range	Basin area	Maximum possible annual energy 10^6 kWh
Minas-Cobequid, United States-Canada	10.7 m	770 km^2	171,000
White Sea, Soviet Union	5.6 m	1980 km^2	122,000
San Jose, Argentina	5.9 m	740 km^2	50,000
Severn, United Kingdom	9.8 m	70 km^2	13,100
Mezen, Soviet Union	6.6 m	138 km^2	11,600
La Rance, France	8.4 m	23 km^2	2,400

Source: After (198).

160. Tidal energy is not without environmental impacts. The creation of man-made reservoirs in coastal areas receives little spontaneous sympathy from the community at large. Land drainage and movement of sediments (mud flats, etc.) are among the important geomorphological impacts that deserve detailed study. Furthermore, the ecological effects associated with the change in the environment in the coastal zone need careful consideration.

161. Large quantities of energy are available in the waves near the coasts of a number of countries, and with further development of simple modular devices could provide surprisingly large supplies of electric power: e.g., about half the total electricity requirement of the United Kingdom could be met in a stretch of ocean as short as 1,000 km. Availability is high throughout the year and tends to correspond to the pattern of electricity demand. Large-scale use of wave generators would have significant environmental effects. Their low profile would mitigate their visual impact, but they would involve power transmission systems on shore. The removal of a large fraction of natural wave energy might affect coastal erosion, deposition and sea-water turbidity. The devices would also interfere with coastal navigation, fishing and recreation and would require special protection against storms.

E. SOLAR ENERGY

162. The sun supplies the earth with a huge amount of energy, estimated at 173,000 x 10^{12} watts. However, about 30 per cent of the incident solar energy is directly reflected and scattered back into space as short-wave length radiation, while about 47 per cent is absorbed by the atmosphere, the land surface and the oceans are converted directly into heat at the ambient surface temperature. Another 23 per cent is consumed by the evaporation, convection, precipitation and surface runoff of water in the hydrological cycle. A small portion of the solar energy is captured by the chlorophyll of plant leaves, where it becomes the essential energy supply of the photosynthetic process and eventually of the plant and animal kingdoms.

163. The most favourable sites for collecting and exploiting solar energy are confined to desert areas between latitudes 35° north and south of the equator. These areas receive some 3,000 to 4,000 hours of sunshine per year; the amount of solar energy incident on a horizontal surface ranges from 300 to 650 calories per square centimetre per day. It is of particular importance to note that about 80 per cent of the earth's population lives between these two latitudes, which include many of the poorest and most underdeveloped human settlements. The energy needs of such settlements are quite modest compared to the needs of more developed urban areas. Power for these small local settlements cannot be provided economically by large-scale conventional generation at central sites, largely because of the high cost of transmission where the population density is low. The cost of fuels for local power plants is also greatly inflated by distance, doubling in a few hundred kilometres over land. It seems, therefore, that solar-powered devices (together with other alternative sources of energy) are the most promising solution to raise productivity and the standards of living in such local human settlements.

164. Solar energy could be exploited in four different ways (see also (292):

(a) Use of direct solar energy without conversion;

(b) Use of power derived from small-scale conversion of solar energy;

(c) Use of power derived from large-scale conversion (either thermal or photovoltaic conversion);

(d) Use of solar energy for photosynthesis, bio-gas production and other chemical processes.

165. Direct use of solar energy without any conversion has been known for centuries. Crop drying, food cooking, water heating, water distillation, greenhouses, space heating and high-temperature solar furnaces for research or for industrial purposes (e.g. production of some chemicals, baking of bricks, etc.) are among the most important uses of direct solar energy. New technologies in this field have given rise to a great number of designs of equipment that are used in many countries.

166. Small-scale conversion of solar energy into power to operate water pumps, refrigerators, etc. is also developing rapidly. Arrays of silicon cells are used in spacecraft to supply electrical needs. Terrestrial uses include power for navigation lights on offshore platforms, microwave repeater stations, air-navigation beacons, highway emergency call systems, etc.

