commercial and other industrial sectors. However, the value obtained is in surprising agreement with information received during our hearings and, in particular, values arrived at for the year 2000 in the NZERDC "Continuation" scenario (6). If past, but not necessarily present, intentions for development are realised, consumption in the major industrial areas for the year 2000 could be of this order: forestry, 7000 GWh; aluminium smelting, 4000 GWh; New Zealand steel, 1000 GWh; other, including transmission losses, say 3500 GWh.

31. Thus for a constant 3.5 percent of change in real GDP per annum, the electricity needs for the commercial and both industrial sectors could be 39 000 GWh per annum by the year 2001. An 0.5 percent change in the rate of growth of real GDP either way could either increase or decrease this estimate by about 3300 GWh, that is, by about 8.5 percent. Of the 39 000 GWh, we might anticipate from table 8.1 that the commercial sector would require about 11 000, and the total industrial sector about 28 000.

32. In the previous section it was noted that the total process heat used by the industries surveyed (table 8.2) was about twice their total electricity consumption. As a crude measure, this appears to generally apply to industry as a whole, as implied by MER demand forecasts (33). That is, by the year 2001 industry could be demanding the equivalent of about 50–60 000 GWh of process heat per annum. It is to be expected on economic grounds that this will be supplied directly by solid, gas, and liquid fuels. There could be, however, a danger that if there are difficulties in obtaining a suitable substitute for oil, and if and when the real price of oil should again rise, certain sections of industry could turn to electricity for their process heat. Even though their demands may represent only a small fraction of their total needs because of the large quantities of process heat used, such demands could have a significant impact on electricity supply. The source of energy for industrial process heat would appear therefore to warrant continual surveillance.

*Table 8.5*

## ELECTRICITY REQUIREMENTS FOR THE NON-DOMESTIC SECTOR FOR THE YEAR 2000

(Excludes large forest-based and metal-smelting industries)

(*Source:* Royal Commission on Nuclear Power Generation)

| Rate of Change of Real GDP per annum % | Electricity Requirement GWh |
|---|---|
| 4.0 | 25 600 |
| 3.5 | 23 400 |
| 3.0 | 21 500 |
| 2.5 | 19 500 |
| 2.0 | 17 900 |
| 1.0 | 15 000 |
| 0.0 | 13 000 |

### *Transport Sector*

33. In reply to a question about the needs of a possible electrified public transport system, the NZED was uncertain but gave an estimate of 5 to 7 percent of our present total electricity consumption if most cities had suburban electrified trolley bus services (*Evidence* p. 2255). That is, the requirement could be about 1000 to 1400 GWh a year. For the year 2000 it could perhaps be double this, but if such services should become at all viable it could well be that the local authorities involved would generate their own electricity, as some do now. It is unlikely that such a demand would have any significant effect on the national system. Again, it was stated by the NZED that electrification of the North Island main trunk railway would need only about 200 GWh per annum (53). Thus public transport in general is unlikely to be of serious concern.

34. But it was pointed out by the NZED in considering their "Electrified Transport" scenario that if the entire New Zealand transport system, including private vehicles, should be electrified by the year 2000 the demand on the electrical system for battery charging could amount to 24 000 GWh per annum ( (53) and appendix C). For this to happen there would have to be a major and early breakthrough in batteries. Although this appears to be unlikely, there is considerable research going on in several countries, including Britain and the United States (*Evidence* p. 2221). Furthermore, owing to the relatively rapid turnover of new vehicles, there is unlikely to be any great capital restraints on the rate of market penetration. Such a possibility must be therefore considered seriously. However, a more plausible figure for the year 2000 could be 12 000 GWh, corresponding to half rather than all the market being captured. All in all we do not see this as a major problem which would require either the greater use of our limited indigenous resources or the immediate introduction of nuclear power. In principle, the oil displaced from the transport sector could be used in either existing or new oil-fired power stations to give the necessary electricity. The overall load factor of the generating system would be improved, owing to night battery-charging, and there would be a net increase in the efficiency of primary energy use. (Present efficiencies in the transport sector are only about 20 percent, while electrification could result in efficiencies of nearer 30 percent.) The capital cost of new oil stations, if needed, is relatively low, and the construction time relatively short compared with nuclear, thus enabling a rapid response to market demands (see chapter 14).

## CONSERVATION AND SUBSTITUTION

35. In their 1977 biennial report, the California Energy Resources Conservation and Development Commission gave the following (partial) interpretation of energy conservation (their italics): " . . . energy conservation means doing *better* with the limited energy resources available —*not doing without* the valuable and necessary functions that energy can provide" (71).

36. We appreciate, as the Commission for the Environment pointed out to us, that energy conservation can be perceived in a much broader context than this, realising "economic, social, and environmental benefits well beyond those directly associated with energy use" (72). However, for the purposes of this chapter we find the California Commission interpretation adequate and confine this part of the report to certain specific aspects.

In particular, we discuss space heating, water heating, and the possible generation of combined heat and power. Other aspects will be touched on later.

37. In general, if the cost of a conservation technique to save 1 kWh is comparable with or less than for 1 kWh of delivered electricity, a strong economic incentive will exist to adopt it. However, this cost may be primarily due to a large initial capital cost which inhibits the growth of the technique. Interest-free loans can help in such cases, as in the State-sponsored home-insulation scheme. The prices of delivered electricity set at 1 April 1977 averaged over the main centres were:

*Table 8.6*

THE AVERAGE DELIVERED PRICE OF ELECTRICITY
(As at 1 April 1977)

(*Source:* Based on MER submission 129, tables 1 and 2)

| | $/GJ |
|---|---|
| Domestic— | |
| Water heating … … … | 2.02 |
| Other …. … … … | 2.55 |
| Commercial … … … | 5.25 |

Details for the commercial sector were not given. In the long term the incremental cost of generation is expected to lie in the range 3.5 to 4 cents per kWh, and thus significant increases in these costs can be expected (33).

*Space Heating*

38. In general an insulation level which can save up to 60 percent of energy consumption for space heating can be readily attained in the timber-frame housing construction most commonly used in New Zealand. Other types of construction could be brought up to the same standard in time (33). The present cost of the saving is 1.8 cents per kWh, and from table 8.6 is clearly worthwhile. Over the past 2 years approximately 100 000 existing homes have been partially insulated, and mandatory requirements for a given level of insulation in all new buildings were introduced in the 1977 Budget.

39. The potential use of heat pumps was strongly advocated in the Ecology Action (Otago) submission (3). The heat pump is the essence of a refrigerator. It transfers heat from one body at a lower temperature to another at a higher temperature. The quantity of heat transferred plus that generated by the pump itself is greater than the energy dissipated by the pump motor. A figure called the coefficient of performance (COP) is defined as the ratio of the heating energy delivered to the input energy required for pumping. In applications to space heating, heat is transferred from some source such as air, water, etc., from outside to inside a building. In a typical New Zealand climate, a heat pump can achieve a seasonal COP of between two and three (53). That is only one-half to one-third of the electricity would be needed to provide the same amount of heat with electric resistance heating. A main domestic disadvantage is the relatively high capital cost. For present rates of consumption the cost of saving in an insulated house would be 12 cents per kWh, and 6 cents in an

uninsulated house (33). The cost decreases with heating needs and for a building requiring 8000 kWh of heat per annum, the cost of saving is 3.6 cents per kWh (33). It follows that there could already be a major market in the commercial (and perhaps industrial) sector, and in view of previous discussion significant inroads into the domestic market could occur by the end of the century. It is also possible that in the commercial sector the pumps could be used in their dual role of heating and cooling.

40. There are difficulties with air-source heat pumps in that in very cold weather supplementary heating may be needed. If this is of the conventional electric resistance, much of the advantage of heat pumps in reducing increased winter power demands may be lost. Because of this there is considerable interest, especially in the United States, in assisting heat pumps with solar panels which would boost the temperature of the input air. In spite of this problem, a recent Electric Power Research Institute (EPRI) study in the United States has shown that heat pumps are now cheaper than electric resistance or oil furnace systems, with only natural gas furnace systems being superior. There are still problems of reliability with some manufacturers' equipment, but further improvements are possible with corresponding reductions in maintenance costs (73).

41. Other possible improvements relevant to space heating lie in building design associated with the direct use of solar energy. Many passive techniques are well known and others may be developed. All should be inherent in architectural design. We can only comment that greater attention should be paid to these aspects in future.

42. The potential savings in space heating needs have already been discussed in paragraph 21. As implied there, initial savings will be more apparent than real, such techniques being used to increase thermal comfort rather than to save electricity. However, we would recommend that at least large users of space heat, especially those in the commercial (and perhaps industrial) sector should even now be encouraged to use heat pumps. Not only does it appear to be economic to do so, but it will take a considerable time to develop the necessary labour force for servicing. If there is no good servicing, a reputation for unreliability could well develop leading to wholesale and most undesirable rejection of the technique, if and when the domestic sector's needs warrant the use of heat pumps.

### *Water Heating*

43. There are three methods of reducing electricity consumption in this area. The first is reduction in the thermostat setting from say 74°C (165°F) to 54°C (130°F), giving a daily saving of over 1 kWh per cylinder. There is probably little point in doing this, however, if insulation is improved with flock being replaced by a suitable alternative. The resulting annual saving if this were done would be about 550 kWh for 74°C (165°F) and 210 kWh for 54°C (130°F), the cost of the savings being 0.2 cents per kWh and 0.6 cents per kWh respectively (33). A third method of saving energy is to install solar heaters.

44. To save 2000 kWh a year per household (note present average annual consumption of about 4000 kWh) by the installation of solar hot water heaters, the thermostat setting of the hot water system must be set to give water at 52°C (125°F). As previously implied, most household hot water heaters are probably set to give water at temperatures higher than

60°C (140°F). At 60°C the savings drop to 1500 kWh and for higher temperatures the savings would be less still. In Auckland the savings appear to be as low as 1250 kWh per annum (53). However, the situation is not clearly understood and trials being made by the MWD and by the Housing Corporation should clarify the problem. The estimated cost of saving for an annual saving of 2000 kWh is 4.5 cents per kWh for new houses and 4.8 cents per kWh for old houses (33), although there may be existing houses in which the cost could be significantly more. From table 8.6 the present economic viability is therefore questionable. In the long term the situation could be different. For an annual average saving for a household of 1500 kWh, to be pessimistic, there could be a potential overall saving of about 1500 GWh by the year 2001. It is assumed that most new and about half the existing houses would be equipped with solar heaters.

45. Taking into account all the types of conservation techniques so far discussed (excluding improvements in architectural design), the MER has estimated an upper limit of about 10 percent for a possible reduction in the projected domestic demand for the year 1990, that is about 1400 GWh (33).

### *Combined Heat and Power Generation*

46. In combined heat and power generation both heat, at a desired temperature, and electricity are simultaneously produced. The heat can be produced by back pressure and extraction steam turbines delivering steam at temperatures of 200–300°C, or from the exhaust gases from gas turbines which can supply gas at 500°C for drying purposes or to raise steam in waste-heat boilers (1). The exhaust of diesels and gas engines fuelled with natural gas can also be used. Overall fuel utilisation efficiencies of up to 85 percent can be reached (53). The actual ratio of electrical to heat energy produced will depend on many factors, including the system used and the required temperature of the output heat.

47. In Britain 20 percent of industrial power needs are supplied by such systems (1). There appears to be considerable scope for their introduction into New Zealand. As an order of magnitude estimate of the electrical energy that might be available, we note from paragraph 32 that by the year 2001 industrial process heat could be running at a level of about 60 000 GWh per annum. Assuming that about one-third of this could be supplied by combined heat and power generation systems, and that the ratio of heat output to electricity generated is about 4 : 1, this gives an electrical generating capability of 5000 GWh per annum. This is a significant amount when compared with the estimated total electrical needs for industry of about 30 000 GWh per annum by that year. Obviously a careful and detailed study is warranted. However, the technique appears to be capital intensive, and as noted by the NZED:

> While the use of this technique with large installations may be in the national interest because of the efficiency of fuel use achieved, the return on capital invested may not meet the investment criteria of the companies concerned. Government action may be necessary to encourage investment in capital intensive conservation measures of this kind (53).

48. The concept may be extended to large thermal power stations. In such stations only about one-third of the energy input is converted into electricity. The remainder is waste heat normally in the form of hot water and is disposed of in cooling towers, cooling ponds, or discharged into

natural waters. If the heat is discharged at an appropriate temperature it can be used in the hot water reticulation systems sometimes called "district heating". This is a well established technique of energy distribution in Europe and North America (59). In Sweden, for example, about one-third of the waste heat from thermal power stations is used for domestic and other heating.

49. During our hearings we were presented with a very favourable appraisal of the possible introduction of such schemes into New Zealand (59). On balance we were not convinced, especially when we realised that the viability of such schemes is still in question in Britain even with its much higher housing densities (74). Again, any such scheme as heat pumps, is more likely to introduce apparent rather than real decreases in electricity consumption, higher levels of thermal comfort being sought. Nevertheless, we support further studies in this area and understand that such are being done. We also recognise that district heating would compete with heat pumps and natural gas, as well as resistance heating, and should be judged accordingly.

### *Substitution*

50. The NZED has commented on the lack of detailed market projections of natural gas, stating that "This lack of information on the expansion plans of the gas industry presents a difficulty in electricity forecasting and planning" (53). That there should be uncertainties is perhaps not at all surprising when the MER comments:

> . . . the substitution in households of natural gas for electricity . . . is economically justifiable only if at least 50 percent of the households in a reticulated area are prepared to accept gas for two out of the three uses—space heating, water heating, or cooking. (The relative benefits of this would be eroded somewhat if combined cycle electricity generation and/or the widespread use of heat pumps becomes possible) (33).

51. Again, although the direct use of natural gas is certainly preferred to its use as a power station fuel, the gains in efficiency are not at present as high as often stated. For 100 units of raw Kapuni gas the net heat that can be supplied in a household through electricity is 27 units, and by direct use, 44 units: that is, there is an overall improvement of only 60 percent and not 200 or more as often believed. In industrial applications the corresponding figure is 52 units (33). There is a 31 percent loss before use from losses by flare, station use, treatment, and distribution. For household use, the MER gives the following efficiencies (33):

| | |
|---|---|
| electricity ... ... ... | 100 percent |
| gas cooking ... ... | 59 percent |
| gas space-heating ... ... | 60 percent |
| and gas water-heating ... | 72 percent |

with a weighted mean for gas of not much more than 60 percent. With the use of Maui gas there could be an improvement but in terms of being a substitute for electricity, the overall efficiency of natural gas is unlikely to be greater than about 50 percent.

52. The delivered cost of household gas at 1 April 1977 was about 1.1 cents per kWh (33), and even if this is only used at about a 60 percent efficiency, there is from table 8.6 an apparent economic gain in substituting gas for electricity. The corresponding figure for the commercial sector is 1.5 cents per kWh. However, the capital cost of gas appliances, etc., is

relatively high, and in terms of the substitution, cost-savings for a typical house are 2.7 cents per kWh for space heating and 2.5 cents per kWh for water heating (33), higher than the costs of delivered electricity given in table 8.6. Nevertheless, the NZED notes that "given 100 percent acceptance for space heating, cooking, and water heating, in high density developments the situation is very favourable" (53). State-sponsored loans will also help.

53. In industry with its need for process heat, natural gas will be used as a substitute for oil rather than for electricity.

54. The extent to which savings in electricity use can be made by replacing it with natural gas will of course depend on a number of factors. In its scenarios (appendix C), the NZED pointed out that the adoption of gas for water heating and cooking in 300 000 additional houses would reduce electricity consumption by about 1600 GWh per annum, while the substitution of gas space heating to gain high levels of thermal comfort in the same number of houses would result in a further reduction of about 3600 GWh per annum, a total saving of 5200 GWh. This corresponds to about a quarter to a third of all houses in the North Island using only gas for these purposes by the year 2000.

55. Another relevant factor is the size of the resource. The total of reserves for the Kapuni and Maui fields was given in chapter 7 as 6800 PJ, about 1.9 million GWh. This corresponds to about 60 000 GWh a year over a 30-year life. Assuming as an upper limit that 20 percent of this would be available for domestic and similar types of use in the commercial sector (see chapter 7), the total amount available is 12 000 GWh per annum which, used at a 50 percent efficiency, gives an upper limit for electricity savings of 6000 GWh per annum. Significant, but not as large as may have been anticipated. New discoveries could, of course, radically alter this estimate.

56. The use of coal as a substitute for electricity in the domestic area is to be questioned for many reasons. At present its efficiency of use in space heating is only 18 percent (33). That is, on present practices, coal is better used for electricity production. This very low efficiency could no doubt be raised but, as pointed out by Shaw and Stephenson, the seasonable efficiencies for the use of fossil fuels in space heating are only likely to be at best in the range 50–65 percent, even though under optimum conditions 80 percent may be reached (68). The use of oil as a substitute for electricity is not to be considered at the moment " . . . assuming of course as we must for planning purposes at this stage that major oil reserves are not discovered on shore or off shore New Zealand which could be brought into production [by 1990]. Such an event would significantly change our energy options" (75).

## FUTURE GROWTH

57. From the discussion already given, it is apparent that the growth of electricity depends on many factors. These include economic activity, industrial developments, technological innovation, population and/or housing growth, the existence of alternative energy supplies, the desire for high levels of thermal comfort, the acceptance of the need for, and the economics of, conservation. A basic question is, to what extent can growth be controlled? Apart from certain elementary regulations (such as mandatory insulation for new houses, and tax incentives for conservation) tariff and pricing policies are apparently the only useful methods. These can make alternatives attractive and lead to increased efficiency in the use

of the generating system as a whole. To what extent growth can be curbed in an absolute sense, however, is open to question. While the cost of energy as a whole has increased markedly in the past few years, it is still a relatively small proportion of total business and household costs (67). Thus consumption is likely to be relatively insensitive to price changes, for example as illustrated by recent rises in electricity prices.

58. From the late 1940s to the early 1960s the real price of electricity was approximately constant. Then it fell owing to long periods between reviews, and to price control. An appropriate price level was restored by increases in April 1976 and April 1977, so that 1977–78 costs are now being met with a small margin of revenue for capital (53). However, it was claimed by the NZED in cross-examination that the effects of the first price change on total consumption were only short term, and that little other effect was to be expected from the second (*Evidence* p. 2223). In view of the discussion in the preceding sections, this is probably understandable. With relatively low levels of use in discretionary areas such as space heating, and the cost savings of alternatives still being somewhat higher than electricity, little change was to be anticipated. With further increases in price, there may be more positive, though still small, results.

59. The Treasury has prepared demand forecasts based on three different pricing situations: (a) a 20 percent real price increase in 1977 with no future real price changes; (b) a 20 percent real price increase in 1977 with 5 percent real price increases per annum to 1985 and then no real change thereafter; and (c) a 20 percent real price increase in 1977, a 10 percent real price increase in both 1978 and 1979, and a 5 percent real price increase per annum to 1985, and then no real change thereafter (76).

60. These forecasts have led to projected electricity demands in 1991–1992 of 40 698 GWh, 39 370 GWh, 38 780 GWh respectively. Irrespective of the relevance of these estimates for the year 1991–1992, it follows that for an over 50 percent change in real price between the extremes of these forecasts there is only about a 5 percent change in consumption. Thus it appears that pricing in itself is unlikely to have great effects on demand, even if the prices approach marginal costs. If, however, a relatively cheap and abundant substitute existed, they could have very significant results, leading perhaps to a 25 percent reduction in consumption, corresponding to half the substitutable component being replaced by, say, natural gas (see table 8.4).

61. On the other hand, the form of the bulk supply and retail tariffs to different classes of consumer can convey important information to the consumer on the cost of consequences of his consumption and thus perhaps prompt conservation measures. Also peak coincidence, time of day, and seasonal tariffs can lead to more efficient use of the generating system as a whole (53).

62. Inevitably, much of the debate on nuclear power has centred on the reliability of demand forecasts and the merits or otherwise of low energy and high energy societies. We recognise that these aspects are both complex and important but, unfortunately, subject to emotional overtones. However, we feel that we must try to set bounds on the rate of growth in electricity consumption in order to estimate a possible date for which nuclear power may be needed, and the subsequent rate at which nuclear plants may have to be introduced.

63. To evaluate the sensitivity of various projections of consumption to basic assumptions, we take as a first estimate 68 000 GWh per annum for the year 2000. We arrive at this figure thus. We have previously estimated

a plausible upper limit for domestic consumption of 23 500 GWh per annum for 2000, which with 10 percent added for transmission losses, gives about 26 000 GWh per annum. For a 3.5 percent per annum growth rate in real GDP, corresponding to the upper limit of the OECD value for New Zealand for the next decade, we obtained 39 000 GWh per annum for the commercial and total industrial sectors. To these estimates we add a further 3000 GWh (that is about 5 percent of the total) for demands by the public transport sector, giving a total of 68 000 GWh.

