REPORT

OF THE

COMMITTEE OF INQUIRY

ON THE

PROPOSAL TO USE ATOMIC ENERGY

FOR THE

GENERATION OF ELECTRIC POWER IN SRI LANKA

National Science Council of Sri Lanka
47/5, Maitland Place
Colombo 7.

FOREWORD

The global energy crisis has adversely affected the economies of developing countries, especially those which have no known resources of fossil fuels. In Sri Lanka the major indigenous source of commercial energy, hydro-power, is limited. It will be necessary to depend on alternative sources of energy for meeting the growing demand for electricity. Against this background the Cabinet of Ministers took a decision on 23 July, 1980, to start a "programme that would lead to the production of electricity using a nuclear reactor ...."

The place of nuclear energy for electrical power generation has been the focus of much opposition and controversy in the developed countries. The Cabinet decision to start a nuclear programme generated a similar controversy and there was public discussion regarding the benefits and the dangers of nuclear power.

His Excellency the President, by his letter of 16 October, 1980, to the Hon. Minister of Industries and Scientific Affairs, suggested that the controversy on nuclear power would be a suitable matter for examination by the National Science Council. The Hon. Minister, directed the Council to examine and report on the proposal to use nuclear power for the generation of electrical power.

The Council discussed the Hon. Minister's directive, at its meetings of 31 October and 14 November, 1980, and appointed a Committee of six - of these two were members of the Council and one was subsequently appointed to the Council - to examine and report on the subject.

The Committee consisted of the following :-

Dr. J.A. Gunawardena (Chairman) - Professor of Electrical Engineering, University of Peradeniya

Dr. G.A. Dissanaike - Professor of Physics, University of Peradeniya

Dr. J.K.P. Ariyaratne - Professor of Chemistry, University of Kelaniya

Mr. Lyn de Alwis - Director, Department of Wild Life Conservation

Dr. P.L.T. Fernando - Physicist, Cancer Institute, Maharagama

Dr. R.S. Jayatilake - Consultant Oncologist, Cancer Institute, Maharagama

The Committee made a detailed study of the subject. Its report was handed over to the Council on 16 April, 1982. The report was tabled at the meeting of the Council 23 April, 1982. The Council accepted the report, and requested that copies be handed over to the Hon. Minister of Industries and Scientific Affairs to be forwarded to His Excellency The President.

Chairman

RP Jayewardene

Secretary-General

25 April, 1982

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TABLE OF CONTENTS

PREFACE

The National Science Council at its meeting on 14 November, 1980, appointed a Committee to examine and report on the controversy regarding the use of nuclear energy for electric power generation in Sri Lanka, taking into account,

(a) the biological and environmental hazards associated with nuclear power reactors, and counter-measures against such hazards,

(b) the demand for electric power and energy in Sri Lanka,

(c) ways and means of meeting the energy and power requirements.

Following the appointment of the Committee of Inquiry, the National Science Council issued a press notice calling for public representation on the subject. The press notice appeared in all three languages in the national newspapers of 15 and 16 November, 1980. The English version of this notice is given in Appendix 4 (a).

Twenty one persons responded to the press notice with written submissions and sixteen persons were invited to present oral evidence (see Appendix 4(b) and 4(c) for lists of names).

The Committee met on 45 occasions between 28 November, 1980 and 16 April, 1982.

The report is in eight chapters; all subsidiary material is given as Appendices. The conclusions and recommendations of the Committee are listed in Chapters 7 and 8.

Acknowledgements

The Committee wishes to express its thanks to the members of the public who responded to the press notice, and to those who gave oral evidence before the Committee. It wishes to acknowledge with gratitude the useful information, literature and data

provided by Dr. K.G. Dharmawardena, Chairman, Atomic Energy Authority, Mr. E.H. Dharmasena of the Government Cancer Institute, Maharagama, Mr. John Diandas of Messers A.I. Macan Markar and Company, Dr. P.N. Fernando of the Ceylon Electricity Board and Dr. F.R. Senanayake of the State Timber Corporation.

The Committee also wishes to acknowledge the material made available to it by Dr. S.N. Arseculeratne, Mr. A.M. Chanmugam, Mr. N.G.R. Fernando, Dr. S. Gnanalingam and Mr. David Newby.

The work of the Committee was facilitated by the documentation and information services of the Sri Lanka Science and Technical Information Centre of the NSC and several other institutions. In particular it wishes to acknowledge the resource materials provided by the following institutions:

1. The American Centre, Colombo 7
2. The American Centre, Kandy
3. Bhaba Atomic Research Centre, Bombay, India
4. The British High Commission, Colombo 3
5. The International Atomic Energy Agency, Nuclear Data Section
6. International Institute for Environment and Development

The Committee wishes to make special mention of Miss S.M. Jayasuriya of the staff of SLSTIC, who was extremely helpful in obtaining much of the literature required for its work, and Mrs. G.S. Fernando who did much of the typing required.

The Committee wishes to express its gratitude to Miss T.K.A. Peiris and Mrs. S. Ratnayake of the NSC for secretarial services, to Miss I.R. de Silva of the NSC and Mrs. E.M.P. Gamage of the Department of Mechanical Engineering, University of Peradeniya for preparation of figures, and to the machine operating staff of the NSC for photocopying, off-set printing and binding of the Report.

Finally the Committee wishes to make special reference to the excellent facilities placed at its disposal for this work, for which it owes a debt of gratitude to Dr. R.P. Jayewardene, Secretary-General and the Staff of the National Science Council of Sri Lanka.

National Science Council of Sri Lanka
Colombo 7

16 April, 1982

CHAPTER 1

INTRODUCTION

1.1 For the vast majority of our people, struggling against the bonds of poverty, the need to increase agricultural and industrial production is desperate. This in turn makes the need for more energy very urgent, a fact that has not been fully recognised in the past. The steep increases in the prices of petroleum products in the seventies and the power cuts of 1980 and 1981 have made even the affluent minority aware of the need for alternative sources of energy. Conservation of fuel and electricity, although commendable, cannot provide a solution in a context where the per capita consumption of energy is small.

1.2 Energy from fuel and electricity is a substitute for and a supplement to the work done by humans and draught animals. The fundamental laws of nature that govern the processes of energy transfer in material systems are well understood. Science has every reason to believe that these laws are inviolable. A direct consequence of these laws is that, at low levels of consumption, material well being cannot improve without an increase in the consumption of energy. This is a lesson that we can learn from history. The developed countries, extravagant users of energy, can reduce their consumption of energy while maintaining their standard of living. However, the quality of life of the poor nations cannot be improved without an increase in their consumption of energy.

1.3 Measures to control and discourage the use of energy have been suggested in this country. The control of energy consumption will not produce endless queues, as it did in the case of rice and infant foods, for energy is rarely sold over a counter. This makes proposals to control the consumption of energy appear attractive at first sight. But without energy, production will suffer and the effect on the economy will be disastrous.

1.4 Much publicity has been given to research work on the feasibility of harnessing alternative sources of energy such as bio-gas, solar radiation, wind and ocean thermal energy. Although some useful results have been obtained, or are likely to be obtained in the future, none of these sources will provide significant quantities of energy to the national grid during this century. Our own research programmes into alternative sources of energy are poorly funded and suffer from lack of scientific staff. Even if these constraints were to be removed, worthwhile results would take a long time to come. The national economy cannot afford to wait indefinitely for these results. It is therefore imperative that this country makes adequate plans to meet all its energy requirements in the foreseeable future. Such plans should be based on well established technologies.

1.5 We no longer delude ourselves with the belief that this country has enormous resources of hydro-energy. There are only three other sources of energy, based on proven technology, that could supply the national electricity grid. These are coal, oil and nuclear. It is genearlly accepted that, of these three, oil would become prohibitively expensive in the future.

1.6 However, this does not mean that coal and nuclear energy would become preferable to oil for, as the price of petroleum rises, the prices of coal and nuclear fuel, and the capital cost of power plants will also rise. Therefore it is necessary to conduct detailed studies of the economic, financial, technological and international political implications before choosing between these three alternatives. Such detailed studies are beyond the scope of the work of this committee, but we have made certain observations regarding this aspect in Chapters 2 and 3.

1.7 Oil burning power stations of various types have been employed in Sri Lanka for many years. Up to now there have been no large coal burning power stations. However, this technology is not very different from that of power stations that burn oil to raise steam. The boiler of a coal burning plant would be different from that of an oil burning one. Further, special facilities for transporting and stock-piling of coal would be required.

1.8 The generator, turbine, and part of the steam circuit of a nuclear plant are similar to those of a coal or oil burning plant. However, the primary mechanism of energy release is vastly different in a nuclear reactor.

1.9 In a coal or oil furnace, energy is released by the familiar process of burning. In a nuclear reactor, energy is released in the form of intense radiation which gets converted to heat. The temperatures thus produced are far higher than those in a furnace. The radiation emitted is lethal and is contained by various barriers. Any leakage of radiation or radioactive material can have disastrous consequences on the plant, the workers in the plant and living things in the neighbourhood, (see chapters 4 and 5). It is this inherent danger in nuclear power plants that has made nuclear power a subject of such public controversy.

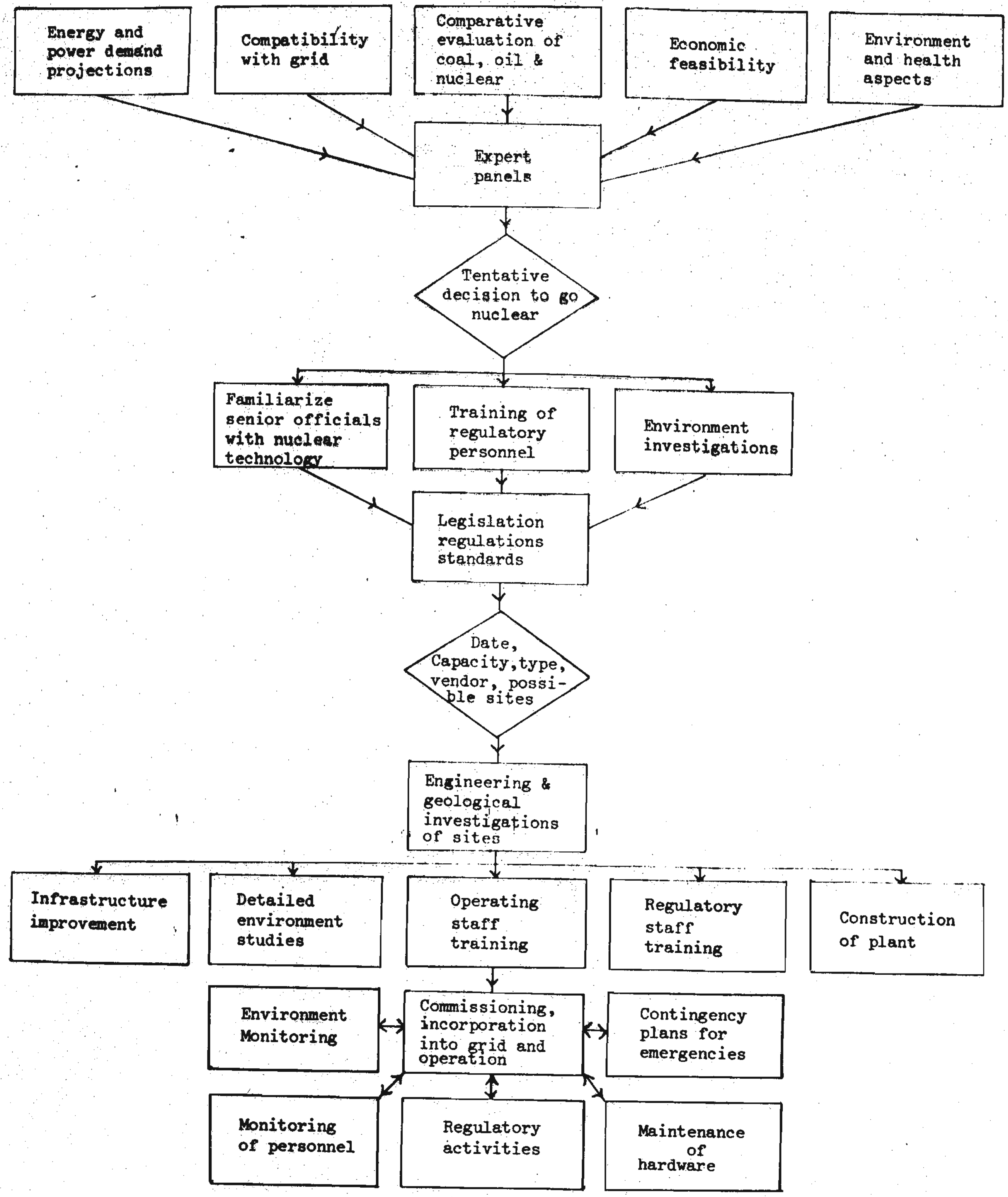
1.10 The civil nuclear industry is said to have a good safety record. The probability of a nuclear accident with serious consequences is low. However, serious accidents have occurred and can be expected to occur in the future (see chapter 6). Therefore, before we can decide to obtain a nuclear power reactor, we must study, apart from economic and technical considerations :

1. the effects of possible accidents (chapters 4 and 5), and
2. our ability to mitigate their consequences (see chapter 6).

1.11 Until such investigations are made, it is not possible to make a firm decision as to whether a nuclear reactor is desirable and if so where it could be located. Fig. 1.1 sets out diagramatically the time sequence of activities in a programme that could lead to the commissioning of a nuclear power plant.

1.12 In this report we have kept two main considerations in mind. On the one hand, the quality of life of our people cannot be improved without adequate supplies of energy. The survival of democracy in this country and perhaps our survival as an independent nation depends critically on our supplies of energy.

Fig 1.1 : Time sequence of activities in a national nuclear energy programme.



On the other hand, if we were to choose nuclear energy, in the event of a major nuclear accident, a significant part of our small country could become uninhabitable. This report is only the first step in a programme of action that may take a decade before we obtain a definitive answer to the question "should Sri Lanka go nuclear"?.

CHAPTER 2

FEASIBILITY OF NUCLEAR POWER FOR THE NATIONAL GRID

2.1 A nuclear power plant (NPP) is one of the costliest investments that a small country like Sri Lanka could make. It is reasonable to presume that such an investment would be made only if feasibility studies show that, at the time of commissioning, it would be the most economical method of obtaining electrical energy for the national grid. A NPP can be economic if it can be made to supply power to the grid at nearly full capacity during most of the operating life of the plant. These conditions can be met only if the power demand from the grid is large in comparison with the power output of the NPP. Hence, one of the first steps in studying the feasibility of a NPP is to determine the power output of plants that are likely to be available. Thereafter, by predicting the growth of demand for power and energy from the national grid, it would be possible to estimate the earliest date at which a NPP may be incorporated in the grid.

Generation Capacity of Commercial Nuclear Power Plants

2.2 The capital cost per MW of generating capacity of a power plant depends on the overall capacity of the plant. For a given type of plant, up to some maximum technically feasible capacity, the larger the plant the lower will be the capital cost per MW. In the case of an electrical generating plant driven by steam turbines, the upper limit of capacity is more than 1000 MW (1 GW). This holds true regardless of whether the primary source of energy to the plant is oil, coal or nuclear, Since the largest generator now connected to our grid has a capacity of only 50 MW, we may conclude that a unit of 1 GW capacity would be far too large during the 1990's or even in the early part of the next century. Therefore it is necessary to ascertain the smallest capacity of nuclear plant that is likely to be commercially available for operation in the 1990's. It would be then be possible to estimate the earliest date on which a nuclear power plant can be connected to our national grid.

2.3 Table 2.1 shows the numbers of nuclear power reactors of different capacities classified in 1980 by the International Atomic Energy Agency (IAEA), as being *under construction* within its member states[01]. This table includes reactors that are expected to be operational as late as 1987.

Net Electrical Capacity MW (e)	Number of Reactors
0 - 99	1
100 - 199	0
200 - 299	6
300 - 399	0
400 - 499	20
500 - 599	7
600 - 699	17
700 - 799	4
800 - 899	27
900 - 999	41
1000 - 1099	21
1100 - 1199	33
1200 - 1299	40

Table 2.1- Nuclear Power Reactors of different capacities under construction in member states of the IAEA in 1980.

2.4 The smallest of the reactors included in Table 2.1 has a net electrical capacity of only 36 MW (e) and is therefore not of any interest in our study. Of the 6 reactors in the category 200-299 MW(e), one is of the fast breeder type and will not be available commercially. The other five are all in India. Thus if we wish to obtain a reactor of capacity less than 400 MW(e) the only supplier would be India. However, India does not at present export nuclear reactors and is not likely to do so in the next decade.

2.5 In the range 400-499 MW (e), there are 20 reactors under construction. All 20 are in the socialist countries and based on Soviet technology. Thus in this range of generating capacity, there would be only one supplier, viz. the U.S.S.R.

2.6 The seven reactors in the range 500-599 MW are in Canada. Therefore, in this range there would be one supplier, viz. Canada or possibly one more, viz. the U.S.S.R. Beyond a capacity of 600 MW, there would be several suppliers.

2.7 Table 2.1 does not necessarily show an accurate picture in respect of reactors that may be commissioned in the 1990's, the decade of interest to this study. Table 2.2 shows the number of nuclear power reactors *in the planning stage* in member states of the IAEA in 1980[02]. This table includes reactors that are due to come into commercial operation as late as 1994.

Net Electrical Capacity MW	Number of Reactors
200 - 299	1
300 - 399	1
400 - 499	16
500 - 599	0
600 - 699	13
700 - 799	1
800 - 899	5
900 - 999	13
1000 - 1099	29
1100 - 1199	10
1200 - 1299	26
1300 - 1399	1
1600	1

Table 2.2- Nuclear Power Reactors of different capacities in the planning stage in 1980 in member countries of the IAEA.

2.8 Table 2.2 has features that are similar to those of Table 2.1. The two smallest reactors of 250 MW and 350 MW respectively are both of the fast breeder type and will not be available commercially. There are no reactors classified as being in the planning stage in India. The 16 reactors in the range 400-499 MW are all based on Soviet technology. There are no reactors with capacities in the 500-599 MW (e) range in this table, evidently because there are no reactors in the planning stage in Canada. Where the capacity exceeds 600 MW (e) there are several manufacturers.

Small Reactors Designed for Developing Countries

2.9 The data given above show that no commercial nuclear power plants of capacity less than 400 MW (e) would be available for commissioning in the 1990's. However, some manufacturers are reported to have under development, small power reactors designed specifically for sale to countries that expect to start using nuclear power. The following development programmes for small reactors have come to the attention of this committee.

1. A conglomerate of U.S. and British companies operating under the name Rolls Royce Ltd. have announced plans to manufacture a plant with a capacity of 200 MW (e) for sale to developing countries [03].
2. A German firm, Interatom, plans to produce a 60 MW (e) reactor [03].
3. A German firm Kraftwerk-Union is developing a 200 MW (e) reactor [04].
4. Japan is reported to be developing a 200 MW (e) plant[05], initially for domestic use and later for export.
5. A French firm, Alsthom-Atlantique is developing a 300 MW(e) plant [03].
6. Alsthom-Atlantique has a demonstration plant [03] of 125 MW(e).
7. National Nuclear Corporation Ltd. of Great Britain intends to export 300 MW (e) reactors based on the plant at

Oldbury which has been in operation since 1967. The plant at Oldbury consists of two reactors each of which was originally designed to generate 300 MW (e). Owing to technical problems these plants were derated to 208 MW (e) each. Negotiations are currently in progress for the export of a 300 MW (e) unit to Bangladesh.

8. Atomic Energy of Canada Ltd. is prepared to sell reactors of the CANDU type of 300 MW (e) capacity. The design would take about six months and would be based on the larger CANDU reactors that have been operating in Canada since 1971. India has had a reactor of 206 MW (e) capacity based on CANDU technology operating since 1973.

2.10 The first five types of reactors mentioned in the previous section are all in the development stage. The sixth is a demonstration plant in the country of origin. The last two, the Oldbury and the CANDU types, have been in operation in their countries of origin and have been considered suitable for operation in developing countries.

Nuclear Generation Capacity Suitable for Sri Lanka

2.11 The foregoing shows that if we consider the possibility of commissioning a reactor of 600 MW (e) we would have a wide choice of reactor type and suppliers. For smaller capacities, the alternatives available would be restricted. However, at 300 MW(e) we would have at least two alternatives available.

2.12 We must also recall that the cost per unit of installed capacity increases as the capacity of the plant decreases. Therefore, although the possibility of obtaining a reactor of 200 MW (e) or even 100 MW (e) capacity cannot be entirely ruled out, it is unlikely that such small plants would be economical in Sri Lanka. The fact that India has a continuing programme for nuclear power plants in the 200-250 MW (e) range does not go counter to this reasoning. This is because, unlike Sri Lanka, India has her own nuclear design and construction capability, built up through a far-sighted national technological effort extending over the past thirty years.

2.13 Therefore, in the following discussion we shall consider two generation capacities;

1. 300 MW (e), because this would be the lowest capacity that is likely to be available in the next decade.
2. 600 MW (e), because this would be more economical.

Reliability of Supply

2.14 In any large electrical power system, reliability of supply is of paramount importance. However, in the past, in Sri Lanka, neither the supplier nor the consumer of electrical energy has paid sufficient attention to reliability. The economic consequences of loss of supply have not been realised or properly evaluated in this country. But as industrialisation proceeds the need for reliable supply of electricity will become imperative. Indeed, the proposal to obtain a nuclear reactor is itself a result of this need.

2.15 The largest unit of generating plant in a power system has an important bearing on the reliability of the system. All generating equipment needs regular maintenance and they need to be laid off at periodic intervals for this purpose. Also, in the event of the sudden outage of any generator, the system should not undergo unacceptable overloading. For these reasons, it is the normal practice to ensure that the capacity of the largest plant is not more than 10 to 12% of the total system capacity. Thus, to commission a nuclear plant of 300 MW (e), the national grid should have a total installed capacity of 2500 to 3000 MW.

2.16 The figure of 10 to 12% of installed capacity given above is merely a rule of thumb applicable where effective repair and maintenance facilities are available. A lower percentage may be desirable for Sri Lanka because of the following special factors.