167. Large-scale conversion of solar energy into power has been experimented with since the beginning of this century. In 1912, Frank Shuman built near Cairo the first such power plant, which generated 50 kW. His model had seven reflectors, spaced apart so as not to shadow each other. They were parabolic in shape to generate the highest temperature at the focal point, in the tubes producing steam. The reflectors, each 61 m long, followed the sun automatically as it moved across the sky. This was accomplished with power from the solar engine, special gears and thermostat sensing elements. Shuman's model worked with about 50 per cent efficiency to provide power for irrigation.

168. Three main schemes for converting solar energy into power are under detailed investigation, particularly from the techno-economic point of view. The first involves the use of photocells, which have an efficiency of about 10 per cent (such photocells have been used on space vehicles). This means that for a 1,000 MW generating station, 10,000 MW of solar energy must be collected. Under favourable meteorological conditions, and allowing for night-time, the cells will receive only one sixth of the incident sunlight, which means that to produce 1,000 MW of power, the solar station would have to cover a considerable area. The second scheme makes use of the hothouse effect by means of selective coatings on pipes carrying a molten mixture of sodium and potassium raised by solar energy to a temperature of 540°C. By means of a heat exchanger this heat is stored at a constant temperature in an insulated chamber filled with a mixture of sodium and potassium chlorides that has enough heat capacity for at least one day's collection. Heat exchanged from this chamber operates a conventional steam power plant. The computed efficiency for this proposal is said to be 30 per cent. The third system entails reflecting the radiation reaching a suitable area into a solar furnace and boiler at the top of a 1,500 feet tower. Heat from the boiler would be converted into electric power. An energy-storage system based on the hydrolysis of water is also proposed. An overall efficiency of about 20 per cent is estimated.

169. Solar generation of electricity for use on earth holds the promise of an abundant clean source of power. The question of utilizing solar radiation for central power generation thus becomes primarily a question of establishing its economy in comparison with contemporary power systems considering future trends in energy conversion, fuel cost, and the cost of environmental protection.

170. Since energy from the sun is very diffuse, large land areas are required for solar energy collectors (estimated area requirements for a 1,000 MWe plant are about 10 km^2 and 30 km^2 for power produced by thermal conversion and photovoltaic conversion, respectively). The construction of solar power plants will have an impact on the local ecosystem (through the construction of roads and sites for solar collectors, shading of parts of the land, the threat to some species of mammals, reptiles, birds, etc.).

Collecting surfaces absorb more sunlight than the earth does, and while small-scale use is not likely to alter the local thermal balance, the larger collecting surface in a central power plant might. Thermal pollution will also be a problem if water-cooled turbines are used. However, because of the lack of particulate emissions and radiation hazards, solar thermal power plants would be more environmentally acceptable than fossil-fuel or nuclear power plants. It is important, therefore, that a policy of research and review for environmental effects be made an integral part of the research and development process of solar energy. When considering large land-based systems, great care must be taken to find suitable areas that would not be of unique ecological or recreational importance, and whose use would not cause serious alternations in local climate or weather.

171. The use of solar energy for space heating, air conditioning, and water heating is one of the most environmentally benign systems and an attractive possibility for conservation of non-renewable energy resources. It would, therefore, be appropriate to mount efforts to utilize solar energy in local applications for building services. An important consideration in such applications is that most of the energy required by buildings is low-temperature heat. For example, space heating requires air at approximately 28°C and water-heating temperatures are commonly 60-65°C. These temperatures are below the reject heat temperatures of most steam power plants. At present, combustion of high-energy fuels, such as natural gas or fuel oil, is used to provide this low-temperature heat. But in this practice the capacity of the fuel to produce energy is permanently lost. The utilization of solar energy would therefore be an important means of conservation.