64. If the growth rate in real GDP should be 4 percent rather than 3.5 percent, and the number of new houses 800 000 rather than 700 000 (that is, a building rate of 32 000 a year), the total would increase to 73 000 GWh. This we regard as an upper limit, recognising that we have completely ignored major developments in the transport sector and neglected possible, but unlikely, demands for electricity for industrial process heat beyond the type of demand at present made. It is important to realise that this estimate is in almost every way consistent with past patterns of growth. It is, however, quite inconsistent with the so-called "historical" growth pattern of 7.2 percent a year, corresponding to a 10-year doubling time, which gives for the year 2000 a consumption of 124 000 GWh (4). It is apparent that the market potential for such a figure exists.

65. If all houses were all-electric and heated to high comfort without the use of conservation techniques (that is, with resistance heating only used), then for 1.83 million houses by the year 2001 domestic consumption, according to our previous estimates, would be about 52 000 GWh per annum, transmission losses included. If we assume, furthermore, that the transport sector is completely electrified, another 26 000 GWh would be needed. Adding 43 000 GWh for the commercial and industrial sectors (for a 4 percent per annum increase in real GDP), we obtain a total of 121 000 GWh, near enough to the "historical" projection for the year 2000. Since we have previously identified in general terms all components of the energy sector, the "origins" of the difference between the "historical" estimate and our upper bound appear to lie in the transport sector and the potential for resistance heating in the domestic sector. Irrespective of the validity of our upper bound, these simple estimates clearly identify the impact that these two sectors could have on electricity consumption. Since, however, we believe our estimate of 26 000 GWh for the domestic sector to be more plausible than the 52 000 GWh, it also raises the question of the relevance of past concepts of "historical" growth corresponding on average to a 10-year doubling time. Before discussing this we attempt to set a lower bound to the electricity generated by the national system in the year 2000. Again, we try to be consistent with past patterns of consumption.

66. Known reserves of natural gas could provide 6000 GWh per annum of useful heat in the domestic and commercial sectors. Since half of this could be used for high comfort heating, to be consistent with previous arguments, this could replace only 4500 GWh rather than 6000 GWh per annum of electricity. The installation of solar hot water heaters could save about 1500 GWh per annum, while a reduction of transmission losses from 10 percent to 9 percent consistent with the NZED predictions (appendix C) could save about another 1000 GWh a year. Combined heat and power generation could perhaps reduce the NZED load by a further 3000 GWh, and "in house" production of electricity by local authorities for public transport could give a further decrease of 1500 GWh. This

reduces our initial estimate of 68 000 GWh for the year 2000 to 57 500 GWh. It was also noted by the NZED in their scenarios that the major industries, instead of requiring about 16 000 GWh as estimated, may only need 10 000, including transmission losses. Since we may have already accounted for a fraction of this by the use of combined heat and power systems, any corresponding reductions that can be made may be nearer 4000 GWh. Add to this the possibility of a 5 percent reduction in absolute demand due to price increases, and we obtain a lower bound of about 50 000 GWh. Thus for the year 2000, we estimate that electricity consumption could lie in the range 50–73 000 GWh.

67. It is doubtful that further discoveries of natural gas would lead to a lower bound in the time scales involved. On the other hand a decrease in the rate of growth of real GDP could. Changes in population are not explicitly accounted for, as these are implicit in housing-growth and GDP values. Again it is to be noted that no direct allowance has been made for heat pumps etc., since, at least in the domestic sector, the effects of these will be more apparent than real. There could, however, be associated savings from the commercial sector. The value for the upper bound could be invalidated by major developments in the transport sector. But, as already noted, in the short term, the appropriate action would appear to involve oil-fired rather than nuclear-powered stations.

68. The most likely demand to be met by the NZED could be about 60 000 GWh per annum, although planning should take into account an upper limit of about 70 000. The Treasury estimate a figure of about 60 000 GWh (76), while the NZED scenarios (see appendix C) also imply 60–70 000 GWh. At first sight it is not surprising that our estimate should be about the same as that of the NZED, since their model for the commercial and industrial sectors formed a large part of our analysis. We have, though, investigated in a somewhat different way the sensitivity of the estimates to various assumptions.

69. In terms of past behaviour the NZED model for the non-domestic sectors gives an exceedingly good fit. Although other similar models no doubt exist, the NZED model is remarkable in that it relates present to past growth rates and has been developed from a pattern which changes relatively rapidly with time (see figure 8.2). Eighty percent of the changes in electricity growth in the non-domestic sector (ignoring the large industries) can be attributed to changes in rate of growth of real GDP. The general characteristics of the model were summarised in paragraph 29 and further details are given in appendix C. Of considerable significance is the fact that, for constant rate of change in real GDP, it leads to the logarithm of energy consumption being a quadratic rather than a linear function of time. In their second submission to us, the Campaign for Non-Nuclear Futures (66) presented a number of mathematical models of consumption over the past 20 years, which had been developed at their request by the Applied Mathematics Division of the DSIR. Two of these, one with and one without Comalco consumption, were quadratic fits to the logarithm of the total energy consumption, and are similar to that obtained from the NZED model. In fact the NZED model yields values surprisingly close if Comalco is included. (This is discussed in detail in appendix C). One of the most important aspects of these models is that they imply that the so called "historical" rate of growth corresponding to a constant doubling-time is simply an approximation to the true situation, its applicability being limited to a given period in time. At any instant in time, changes in consumption can be adequately represented by a

constant doubling-time, but this time will gradually increase over a period of years. (This is also discussed in appendix C). This is, of course, obvious from figure 8.1, where the rates of growth in the 1920s and 1930s were considerably faster than they are now. If models of the NZED type are to be believed, they will be significantly less by the end of the century.

70. Of course, even a model of the NZED type, like any such model, cannot be said to be exact. The real pattern of past consumption is undoubtedly a complex function of time, which even if known would not necessarily apply to the future. Such models can only give a guide and any associated forecasts must be tempered by both judgment and planning. Because of this it is obvious that the greater the detailed identification of the sources of consumption the more reliable the forecasting is likely to be. It appeared to us that the NZED is well aware of all these matters, the situation being summarised in the 1977 CRPR report, thus:

> Firstly, the committee uses no single or simple formula, but takes into account all the information available to the parties represented and consulted, before making a collective judgment on an appropriate level of forecast requirements. While this is fully and carefully argued it is not a purely numerical process, basically because the judgments involved are interpretive ones with incomplete information on a complex and changing situation (41).

71. The consequences of a mistake were emphasised to us by Hydro-Quebec (77). They pointed out that if one planned for a 3 percent growth rate a year, and demand warranted 6 percent, it would take 15 years to bring the system up to the necessary level. Nevertheless, in view of the discussion in this chapter, we are prepared to accept that the likely range for electricity consumption for the year 2000 is 50 000–70 000 GWh, and present planning should be based on the assumption that it could be the upper limit of 70 000 GWh. Consistent with this we might expect doubling-times closer to 20 rather than to 10 years by the end of the century, with perhaps consumption by 2020 being no more than twice that in the year 2000. This is discussed in some detail in chapter 15. However, a great deal of further study is necessary before any definitive growth rate can be estimated.

# PART IV

## *Chapter 9.* ENVIRONMENTAL CONSEQUENCES

### INTRODUCTION

1. The generation of electricity, whether by means of nuclear or fossil fuel, hydro, or by one of the unconventional methods, affects the physical and social environment, usually (but not always) to its disadvantage. Some generation methods may also affect human health, either insidiously as a consequence of emanation of detrimental discharges, or directly in the event of accidents. This health aspect is discussed in chapter 11.

2. Environmental effects differ with different methods of generation, but the choice of method and siting of a power station represents a compromise between many options and factors. A comparison of the environmental effects of nuclear and other types of power stations was presented in the FFGNP report under the following broad divisions—impacts on land use, on water resources, on air quality, on noise, and on social conditions (4).

3. In the present chapter we define the environmental significance of the nuclear alternative or option in electricity generation in New Zealand. In this context the site chosen, and the consequences thereof, would be expected to be of fundamental significance.

### SITING

4. When commercially operable (as distinct from experimental or military) nuclear reactors were first installed overseas they were sited in fairly remote places, in partial admission that the new technology was potentially hazardous. Now, after two decades of experience in the nuclear generation of electricity, siting decisions relating to future units in Britain, for example, tend to favour near-urban siting. Thus, from the Flowers report:

> It is Government policy [in Britain] that future commercial reactors should all be acceptable in principle for "near urban" siting . . . The safety of the public is considered to derive more from high standards in the design, construction, and operation of nuclear power stations than from remote siting. We agree and would go further. Because of our views on the desirability of using the waste heat . . . for district heating we should wish to see nuclear stations developed that could be sited sufficiently close for this purpose to areas where a large enough heat load exists; this would dictate siting within about 30 km of the urban areas involved. The need for transmission cables would also be reduced and hence their adverse effects on amenity . . . We acknowledge, however, that urban siting would present some conflict with security considerations. . . .

5. The consensus, however, among organisations holding an attitude of guardianship to the environment (e.g., Friends of the Earth) was that any nuclear station in New Zealand should be situated in a sparsely-populated region (2). It was submitted by both the Department of Lands and Survey (85) and the Department of Internal Affairs (86) that, in the search for a relatively remote site, national parks and reserves should be excluded. It seems most unlikely that a national park would be selected as a site. Another constraint on siting is introduced by the need to minimise risks to the nation's primary industries—especially agriculture. Analyses of prevailing wind records in relation to land use and occupancy would be needed to minimise the danger of radioactive contamination of agricultural and pastoral land in the event of an accidental release from a nuclear station. This danger is further considered later in our report.

### *Seismic Considerations*

6. Most nuclear reactors in the world are built in areas where the seismic risk is considerably lower than it is in most parts of New Zealand. A country with a record of earthquakes and volcanic eruptions must pay great attention to geology in selecting a site for a nuclear station. Although no part of New Zealand can be considered as free from the possibility of a large earthquake, the level of seismicity varies considerably over the country.

7. The Geological Society of New Zealand, though not saying that a suitable site for a nuclear power station could not be found here, was "not very enthusiastic" at the chances of finding one (*Evidence* p. 1907). However, there are nuclear reactors in Japan and California, both earthquake prone regions. There, geological factors dominate site selection, and strict codes of site selection and reactor construction are enforced (44).

8. "Base isolation", a system of construction in which the movement of a structure is effectively isolated from the shaking ground in an earthquake, was presented to us as being capable of being used in constructing a nuclear plant. This type of technique has been used in bridge building, but much study is still needed to determine its suitability for reactor buildings (56).

9. As an added safeguard some reactors have been built underground. In a recent Japanese review, underground siting was given as the first goal, and it is expected that underground plants will be realised there in 1990. In New Zealand, underground siting is feasible but suitable sites may be hard to find (44).

10. The NZAEC made the following recommendations based on the report of its working group on seismic effects on nuclear installations (87):

(a) There should be established New Zealand criteria in design and standards for materials, manufacture, testing, and surveillance using United States codes and standards as a guide for judging the safety of reactors in respect of earthquake risks.

(b) The New Zealand licensing authority should assess the risk of surface faulting after consulting with scientists familiar with New Zealand conditions.

To define New Zealand's requirements for reactor suppliers, there should be specified for any reactor site, a safe shut-down earthquake (SSE), and an operating base earthquake (OBE). These are defined thus. An SSE is that earthquake which is based on an evaluation of the maximum earthquake potential considering the regional and local geology and seismology, and specific characteristics of local sub-surface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure:

(i) the integrity of the reactor-coolant pressure-boundary;
(ii) the capability to shut down the reactor and maintain it in a safe shut-down condition;
(iii) the capability to prevent or mitigate the consequences of accidents which could result in potential off-site exposures comparable to any agreed guideline exposures.

An OBE is that earthquake which, considering the regional and local geology and seismology, and local sub-surface material, could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the maximum vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

11. The NZAEC further recommended that the SSE be defined as sufficiently severe and infrequent that the probability of its occurring during the life of the reactor with consequent release of radioactivity, could not be considered to add significantly to the risk of such a release from non-seismic causes. It also recommended that instruments should be installed to record tectonic information at prospective nuclear sites. This should be done as early as possible because large earthquakes are relatively uncommon, and valuable information would be got from recording even one at a site.

12. At present it is not known whether there are any sites in New Zealand which are geologically and seismicly suitable. There is a need for a general decision on the order of safety that would be needed in a nuclear plant in New Zealand. If seismic risks are to be no greater than any agreed criteria, then the level of risk decided on can be translated into seismic terms. Though it is essential that adequate safety standards are adopted, unrealistically low SSE values would effectively prohibit the building of any nuclear power station. This may at some future date be found to be an undesirable restriction.

### *Environmental Considerations*

13. Various Governments have made laws and regulations to help protect New Zealand's environment. Any works development must meet the requirements of the Town and Country Planning Act, the Water and Soil Conservation Act 1967, and the Clean Air Act 1972. The requirements of these, together with environmental impact reports, would certainly and prominently feature in any public debate on a projected nuclear installation.

*Engineering Considerations*

14. The NZED specified certain requirements of land, water-supply, access, public health and safety, hydrology and geology, etc., and social impact (40). *Land*: about 40 to 60 hectares of flat land would be needed; if coastal, above high-tide level without danger of flooding.

15. *Water-supply* must be adequate for condenser cooling. A nuclear station of the type likely to be used in New Zealand is expected to use 50 percent more cooling water than a similar fossil-fuelled power plant. There are two cooling methods. The "once-through" or "direct" method takes cooling water from the source (river, lake, estuary, sea) pumps it through the condensers and returns it to the source. The "closed-circuit" method distributes the water through cooling towers in which the heat rejected by the condensers is dissipated. The NZED stated that a 1200 MWe nuclear station having a "once-through" cooling system would need a throughput of about 60 cubic metres a second. As New Zealand has no rivers which could supply such quantities without suffering harmful effects from thermal pollution, "direct" systems would only be considered for use at open coastal sites, or where cooling ponds of adequate size (estimated at 600 hectares) could be constructed.

16. *Access* to the site for some of the plant items would present difficulty where maximum loads for road transport are set at 200 tonnes. The transport weight of the pressure vessel for a 600 MWe BWR is over 400 tonnes. The same component for a PWR weighs 230 tonnes, and the PWR steam generator, 320 tonnes. The calandria and end shield of a 600 MWe CANDU exceed 200 tonnes. Transportation of fuel to and from a nuclear power station would also depend upon very rigidly specified safety requirements.

17. *Public health and safety* must be recognised in determining a site. Remoteness has only limited effect on safety though the density of the population surrounding prospective station sites must be a factor in site evaluation. There are two broad categories of safety criteria for siting nuclear power plants. In the first category (as in the United States, Canada, Japan), sites are chosen on the basis of limiting the radiation dose from a maximum credible reactor accident to a given value at the boundary of the site, that is, the criteria as in the Code of Federal Regulations (88). The second category applies to Britain where sites are graded in four classes depending only on density and distribution of surrounding population. Site-rating factors are computed from a system of weighting derived from the dispersion of radioactive iodine downwind in stable air conditions (89).

18. *The hydrological, meteorological, and geological* conditions at a site can all be significant for construction and safety. Some aspects of these are referred to again later.

19. *Impacts on society* must also be considered. These include access to and enjoyment of the countryside, and avoiding visual intrusion or change in land use. Fossil-fuelled stations which need tall stacks and large fuel-storage areas can be less pleasing than nuclear stations which have minimal storage structures and only a small stack or none at all. The latter tend also to be more aesthetically pleasing as buildings, though they are inevitably large and with their transmission lines dominate the immediate surroundings.

### *Communication with Local People*

20. We cannot stress too strongly the importance and need for frank and open communication with the local people at every stage in any proposed nuclear power programme. The NZED has in the last few years made moves to explain to the public the relevance of the Clutha scheme, the Huntly station, and the proposed Auckland Thermal No. 1 station. A nuclear programme demands even greater efforts because of the widespread public distrust of a new and unknown technology. The record of the British CEGB in its relations with the public, both nationally and locally, presented us with a model worth careful study. We were able to observe and assess this when members visited the nuclear stations at Oldbury, Hinkley Point, and Heysham in September 1977.

21. The CEGB stressed that:

> Initial communication with local people at the outset of site investigations can set the tone for what is to become a long association, and the degree of rapport that is achieved can strongly influence their attitudes and eventual acceptance of nuclear power. An important objective of the CEGB is to establish a basis for mutual confidence and frank communication which can be continued and developed throughout the life of the station (90).

The communication with the public starts before beginning the search for a site. Local planning authorities and any other organisations with special interests are informed, and public statements are made in the national and local press and on radio and television. As part of the site investigations, CEGB staff discuss with local authorities, societies, and individuals the need for nuclear power, and the merits of specific sites. Representatives of the community have been assembled as liaison committees, closely identified with the CEGB staff. The recent applications of this policy have proved very effective. It should perhaps be pointed out that the policy was first implemented at a time when world-wide objection to nuclear power did not exist. But without full communication from the local to national level, public acceptance of nuclear power is not possible. Consulting local people is an important aspect of siting a nuclear station.

### *Environmental Comparisons: Hydro and Nuclear*

22. In its final submission (No. 134) the MWD replied to an earlier request for comment on the comparative environmental effects of a hydro and a nuclear development. This was sought to provide a measure of the effects of a nuclear station in terms of more widely known effects of hydro. A comparison was made between the Upper Clutha Scheme F hydro development and a 1200 MWe nuclear power station. The comparison was limited to the topics discussed in part 6 of the FFGNP report, that is, those associated with the siting of the facilities and excluding other matters such as costs, and consequences of structural or operational failure.

23. The MWD said that the two developments were not equivalent in terms of either power or energy production. The Upper Clutha Scheme F has an installed capacity of 1515 MW and an estimated energy production of 4670 GWh per annum. A 1200 MWe nuclear station (assuming a 70 percent output factor) has an energy production of 7350 GWh per annum.

24. The MWD stated that the environmental differences could be expressed in broad terms as follows:

*Impacts on Land Use*

(1) Occupation of Land by Power Stations—

(a) Nuclear:

With once through cooling—300 ha.
With pond cooling—900–1050 ha.

(b) Clutha:

Power stations, canals and lakes—1850 ha.

Additional for: temporary use during construction; lake reserves; relocated roading; and transmission facilities—400 ha.

*Comment:* It is likely that the nuclear station would be sited in an isolated locality where the land was not intensively developed. After completion of the station most of the land within the station boundary would be grazed. The probability of a cooling pond option is very low, but, if it were adopted, it is likely that inter-tidal land would be used. On the Clutha, two-thirds of the land to be occupied is farmed, ranging from grazing through irrigated cultivation (18%) to horticulture.

(2) Occupation of Land by Fuel Sources and Fuel Wastes—

(a) Nuclear:

No requirement by the fuel source. Fuel would be imported in manufactured form. Provision required for an annual active waste production of about 100 $m^3$ of low level waste, 400 $m^3$ of intermediate level waste, and 30–40 tonnes of spent fuel. These would be stored on site initially, but might ultimately have to be removed for disposal or storage elsewhere (FFGNP report, section 5.4).

(b) Clutha:

While the lakes, strictly, could be regarded as fuel sources, the area occupied has been included earlier.

(3) Associated Housing Land—

(a) Nuclear:

During the construction phase a work force of some 1600 peak will be required. The total construction period will be of the order of 8 years with the peak occurring in the latter half and being of some 2 years duration. A permanent operating staff of 150 will be required.

(b) Clutha:

The construction phase requires a work force of some 1400 peak. The total construction period will be of the order of 20 years, the peak occurring from years four to seven. A permanent operating staff of 60 will be required.

*Comment:* It is expected that persons living up to 60 km from site will be prepared to travel to it daily. If a population of say 100 000 plus were to live within this radius, then housing would be required for perhaps 25% of the work force. In an isolated area housing could be necessary for up to 75% of the work force. In the case of an isolated site, either nuclear or Clutha, a township approaching 5000 in total population could be needed during the construction phase. It is difficult to predict how much of such a township would remain after completion of the station, but there is a tendency for such towns to become permanent (e.g., Mangakino and Turangi). The operator housing requirements for either nuclear or Clutha are likely to be small compared with other possible re-uses of a town.

A township of 5000 would occupy approximately 150 ha. At the other end of the scale, should housing be associated with existing population centres, little impact would result.

(4) Impacts on Adjacent Land—

(a) Nuclear:

It is normal to site nuclear stations in places remote from large centres of population and, in New Zealand, such sites could be up to 30 km from population centres of less than 1000. Adjacent land will be rural and is likely to be farmed at only a low level of intensity. A major access road would be required to connect the station to the state highway system.