2.17 Fig. 2.1 shows the variation of the system demand during a working day, a Saturday and a Sunday in 1980. Note that the night time peak demand is about 50% more than the average

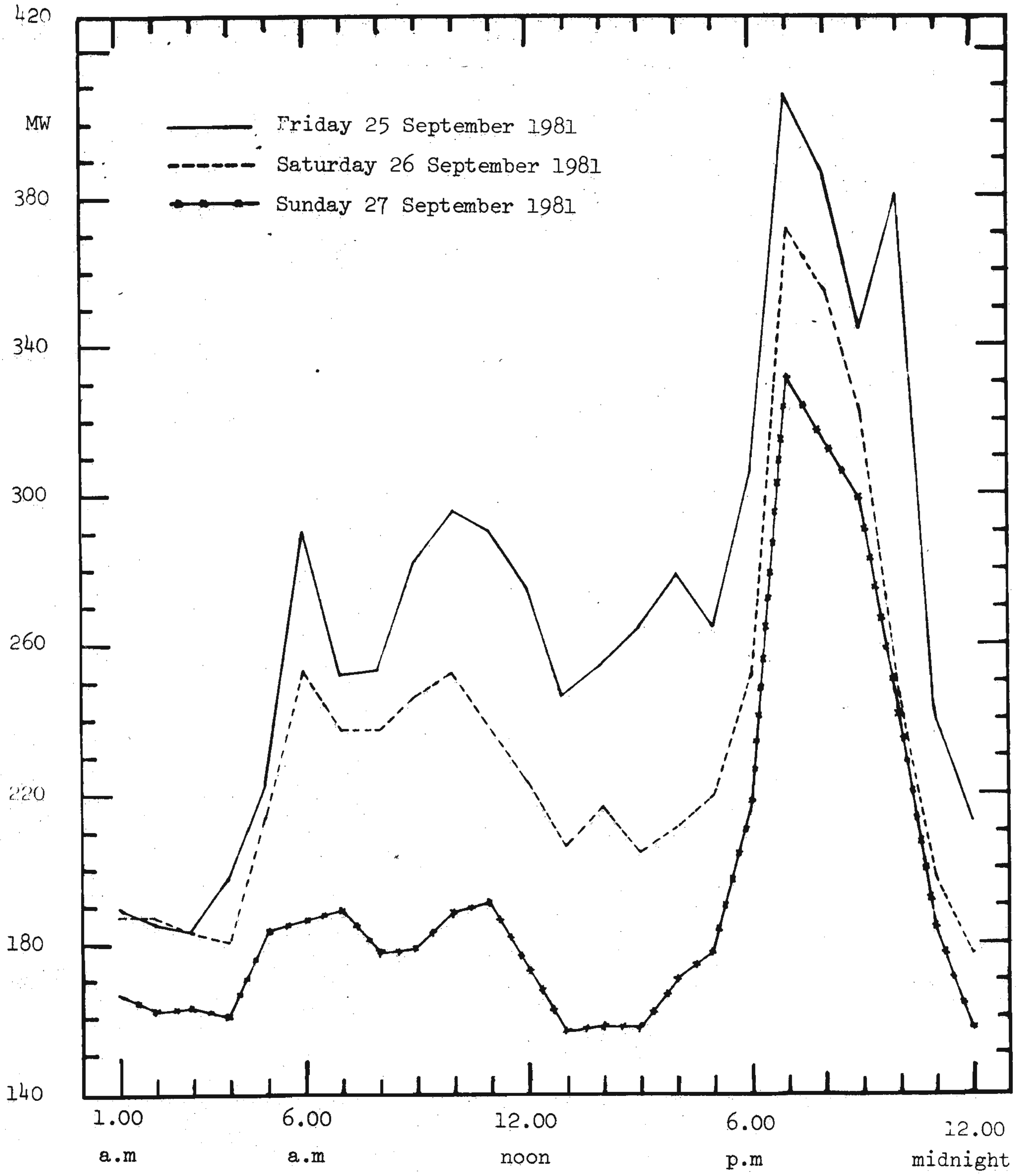


Fig. 2 . 1 Power demand from the Ceylon Electricity Board grid during three days in 1981. **(From data provided by Dr. P.N. Fernando, Ceylon Electricity Board).**

demand during the working daylight hours. The night time peak is caused by the lighting load. In 1976 only 8% of the households in Sri Lanka used electricity for lighting. There can be no serious doubt that the other 92% that use kerosene for lighting will use electricity at the first available opportunity. Therefore when the daytime industrial load grows and the benefits of industrialization spreads, there will be an increase in the night-time demand as well due to the use of electricity by these new consumers. Thus the peaky nature of the demand curve will persist for many decades to come. Under these conditions the capacity of the generating equipment operating in the daytime would be much less than the total installed capacity. Thus, if the largest plant had a capacity of say 10% of the total installed capacity, it would in fact amount to about 15% of system capacity in the daytime. A sudden outage of the largest plant in the daytime may then cause an unacceptable loss of generating capacity, precisely at the time that the industrial load most needs a reliable supply.

2.18 Even up to the end of this century, the major part of our electrical generating plant will use hydro-power. Most of the reservoirs would have been designed to operate the turbines at a low load factor, i.e., for 6 to 8 hours per day. On the other hand a nuclear power plant would provide base load power, that is, nearly constant power output throughout. If the nuclear plant were to provide say 10% of the power, it would in fact provide a much greater percentage of the total energy taken by the grid over a period of say one year. Therefore, when the nuclear plant is shut down for maintenance, it may not be possible to meet the shortfall in energy using the hydro-resources. Also, even if the necessary water were available in the reservoirs, it may not be possible to use the hydro-plant, to meet such an emergency, because many of the reservoirs would have been designed to provide water for both power and irrigation. These difficulties would naturally be multiplied in the event of any shutdowns which have not been anticipated during the planning stage of the nuclear plant.

2.19 It is well known that the repair of machinery in this country is subject to far greater delays than in a developed country. This would be particularly true in the case of the highly sophisticated equipment of a nuclear power plant. This factor too aggravates the difficulties outlined above in connection with shut downs of the nuclear plant.

2.20 The distribution of electric power over our national grid is subject to frequent interruption. These are often caused by lightning. When part of the distribution system fails, the demand from the grid decreases and the output from the generators must be lowered. This is very undesirable in the case of a nuclear power plant.

Earliest Possible Date of Commissioning

2.21 At the beginning of 1982 the total effective generating capacity of the Ceylon Electricity Board grid was 523 MW. Thus,to install a NPP of 300 MW(e) the installed capacity would have to increase almost six-fold. The time that would be taken for such a large increase cannot be estimated accurately. However, we can state with a high degree of confidence that the installed capacity of the national grid will continue to increase in the foreseable future. The Committee has therefore obtained the latest available forecasts of the Ceylon Electricity Board as the basis for planning a schedule of activities that could culminate in the installation of a nuclear power plant, if such a plant were to be considered desirable.

2.22 In October 1981 the Ceylon Electricity Board completed a detailed study of the future requirements of power and energy for the national grid [06]. The results of the study were made available to this Committee in November 1981. Table 2.3 shows the growth in the maximum power demand as forecast in this study, up to the year 1995 when it reaches the figure of 1744 MW. From this table it is clear that the maximum demand will not reach 3000 MW even by the year 2000. Thus, on grounds of reliability and operational flexibility, it would not be possible to commission a NPP of 300 MW(e) before the year 2000 or a NPP of 600 MW(e) before the year 2008.

YEAR	MAX. LOAD(MW)
1984	657
1985	744
1986	808
1987	883
1988	961
1989	1046
1990	1139
1991	1242
1992	1352
1993	1472
1994	1602
1995	1744

Table 2.3 : Predicted maximum power demand on the national grid (courtesy Ceylon Electricity Board).

CHAPTER 3

ECONOMIC ASPECTS OF NUCLEAR POWER

3.1 For several decades, proponents of nuclear energy have claimed that it would be cheaper than that obtained from fossil fuels. On the other hand opponents of nuclear energy have been very vociferous in claiming that nuclear energy is dangerous, unreliable and more expensive than the alternatives. Chapters 4 and 5 of this report discuss the hazards of nuclear reactors. In this chapter we discuss briefly the cost of nuclear energy in comparison with established alternative sources of energy and the related questions of reliability of nuclear power plants and the long term availability of nuclear fuel.

Nuclear Energy Versus Hydro-Energy

3.2 In any major enterprise the conventional method of comparing the costs and benefits of alternatives is to apply the technique of Discounted Cash Flow Analysis. This method emphasizes benefits obtained in the short term while it attenuates the benefits obtained in the long term. While the conclusions obtained from Discounted Cash Flow Analysis may be valid in the case of business enterprises in which profit is the prime motive, in the case of major projects for national development, other criteria may have to be employed. The civil engineering work which comprises the major part of the expenditure in a hydro-energy scheme has an almost indefinite life time and benefits continue to be reaped over a very long period. For instance if the conclusions of Discounted Cash Flow Analysis were used as the sole criterion, the Parakrama Samudra may never have been constructed.

3.3 On the basis of discounted cash flow, it may be possible to show that nuclear energy can be cheaper than energy available from some of the proposed hydro-schemes. However, where we are concerned with the long term interest of this nation, such comparisons cannot be accepted at face value. Apart from the long term returns, once a hydro-power plant is constructed, the energy obtained is independent of any foreign supplier. We shall show in a later section of this chapter that this would not be true of nuclear energy. Since independence, successive governments have expressed a firm commitment towards the development of all possible hydro-resources. We consider the wisdom of this policy to be beyond question and shall not discuss it any further.

3.4 However, as stated in the introduction, we must recognize the fact that our hydro-resources are limited. Therefore it is necessary that we find other sources of energy and such sources should not be subject to the vagaries of the weather.

Nuclear Energy Versus Oil

3.5 At present the major sources of energy in the industrialised countries is petroleum. In Sri Lanka, although the main source of energy is firewood, oil makes a very important contribution to total energy requirements. However, the petroleum products supply energy mostly for the transport sector. The contribution to electrical energy from petroleum is relatively small.

3.6 There is a widely held belief that as the cost of petroleum increases, electrical energy from this source will become more expensive than nuclear energy. This belief is erroneous for the following reasons :-

At the most basic scientific level, all energy is the same. Therefore when the price of the major source of energy in the world, petroleum, rises the price of energy rises whether it be obtained from petroleum or other sources. In the case of nuclear energy, the largest component of the cost arises from the capital investment on the plant. The cost of an NPP would be very strongly dependent on the price of energy which in turn depends on the price of petroleum.

Part of the cost of nuclear energy arises from the cost of uranium. Here again, the cost of mining and processing of uranium and in turn the market price of uranium would be dependent on the price of petroleum.

3.7 There is no quick or easy answer to the question 'Will nuclear energy be cheaper than that obtained from petroleum?'. The answer would depend on a number of factors: the geographical location of the country, the size of the power plant, the component of local expenditure on construction, ability to operate the plant steadily, the price of petroleum, the price of uranium, ability to maintain the plant and ability to manufacture the fuel assemblies.

3.8 Even the fact that world resources of petroleum are limited, does not lead to a quick answer to this question, because, world resources of uranium too are limited. Further, as in the case of petroleum, suppliers of uranium too could form into a cartel.

Nuclear Energy Versus Coal

3.9 Deposits of coal exist in many countries. The energy that would be available from known reserves of coal in the world is far greater than that from uranium, if the uranium is consumed in thermal reactors only. Unless breeder reactors and the associated fuel reprocessing facilities are installed in the countries with large scale nuclear energy programmes during the next decade or so, the world's uranium supplies could get exhausted early in the 21st century. On the other hand, reserves of coal, exploitable using well established technology, would be sufficient for several centuries.

3.10 As in the case of oil, it is possible that coal exporting countries would form into a cartel when the use of coal expands. However, the formation of a cartel for coal is much less likely than for oil or uranium, because the world has vast resources of coal and there would be many exporting countries.

3.11 Coal burning power plants are not entirely free of hazards to health and the environment. The burning of coal releases noxious gases such as sulphur dioxide to the atmosphere. Unless carefully controlled these could present a serious hazard.

3.12 Further, coal-burning plants release small quantities of radionuclides to the atmosphere. Proponents of nuclear energy claim that the danger from radionuclides so emitted is greater than from those emitted by an equivalent NPP under normal operating conditions. In an initial draft report released in August 1979, the U.S. Environmental Protection Agency (EPA) concluded that coal-fired generating plants were up to 80 times riskier than nuclear powered plants in terms of radionuclides emitted during normal operation. However, a report on a later study by EPA, available in its preliminary draft stage, effectively reverses this conclusion. This study is titled, "Technical Support for the Evaluation and Control of Emissions of Radioactive Material to the Ambient Air". In concludes that nuclear plants can be up to 50 times riskier than coal plants[07]. Whatever the final conclusion of such studies may be, the fact remains that (see Chapter 4), in the event of an accident, a large amount of radio-active material may be released to the environment by a NPP, whereas no such release of radionuclides is possible in the case of a coal-fired plant.

Long Term Planning for Generation Expansion

3.13 The process of planning to meet our future requirements of electrical power and energy is such a complex task that it is not possible to decide for or against any primary source of energy on the basis of qualitative reasoning. Only a detailed study of the many possibilities could give a useful plan for the growth of the power system. Such a study[06] has been completed by the Ceylon Electricity Board in October 1981. The results, made available to this Committee in November 1981, show that during the period 1984 to 1995, the following types of generating plant will have to be introduced into the grid:

(a) Long term storage hydro,
(b) Short term storage hydro,
(c) Coal fired steam,
(d) Large diesel.

3.14 The CEB study has not been concerned with plans for generation expansion beyond 1995. Indeed, even if plans were to be made now they would be speculative in nature. The CEB report has not dealt with the economics of nuclear energy. We have as yet no quantitative data regarding the economics of nuclear energy in Sri Lanka. Hence it is necessary to study information available from other countries.

3.15 The fact that most of the developed countries have nuclear energy programmes shows that under certain conditions, this source of energy could be the most economical. Tables 3.1 and 3.2 show the results of studies made by the Central Electricity Generating Board (CEGB) of Britain[08]. Table 3.1 is a comparison of the costs and other performance data between nuclear, coal-fired and oil-fired power stations commissioned by the CEGB between 1965 and 1977. Table 3.2 is a comparison of the performance of the Hinkley Point-B nuclear power plant commissioned in the late seventies and the first half of the Drax coal-fired power plant commissioned about the same time. An examination of these tables shows clearly that in Britain, during the periods covered by the tables, nuclear energy has been cheaper than that obtained from coal or oil.

3.16 Figure 3.1 shows a comparison of the cost of generation of electrical energy from the coal-fired Lambton plant and the Pickering NPP, both operated by Ontario-Hydro of Canada[09]. Here again it is clear that nuclear energy is cheaper than energy from coal. The above are from developed countries which pioneered independent, large scale nuclear energy programmes.

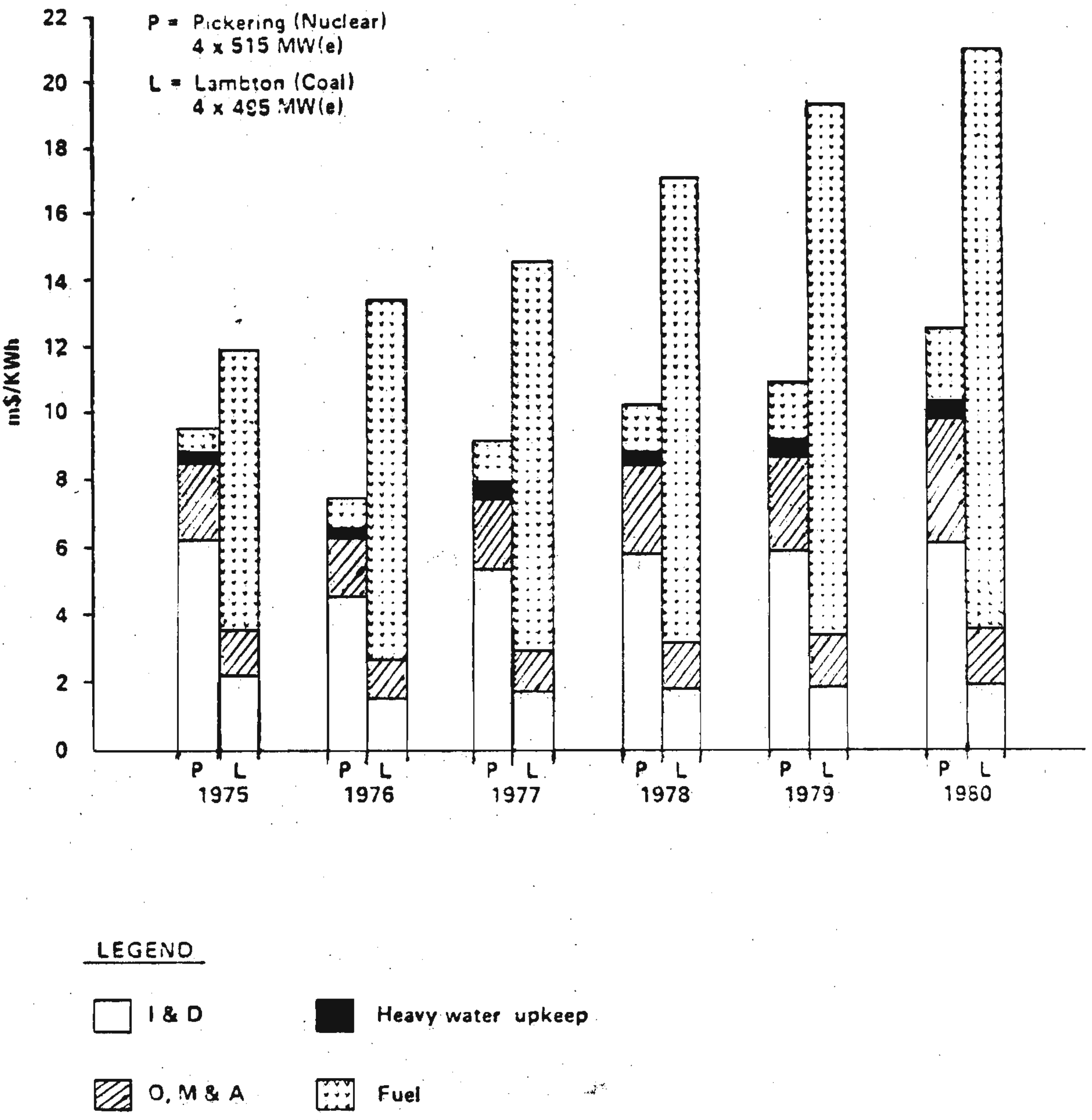
3.17 In the case of a developing country, the cost of nuclear energy could be higher because all the technology would have to be

	1980-81			1970-80		
	Nuclear (Magnox)	Coal-fired	Oil-fired	Nuclear (Magnox)	Coal-fired	Oil-fired
	p/kW h	p/kW h	p/kW h	p/kW h	p/kW h	p/kW h
Capital charges and provision for decommissioning	0.41	0.08	0.20	0.34	0.09	0.14
Interest during construction	0.07	0.02	0.03	0.06	0.02	0.02
Inclusive fuel costs	0.74	1.54	2.15	0.60	1.29	1.61
Other costs of operation	0.39	0.19	0.22	0.26	0.14	0.14
Research	0.03	0.01	0.01	0.03	0.01	0.01
Training	0.01	0.01	0.01	0.01	0.01	0.01
Generation cost	1.65	1.85	2.62	1.30	1.56	1.93
	per cent	per cent	per cent	per cent	per cent	per cent
Load factor on design output	47	63	29	53	60	43
Load factor on declared net capability	64	67	29	71	63	43
Availability on declared net capability	64	72	84	71	68	77

Table 3.1 : Comparative generation costs, load factors and availabilities for nuclear (Magnox), coal-fired and oil-fired power stations commissioned between 1965 and 1977.

	1980-81		1979-80	
	Hinkley Point B p/kW h	Drax First half p/kW h	Hinkley Point B p/kW h	Drax First half p/KW h
Capital charges and provision for decommissioning	0.35	0.13	0.37	0.12
Interest during construction	0.15	0.05	0.18	0.04
Inclusive fuel costs	0.70	1.45	0.55	1.25
Other costs of operation	0.18	0.22	0.16	0.09
Research	0.06	0.01	0.07	0.01
Training	0.01	0.01	0.02	0.01
Generation cost	1.45	1.87	1.35	1.52
	per cent	per cent	per cent	per cent
Load factor on design output	51	66	43	73
Load factor on declared net capability	63	66	67	73
Availability on declared net capability	63	67	67	74

Table 3.2 : Comparative generation costs, load factors and availabilities for Hinkley Point B (AGR) and Drax first half (coal-fired) power stations.



(From CANDU Nuclear Power System)

Fig. 3.1 Comparison of cost of generation of electrical energy from the Pickering NPP and the coal fired Lambton plant (courtesy Ontario-Hydro of Canada).

imported. Table 3.3 shows the results of a study conducted in the Phillipines[10] that conclude that nuclear energy would be the most expensive out of the available alternatives.

3.18 We have presented in this section, only a small part of the literature regarding conflicting claims made by proponents and opponents of nuclear energy. Although a great deal of published material on the question is available, it is not possible to come to a definite conclusion as to whether nuclear energy would be cheaper than the alternatives in the case of Sri Lanka.

Operational Reliability of Nuclear Power Plants

3.19 An examination of the performance of NPPs in developing as well as developed countries shows that NPPs are in general less reliable than power plants that burn coal or oil.

3.20 For example an examination of Tables 3.1 and 3.2 brings out the following factors in respect of power plants in Britain,

1. for oil-fired power plants the declared net capability is the same as the design output,
2. for coal-fired plants the declared net capability is equal to or a little less than the design output,
3. for NPPs the declared net capability is considerably less than the design output,
4. For NPPs, the figures for availabilty as a percentage of design output would be much lower than for oil or coal fired stations.

3.21 Appendix 3 tabulates information regarding the performance of NPPs as published by the IAEA[11].
The data show that NPPs tend to have considerable periods during which they are shut-down. Shut-down periods are long and frequent for the follwing reasons:

1. Even small accidents often require that the plant be closed down.
2. Periods of shut down tend to be long sometimes months or years due to the risks associated with radio-activity.

Mode of Generation	Capital Cost per KW b/ US$	Fuel Cost per KWh US ¢	Index Cost of Fuel & Capital a/ US$ per KW
Oil fired	750	6.0	2760
Coal	1000	4.0	2340
Geothermal	1000	4.0	2340
Hydro Run of river	950	Nil	950
Hydro Reservoir	2000	Nil	2000
Nuclear (at 600 MW)	2800	2.0	3470

a/ This index is explained in para below.

b/ Includes an element of cost for waste disposal.