172. For these reasons, several development programmes for harnessing solar energy are presently being carried out. In the United States a National Science Foundation/National Aeronautics and Space Agency Panel concluded in 1972 that building heating could be in public use within 5 years, building cooling in 6 to 10 years and electricity production in 10 to 15 years. It has also been concluded that by allocating suitable funds (considerably less than those allocated to the development of nuclear energy), solar energy, which so far has had a minimal impact on the environment, could be made available on a large scale. By the year 2020, solar energy could provide in the United States at least 35 per cent of the heating and cooling of buildings, more than 30 per cent of methane and hydrogen requirements and more than 20 per cent of the electricity needs.

F. SEA THERMAL POWER

173. Between the tropics of Cancer and Capricorn the ocean's surface temperature stays almost constantly at 25°C because of the equilibrium between the heat collected from sunlight and the heat lost through evaporation. Far from the equator, the cold water melted from snow and ice sinks to the depths of the oceans and slowly moves toward the equator. In the tropics this cold water provides a nearly infinite heat sink at about 5°C at a depth as shallow as 1,000 feet. The temperature difference between the surface and the depths could be used to drive a Rankin-cycle heat engine. Although the theoretical efficiency is 9 per cent for a 10°C temperature difference, the efficiency of a real power plant would be 2-4 per cent. The first sea thermal power plant was built by Claude in Cuba in 1930 and produced 22 kW. Two experimental units of 3,500 kW net output were installed off the Ivory Coast in 1956 by the French. Experiments are at present being carried out aimed at demonstrating the feasibility of this system using modern technology and material.

174. Large-scale use of sea thermal power is actually limited by a combination of technical and economic problems. Several concepts have to be investigated in detail: floating units near or offshore, the type of working fluid (the most promising at present seem to be water vapour, ammonia and propane), and the energy transmission systems to be used. However, the magnitude of sea thermal power makes it important to increase efforts in research and development aimed at exploiting this resource. Like any solar process, this power is continuously renewed by the sun.

175. In a sea thermal power plant operating without a secondary working fluid, the warm sea water found at the surface of tropical seas is boiled under vaccum. This produces large quantities of purified water as a by-product of the production of electricity. The availability of considerable quantities of purified water from a sea thermal power plant could be of particular importance to the environment of a water-short area if the plant were located close enough to the shore. It is not difficult to envisage circumstances where the output of purified water from the power plant would be more significant to the local environment than the production of electricity.

176. The possible environmental effects associated with large-scale use of sea thermal power, involving possible regional changes in sea temperature and the associated effects on marine life would need to be studied. The pumping of deep cold water to the ocean surface for cooling purposes in a sea thermal power plant would result in a substantial enrichment of the nutrient level of the surface water. This could be expected to have an effect upon marine growth in the vicinity, but whether the result would be environmentally beneficial in the form of a more plentiful supply of fish, or environmentally objectionable because of the creation of vast beds of algae growth would need careful investigation.

G. WIND ENERGY

177. Man has been using wind for sailing ships, for pumping water and for supplying mills with power for centuries. Wind generators of about 0.1 MW have been built and operated in the Soviet Union, Denmark, the Netherlands and other countries. Several hundred thousand wind pumps have made an essential contribution to the utilization of semi-arid deserts and for many decades have been the very precondition for farming in these regions.

178. The potential amount of wind energy available is very large, since it is continuously regenerated in the atmosphere under the influence of radiant energy from the sun, and this is a self-renewing source of power. However, a number of techno-economic problems need to be solved if wind power is to be used for electricity production on a large scale. A conceptual design using aerotubines to produce 160 billion kWh of electricity per year has recently been completed for the offshore New England region of the United States. This preliminary study shows that the electrical power, when used to produce hydrogen which is then piped on shore for consumption in power plants, is cost-competitive with conventional methods of producing electrical power.