(b) Clutha:

The stations, by virtue of the inundation arising from associated lakes, have substantially greater impact than a nuclear site. In the context of adjacent land some farms may become uneconomic because flat areas are lost. Resettlement of owners or rearrangement of land holdings are solutions. It will become economic to irrigate some twenty-five times the amount of already irrigated land subject to inundation and six to seven times the area of land subject to inundation. Other effects may arise from higher or lower ground water levels.

(5) Reservoir-Induced Seismicity—

(a) Nuclear:

Nil.

(b) Clutha:

There could be changes in the amount of minor seismic activity, following impounding, but significant earthquake activity is unlikely.

(6) Transport Routes for Fuels and Wastes—

(a) Nuclear:

The fresh fuel would be imported in manufactured form and delivered from ship to power station by normal road or possibly rail transport. A 1200 MWe station requires about eight truck loads per year. Disposal of fuel wastes requires about 60 to 70 truck loads per year.

(b) Hydro:

Nil.

(7) Rehabilitation of Land—

(a) Nuclear:

It is expected that a site would be of sufficient area to accommodate both a decommissioned station and an operating station. But unless the structures were removed (which is unlikely in New Zealand) the long-term use of the site for other purposes would be inhibited.

(b) Hydro:

The life of a hydro station is likely to be virtually unlimited in terms of current technological standards, certainly many times that of a nuclear station, but not necessarily of a nuclear site. Decommissioning would not be impossible and probably less difficult than the initial construction. Decommissioning cannot be envisaged as likely in the light of existing technology.

(8) Transmission Lines—

(a) Nuclear:

Will be required.

(b) Clutha:

Will be required and because of the number of smaller stations spread over a likely more scenic area, could have a rather greater impact.

(9) Public Facilities—

(a) Nuclear:

The station will be of interest and public tours and information centres would be provided. If associated site development included park-type amenities, public use could be expected.

(b) Clutha:

A hydro lake has high recreation potential for swimming, boating, and fishing. Access roads, picnic facilities, boat ramps, and active and passive recreation areas will be provided. Such amenities are in great public demand and considerably enhance the holiday, tourist, and retirement population potential of the area. A stable base for the prosperity of Cromwell Borough will result.

(10) Impacts on Natural Systems, Wildlife and Plant Life—

(a) Nuclear:

Negligible impact is envisaged from the station site and normal activity thereon.

(b) Clutha:

Surveys of existing types of vegetation are being carried out and reserves are proposed. Policies for the most advantageous future planting will be developed. The impact of a series of hydro lakes is substantially greater than a single small nuclear site. Proper design of lake edges will provide replacement habitats for wild life. A series of lakes is likely to inhibit the passage of migratory fish along the river system. Alternatives for dealing with the impact are either the provision of fish passes at each dam or the artificial breeding and stocking of individual lakes. The latter can be supplemented by ensuring that natural breeding areas are retained or created by suitable design.

(11) Scenic and Visual Aspects—

(a) Nuclear:

The physical structure of the station will make it a dominant feature in any landscape.

(b) Clutha:

The major effects are as follows:

(i) Objection to change—loss of the familiar scene.
(ii) Loss of gorge river scenery associated with rapids, rock masses, defiles, and broken water, and replacement of these features by linked placid bodies of water.
(iii) Loss of the "meeting of the waters" at Cromwell.
(iv) Loss of river scenery as at Lowburn.
(v) Loss of orchards.
(vi) Loss of trees in the Clutha River bed.
(vii) Risk of unsightly lake shores, shallows, mudflats, and erosion areas.
(viii) Loss of some historic dredge-tailing areas.
(ix) Risk of unsightly transmission structures.

The impact of these items can be mitigated by appropriate design and construction and sensitive landscaping.

*Impacts on Water Resources*

(1) Adequacy of the Water Supply—

(a) Nuclear:

The station will require cooling water and this will be obtained either by open or closed circuit methods. Significant impacts arise because of the quantity of waste heat to be absorbed and the large works required to accomplish this. The likely solutions are either open cooling to the sea or closed cooling through towers. With appropriate design neither has significant impact on water resources as there is likely to be no competing use.

(b) Clutha:

Other users have major interests in river water with irrigation, fishery, stock water, water supply, and recreation aspects having to be considered.

(2) Impact of the Power Station Facility—

(a) Nuclear:

The open circuit system using sea water can cause damage to aquatic life by entrainment, impingement, and heat. Proper design can minimise impacts. No significant effect is likely on commercial fisheries, and recreational fishing may be improved. Closed circuit systems with cooling towers have insignificant impact in this context.

(b) Clutha:

(i) River flows. River flows will be modified by the operations, and at the station furthest down-stream flows ranging from one-third of mean to two and a half times mean could be expected daily. Residual flows would be left in sections of river from which the main flow had been diverted, for fishery, amenity, and stock boundary purposes.

(ii) Floods. While floods can be passed safely, there is no provision of storage in the new lakes for flood control purposes.

(iii) River stability. Removal of bed load by deposition of the material in lakes might cause channels down-stream to degrade, causing damage to banks and reducing water tables. Fluctuating flows for generation purposes would probably cause some bank damage. Absence of normal flows in sections of river bypassed by canals could allow growth of vegetation which would impair flood capacity in such sections. All these problems are amenable to treatment by suitable river control works which would be carried out.

(iv) Bank stability. Lake perimeter banks, above and below water level, would suffer changed conditions arising from inundation, water level fluctuations, and wave action. Major slips could occur. Proper design and treatment of the lake banks will be carried out to control the lake edges.

(v) Siltation. It is possible that an acceptable stable state of siltation in the lakes might eventuate, with the river's silt burden passed through the stations. If this did not happen, means have been envisaged for passing the silt down-stream via suitable sluices using methods which have been used elsewhere.

(vi) Eutrophication. Lakes are liable to eutrophication, and hydro lakes particularly so. The causes of the problem are understood and solutions are possible. Potential problem areas in the new lake can be identified and physical bed and shore conditions modified to eliminate or minimise problems.

(vii) Control of waste discharge. Existing waste discharges to the river will be subject to review where they discharge into the new lake. Water rights practices will control.

(viii) Weed growths. Control measures will have to be used.

(ix) Water temperatures. River temperatures down-stream of lakes may increase marginally. No adverse effects are envisaged.

(3) Impact of the Fuel Supply—

(a) Nuclear:

Nuclear fuel is unlikely to have a direct effect on the water resource.

(b) Clutha:

Water taken for hydro generation may restrict its availability to other users. This aspect has been referred to earlier.

(4) Impact from Effluents—

(a) Nuclear:

This is a wide-ranging topic in any consideration of nuclear plants and has been dealt with in detail in other submissions.

(b) Clutha:

Not applicable.

*Impacts on Air Quality*

(a) Nuclear:

If cooling towers were used, the water vapour plume created would be visible but the effect would not be measurable in meteorological terms. No other impacts are likely.

(b) Clutha:

Very minor effects on climate are anticipated such as: small change in incidence of frosts in gorges; small changes in wind patterns; and slight increase in local fog incidence.

*Noise Impacts*

(a) Nuclear:

During construction there will be noises which could disturb adjacent residents. On the type of site postulated, no persons are likely to be sufficiently close to be affected. No significant noises will occur during operation.

(b) Clutha:

The dam site adjacent to Clyde will be worked on shift and involve a greater period of noisy activity (e.g., earthmoving machinery, concrete batching) than a nuclear site. The noise will be minimised as much as possible but with the contrast to the existing scene, some nuisance will exist over a 5-year period. This is likely to have a major effect on many residents, but will become background to others.

*Social Impacts*

(a) Nuclear:

In this category come:

(i) disturbance to persons who have to leave established homes—minor displacement only,
(ii) accommodation of construction workers,
(iii) accommodation of operators,
(iv) security matters—dealt with in other submissions.

(b) Clutha:

(i) Disturbance. A very significant effect has resulted with up to 100 persons being displaced, many from long established farms.

(ii) Accommodation. Likely to be similar to that required for the nuclear station except that fewer permanent operators will be required.

(iii) Security. Insignificant.

*Safety Aspects—Natural Hazards*

(a) Nuclear:

It can be accepted that a nuclear site will have been subjected to intense subsurface investigation, and foundation conditions identified with a high degree of certainty. The siting will be such that the effects of floods and earthquakes can be predicted reliably.

(b) Clutha:

The civil engineering works for the Clutha, embracing five major dams, canals, and lakes will cover a much greater area and consequently a much wider range of foundation conditions and materials, than a relatively small nuclear site. At commitment, foundation performances will be much less certainly known than for a nuclear station, but more detailed investigation would be impractical at that stage. By their nature the Clutha sites will be more vulnerable to floods and, probably to earthquakes, than nuclear sites. Nevertheless the risk of failure is extremely low.

## WASTE MANAGEMENT

25. All conventional methods of electricity generation produce wastes which affect the environment. The management of these wastes to minimise adverse effects has usually come late in the development of the technology.

26. The nuclear industry has followed this pattern in both the weapons programme and power generation in that only in the last few years has attention been paid to the more serious aspects of nuclear waste disposal. The Flowers report expressed disquiet at what it saw as insufficient appreciation of long-term waste disposal requirements either by State departments or by other organisations. It considered that there must be "a means to ensure that the issues posed by waste management are fully considered at the outset of a nuclear programme, not dealt with many years after the decisions on development that lead to wastes have been made and when options have been effectively foreclosed."

27. The DSIR in assessing the nuclear waste disposal problem concluded "that New Zealand could well consider adopting the policy of

some overseas countries which advocate not entering into a nuclear power programme until greater assurance of safety of waste management procedures can be given than is available at present" (44).

28. Dangers from radioactivity arise at every stage of the nuclear fuel cycle. New Zealand, should it embark on a nuclear power programme, would not be involved in preparing fuel elements for the reactor. This would be done overseas. However, the wastes from any kind of reactor would have to be handled and disposed of in New Zealand or elsewhere.

29. As has been described in chapter 4, radioactive waste is generally classified as being of "high", "intermediate", or "low" level. High-level waste has relatively small volume but intense radioactivity, and needs long-term shielding and containment, and cooling. The term may be applied to irradiated fuel but is normally used for the highly concentrated waste generated from the reprocessing of spent fuel. Intermediate-level waste is more bulky and less radioactive, and needs containment and shielding, but not cooling. Low-level waste needs least shielding during storage, and some may be discharged into the environment. Information on the constitution of the wastes from an LWR and the rate of decay of the various waste products has been given in full in a DSIR background paper (44), and in the FFGNP report.

30. In any New Zealand nuclear power programme, low-level, intermediate-level, and small amounts of high-level wastes would have to be managed. However, it would be unlikely to need a fuel-reprocessing plant. This stage is associated with the management of 99 percent of all the waste radioactivity from nuclear power generation (44). Probably the only thing needed here would be to store radioactive fuel elements in cooling ponds to allow enough time for heat and radioactivity to decay before shipping them overseas in heavily shielded casks for reprocessing. It has been suggested that the radioactive residue might have to be accepted back from an overseas reprocessing plant after the plutonium and uranium were extracted.

31. Many of those appearing before us were concerned about the management of radioactive waste. The DSIR pointed out that "questions of interim management and long-term storage of long-lived radioactive waste have drawn both reassuring comments and warnings for the safety of future generations" (44). The morality of producing wastes that will be left as a problem for future generations was often mentioned to us and is discussed in chapter 10.

32. The wastes from a nuclear fission power plant differ in two ways from those from a fossil-fuel thermal plant. The amount of nuclear wastes is much less, and the dangers to health arise not from chemical properties but from radiation. We deal with the latter in chapter 11.

33. There is interest in comparing the wastes from a large (1000 MW) coal-burning station with those from a nuclear station of the same size. In the coal-burning station the main waste is the carbon dioxide emitted from the station's stacks at the rate of 270 kg per second. Although carbon dioxide is not in itself a dangerous gas, there is growing concern that its increasing concentration in the atmosphere may have a deleterious effect on the world's climate.

34. It has been estimated that the 266 power plants in the eastern United States were in 1973 putting 17 million tonnes of sulphur dioxide into the air, about two-thirds of that from coal plants, and the rest from oil-fired stations (91). Nitrogen oxides and particulate matter are also discharged. Air pollution from fossil-fuelled plants was said to cause up to

21 000 premature deaths each year in the eastern United States, and it was advocated that any new coal-fired stations built should be made to use coal with the lowest available sulphur content, and to install scrubbers which could remove the greater part of the sulphurous discharges.

35. The Ford Foundation - MITRE group concluded that on balance nuclear electricity generation has significantly less environmental impact than coal (12), a conclusion also advanced by Professor B. G. Wybourne (93). However, our inquiry is concerned primarily with the implications of nuclear technology. It has been estimated that the spent fuel from a 1100 MWe LWR weighs 29–37 tonnes a year for a core-loading of 87–149 tonnes (4). Or considering the volume of wastes produced, a 2 × 600 MWe nuclear station would produce 70 to 140 cubic metres of low- and intermediate-level waste in a year. This would fill between 350 and 700 forty-four-gallon drums. High-level wastes are produced at the rate of 34 cubic metres of liquid waste a year which, when vitrified, is reduced to 17 rods each 3 metres long and 0.3 metres in diameter (40). The amount of wastes from a nuclear plant is insignificant in volume compared with that from a coal-fired plant of equivalent size.

36. The FFGNP described the methods of dealing with radioactive waste. Intermediate-level wastes would be dried and mixed in cement or bitumen in drums. Management policies for low-level wastes may consist either of "concentrate and confine", "delay and decay", or "dilute and disperse". In the event of a nuclear power programme in New Zealand, intermediate- and low-level wastes would be managed locally. They would be disposed of by burial on land or dumping at sea. Sites for burial would have to be carefully chosen, and be in rock of low permeability and porosity, away from people, and in places where groundwater patterns are well understood. The actual burial site should be well above groundwater levels (4). Site investigations would be lengthy and expensive according to the Geological Society of New Zealand (94).

37. Small quantities of radioactive waste, mainly from universities and research institutes, have already been dumped at sea. In 1968 two areas, one south-east of Cook Strait and the other north-east of East Cape were designated as suitable for the disposal of radioactive wastes.

38. New Zealand has signed the international Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter ("London Convention"), and the Convention was given effect by Part II of the Marine Pollution Act 1974. Under the Convention, the permissible level of radioactivity which may be contained in wastes to be dumped at sea is determined by the IAEA. The Marine Pollution Act requires a special permit to be obtained before any waste is dumped in the sea around New Zealand.

39. The two designated sites, which have been adequate for the small amounts and low toxicity of the wastes dumped so far, are not entirely satisfactory long-term, as they may have potential for minerals or petroleum. It is considered that a permanent site should be selected to the east of the Kermadec Trench, well away from the New Zealand continental shelf (95). In July 1976, however, the New Zealand Seamen's Union formally stated that their members would protest at all dumping of nuclear and radioactive waste at sea, and would not be party to the dumping.

40. The Ministry of Transport, which administers the Marine Pollution Act, recommended to us (95) that before any decision is made to establish a nuclear power plant the alternative methods of disposal of the radioac-

tive waste be thoroughly investigated; and that if a nuclear power plant is to be established, and it is intended to dump large amounts of low-level waste at sea, the present International Convention and legislation (together with the procedures laid down in the legislation) would be adequate. Present practices would need some change, mainly to increase supervision.

41. Most of the high-level waste so far produced overseas in commercial power reactors is still incorporated in the spent fuel elements. These are stored in enclosed, water-filled pools which provide radiation shielding and cooling. This well-proven method can be regarded only as an interim solution. It requires continuous surveillance.

42. Though various methods have been proposed for the permanent disposal of high-level wastes, none has yet been used. A New Zealand nuclear programme may have to deal with waste shipped back after reprocessing overseas or waste that has not been reprocessed. The most favoured disposal method proposed has been to solidify the waste and bury it deep underground in geologically stable formations. But New Zealand, situated at the boundary of the Indian and Pacific tectonic plates, and with a consequent history of earthquakes, may be an unsuitable region for the deep underground disposal of high-level radioactive waste. The DSIR and the Geological Society of New Zealand thought it uncertain that suitable geological sites exist here (46, 94).

43. The dumping of high-level liquid wastes on the sea floor is generally prohibited by the London Convention. It has been suggested that wastes incorporated into a glass material to form a solid could be so dumped. The glass is expected to leach away in 3500 years, releasing the radioactive material which would eventually enter the food chain. However, the predicted concentrations are calculated not to exceed natural levels of radioactivity. Though the study has some uncertainties in its results it indicates that the sea floor should not be ruled out as a possible site for the disposing of high-level wastes (96). The Antarctic icecap has also been suggested as a repository. The Antarctic Treaty 1959 prohibits waste disposal in Antarctica. There are good environmental reasons for this.

44. Some of the people Royal Commission members met during their visit to the United States (for example, Dr Chauncey Starr, President, EPRI) expressed a general confidence that means could be found to satisfactorily bury solidified waste if adequate Federal funds were forthcoming. It was claimed that the geologically stable sites had been defined, and were available without foreseeable detriment to the environment. But some British scientists and plant operators were more cautious or less confident about underground disposal of waste, and could not see early action on this matter either in terms of money forthcoming, or of environmental acceptability.

45. When visiting the Harwell Laboratories of the British Atomic Energy Authority, members discussed the progress being made in researching and developing the conversion of high-level fission waste into the form of durable glass. Harwell seems to have done enough development work to justify a plan to store at Windscale until the end of this century glass blocks incorporating the British high-level waste. After that, as discussed in chapter 4, they will be either buried deep underground or placed on or under the bed of the ocean, without prospect of retrieval. The radioactivity of the fission products in the glass will gradually lessen. It was claimed at Harwell that even if this diminished radioactivity was to escape into underground waters or into the sea, the threat to man would

be little worse than that arising from naturally-occurring radioactive materials, or from the dangers arising from metals like mercury, cadmium, and lead.

46. A joint Common Market research programme on the underground disposal of wastes in the three most promising types of rock formation is under way. This has already been briefly mentioned in chapter 4. Under this programme, Britain and France are studying hard rocks such as granite, Belgium and Italy are studying clay, and West Germany and Holland are studying salt. To be suitable as a disposal site, a rock formation must show that it is impermeable to water and is likely to remain so through foreseeable geological and climatic changes. It must be free from fissures and old mine-workings, and preferably from worthwhile mineral resources. It must be able to withstand flooding and erosion, and not be in an area liable to earthquakes. The rock itself must be non-porous, and resist heat and chemical change (97).

47. Sir John Hill, Chairman of the UKAEA, has said that the high-level wastes arising from even a large nuclear programme will be small compared with, say, the world stock of mercury and arsenic (98). He said that burning the actinides in reactors may be more promising as a precursor to disposal than vitrification. Sir John warned of two possible dangers:

> On the one hand we might be driven by short-term expediency, under pressure from various quarters, to adopt prematurely, inadequate measures that are expensive, insufficiently researched, or both. On the other hand the decision-making process could become paralysed so that our nuclear programme was delayed until some magical final solution was found. The truth of the matter is that the engineered storage that we are all planning for the short and medium term will be sufficiently good for there to be no hurry at all in determining the best and most convenient of the many possible methods of ultimate disposal. But this very satisfactory situation is being used to our disadvantage by some of our critics. They contend that since we have not determined how nuclear wastes will be ultimately disposed of, we should stop our nuclear programme until we have determined and proved the disposal method. . . . We must I think, to satisfy our critics, establish one method of disposal whether or not it is the most satisfactory or economic . . . We should also continue . . . to achieve a method of disposal which is not only fully acceptable environmentally but also the best practical and economic solution.

48. The NEA group of experts on waste management made three points about radioactive waste disposal: that discharge into the environment is at present adequately controlled through ICRP recommendations; that the nuclear industry has the technical ability and means to ensure the safe handling and storage of all types of radioactive waste for as long as a century or more; and that safe waste-disposal practices (for example, shallow burial on land, deep burial in geological formations on land, and sea dumping) are already in use for the less radioactive types which do not need long-term containment (99).

49. The ultimate disposal of high-level waste remains unresolved. The NEA group suggested that the only acceptable arrangement is that governments take direct responsibility for the long-term management of waste. This would give the best guarantee that the most appropriate solutions would be adopted and that administrative control and possible surveillance over storage and disposal sites would be maintained. The group also confirmed that technology for dealing with waste management exists, but concluded that a demonstration phase is nevertheless necessary before adopting full-scale application of waste-management techniques.

50. Unless New Zealand could persuade Australia or some other country with geologically stable sites suitable for deep underground burial to take its high-level waste, it is difficult to see an easy solution to high-level waste disposal in this country. And we agree with recommendation No. 27 of the Flowers report that:

> There should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long-lived highly radioactive waste for the indefinite future.