Assumptions

i. Capital cost given are order of magnitude figures obtained from an analysis of projects in Philippines to be completed in the 1980-85 period. Their load factor capabilities vary widely;

ii. Final cost are based on oil = $35/barrel
coal = $70/tonne of calorific value 4500 Kcal/kg.
geothermal Maximum, as contracted

If a power plant produces 5000 KWh of energy per year, the difference in cost of total energy generated would be $50 per one cent of difference in fuel cost. If the capital charges are say, 15 per cent per year, this would mean roughly that a capital cost difference of $335 would be equivalent to ¢1 difference in fuel cost. Based on this one can build up a crude index (of capital and fuel cost). These are given in table above.

Table 3.3 Comparative costs of different modes of power generation in the Phillipines.

3. Extensive and costly investigations are necessary after shut-down in order to be assured that re-start does not entail any risks.

3.22 In a developing country such as Sri Lanka, shut-down periods of an NPP may be expected to be considerably longer than in a developed country, where the expertise and facilities for diagnosis, repair and safety assurance would be readily available.

3.23 The low load factor that would result from frequent or long periods of shut down would make NPPs commercially unattractive in comparison to plants that burn coal or oil. This could also make power from the national grid less reliable.

3.24 The greatest advantage of a centralised grid supply should be its reliability. Unfortunately, reliability of power supply has received scant attention in Sri Lanka. Frequent power failures have always been taken for granted. In the recent past, regular power cuts during drought periods have become a fact of life.

3.25 In order to clarify the concept of a *reliable* power supply it is necessary to look at an example from a developed country. The United Kingdom is a good example of a country with a highly reliable central grid. We quote from "The Economics of the Reliability of Supply" (A comparison of standards adopted in various countries). Institution of Electrical Engineers Conference Publication No. 34[12].

> "The planning standard which was settled arbitrarily some 12 years ago and has not since been changed, is that in three winters in 100, some consumers will have to be disconnected because of shortage of generating plant capacity. It is practicable to shed about 7½% of the demand by reducing voltage and frequency before disconnecting consumers, and it is accordingly accepted that some such reduction will be necessary in 24 winters in 100. There is thus a 24% risk of failure to meet the demand in full and a 3% risk of failure to meet 92½% of the demand. With the present load duration pattern this corresponds to 160 hours

(in 100 years) of failure to meet the load in full of which 100 hours involve disconnection".

3.26 In summary, the above reliability criterion adopted in Britain corresponds to disconnections of supply from some consumers for about 6 minutes per year and the possibility of low voltage and frequency to some consumers for about 100 minutes per year ! Any national grid should aim at such a high standard of reliability. Such a high standard of reliability requires that the technical facilities and know how for coping with all possible breakdowns be available within the country, in respect of all installations in the power system. In Sri Lanka where advanced technology is lacking, the introduction of a NPP could make the supply of power from the grid even less reliable than it is now.

Long Term Availability of Nuclear Fuel and Heavy Water

3.27 The fission of a kilogram of uranium-235 can in principle release about 3,000,000 times as much energy as the combustion of a kilogram of conventional fossil fuel. This dramatic comparison has led to the popular but erroneous belief that nuclear reactors can supply the world with unlimited quantities of energy. The real situation is very different from the popular belief.

3.28 Almost all of the commercial nuclear energy produced in the world comes from what are known as 'thermal' reactors, that is of the LWR, HWR or GCR* types. These reactors burn uranium-235, which is present in small quantities in the naturally occuring ore. If the spent fuel rods of thermal reactors were to be all disposed of, the world could run out of uranium resources in a few decades. Some of the advanced countries have developed 'reprocessing' facilities where the fissile material from the spent fuel rods are extracted and reused as fuel. Even if reprocessing were to be extensively used, world demand for uranium could outstrip production by about 2000 A.D.[13]. It is necessary to state here that reprocessing plants are so costly that they are beyond the reach of all but the largest economies.

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*LWR - Light Water Reactor. HWR - Heavy Water Reactor, GCR - Gas Cooled Reactor

3.29 The introduction of the Fast Breeder Reactor (FBR) could, in principle, reduce the demand for uranium. Again, the real situation is significantly different. Several countries are developing FBRs. However, even the most advanced of the FBRs, at Dounraey in England is still classed as a 'prototype'. Much further work therefore remains to be done. Further, FBRs must initially be fuelled from reprocessed fissile material generated in thermal reactors. The word 'Fast' in 'Fast Breeder Reactor' refers to the speed of the neutrons emitted and not to the rate of regeneration of fissile material. Indeed a FBR can take over 30 years to produce sufficient fuel to load another similar reactor. Thus the introduction of FBRs requires that the use of thermal reactors continues to expand, causing continuing depletion of uranium resources. However, given international co-operation, it is possible to conceive of reactor strategies that would make it possible for nuclear power generation to continue to expand for several centuries. Further, in addition to the technical difficulties, there are major political barriers to be overcome. For instance, improvements in reprocessing technology, essential for the introduction of FBRs, could also make it possible for reprocessed material to be used for the manufacture of weapons. Because of such international political implication, if Sri Lanka were to depend on imported nuclear fuel, her future in respect of energy would be no less uncertain than if she were to continue to depend on imported oil.

3.30 A comprehensive study of the availability and projected demand for uranium, thorium and heavy water was undertaken by the International Nuclear Fuel Cycle Evaluation (INFCE). We quote from its findings[13] :

> "Comparisons of uranium supply and demand as illustrated ..... indicate the need for additional sources of production before the end of the century as well as the importance of fuel-efficient reactor strategies. The bulk of the required new production will have to be supported by new discoveries. Estimated lifetime uranium requirements for reactors projected to be put in place up to 2000 exceed current estimates of RAR*for most of the projections. Indeed, by 2000 the highest estimated lifetime requirements approach

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* RAR : Reasonably assured resources

current estimates of RAR plus EAR* . Since not even all of the RAR can be made available by that time, the need for continued exploration and development activity is apparent. Based on global resource comparisons alone, if nuclear capacity deployment strategies based on substantial and/or early post 2000 deployment of improved thermal reactors and fast breeder reactors would be required to provide assured nuclear electricity supply".

3.31 We have earlier shown that for purely operational reasons, it would not be possible to supply power from a nuclear reactor, to the grid, before the year 2000. Thus on the basis of the findings of INFCE there is a distinct possibility that just at the time that Sri Lanka can use a nuclear power reactor, the world may be faced with a shortfall in supplies of nuclear fuel.

3.32 It is necessary to keep in mind the fact that on several occasions, suppliers of uranium have abrogated or suspended contracts owing to disagreements regarding the policies of the recipient countries. The most recent example of such action was the refusal of the United States to supply enriched uranium to India.

3.33 All these factors make it clear that there is no basis for Sri Lanka to expect to achieve self-sufficiency in energy through nuclear technology

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* EAR : Estimated additional resources

CHAPTER 4

RADIATION HAZARDS TO HEALTH

4.1 The main danger to health and the environment posed by a nuclear power plant results from the unavoidable production of large amounts of radioactive materials, primarily fission products. A nuclear reactor with an electrical output of 500 MW produces as much fission products in one day as did the atom bomb dropped on Hiroshima[14].

4.2 Nuclear reactors are designed to contain these fission products within their shields even under severely adverse conditions such as cyclones and earthquakes. However, even under normal operating conditions it is not technically feasible to completely eliminate the release of radioactive substances to the environment. From time to time, gaseous effluents containing radioactive materials are released to the atmosphere. The waste water and secondary cooling circuits too may transfer some radioactivity to the environment.

4.3 During the course of a nuclear reactor accident, much larger quantities of radioactive material may be released to the environment. Before discussing the effect of such releases it is relevant to consider briefly the nature and effects of natural and man-made sources of radiation to which people have been exposed. Since many of the terms used in this report may be unfamiliar to the reader, we give a glossary of terms in Appendix 2 . A brief introduction to radioactivity, nuclear fission, fission products and nuclear reactors is given in Appendix 1 .

Early History of the Effects of Radiation

4.4 Scientific work with radiation commenced after the discovery of x-rays by Roentgen and of radioactivity by Becquerel in 1895. Soon afterwards, cases of injury caused by radiation were reported. As early as 1896 it was noted that external exposure to x-rays could produce erythema (abnormal redness of the skin), oedema (swelling due to accumulation of fluids) and epilation (abnormal loss of hair). Becquerel and Mme. Curie suffered such effects after handling radioactive materials. The ability of radiation to induce cancer was observed soon afterwards and by 1911 about one hundred cases of tumours induced by x-rays were reported. Fifty of these were radiologists. It was estimated that by 1922 a hundred radiologists had died as a result of cancer induced by radiation. Sometime later the incidence of leukaemia was found to be significantly higher among radiologists than among other physicians.

4.5 It was also observed that there was a high incidence of lung cancer among miners working in sites containing high concentrations of uranium. We know today that they were victims of internal exposure to radiation caused by inhaling radon gas, a decay product of uranium. Much publicity was given to the cases of internal exposure among women workers who painted numerals on the dials of watches with paint containing radioactive radium, and who were in the habit of tapering their brushes with their lips. About fifty of these women died of various forms of cancer.

4.6 Such deaths and serious injuries, through the use of x-rays and radioactive materials, were the result of ignorance, at that time, of the deleterious effects of radiation on man. But through such incidents much knowledge was obtained. It was soon recognized that the utilization and handling of radiation must necessarily be governed by strictly enforced measures of control and safety. Standards of radiation exposure have been developed and a set of units of radiation exposure defined. Radiation intensities, or doses, and their effects can be expressed quantitatively in terms of these units.

Radiation Doses and Standards

4.7 The biological effect of radiation is dependent on the amount of energy deposited by the radiation in living tissue. The energy deposited per unit mass of tissue is the *absorbed dose*. The unit of absorbed dose is the rad, which is equal to 0.01 Joule per kilogram or 100 ergs per gram.

4.8 Radioactive substances emit three types of radiation, viz. alpha particles which are absorbed within a millimetre of tissue, beta particles which are absorbed within approximately one centimetre of tissue, and gamma rays which can penetrate several centimetres of tissue. The properties of x-rays are much like those of gamma rays. For the same absorbed dose, the biological damage caused by alpha particles is much greater than that caused by beta particles and very much greater than those caused by gamma rays or x-rays. Hence the quantity *dose equivalent* is introduced to take account of the differences in the biological effects of different types of radiations. The unit of radiation dose equivalent is the rem. Gamma rays, x-rays and beta particles of high energy produce nearly equivalent effects. Therefore for all these radiations an absorbed dose of 1 rad gives a dose equivalent of 1 rem. One thousandth of a rem is referred to as a millirem. A more recent unit of dose equivalent is the sievert (Sv) equal to 100 rem.

4.9 The International Commission on Radiological Protection (ICRP)[15] has set standards of permissible exposure to radiation, or dose equivalent limits. The Commission distinguishes two classes of individuals: radiation workers and the general public. For the radiation worker, who is subject to occupational exposure, the maximum permissible dose equivalent (MPD) for the whole body is 5 rem in any one year. This is approximately equivalent to a dose of 100 millirem per week or 2.5 millirem per hour in a 40-hour working week. For an individual member of the general public the MPD is 500 millirem per year, i.e. one tenth of the MPD for a radiation worker.

4.10 The above two MPD values take into account the risk to which an individual may be subjected. But when considering a population, the possibility of genetic damage, which can place future generations in jeopardy, arises. Therefore, in the United States, for instance, for the population as a whole, the maximum permissible accumulated dose to an age of 30 years has been placed at 5 rem[16]. This is equivalent to an average annual dose of approximately 170 millirem.

4.11 The MPD levels do not represent a threshold below which there is safety and above which there is hazard. The concept of a threshold below which radiation does no harm has been discarded by scientists. There is ample evidence to show that radiation at all levels is harmful, although in some instances such as in the treatment of cancer, the beneficial effects (to the patient) may outweigh the harmful effects (to the patient as well as the workers). The choice of MPD levels therefore represent a balance between the risks as against the benefits of the use of radiation and of nuclear power. It is generally recognized that, notwithstanding the MPD levels, exposure to radiation should be kept as low as possible.

Natural Background Radiation

4.12 From the beginings of time life has evolved in the midst of nuclear radiation. Mankind is continuously exposed to radiation from cosmic rays from outer space, from naturally occuring radioisotopes, and from the radioactivity released to the atmosphere from nuclear weapons tests. The average annual external dose from cosmic rays at sea level varies from about 30 millirem to about 80 millirem depending on the latitude. The annual dose from background radioactivity on the earth's surface varies from region to region, from 60 to 200 millirem. However, in some parts of Brazil, India and Sri Lanka, for instance, there are extensive deposits of thorium-bearing monazite sands, and people have lived over generations near such places while being exposed to doses in the region of 2000 to 3000 millirem per year.

Biological Effects of High and Moderate Doses

4.13 Apart from the experience of the early workers, who used x-rays and radioactive materials, evidence regarding the harmful effects of high levels of nuclear radiation has been obtained by studying the survivors from Hiroshima and Nagasaki, the victims of accidents in nuclear installations, and patients exposed to radiation for therapeutic purposes. A great deal of evidence has been obtained from experiments on animals.

4.14 A dose of 500 rem delivered over the whole body will kill about half of the exposed population and the survivors will suffer from very serious maladies. The reproductive organs, blood forming organs such as bone marrow and the spleen, and the intestines are sensitive to lower levels of radiation and suffer from serious adverse effects. The skin and irradiated organs tend to develop cancer, sometimes after latent periods of 30 to 40 years. With doses of about 50 rem, anorexia, nausea, vomiting and diarrhoea occur within 2 or 3 hours, and death may result unless treatment is instituted immediately. With doses of about 25 rems, changes in the blood count occur in a few hours, and also genetic damage is caused in the chromosomes of lymphocytes.

4.15 A high incidence of leukaemia has been observed among patients treated with radiation for ankylosing spondylitis, a non-malignant condition affecting the spine. The population affected by the atomic bombs of Hiroshima and Nagasaki showed a high incidence of malignancy. Thus exposure to moderate or low levels of radiation over prolonged periods causes cancer.

Ingestion of Radiation Materials

4.16 In paras 4.9 to 4.15, we have considered the effects of radiation incident on the body from external sources. In the case of radioactive materials released to the environment, it is also necessary to consider the more insidious hazard caused by ingestion, inhalation and adsorption by the skin.

4.17 In respect of a radioactive source external to the body, it is the gamma rays that must be considered in reckoning the harmful effects, for the gamma rays have high penetrating power, while the alpha and beta particles get absorbed even by thin layers of protective materials. However, in the case of radionuclides within the body, the effects due to the alpha and beta particles become even more serious.

4.18 It is very difficult to control the ingestion of radionuclides by plants and animals. The paths through which the human body ingests radionuclides are very complex. It is known that plants and animals tend to concentrate certain chemical elements at specific sites within their systems. Radionuclides are also similarly ingested and concentrated, (See Chapter 5., paras 5.26 to 5.30).

4.19 Once a radionuclide is ingested it can remain within the body, emitting harmful radiation over varying periods of time, which in some cases may last for the entire life of the victim. The damage caused by such radiation can be measured by observing biological effects, such as changes in thyroid function following ingestion of radioactive iodine-131, and changes in the blood count due to marrow depression caused by ingestion of bone seeking radio-istopes, strontium-90 and caesium-137. The long term result of these would be the appearance of malignancy and other somatic effects. Unfortunately, sometimes these effects become perceptible only after it is too late.

4.20 It is necessary to recognise that when radionuclides are released to the environment, there exist two distinct mechanisms through which radiation affects the population adversely. We indicate again these mechanisms, and give examples arising out of two nuclear reactor accidents:

1. While the radioactive pollutant is present in the environment, any person in the vicinity is exposed to radiation from that environment. For instance, after the accident at the nuclear power plant at Three Mile Island in 1979, radionuclides were released to the atmosphere.
   We quote from the document NUREG-0558[17] of the U.S. Nuclear Regulatory Commission:

   > "The collective dose to the total population within a 50-mile radius of the plant has been estimated to be 3300 person-rem.This is an average of four separate estimates that are 1600, 2800, 3300 and 5300 person-rem. The range of the collective dose values is due to different methods of extrapolating from the limited

> number of dosimeter measurements. An estimate provided by the Department of Energy (2000 person-rem) also falls within this range. The average dose to an individual in this population is 1.5 millirem (using the 3300 person-rem average value)".

It is to be noted that the value of 1.5 millirem is an average dose to any individual in a population of about two million in a region of radius 50 miles. However, the dose received by a particular individual who was present on Hill Island (1.1 miles NNW) has been estimated at 37 millirem. The figure of 37 millirem is described as being "the most probable estimate of dose", while the highest estimate is about 180 millirem for the dose received by that individual. Arising out of this accident, the projected number of excess fatal cancers in respect of the population of about two million is 0.7, (vide Kemeny Report[18]).

2. Some radionuclides enter the bodies of human beings, animals and plants in the polluted area, through ingestion, inhalation and absorption by the skin. The bodies would then be subjected to radiation from within, even after the radio-active pollutant in the envirionment has been dispersed by natural phenomena such as wind and rain. The following examples illustrate the possible danger from such internal radiation.

   After the accident at the nuclear fuel reprocessing plant at Windscale in England in 1972, it was found that milk produced in the surrounding area was contaminated with radio-active iodine-131. It was therefore necessary to give prophylactic doses of iodine to the people in the area, so as to reduce their intake of radio-active iodine from the milk.

   It is reported[19] that about four months after the accident at Three Mile Island, infant mortality in the state of Pensylvania increased. A few months later the mortality figures dropped down to normal. The increase in infant mortality was most marked in Harrisburg, a town close to Three Mile Island. The incidence of hypothyroidism among infants born in the area increased markedly. Dr. Ernest Sternglass, professor of radiation physics at the University of Pittsburgh, School of Medicine, believes that these effects[20] were the result of ingestion of radionuclides released during the accident. It is necessary to mention here that the conclusions of Dr. Sternglass have been contested[21].

Biological Effects of Low Levels of Radiation

4.21 It is difficult to study and determine with any degree of certainty the effects of radiation at levels close to the natural background of 100 to 200 millirem per year. There is no area on earth which is free of background radiation and there is no species of plant or animal which is free of the effects of radiation. This makes it very difficult to conduct controlled experiments. The little information that is available has been obtained by extrapolation of the effects of higher levels of radiation. In respect of low levels of radiation, both somatic and genetic effects must be considered.

Somatic Effects :

4.22 Two of the most authoritative and comprehensive reviews of the effects of radiation on man are those prepared by the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[22] and the US National Academy of Sciences Committee on the Biological Effects of Ionising Radiation (BEIR). The BEIR III Report (1980)[23] reflects disagreements between members of the committee in attempting to answer two major questions: (1) Will somatic effects actually occur in a general population exposed to tens or a few hundreds of millirem per year of radiation in addition to the natural background of about 100 millirem per year already being received? (2) Will the effects occur in an occupational population exposed to about 0.5 to 5 rem per year in addition to the natural background and medical exposure? The Table 4.1 gives estimates of the somatic effects of low level radiations as represented by different reports, in respect of the general population[24].

			Cancer deaths per million per rem
BEIR	III	(1980)	67-226
BEIR	I	(1972)	115-621
UNSCEAR		(1977)	100
ICRP		(1977)	125

Table 4.1 : Somatic Effects of Ionising Radiation. Projected number of deaths caused by cancer per million of population per rem of radiation[24].

Genetic Effects :

4.23 With the experience of over four decades of radiation mutagenesis work, a solid body of knowledge on the genetic effects of ionizing radiation has been accumulated. In the absence of human data on radiation induced, transmitted genetic effects, estimates continue to be based on laboratory animal data.

4.24 There are considerable uncertainties in extrapolating from animals to man. There is information on the nature of basic lesions and experimental data on various aspects of radiation mutagenesis. Some limited information is available on the hereditary patterns of atom bomb survivors and American radiologists.

4.25 The number of mutations induced after irradiation (in animal populations) is proportional to dose. The concept that all genetic damage is cumulative and irreversible is no longer accepted. Experiments on mice show that x-ray induced mutations are not a simple linear function of dose, but are dependant on dose rate. There is greater recovery at low dose rates than at high intense exposures. Such detrimental radiation mutations have been clearly demonstrated in animal studies.

4.26 Radiation induced mutations fall into two catogories: *chromosome aberrations* and *point (gene) mutations*. On the basis of studies in large populations, the former seems to predominate in the first generation, the latter, which are more common defects, skip the first generation.

4.27 Following exposure to radiation, the visible mutations in the off-spring tend to be similar to spontaneous mutations, but have an increased incidence over the latter. There are two ways in which genetic effects are measured: (1) In the *doubling dose method*, radiation induced mutation rates, derived from experiments on mice, are compared with spontaneous mutation rates, derived from surveys of the natural incidence of genetic disorders in man. Thus the dose of radiation required to double the spontaneous rate in man can be calculated. The BEIR III estimate of the doubling dose is 50-250 rem; this can be compared with BEIR I estimate of 20-200 rem and the UNSCEAR estimate of 100 rem. (2) In the *direct method*, data on radiation induced mutation rates for genes or chromosomes in mice is applied, with suitable corrections, to estimate directly the number of gene or chromosome mutations that will occur in man as a result of a given dose of radiation. The BEIR III estimate on the basis of this method is that one rem of parental exposure before conception will result in 5 to 65 additional genetic disorders per million live births in the first generation.

4.28 The estimates arrived by the two different methods are claimed to be in reasobable agreement. The doubling dose method is applicable to effects seen at equilibrium, after long continued exposure of the population. The direct method is applicable to single generation effects. Results of such estimates are summarised in Table 4.2.

			Genetic disorders for 10^6 live births per rem of parental exposure received before conception	
			1st generation after exposure	Equilibrium after many generation of exposures
BEIR	III	(1980)	5-65	60-1 100
BEIR	I	(1972)	12-200	60-1 500
UNSCEAR		(1977)	63	185
ICRP		(1977)	50	200[2]

Table 4.2 : Genetic effects of ionising radiation. Number of genetic disorder per million live births per rem of parental exposure received before conception[24].

4.29 The danger of possible genetic effects, after exposure of a population to ionizing radiation, creates a social stigma. This is well documented and still seen with respect to the *hibakusha* - "the bombed ones" (as they are called in Japan) who have survived the nuclear bombing of Hiroshima and Nagasaki. Even those that do not show signs of ill effects from the bombing are victims of the prejudice of their own countrymen who fear the genetic damage suffered by the hibakusha, and do not wish to marry them or their descendents. Hibakusha, who have moved from the bombed sites, keep their background secret, especially when they have children of marriageable age.