179. The total power which could be generated by wind by the year 2000 has been estimated at about 19 per cent of the electricity production in the United States in that year. This would necessitate the use of land areas of up to 550,000 square kilometres to install the wind-powered generators, transmission lines and necessary roads, etc. Besides this impact on land use, large numbers of densely concentrated wind-powered generators might also alter local wind patterns. These potential effects have not, hitherto, been studied in detail. Nevertheless, wind could constitute a useful source of energy, either primary or supplemental, in villages of many of the developing countries.

H. RENEWABLE FUEL SOURCES

180. The natural conversion of solar energy into plant materials by photosynthesis and the further conversion of this stored energy into more concentrated forms such as natural gas, petroleum and coal is the basis of the world's fossil-fuel supply. The managed production of plant tissue (e.g. trees, grasses, water plants, fresh water and marine algae) on suitable land and water areas, with more efficient use of solar energy and required nutrients, could provide materials that could serve directly as fuels for production of part of man's energy needs, or could be subsequently converted into other forms of higher-quality fuels. Estimates are that such managed production could yield up to 40 tons of trees per acre per year, between 13 to 15 tons of grasses, between 20 to 30 tons of algae and up to 85 tons (as dry weight) of water plants (for example, hyacinth). It has also been estimated that an energy plantation covering between 1,000 and 1,300 square kilometres could produce enough fuel to provide 1,000 MW electric power plant with a continuously renewable fuel supply. Furthermore, large amounts of solid wastes - agricultural, animal, industrial, and urban - which are presently creating grave environmental problems represent a rich energy resource that could be utilized. However, the amount of organic wastes available varies from one country to another, according to the degree of development.

181. Plant tissue and organic wastes can be converted directly into thermal energy by combustion, or into more concentrated fuels by a number of biological or chemical processes (Figure 5). The choice of conversion method is frequently dictated by the physical nature of the material. The biological conversion of organic wastes (anaerobic digestion process) has long been used for the treatment of municipal sanitary sewage sludge in which the principal objective is the reduction in volume and stabilization of the sewage sludge. The production of methane has been of only secondary importance. However, with increasing interest in exploring new energy sources, special efforts have been devoted to the development of different types of digesters for the production of methane. The character of the digester is mainly determined by the composition of the material fed to it and the species of micro-organisms present, and by other factors such as temperature, loading rate, hydraulic residence time, sludge (biomass) retention time, and the degree of mixing of the digester contents. The volatile products produced contain from 50 to 70 per cent methane, with carbon dioxide representing almost all of the residue. Trace amounts of hydrogen sulphide and nitrogen are also encountered.