51. The Ford Foundation - MITRE report considered that disposal of such wastes in stable geological formations appeared to give adequate assurance "against the escape of consequential amounts of radioactivity even over long periods of time". It stressed, however, that problems of waste-management are potentially more serious than the purely technical aspects of disposal.

52. Thus we recommend that, before nuclear power is introduced into New Zealand, the feasibility of a suitable local plan for the disposal of high-level radioactive waste should be demonstrated, and details of a waste-management organisation be formulated.

### *Decommissioning*

53. A nuclear power station has a useful life-expectancy of about 30 years. Dealing with it then can be considered a part of waste disposal. During the operational life of the station some structural components become radioactive. These would be left after shut-down and after fissile material and potentially dangerous portable components had been removed. A localised danger would remain and the building might be dangerous to enter without protection. Nuclear stations thus pose more severe disposal problems than most other industrial structures. The difficulties are often compounded because ultimate disposal has not generally been kept in mind when the plant was designed.

54. Regulatory authorities recognise decommissioning to one of three stages described in the FFGNP report as: lock up with surveillance ("mothballing"); conversion and restricted site access ("entombment"); and unrestricted site access ("dismantling"). No large nuclear station has yet been decommissioned. There are reports of nine small reactors having been dealt with (12). Two have been put in protective storage, five have been entombed, and only two have been totally dismantled so that the site became available for alternative uses.

55. The environmental and economic costs of decommissioning are an inevitable part of a nuclear power programme. We agree with the conclusions of the FFGNP that:

> It would seem essential for our future environmental interests that a plan and financial provision for decommissioning be established at the time of the initial planning of the siting, the design and the construction of a nuclear power station so that the ultimate environmental impact of the decommissioned facility is made acceptable (4).

## POLLUTION

56. Any method of thermal power generation pollutes the atmosphere in some way with either local or global effects. In normal operation such stations pass waste heat, gas, particulate matter, and radioactive material to the atmosphere. These can not only affect health locally, but it has been suggested, could alter local or global climates. As New Zealand is more

likely to suffer from global pollution than to contribute to it, we shall now discuss some aspects of this problem.

57. The Ford Foundation - MITRE report has said that the man-made contribution in 1975 corresponds to an average global input only of about 0.02 percent of the radiation balance.

> It has probably not affected climate on a large scale. However . . . some local areas do show effects. If energy production should grow at an average annual rate of 4.5%, then in about 50 years the average global artificial heat input will be . . . of the order of 0.2% of the radiation balance; in 80 years, the heat input would be about 0.6% of the radiation balance. An increase of a few tenths of 1% of the global radiation balance could over several decades cause melting of polar sea ice. This man-made heat input may have dramatic effects on the earth's climate over a relatively short time span.

Whether these rates of growth will in fact occur is uncertain.

58. It has been found that the heat emitted from industrial conurbations of north-eastern United States or north-western Europe can alter local climate. The collocation of a number of 1000 MWe nuclear generating plants into a nuclear park has been suggested as a means of reducing the problems of dispersed sites. The waste heat emitted to the atmosphere from a large nuclear park would be equal to a significant fraction of that released in a thunderstorm. The possibility of severe storms near large nuclear parks could not be discounted.

59. The rapid increase in the use of fossil fuels in the twentieth century has raised world-wide concentration of carbon dioxide in the atmosphere. Some of the carbon dioxide is taken up by vegetation, and some by the oceans. Approximately 60 percent is retained in the atmosphere. A doubling of the nineteenth century concentrations is considered possible by as early as 2025.

60. It is generally accepted that the amount of carbon dioxide in the atmosphere has increased from a value of about 290 to 295 parts per million (mid nineteenth century) to about 325 ppm today; that is, an increase of about 12 percent (100). About 13 ppm of the increase has occurred since 1958. The present consumption of fossil fuels implies an annual injection of about 16 256 million tonnes of carbon dioxide into the atmosphere, corresponding to an increase of about 2.1 ppm a year. The observed increase would be only about half this, because the land biota increase their assimilation, and the oceans serve as a sink for carbon dioxide. It has been suggested that at least part of the measured carbon dioxide increase is a consequence of the extensive clearing of some tropical forests, but there is no agreement on what this contributes to the total increase. The significance of carbon dioxide as a pollutant lies in its ability to absorb the long-wave radiation emitted from the surface of the earth (see chapter 3), and, through the so-called greenhouse effect, to increase global air temperature.

61. Manabe and Weatherald calculated that a doubling of carbon dioxide in the atmosphere might imply an average increase in temperature at the earth's surface of about three degrees (within polar regions, more) (101). Although there can be argument about details of such a theoretical calculation, the scientific community takes seriously the possibility of marked global temperature rises. Oak Ridge National Laboratory pointed out that if we are to judge how rapidly we can safely use our fossil fuel reserves a greater knowledge is needed of the way carbon dioxide is exchanged with the oceans and with plants in order to judge how the airborn fraction will change in the future; the climatic effects of increased atmospheric carbon dioxide; and the impact of a change in regional

climate on the environment and on society (102). We were informed that an "Office of Carbon Dioxide" was to be established (1977) within the United States ERDA to assess the effects of carbon dioxide increases in the atmosphere. There appears to be no immediate practical solution to the problems that may arise from carbon dioxide from increasing use of fossil fuels. The Ford Foundation - MITRE report considers them as "the most serious potential impacts on the environment from greatly increased power generation . . . "

62. Thus nuclear power must be seen partly at least in a context of the environmental consequences associated with some of the non-nuclear alternatives. Increasing the number of large coal-burning power stations in the world would appear to be unwise until there is a better scientific understanding of the role of carbon dioxide in climatic change. It has been suggested that the large amount of particulate matter from the combustion could be responsible for altering the amount of solar radiation reaching the earth's surface, and calculations have been made of changes in climate due to this. Again there are uncertainties in the result, and more research is needed.

# *Chapter 10.* MORAL AND SOCIAL CONSIDERATIONS

## INTRODUCTION

1. As we have said in chapter 1, a nuclear power programme raises far wider issues than those of generating enough electricity to enable the nation to meet its social and economic goals. It calls into question the assumptions underlying policies—the considerations of continually increasing economic growth and centralising administration. The proponents of nuclear power point out that it presents an electrical energy source which is a natural and necessary successor to the world's diminishing fossil fuels, and is environmentally far less adverse than them in its effects. The admitted dangers associated with nuclear power have, it is said, either been solved or are capable of technical solution, and have up to now been proved to be potential and not actual.

2. But some see a nuclear power programme in New Zealand as bound to alter our way of life for the worse. Nuclear radiation is widely feared as an unseen and unfelt danger to health. News references to leaks of radioactive material in nuclear plants (even when later shown to be insignificant) reinforce the distrust of nuclear power. It is often forgotten that nuclear power is the first large industry to be subjected to such close public scrutiny. Other means of electricity generation, the oil industry, and the chemical industry all have individual and community dangers associated with some aspect of their operation. None has so far had to undergo the same intensive investigation of every facet of its activity as has the nuclear industry. The investigation is, of course, essential, for in a democracy any large-scale nuclear power programme can be implemented only if the majority is convinced that it can live with the consequences. In this chapter we discuss what we see as the more important moral and social considerations that many see as implicit in a nuclear power programme.

3. The National Council of Churches at its 1976 annual general meeting expressed concern at the apparent trend towards New Zealand's adopting nuclear power without sufficiently examining the implicit moral issues. And as well, many submissions to us expressed similar moral and social concern. The Commission for the Future, after discussing the principles of making a decision on nuclear power, added:

> Each of the aspects . . . developed by the Commission for the Future involves an appreciation of the appropriate course of political action, which will be determined by the response of the political machine to the views of the population at large. The latter in turn are influenced by the philosophical and ethical stances of individuals. The debate is, therefore, really about the ethical view which can command a consensus (113).

4. There is no general agreement on the precise meaning of "moral consequences" in respect of a nuclear power programme. Many matters were raised before us under this heading. We shall discuss only the most important which arose mainly in a context of (a) the prodigal and unequal use of the world's resources; (b) the possible links of nuclear power generation with nuclear weapons; and (c) the legacy of radioactive waste to future generations.

## THE USE OF THE WORLD'S RESOURCES

5. Chapter 3 discusses in general the rapidly increasing use of energy and the depletion of solid fuel resources. The morality of a relatively few affluent nations being profligate users and the major consumers of the earth's finite energy resources raises much wider considerations than those of nuclear power—the more equitable apportioning of the world's resources, for example. We cannot attempt to discuss here such far-reaching problems. It is sufficient to say that we regard the continual growth of electricity generation in New Zealand, however it is brought about, as a continuation of present social and economic policies. Some advocated changing our life-style to one, which being simpler, would make smaller demands on natural resources and thus conserve them for posterity. Although a return to a less complicated way of life has a certain nostalgic appeal, as we indicate in chapter 3, we have grave doubts whether our largely urban society could be recast in such a mould. However, even in an urban society, there is, as has also been shown in chapters 7 and 8, room for greater efficiency in the generating and consuming of electricity.

6. A proposal that New Zealand should concentrate on exports with a low energy content, although superficially attractive, does not seem to us to be a moral solution to the problems of diminishing resources or polluting the environment. Indeed, some see it as an evading of responsibility by using somebody else's resources and keeping New Zealand unspoiled at the expense of some other country's despoliation. However, as the Department of Trade and Industry pointed out, important contributions to New Zealand's export earnings and industrial growth could be made by non-energy-intensive industries (137). The reasons for promoting such industries would appear to be economic and not moral.

7. Certainly the depletion of fossil fuels, an already rapid process, could be regarded as showing a morally irresponsible attitude towards further generations. However, as was pointed out by Professor J. W. Rowe at the Third New Zealand Energy Conference:

> Confronted with such uncertainty [about the future], it is sensible to leave open as many options as possible for as long as possible. More arguably, the unavoidable uncertainty about the future weighs against currently avoidable sacrifices in the interests of generations to come. We simply do not know whether the twenty-first century will judge them to have been worthwhile or not (138).

There is no consensus in New Zealand on what present sacrifices in the use of resources we should be making for posterity, or indeed whether any sacrifices should be made at all. We consider that:

> The minimisation of illfare is a much safer guiding principle [in these matters] than the maximisation of welfare, even if it is less high sounding because it leads less seductively to imposing one's own values on others (138).

8. Besides the principle of "minimisation of illfare" applied to use of natural resources, there is a moral duty to posterity to hand on as many developed energy producing technologies as possible. Only in this way will posterity have the greatest freedom of choice in the circumstances then prevailing.

## POSSIBLE LINKS WITH NUCLEAR WEAPONS

9. As nuclear power generation was an offshoot of a military application of nuclear technology, some people have seen it as essentially evil. Many of those opposed to nuclear power (Women's International League for Peace and Freedom (139), Campaign Against Nuclear Warships (140) ) contended that New Zealand, by adopting this technology, would be adding to the possibility of nuclear war. A similar type of argument is to be found in the Fox report which stated that: "The nuclear power industry is unintentionally contributing to an increased risk of nuclear war. This is the most serious hazard associated with the industry" (10). India's explosion of a nuclear bomb demonstrated quite clearly that a country may attain some measure of nuclear weapons capability through a commercial nuclear programme.

10. The problems associated with the proliferation of nuclear weapons are dealt with later in this chapter. We are not, however, convinced that, by rejecting a fission-based nuclear power programme, New Zealand would in any significant way either aid the cause of world peace or set a moral example to the rest of the world as some claimed it would do.

## LEGACY OF RADIOACTIVE WASTE

11. The storage of waste fission products was quoted to us many times as involving moral considerations because of the long life and high radiation levels of some isotopes. Thus Professor D. W. Beaven was among those "concerned with the ethical and moral implications of our own particular generation committing hundreds of subsequent generations to the guarding and disposal of radioactive fissile wastes . . . I believe we should come up with the solution to this problem before we commit future generations . . ." (105). Similarly B. E. and G. F. Preddey stated that:

> A consequence of a New Zealand nuclear power programme could be that these questions [on waste disposal] hypothetical for us now, would not be so for future generations. They could have reason to regard their predecessors (us, today) with less than admiration (141).

12. The NEA has stressed the need to consider the effects on posterity of nuclear waste management practices:

> One responsibility of present generations, relying on nuclear fission for their energy needs, is not so much the consequences of deliberate releases of effluents to the environment, which can be adequately controlled even in relation to possible cumulative effects, but the need to manage the remaining waste in such a way that it does not become a burden for future generations. To achieve this objective, present generations should look for technical solutions for the required degree of long-term isolation for the long-lived radioactive waste, in such a way that future generations will not be faced with conditions that we would not accept ourselves (99).

13. We found in our discussions overseas that representatives of the nuclear industry were optimistic about high-level waste disposal. The management of low-level wastes poses no real problems. There are several experts, particularly in Britain, who feel that the public is seeing the problem of high-level waste disposal in the wrong perspective. They imply that, with reprocessing (that is, in particular, the removal of plutonium, and vitrification), storage by burial would be adequate. On the other hand the public may be correct, and in this case there is the real danger

that, even though disposal may prove to be technologically simple, if left too long, it could become unmanageable. NEA experts in Paris claimed to some of us that the lack of action in disposing of military wastes in the United States and Britain is a political and economic rather than a technical problem. The cost is very high so that politicians show little enthusiasm to have it done. Public suspicion and watchfulness will probably prevent a repetition of some earlier slipshod waste disposal. Careless disposal practices or the failure to use the best available technology could rightly be considered as irresponsibility to the future.

14. As in so many moral questions, the issues in the nuclear controversy are by no means clearcut. Professor Wybourne expressed to us the view that the rapid depletion of the world's oil and coal reserves in energy production when they have value as petrochemical raw materials, could be regarded by our descendants as squandering a heritage (93). We could make amends for the materials we are denying posterity by leaving a technology that would enable them to do without those materials. Such a technology must depend on cheap and abundant energy. He concluded that at present the only source we can guarantee is nuclear fission.

15. In essence this argument raises the further question of the morality of depleting our non-renewable resources of oil, gas, and coal while ignoring the enormous quantities of energy in the plutonium contained in high-level wastes from fission reactors. It can be argued that it is far safer to use the plutonium as a fuel in an FBR than to have to provide either temporary or permanent storage for high-level wastes. However, many resolutely oppose the extraction of plutonium from wastes and its use as a fuel in the FBR as possibly leading to greater proliferation of nuclear weapons and nuclear terrorism. From the point of view only of using energy, ignoring plutonium as a fuel is an inefficient use of natural resources. But in a democratic society before plutonium is widely used for energy the public must be convinced that the advantages of its efficiency outweigh the possible dangers.

16. The use of the thorium cycle with breeder reactors has been suggested in an attempt to multiply the energy value of uranium as much as the plutonium cycle would, but without the latter's potential disadvantages. Chapter 4 discusses the conversion of thorium into fissile uranium-233 which can be made unsuitable as bomb material ("denatured") by dilution with non-fissile uranium-238. The United States nuclear industry sees the thorium cycle as a technical solution to a political problem, and does not regard it favourably (142).

## THE ILLICIT USE OF NUCLEAR MATERIALS

17. Many submissions stressed the dangers from diverting nuclear fuels to illicit ends, and from the effects on society of the methods that would have to be used to guard fissile materials from theft and nuclear installations from sabotage. With sabotage and terrorism becoming more commonly used by dissident groups and individuals, any increase in nuclear power was seen as adding to the possibility of violence and anarchy. New Zealand's relative geographic isolation was not expected to save it from becoming caught up in these worldwide problems. We fully agree that a solution for such problems of nuclear weapon proliferation, and the possibility of nuclear blackmail, must be found.

18. Nuclear installations could presumably give rise to blackmail and terrorist activities because diversion of fissionable explosive material would result in a real threat to society if the material could be made into a bomb or dispersed in the atmosphere; and sabotage of a nuclear plant could allow radioactivity to escape. We now discuss these possibilities, and the effects on our normal freedoms of the security measures needed to provide safeguards.

### *Diversion of Nuclear Material*

19. Low-enriched uranium or natural uranium used as fuels in the LWR and the CANDU respectively cannot be made to explode or be fashioned into a nuclear weapon. Nuclear weapons are made from either highly-enriched uranium, or from plutonium.

20. However, as we have seen in chapter 4, spent fuel from commercial power reactors contains plutonium which, in a reprocessing plant, can be separated out when making new reactor fuel. Thus a terrorist organisation wishing to make a nuclear weapon would first have to acquire plutonium or highly-enriched uranium from fuel fabrication, from reprocessing plants, or from spent fuel from a commercial reactor. All of these undertakings are dangerous. For instance, spent fuel is extremely radioactive and can be handled only with special shielding and equipment, and the heavy casks (from 30 to 100 tonnes) in which it is shipped further complicate theft. Even if spent fuel is successfully stolen, access to reprocessing facilities are necessary to separate out the weapons material. It appears improbable that bomb fuel could be got from this source unless the operation was a national one. Much greater opportunities of theft occur during the separation of plutonium, and the production of highly-enriched uranium fuels, or when these materials are in transit. Their use in bomb making presents very great difficulties which are, however, not insuperable.

21. It seems to be generally agreed that a determined group of terrorists, with the necessary scientific background and knowledge of the properties of high explosives and the principles of bomb construction, could make a crude bomb which might explode with a force of a few tonnes of TNT. Even though inefficient, such a device would have an enormous psychological effect. There is no general agreement on whether an illicit group could construct a weapon with a yield of 100 tonnes of TNT or more. The Ford Foundation - MITRE report pointed out that details necessary for the manufacture are freely available, but the actual construction needs "substantial knowledge, planning, and extraordinary care in execution. A small group of even highly intelligent people is unlikely to have all the skills needed to carry out such a programme successfully."

22. However the Flowers Royal Commission, because of the dispute about the possibility of making such a bomb, consulted eminent physicists both in Britain and the United States. "Their judgment was that the construction of a bomb that would give such a yield was indeed possible though the actual yield would be very uncertain, for it would be as much a matter of luck as good judgment." The report concluded that "it is entirely credible that plutonium in the requisite amounts could be made into a crude but effective weapon that would be transportable in a small vehicle."

23. Although the use of the thorium cycle has been proposed as a means of combating proliferation, doubts of its effectiveness in this role have been expressed by Karl Cohen, a scientist with General Electric in the United States. He thinks that the cost of enriching the denatured uranium-233 to weapons level may not be beyond the purse of a terrorist organisation. It would need merely a centrifuge system in no more space than that of a 3000 square foot building. He said: "Legend has it that a weapon can be fabricated in a garage if enough fissile material is available. We see that we can undenature U233 in a modest house conveniently adjacent to the garage" (142).

24. A country wishing to build up a large stockpile of nuclear weapons cannot do so on the basis of a civil nuclear programme. It would need dedicated facilities. It is, however, possible to produce one nuclear weapon a year from the plutonium from a heavy water or graphite-moderated natural uranium reactor with a thermal capacity of a few tens of megawatts (155). Details of the technology are in the open literature, and the cost is some tens of millions of dollars. Apparently India followed this route.

### *Sabotage and Terrorism*

25. It has been suggested that terrorists may hold a nation to ransom by threats of sabotaging a nuclear power plant or of dispersing small amounts of plutonium in the atmosphere. It is possible that a raid on a nuclear plant may cause such damage as to bring about an escape of radioactivity. Though it would not be difficult for sabotage to stop generation in an electricity plant, sabotage of a nuclear power station to cause release of radioactive material is much more difficult. The most serious release would come only from producing a core melt sequence. An intimate knowledge of the nuclear plant design would be needed for a successful terrorist raid, and though great damage could be caused to the reactor, it is unlikely that there would be large numbers of casualties (44).

26. Although there have been only a few minor sabotage incidents in nuclear plants, there has been a growing concern that physical protection of installations should be improved. Even if it did not cause loss of life, sabotage could be socially and financially harmful, and the removal of a large block of power from the supply system would have serious consequences. These consequences are, of course, not peculiar to nuclear power stations. The sabotage of any large base-load station could also have serious results. Indeed, a terrorist group, determined on its sabotage producing the maximum effect, could probably gain its ends more easily and effectively *other* than by attacking a nuclear station.

27. Because plutonium in the form of an aerosol is extremely toxic, it has been suggested that even small amounts dispersed in the air could be used for terrorism, leading to many deaths by inhalation. It has been estimated that one gram of plutonium-239 applied in aerosol form to an airconditioning system could cause a lethal dose over an area of about 500 square metres (one floor of an office building) (44). The number of casualties from plutonium dispersed in the open air depends on the weather and the population density at a particular time and place. B. L. Cohen estimated that for average United States conditions, there would be one death from cancer for every 15 grams dispersed in an urban population without warning (91). Such a dispersal would lead to few immediate deaths, most occurring over the ensuing 30–40 years. Clearly

there could be wide divergences from this result because of differences of actual conditions from the averages assumed in the calculations. Because of the uncertainty of the results of malicious dispersal of plutonium, it would appear that terrorism could be more effective by using other methods.