Uncertainity regarding the effects of low levels of radiation

4.30 The following two quotations illustrate the wide differences in conclusions that can be made in respect of low level radiation comparable to the natural background:

1. Report of the Royal Commission on Environmental Pollution[25], September, 1976 p.22, para 62 :-

> "The naturally-occurring incidence of genetic disease is such that it affects some 6 per cent of all babies, so that a population of a million people with an annual birth rate of 12 per 1,000 would in any event generate some 720 cases each year. The additional incidence from radiation doses equal to the legal limit would most likely be far less than the normal statistical variations in this number and would therefore be imperceptible. Moreover such an average radiation dose would be a significant fraction of the natural level, and we would expect that it would have been prevented from reaching such a limit long before in order to keep the numbers of somatic effects at a low figure. We are therefore satisfied that in these circumstances, genetic effects should be of little concern".

2. NRC Translation 520, - Radioecological Assessment of The Wyhl Nuclear Power Plant, - Dept. of Environmental Protection of the University of Heidelberg, Germany, 6900 Heidelberg, Im Neuenheimer Feld 360. May 1978, Revised July, 1979 - p. 119[26]:

> "A comprehensive study by the National Academy of Science in America, which was commissioned by HEW (BEIR report, 1976), contains estimates of the risk for cancer, leukemia and hereditary diseases from chronic low doses of radiation. On the basis of the data in this report, we have determined the following results of an additional radiation dose of 60 mrem/year in West Germany (the legally permitted dose):
>
> (a) an additional 40 to 700 cases per year of serious dominant hereditary disease in the first generation,
> (b) a fivefold increase in the number of cases of hereditary disease after a few more generations, and
> (c) an additional 500 - 1400 cancer deaths per year.
>
> In a risk assessment performed for the AEC, Gofman, J.W.et. al. (1971) estimate even higher values (2000 to 12,000

cancer cases per year at 60 mrem additional radiation exposure for West Germany)".

CHAPTER 5

RADIATION HAZARDS TO THE ENVIRONMENT

5.1 In chapter 4 of this report we have dealt with the effects of radiation on the environment in as much as it relates to Man. In this chapter we wish to discuss ecological changes which affect other forms of life, both animal and plant.

5.2 Ecology is defined as the study of the inter-relations between living organisms and their environment. It has many branches such as Terrestrial Ecology which deals with organisms living on land, and Marine Ecology which studies life in the sea. With the growth of Nuclear technology and its effects on the ecosystem a new branch emerged - Radiation Ecology, which is concerned with radioactive substances, radiation and the environment [27]. There are two rather distinct phases of radiation ecology or radioecology. On the one hand, there are the effects of radiation on individuals, populations, communities and ecosystems. The other concerns the fate of radioactive substances released to the environment and the manner by which the ecological communities and populations control the distribution of radioactivity.

5.3 Radioecology as a science has made rapid and spectacular advances in a relatively short space of time. This has enabled scientists not only to monitor the effects of radiation on animals and plants, but also, by recourse to experiments, predict such effects.

5.4 For instance, it is now possible to classify radionuclides according to their ecological importance. Those with short half-lives are apparently of no interest while at the other end of the scale are radionuclides produced by fission of uranium and certain other elements which are extremely dangerous to living tissue. One of the greatest dangers of the latter is that they readily enter the biogeochemical cycles (and thence the food chains) and many of them, notably strontium and caesium, become concentrated in such food chains.

5.5 Radioecologists have also identified a phenomenon known as comparative radiosensitivity or the degree of tolerance of radiation doses. For example, it is known that a dose of 200 rads will kill some insect embryo in the cleavage stage and that 100,000 rads will destroy all adult insects in a given population.

5.6 We are here concerned more with radiation effects on the fauna and flora in the vicinity of a Nuclear Reactor. But it is not possible to isolate fauna and flora from the rest of the natural environment (or the ecosystem) with which they are in dynamic equilibrium, what is popularly known as the "balance of nature". It is therefore relevant to briefly discuss some of the more important aspects of the ecosystem in order to show how radiation could upset or destroy this equilibrium.

The Concept of the Ecosystem

5.7 The ecosystem is the basic functional unit in ecology since it includes both organisms (biotic communities) and the abiotic (non-living) environment, each influencing the properties of the other and both necessary for maintenance of life on the earth.

5.8 Within this system there are clearly identifiable paths through which interaction takes place. These are cyclic in nature. We need examine only two major transfers or cycles here.

5.9 First, the *Energy Cycle* by which energy from the sun is used by plants to produce organic substances which can be consumed as food by other organisms (herbivores) which, when they die, recycle the energy via micro-organisms and detritus feeders. In common parlance this is a food chain. But this simple food chain can have numerous subsidiary cycles as when the herbivores are eaten by carnivores. The food chain then becomes magnified into a food web. Man too belongs to this web being a consumer of both plants and animals.

5.10 The other noteworthy cycle is the Biogeochemical or *Nutrient Cycle* by which the chemical elements, including all the essential elements of protoplasm, tend to circulate in the biosphere in characteristic paths from environment to organism and back again. Among these elements are oxygen, carbon (as carbon dioxide) and nitrogen which circulate in the air, and the sedimentary elements such as carbon, calcium, phosphorous and potassium contained in the earth's crust.

5.11 Whilst the food web had been fairly well understood, the nutrient cycle actually became the subject of extensive study only as pollution increased with industrialization and with the use of agro-chemicals. One significant contribution made by these studies on pollution was the recognition of a phenomenon known as food chain concentration or, more popularly, *biological magnification*[27]. It is a process by which some substances become concentrated instead of dispersed, with each link in the chain. This was strikingly demonstrated in the case of DDT which was used for insect control in doses which were not lethal to fish and other animals. But the experts who advocated the use of DDT failed to reckon with ecological processes and the fact that DDT residues remain toxic for long periods. Instead of being washed out to sea, as some predicted, the poisonous residues absorbed on detritus were transferred to detritus feeders and small fishes where they accumulated in the body fat. When these fishes were eaten by predators such as birds the concentrated DDT was transferred to them in doses large enough to cause death. We will see later on how radio-active substances too are similarly concentrated by organisms.

5.12 From the foregoing it would be clear how damage to or the removal of a link in the food chain, or the infiltration by certain chemicals of the nutrient cycle, can and does effect the whole environment.

Radionuclides of Ecological Importance

5.13 Two properties of a radionuclide are of ecological interest and importance, namely its half-life and its penetrating power.

Generally speaking, very short-lived radionuclides are unimportant, for they may disintegrate in a few minutes or hours.

5.14 Radionuclides disintegrate emitting three types of radiation, alpha and beta particles, and gamma radiation, (see chapter 4, para 4.8). The gamma rays are the most penetrating, the beta particles much less so, while the alpha particles are readily stopped in a few centimetres of air. In respect of any one type of radiation, the penetrating power increases with increasing energy of the radiation. Thus, the greater the energy of radiation, the greater the potential danger to biological material. Radionuclides emitting radiation of energy between 0.1 and 5 MeV are ecologically important.

5.15 Radionuclides may be considered in three major groups as follows :

(a) naturally occuring radionuclides,
(b) metabolically important radionuclides,
(c) radionuclides produced by fission of uranium and certain other elements.

Of these, group (c) contains the nuclides which are potentially the most dangerous because they are produced in appreciable quantities in both nuclear explosions as well as nuclear reactors which produce electricity. They readily enter the biogeochemical cycle, e.g. strontium and caesium, and become concentrated in the food chain. Besides when they disintegrate, they produce daughter products which may emit radiation and which may be more dangerous than the "parent".

5.16 Table 5.1 lists the radionuclides of ecological importance, giving their occurrence, half-lives, the types of radiation and their comparative energy[27].

Group A. Naturally occurring isotopes which contribute to background radiation

Nuclide	Half - Life	Radiations	Emitted
Uranium-235 (^{235}U)	7 x 10^8 yrs.	Alpha^3	Gamma ^{0}
Uranium-238 (^{238}U)	4.5 x 10^9 yrs.	Alpha^3	
Radium-226 (^{226}Ra)	1620 yrs.	Alpha^3	Gamma ^{0}
Thorium-232 (^{232}Th)	1.4 x 10^{10}yrs.	Alpha^3	
Potassium-40 (^{40}K)	1.3 x 10^9 yrs.	Beta^2	Gamma ^{0}
Carbon-14 (See Group B.)			

Group B. Nuclides of elements which are essential constituents of organisms, and therefore important as tracers in community metabolism studies, also because of the radiation they emit

Nuclide	Half - Life	Radiations	Emitted
Calcium-45 (^{45}C)	160 days	Beta^1	
Carbon-14 (^{14}C)	5568 yrs.	Beta^0	
Cobalt-60 (^{60}Co)	5.27 yrs.	Beta^1	Gamma^2
Copper-64 (^{64}Cu)	12.8 hrs.	Beta^1	Gamma^2
Iodine-131 (^{131}I)	8 days	Beta^1	Gamma^1
Iron-59 (^{59}Fe)	45 days	Beta^1	Gamma^2
Hydrogen-3 (Tritium)(^{3}H)	12.4 yrs.	Beta^0	
Manganese-54 (^{54}Mn)	300 days	Beta^2	Gamma^2
Phosphorus-32 (^{32}P)	14.5 days	Beta^2	
Potassium-42 (^{42}K)	12.4 hrs.	Beta^3	Gamma^2
Sodium-22 (^{22}Na)	2.6 yrs.	Beta^1	Gamma^2
Sodium-24 (^{24}Na)	15.1 hrs.	Beta^2	Gamma^2
Sulfur-35 (^{35}S)	87.1 days	Beta^0	
Zinc-65 (^{65}Zn)	250 days	Beta^1	Gamma^2

Also barium-140 (^{140}Ba), bromine-82 (^{82}Br), molybdenum-99 (^{99}Mo) and other trace elements.

(contd. over leaf)

Table 5.1 Radionuclides of Ecological Importance

Group C. Nuclides important in fission products entering the environment through fallout or waste disposal.

NUCLIDE	HALF-LIFE		RADIATIONS	EMITTED
The strontium group				
Strontium-90 (^{90}Sr) and	28	yrs.	Beta^{1}	Gamma
daughter yttrium-90 (^{90}Y)	2.5	days	Beta^{2}	
Strontium-89 (^{89}Sr)	53	days	Beta^{2}	
The cesium group				
Cesium-137 (137Cs) and	33	yrs.	Beta^{2}	Gamma
daughter barium-137 (^{137}Ba)	2.6	min.	Beta	Gamma^{1}
Cesium-134 (^{134}Cs)	2.3	yrs.	Beta^{1}	Gamma^{2}
The cerium group				
Cerium-144 (^{144}Ce) and	285	days	Beta^{1}	Gamma^{0}
daughter praseodymium-144 (^{144}Pr)	17	min.	Beta^{2}	Gamma^{2}
Cerium-141 (^{141}Ce)	33	days	Beta^{1}	Gamma^{1}
The ruthenium group				
Ruthenium-106 (^{106}Ru) and	1	yr.	Beta^{0}	
daughter rhodium-106 (^{106}Rh)	30	sec.	Beta^{3}	Gamma^{2}
Ruthenium-103 (^{103}Ru)	40	days	Beta^{1}	Gamma^{1}
Zirconium-95 (^{95}Zr) and	65	days	Beta^{1}	Gamma^{1}
daughter niobium-95 (^{95}Nb)	35	days	Beta^{0}	Gamma^{1}
Barium-140 (^{140}Ba) and daughter	12.8	days	Beta^{1}	Gamma^{1}
lanthanum-140 (^{140}La)	40	hrs.	Beta^{2}	Gamma^{2}
Neodymium-147 (^{147}Nd) and	11.3	days	Beta^{1}	Gamma^{1}
daughter promethium-147 (^{147}Pm)	2.6	yrs.	Beta^{1}	Gamma
Yttrium-91 (^{91}Y)	61	days	Beta^{2}	Gamma^{1}
Plutonium-239 (^{239}Pu)	$2.4\text{x}10^{4}$	yrs.	Alpha^{3}	Gamma^{1}
Iodine-131 (see Group B)				
Uranium (see Group A)				

(Table 5.1 (contd.)

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* ^{0}Very low energy, less than 0.2 Mev, ^{1}relatively low energy, 0.2 Mev, ^{2}high energy, 1-3 Mev, ^{3}very high energy, over 3Mev.

Comparative Radiosensitivity

5.17 From the early work done with X-rays, scientists had observed that organisms differed widely in their tolerance of radiation doses. The quantum of the dose, too, mattered. Large single doses delivered at short intervals (minutes or hours) are known as *acute doses*, while *chronic doses* were identified as sublethal radiation spread over a long protracted period like an entire life cycle. Eventually these experiments and observations indicated that organisms exhibited what is known to radioecologists to-day as comparative *radio sensitivity*.

5.18 Among the results of scientific experiments concerning radiosensitivity, the following are of ecological importance and show how quickly the balance of nature can be upset.

(a) acute doses of X-ray or gamma radiation (up to 100,000 rads) can destroy all individuals of a insect population;

(b) mammals are the most sensitive, and micro organisms the most resistant to radiation;

(c) seed plants and lower vertebrates fall between insects and mammals in radio sensitivity;

(d) rapidly dividing cells are most sensitive, i.e. any growing or developing organ of any living thing is seriously affected by radiation.

(e) in higher plants, sensitivity is proportional to the size of the nucleus of the cell, or more accurately, to the chromosome volume or DNA component. Plants with large nuclei, e.g. pine, were killed by a dose less than 1000 rads.

(f) mammals are very sensitive because the rapidly dividing blood-making tissue in the bone narrow is especially vulnerable.

5.19 From these findings it is possible to say that if an ecosystem receives a higher level of radiation than to which it is naturally. accustomed, serious changes may take place, including the elimination of whole species. Then, as we saw earlier, there will be a dislocation of the links in the different "cycles". One of the quickest manifestations could be in the energy cycle, such as the disturbance of the predator-prey equilibrium which in turn can throw up an eruption of pest species.

Radiation Effects on Ecosystems

5.20 It is clear that man is affected by radiation directly as an individual and indirectly as part of an ecosystem. Whereas scientists had made extensive studies on human health hazards, there there was very little understanding of the effects of radiation on the environments as as a whole. This gap in knowledge is being rapidly bridged by recourse to scientific experiment.

We mention below some of the methods being used.

5.21

1. Very strong gamma sources,such as cobalt-60 and caesium-137, of 10,000 curies or more, have been placed in fields and forests at the Brookhaven National Laboratory on Long Island (Woodwell 1962, 1965), in a tropical rain forest in Puerto Rico (Odum & Pigeon 1970) and in a desert in Nevada (French 1965).
2. The effects of unshielded reactors (which emit both neutrons and gamma radiation) have been studied in Georgia (Plant 1965).
3. A portable gamma source has been used to study short-term effects on a wide variety of biological communities at the Savannah River Ecology Laboratory in South Carolina- (Mc Cormich & Golley 1966, Mc Cormich 1969)[27].
4. A lake bed community subjected to low-level chronic radiation from atomic waste has been under study at the Oak Ridge laboratory for many years.

If we consider the results of the experiments at the oak-pine forest at Brookhaven they could be summarized as in Fig. 5.1.[27].

5.22 The experiment shows that a chronic radiation gradient resulted, varying from 1000 rads at 10 metres from the source to the natural background value at 140 metres. Although the experiment was carried out in a temperate climate and the flora studied were pines, oaks, etc., the scientific deductions are valid for all living organisms and their systems.

5.23 The reduction in species diversity by the death of certain components of the above forest and an unusual outbreak of leaf aphids that resulted are indicative of the imbalance that was caused by irradiation. If a similar experiment were to be conducted in a tropical climate where both species diversity and biomass are greater it is reasonable to expect a far more significant disruption of ecosystems.

The Fate of Radionuclides in the Environment

5.24 Besides the natural or background radiation from cosmic and other sources to which, of course, all organisms are adapted, there are man-made sources which release radionuclides into the environment. Two such sources are nuclear reactors and atomic explosions.

For the purposes of this report we need consider only the problems caused by radiation from nuclear reactors.

5.25 When radionuclides are released into the environment, they quite often become dispersed and diluted, but they may also become concentrated, in living organisms and during food-chain transfers, by a variety of means, which we have previously referred to collectively under the general heading of "biological magnification" (see para 5.11). Radioactive substances may also accumulate in water, soils, sediments, or air, if the input exceeds the rate of natural radioactive decay. This means that apparently harmless amounts of radioactivity may very well accumulate in the environment and produce subsequent lethal effects.

5.26 The ratio of the concentration of a radionuclide in an organism to that in the environment is called the concentration factor. A radioactive isotope behaves chemically essentially the same as the nonradioactive isotope of the same element. Therefore, the observed concentration by the organism is not the result of the radioactivity, but merely demonstrates, in a measurable manner, the difference between the concentration of the relevant chemical element in the environment and in the organism.

5.27 Some of the earliest data on the concentration of radionuclides in both aquatic and terrestrial food chains were obtained by radioecologists at the AEC Hanford plant on the Columbia river in eastern Washington state (see Foster and Rostenbach, 1954; Hanson and Kornberg, 1956; Davis and Foster, 1958)[27]. Here, trace amounts of induced radionuclides (^{32}P, etc.) and fission prouducts (^{90}Sr, ^{137}Cs, ^{131}I, etc.) are released into the river, into waste holding ponds, and into the air. The concentration of chemical phosphorus in the Columbia River is very low, only about 0.00003 mg per gm water (ie. 0.003 ppm), whereas its concentration in egg yolks of ducks and geese (that obtain their food from the river) is about 6 mg per gm. Thus, a gram of egg yolk contains two million times more phosphorus than a gram of water in the river. We would not expect to find a concentration factor for radioactive phosphorus quite this high since, while it was moving through the food chain to the eggs, it would have decayed and reduced in amount. Ocassionally a concentration factor as high as 1,500,000 was recorded, but the average was about 200,000, (Hanson and Kornberg, 1956)[27]. Some other concentration factors reported are as follows: 250 for caesium-137 in muscle and 500 for strontium-90 in bone of waterbirds, as compared with concentration of these radio-nuclides in the water of waste ponds in which these birds were feeding. The concentration of radioactive iodine in the thyroids of jack rabbits was 500 times that in the desert vegetation, which in turn had concentrated the nuclide released into the air in stack gases from the atomic plant.

5.28 While radioactivity does not affect the uptake of the isotope by living systems, it does have detrimental effects on active tissues once it is absorbed. The point is that allowance must be made for such ecological concentration of radionuclides in establishing "maximum permissible levels" of their release into the environment.

Radionuclides that are specifically concentrated in certain tissues (such as iodine in the thyroid or strontium in the bone), and/or those with long effective half-lives, are obviously the ones to be concerned about.

5.29 There are two other aspects of radioactivity which affect the environment. One is the radioactive dust which falls after nuclear explosions and the other is the disposal of radio-active wastes.

5.30 The question of radioactive fallout from nuclear explosions is not relevant to this report.

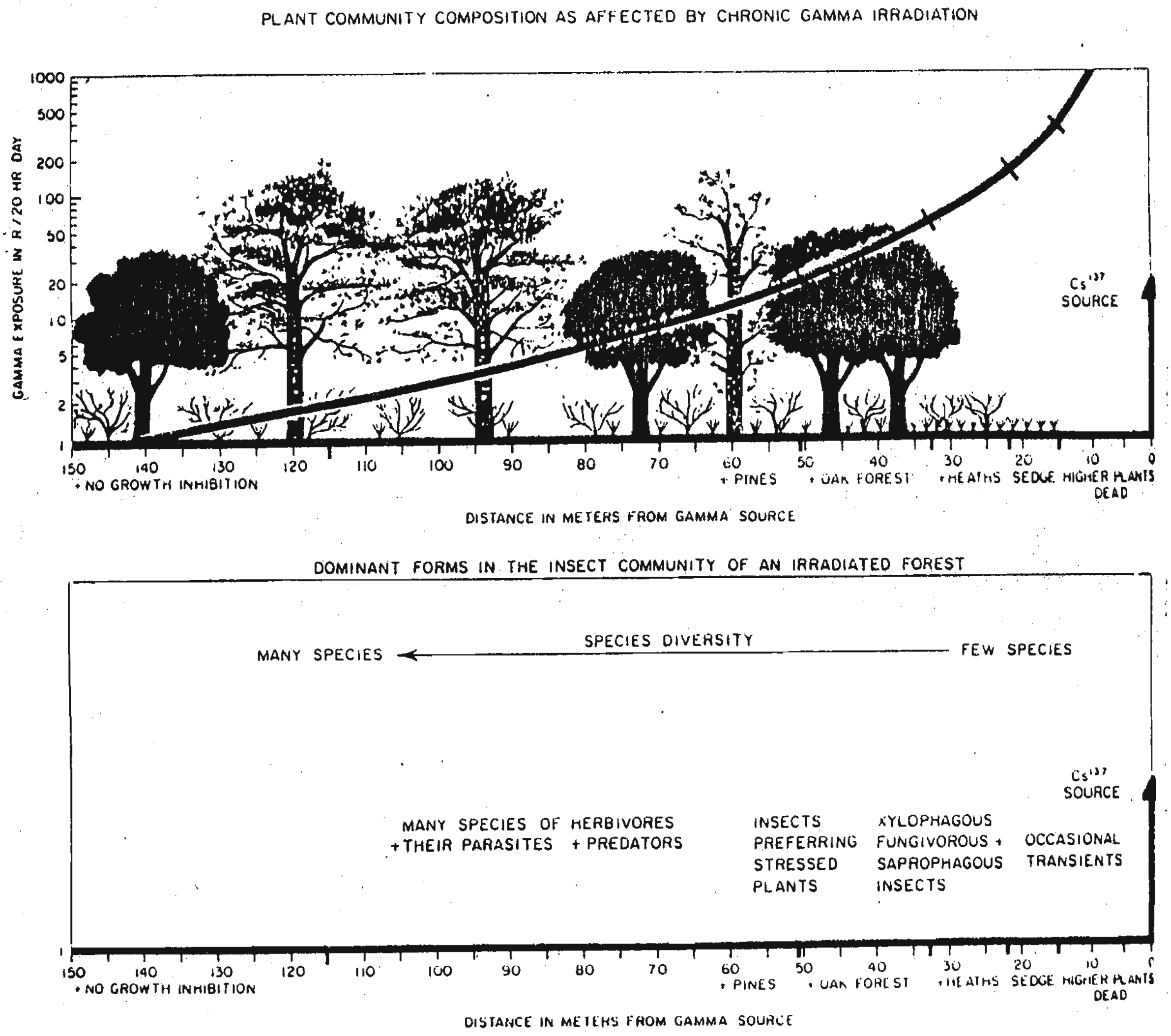
5.31 Waste disposal from a nuclear power plant is a serious problem. Radioactive waste may be dealt with by dispersal or by containment. In the first case, low-level waste is so diluted that the dispersal does not introduce appreciable risks to man and the environment. In the second case, the containment of high level waste must survive or endure until the radioactivity of the waste has decayed sufficiently so that all possible risks are avoided. Medium and high level wastes are usually held in stores on the site where they are produced. Such containment of high level waste, for example of burnt, unreprocessed nuclear fuel, may have to be ensured for thousands of years. If the burnt nuclear fuel is reprocessed, the resulting high level waste must be contained for over 500 years.