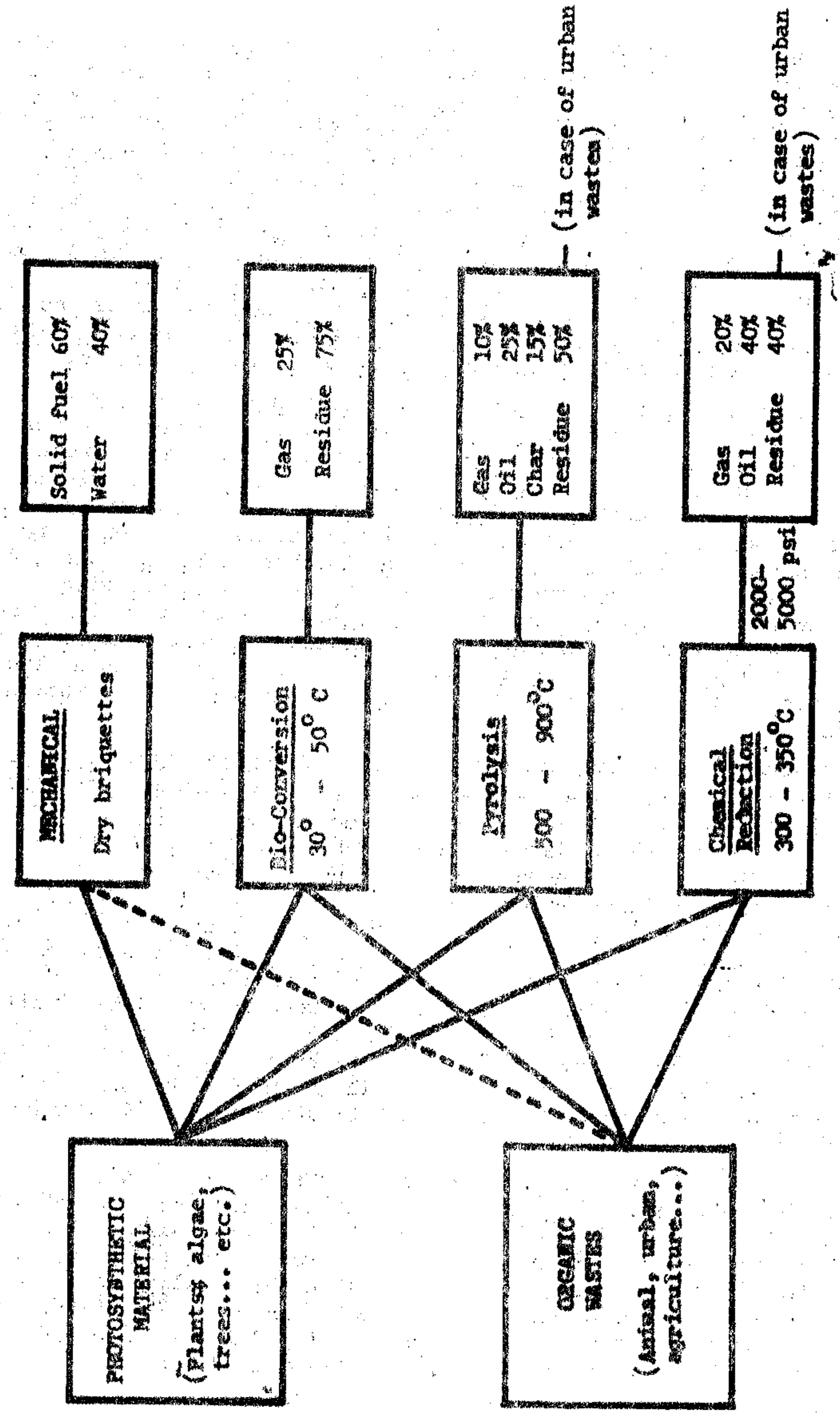

Figure 6.5. PRODUCTION OF RENEWABLE FUEL FROM ORGANIC MATERIAL

182. Although bio-conversion is theoretically a simple process, a large number of problems remain to be solved. They include the need for new techniques to feed solids into the digesters and inexpensive ways to collect and purify the methane, recirculate the effluents, and control pollution. A major environmental problem is the disposal of the organic sludge that remains after digestion, which may amount to 40 per cent weight of the starting material. However, this sludge generally has a high protein content and could be used as a raw material for the manufacture of animal feed and/or fertilizers. The first successful "gobar gas" (gobar means dung) plant, devised in India in 1959, can take in all forms of animal excreta. Between 1961 and 1973, about 7,500 such plants were installed and plans are that 20,000 more will be installed by the end of 1975. Apart from the gas, organic manure obtained from the residual slurry is used as a fertilizer.

183. Chemical conversion of organic wastes into fuel is carried out either by a deoxygenation (or chemical reduction) process by carbon monoxide and steam, or by pyrolysis. Under optimum conditions, the former process converts as much as 99 per cent of the carbon content to oil, yielding about 290 kg per ton of dry waste. In practice, more than 85 per cent conversion is normally obtained, but because some of the oil must be used to provide heat and carbon monoxide for the reaction, the net yield is about 180 kg per ton of dry waste. The product is a heavy paraffinic oil with an oxygen content averaging about 10 per cent and a nitrogen content that may reach 5 per cent when manure is the starting material. Sulphur content is generally lower than 0.4 per cent well below the limits for heating oils applied in many cities. The energy value of the oil is about the same as that of normal fuel oil.