28. In New Zealand, enrichment of uranium and reprocessing of spent fuel would, for economic if for no other reasons, be unlikely in the foreseeable future. There would therefore be no stocks of fissionable explosive material. The possibility of terrorists trying to divert nuclear material would be very small if we were to have a nuclear power programme.

## PROLIFERATION OF NUCLEAR WEAPONS

29. Given areas of political instability, any increase in the number of sovereign states with nuclear weapons increases the risk of nuclear war. There is always the possibility that armed conflict between small states in which there is the threat of the use of nuclear weapons will involve the super-powers. The dangers of proliferation are well recognised by the super-powers which have tried to stop it happening by various means while still allowing non-nuclear countries access to the peaceful uses of nuclear technology.

30. The Non-Proliferation Treaty (NPT) described in more detail in chapter 13 is one such attempt. It has been ratified by 105 countries. In return for accepting restrictions on the possession or manufacture of nuclear arms, non-nuclear countries are allowed to buy nuclear power generation plant together with the necessary fuel, and are given access to nuclear technology.

31. Another agreement with much the same aims has just been concluded by the so-called "suppliers group" of countries which export nuclear technology (156). This 15-nation agreement permits the signatories to continue to sell nuclear power generation equipment and technology but lays down an extensive programme of international safeguards to ensure that there is no military use made. Suppliers have tried to meet world power-demands without the risks of proliferation, and at the same time demonstrate to the non-nuclear nations that there is no cartel aiming to raise the price of nuclear fuel and equipment. The agreement bans the sale of reprocessing equipment, but as it applies only to future deals, does not prohibit their current sales by West Germany to Brazil, or by France to Pakistan.

32. In spite of all these safeguards, there can be no absolutely effective restrictions on the proliferation of nuclear weapons. If a sovereign State wishes to become a nuclear weapons power, it can do so as long as it possesses the resources in money and technical expertise. The guiding principle behind the nuclear power policies of the present United States administration is that the development and commercial use of nuclear technology by any non-nuclear state should leave that state no closer to a nuclear weapons capability than if all its nuclear power were derived from low-enriched uranium reactors operating with verified spent fuel storage in secured international facilities. This rules out, at least for the present, the reprocessing of spent fuel, and the plutonium breeder reactor.

33. The nuclear power policy announced by President Carter in his 1977 energy plan (146) defers any United States commitment to advanced nuclear technologies based on the use of plutonium. To set an example to the world in preventing nuclear proliferation, the President announced that the United States would defer indefinitely commercial reprocessing and recycling of plutonium, and the commercial introduction of the plutonium breeder reactor. Also the President proposed to reduce the funding for the existing breeder programme, and use the funds for alternative nuclear technologies with emphasis on non-proliferation and safety measures. Thus there is doubt about the Clinch River FBR project though work on breeder reactors in the United States is by no means finished. A 60 MWe light-water breeder reactor using a thorium/uranium-233 fuel cycle went into commercial service in early November, 1977 (158). The United States nuclear industry disagrees strongly with the President's policy on the commercial FBR, especially as some other nations are pressing ahead with FBR development.

34. The Flowers report, although recognising the increased efficiency of burning plutonium in a breeder reactor, considered that the dangers were such as to negate the advantages of its use and concluded that:

> The dangers of the creation of plutonium in large quantities in conditions of increasing world unrest are genuine and serious. We should not rely for energy supply on a process that produces such a hazardous substance as plutonium unless there is no reasonable alternative.

35. The Flowers report hoped that the large-scale use of the FBR could be avoided by developing fusion power. However, an energy group set up by the council of the Royal Society concluded that the lack of uranium resources in Britain implied that "a credible nuclear policy must be based, in the long run, on fast breeder reactors" (159).

36. The future of commercial spent-fuel reprocessing and the FBR in Britain depends on Government decisions following the Windscale inquiry into building a plant to reprocess spent fuel from Britain and Japan (see chapter 4). The inquiry under Mr Justice Parker finished its public hearings in November 1977.

37. The British Government could face a dilemma in making its decision after the findings of the inquiry are published. The nuclear industry naturally wishes to proceed with the Windscale plant as a first step towards a fast breeder system, for which a second public inquiry is promised. Possibly large foreign earnings are a great incentive to proceed. On the other hand, there is a strong section of the Government which supports President Carter's plan to halt the spread of reprocessing and breeder technology around the world.

38. The communist world is committed to an extensive FBR programme; western countries are divided on the issue, France, for instance, being committed to the commercial breeder reactor. An international reprocessing plant has been suggested to maintain safeguards against proliferation. Clearly the non-communist countries are in the middle of widespread public debate on the so-called plutonium economy, and the only point of general agreement is the strong desire to halt the proliferation of nuclear weapons. In the next few years we can expect both national and international debate to continue on the consistency of such aims with the advantages of the use of plutonium as a fuel.

## CIVIL LIBERTIES AND NUCLEAR SAFEGUARDS

39. Some saw the loss of civil liberties as a consequence of the security measures that would accompany nuclear power generation in New Zealand. This contention seemed sometimes to have a more emotional than rational basis. Though affected by a genuine disquiet, many of those who used it could not state precisely what civil liberty of the ordinary citizen would be endangered if nuclear power were to be introduced. The position was more clearly outlined to us in London by representatives of the Friends of the Earth who contended that loss of civil liberties was not brought about by nuclear power *per se*, or by the present nuclear programme. They expected, though, that an advanced nuclear programme involving the extensive use of plutonium would inevitably necessitate a safeguard system which would bring about a hard attitude on the part of the law-enforcement agencies. Methods employed in some countries to combat the drug traffic (such as the use of informers and infiltrators, telephone tapping, opening mail, and forced entry to premises) were expected to be used to a much greater extent to safeguard the plutonium. The need for the quick recovery of stolen nuclear fuel would tend to force the authorities to employ shortcuts in methods of search and interrogation, so that some civil liberties would almost certainly be violated.

40. These dangers may well be real, and we can see that, given certain circumstances, an insidious growth in the use of surveillance methods usually associated with a police state could happen. The growth of anarchy and a widespread disregard for the rule of law, both within nations and in international relations, would bring about conditions conducive to nuclear blackmail. The beleaguered civil authorities and governments would probably have to enforce rigid security measures in nuclear plants where plutonium was used or stored. The scenario postulated by the Friends of the Earth could in these circumstances become a reality. However, in these conditions, nuclear blackmail is but one form of terrorist weaponry, and to combat other more conventional threats, repressive measures could also be used. We consider that although the presence of plutonium might aggravate a lawless situation (which is by no means certain to arise), it would not bring one about.

41. New Zealand, if it introduced nuclear power, would be required under the NPT to ensure the safety of its nuclear materials, by guaranteeing that: unauthorised persons were unable to gain access to and remove nuclear material; there was an effective surveillance system to forestall removal of nuclear material; and quantities and movements of nuclear materials were meticulously recorded. (The records would be subject to inspection by IAEA officers.)

42. There was concern at the possibility of guards being armed thereby creating a state of affairs which, although possibly commonplace elsewhere, is foreign to New Zealand custom. The enacting in June 1977 of the Atomic Energy (Special Constables) Bill in Britain was seen as the pattern New Zealand might follow in the event of starting a nuclear power programme. The Act allows guards on nuclear facilities to carry firearms without obtaining individual firearms certificates as civil police must. The special constables are also now permitted to exercise their powers when guarding nuclear material in transit or pursuing persons suspected of removing or attempting to remove nuclear material unlawfully. In our visits to nuclear installations in Britain we did not see any use of security measures that gave us offence.

43. The contention that guards, armed or unarmed, at electricity generating plants would be the first step on the way to a police state is, we think, exaggerated. But we can see that such conditions might produce a feeling of disquiet in some people in our relatively open society. There are regrettably some other aspects of our society which, following overseas trends, have more reason to cause us concern than the guarding of power stations.

# *Chapter 11.* HEALTH CONSEQUENCES

## INTRODUCTION

1. There is much scientific literature about the effects of ionising radiation on living tissue, a survey of which is given in the report of the FFGNP, and summaries in the Flowers, and Ford Foundation - MITRE reports. We do not intend to repeat the material given in these accessible general accounts.

2. Some lay people and organisations appearing before us were apprehensive about the possible effects on man of radiation produced even in the routine working of a nuclear power programme. There were also marked differences of opinion among some scientists and some medical witnesses, especially on the genetic effects of ionising radiation. The differences are an indication of the uncertainties in some areas of radiobiology.

3. Though not competent to resolve these uncertainties, we spent many hours discussing them, and consider that we must at least describe the contentious issues, and show where the differences of opinion lie. This chapter is not intended to be a complete survey of the biological effects of ionising radiation. It aims rather to give the background to the most important matters raised before us, and the essence of the public debate that took place before us.

4. Quantitative analyses of the effects on health of the nuclear power industry must be assessed by comparing them with corresponding effects from alternative energy sources. In such assessments, data should be treated equivalently, that is, for equal energy output, and for the complete cycle of operation.

### *Units of Absorbed Radiation*

5. A short account of the radiation process has been given in chapter 4. We introduce here the physical units used to express the amount of radiation absorbed in irradiated tissue. When radiation penetrates tissue it gives up its energy through a series of collisions with the material of the tissue. The amount of energy deposited in relation to the mass of tissue is used as a measure of the intensity of the radiation. The unit of absorbed radiation dose (the *rad*) is defined as the quantity of radiation which would cause 1 kg of material to absorb 0.01 joules.

6. Different kinds of radiation cause differing amounts of biological damage for the same amount of energy deposited. The relative biological effectiveness of radiation depends also on the nature of the tissue being irradiated. The unit of biological dose is the *rem* which is defined as the product of the radiation dose in rads and the relative biological effectiveness of the radiation. In practice only the effects of different types of radiation are taken into account. The radiation dose in rads is multiplied by a quality factor to give a dose equivalent in rems. The quality factor is taken as 1 for beta, gamma, and X-rays, and as 10 for alpha and fast neutron radiation. Dose equivalent in rems (or millirems) is the appropriate measure when considering the health effects of radiation.

## NATURAL AND MAN-MADE RADIATION

7. There is a natural background radiation which affects us all. If nuclear power came to New Zealand, any radiation from the reactor would merely be an addition to this, and would come from the small amounts of liquid and gaseous effluent released during normal operation. Large amounts of radioactive effluent could be emitted only in the unlikely event of a reactor accident breaching the containment. Chapter 12 discusses such dangers.

8. The background radiation is made up of cosmic radiation from space, terrestrial radiation present in the earth and air (and consequently in material used for building), and internal radiation derived from radionuclides present in body constituents. The dose rate from cosmic radiation depends mainly on altitude, and has its least value at sea level at the equator where it is about 28 millirems per annum. It is a little greater at the poles, and much greater with altitude, being about 60 mrems per annum at 1000 metres above sea level. The main source of internal radiation is potassium-40 which contributes an annual dose of about 20 mrems. Terrestrial radiation varies considerably from place to place. Table 11.1 shows variations, largely due to building materials, in various places around Wellington.

*Table 11.1*

### TERRESTRIAL GAMMA-RAY BACKGROUND IN VARIOUS LOCATIONS IN WELLINGTON

(*Source:* FFGNP report)

| Place | Annual Dose/mrem |
|---|---|
| Inside an electric unit (train), Upper Hutt line ... ... | 44 |
| Inside a wooden house, Waterloo, Lower Hutt ... ... | 88 |
| Inside a brick-veneer house, Waterloo, Lower Hutt ... | 120 |
| Kelburn Park, Wellington ... ... ... ... | 105–130 |
| Reserve Bank, Wellington (9th floor) ... ... ... | 114 |
| Wellington Railway Station, platform 3 ... ... ... | 123 |
| Wellington Railway Station, main foyer ... ... ... | 193 |
| Rutherford House (Electricity Department) 2nd floor ... | 175 |
| Lambton Quay, Wellington ... ... ... ... | 175–260 |
| Archway at rear of Parliament Buildings ... ... ... | 280 |

9. Besides background radiation, additional doses may be received from medical and dental X-rays, and other man-made sources, including radiation from wrist watches, TV, and global fall out from past bomb tests. Nuclear weapons testing up to 1971 has been estimated to commit New Zealand residents to a dose of about 60 mrems to the year 2000. This is about half the average dose commitment in the northern hemisphere. Professor B. G. Wybourne quoted the following typical doses from man-made sources.

*Table 11.2*

## RADIATION EXPOSURE OF NEW ZEALAND RESIDENTS

(*Source:* FFGNP report)

| Source of Radiation | Average Annual Dose/mrem |
|---|---|
| Natural radiation … … … … … | 120 |
| Medical irradiation … … … … | 14* |
| Occupational exposure … … … … | 0.07* |
| Other man-made and miscellaneous radiation … … | 3 |

*Indicates genetically significant dose (GSD)

10. These levels, especially those due to medical sources, would vary greatly. Each chest X-ray over and above the average would add about another 100 mrems. The effects of the extra radiation dose that people would have to accept from a nuclear power programme should be evaluated by comparing them with those of background radiation from which there is no escape.

11. There appears to be no dispute that the radiation exposure of workers in the nuclear power industry is generally kept to doses well within limits recommended by the International Commission on Radiological Protection (ICRP). The World Health Organisation (WHO) has reported that even high average radiation exposures locally and globally from nuclear power are low compared with those from natural sources or medical practices. However, the annual collective radiation dose of inspection, maintenance, and repair workers in nuclear plants is greater than that of the general population. The New Zealand Medical Association accepted that though a normally functioning nuclear power generator produces much radioactive material, the largest part is contained within the reactor (92). It concluded that if the discharged part is kept within specified limits, the added increment of absorbed radiation dose would be clearly within limits of public acceptability.

## THE EFFECTS OF IONISING RADIATION ON CELLS

12. Living tissue consists of cells, many of which can divide and so reproduce themselves. The FFGNP report describes how ionising radiation changes the large organic molecules on which the cell functioning depends (4). Very high doses can kill a cell. A single dose of 320 rads to the whole human body has a probability of 1 percent of causing death within a year, while a similar dose of 750 rads has a 99.9 percent probability. The main cause of death is damage to the bone marrow which stops new blood cells from forming. Cells are more likely to be damaged if irradiated while they are growing and dividing. Thus foetuses and young children are much more sensitive to radiation damage than adults.

13. Sub-lethal irradiation may cause cells to divide abnormally or may stop them dividing. A radiation dose received all at once more effectively produces cell damage than if it is given in a series of small doses, or given slowly over a long time. Repair mechanisms may heal some of the damage. Damage to ordinary human body cells may show as a cancer years after irradiation. In reproductive cells radiation may damage the

genes in the chromosomes, and thus affect offspring. The changes, from mild to lethal, may be dominant and appear in the first generation of descendants, or they may be recessive and appear only possibly in future generations.

### *Genetic Effects*

14. The genetic effects of ionising radiation have been studied in simple organisms (for example, in the fruit fly, *Drosophila*-species), and have been produced in laboratory animals (usually mice). There are no quantitative data of genetic damage to man by radiation. Children born to the Hiroshima and Nagasaki survivors who had received doses averaging 100 rads showed no observable genetic effects. However, it is not assumed that man is immune from genetic damage, for 6 percent of all live human births have some sort of hereditary disease. Studies are complicated by the great variety of mutation types, the variation of genetic diseases which may range from the invisible to the conspicuous or from the trivial to the lethal. Some may show up in the first generation, but some may appear later and persist for tens of generations.

15. The genetic effects of a given radiation dose must be indirectly estimated, and such estimates are thus most uncertain. Human response to dose is not known. It is assumed that there is no radiation level below which there are no genetic effects, and also that doubling the radiation dose will double the genetic damage. The WHO working group pointed out that present estimates of radiation-induced genetic effects were based on experimental data from small animals mainly exposed to low dose rates. The data analysed supported the concept of linearity in the dose range, and did not indicate the presence of a threshold dose.

16. An assessment of the genetic damage from a single radiation dose is based on experiments on animal germ cells. The number and type of mutations in genes or chromosomes are analysed, or an estimate may be made of the dose needed to double the naturally occurring genetic effects. The aim is to estimate the number of genetic diseases likely to be caused in the first and subsequent generations from exposing the population to a given radiation dose.

17. The Flowers report in discussing the mutagenic properties of radiation pointed out that the risk of genetic mutations from man-made radiation must be seen in relation to those from natural sources. Genetic mutations which take place all the time are a mechanism whereby a species can adapt and survive in a changing environment. However, for every beneficial mutation there are many that are harmful, but the evolutionary process would usually eliminate harmful mutants from the gene pool of the species. The report concluded that, as the allowable radiation levels from the nuclear power industry were such as to keep the somatic effects at a low level, the genetic effects should be of little concern. It is unlikely that they could be observed.

18. However, we heard argument that the following three points (better medical care preserving human mutations; the genetic effects of carbon-14; the risk of creating a harmful mutant micro-organism) could make the mutagenic effects much more damaging than the Flowers report tended to reveal.

### *Better Medical Care and Human Mutation*

19. Because of the much higher standards of medical care *any* additional human mutations would now tend to be preserved where as formerly they would have died. Dr E. Geiringer and Professor D. W. Beaven submitted that any increase (however small) in ionising radiation is therefore likely to be harmful and should be resisted (104, 105).

20. The Advisory Committee on the Biological Effects of Ionising Radiation (BEIR) estimated that only 3 percent of inherited genetic disease is caused by background ionising radiation. The remaining 97 percent is attributed to other natural causes such as heat, or chemical mutagens (106). Dr H. C. Sutton (*Evidence*, p. 2179) has also estimated that, if by the year 2000 half the world's electricity came from nuclear power, the additional public radiation dose from that source might rise by then to 3 percent of that due to natural causes.

21. We conclude on the evidence given us that nuclear power is unlikely to add to the human mutation rate, a view accepted by the Flowers report. Some submissions, however, rejected it, because of the complicated nature of genetics, and the great uncertainties in the calculations, and statements of the various expert committees—calculations which are only best *present* estimates and which must change in the light of more exact knowledge. The suggestion that any ionising radiation additional to background may cause damage which would not be eliminated from the gene pool of our society seems to us to need investigation. We have no measure of the magnitude of this effect.

22. Unless the estimates produced by BEIR and the Flowers report are wrong by a factor of 10, we would agree with the validity of the basic conclusion of the latter that the genetic effects of a nuclear power programme are of little consequence.

### *Genetic Effects of Carbon-14*

23. Dr E. Geiringer contended that the genetic effects of a nuclear power programme had been further underestimated because of the properties of the radioactive isotope carbon-14, formed in the routine operation of nuclear power stations (*Evidence*, p. 415). It can replace the non-radioactive isotope carbon-12 in atmospheric carbon dioxide and in the cells of the body. Carbon-14 emits beta radiation which has a range of a few cell diameters and decays to nitrogen, emitting energy. Thus, if changes to carbon-14 take place in the molecules of genes and chromosomes, mutation could result from both the beta radiation and the transformation of the carbon to nitrogen. The question is whether the effect of this transformation is greater than that of beta radiation from either inside or outside the cell.

24. Experimental studies to measure the comparable size of these two effects have dealt mainly with carbon-14 decay in chromosomes of bacteria and of plant cells. They have shown (but with great uncertainty) that the effects from chemical transformation are greater by factors of between 2 and 5 than those from beta-ray ionisation (107).

25. The few experimental data from larger organisms give contradictory results. Where the overall size of the tissue exceeds the range of the beta radiation, a beta ray which passes through one cell without causing damage has the chance of bringing about ionisation in one of its neighbours. Thus ionising effects are greatly increased, while those of transformation are unaltered. Although there is no absolute certainty, it is

reasonable to conclude (as the IAEA does) that the effects on human health and genetics from atmospheric carbon-14 are mainly due to beta rays from its decay. We were given no compelling evidence to refute this view.

26. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Council for Radiation Protection and Measurement (NCRP) in the United States have estimated the annual human dose from atmospheric carbon-14: 0.7 mrem per annum to the gonads and 1 mrem per annum to the whole body. The background radiation is about 100 mrems per annum (107). These figures which we accept as the best available estimates, show that even a doubling of the carbon-14 in the atmosphere would bring about only a very small increase in the dose to the population.

### *Mutant Micro-organisms*

27. Dr Geiringer spoke of the likelihood of a mutant and damaging form of micro-organism arising from man-made radiation, particularly from the nuclear power industry (*Evidence*, p. 287). He warned that nuclear technology was likely to bring into circulation increasing numbers and concentrations of new radioactive elements, the biological effects of which are as yet uncharted. We asked the DSIR to refer the matter to the British Medical Research Council. Dr R. H. Mole, Director of its Radiobiology Unit at Harwell, writing in a personal capacity, made the following points (108):

(a) Micro-organisms are less mutable than mammals for the same level of radiation dose, and the mutation rate after exposure to background radiation will be relatively low.