5.32 Waste heat from a NPP can cause serious thermal pollution. A NPP produces more waste heat than a conventional thermal power plant of equivalent electrical output. The pollution from this source can be minimised by directing the waste heat to the sea.

5.33 It is clear from the foregoing that the Environment is a complex, interdependent and inter-related, yet fragile, system whose natural processes are only now being understood. Still less is our understanding of the effects of Man's interference with it, especially with the introduction of noxious substances. The science of Ecology is no more than a century old and that of Radioecology goes back only a couple of decades.

5.34 It is incumbent on those responsible to commence investigations on the effects of radionuclides on the environment by means of experiments under controlled conditions well in advnace of the establishment of a nuclear power plant. These experiments should be done in the special situation in our country for, in ecology, we cannot generalize from results obtained elsewhere. The following extract from the report of The Windscale Inquiry by Hon. Mr. Justice Parker [28] confirms this view :

> "In certain areas the benefit of world-wide research accrues to the United Kingdom Authorities. For example, work on the effects of a particular radionuclide, when ingested or inhaled by man, is of general application. In other areas the necessary research for the protection of the public can only be done in the United Kingdom and is, to a large extent, only applicable to the United Kingdom. What happens to discharges to the Irish Sea from Windscale is a simple example. The radionuclides will be dispersed in the sea but they must then be followed. It must be ascertained, for example, to what extent they are taken up by various kinds of fish, which may be eaten or turned into fertilisers, or by seaweed, which may also be incorporated into foodstuffs or fertilisers, whether they are redeposited on land, and if so, where, or whether they get or can get back to man in the form of sea spray. But such matters are only the beginning of the research operation. Next it must be ascertained how much of the radioactivity in the fish or seaweed or deposited on the shore gets back to the most exposed members of the public". [28]



PLANT COMMUNITY COMPOSITION AS AFFECTED BY CHRONIC GAMMA IRRADIATION

DOMINANT FORMS IN THE INSECT COMMUNITY OF AN IRRADIATED FOREST

Figure **5.1** The response of an oak-pine forest to a gradient of gamma radiation from a high-level, fixed source that was unshielded for 20 hours each day for a period of two years. See text for explanation. (Used by permission of Brookhaven National Laboratory, Long Island, New York.)

From : Fundamentals of Ecology by : Eugene P. Odum

W.B. Saunders Company, Philadelphia - 1971, p. 458

CHAPTER 6

SAFETY AND REGULATORY ASPECTS IN A NUCLEAR PROGRAMME

Government Responsible for Control and Safety

6.1 The ultimate responsibility for the protection of the people in any country rests with the national government. This responsibility becomes a vital concern when the country seeks to install and operate a nuclear power plant.

6.2 The unique feature of nuclear power plants, as distinct from all other power generating facilities, is the presence of considerable amounts of radioactive fission products. Thus, the major problem in the design, construction and operation of a nuclear installation is to ensure that these fission products remain safely confined at all times and under all possible circumstances, - during the installing and operation of the nuclear reactor, during re-fueling, in the procedures of disposing spent fuel and during and after decommissioning of the plant.

6.3 Many learned articles on the subject portray that the calculated risks to the society from nuclear power are very low compared with risks from other activities essential to a modern society. They claim that the *nuclear* safety record of the nuclear power industry has been quite good. But in all countries that may claim such a good record, there has been strict discipline in all nuclear operations, enforced by a competent governmental regulatory body which is backed by a Code of Regulations that have the force and effect of law.

6.4 It is not within the purpose and function of this Report to spell out details of the provisions and requirements of such a national code of regulations that must govern all nuclear procedures, or of the functions and composition of a national regulatory body.

6.5 The International Atomic Energy Agency, under its Nuclear Safety Programme has published Codes of Practice and accompanying Safety Guides. The following is a list of the Codes of Practice published by 1978.

1. Governmental organization for the regulation of nuclear power (50-C-G).
2. Safety in nuclear power plant siting (50-C-S).
3. Design for safety of nuclear power plants (50-C-D).
4. Safety in nuclear power plant operation, including commissioning and de-commissioning (50-C-O).
5. Quality assurance for safety in nuclear power plants (50-C-QA).

Licensing Process

6.6 The necessary government control and authority are exercised through the issue of licences. The licensing process should be considered as an ongoing process, with five major stages: siting, construction, commissioning, operation and decommissioning of a nuclear power plant.

6.7 Licensing procedures vary from country to country. Generally, before any group or organization can build a nuclear power plant at a particular site, they must apply to the government regulatory body for a construction permit, submitting comprehensive data on the proposed site, a description of the proposed nuclear plant with special reference to safety features, a study of hypothetical accident situations and their consequences, a preliminary plan for the organization of personnel at the plant and for the conduct of operations, and plans for coping with emergencies, including plans for the evacuation of people from the neighbourhood. It would then be the duty of the regulatory body to study the applicant's submissions, ensure that the proposals conform to all the requirements of the Code of Regulations, and be satisfied that the nuclear power plant can be constructed without undue risk to the health and safety of the public. In the United States, for instance, two other stages are necessary: the application and documentation must be reviewed and assessed by an independent Advisory Committee on Reactor Safeguards, and then be subject to the proceedings of a public hearing in the vicinity of the proposed site so that any person whose interests are affected by the issuance of the permit may intervene and be a party to the proceedings.

6.8 Once the applicant has obtained his construction permit, he can proceed to build the nuclear installation. However, before the nuclear plant can be commissioned and operated, the applicant must apply for the relevant licence or licences to the same national authority. Much of the procedures then may be a repeat of what was done earlier for the consideration and issue of the construction permit.

6.9 Thereafter, the regulatory body continues to ensure that the nuclear facility conforms to the Regulations throughout the operating life of the plant and even after it has been decommissioned, until all risks from radiation have been eliminated.

The Regulatory Body

6.10 The complete proceedings for issuing the necessary licenses for the construction and operation of a nuclear power plant must necessarily take both time and effort on the part of the regulatory body and of the licensee. It should be clear that the government regulatory body must be an independent entity, with its personnel qualified, knowledgeable and experienced in nuclear power plant design, construction and operation, also capable of evaluating the environmental impact of the operating nuclear plant, and of ascertaining the radiological consequences of reactor accidents. This regulatory function should not be carried out by any foreign agency, national or international. It must be the responsibility of a national regulatory body, staffed by persons whose ultimate loyalty is to the country concerned.

6.11 We quote from the Code of Practice 50-C-G, Government organization for the regulation of nuclear power plants, published by the International Atomic Energy Agency, Vienna[29].

In Section 4.2.1 it states :

> "The regulatory body shall not rely solely on the applicants, licensees or their contractors for performing the assessments required by the regulatory programme. Accordingly, the regulatory body should have a full-time staff capable of performing these assessments or of evaluating the adequacy of assessments performed for the regulatory body by its consultants".

In Section 4.3.2 it states :

> "It is essential that the regulatory body possess sufficient staff competence to evaluate independently the quality of the work being performed for it. The use of consultants shall not relieve the regulatory body of its responsibilities for making decisions or recommendations".

6.12 . We also quote from the proceedings of the Vienna Symposium of March 1978 held by the International Atomic Energy Agency on the problems associated with the export of nuclear power plants[30] .

> "The basis for almost all regulatory activities in the field of Nuclear Power generation is a detailed and thorough knowledge of the technical aspects of the many areas in which the regulatory body will be involved. In other words, the regulatory body must have at least the same level of technical expertise as the utility being regulated and preferably more" (Jacobs and Chung, p.52).

> 'A great majority of the problems occuring at exported nuclear power plants could be eliminated by a strong, independent national regulatory agency. Governments and developing nations ... must establish a well trained, well staffed, and well organized regulatory agency at the earliest stage of the national nuclear plant programme... This independent national regulatory agency should be the cornerstone of the nuclear programme. It's duties should include the establishment of the national nuclear energy policy, a survey of utility preparedness for nuclear power, an evaluation of proposed sites, a survey of domestic industry for participation in the nuclear programme, assistance to the utility in bid evaluation, the establishment of quality assurance requirements for the utility and domestic industry, etc. The costs of the agency would be minimal compared to the benefits of an organized nuclear industry" (Fitz, p.63).

6.13 We do not believe that Sri Lanka today has the necessary qualified and experienced personnel to constitute such a regulatory body that could carry out the functions and duties indicated above, and take responsibility for making decisions and recommendations in all matters of design, siting, construction, commissioning and operation of a nuclear power plant. Before Sri Lanka can institute a competent national regulatory body, it is essential that adequate numbers of regulatory engineers and scientists be trained. A programme for such training and work experience should be initiated as early as possible.

Regulatory Problems in Developing Countries

6.14 It is of interest to summarize some of the difficulties and problems of regulatory activities as discussed at the IAEA Vienna Symposium of 1978[30].

1. Developing countries are usually not in possession of a large, diversified industrial technology.
2. Developing nations fail to show adequate concern for safety when considering the introduction of nuclear energy. Despite the fact that each country may have a core of highly educated nuclear engineers and scientists, the government, the utility, and the industry do not fully understand the safety and radiological aspects of nuclear power.
3. In some developing countries, rigorous quality assurance programmes, involving design, manufacturing, installation, testing and operation are unknown; formal procedures for manufacturing, quality control, testing and training are nonexistent.
4. The first plants are usually bought on a turnkey basis with the assumption that the contractor will handle all the special nuclear related tasks. In fact, this assumption holds only for the plant construction and start up. The responsibility of regulation, licensing and operational surveillance remains with the national regulatory body.
5. Since safety and radiological aspects of nuclear power are not fully appreciated or understood, regulatory agency budgets are extremely limited both in foreign and local currencies. The costs of imported large machinery, piping, special equipment, and their installation, are covered by foreign loans. A large sum of local currency is allocated for the domestic industry, performing standard construction services like

civil/structural work, heating/ventilating/plumbing installation, etc. To minimize associated expenditures, governments keep regulatory agency budgets at very low levels despite the ambitious and expanding nuclear power programmes.

6. Due to budget and other limitations, regulatory agencies are short of competent personnel both in number and technical skill.
7. Lacking proper governmental recognition, regulatory bodies are often placed in the governmental hierarchy as any other department, without having independent authority for ensuring the health and safety of the public.
8. For some developing countries, comprehensive national policy, laws, standards and criteria regulating the nuclear plant industry are either non-existent or incomplete. Usually, turnkey plants are built with compliance to the exporting country's regulations in effect on a mutually agreed cut-off date. The full adoption of these regulations, however, may not be economical and practical for developing countries.
9. The role and representation of regulatory agencies in contract negotiations is very limited. Nuclear power plant investments are major financial ventures for developing nations; therefore, contract items are judged primarily from financial aspects. Safety considerations are often of secondary importance. Due to the position of the regulatory bodies in the governmental structure, their safety oriented requirements could be overruled for the sake of financial benefits.
10. Cooperation between utilities and regulatory agencies is not always satisfactory and the interface is not well understood. In many instances, utility engineers are better trained in nuclear plant operations than the regulatory personnel. Therefore, utilities often fail to involve regulatory agencies in safety matters.
11. During the design and licensing phase, the review of the very limited number of design documents submitted is belated or non-existent. Deadlines for review and comment are missed. Comprehensive design review plans are not prepared. Review of safety analysis reports is not thorough enough.
12. During construction, preoperational tests and startup, the various inspections, quality assurance and safety audits,

witnessing of tests, and recording and evaluation of test results are not satisfactorily performed. Because of budget restrictions, the technical skill, the time allocation and the number of inspectors are far from adequate.

13. Prior to plant operation, the regulatory agencies are not well prepared to conduct practical examinations for reactor operators. Budget limitation prohibits regulatory agency engineers from attending training courses given by nuclear steam supply system vendors.

14. During plant operation, the regulatory agencies are not properly organized to handle violations of limiting conditions of operation, to cope with radiation emergencies, and to conduct quality assurance, health physics and operational safety audits. The regulatory agencies might not possess the full authority necessary to shut down plant operations because safety limits have been exceeded.

Radiation Safety and Monitoring Services

6.15 An efficient and reliable radiation safety and monitoring system is absolutely essential in connection with any occupation involving the handling and use of sources of ionizing radiations. Such occupational activities range from routine radiography and radiotherapy to the use of high-intensity radiation sources, research reactors and power reactors. Even in respect of radiation dose levels that are considered low, an effective radiation monitoring service covering all users in the country is essential and obligatory.

6.16 In Sri Lanka a Radiation Protection Service (RPS) was set up in 1961, primarily to provide a film badge monitoring service to radiation workers at the Cancer Institute at Maharagama, the General Hospital at Colombo and the Chest Hospital at Welisara. The RPS was expected to so develop eventually as to cover all radiation workers in the country. It was intended that the RPS have its headquarters at the Cancer Institute because of the availability of physicists and radio-therapists at the Institute, the extensive use of radiation for therapeutic purposes and the availability of laboratory facilities there.

6.17 However, at the present time, the number of radiation workers has increased to about 500 throughout the country, and the available resources of the RPS staff, laboratory space, equipment and materials, scientific literature, transport and maintenance facilities are woefully inadequate to meet present commitments. In particular, we learn that the RPS staff is limited to just one individual, a physicist. A much bigger specialised staff is necessary to maintain an adequate film badge monitoring service, to conduct regular monitoring surveys of the cobalt-60 and x-ray units throughout the country, and to deal with emergency situations involving radiation hazards.

6.18 Further,the physicist of the RPS reports that the radiation monitoring equipment is inadequate and the supply of film badge material not continuous, and as such the RPS is not able to perform its functions and obligations effectively. In fact, he reports that there has been no radiation film badge service from February 1980 to April 1981. This is a very serious matter in respect of the personal health histories of radiation workers in the country. Under the Atomic Energy Regulations of 1975[31]. every employer is expected to maintain a continuous record of each radiation worker in respect of radiation dosage received. As discussed in Chapter 4, paragraph 4.9, the radiation dose rate received must be less than that corresponding to the Maximum Permissible Dose (MPD) in one year. The RPS would be expected to inform a radiation worker if the radiation dose received in any one week is excessive. In this context, a break of over one year in the personal monitoring system in the country, and a consequent break in the radiation history record of an occupational worker, is both discreditable and unpardonable. Unless the RPS is so provided with the necessary manpower, facilities and materials, there can be no assurance that radiation workers are not being exposed to unduly high doses of radiation. Indeed, considering the fact that there is no regular surveying of x-ray and other irradiating facilities in the country, it is likely that many workers have received excessive doses of radiation, with consequent health hazard.

6.19 The lapses in the supply of essential equipment and materials for the RPS is evidently the result of the RPS having to follow standard procuring procedures adopted by government institutions. It is well known that such government procedures give rise to interminable delays, worsened by the seeming apathy and indifference of the public officials concerned. This poor state of affairs in respect of the RPS must be corrected immediately. A good RPS covering all occupational workers is an absolute necessity in this country. (This necessity is there whether Sri Lanka decides for or against obtaining a nuclear power reactor).

6.20 An effective radiation safety and monitoring service cannot be maintained unless the RPS, or an equivalent body, functions as an independent entity, unhindered and unembarrassed by the usual bureaucratic tardiness.

6.21 Although the Atomic Energy Regulations[31] have been in force since 1975, there appears to be no proper mechanism to enforce these regulations and to prevent the unauthorized and uncontrolled use of irradiation units. It is believed that a number of x-ray units, used for medical purpose in the private sector are being operated by unauthorised personnel. X-ray sources are also being used for industrial purposes and such use of ionizing radiation will increase as the country develops industrially. An effective mechanism for the enforcement of the Atomic Energy Regulations is therefore a vital necessity. This mechanism must include a well-equipped and qualified inspectorate that makes regular surveys of all irradiating facilities in the country, and an authoritative and mandatory body that is knowledgeable and experienced in radiation safety and health physics.

6.22 This discussion so far has not considered safety aspects relating to nuclear power. If Sri Lanka intends to install a nuclear power plant for the generation of electrical energy, the problem of radiation safety, health physics and personal monitoring becomes colossal (in comparison). Within the nuclear power plant complex there must be a radiation safety and monitoring system that is specific and specialised; this should form an inherent part of the operational organization of the power plant. Such systems are well developed in present-day nuclear power plant design and operation. It would be the responsibility of the operating organization to strictly maintain such safety and monitoring services within the complex. The governmental regulatory body and its inspectorate would have to ensure that all operations within the nuclear facility would conform to the existing regulations and codes of practice.

Nuclear Accident Analysis, Safeguards and Emergency Measures

6.23 Nuclear Power Plants, containing enormous quantities of radioactive fission products, carry the potential for major accidents affecting a great number of people. The probability of accidents is however claimed to be very low. The term "Risk" is commonly used to describe the consequences of a specified event per unit time. For instance, if in a country of 100 million people there are, in each year, 15 million motor car accidents, of which one in three hundred end in a fatality, the risk to the society is 50,000 deaths per year. On the other hand, there may be another event or accident that may occur only once a year, but results in 50,000 deaths. The societal risk is still the same. However, the public attitude to a given risk depends not only on the size of the risk, but also on the magnitude of the consequences of the event. The public tends to view the second type of accident with greater trepidation because its consequences are sudden and unexpected. Estimates of risk of serious illness or death, due to nuclear accidents, give values that are several thousand times smaller than those due to motor car accidents, yet it is easy to understand the public aversion to the use of nuclear power, because of the possibility of disastrous consequences following a single nuclear accident.

6.24 In the history of commercial nuclear energy, the number of accidents reported have been low. It is not possible therefore to evaluate the risk of nuclear accidents as directly as, say, that of road accidents, where the data available is extensive and is in fact being continously provided. Risks due to nuclear accidents have to be analysed in terms of hypothetical estimates, to make up for lack of data from experience. The calculation of risk is usually a three-step process :

i. determination of the probabilities of the various radioactive releases from an accident at the power plant,
ii. the evaluation of the consequence to the public of such releases to the environment, and
iii. the assessment of the overall risk by combining the release probabilities and their consequences.

6.25 A nuclear power plant (NPP) is designed with many safety features. The failure of a single component, by itself, cannot lead to a major release of radio-activity. Such a component failure sets into operation a sequence of safety systems that are intended to mitigate the effects of the failure. Yet, each failure or initiating event leads to several outcomes or sequences, each with its own probability of radioactive release. It is usual to make up a suitable model to identify and analyse such accident sequences. The whole subject of nuclear accident analysis is a vast one that is outside the scope of this report.

6.26 The use of multiple, successive barriers to the escape of radioactivity is basic to NPP design. To take into account abnormal occurrences, such as equipment failure, human error, or natural phenomena, the U.S. Atomic Energy Commission (now succeeded by the Nuclear Regulatory Commission) for example, has a safety philosophy recognizing three levels of safety: [32]

i. "Design for maximum safety in normal operation and maximum tolerance for system malfunction. Use design features inherently favourable to safe operation; emphasize quality, redundancy, inspectability, and testability prior to acceptance for sustained commercial operation and over the plant lifetime". This first level of safety seeks to prevent accidents by virtue of careful design and construction, and proper surveillance of the plant.

ii. "Assume accidents will occur in spite of care in design, construction and operation. Provide safety systems to protect operators and the public and to prevent or minimize damage when such incidents occur". The object here is to protect the operating personnel and the public from the consequences of such accidents.

iii. "Provide additional safety systems as appropriate, based on the evaluation of the effects of hypothetical accidents, where some protective systems are assumed to fail simultaneously with the accident they are intended to control". This third level adds a margin of safety in the event of extremely unlikely or unforeseen events.

6.27 An applicant for a reactor licence must analyse a set of postulated, hypothetical accidents, and show that the nuclear facility can be operated without undue risk to the health and safety of the public.

6.28 A comprehensive study of the risks of accidents in U.S. commercial nuclear power reactors was made by a task force headed by Dr. N.C. Rasmussen. The findings were published in 1974 by the U.S. Atomic Energy Commission under the title: "Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants". USAEC Report WASH - 1400, or Nureg -75/014[33].The spectrum of possible accidents is divided into nine classes, in increasing order of severity. Class 1 includes trivial accidents where the accompanying release of radioactivity is not significant. Class 9 would have grave consequences, and involve a broad range of events which, while more serious than those of Class 8, are so improbable that they can generally be ignored in analyzing both the safety and the environmental aspects of the facility.

6.29 In respect of each type of accident, the consequences of the accident must be analyzed and the necessary corrections or safeguards set out to mitigate the consequences. The operating personnel of a nuclear power plant are required to be fully alert to possible failures or accidents, and be knowledgeable of the emergency measures to be taken immediately. Linked with such corrective operations, there must be continuous environmental and personnel monitoring of radioactivity. Also there should be a planned programme of emergency measures relating to the public in the neighbourhood of the NPP, even to the complete or partial evacuation of the population at short notice.

6.30 It must be recognised that the analyses of hypothetical accidents, even though carefully carried out, may not be complete. Further, as the number of nuclear power plants within a country increase, there will be a corresponding increase in the probability of a nuclear accident in the country. We quote form ALO-62, 'Improving the Safety of LWR Power Plants, - Final Report, 1980:[34]

> "The history of the U.S. nuclear power programme has shown that, in many cases, the accidents which occur are not the ones which have been analysed in the licensing process". (page 2-5).
>
> "Nuclear events may have low probability but can have very major consequences. It is possible that the effects of a major reactor accident may be so large as to prove unacceptable to the public and the policy makers. With a score of reactors in operation, the probability that a single large, but by no means the largest, accident will occur within a few decades is not negligible. If the decision is made to continue to increase the United States nuclear commitment, the policy makers and the public must understand their own personal risk related to that decision". (Page 1-13).
>
> "The ATWS* event is potentially one of the most severe reactor accidents that could occur. It involves not only

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*ATWS - Anticipated transient without scram the decay heat but full power heat as well and can lead to severe breaches of containment. The ATWS controversy (now ten years old) has centred around how likely the event is to occur. However, there is value in assuming it would occur and then working to mitigate the effects, or working to reduce the probability of occurrence. The NRC staff estimated the chances of a severe ATWS accident at four-in-seven between now and the year 2010. This has been refined to a slightly lower probability (about four-in-ten chance), but is still far from an incredible event". (Page 2-20).