184. The conversion of organic wastes into fuels by pyrolysis is a process of destructive distillation carried out in a closed vessel in an atmosphere devoid of oxygen. The gases produced are usually a mixture of hydrogen, methane, carbon monoxide, carbon dioxide and the lower hydrocarbons. The liquids are oil-like and the solids are similar to charcoal. Several pilot and semi-industrial projects have been developed (for example, the Garrett flash pyrolysis process, the Monsanto pyrolysis process, etc.) for the recycling of municipal solid wastes. Such processes enable more than one barrel of low-sulphur oil to be obtained from each ton of raw wet minicipal refuse (152). Most of these processes are highly versatile. Such diverse feedstocks as coal, tree bark and waste timber, rice hulls, sewage sludge, cattle feedlot waste and used rubber tires could be converted to gas or oil. Combustion tests on the oil produced from these wastes have shown it to be a perfectly acceptable substitute for the oil commonly burnt by electric utilities.

185. The production of fuels from organic materials is not without environmental impacts. Apart from the extensive land areas and/or ponds necessary for the photosynthetic production of plants and/or algae, several environmental problems have to be solved during the processing of the organic material. The main issues include the handling of organic wastes and the disposal of sludge and residues from the digesters. Once the fuel is produced, the environmental impacts of its use are more or less similar to those encountered in using conventional fuels.

186. Useful amounts of energy may be obtained by the burning of domestic garbage, and there are many examples of power plants operating in North America and Europe which rely entirely upon this fuel. Although there are the usual environmental disadvantages which apply to all thermal power stations, the burning of garbage in this manner avoids the environmental hazards associated with dumping garbage on open land or in the sea. It should be stressed however that the success of these garbage-fired power stations in the developed parts of the world is due to the constitution of the garbage which includes a high proportion of paper, cardboard and other combustible material. An analysis of typical garbage from developing countries in the tropics reveals that the calorific value is lower since it contains a low proportion of paper and a high proportion of vegetable material.

187. For more than a billion people in the rural areas of developing countries, energy needs are largely met by the use of firewood and charcoal from plants. Extensive use of these fuels is leading to deforestation with consequent gradual changes in climatic conditions, particularly rainfall. The other impacts of this unplanned deforestation are soil erosion and reduction of soil fertility, thereby reducing crop-bearing capacity.

CHAPTER V: ENERGY AND FUEL CONSERVATION

188. In the past, insufficient attention has been given to the need for energy conservation. Largely as a result of recent increases in price of fossil fuels, the situation has now changed. Several studies are being carried out to find the most efficient ways of utilizing energy, thereby reducing the ever-increasing consumption of our energy resources. Some of the general policy options for reducing the demand for energy are: limiting the rate of growth of population, altering the character of economic growth, changing life styles, mainly by land-use planning, greater use of public transport and telecommunications, and modifying existing regulations that contribute to increased use of energy resources. It should be emphasized that lower energy consumption can go hand in hand with environmental enhancement. The reduction in energy demand through energy conservation measures, particularly in developed countries, can improve environmental quality and life style, and offers potential for economic improvements throughout the world by reducing the demand for scarce resources. Conservation is probably the most fruitful approach to the world's energy problems, but the legitimate needs of the developing countries indicate that, no matter the extent to which industrial nations can reduce their profligate consumption, demand for energy will increase over the next several years. Energy production and use have both direct and indirect impacts on the environment, and every effort must be made to assess their environmental and social costs and benefits, as well as the purely monetary ones.