(b) There is no evidence of mutation having converted a known non-pathogenic organism into a pathogenic.

(c) Micro-organisms in the cooling gas or cooling water of a reactor are kept to a minimum so that the likelihood of exposure is greater in the natural environment than in a reactor.

(d) One action of ionising radiation is to prevent the micro-organism from dividing. High-level exposures to radiation are self-protecting.

(e) Micro-organisms have existed and multiplied since life began to evolve.

(f) It is probable that a mutagenic agent can only cause to happen something which has previously occurred "spontaneously". Past mutations which have not survived to the present must be biologically inferior. Similar present or future mutations would disappear for the same reason.

28. The Department of Health was asked about the likelihood of a mutant and detrimental form of micro-organism arising from man-made radiation, including that from nuclear power. Its conclusions were essentially similar to those of Dr Mole:

> Any alteration in mutation rates of micro-organisms as a result of the nuclear power industry will be extremely small, and cannot be regarded as a health hazard to man or other species (109).

Dr Geiringer contested the basis of the department's conclusions in his cross-examination (*Evidence*, pp. 2123–2148).

29. Professor D. W. Beaven also doubted whether mankind should in the future carry an increasing rate of harmful mutation.

> . . . as a person generally concerned with the healing services, one must raise the real question as to whether any increased ionising radiation, however small, should be accepted with equanimity in view of the likely increase in radioactivity currently being yearly added to the gene pool as a result of the necessary diagnostic investigations being carried out by the medical profession. . . (105)

30. In spite of uncertainties in radiobiology, and issues raised above, we do not see any adequate reasons for not accepting the conclusions of the Flowers report that: "At the levels of radiation likely to be permitted in relation to possible somatic effects, the genetic effects should be of little concern". We found the interplay of argument on the possible significance of irradiation from nuclear power sources highly interesting. However, some of the contentions seemed to lack objectivity. It is known that several agencies other than ionising radiation induce among micro-organisms and viruses an inherent tendency to mutate. No one chose to describe the general situation, and show irradiation relative to other mutagenic agents likely to be working within man's contemporary environment.

### *Somatic Effects*

31. Besides causing damage to human reproductive cells, ionising radiation may also bring about changes in the non-reproductive or somatic cells. The changes may occur soon after the cells are irradiated ("prompt" changes) or they may be "delayed", not appearing for years or even decades. The delayed changes appear as cancers of various types, and the cancer-inducing effects of high sub-lethal doses of radiation are fairly well established. Information has come from the study of the Japanese atomic-bomb victims, from the after effects of massive medical X-rays, and from experiments on animals. It was found that the incidence of cancer increased with radiation dose and in some cases was approximately proportional to the dose.

32. There are considerable uncertainties in the cancer-inducing properties of small radiation doses. Information on the effects of doses likely to be caused by the normal operation of a nuclear power station is hard, if not impossible, to obtain, for two main reasons: first, delayed radiation-induced cancers are no different from natural cancers; and, second, the number of cancers induced by radiation additional to the background is small, and fewer than the variation in the annual numbers of natural cancers. The existence of extra cancers can thus be established only by statistical means needing very large data samples to get useful results.

33. The possibility that doses below some threshold value may have no carcinogenic effect brings in further uncertainties. There is also some evidence from animal experiments that radiation given continuously or in several discrete doses is less carcinogenic than if a single dose is given within a short period. It is usually assumed that the incidence of cancer from radiation is directly proportional to the size of the dose down to zero, and is independent of the rate at which the dose is received. Although there are many uncertainties in this procedure, it is generally agreed that it leads to overestimation of results.

34. BEIR, UNSCEAR, NRCP, and the ICRP have all interpreted the available data (mainly on high dosage) to establish a relation between dose and death from cancer. The best estimate is that a dose of 1 rem to each of a million people would result in 165 lethal cancers of all forms.

Uncertainties in the calculations give a range of cancer deaths from 88 to 440. Thus in New Zealand one would expect about 50 cancers a year from natural background radiation of 0.1 rem per year. The DSIR estimates a New Zealand incidence (excluding radiation workers) in the year 2000 as 0.15 a year or one in 7 years from a world-wide nuclear power operation of 4300 GW giving a dose of 0.3 mrem a year (44). In 1973, 4700 New Zealanders died of cancer according to the official Yearbook for 1976.

35. The New Zealand Medical Association also thought that the induction of cancer was the only significant effect that needed to be considered at low levels of radiation (92). The association considered that large doses of radiation leading to prompt deaths were unlikely to be met with. It concluded that if a normally functioning reactor were to be operated to the safety standards already achievable, then the added increment of radiation received by the public would be within limits already acceptable by most people.

## PERMITTED LIMITS OF RADIATION EXPOSURE

36. Several national and international bodies (among them the ICRP whose standards are advisory only) have recommended maximum permissible radiation doses for the general public as well as for workers with radiation. In New Zealand the Radiological Advisory Council sets standards which are promulgated in the Radiation Protection Regulations 1973 under the Radiation Protection Act 1965. The National Radiation Laboratory administers the regulations, and has established a service to monitor environmental radioactivity.

37. The FFGNP report discusses the permitted limits of radiation exposure and gives the ICRP summary of dose limits for individuals. The ICRP recommends that workers exposed to radiation should limit their dose of radiation to less than 5000 mrem a year over the whole body, and to prescribed higher dose rates for particular organs. This is 10 times the recommended dose rate for any of the general public. If a worker were to receive the maximum permissible dose rate all his life, it is calculated that his risk of death from cancer would increase from its normal incidence of 1 in 670 to approximately 1 in 430. According to the DSIR the health record in the nuclear industry shows in fact no signs of increased incidence of cancer (44).

38. The DSIR also commented on a contention that present radiation standards are too lenient in view of the "hot particle" theory, which states that if finely dispersed particles emitting alpha radiation are lodged in the lung then the effect of the radiation in the immediate neighbourhood of the particle is more likely to cause cancer than if the same dose was spread uniformly throughout the whole lung (44). The theory applies particularly to finely dispersed particles of plutonium. Supporters of the "hot particle" hypothesis assert that the maximum permissible lung burden should be lowered by a factor of 2000, because, by ICRP standards, allowable doses are supposed to spread over the whole mass of an organ (12). Independent investigations have supported the British Medical Research Council which reported that ". . . there is no evidence that irradiation by 'hot particles' in the lung is markedly more hazardous than the same activity uniformly distributed. . ." (4).

## SURVEILLANCE AND MONITORING OVERSEAS

39. We now summarise what members of the Commission observed overseas in respect of safety surveillance and monitoring of radiation in typical working nuclear plants. At Pickering, Ontario, the plant is entered through one point in the security control office. The whole plant is divided into four zones rated in terms of potential radioactivity. In passing from a high-rated zone to a lower one, a visitor's hands and feet are machine-checked for radioactivity. At Windscale, Cumberland, one enters the chemical area after passing through a clean room where sterile overshoes and a covering garment are put on, together with radiation badge. Hands are washed on leaving the area, and checked by radiation monitor. The medical department at Windscale keeps records of all staff for 30 years including those who have left. Particular attention is given to plutonium contamination which if it occurs, is removed. The whole body is monitored every 6 months by a counter which is extremely sensitive. It can pick up the body burden of naturally occurring radioactive potassium, and even caesium-137 from bomb fall-out. At estuarine stations like Hinkley Point, Somerset, liquid effluent is closely monitored. It has been shown at Hinkley that radiation on the sea shore is unaffected by the liquid effluent.

40. It is interesting to note in this connection that one of the members of the community Liaison Committee at Hinkley has developed a private enterprise, using the water outflow from the nuclear station to rear fish in tanks for commercial sale. The benefits of using low-grade waste heat from nuclear power stations for fish farming have been demonstrated at three of the CEGB Magnox stations. Dr D. J. Groom, Senior Health Physicist (CEGB), said that it has been demonstrated that more than 70 percent of the radioactivity in fish flesh comes from the fish eating contaminated food. The amount taken up directly from the water is small compared with that from the food chain. Trout are fed with special pellets, while they are being reared, so that even though they live in water with an enhanced radioactivity, little of this is transferred to the flesh of the trout. The farmed trout have radioactivity concentrations in their flesh of about an order of magnitude lower than mature fish which have grown up in a natural lake. It has been calculated that a person eating some 35 kg of trout from the fish farm every year would receive less than 2 percent of the ICRP recommended limit for the general public. In this context it is also worth noting that during the Windscale inquiry Mr Justice Parker called for community volunteers to eat fish caught in the Irish Sea and have continual checks on the whole-body counter to determine changes in body levels of caesium-137. This was intended to assess the possibility of harm arising from the low-level liquid effluents from the Windscale plant which are at present being discharged into the sea.

41. The Ford Foundation - MITRE report concluded that there are uncertainties in assessing the effects on health of nuclear power. It stated:

> Some fuel cycle sources of radiation have not been determined precisely and the many environmental and biological pathways to man are not well understood . . . there is still considerable uncertainty about the relationship between radiation and biological effects, such as the incidence of cancer and genetic disease (12).

Later the report said that health risks, potentially involving deaths, injuries, and illness, arise at all stages of the fuel cycle, from uranium mining to plant decommissioning, and concluded that assessments of health effects from nuclear power are complicated by the fact that there has been relatively little operational experience, and data accumulated thus far have been derived from practices that are changing. Despite the large uncertainties, the general conclusion of the report was that, on average, new coal-fuelled power plants in the United States meeting new source standards will probably exact a considerably higher cost in life and health than new nuclear plants. However, both coal and nuclear power plants built in the rest of this century could have much reduced health risks relative to existing plants. This can be accomplished, said the report, in the case of coal plants by limiting sulphur dioxide and other emissions, and in the case of nuclear power plants, by improving siting and safety controls.

# *Chapter 12.* ACCIDENTS AND COMPENSATION

## INTRODUCTION

1. Although commercial nuclear power reactors have had an excellent safety record, most of those opposed to their introduction in New Zealand are concerned with what is seen to be their inherent danger. Dr S. Eklund, Director-General of the IAEA, in discussing reactor safety said:

> In over 1400 reactor-years of commercial power reactor operation no accident leading to a radiation-related disability has occurred—a kind of record that is unparalleled in any other modern large-scale industry. In spite of this record, improved safety features continue to be developed and incorporated in reactors. To help attain a high international standard in the field, member states have supported the IAEA in working out safety codes and guides for thermal power plants (110).

2. This good safety record is not universally accepted as ensuring future safety. Some reckon that the 1400 reactor-years of commercial operation is too short a time for complete confidence. The common association of nuclear power generation with nuclear weapons still continues to influence the public's views on the safety of the nuclear power industry.

3. The industry's high safety standards have led, especially in the open society of the United States, to publicity being given to minor accidents within the plant which in other technologies would not merit public attention. There have also been a few serious accidents within nuclear plants which if they had not been contained could have had serious consequences (111). Proponents of nuclear power see the operating record as indicating that the many safety features designed to cope with accidents are working effectively.

4. The safety record of the commercial nuclear power industry in Britain and the safety organisation and procedures adopted were described to us there by officers of the CEGB. They claimed in October 1977 that since the start of the board's nuclear programme in 1962, no employee or member of the public had been harmed by radiation. We quote a CEGB publication on safety measures:

> The CEGB has a statutory responsibility for the safe operation of its nuclear plant. Additionally, each station is built and operated to the conditions of a nuclear site licence issued by the Health and Safety Executive—the independent Government licensing authority—on the recommendations of its Nuclear Installations Inspectorate (NII).
>
> The Station Manager and his staff have the immediate responsibility for operating the station safely. They have to conform to operating rules and radiological safety rules. The operating rules are drawn up so that the plant is operated in such a way that it will remain safe even under fault conditions. These rules cannot be altered without the sanction of all the experts who have approved them: the NII, senior members of three CEGB Headquarters Departments (Nuclear Health & Safety, Operations, and Research), and the CEGB engineers responsible for power station design and construction. In addition certain maintenance procedures, tests and inspections have to be carried out periodically.

> Neither the reactor nor any safety-related equipment can be modified without examination and agreement from CEGB Headquarters Departments and the NII. A committee for each station, which includes senior experienced staff of the CEGB, the UK Atomic Energy Authority and British Nuclear Fuels Ltd. (BNFL), meets regularly to consider proposals for any modifications to operating procedures, and to receive reports of any problems which might affect safety.
>
> Within the CEGB there is [a] Nuclear Health & Safety Department which is independent of all other parts of the Board's organisation. [It] report[s] directly to the Chairman and Board Members, and the Department is responsible for ensuring that there is adequate provision for safety in the CEGB's nuclear plants, right through from design to operation. We have 55 qualified engineers and scientists. They include a team of inspectors who are based at the nuclear stations and carry out checks of the stations' activities. Safety assessments are also regularly carried out by the NII while the stations are being built and when they are in operation.
>
> Another independent body, the Nuclear Safety Advisory Committee, advises the Government on nuclear safety, particularly in respect of siting policy and basic safety principles. The Committee consists of experienced engineers and scientists from industry and the universities who have no direct responsibility within the nuclear power programme (112).

It is claimed that in no other industry are so much time, expertise, and resources given over to the supervision of safety.

5. There is no disagreement that the consequences of a major reactor accident, with the release of a significant proportion of the radioactive material contained in the core, could be very serious. What we have to attempt here is to put the chances of a serious reactor accident into perspective with other dangers, and see what the consequences of such an accident would be in New Zealand. The basic question to be answered is: "Are the risks to New Zealand of a reactor accident so great that safety should be a main consideration in any decision to forego a nuclear power programme?"

6. No technology (including any kind of electric power generation) is absolutely safe. Risk of death or injury is a price of existence. Modern technological society tries to reduce the risk to what it considers to be acceptable. At this level the risks are assumed to be less than the advantages, which implies a subjective evaluation of what is an acceptable level of risk.

### *Quantification of Risk*

7. To compare risks of various sorts one often makes probability statements about the chances of the accident happening to individuals. For example, the death rate in New Zealand each year from motor vehicle accidents is between 200 and 300 a million of the population. One could say that the individual's probability of death from a motor accident each year is between 200/1 000 000 and 300/1 000 000, and express it as $2 \times 10^{-4}$ to $3 \times 10^{-4}$ a year. Other sorts of risk to the individual can also be quantified from accident statistics. As the FFGNP has noted, public attitudes towards familiar risks are apparently consistent.

> Types of accidents with a death risk of $10^{-3}$ (1/1000) per person per year to the general public are difficult to find. Evidently this level of risk is unacceptable, and when it occurs, immediate action is taken to reduce it.
>
> At an accidental risk level of $10^{-4}$ deaths per person per year, people are less inclined to take concerted action but are willing to spend money to reduce the

> hazard. Money is spent for traffic control, fire departments and fences around dangerous areas . . .
>
> Risks of accidental death at a level of $10^{-5}$ (1/100 000) per person per year are still recognised in an active sense. Parents warn their children about the hazards of drowning, firearms, poisoning etc., and people accept a certain amount of inconvenience to avoid risks at this level . . .
>
> Accidents with a probability of death of $10^{-6}$ (1/1 000 000) or less per person per year are apparently not of great concern to the average person. He is aware of them but feels they will not happen to him . . . Phrases associated with these hazards have an element of resignation: "Act of God" (4).

8. Though this classification may be useful when applied to small events, public reaction is quite different towards accidents involving a large number of people at the one time. New Zealand society appears to be much more tolerant towards 150 drownings a year, than it would be towards an air crash of extremely low probability which killed 150 people.

9. As will be seen later the probability of a major accident involving the public occurring at a nuclear power plant is very small. The consequences may, however, be very serious. Because of this, there are some who consider that the consequences of a major nuclear accident are "unacceptable" no matter how small its predicted probability may be. This attitude was strongly represented to us by the Federation of Labour which said "until such time as the Government through its agencies can prove to us that there is no risk involved then we are not prepared to support nuclear power stations" (*Evidence*, p. 1079).

10. This attitude would seem to imply total opposition to nuclear power generation regardless of the fact that no technology can ever be shown to be absolutely safe. However, the Federation did not consider their stand to be irreversible. It is one which could be reviewed if there were changes in the national economy and employment, or in nuclear technology. At present it seems that the co-operation of the Federation of Labour in a nuclear power programme may be difficult to obtain because of suspect reactor-safety.

11. We noted that organised labour in both the United States and Britain has not seen this issue as a bar to union co-operation in the construction and manning of nuclear power plants. The attitude in the north-eastern United States in particular appears to be that nuclear power is the most promising source of generating electricity in a situation of diminishing alternatives, and that without the necessary electricity, employment prospects would be greatly restricted.

12. The Commission for the Future, in discussing general principles of nuclear safety, concluded that safety standards should be set at a level where the risk, as previously defined, to the general population is no greater than that imposed in everyday life (113).

## FREQUENCY OF ACCIDENTS

13. Almost all of the radioactivity in a nuclear power plant is generated by the fission process in the reactor core. Most of this radioactivity will be retained within the fuel unless the fuel melts, which could happen only if the heat generated by the fission process in the fuel is greater than the heat being removed from the fuel by the cooling system. Such an imbalance can occur in only two ways: first, as a result of surges or transients in which the power generation in the core exceeds the capacity of the heat

removal systems to dissipate it; and second, as a result of a rupture in the reactor cooling-system causing a loss of coolant followed by a failure of the emergency system for cooling the core. Melting of the core does not alone create a risk to the public because it occurs within a massive containment structure. But the molten fuel could slump to the bottom of the reactor vessel and melt through the containment. Depending on the type of reactor it is also possible that the containment could be breached by pressure forces generated by thermal or chemical interaction between the fuel and the coolant.

14. If the containment does fail the radioactivity will escape. The concentration of the airborne radioactive material received by people downwind from the accident, and also that deposited on the ground, is determined by the amount of radioactive material that escapes from the reactor and the meteorological conditions at the time (the speed of the wind and the strength of the stirring or turbulent motions in the air).

15. In normal operation there are occasional controlled releases of radioactivity from nuclear plants. These allowable and carefully controlled emissions have now been reduced to the point where few critics of nuclear power consider them to be an issue of concern. The debate on nuclear safety focusses on the possibility of large accidental releases.

16. An accident releasing a substantial amount of radioactive material cannot happen unless a number of the barriers designed to limit the spread of a malfunction are breached. The safeguards in a reactor system are designed to provide a defence in depth. They comprise:

(a) large safety margins built into components, and replication of control systems to guard against defects in materials, unforeseen natural events, and possible human error;

(b) automatic back-up systems to compensate for failure of essential equipment, or for human error;

(c) the reactor enclosed in a structure designed to contain the radioactivity even if the other barriers fail.

17. The probability of the containment structure being breached with release of radioactive material cannot be estimated from operating experience. The event has never happened, and the number of years of reactor operation is still relatively small. But many of the hardware components in a reactor (valves, switches, and pipes of various sorts) have been used extensively in other technologies. Their operating record and their probability of failure are well known. If one particular component fails, and its failure is followed by a succession of failures of other components, one can postulate a chain effect leading to a release of radioactivity. If the probability of failure of each component in the chain is known, the probability of the event of the final accident occurring is found by multiplying each of the individual probabilities together if the failure of each component is independent of the failures of the others.

18. An accident sequence of four steps, with the probability of each step occurring once in 10 working years (1/10), would have a probability of $(1/10)^4$, or a chance of occurring once in 10 000 years. However, if the first failure was *invariably* followed by the other three, the accident sequence would have a probability of 1/10, a type of failure called "common mode failure".

19. In a nuclear power plant it is possible to identify the accident sequences which would follow the failure of various components. A complete analysis of accidents would require the identification of all

possible accident sequences, and the ability to assign probabilities of failure at each step of each sequence. In some cases engineering experience does not give probabilities of failure, so that a best estimate must be judged, leading to uncertainties in the calculated accident probability.

20. The technique of failure analysis described above was developed in Britain. It has been most publicised and applied most ambitiously in the United States. The AEC there initiated a reactor safety study of commercial LWRs in 1972 to assess nuclear risks realistically and to compare them with non-nuclear risks. The study known as the Rasmussen report (114), published in final form in 1975, is described in the FFGNP report along with various criticisms of it. The full report is a large, highly technical document which has been described as "virtually impenetrable to all but the professional reader" (115). As it was often referred to during our inquiry, we give here a brief account of its results, and of some of the criticism it gave rise to.

21. As explained above, there cannot be an accident in which a substantial amount of radioactivity is released without breaching a series of barriers, designed to limit the propagation of a malfunction. To calculate the total probability of a release of radioactivity, the probability of an initiating event for all possible routes to a release is multiplied by the probability that every safety barrier on those routes is breached or bypassed. The product of the probabilities for each accident route are added up for all possible routes to the release.