6.31 It is appropriate here to discuss briefly the events and consequences of the Three Mile Island (TMI) accident of March 1979. Three Mile Island lies about 10 miles South-East of Harrisburg, Pennsylvania, U.S.A., and is the site of a two-unit nuclear power station, of 800 MW and 900 MW respectively. The original accident was initiated by mechanical malfunctions in the TMI-2 unit and may have by itself been considered Class 1, but due to a combination of human errors in responding to it, it developed into a very serious accident, considered as Class 9 type according to the staff of the U.S. Nuclear Regulatory Commission. This means that it has exceeded the accidents analyzed in the licensing process and would have been classed as *incredible* prior to its occurrence, (ALO-62 p.2-21) [34].

6.32 We consider it relevant to include extracts from the Final Report of the U.S. President's Commission of the TMI accident[18] headed by Dr. John G. Kemeny. The Commission said that in the evidence they received they have noted a preoccupation with regulations: but regulations alone could not assure safety...

> "While scientists and engineers have worried for decades about the safety of nuclear equipment, we find that the approach to nuclear safety had a major flaw... Some potentially dangerous scenarios, such as the break of a huge pipe that carries the water cooling the nuclear reactor, were studied extensively and diligently, and were used as a basis for the design of plants. A pre-occupation

developed with such large-break accidents as did the attitude that if they could be controlled, we need not worry about the analysis of 'less important' accidents. Large-break accidents require extremely fast reaction, which therefore must be automatically performed by the equipment. Lesser accidents may develop much more slowly and their control may be dependent on the appropriate actions of human beings. This was the tragedy of Three Mile Island, where the equipment failures in the accident were significantly less dramatic than those that had been thoroughly analysed, but where the results confused those who managed the accident. A potentially insignificant incident grew into the TMI accident, with severe damage to the reactor. Since such combinations of minor equipment failures are likely to occur much more often than the huge accidents, they deserve extensive and thorough study. In addition, they require operators and supervisors who have a thorough understanding of the functioning of the plant and who can respond to combinations of small equipment failures".

6.33 The Commission stated that many factors contributed to the inappropriate operator action at TMI, such as the deficiencies in the training of operators, lack of clarity of the operating procedures, failure of organizations to learn the proper lessons from previous accidents, and deficiencies in the design of the control room. These shortcomings were attributable to the utility, to the suppliers of equipment, and to the federal commission that regulated nuclear power.

6.34 Among the main recommendations made by the Kemeny Commission that are relevant to this discussion are: 1. The nuclear industry must dramatically change its attitudes towards safety regulations. Merely meeting the requirements of a government regulation does not guarantee safety. The industry must also set and police standards of excellence to ensure the effective management and safe operation of nuclear power plants. 2. Training of operating personnel should be emphasized, particularly in the understanding of the fundamentals of nuclear power plants and the possible health effects of nuclear power, and to the proper responding to emergencies. 3. The Commission recommended the establishment of better coordinated research on radiation effects, and a programme for educating health professionals and emergency response personnel in the vicinity of nuclear power plants. 4. Emergency plans must detail clearly and consistently the actions that public officials must take in the event of off-site radiation doses resulting from the release of radioactivity. 5. There should be adequate preparation for a systematic public information programme, so that at the time of a radiation-related emergency they can provide timely and accurate information to the news media and the public in a form that is understandable.

6.35 In the introductory part of the Kemeny Report on the TMI accident, the Commission states :

> "The accident was initiated by mechanical malfunctions and made much worse by a combination of human errors in responding to it ..... During the next four days, the extent and gravity of the accident was unclear to the managers of the plant, to federal and state officials, and to the general public. What is clear is that it's impact, nationally and internationally, has raised serious concerns about the safety of nuclear power".

High Technology and Discipline

6.36 It would be clear from the discussions in this chapter that the stringent requirements connected with the safety and regulatory aspects of a nuclear power programme must be met in full, and that the nuclear industry must set and police standards of excellence to ensure the effective management and safe operation of nuclear power plants.

6.37 Several knowledgeable people have expressed the view, at informal discussions and as evidence before this Committee, that Sri Lanka, in common with other developing countries, cannot cope with or sustain the high technology of a nuclear power programme, requiring safety, reliability and optimum efficiency. They believe that a lack of concern for maintaining proper procedures and ensuring standards, is now deeply rooted in our society and would be difficult to eradicate. Although this Committee does not subscribe to the belief that Sri Lankans are inherently incapable of handling high technology, we do note that there have been, and there are today, major technical shortcomings and a lack of discipline in almost all large scale technological enterprises in this country. Such lapses have led to great loss of profits, much inconvenience to the public, and even to injury and death. We cannot over emphasize the fact that, in the case of a nuclear power programme,such shortcomings or lapses can result in a major national catastrophe.

6.38 It is therefore of vital importance that the national organization that is to be entrusted with the management and operation of a nuclear power plant should have shown a record of sustained ability to operate a high technological system safely, reliably and efficiently.

Nuclear Power Plants from Overseas

6.39 In respect of **countries** like Sri Lanka, where the potential for a self-developing and self-sustaining nuclear industry is absent, there would naturally be overtures or offers from foreign vendors of nuclear power plants, offering seemingly attractive conditions for supplying complete nuclear plants, together with personnel for the construction of the building and installations and for the commissioning and operation of the plants. To the layman, in legislative and executive positions, the proposal for installing a nuclear power reactor to meet the shortage of electrical power in the 1990's may sound attractive. Perhaps, to some, a nuclear power reactor would seemingly be a complex device that can be purchased, as it were, over the counter, and need only be switched on to provide the necessary additional power.

Prerequisites to a Nuclear Power Programme

6.40 Without considering here the economics or the feasibility and reliability criteria for a nuclear power plant in Sri Lanka, but examining only the control and safety aspects, we believe that Sri Lanka is not yet in a position to consider offers of foreign nuclear power plants, or to make firm decisions about a nuclear power programme. Sri Lanka must first satisfy certain prerequisites or preconditions :

(a) assemble in this country a sufficient number of trained and experienced engineers and scientists who can serve in a national regulatory body that can make responsible decisions about nuclear power,

(b) enact nuclear legislation, embodying a satisfactory code of regulations,

(c) adopt a system of safety requirements, criteria, guides and standards,

(d) Set up and develop a scientific and technological infrastructure to support the relevant technologies of a nuclear power programme,

(e) develop reliable communications systems and means of transport,

(f) institute training programmes for power plant operators, technicians and skilled workers, and

(g) develop institutes and laboratories for specialised testing and quality control, for analyses of materials and calibrations of instruments, and for other ancillary services.

CHAPTER 7

CONCLUSIONS

1. It is necessary that Sri Lanka's long term plans to meet her energy requirements be based on well established technologies. Apart from hydro energy, the only well established systems are those that depend on the use of oil, coal or nuclear fuel (Chapter 2).

2. In the forseeable future, the demand for energy from the national grid will exceed the energy available from all hydro resources. Further, in order to obtain a reliable power supply, energy from hydro resources will have to be supplemented with that from other sources (Chapter 2).

3. The smallest commercial nuclear power plant based on a proven model and available for purchase by Sri Lanka has a net electrical output of 300 MW (Chapter 2).

4. At the beginning of 1982 the total effective generating capacity on the national grid was 523 MW. On grounds of operational flexibility and reliability, the total installed capacity must exceed 3000 MW before a nuclear power plant of 300 MW(e) can be incorporated in the grid. From the latest available forecasts of the Ceylon Electricity Board, the total installed capacity of the grid would not exceed 3000 MW before the year 2000 (Chapter 2).

5. Nuclear power plants in the 100 - 200 MW(e) range are being developed by some manufacturers, specifically for sale to developing countries. At present no such plant has gone beyond the demonstration stage. Such plants may be available for purchase in a few years, but it is doubtful whether sufficient operating experience would have been gathered before the year 1990, for Sri Lanka to be able to make a firm decision to purchase one. Thus allowing for lead time, it would not be possible to commission one in Sri Lanka till about the year 2000 (Chapter 2).

6. Most models of nuclear power plants are less reliable than coal-burning or oil-burning plants. This difference would be magnified in Sri Lanka because of unfamiliarity with nuclear technology. Even though a nuclear power plant could be economical in a developed country, it could be uneconomical in Sri Lanka for a number of reasons. Apart from the very high costs of imported technology, shut down periods may occur more frequently and be of longer duration than in a developed country (Chapter 3).

7. It is possible that by the beginning of the next century, the world demand for uranium would outstrip production (Chapter 3).

8. At present, there is no evidence that uranium ore occurs in Sri Lanka in quality and quantity usable in a nuclear power plant. Thus, in the event of a nuclear power plant being installed in Sri Lanka, the fuel would have to be imported. Some of the maintenance and regulatory services too would have to be obtained from abroad. Hence, a nuclear power plant would not make Sri Lanka independent of foreign sources for her energy (Chapter 3).

9. A nuclear power reactor presents hazards to man and the environment, not only in the event of an accident but even under normal operating conditions. Since these hazards would be greater, and the counter measures likely to be less effective, in Sri Lanka than in a developed country, decisions regarding the acquisition of a nuclear reactor must be made with extreme caution (Chapters 4, 5 and 6).

10. There is scientific evidence that radiation hazards to the natural environment are greater in tropical climates than in temperate ones. Little or no scientific studies have been conducted on the effect of radiation on the environment in Sri Lanka. It would be dangerous to extrapolate data from other countries in order to estimate risks to man and the

environment and to plan counter measures in this country (Chapter 5).

11. In almost all large-scale technological enterprises in Sri Lanka there are technical deficiencies and a lack of discipline. Such lapses lead to financial losses, inconvenience to the public and often, injury and death. In the case of a nuclear power programme such shortcomings and lack of discipline can result in a major national catastrophe. It would be dangerous to entrust a nuclear power plant to an organisation that does not possess a record of sustained efficiency and discipline (Chapter 6).

12. The scientific and technological infrastructure and the communication and transport systems in Sri Lanka are totally inadequate to meet the stringent requirements of operating a nuclear power plant (Chapter 6).

13. Existing radiation protection services and nuclear regulatory mechanisms in Sri Lanka are inadequate (Chapter 6).

14. On presently available information, it is not possible to predict whether, in Sri Lanka by 2000 A.D., energy from a nuclear power plant of 300 MW or less would be cheaper than that from an equivalent plant burning coal or oil. It is therefore necessary to continue studies on this question as more information becomes available (Chapter 3).

CHAPTER 8

RECOMMENDATIONS

1. A decision to embark on a programme for nuclear power generation must be taken only on the technical advice of experts in the fields of energy, economics, nuclear technology, health and the environment.

2. Any subsequent decision to acquire a nuclear power plant should be made only on the advice of Sri Lankan experts permanently resident in the country.

3. Any commitment towards acquiring a nuclear power plant should be made only after detailed technical studies have established that -

   a. the national grid can accommodate the output of a nuclear power plant without loss of reliability and operational flexibility, and

   b. the energy from such a plant would be more economical than that from any alternative sources.

4. Technical studies on the economics of energy from different sources must be undertaken by a responsible national body. Such studies should, among other aspects, assess the economic consequences of disruptions to the power supply.

5. The results of all necessary technical studies should be made available by the year 1990.

6. In order to ensure that sufficient expertise is available to conduct these studies, a programme of education, training and experience should be instituted immediately. It is also necessary to familiarise senior decision makers (engineers, scientists, administrators and legislators) with relevant aspects of nuclear technology.

7. Preliminary investigations on the safety, health and environmental aspects of a nuclear power programme in the particular context of Sri Lanka should be commenced. Such investigations would require expertise in seismology, meteorology, geology, hydrology, ecology and health physics.

8. An effective, well-staffed and well-funded nuclear regulatory agency should be established. This agency should be responsible for all the regulatory functions connected with activities involving nuclear radiation. The staff of this agency should be so trained that in the event of a decision being made to commence a nuclear power programme, the agency could be expanded to undertake all the necessary additional regulatory activities.

9. Adequate incentives should be offered to trained personnel at all levels so that their services may be retained.

10. Training programmes should be wide in scope and designed to provide job satisfaction after the period of training. For example, nuclear power plant operators, should also be trained, say, in steam technology so that they can perform a useful service even if a nuclear energy programme is not instituted.

11. Teaching programmes at both undergraduate and post-graduate levels in all areas connected with nuclear energy should be expanded and suitably funded.

APPENDIX 1

A BRIEF INTRODUCTION TO RADIOACTIVITY, NUCLEAR FISSION, FISSION PRODUCTS AND NUCLEAR REACTORS

Natural Radioactivity

A1.1 Shortly after Roentgen's announcement of the discovery of a penetrating radiation, called x-rays, Becquerel in 1896 found a similar type of radiation emitted by compounds of uranium. His startling discovery stimulated a train of research in France and elsewhere, and Pierre and Marie Curie soon discovered several other elements, that emitted such radiations. These elements termed *radioactive elements* included thorium, polonium and radium. The radiations emitted were later found to consist of (a) alpha particles: positively-charged, energetic particles, that lose energy rapidly in matter and could be stopped by a very thin foil of aluminium; (b) beta particles: negatively-charged, energetic particles, that lose energy less rapidly and are therefore more penetrating, requiring a much thicker sheet of aluminium to stop them; and (c) gamma radiation: uncharged and highly penetrating rays that could pass through several centimetres of lead.

A1.2 Radioactive decay of an element results in the transformation of the element into another, chemically different. Uranium-238 for instance, gives out an alpha particle to form thorium-234 and this 'daughter' product can be separated out chemically. Thorium-234 decays giving out a beta particle and forms another radioactive element, protactinium-234, and so on down the line of successive transformations, until a stable end-product, lead, is reached.

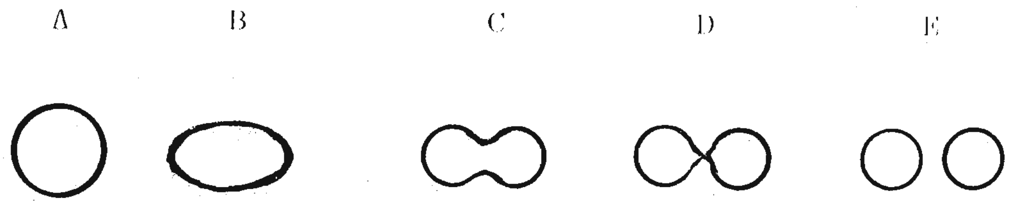
A1.3 A given radioactive element decays at a characteristic rate, and the number of atoms decaying is proportional to the number of atoms present at the time. The time interval over which a radioactive element decays to half its quantity is called the half-life of the element. For example, suppose we start with 100 grams of a radioactive element of half-life 10 years. After 10 years we would be left with 50 grams, after 20 years 25 grams, and so on.

A1.4 Different radioactive elements have different half-lives, which are not affected by external conditions. Naturally occuring uranium-238, for instance, has a half-life of four and a half billion years. However, its daughter products have much smaller half-lives, some even as low as a few minutes or seconds. Uranium-235, used as fuel in nuclear reactors, has a half-life approximately 800 million years.

A1.5 Early research workers, like Madam Curie, who handled large quantities of radioactive substances, were (in ignorance) exposing themselves to high doses of radiation, that caused harmful effects to the tissues, leading to severe burns, and in certain cases, to cancerous growths that became manifest much later in time.

Nuclear Fission

A1.6 The term 'nuclear fission' is used to describe the break-up of an atomic nucleus into two fragments of comparable mass. An atomic nucleus may be considered analogous to a liquid drop, and the mechanism of nuclear fission may be understood in terms of the behaviour of a liquid drop, originally spherical, that is subject to a deforming force. A drop, as at A. that



undergoes deformation and is elongated into an ellipsoid, as at B, will normally be set into oscillation and eventually return to its original form. But if the deforming force is sufficiently large, the drop acquires a dumbbell shape, as at C, and then rapidly passes to stages D and E as the drop breaks into two droplets.

A1.7 Similarly, a heavy nucleus, like uranium-235, can capture a slow neutron to form uranium-236 and thus acquire a significant energy of excitation. As a result, the nucleus will be subject to a strong deformation, and pass from stage B to stage C and thus break up into two fission fragments. The excess energy of the excited nucleus is shared by the fragments, which fly apart with considerable kinetic energy. The excited nucleus can break in two in more than 40 different ways, yielding over 80 primary fission products. At each fission, a few neutrons are also released. These neutrons can now be captured by other uranium-235 nuclei to produce further fissions and more neutrons, and so on. In this way, a *chain reaction* of fission processes will result. If there is sufficient uranium-235 present and there are no controls, the chain reaction would expand out unrestricted, until all the uranium fuel is consumed, thus producing an enormous amount of energy in a very short time. An explosion of great magnitude would result, as happens in an atom bomb, like the one dropped in 1945 on Hiroshima.

A1.8 If, however, the chain reaction is controlled, the energy released too is under control. This regulated release of energy takes place in a device called a nuclear reactor. In a nuclear power reactor, the energy is released in the form of heat. This heat is used to raise steam, which drives a turbine and a generator in the conventional manner, to produce electrical energy.

A1.9 Natural uranium contains about 0.7% uranium-235. The rest is uranium-238. Some reactors use natural uranium as a fuel. Others use uranium which has been processed so that there is a higher fraction of uranium-235. This is referred to as enriched uranium. With either kind of fuel the energy is derived from the fission of the uranium-235 nuclei. The neutrons released in the fission transform some of the uranium-238 to plutonium-239. This plutonium may then be used as a nuclear fuel. In a breeder reactor this process produces plutonium in greater measure than the uranium-235 burned. Thus in effect the amount of fuel created may be greater than that burnt.

The Nuclear Reactor

A1.10 As indicated in the section on nuclear fission a rapidly multiplying sequence of fissions, called a chain reaction, can occur in a lump of material like uranium-235. A chain reaction can be described quantitatively in terms of the multiplication factor, which is simply defined as the number of neutrons, emitted in each fission, that are able to induce further fission. If we assume that the multiplication factor is two, and that the time elapsed between the emission of a neutron and its subsequent absorption is 10^{-8} seconds (10 billionth of a second), a chain reaction starting with a single fission will release twenty billion joules of energy in less than one millionth of a second. Thus, an uncontrolled chain reaction can produce an explosion of gigantic magnitude. However, when the chain reaction is so controlled as to ensure that exactly one neutron per fission causes further fission (a multiplication factor of exactly one), the reaction proceeds steadily (see Figure A1.1), and the system become a controlled source of power. Such a device in which the fission chain reaction is controlled is called a nuclear reactor.

A1.11 A number of basic problems must be overcome for a nuclear reactor to be a suitable source of power. The fuel for the reactor may be natural uranium (containing 0.7% of uranium-235 and 99.3% of uranium-238), or enriched uranium, which contains a greater content of uranium-235. Suppose that natural uranium is used. Uranium-238 absorbs fast neutrons readily, but fission does not occur and as a result the neutrons are wasted. However, uranium-238 has little ability to capture slow neutrons, while uranium-235 absorbs slow neutrons readily to cause fission. The neutrons emitted in fission are fast, and accordingly must be slowed down as soon as possible, both to prevent them

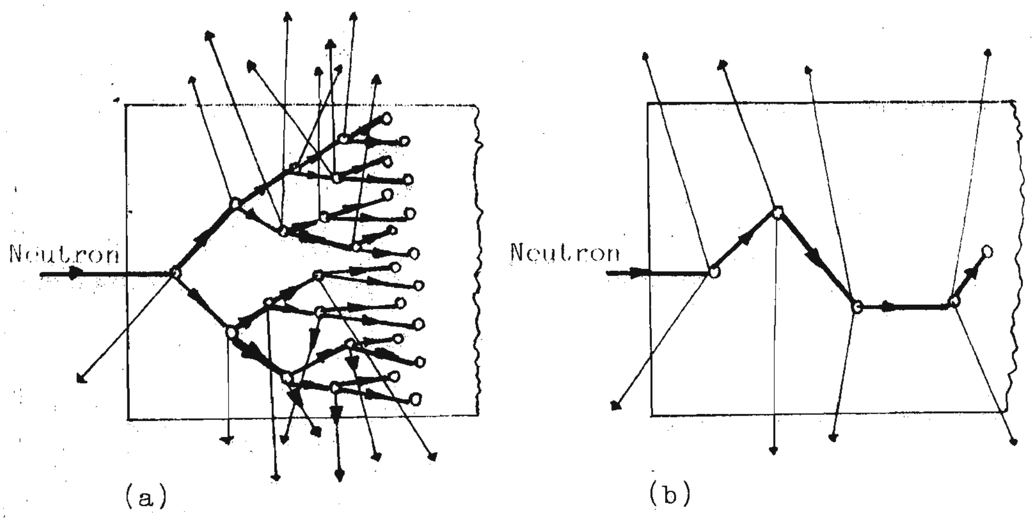


Figure (A1.1). A fission chain reaction

(a) where each fission causes <u>two</u> further fissions, so that the reaction builds up very rapidly to produce an explosion,

(b) where each fission causes exactly <u>one</u> further fission, so that the reaction is controlled and proceeds at a steady rate.

being absorbed by uranium-238 and to enable them to be captured by uranium-235 in order to produce further fission. This slowing down of fission neutrons is done in a medium called moderator, where the fast neutrons undergo elastic collisions with the atoms of the moderator. The lighter the atoms of the moderator, the more rapid the slowing down. Hence, light materials like hydrogen (in the form of water), deuterium (as heavy water), and graphite are used as moderators. However, the nuclei of hydrogen have a much greater tendency to pick up neutrons than the nuclei of deuterium have. Thus, when natural uranium is used and the content of uranium-235 is very small, heavy water is much superior to ordinary water as a moderator. When enriched uranium is used as fuel, ordinary or light water may be satisfactory as a moderator.

A1.12 The chain reaction is controlled and not allowed to go too fast by the use of control rods, made of materials that are very good absorbers of neutrons, like boron and cadmium. The control rods are inserted into the core of the reactor, and by careful adjustment of the lengths inserted, the multiplication factor of the system may be controlled. Withdrawal of the rods increases the multiplication factor and insertion decreases it. Thus the reactor can be started up, shut down, or its power output changed, by the appropriate movement of the rods. In this way the rate of energy output of the nuclear reactor may be controlled. In an emergency, when the reactor begins to go too fast and out of control, a set of control rods, or shut-off rods, drop in automatically so that the chain reaction stops entirely. The reactor is then said to be "scrammed".