189. The multi-purpose use of energy resources is a fertile untapped area for energy conservation. For example, the utilization of waste heat for certain specific applications would appear to have both economic and environmental advantages, and would appear to be a viable conservation measure. It has been pointed out (33) that multi-purpose use of geothermal resources has many advantages - both economical and environmental - over single-purpose development.

190. Improvements in methods of resource extraction and processing for coal, oil, gas and uranium could result in the availability of additional fuel. Such methods include, for example liquefaction or gasifiction of low-grade coal, production of methanol from oil and coal, secondary recovery of oil, extraction of oil from oil-shales and tar sands, etc. This increased fuel availability would however require substantial investment in improving extraction efficiency, and would result in various environmental impacts beyond those associated with current resource extraction methods. Any decisions to employ methods of extracting increased resources would have to balance the potential payoff in fuel availability against the economic and environmental costs associated with each method.

191. It is anticipated that hydrogen will play an important role in future energy uses. It is not a primary source of energy, but could be a convenient form for transport, storage and utilization of energy. Hydrogen is readily synthesized from natural hydrocarbons; it is also a by-product of some petroleum refinery operations, and has also been manufactured by gasification of coal, coke and lignite. Gasification of carbonaceous fuels requires a supply of heat at a high temperature, and this could be

of nuclear origin if a suitable heat carrier such as helium and adequate refractory containment were available, or of conventional origin if electrical energy for heating were sufficiently cheap. Very cheap electrical energy could also be used to generate hydrogen by the electrolysis of water. It will be apparent, however, that whatever the means used for manufacturing hydrogen its thermal value will be less than that of the energy required to produce it, and therefore its production can only be justified in circumstances where its special characteristics make it particularly desirable or where the energy consumed in its manufacture would otherwise be wasted. Hydrogen can be stored in many forms: as a cryogenic liquid, as a gas under pressure, or in metal hydrides from which hydrogen can be recovered by heating. The most promising future large-scale use of liquid hydrogen would be as fuel for jet aircraft, long-haul motor freight and city buses. With regard to its environmental characteristics, hydrogen is a clean fuel in that it is made from water and its combustion results primarily in water vapour, with little or no pollutants or emissions of the type associated with most other fuels (some NO_x may be emitted). However, in producing hydrogen either from fossil-fuels or from water, there are some environmental effects. Furthermore, there is the question of safety in handling liquid hydrogen (fire and explosion hazards).

192. Potential improvements in power plant conversion efficiencies using current technology appear to be limited, and are not expected to change significantly the amount of usable energy that may be extracted from fuels. However, recent trends in conversion development will lead to a reduction in the amounts of fuels. One of the energy conversion systems is the combined gas-steam cycle system, which is a combined gas turbine and steam plant. Here the hot exhaust from the power turbine (gas) is used to generate steam in an unfired boiler. The steam is used in a conventional system to generate about 50 per cent more power without additional fuel. The combined cycle thermal efficiency is comparable with that of a modern steam plant (it varies from 36 to 38 per cent). This system involves the emission of almost negligible amounts of stack gas pollutants (CO, HC, SO_x and fly ash).

193. Another conversion system under development is the binary cycle system. In this system a combination of two different cycles is used to take maximum advantage of the temperature range available. When a second cycle is added to the high-temperature end of another cycle, it is called a topping cycle (usually using mercury or potassium as working fluid). On the other hand, when the cycle is added to the low-temperature end, it is called a bottoming cycle (usually using ammonia or organic fluids as a working fluid). The thermal efficiency of the binary cycle system varies from 45 to 55 per cent, according to the type of cycle used. This high efficiency reduces the burden of thermal discharges on the environment and the consumption of fuels. The reduction of fossil fuel consumption automatically reduces the quantity of most of the air pollutants produced per unit of electrical energy generated. However, any leakage of working gluid may have detri- -tal effects on the environment.