22. In analysing BWRs and PWRs the Rasmussen report considered a range of accidents increasing from those giving relatively small releases of radioactivity to those releasing a large part of the isotopes in the reactor core. Briefly, it showed that the probability that the core would melt accompanied by a breach of containment in the present generation of LWRs is $5 \times 10^{-5}$ per reactor year, but that only 10 percent of these meltdowns are estimated to lead to substantial radioactivity releases after a containment breach (12). Thus, the Rasmussen study implies that the probability of a serious accident leading to a release of radioactivity is 1 in 200 000 for each LWR a year.

23. The Rasmussen techniques give in theory a logical basis for systematically analysing and quantifying risk. In practice there are serious problems. The American Physical Society (116), the United States Environmental Protection Agency (118), and the Union of Concerned Scientists (117) have criticised the report. These criticisms were quoted to us by Ecology Action (Otago), Friends of the Earth, and others (2, 3). We were informed while overseas that further studies are at present being made into the validity of the assumptions on which the report is based.

24. The Ford Foundation - MITRE report considered the following were the main technical deficiencies in the methods used:

(a) unknown or unsuspected failure mechanisms cannot be included in the analysis;

(b) the final answers are the result of the assigned probabilities at each of the branch points, and though these can sometimes be based on experience, they must at times be founded on judgment;

(c) the probabilities of breaching each safety barrier are not necessarily independent since common mode failures can increase the likelihood of failure of one barrier once another has been penetrated. Unless the physical mechanism coupling the supposedly independent barriers is understood, the probability of such common mode failure is uncertain; and

(d) the various probabilities may be correlated in different ways for different reactors over which safety predictions are averaged.

The Rasmussen report was also criticised by the American Physical Society for an inadequate treatment of the effects of earthquakes on nuclear plants (116). Although the criticisms appear to be valid, some of them are impossible to quantify so cannot be used to refine the estimates of probability given by Rasmussen.

25. In New Zealand estimating the effects of earthquakes on reactor safety is undoubtedly an important consideration. The Rasmussen report deals with the effects of earthquakes on the probability of LWR accidents occurring in the eastern United States. Its conclusions cannot be applied to New Zealand unless the differences in seismic risk are taken into account. The Rasmussen report assumed a reactor designed for a safe shut-down earthquake (SSE) of 0.2 g. An SSE is an earthquake which produces ground motion for which the structures, systems, and components important to safety are designed to remain functional. The report concluded that accidents induced by earthquake should not contribute significantly to reactor accident risks.

26. The MWD has applied the Rasmussen methods to an LWR situated in the central region of New Zealand and designed for a SSE of 0.67 g. They found that the probability of a core melt as a result of an earthquake was $10^{-6}$ per reactor year. This is 10 times higher than the United States figure, even though the earthquake is only three times as great (56). The ministry concluded that:

> The level of risk in the New Zealand study may be deemed acceptable. The WASH-1400 (Rasmussen) estimate of probability of core melt from all causes is $5 \times 10^{-5}$ per reactor per year. So although the estimated contribution of earthquakes in NZ is greater than that derived in WASH-1400 it is still a small contribution to the total; it raises it from $5 \times 10^{-5}$ to $5.1 \times 10^{-5}$ per reactor per year.

27. The risks to reactors could be reduced in New Zealand by restricting them to less earthquake-prone areas, or by the careful selection of sites where conditions would tend to reduce the ground response to earthquake excitation. These aspects, and engineering protection serving to reduce the risk, are referred to also in chapter 9.

28. The FFGNP said about the Rasmussen report and its various criticisms:

> Although the Reactor Safety Study [Rasmussen Report] estimates of accident probability are not accepted by all authorities, it seems unlikely that they will prove incorrect by a factor of more than ten and there is fairly general agreement, again within a factor of ten, concerning the likely quantities of radionuclides which might be released in a severe reactor accident with breach of containment.

We fully agree with the FFGNP's summing up:

> It is clear that it is not sensible to accept completely or to reject outright the probability estimates and bounds [for core-melt accidents in Commercial Power Reactors] given in table 4 (iii). They can be used for taking a first step towards reaching a numerical (as distinct from a qualitative or subjective) assessment of the public risk in an overall value judgment of the costs that could offset any benefits from the introduction of nuclear power in New Zealand.

Similar probability techniques for analysing reactor safety have been used in other countries.

29. Britain adopts the pragmatic approach of assigning an upper limit to acceptable public risks, and then by means of quality assurance, engineering standards, reactor licensing, inspection, and control ensures that these risks are not exceeded (103). This is done for individual sites and reactors. The overall policy of the Health and Safety Executive has already been given in chapter 4. A comparison of the results obtained by these methods with those from the Rasmussen analysis appears to show reasonable agreement.

30. Many of those taking part in our inquiry clearly did not like having to base safety to the community on a theory of probability. The PSA, for example, expressed distrust of probability methods and their application to safety analysis (119). This attitude is understandable, especially as specific data on occurrences in nuclear power are still of limited scope and range. We commend the attitude of Friends of the Earth who, though highly critical of many aspects of the Rasmussen study, were able to conclude:

> With these reservations in mind, we nevertheless accept the RSS [Rasmussen report] as a valuable contribution to investigations of reactor safety. We do not believe it proves the safety of LWR's, nor do we believe that this claim is even made in the main report (2).

31. In the attempt to put the risk of a serious nuclear accident into some sort of perspective, comparisons have been made with the risks associated with catastrophes caused by man (air crashes, dam failures) and nature (earthquakes, hurricanes). Sir John Hill, Chairman of the UKAEA, said of nuclear reactor safety:

> Over a period of perhaps 5 years detailed comparisons with other hazards of an industrialised society have shown that tanks of chlorine or ammonia or liquefied petroleum gas, aircraft flying over football matches and large dams pose risks of equal magnitude and much higher probability (120).

## ACCIDENT CONSEQUENCES

32. The consequences to the public of a hypothetical serious reactor accident have been the subject of considerable scientific and lay disagreement. The estimates of casualties and damage range from the sensational predictions of R. Nader who said: "[A nuclear accident would result in] up to 100 000 deaths and the destruction of an area the size of Pennsylvania" (121), to the less alarming estimates of the Rasmussen report. There are many uncertainties in assessing consequences. Science does not completely understand the physical and biological problems involved, and the consequences in a particular situation are critically dependent on siting, and on the weather at the time of the accident.

33. A serious accident leading to a breach of the containment vessel would be likely to cause immediate deaths, and some delayed deaths from latent cancers spread over about 30 years. The probability of a cancer developing depends on the magnitude of the radiation dose and to a large extent the age of the person exposed. In a real sense radiation emitters are carcinogens, their effect being little different from similarly classified chemical compounds. The actual consequences of a reactor accident would depend on:

(a) the fraction of isotopes of the fission product released from the core;
(b) the diffusive properties of the atmosphere at the time determining the concentration of the radioactive cloud;

(c) the population density and land use downwind of the reactor; and
(d) the effectiveness of civil defence in evacuating people, warning people to stay indoors, or dispensing iodine tablets as a precaution against thyroid cancer.

34. The Rasmussen report considered a number of accidents giving a spectrum of releases ranging from small to large fractions of the volatile fission product isotopes in the core. The consequences of an extremely serious accident in typical United States population densities and average weather conditions as found by the Rasmussen report are given in table 12.1.

*Table 12.1*

CONSEQUENCES OF AN EXTREMELY SERIOUS ACCIDENT

(*Source:* Ford Foundation - MITRE report, p. 224)

| | Rate per Annum | Assumed Total |
|---|---|---|
| Prompt fatalities | – | 3 300 |
| Early illness | – | 45 000 |
| Thyroid nodules | 8 000 | 240 000 (30 years) |
| Latent cancer fatalities | 1 500 | 45 000 (30 years) |
| Genetic defects | 200 | 30 000 (150 years) |
| Economic loss due to contamination | | US$14 billion |
| Decontamination area | | 3200 square miles |

35. The Ford Foundation - MITRE report said about such consequences:

> The natural decontamination time for caesium-137, the principal source of ground contamination is three to five years. It is difficult to predict how many individuals would leave their homes for extended periods to reduce their chance of eventually dying of cancer. If land contaminated in excess of current standards for permissible concentrations of caesium-137 is withdrawn from use, the economic cost is estimated in WASH-1400 [Rasmussen report] at $14 billion for the accident considered. The figure depends not only on land values but on the use of contaminated land and the effectiveness of decontamination procedures not yet developed.

It must be stressed that the catastrophe described has an extremely small chance of happening, and that the fatalities and damage listed in table 12.1 would occur only in unfavourable weather and with a large exposed population. Rasmussen gave the probability of these conditions as $5 \times 10^{-9}$ per reactor year.

36. The principles used in deriving this result have been criticised. Many hold it to be an underestimation. The United States Environmental Protection Agency believed that the study understated the risk by something between one hundred and several hundred because health effects as well as probabilities of releases were underestimated (118). The Ford Foundation - MITRE report appears to arrive at much the same conclusion by taking a pessimistic view of possible accident sequences. It also stressed that the estimates apply to "average" conditions, and so cannot be applied to a particular site because consequences could differ considerably from place to place and from time to time. In spite of this the report concluded that the risks associated with nuclear accidents were acceptable in United States conditions since the average rate of loss from nuclear accidents compared favourably with that from the competing fossil-fuel technology. As the result of 20 years' experience with nuclear power, the British Government does not see doubts about reactor safety as hindering the siting of future commercial reactors near cities or towns. As the Flowers report says: "The safety of the public is considered to derive more from high standards in the design, construction and operation of nuclear power stations than from remote siting".

## ACCIDENT CONSEQUENCES AND NEW ZEALAND

37. When the Rasmussen analysis is applied to New Zealand, obvious differences from the United States must be taken into account. We have fewer people; a nuclear reactor would almost certainly be built on the coast. Careful siting could greatly reduce the chances of released radioactive material being blown towards a sensitive area. As the Rasmussen report applies to average United States conditions, its results cannot be transferred directly to a specific New Zealand situation. The actual conditions of any particular site would have to be independently surveyed for safety, using probability techniques.

38. A serious reactor accident in New Zealand besides killing people could conceivably contaminate large areas of farmland, with the possible loss for years of a substantial part of our primary produce. The contamination of pasture and hence of milk by the isotope iodine-131 would be the most immediate and widespread agricultural effect. Restrictions on the use of milk from the contaminated area would probably last less than 2 months. One season's grain and vegetable crops might be made valueless over a more limited area mainly by iodine-131 but also by other radioactive products. Caesium-137 (half life 30 years) and caesium-134 (half life 2 years) would produce the greatest risk from long-term contamination of the ground. Their entry into animals and milk is greatest in the first year after release because of the direct contamination of foliage. Once caesium enters the soil, its entry to plants through the roots is much slower, except in soils low in potassium such as those found in Taranaki. Thus the concentrations in dairy products, beef, and mutton in the first few years after an accidental release, would be much higher in Taranaki (and somewhat higher in the Waikato) than they would be in the South Island.

39. The DSIR has analysed the occupational and agricultural restrictions applied after the release of radioactive materials in reactor accidents (44), and the FFGNP report has summarised related material. Casualty figures and agricultural damage produced by a very serious reactor accident cannot be confidently estimated. We fully agree with the FFGNP's qualitative estimate of the consequences:

> It is clear that in the worst possible circumstances in which a major accident as defined occurred when the wind was blowing gently onshore towards a major population centre and highly productive farm land, the personal, social and economic consequences for N.Z. could be disastrous to a degree unparalleled in our history.

One can imagine other catastrophes in New Zealand which would also have consequences unparalleled in our history. A severe earthquake in one of the main centres, volcanic eruptions in the central North Island or in Auckland, dam failures on the Waikato River could all produce disastrous social and economic effects.

40. Deaths from latent cancers for many years after a nuclear accident make comparisons with some other dangers not strictly valid. However, we think it valid to compare the risks of nuclear power with those of other methods of electricity generation. It has been claimed in Britain and in the United States that the risks to employees in a reactor programme are well below those in normal manufacturing industry (122, 123). Mr. I. D. Dick, Secretary of Mines, drew attention to the loss of human life in New Zealand associated with coal mining:

> To supply the coal necessary for one coal-fired power station to replace a nuclear station would require the underground mining of about 3 million tons of coal a year for 30 years. Over this period 20 men would certainly be killed; the probable number of lives lost would be about 50; the maximum credible disaster would be 3–500 lives lost. These figures are not hypothetical; they are regrettably based on hard, operational results (52).

41. The indications are then that under normal operations nuclear power production poses no threat to the general public, and less risk to employees than other kinds of energy production. This was emphasised through our own observations at Peach Bottom (United States), Pickering (Canada), and Oldbury, Hinkley Point, and Heysham (Britain). For any recommendations on a nuclear programme in New Zealand, the emphasis on safety should be based on the likelihood of a serious reactor accident which has a very low chance of happening. The FFGNP was definite on the matter:

> Although the likelihood of such a [major reactor] accident occurring is considered to be very small, we find the magnitude of the possible effects so great as to constitute a major factor to be considered in any decision regarding the acceptability of a nuclear power programme in this country.

42. The evidence we have heard demonstrates that the consequences of the rare serious accident depend on siting and weather. Thus careful selection of a site for a reactor in New Zealand could minimise considerably the consequences of the rare accident. A conclusion of the Flowers report gives an emphasis to safety matters which appears to us to be reasonable:

> The risk of a serious accident in a single reactor is extremely small; the hazards posed by reactor accidents are not unique in scale nor of such a kind as to suggest that nuclear power should be abandoned for this reason alone.

The Ford Foundation - MITRE report, in deciding whether the risks of nuclear accidents were acceptable, also concluded:

1. On a predicted average rate of loss basis nuclear power compares favourably with competing technologies.
2. The health and property consequences of a single extremely serious accident would not be out of line with other peacetime catastrophes that our society has been able to handle.
3. Despite large uncertainties, a reasonable upper limit or ceiling that is not in itself unacceptable, can be placed on the probability of the class of extremely serious accidents.

43. It should be stressed that the confidence of both the Flowers and Ford Foundation - MITRE reports in reactor safety is based on the nuclear industry's very high standards of technical expertise in design, operation, and maintenance. Mr G. G. Page claimed that New Zealand is lacking in some of these skills not only in the nuclear field, which is to be expected, but in quality-assurance techniques in basic engineering (124). Although safety considerations must be given the highest importance in deciding on the introduction of nuclear power in New Zealand, we believe that, if overseas standards of quality control and engineering practice can be guaranteed here, safety should not be a major stumbling block to a nuclear power programme. However, the successful adoption of a nuclear power programme in our society depends on the majority accepting it. This could be ensured only by informing the public on safety matters as fully as possible (see chapter 5).

## COMPENSATION AND INSURANCE

44. In the early years of the commercial use of nuclear power, it became clear that the development of the industry would be severely restricted, if not stopped, unless limits were put on the liability of the operator of a nuclear installation for damage suffered by injury to person or losses to property. The technology was new and its safety unproven. There were few installations—too few to give that spread of risk which is the essential base for normal commercial insurance. Though the likelihood of any major accident in a nuclear power plant was regarded as being extremely small, the possibility could not be disregarded. Its likely consequences in terms of the potential liability of the operator were recognised as major in scope but difficult to quantify in its upper limits (125).

45. The main concerns of an operator of a nuclear power plant for insurance relate to: (a) the buildings, machinery, equipment, etc., comprising the plant; and (b) the potential legal liability to those who may suffer death or bodily injury, or property losses, as the result of the escape of radioactivity from the power station. The risk of damage to the buildings and plant could be quantified and insured. It was the potential liability to others that created the need for unique provisions which came to be regarded as an acceptable prerequisite to developing nuclear power in western countries: indeed, a unique law for a unique technological development. There were two further special aspects of nuclear insurance: first, the fact that personal injury caused by radioactive contamination might not become apparent for a long time after the exposure (126), and second, that damage or loss could conceivably spread over national boundaries (125). Especially in Europe the nearness of neighbouring countries was a strong incentive to developing a co-ordinated policy on liability to those suffering loss or injury.

46. Action was both positive and quick. In 1960 the Paris Convention on Third Party Liability in the Field of Nuclear Energy, was signed by Britain, France, the Federal Republic of Germany, Italy, Belgium, and most other west European countries (127). The IAEA later organised a wider international conference which led to the Vienna Convention on Civil Liability for Nuclear Damage which was signed by China, Britain, and other countries, but has not yet been implemented. In scope and concept there is little difference between the two conventions (125). They both contain two important concepts: first, the setting of an upper limit on the amount of compensation that may be claimed by third parties in the event of an accident; and second, the imposition of an absolute and exclusive liability upon the operator of the nuclear installation for third party claims.

47. Underlying the second of these concepts is the recognition of the fact that identifying and proving fault in the case of a major accident could be very difficult, and thus could effectively preclude a claimant from obtaining redress. A claimant does not now have to prove fault, but merely that the damage was caused by the nuclear installation. Making the operator exclusively liable simplifies both the insurance of the risk and the claim procedures. The operator is solely liable even if he is entirely blameless or can prove that the damage was caused by the negligence of someone else.

48. The first concept, the limiting of the amount of compensation, does not so work as to prevent Governments from providing additional compensation directly from their own resources if a catastrophe were to occur. Such provision is to be found in many countries' legislation. The United States and Canada, though neither has signed the Paris Convention nor the Vienna Convention, both incorporate the two basic concepts in their laws. The conventions also define which court will have authority over claims, define time periods within which claims must be made, and oblige operators to maintain insurance or some other financial security to cover their liability. This last provision does not apply to Governments which may, and commonly do, carry their own insurance.

### *Atomic Risks Pools*

49. To provide the large amounts of cover needed by the nuclear industry, insurers in many countries have grouped together to form "atomic risks pools" thus enabling each country's maximum insurance capability to be marshalled at one point (125, 128, 129). Further reciprocity among national insurance pools has been established enabling risk to be spread internationally (128, 129). There are now insurance pools in at least 19 countries giving a large cover on individual installations (130). For example, in the United States, the pools are at risk for sums up to $US300 million on some nuclear power stations.

### *The Nuclear Exclusion Clause*

50. Most if not all insurance policies issued by the insurance market and covering loss or damage to real or personal property exclude "loss or damage caused by contamination by radioactive material". The reason is that the nuclear risk is already covered by the insurance and/or Government indemnity arrangements adopted by countries with active nuclear programmes. It would amount to "double insurance" to include it in private insurance contracts. Insurance policies issued in New Zealand contain the exclusion even though, with no nuclear industry here, the risk

of such contamination is decidedly minimal. The New Zealand market has merely followed international practice.

*Nuclear Insurance in Canada*

51. The Canadian Nuclear Liability Act 1970 includes the most important provisions of the Paris and Vienna Conventions. The Act makes the operators of nuclear installations absolutely liable for injury or damage resulting from nuclear accidents, limits the liability of such operators to $75 million, and requires all operators other than the Crown to maintain insurance against their liability. The Act also makes provision for compensation by the Government in the event of a major accident where the liability could exceed $75 million.

52. Under the Nuclear Liability Act, the Atomic Energy Board of Canada recommends to the Treasury Board the amount of insurance to be carried by any particular installation. In the event of the insurance carried being insufficient to cover third party claims resulting from an accident, the Act enables the Government to proclaim that special measures for compensation are called for. On such a proclamation, the Act provides for the setting up of a special Nuclear Damage Claims Commission to deal with all claims for compensation. The Commission has exclusive original jurisdiction to hear and determine the claims and to award compensation. The decisions are final and conclusive, subject only to a limited right of review by the Exchequer Court of Canada, and subject also to the right of the Government to control the total amount of compensation to be paid by *pro rata* scaling of awards and other means.

*Nuclear Insurance in the United States*

53. In the United States the Price-Anderson Act contains the rules for indemnifying the public against damage caused by a nuclear accident. It embodies the same basic concepts as the Paris and Vienna Conventions and includes the following as two of its main provisions (131).

(a) Owners of nuclear power plants must furnish the maximum financial protection available to cover public liability claims. (The indemnity available from the insurance industry in 1957 was limited to $60 million for each installation. It has since risen to $125 million.)

(b) The Act made certain that there would be a total of $560 million for each large installation to indemnify the public. It did so by the Government undertaking to pay indemnity in excess of the market insurance cover up to the maximum. Now that there is private protection of up to $125 million, the Government's coverage has dropped from the original $500 million to $435 million. The Act further gives a means of allocating extra money should the total insurance and indemnity cover of $560 million be exceeded by claims from a nuclear accident.

The utilities in the United States are reported to pay about $100 a megawatt for the Price-Anderson governmental insurance cover (132). The Government has already collected more than $8 million without being called upon to pay out a cent (131).