A1.13 The energy liberated in the reactor appears as heat, which is extracted by circulating a liquid or a gaseous coolant. The coolant is made to circulate through the channels in the moderator or fuel tubes. The hot coolant can then be used as the heat source for a conventional steam turbine. The various components, the fuel, the moderator, the control rods and the coolant, are all located within the reactor vessel. The reactor vessel, and all other components of the nuclear steam supply system that contain radioactive fission products, are surrounded by adequate radiation shielding for the protection of the personnel operating the reactor. The entire reactor installation is enclosed in a containment structure.

A schematic diagram of a typical heavy water reactor is shown in the Figure A1.1. In this reactor, the coolant (heavy water) is pressurized to prevent boiling, and passes through pressure tubes containing the fuel (natural uranium) without coming into contact with the moderator (also heavy water). Such a reactor is called a pressurized heavy water reactor (PHWR). There are many such in Canada, designated CANDU types.

Light water reactors like the pressurized water reactor (PWR) and the boiling water reactor (BWR), are both well established, with over 80 power reactors in the United States (alone). These light water reactors use enriched uranium as fuel, and ordinary or light water as moderator and coolant. Other examples include the light-water, graphite-moderated reactor (LWGR).

Gas cooled reactors (GCR), using natural uranium as fuel, carbon dioxide as the coolant and graphite as the moderator, became the starting point of the nuclear industry in Great Britain and in France. British reactors at Calder Hall and at Oldbury are early examples. Later, advanced gas reactors (AGR) were developed using enriched uranium instead of natural uranium, for example the Windscale and the Hinkley Point-B in Britain. Other modifications of gas cooled reactors are the high-temperature gas-cooled graphite moderated reactor (HTGR) and the heavy-water moderated gas-cooled reactor (HWGCR).

It is recognised that because of limited resources of uranium-235 the nuclear power industry must develop the breeder reactor, where more than one fissile atom is produced for every fissile atom consumed. Such breeder reactors are remarkable in that, in addition to providing power, they actually produce more fissile material than they consume. Since the bulk of the fissions are induced by fast neutrons, they are usually called fast breeder reactors (FBR).

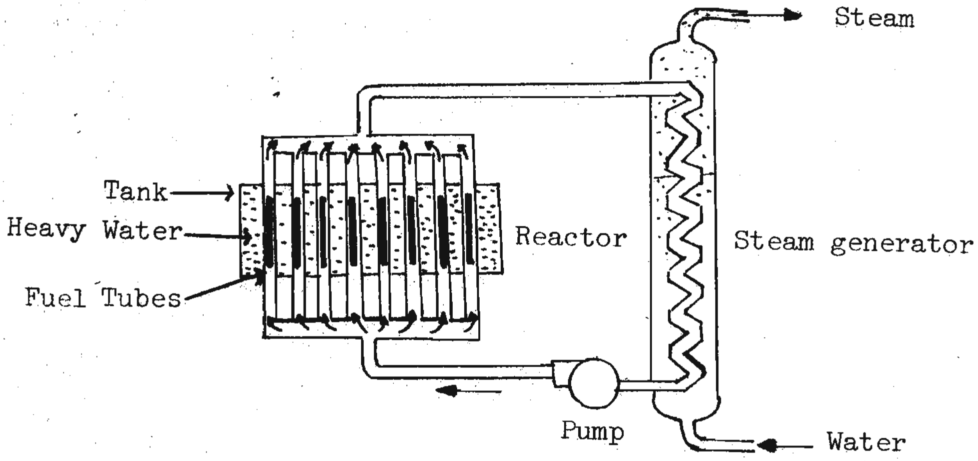


Figure (A1,2) Schematic diagram of a pressurized heavy water reactor (PHWR) and the steam supply system.

Fission Products and their Radioactivity

A1.14 The fission fragments, or fission products, consist of nuclei having an excess of neutrons above that required for stability. These therefore are unstable, emitting beta particles to get to a a more stable nuclear configuration. On the average, each primary fission product is followed by three stages of beta particle decay before a stable nucleus is formed. We have noted earlier that there are about 80 different primary fission products. Hence there would be over 200 different radioactive species among the fission products after a short time. In addition to the beta particles, the fission products also emit the highly penetrating gamma rays. As such, a nuclear reactor, where fission takes place with great intensity, must be provided with heavy shielding arrangements.

A1.15 Because of the large number of different radioactive species, (of widely different half-lives) comprising the fission products, the rate of decay of the mixture of fission products (in reactor that is being operated) cannot be computed easily. But it has been found that the rate of emission of beta particles and of gamma rays (per single fission event) can be expressed empirically as a simple function of time. Thus, by summing up for all fissions during the entire operation of the reactor, it is possible to get an expression for the rate of release of energy (decay heat power) due to the beta particles and gamma rays produced in the nuclear reactor at a given time, before or after shut down. For instance, for a nuclear power reactor operated for a period of 1000 days, the heat power due to the decay of the fission products at a time 10 seconds after shutdown can be as large as 5% of the operating power of the reactor. At the end of 90 days after shutdown, the heat power would reduce to 0.1%, at the end of 3000 days to about 0.05% of the reactor power. In terms of radio-activity, a 1000 MW (e) reactor that has been working for 1000 days will, when shut down, release after 90 days as much as 220 megacuries of beta activity and about 110 megacuries of gamma activity; these activities would be reduced to about half value 200 days later.

A1.16 We realise then that the spent fuel of a nuclear power reactor gives out appreciable radioactivity even several years after shutdown, and must therefore be set aside and heavily shielded for a considerable time before attempts can be made to further treat the fuel material. Thus, years after shutdown, the radioactivity of the fuel rods can present a serious hazard to personnel handling them, during the decommissioning of a nuclear plant, during the treatment of spent fuel or during the disposal of radioactive waste.

APPENDIX 2

GLOSSARY OF TECHNICAL TERMS

Alpha Particle:	A positively-charged particle, identical with the helium nucleus, which is emitted in the radioactive decay of the heaviest atomic nuclei, for example uranium and radium. It has four times the mass and twice the charge of the hydrogen atom.
Availability:	Referring to a power plant, the percentage of time a power plant is usable for generating electricity.
Beta Particle:	A fast moving electron, either negatively or positively charged, emitted during certain types of radioactive decay.
Breeder Reactor:	A nuclear reactor which makes fissionable fuel, such as plutonium-239, more rapidly than it uses its own fuel. (More strictly, the term applies only when the fuel made is the same as that used).
Capacity factor:	The amount of electricity a power plant actually produces compared with the amount it would have produced if it had been operating at full power for the same period of time.
Chain Reaction (Nuclear)	When a fissile nucleus like uranium-235 captures a neutron and breaks up into two fission fragments, several neutrons are also released; these in turn cause fission in other fissile nuclei which release yet more neutrons to cause further fission, and so on. Such a rapidly multiplying sequence of fissions is called a chain reaction.
Commissioning:	The process during which nuclear plant components and systems, that have been already constructed, are made operational and then tested to be in accordance with design requirements and to have met the performance criteria. This includes both nuclear & non-nuclear tests.

Decay heat:	The heat generated in the reactor, not by fission but by the radioactive decay of the fission products. The longer the fuel element remains in the reactor core, the greater the amount of fission products and the greater the decay heat generated. Decay heat cannot be "turned off" by inserting control rods, but must be controlled by the circulation of adequate coolant.
Decommissioning:	The process by which a Nuclear Power Plant is finally taken out of operation.
Deuterium:	The isotope of hydrogen twice as heavy, often called heavy hydrogen.
Dose:	Referring to radiation, gives the energy deposited or absorbed per unit mass of biological material and is a measure of the biological effect of the radiation. The unit is the rad.
Dose equivalent:	The equivalent dose, taking into account the relative biological effectiveness of the type of radiation. The unit is the rem, which is given by the absorbed dose of one rad in respect of gamma rays, x-rays or fast moving beta particles. Heavier particles will cause greater biological effects, and one rad would give a dose equivalent much greater than one rem.
Dose equivalent limit:	Limit of permissible exposure to radiation, also called the maximum permissible dose equivalent (MPD), (see chapter 4, paras 4,9 and 4.10)
Enriched Fuel:	Fuel (used in a nuclear reactor) that has a greater content of a fissionable isotope (e.g. Uranium-235) than found in the natural form of the element.

Fertile:	Capable of being transferred into fissile material, as for example uranium - 238 and thorium -232 that can absorb neutrons to give plutonium -239 and uranium -233 respectively.
Fissile:	Capable of undergoing fission. Examples are the isotopes uranium -233, uranium -235 and plutonium -239. (The word fissionable is used for fissile in America).
Fission:	The splitting of a heavy nucleus into two or more approximately equal fragments (the fission products), accompanied by the emission of neutrons and the release of energy. Fission can be induced by particles or by gamma-rays, or can occur spontaneously. Fission induced by neutrons is the most important technologically, because it makes a chain reaction possible.
Fuel (Nuclear):	The material, containing fissile nuclei, used as fuel for the production of energy in a nuclear reactor.
Fuel Element:	Generally, the smallest unit containing nuclear fuel which is loaded into a reactor. A fuel element usually consists of the fuel, in the form of rods or plates, enclosed in a protective can, the can preventing the escape of fission product atoms and the oxidation of the fuel.
Gamma Radiation:	Electromanetic radiation, similar to X-rays, emitted by radioactive nuclei.
Half Life:	The time taken for the activity of a radioactive substance to decay to half its original value, that is for half the atoms present to disintegrate. Half lives may vary from less than a millionth of a second to millions of years.
Heat Exchanger:	A device in which heat is transfered from one fluid to another (e.g. from gas to water) without allowing the two fluids to come into contact.

Heavy Water:	Water in which at least one of the atoms of hydrogen is deuterium. It is present in natural water, including sea water in about 1 part in 5000.
Isotopes:	Atoms whose nuclei contain the same number of protons but different numbers of neutrons.
Licence:	Written authorization issued to the Licensee by the national Regulatory Body to perform specified activities related to Siting, Construction, Commissioning, Operation and Decommissioning of a Nuclear Power Plant.
Moderator:	The material in a reactor used to reduce the energy, and hence speed, of fast neutrons, as far as possible without capturing them. Slow neutrons are much more likely to cause fission in a uranium -235 nucleus than to be captured in a uranium-238 nucleus, so that by using a moderator a nuclear reactor can be made to work with fuel containing only a small proportion of uranium -235.
Multiplication Factor:	In a nuclear reactor, the ratio of the number of neutrons in any one generation to the number in the immediately proceding generation. For a chain reaction that is controlled and proceeding at a steady rate, the multiplication factor is unity.
Mutation:	A change in the hereditary material (chromosomes or genes) of a living cell due to the effects of radiation.
MWe:	One megawatt (one million watts) of electrical energy.
Neutron:	Elementary particle having about the same mass as the proton but without electrical charge; a constituent of the nucleus.

Nuclear Power Plant:	A thermal neutron reactor (or reactors) together with all structures, systems and components necessary for safety and for the production of power, thermal or electrical.
Plutonium:	The element of atomic number 94. The isotope plutonium-239, produced by neutron irradiation of uranium-238, is an important fissile material.
Quality Assurance:	Planned and systematic actions necessary to provide adequate confidence that an item, material or facility will perform satisfactorily, in service.
Rad:	Unit of radiation dose absorbed in a material. One rad is equal to 0.01 Joule per kilogram or 100 ergs per gram of the material.
Radiation:	This word covers electromagnetic waves (especially X-rays and gamma-rays) and also streams of fast-moving charged particles (electrons, protons, etc.) and of neutrons of all speeds.
Radioactive:	Possessing or pertaining to radioactivity.
Radioactivity:	The property possessed by nuclei of some atoms of disintegrating (or decaying) spontaneously, emitting alpha or beta particles and gamma radiation.
Radioisotope:	An isotope that is radioactive. Also called a radionuclide.
Reactor, Nuclear:	A structure in which a fission chain reaction can be maintained and controlled.
Regulatory Body:	A national authority or a system of authorities appointed by a country, assisted by technical and other advisory bodies, and having the legal authority for conducting licensing procedures, for issuing licences and thereby for regulating nuclear power plant Sitting, Construction,

Commissioning, Operation and Decommissioning, or other specific activities.

Regulatory Inspection: An examination, observation, measurement or test undertaken by or on behalf of the Regulatory Body during any stage of the licensing process to ensure conformance of materials, components, systems and structures; also inspection of operational activities, processes,procedures and personnel competence.

Rem: (Roentgen equivalent man). Unit of dose equivalent. The dose equivalent (in rems) is the product of the radiation dose (in rads) and the quality factor for the type of radiation. The quality factor is 1 for x-rays, gamma rays and energetic beta rays; it is much greater than 1 for neutrons and alpha particles.

Safety: Protection of all persons from undue radiation hazard.

Scram: Rapid shut down of the nuclear reactor (by the rapid insertion of control rods or shut-off rods) to terminate the chain reaction; this may be done manually or automatically.

Siting: The process of selecting a suitable site for a Nuclear Power Plant. This includes the appropriate assessment and definition of design bases taking into account external events (natural or man-made). The evaluation of the suitability of a site covers such important aspects as the physical characteristics of the site,including the seismology, meteorology, geology, hydrology & ecology of the area, the population density in the locality, and the design characteristics, mode of operation and

	special engineering safeguards of the nuclear power reactor to be used.
Thorium:	The element of atomic number 90; a heavy metal. Thorium-232 is a fertile material since it can be transformed by neutron absorption into the fissile uranium-233.
Uranium:	The element of atomic number 92; a heavy metal. Uranium-235 is the only naturally-occuring fissile isotope; Uranium-238 is a fertile isotope; uranium-233 is a fissile isotope that is produced by neutron irradiation of thorium-232.

Sheet 1

APPENDIX 3

Operating experience of Nuclear Power Station in IAEA Member States

(Data extracted by J. Diandas)

page	station	type	start	MW	Cumulative energy output		1978 Performance					1978 outages			1978 hours lost				Cause of longest unplanned outage + (where significant) other event causes and other anotations
							gwh	Work %		gwh under %					total hours	longest close		least stop	
					twh	%		gwh	hours	plan	unplan	P	U	T		plan	unplan		
USA																			
227	Arkansas One-1	DWR	Dec.74	836	19.3	66	5,250	72	76	16	3	1	7	8	2,085	1,367	508	11	3 scrams
229	-2	PWR		912			4												start-up period
231	Beaver Valley-1	PWR	Oct.76	800	5.8	38	2,481	36	41	17	47	1	14	15	5,168	1,408	3,431	12	transformer failure
233	Big Rock Pt	BWR	Mar.63	65	5.3	59	401	70	78	7	23	1	4	5	1,936	483	1,280	22	control rod high temperature
235	Browns Ferry 1	BWR	Aug.74	1,065	16.3	40	5,818	63	81		29	3	7	10	1,699	843	159	16	recirculation flow
237	2	BWR	Mar.75	1,065	13.9	40	5,547	59	69	28	13	5	7	12	2.733	2,427	47	11	value opened inadvertantly
239	3	BWR	Mar.77	1,065	11.4	70	5,554	60	71	22	19	4	11	15	2,523	1,869	154	12	low oil pressure
241	Brunswick 1	BWR	Mar.77	790	7.6	63	5,123	74	87	4	22	6	16	22	1,165	744	335	10	breaker relay failure
243	2	BWR	Nov.75	790	10.4	49	4,794	69	80	6	25	2	15	17	1,743	423	247	12	pump thermal barrier
245	Calvert Cliff 1	PWR	May.75	810	19.5	77	4,676	65	70	20	15	4	12	16	2,637	1,520	341	12	turbine vibration
247	2	PWR	Apr.77	810	9.8	83	5,227	74	82	12	14	3	15	18	1,612	1,032	143	13	scram after operator's error
249	Cooper	BWR	Jul.74	764	18.7	82	4,887	73	91	9	18	2	1	3	806	765	29	29	electric storm
251	Crystal River 3	PWR	Mar.77	797	6.6	54	2,592	37	42	1	62	1	5	6	5,116	98	4,769	14	burnable poison rods found in steam generator
253	Davis Besse 1	PWR	Nov.77	906	3.0	35	2,612	33	49	32	34	6	18	24	4,459	2,115	432	11	coolant pump seals
255	Donald C Cook 1	PWR	Aug.75	1,044	22.3	73	6,287	69	74	17	14	7	9	15	2,313	1,898	41	12	non-isolable steam leak
257	2	PWR	Jul.78	1,082	3.8	65	3,814	65	77	17	18	2	5	7		385	149	15	bearing & gear failures
259	Dresden 1	BWR	Aug.60	197	15.8	50	759	44	73	17	39	2	8	10	2,391	1,470	540	16	NRC licences requirement
261	2	BWR	Jan.71	772	31.9	60	5,704	84	94	-	16		10	10	517		199	18	bonnet leak
263	3	BWR	Jul.71	773	28.2	56	3,832	57	71	16	27	2	7	9	2,558	1,400	476	10	fire in main transformer
265	Duance Arnold 1	BWR	Feb.75	515	8.7	50	1,227	28	33	11	61	2	3	5	5,825	959	4,752	13	crack in recirculation system
267	Farley 1	PWR	Dec.77	829	6.3	81	5,920	81	86	7	11	3	16	19	1,191	484	87	10	flooding after heavy rain
269	Fitzpatrick	BWR	Jul.75	800	13.8	58	4,197	60	72	24	16	2	9	11	2,453	1,973	70	15	drywell leakage
271	Ft Calhoun 1	PWR	Sep.73	457	13.0	62	2,849	71	75	22	7	2	2	4	2.172	1,715	231	23	coolant pump blockage
273	Ft St. Vrain	HTG		330	.8		609	21	51	10	69	5	14	19	4,275	635	1,710	17	water in primary coolant
275	RE Ginna 1	PWR	Mar.70	470	24.2	67	3.219	78	81	16	6	2	4	6	1,699	1,382	212	18	steam generator leak
277	Haddam Neck	PWR	Jan.68	550	42.8	81	4,707	98	97	1	3	1	7	8	298	66	51	11	containment electric terminals
279	Hatch 1	BWR	Feb.76	786	15.3	78	4,277	62	73	12	27	2	14	16	2,374	1,008	996	11	off-gas leak
281	2	BWR		795	.5		497					1	3	4		150	25	12	low water level in reactor
283	Humboldt Bay 3	BWR	Aug.63	63	4.5	53				100		1		1	8,760	8,760			seismic modifications
285	Indian Pt 1	PWR	Oct.62	257	12.3	34	-			100		1		1	8,760	8,760			shut down from Oct. 74
287	2	PWR	Aug.73	864	19.2	48	4,369	58	63	34	8	4	1	5	3,276	2,434	237	11	seal water leak
289	3	PWR	Aug.76	965	12.8	65	5,457	65	73	24	11	4	5	9	2,391	1,913	173	12	steam generator leak
291	Kewaunce	PWR	Jun.74	535	15.8	75	3,890	83	90	10	7	2		2	911	875			refuelling
293	La Crosse	PWR	Feb.71	50	1.8	52	174	40	62	27	33	2	15	17	3,355	1,751	281	12	circulation pump vibrations
295	Maine Yankee	PWR	Dec.72	790	28.3	68	5,355	77	84	13	10	4	14	18	1,375	1,046	282	10	transformer winding failure
297	Millstone 1	BWR	Mar.71	654	29.4	66	4,655	81	88	10	9	1	5	6	1,077	866	100	14	containment isolation valve
299	2	PWR	Dec.75	796	13.4	64	4,500	64	65		36	1	7	7	3,040		2,791	23	overextended refuel outage
301	Monticello	BWR	Jun.71	536	25.2	72	3,856	82	87	10	8	3	8	11	1,121	792	92	10	scram pilot valve defect
303	Nine Mile Pt 1	BWR	Dec.69	610	29.4	61	4,467	84	95	4	12	4	5	9	420	149	52	18	feedwater pump
305	North Anna 1	PWR	Jun.78	898	3.7	81	3,665	81	93	6	13	5	6	11		268	19	11	operator's error
307	Oconee 1	PWR	Jul.73	860	24.2	59	5,054	67	72	15	18	2	7	9	2,444	1,224	765	10	steam generator leak
309	2	PWR	Sep.74	860	19.2	60	4,786	64	70	16	20	3	11	14	2,593	1,074	263	16	heater bundle seal pressurizer leak
311	3	PWR	Dec.74	860	21.2	70	6,064	80	85	11	9	1	6	7	1,314	939	158	10	feedwater valve
313	Oyster Creek 1	BWR	Dec.69	620	32.9	67	3,646	67	74	23	10	1	4	5	2,251	2,004	124	28	MSIV closed during test
315	Palisades	PWR	Mar.72	635	17.2	46	2,624	47	49	33	21	5	12	17	4,433	2,499	357	12	CRDM seals and pump seals
317	Peach Bottom 2	BWR	Jul.74	1,051	25.	61	6,794	74	83	14	12	2	4	6	1,480	956	86	17	drywell packing valve leak
319	3	BWR	Dec.74	1,035	23.2	64	6,966	77	85	14	9	1	5	6	1,349	1,199	37	17	" " " "
321	Pilgrim 1	BWR	Dec.72	670	18.4	52	4,377	75	83	9	16	2	4	6	1,472	653	438	25	turbine overcurrents relay
323	Point Beach 1	PWR	Dec.70	495	26.1	75	3,795	87	90	9	4	3	2	5	902	535	76	63	transformer internal shorting
325	2	PWR	Oct.72	495	21.4	79	3,859	89	92	8	3	2	1	3	727	664	18	18	freezing water intake crib
327	Prairie Isl 1	PWR	Dec.73	507	15.9	72	3,811	86	91	6	8	2	1	3	745	560	126	13	turbine bearing damage
329	2	PWR	Dec.74	507	13.6	77	3,924	88	93	7	5	2		2	622	466			
331	Quad Cities 1	BWR	May.72	769	26.6	60	4,721	70	95	12	18	2	2	4	473	69	128	60	water regulating valve failed
333	2	BWR	Aug.72	769	26.8	63	4,426	65	80	18	17	3	1	4	1,778	1,313	186	32	EHC oil leak