194. A third trend in conversion systems is the development of magneto-hydrodynamics (MHD) power generation systems. The MHD genera is a heat engine that converts thermal energy directly into electric it has an efficiency in the range of 50 to 60 per cent. The environmen..

problems associated with MHD power plants are essentially those associated with the energy source used (fossil fuel or nuclear fuel). However, the MHD systems have the potential to reduce thermal discharges and conserve fuel supplies, due to their high conversion efficiencies. The seed materials used in some MHD systems (mainly alkali metal salts) must be removed from effluent gases for environmental as well as economic reasons (the cost of these materials dictates that they must be recycled for economic operation).

195. A fourth trend in energy conversion development is the use of fuel cells. Such cells have been manufactured on a limited production basis for space application, and several fuel cell power generation systems in the 10 to 20 KWe range have been constructed and operated. The current fuel cells use carbon monoxide, hydrogen or methane; their efficiency is claimed to vary from 55 to 70 per cent.

196. The "Energy Park Concept", which consists of concentration of electric generating capacity in a relatively small geographic area, has been recently proposed. Energy parks with a range of capacity between 10,000 and 20,000 MWe have been proposed by the year 2000. These parks could be fossil-fuelled, or mixed fossil and nuclear fuelled. Besides the engineering and techno-economic problems that need to be solved before the energy parks can become a reality, there are some potential environmental problems that need careful investigation (see 254). The types of environmental impacts for an energy park are essentially the same as those of the dispersed siting alternative. However, the intensity of the impacts will be accentuated at the specific location of the energy park. This is particularly true with respect to the water-consumption demand and the meteorological impact of heat dissipation. The meteorological impacts associated with evaporation and waste heat rejection may produce increased incidence of storms and rainfall, and the combined shadowing/microclimatological effects of persistent tower plumes. Air pollution control requirements, as well as water availability and heat rejection considerations, tend, therefore, to favour dispersed siting of power generation plants, particularly fossil-fuel units. On the other hand, from an overall waste management or effluent control standpoint, the approach of "concentrate, contain and control" would appear to have significant advantages, from an overall environmental impact view, over a "dilute and disperse" concept. Models should, therefore, be developed and data must be gathered on a site-specific basis to obtain a better understanding of the environmental impacts of energy parks. Special studies should be devoted to the possible effects of the huge amounts of SO_X and particulate emissions from the fossil-fuel components of the park on the local and regional ambient air quality.

197. Conservation of energy at the point of end use has only recently begun to receive wide attention. In contrast to the several measures discussed above, end-use conservation can result in very substantial and worthwhile energy savings. The technical means by which these savings may be achieved are known and include the installation of improved insulation in buildings, the use of more efficient space heating and cooling systems, the introduction of more efficient industrial processes and the shift to more efficient modes of trasportation. In the field of energy-intensive industries, for example,

new methods of steel-making promise reductions in energy consumption of up to 25 per cent, and similar reductions might be possible through improved cell design for the manufacture of aluminium. Low-grade ores that will probably be used in the future will increase energy consumption, but recycling of aluminium would use only one-fifth of that energy.

198. Environmental enhancement in some cases requires the consumption of more energy. However, no attempt has so far been made to quantify all the additional energy demands of environmental control efforts. Preliminary calculations have been made for two important energy consuming sectors, power plants and the automobile. For power plants an increase of about 7 per cent in the fuels used will be required to remove particulates and sulphur oxides and to control thermal pollution. An additional 18.4 per cent in energy use will be needed to meet future auto emission standards (337). The introduction of the "electric car", at least in urban areas, would lead to a marked reduction in local air pollution. Some electric cars are now used on a limited scale (for example, in Zermatt, Switzerland), and various research programmes are being carried out to increase the efficiency of these vehicles (especially mileage without recharging the batteries). Another development in the transportation sector is to use methanol obtained from coal or organic wastes as a fuel, either alone or in combination with gasoline. This will not only reduce the consumption of gasoline, but will also eliminate the use for lead additives and markedly reduce air pollution.

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