Sheet 2

page	station		type	start	MW	Cumulative energy output		1978 Performance					1978 outages			1978 hours lost				Cause of longest unplanned outage + (where significant)other event causes and other anotations
						twh	%	gwh	Work %		gwh under %		P	U	T	total hours	Longest close		least stop	
									gwh	hours	plan	unplan					plan	unplan		
USA																				
335	Rancho Seco	1	PWR	Apr.75	873	14.4	53	4,988	65	80	12	23	5	4	9	1,708	8,972	439	19	safety valve replacement
337	Robinson SE	2	PWR	Mar.71	665	32.9	73	3,980	68	71	23	9	1	4	5	2,497	1,941	191	40	steam generator leak
339	Salem	1	PWR	Jun.77	1,079	6.6	47	4,529	48	56		52		19	19	3,872		2,179	12	main turbine vibration
341	San Onofre	1	PWR	Jan.68	436	29.5	71	2,679	70	80	29	2	2		2	1,577	1,215			
343	St Lucie	1	PWR	Dec.76	777	10.4	76	5,000	74	76	22	4	3	1	4	2,076	1,547	64	64	gasket failed
345	Surry	1	PWR	Dec.72	775	25.0	61	4,704	69	72	23	8	2	1	3	2,453	1,882	478		steam generator leak over 3 gmp
347		2	PWR	May.73	775	23.9	63	5,372	79	83	15	6	3	3	6	1,489	613	129	22	snubber inspection
349	Three Mile Is.	1	PWR	Sep.74	792	23.0	78	5,674	82	85	12	6	1	1	2	1,314	1,086	213		Coolant pump seal
351	"	2	PWR	Dec.78	880	.6		589	54	68			3	5	8	2,759	198	3,374	47	repair & test safety valves
353	Trojan		PWR	Dec.75	1,080	9.8	35	1,666	18	21	21	61	2	1	3	6,929	1,800	5.105		pending seisure license
355	Turkey Pt	3	PWR	Dec.72	666	24.6	70	4,500	77	81	18	5	7		7	1,682	1,147			refuel
357		4	PWR	Sep.73	666	20.7	68	3,788	65	76	25	10	4		4	2,085	1,181			refuel
359	Vermont Yankee		BWR	Nov.72	504	18.3	68	3,241	74	76	8	18	1	5	6	2,085	661	1,042	26	crack from butter/temper pad
361	Yankee		PWR	Jul.61	175	19.4	73	1,193	78	81	18	4	1	1	2	1,664	1,472	161		loose washer fell on printed circuit
363	Zion	1	PWR	Dec.73	1,040	24.9	55	6,770	74	80	16	10	3	7	10	1,726	1,159	98	16	EHC pump tripped on overload
365		2	PWR	Sep.74	1,040	23.4	60	6,732	73	80	20	7	2		2	1,770	1,659			refuel

JAPAN :

125	Fukushima	1	BWR	Mar.71	439	11.6	39	1,498	39	51	61		6	1	7	4,301	2,928	13	13	+ output lowered to match demand
127		2	BWR	Jul.74	760	12.4	22	3,876	58	75	42		4		4	2,225	1,453			+ " " " " "
129		3	BWR	Mar.76	760	13.0	71	2,754	41	41	59					5,133	4,430			+ " " " " "
131		4	BWR	Oct.78	760	3.2	85	3,163	85	99	14	1	2	1	3	53		14	14	+ " " " " "
133		5	BWR	Apr.78	760	5.6	81	4,806	81	99	19		3		3	87				+ " " " " "
135	Genkai	1	PWR	Oct.75	529	12.8	87	3,416	74	76	26		1		1	2.079	2,079			
137	Hamaoka	1	BWR	Mar.76	515	6.8	55	56	1	3	27	72	3	1	4	8,480	2,160	6,299		leak on CRD piping
139		2	BWR	Nov.78	814	2.7	88	2,691	88	92	12					675				start up period
141	Ikata	1	PWR	Sep.77	538	5.4	92	3,138	67	72	25	8	1	2	3	2,488	1,888	609	13	RCS temperature measuring system
143	Mihama	1	PWR	Nov.70	320	5.1	22	119	4	12		96		2	2	7,700		7,700		SG tube leakage
145		2	PWR	Jul.72	470	14.5	42	2,649	64	67	36		1		1	2,906	2,906			+ refuel
147		3	PWR	Dec.76	780	11.2	82	4,067	60	63	40		3		3	3,224	2,583			+ output lowered to match demand
149	Shimane	1	BWR	Mar.74	439	13.2	72	2,702	70	73	30		2		2	2,365	2,109			+ refuel
151	Takahama	1	PWR	Nov.74	780	14.	50	2,763	40	47	57	2	5	2	7	4,669	3,072	182	14	RCP high vibration
153		2	PWR	Nov.75	780	15.8	75	4,170	61	66	39		3		3	3,013	3,003			+ refuel
155	Tokai	1	GCR	Jul.66	133	11.	76	961	82	87	16	2	1	11	12	1,174	1,286	118	12	
157		2	BWR	Nov.78	1,056	3.6	94	790	94	100	6									
159	Tsuruga		BWR	Mar.70	340	16.4	63	2,040	68	75	30	2	3	3	6	2,199	2,064	106	96	lighting on transmission line

Sheet 3

page	station	type	start	MW	Cumulative energy output		1978 Performance					1978 outages			1978 hours lost				Cause of longest unplanned outage + (where significant) other event causes and other anotations
								Work %		gwh under %					total hours	longest close		least stop	
					twh	%	gwh	gwh	hours	plan	unplan	P	U	T		plan	unplan		
BRITAIN :																			
193	Berkeley (2)	GCR	Nov.62	276	30.8	79	1,447	60	98		38	2	6	8		3,720	134	44	fuel element car failure +
195	Bradwell (2)	GCR	Nov.62	250	30.4	86	1,528	70	99		30	5	4	9		4,690	132	31	boiler tube leak
197	Calder (4)	GCR	56-59	200	27.2	72	1,021	58											
199	Chapelcron (4)	GCR	59-60	192	26.9	82	1,424	85	87		15								
201	Dungeness A (2)	GCR	Dec.65	410	42.1	90	2,667	75	100		25	3	7	10		3,008	342	18	CO2 shortage due to strike
203	Hinkley Pt A (2)	GCR	May.65	430	39.3	77	3,183	85	100		12	3	2	5		2,841	26	22	air ingress caused BCD signal trip
205	B (2)	AGR	1977	800	3.8		2,793	60	79		37	3	19	22		1,045	686	11	damage to a fuel stringer
207	Hunterston A (2)	GCR	1964	300	31.8	86	2,129	81	100		19	1	1	2		1,691	45	45	grid voltage surge
209	B 1	AGR	Feb.77	500	5.2	65	2,158	49	62		50	4	7	11	3,364	769	527	35	condenser tube leak
211	B 2	AGR		500	1.0						100				8,760		8,760		sea water ingress
213	Oldbury A (2)	GCR	Jan.68	416	29.9	75	3,067	84	100		15	2	5	7		2,073	157	31	circulator gas seal
215	Dounreay	FBR	1977	180	.5		232	15	29		85								no details given
217	Sizewell (2)	GCR	Mar.66	420	38.4	82	3,372	92	100		8	2	3	5		1,184	65	36	LP boiler tube leak
219	Trawsfynydd (2)	GCR	1965	390	36.4	82	2,578	76	100		24	3	4	7		1,123	1,235	50	cracks in 3 gas circulator rotors
221	Windocale	AGR	Feb.63	24	2.4	72	139	66	68		32	5	1	6	2,803	1,190	204	12	circulator damage by temperature increase
223	Winifrith	HWL	Jan.68	92	4.7	53	551	69	67		31	1	2	3	2,873	1,791	1,075	29	transformer winding caused trip
225	Wyfla (2)	GCR	71-72	840	25.5	53	3,801	52	90		47	3	11	14		3,096	2,262	31	Insulation cover plate modification + several unusual incidents including loss of 2 turbines and spurious BCD alarm.
GERMANY :																			
81	Avr Julich	HTG	May.69	13	.8	82	39	35	36		65		4	4	5,624		5,432	24	steam generator leak
83	Biblis A	PWR	Mar.75	1,089	27.0	75	7,100	74	75		25	1	3	4	2,216	1,896	214	12	rotor earth fault
85	B	PWR	Jan.77	1,178	14.3	72	5,652	55	69		44	1	7	8	2,751	1,737	500	12	coolant pump seals
87	GKN Neckar 1	PWR	Dec.76	810	11.8	83	4,937	70	75		30	1	4	5	2,172	1,704	480	24	primary coolant pump
89	KKB Brunobuttel	BWR	Feb.77	770	6.7	54	2,324	35	39		65		5	5	5,317		4,704	11	steam leak in turbine area
91	KKI Isar	BWR	Dec.77	870	2.4	31	2,337	31	47		69	1	11	12	4,634	2,988	396	23	internal axial pump
93	KKS Stade	PWR	May.72	630	32.2	89	5,239	95	95		5	1		1	429		404		+ refuel
95	KKV Unterweser	PWR		1,230	.8	29	788	29	57		63								+ not yet commercial
97	KNK Karlsruhe	FBR		18	7.0		6	5	29		93				6,228				+ not yet commercial & KNK II start up
99	KRB Gundremmingen	BWR	Jan.67	237	15.1	61					100				8,760		8,760		welds
101	KWL Lingen	BWR	Oct.78	183	7.7	47					100				8,760		8,760		steam generator replacement
103	KWO Obrigheim	PWR	Mar.69	328	22.8	81	2,220	77	78		22	1	3	4	1,883	742	1,104	22	plan shutdown lasts longer
105	KWW Wurgasson	BWR	Nov.75	640	14.8	83	2,741	49	62		51		6	6	3,303		2,041	10	steam dryer inspection also turbine sheft vibration
107	MZFR	PHW	Dec.66	51	3.2	60	390	87	88		13	1	5	6	1,042	696	90	24	
109	VAK Kahl	BWR	Feb.62	15	1.4	63	52	39	52		59	1	6	7	4,178	1,641	1,653	47	testing steam generator

page	station	type	start	MW	Cumulative energy output		1978 Performance					1978 outages			1978 hours lost				Cause of longest unplanned outage + (where significant) other event causes & other anotations
					twh	%	gwh	Work gwh	% hours	gwh under % plan	unplan	P	U	T	total hours	longest close plan	unplan	least stop	
FRANCE :																			
53	Ardennes	PWR	Apr.67	305	17.	55	2,008	75	77		25	1	4	5	2,041	727	1,078	26	annual shutdown prolongation
55	C Bugey 1	GCR	Mar.72	540	18.8	59	2,610	56	68		44	1	6	7	2,768	2,132	245	37	strike
57	2	PWR		925	.5		505	10	29										not yet commercial
59	3	PWR		925	.4		417	16	48										" " "
61	Chinon 2	GCR	Nov.66	210	15.5	70	1,053	57	67		42	1	1	2	2,900	1,374	1,436		CO_2 circuit
63	3	GCR	Aug.67	400	17.	43	2,308	66	75		33	1	8	9	2,172	1,986	60	10	iodine filter
65	Monts d' Aree	HWG	Mar.68	70	3.6	55	526	86	86		15	1		10	1,209	706	82	38	low voltage for auxiliaries
67	Fessenheim 1	PWR	Dec.77	890	6.9	82	6,071	78	81		22		10	10	1,673		647	12	dryer re-superheaters
69	2	PWR	Mar.78	890	5.9	81	5,760	81	85		18		8	8			510	11	" " + strike
71	GZ	GCR	Apr.59	40	4.8	70	97	28	30		72		5	5	6,088		4,596	153	commission order + graphite pile problem + bomb alarm
73	G3	GCR	Apr.60	40	4.7	72	225	64	71		36	1	4	5	2,558	1,072	1,291	15	prolong annual closure + 2 bomb alarms
75	Phenix	FBR	Jul.74	233	4.7	52	1,231	61	68		39	3	10	13	2,829	1,086	72	23	+ 2 annual closures (Mar + Sep) + thunderstorm & bomb alarm closures
77	St Laurent 1	GCR	Aug.69	460	21.9	58	2,738	68	87		31	1	3	4	1,113	1,012	54	21	strike + grid incident
79	2	GCR	Aug.71	515	23.9	71	3,421	76	91		23	1	2	3	797	718	55	43	strike + grid incident
CANADA **CANADA :**																			
25	Bruce 1	PWH	Sep.77	740	6.0	74	4,152	64	76	13	12	1	11	12	2,095	1,095	200	12	bleed cooler leak
27	2	PHW	Sep.77	740	5.2	64	3,604	56	68	15	18	1	10	11	2,794	1,289	394	45	hydrogen leak
29	3	PHW	Feb.78	740	4.8	82	4,793	82	93		7		7	7	596		235	39	heat transport pump motor
31	Douglas Pt 1	PHW	Sep.68	206	8.8	48	855	47	77	6	45	1	14	15	2,032	666	823	41	RTO leak in reactor header
33	Geintilly 1	HWL	Jan.72	250	.7	5									8,760	8,760			assessment of programme
35	NDP	PHW	Oct.62	22	1.9	61	135	70	74	5	22	1	13	14	2,234	268	1,257	27	boiler tube leak
37	Pickering 1	PHW	Jul.71	515	26.9	80	4,273	95	96		4		2	2	377		319	57	bleed cooler replaced
39	2	PHW	Dec.71	515	25.6	81	3,797	84	86	5	10	1	5	6	1,261	443	540	40	turbine notor installed
41	3	PHW	Jun.72	515	21.5	73	3,692	82	83	8	9	1	2	3	1,454	702	708	43	heat exchange moderator leak
43	4	PHW	Jun.73	515	18.7	75	4,034	90	90	7	3	1	2	3	858	625	160	75	hydrogen leak
SWEDEN :																			
175	Barsebaeck 1	BWR	Jul.75	570	11.5	64	3,908	78	84	7	15	1	3	4	1,437	593	605	33	generator coil + containment leak
177	2	BWR	Sep.77	570	6.	96	3,836	77	81	16	7	1	6	7	1,682	1,294	103	23	steam reheater + containment leak
179	Oskarshamn 1	BWR	Feb.72	440	15.6	59	3,114	81	84	7	9	1	14	15	1,367	605	252	12	turbine bearing vibration
181	2	BWR	Dec.74	570	13.3	67	3,638	73	76	20	7	1	7	8	2,067	1,757	133	11	decay heat removal system leak
183	Ringhals 1	BWR	Jan.76	750	11.1	58	4,153	63	70	21	16	1	7	8	2,663	1,852	380	12	annual closure extended
185	2	BWR	May.75	800	15.7	63	4,094	58	77	18	24	1	12	13	1,989	1,394	120	12	turbine reheater tube leak
BELGIUM :																			
17	BR3	PWR	1962	[illegible]	.5	35	21	24	26		76	1	3	4	6,439	6,240	136	35	physical tests + end of core BR 3/4 A life time
19	DOEL 1	PWR	Feb.75	395	10.8	81	2,731	78	80		21	1	2	3	1,726	1,554	48	12	hydrogen leak
21	2	PWR	Dec.75	395	8.5	82	2,751	80	81		20	1	2	3	1,638	984	384	192	S1 tests
23	Tihange 1	PWR	Oct.75	870	19.7	82	6,364	83	85		16	1	2	3	1,323	1,138	16	16	control cluster

Sheet 5

page	station	type	start	MW	Cumulative energy output twh	Cumulative energy output %	1978 Performance gwh	1978 Performance Work % gwh	1978 Performance Work % hours	1978 Performance gwh under % plan	1978 Performance gwh under % unplan	1978 outages P	1978 outages U	1978 outages T	1978 hours lost total hours	1978 hours lost longest close plan	1978 hours lost longest close unplan	1978 hours lost least stop	Cause of longest unplanned outage + (where significant) other event causes & other anotations
ITALY :																			
117	Caorso	BWR		548	.5		458	14	32										not yet commercial
119	Garigliano	BWR	Jun.64	151	11.7	61	452	34	38		66		5	5	5,378		3,487	68	secondary steam generators
121	Latina	GCR	Jan.64	153	16.9	85	1,185	88	95		11		12	12	403		44	23	external grid + several scrams on erroneous signals
123	Trino Vercel	PWR	Jan.65	260	18.0	57	2,095	92	96		7		4	4	359		140	26	man-hole cover leaks
SWITZERLAND :																			
187	Beznan 1	PWR	Sep.69	350	19.7	69	2,762	90	92	10		2		2	727	795			refuel
189	2	PWR	Dec.71	350	18.1	84	2,753	90	90	10	2	1	2	3	876	818	108	100	U-tube leak
191	Muhleberg	BWR	Nov.72	320	14.3	84	2,466	88	91	10	2	3	2	5	762	750	18	13	turbine turning motor
SPAIN :																			
169	Jose Cabrera	PWR	Aug.69	153	9.7	77	1,008	75	81	13	12	5	2	7	1,699	723	987	11	steam generator tubes leak
171	Santa Maria	BWR	May.71	440	19.1	65	3,111	81	85	11	8	1	8	9	1,349	118	242	12	low vacuum in condenser
173	Vandellos	GCR	Jul.72	480	21.	78	3,179	76	91	6	18	1	8	9	771	580	66	10	alternator defect
NETHERLANDS :																			
163	Dodewaard	BWR	Jan.69	51	3.5	78	409	90	94		6	1	1	2	526	463	14	14	turbine disc rupture
165	Borssele	PWR	Oct.73	445	16.1	80	3,424	88	91		12	1	1	2	762	696	10	10	low feedwater level
FINLAND :																			
49	Loviisa 1	PWR	May.77	430	5.9		2,976	79	86	13	8	2	4	6	1,226	1,029	111	13	valve repair
51	TVC 1	BWR		660	.1		103												start-up period
CZECHOSLOVAKIA :																			
45	Bohunice A	HWG	Dec.72	93	1.0										8,760	8,760			shut-down for modification
47	1			380			9	2	18										start up period
INDIA :																			
111	Rajasthan 1	PHW	Dec.73	206	2.9	32	153	8	17		91		5	5	7,227		548	54	severe grid fluctuations
113	Tarapur 1	BWR	Oct.69	210	8.6	51	941	51	73	19	30	1	10	11	2,330	1,635	193	13	PRM high flux
115	2	BWR	Oct.69	210	9.0	53	1,146	62	76	18	20	2	7	9	2,085	1,406	134	36	leak fixing

page	station	type	start	MW	Cumulative energy output		1978 Performance					1978 outages			1978 hours lost				Cause of longest unplanned outage + (where significant) other event causes & other anotations
					twh	%	gwh	Work %		gwh under %		P	U	T	total hours	longest close		least stop	
								gwh	hours	plan	unplan					plan	unplan		
PAKISTAN :																			
167	Kanupp	PHW	Dec.72	125	2.9	44	228	21	51	25	54	1	11	12	4,266	2,138	419	38	operator error with gas locks also MHZH malfunction of absorber rods also fire outside & smoke in control room also D_2O leak from welding crack also oil temp rose to 126% also rods pulsing & steam pressure sagged also sea weeds problem
KOREA :																			
161	KO-RI-1	PWR	Apr.78	555	2.2		2,143	45	65	31	24	5	16	21	3,092	1,632	153	11	steam line rupture
ARGENTINE :																			
15	Atucha	PHW	Jun.74	319	10.	79	2,712	97	92		10		5	5	736		306	44	D_2O leak in moderator tubing

OTHERS (data not given) :

USSR	20 stations
Germany (GDR)	4 stations
Bulgaria	2 stations

Non-MEMBERS (not listed):

Taiwan
S. Africa

APPENDIX 4(a)

PRESS NOTICE

National Science Council

Committee of inquiry on the use of atomic energy for generation of power

The National Science Council has appointed a Committee to inquire into all matters related to the proposal to use atomic energy for the generation of electric power in Sri Lanka.

Any members of the public who wish to make representations, or who are in possession of any information, whether published or otherwise, on the subject, are kindly requested to get in touch with the Secretary-General of the National Science Council as soon as possible, and in any case not later than 10 December, 1980. It would be most helpful if such persons would communicate in writing, giving a concise account of the information they possess or of the views they wish to express. Such communications will be passed on to the Committee which would, if it wishes to have further clarification, request the persons concerned to appear before it.

Secretary General
National Science Council of Sri Lanka

47/5, Maitland Place,
Colombo 7.

APPENDIX 4 (b)

Persons who responded to the Newspaper announcement

1. J. Diandas, F.CA, Galle Face Terrace, Colombo 3.
2. E. Carlo Fernando (Consultant CEB) Katuwapitiya Road, Negombo.
3. G.B.A. Fernando, Assistant Director, Ministry of Planning & Economic Affairs, Colombo 1.
4. Dr. P.N. Fernando, Chief Engineer (Hydropower Development) CEB, Colombo 2.
5. P.G. Joseph, BSc(Eng)., Chief Engineer, Plywood Corporation, Kosgama.
6. K.T.R. Luxhman, Kandewela Estate, Ratmalana.
7. Mr. David Newby BSc(Eng). CEng., MI Mech. E (Formerly of the UK Atomic Energy Authority and also of IAEA). Navajeevanam, Paranthan.
8. Anura Palamathusura Malalpola, Yatiyantota.
9. Clifford Perera, Kirula Road, Colombo 5.
10. M. Nimal Perera, General Accident Department, Insurance Corporation Colombo 1.
11. S.P. Prematilake, RRI., Agalawatta.
12. Vinoth Ramachandra, BSc(Eng) PhD, DIC, Sulaiman Terrace, Colombo 5.
13. J.P. Ranasinghe, Gallingawa Estate, Kuruwita.
14. Dr. Ranil Senanayake, 41 Gregory's Road, Colombo 7.
15. K.V. Subramaniam, Dawalasinharama Mawatha, Colombo 15.
16. P. Suraweera, Chief Engineer Distribution Maintenance, CEB, Colombo 2.
17. S. Thamodharam, Ponnu Sirna Road, Tellippalai.
18. Veromal Weerasinghe, Dangolla Road, Kandy.
19. V.D. Wickramaarachchi, Akurugoda, Kamburupitiya.
20. Dr. T.W. Wickramanayake, Faculty of Medicine, Ruhunu University College, General Hospital Galle,
21. S. Wickramasooriya, Electrical Engineer. CEB., Colombo 1.

APPENDIX 4(c)

List of others invited to give oral evidence

1. Mr. K.J. Cooke, Atomic Energy of Canada Ltd.,
2. Mr. E.H. Dharmasena, Physicist Government Cancer Hospital Maharagama.
3. Dr. G. Dharmawardena, Chairman, Atomic Energy Authority, Colombo 7.
4. Prof. P.C.B. Fernando, University of Sri Jayewardenapura, Nugegoda.
5. Mr. J.O. Joss, Project Manager, Nuclear Power Company of Britain.
6. Prof. S. Karunaratne, University of Moratuwa, Moratuwa.
7. Mr. J.H. Lanerolle, Secretary Ministry of Power & Energy, Colombo 2.
8. Prof. K.K.Y.W. Perera, Chairman, CEB , Colombo 2.
9. Mr. R.D. Vaughan, General Manager of the British National Nuclear Corporation Ltd.,

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