54. The Price-Anderson Act was due to expire in August 1977, but in 1975 Congress passed an amending Act extending the principal Act for 10 years subject to three main changes: the limit of liability was to be

increased, the Government indemnity was to be phased out, and the indemnity coverage outside the territorial limits of the United States for certain limited activities was to be extended (125). The phase-out of governmental indemnity is to be done by a "deferred premium system" which will eventually transfer to the utilities the entire responsibility for liability protection, both for personal injury and for property damage. Under this plan, each utility will be responsible for between $2–$5 million protection for each of its operating nuclear plants to cover any accident that results in damage costing more than can be privately insured for. As new plants are constructed, utilities will eventually assume responsibility for the entire $560 million specified by the Price-Anderson Act. In the longer term, if the nuclear programme develops on the scale anticipated, the limit of liability itself will extend beyond $560 million.

### *Nuclear Insurance in Britain*

55. In Britain the Nuclear Installations Acts 1965 and 1969 cover nuclear insurance (133). They follow the Vienna Convention in prescribing a general rule of absolute liability which channels all liability to the operator of the nuclear installation.

56. Article V of the Vienna Convention leaves it to the Government of a country to determine the limit of an operator's liability as long as it is not less than $5 million for each nuclear incident. British law limits operators to £5 million. If this limit is exceeded, claims are to be made to the Minister instead of to the operator. All claims up to £50 million are paid out; for those beyond, Parliament provides the money and determines the extent of payment.

57. Article VI of the Vienna Convention limits the period of liability to 10 years from the date of the nuclear incident. British law sets a longer time. For the operator the 10 years is retained. But there is also a second limit of 30 years from the date of the nuclear incident within which (but after the expiry of the 10-year limit) claims are made to the Minister and met out of money provided by Parliament.

### *Nuclear Insurance Overseas—General Observations*

58. Over the last 15 years or so, an effective pattern of collaboration and mutual support has grown up among the insurance markets of the world through the atomic risks pools. The large risks insured are thus spread internationally in accordance with sound reinsurance principles, and these arrangements are as essential to the development of the nuclear industry as they have proved to be for other large industries such as aviation.

59. By marshalling world-wide insurance capacity, nuclear insurers have not only covered material damage to the nuclear installations themselves, but have made much progress in covering the legal liability of nuclear operators. The nuclear industry is now at a stage where its record is beginning to give the experience essential to evaluating the risk and determining appropriate premium rates. There seems to be no reason to believe the insurers will not continue to give the financial protection so essential to the continued development of the nuclear industry.

60. In Britain, as in the United States and Canada, the operator's liability is absolute; that is, it is independent of any question of his negligence. Nuclear insurance thus indemnifies absolute legal obligations

imposed by statute, and represents a departure from the more normal, common-law principles deriving from the fault concept. It also imposes upon the operator of a nuclear plant financial responsibility for the consequences of the negligence of others.

61. There are some problems remaining to be solved. First, there are some general exclusions to the insurance cover: for example, genetic injuries, damage due to military operations, civil commotion, etc., deliberately occasioned damage, and damage due to natural catastrophes of an exceptional character (134). Second, it may be difficult to establish whether a delayed cancer, for example, was in fact caused by a nuclear incident, or could be attributed to some non-related cause (135). It is difficult to imagine a simple solution to the last problem.

## THE NEW ZEALAND SITUATION

62. If New Zealand proceeds with a nuclear power programme, the Government will need to consider the steps to take to ensure that the public have adequate financial protection from the effects of a nuclear accident. It is assumed that any nuclear power plants here will be owned, controlled, and run by the Government itself through a State department, and that private enterprise will not play the same part in nuclear matters as it does in the United States, where the power utilities are a mixture of public and private ownership.

63. The NZED carries its own insurance, both for material damage to assets owned by the department, and for its legal liability to those who may sustain loss of, or damage to, property through NZED power generating facilities.

### *The Accident Compensation Act, 1972*

64. The Accident Compensation Act 1972 abolished the common law right to sue for damages for personal injury or death by accident, and replaced it with statutory compensation. This means that in New Zealand anybody injured by a nuclear accident would have no right to sue the operator or anyone else for damages but would be limited to the compensation rights of the Act. The Act's purposes and scope set out in section 4 (1) are:

(a) To promote safety with a view to preventing accidents and minimising injury.

(b) To promote the rehabilitation of persons who suffer personal injury by accident in respect of which they have cover under this Act so as to seek to restore all such persons to the fullest physical, mental, social, vocational and economical usefulness of which they are capable.

(c) To make provision for the compensation of:

(i) Persons who suffer personal injury by accident in respect of which they have cover under this Act, and,

(ii) Certain dependants of those persons where death results from injury.

### *Irradiation and Personal Injury by Accident*

65. The expression "personal injury by accident" is defined in a limited way in section 2 (1) of the Act, and specifically excludes "Damage to the body or mind caused exclusively by disease, infection or the ageing process". The Accident Compensation Commission charged with the responsibility of administering the Act commented helpfully on personal injuries suffered by persons from nuclear accidents (136):

[a] To determine whether the claimant has suffered personal injury by accident, the Commission must look at the facts of each particular case. The Commission interprets the expression "personal injury by accident" in its popular and ordinary sense, meaning (in general) an unlooked for mishap or untoward event which is not expected or designed.

[b] The results of exposure to radiation raise a number of questions under the Act. Should there be an escape of radiation from a nuclear power plant, the Commission may expect claims from persons who could show that they received injuries because of their exposure to that radiation. Such claims would be admitted. However, persons who had been exposed to radiation but who could not show that they had yet suffered any injury may have no claim under the Act. Section 150 of the Act provides for the making of a declaration of entitlement, but permits only those who have suffered *personal injury* by accident to apply for such a declaration. The Commission would have to decide in each case whether the exposure to radiation had in fact caused injury. The Commission would probably not regard the mere exposure to radiation (without injury) as giving entitlement under the Act . . .

[c] Section 67 of the Act provides cover for persons who suffer diseases which are due to the nature of their employment, where total or partial incapacity or death arises from that employment within a prescribed period. Section 67 (2) (a) provides that for the purposes of the Section "prescribed period" means: "In the case of any disease due to exposure to X-rays, ionising particles, radium or other radioactive substances or other forms of radiant energy, a period of 20 years or such other period as the Governor-General may (by Order-in-Council) prescribe."

[d] Cover is therefore provided for up to 20 years for workers who may suffer injury as the result of working in an environment which exposed them to the risk of radiation. Other persons, and the public at large, who suffer personal injury by the accidental escape of radiation will be governed by the limitations imposed by section 149 in bringing their claims. Such claims must be brought within 12 months from the date of the accident or the date of death unless the Commission is of the opinion that failure to bring the claim did not prejudice the Commission and was due to a mistake of fact or law or for other reasonable cause.

[e] The Commission's policy [in respect of ante-natal injuries] is to regard each case on its own facts and to apply the normal criteria for determining whether the injured person had suffered personal injury by accident. . . . A foetus may be killed or suffer malformations after doses of radiation as low as 50 rem if received at early stages of development (DSIR paper 7E, Summary A, p. i). Provided the relationship between the radiation and the injurious malformation of a child born alive can be satisfactorily established on medical grounds, the Commission would probably admit a claim from such a person.

[f] However, it is understood that continued exposure to low levels of radiation . . . can have a genetic effect on the reproductive cells of irradiated individuals, leading to defects appearing in later generations. This is not the same as ante-natal injuries and in the Commission's view, children born with genetic defects brought about by chromosome or other cellular damage caused by radiation exposure of a parent, would not have cover under the Act.

66. The Accident Compensation Commission raised with us the question of whether the basis of its funding might need to be specially changed to cope with a major nuclear accident (136). In its view, a catastrophic nuclear accident would probably not be significantly different in its economic effects from any other like disaster. For example, an earthquake

or engineering defect causing hydro dams on the Waikato River to collapse would have immediate economic consequences similar to those from a major incident affecting a nuclear power station in the same area. The Commission does not maintain a disaster or emergency fund to cope with natural, nuclear, or any other type of catastrophe. Its Act does not enable it to do so. Moreover, it is doubtful whether a major disaster could ever be realistically allowed for.

67. The Commission must work on the economic premise that the income for each year must meet all the costs associated with the claims made during the year, including costs incurred in future years for those claims. Thus there is a significant reserve of funds invested ($115 million at 31 March 1977). This is not a free reserve but is the amount of funds set aside to meet the cost of claims already lodged that will be settled in the future. Any major catastrophe would most likely upset this basis and cause the funds to be dissipated more rapidly, because funds held to cover future costs of claims from previous years would be needed to meet the immediate claims being filed. The Accident Compensation Commission believes that its basis of funding would be inadequate to cope with any national disaster—nuclear, earthquake, war, fire, or dam failure. Its existing reserves could prove inadequate even in the relatively short term, and some might themselves be destroyed as the Commission's investments are within the country. A great disaster would most likely call for massive Government aid—organisationally, socially, and financially.

*Compensation Payable*

68. The benefits payable under the Act to persons who suffer personal injury by accident as a result of a nuclear incident would be identical with those payable to any other accident victim. They include the reasonable cost of hospital and medical treatment, rehabilitation, artificial aids, lump sum payments, and where applicable, earnings-related compensation.

*Liability for Third Party Property Damage*

69. Although the Accident Compensation Act 1972 effectively eliminated legal liability for acts which result in death or personal injury, common law principles of liability for damage to the property of others still apply. Under common law, an occupier of land which has a nuclear installation can be liable for damage to property, even though the incident causing the damage occurred without his fault, or that of his servants, or that of independent contractors. The operator of the plant (assuming the unlikely event that he is someone other than the occupier of the land) will be liable also if the incident was caused by his own fault, or by the fault of those for whom he is responsible. This is no place to discuss these areas of liability in detail. It is sufficient that it be understood that they exist and can be onerous.

70. We have noted that many countries put an absolute liability for a nuclear accident on the operator of the plant, but limit the maximum liability for any claims. It is generally acknowledged that nuclear power plants have inherent potential to inflict damage upon the property of others. They are not alone in this. Modern technology in all its forms has the same inherent potential. However, in the case of nuclear power plants, the main perceived danger to others would follow a major release of radioactivity. Though the estimated risk of any such major accident is not high, its consequences could be very great. We shall consider here only the risk of possible damage to property.

71. There is still at large the quite mistaken notion that the reactor core of a nuclear power plant can disintegrate with an explosive force like that of the atomic bombs of the Second World War. On the contrary, a nuclear power plant can never explode like a bomb. As we have noted, its real danger is in contaminating people, land, pastures, crops, livestock, buildings, and other property after any substantial release of radioactivity.

72. The question of liability for damage to property would seem therefore to be related primarily to damage caused by radioactive contamination. Any risk of structural damage to, or physical destruction of, buildings and other forms of property is likely to be confined to the site. Radioactive contamination is another matter. It is not inevitable that irradiated property would have to be destroyed; for example, houses and commercial buildings, furnishings and equipment, motor vehicles, clothing, personal effects, and foodstuff. Some things would certainly have to be destroyed at an immediate cost to their owners. Buildings not structurally damaged but contaminated would have to be evacuated until they could eventually be decontaminated. Decontamination would be expensive. The owners would need alternative accommodation, business would be disrupted, other equipment would need to be hired. These are some of the consequential losses that would follow a nuclear accident, and be the likely subject of claims and damages.

73. The owners of farm land could face considerable losses from radioactive contamination. The DSIR pointed out that, in the worst conceivable accident involving rupture of the containment vessel and the release of a significant fraction of its volatile constituents, the consequences could be disastrous if the prevailing wind spread the released activity over pastoral land. Much of the normal beef and mutton exports of the area could be restricted for up to 10 years; the cost (due mainly to loss of the use of the land) could exceed $1000 million. It can be seen therefore that huge claims for property damage could follow the worst conceivable reactor accident (see paragraph 38).

### *The Earthquake and War Damage Act 1944*

74. This Act replaced the original War Damage Act 1942 and extended protection from war damage to damage caused by earthquake shock and earthquake fire. Parliament has seen it as a convenient vehicle for compensating property losses from other natural causes of unusual scope and severity, and has amended it from time to time to cover these additional risks. We discuss the suitability of the Act in respect of nuclear risks.

75. Under this Act, the Earthquake and War Damage Commission insures material property in New Zealand for damage which directly results from war, earthquake, extraordinary disaster, storm, flood, volcanic eruption, and landslip. Two features of the Act are relevant here:

(a) Only property which is insured under a contract of fire insurance made in New Zealand is automatically insured under the Act.

(b) By regulations under the Act automatic insurance provisions exclude any land, any livestock, any growing crops (including fruit trees and vines), any ensilage insured in the open fields, and any hay or other cut crops insured in the open field. Property excluded from the automatic cover may be voluntarily insured with the Commission on such conditions and at such rates as it may determine.

76. The Act as it stands would thus cover a nuclear risk only if an earthquake or any of the other natural convulsions specified *directly* caused the nuclear accident leading to nuclear damage, and then only for certain classes of property if such property were already insured in New Zealand for fire risk. Excluded property (land, livestock, crops, etc.) would not be covered in the event of nuclear damage. The Act as it stands has only limited application to nuclear damage to property.

77. A large reserve fund has been built up—$268 million at 31 March 1977. But this is clearly not big enough to cover a major disaster—say a force 8 earthquake centred on or near Wellington. There is no reinsurance, and the funds are mostly invested internally in New Zealand Government securities. A major disaster would require massive Government subsidy if this was within the power of Government to give. We think that the fund as at present constituted and financed should not be considered a sufficient security to people who may suffer property loss from a major nuclear accident.

## RECOMMENDATIONS FOR INSURANCE ACTION

78. If a nuclear power programme was implemented in New Zealand, the Government would need to consider very carefully the desirability of introducing in legislation the main concepts of the Vienna Convention: (a) that absolute and exclusive liability be placed on the operator of the nuclear facility; and (b) that the liability of the operator be financially limited. Under (a) above, as the liability for death and personal injury has already been abolished by the Accident Compensation Act 1972, the only remaining liability is for damage to the property of others, for which the fault concept under common law still applies. We see advantages in modifying these common law rules for nuclear damage to property, as has been done overseas.

79. In regard to (b) above, New Zealand is in a peculiar position. Under the Accident Compensation Act the aggregate payments that can be paid to all the victims of a nuclear accident are not limited, nor should they be limited unless a similar limitation applies to the victims of other major disasters. It follows further, that if a monetary limitation cannot in equity be applied to nuclear victims suffering death and injury, then, maybe, no such limitation should be applied to those who suffer damage to property from a nuclear accident. It may therefore be considered undesirable in New Zealand to follow the overseas practice which limits the operator's financial liability.

80. The Government will need to consider also the adequacy of both the Accident Compensation Fund and the Earthquake and War Damage Fund to cope with the financial obligations likely to arise from any major disaster, nuclear or otherwise. The financial stability of both funds must be open to question should any such event occur. This is a matter for governmental policy decision. Countries overseas have found it desirable to avoid anything approaching a guarantee without limit. We would prefer to see a similar approach in New Zealand but we do not see how this could be done without a major restructuring of the present legislation.

# *Chapter 13.* THE REGULATORY CONTROL OF NUCLEAR INSTALLATIONS

1. Because the world-wide development of commercial nuclear power is not without potential dangers to people and their environment, it has been recognised that both international surveillance and control, and the domestic establishment of licensing and regulatory procedures, are needed in all countries that already have, or plan to introduce, this method of generating electricity.

## INTERNATIONAL AGREEMENTS

2. New Zealand's membership of international organisations, and its treaty obligations must be considered in any discussion of the use here of nuclear energy. We thus record them before going on to examine the nature and functions of any licensing and regulatory authority that would need to be set up should it be decided to introduce a nuclear power programme. They were set out for us by the Ministry of Foreign Affairs (78).

3. New Zealand is a member of the IAEA which was founded as a United Nations agency in 1957. It has more than 100 member States who send representatives each year to the headquarters in Vienna. It has among its functions the promotion of the peaceful uses of nuclear power and the establishment and administration of safeguards in respect of nuclear activities, including the transport of nuclear materials and the protection of fissile material. It organises many technical and scientific symposia and publishes their proceedings. It determines basic radiation standards which are based on the recommendations of the ICRP. These are advisory only for member States but binding on States that receive IAEA materials, services, or equipment under an agreement with the agency. Such States are also subject to the detailed safeguards system of the IAEA which provides for inspection by its inspectors.

4. Although New Zealand is a member of the OECD and the IEA (see chapter 3), it is not yet a member of the NEA established by OECD. The NEA has an active secretariat in Paris and promotes a number of scientific conferences whose proceedings are published. It also runs a system of technical committees including the Committee on Radiation Protection and Public Health (CRPPH) which maintains a continuous review of radiation protection standards. Generally, OECD and NEA foster principles which are subsequently incorporated in the administrative and legal systems of member States.

### *Safeguard Measures*

5. New Zealand is a party to the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT) aimed at preventing the diversion and misuse of nuclear materials. According to the treaty, States party to it undertake not to divert "nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices". As a consequence of the treaty, States must conclude agreements with the IAEA for the application of safeguards on all peaceful nuclear activities on their territory or under their control. Such an agreement has been completed between New Zealand and the IAEA.

### *Other International Treaties*

6. New Zealand is also party to: the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, or Under-water; the 1972 Convention on Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly known as the London Convention); and the 1959 Antarctic Treaty. These treaties and agreements bind New Zealand under international law. They are particularly relevant to the questions of protecting the environment from pollution by nuclear material, and of preventing the diversion of nuclear material for military purposes.

### *Pollution Aspects*

7. The London Convention prohibits the disposal at sea of high-level radioactive wastes, with two exceptions only: first, where dumping is necessary to avert a threat to the life of the crew or passengers of a vessel or aircraft; and second, where there is an emergency involving a threat to human life which has no other possible solution. It is implemented in New Zealand by the Marine Pollution Act 1974, which prohibits the dumping of all waste except that the Ministry of Transport can under Part II of the Act, issue permits to dump waste material, such permits requiring strict regard for New Zealand's obligations under the Convention. Article IV of the Antarctic Treaty binds New Zealand not to dispose of any radioactive waste in Antarctica.

### *Diversion of Nuclear Material*

8. The Test Ban Treaty prohibits the carrying out of any nuclear explosion if it could cause radioactive debris to be present outside the territorial limits of the country in question, and in effect, stops New Zealand from ever carrying out a nuclear explosion. The 1968 NPT amplifies this obligation by obliging New Zealand to refrain from receiving, manufacturing, or otherwise acquiring any nuclear weapon or explosive device.

9. It goes further. Article III puts all fissionable material under IAEA safeguards to verify that nuclear energy is not being diverted from peaceful uses to nuclear explosives. It also obliges New Zealand not to provide other States with any nuclear equipment or material which might be diverted to military uses unless that State also accepts IAEA safeguards.

10. The safeguards agreement concluded between New Zealand and the IAEA has not yet been activated, but in accordance with the Protocol to the Agreement it will be activated when New Zealand actually gets specified quantities of nuclear material. There is an obligation to inform IAEA at least 6 months before acquiring such material. Under Article VII of the Non-Proliferation Treaty, New Zealand must maintain a system of accounting for, and control of, all nuclear material subject to safeguards. The IAEA may send inspectors to make independent measurements and observations. These obligations bind the New Zealand Government under international law. Presumably, the only reason they have not been made law here is that the safeguards agreement has not yet been activated.

11. It is also to be noted that before New Zealand could obtain nuclear material it would need to demonstrate to the supplying country that it had set up an effective safeguards system. Supplying countries in their turn, must not send nuclear materials to any other country unless satisfied that those materials will be subject to safeguards, and cannot be diverted to military uses (78).

## REGULATORY CONTROL SYSTEMS—OPTIONS AND CHOICES

12. Every country which has, or is building, nuclear power stations has found it necessary to set up some form of regulatory authority to oversee their design, construction, and operation in the interests of public safety. The forms and functions of these regulatory bodies all have this basic aim, though they may vary among countries. In this section, we give a broad outline of some of the main conceptual and practical differences among the regulatory bodies established in North America, Britain, and Europe. We then consider a possible framework for the New Zealand nuclear regulatory authority that would need to be set up before introducing a nuclear power programme into this country. Much of the material about European practices comes from the submissions of the DSIR (No. 7) and the MWD (No. 16).

13. Variations in regulatory procedures stem largely from differences in the political organisations, the administrative structures of a government, and the nature of the nuclear industry and its degree of development in each country. An historical study of the regulatory systems in OECD countries shows further that these systems have changed as circumstances and technology have changed, and as the need to modify and strengthen the regulatory structure to fulfill basic aims has been perceived. In all OECD countries care has been taken to ensure that the regulatory authority is, and is seen to be, independent of the power utilities (whether publicly-owned or not), and clearly separated from promotion or development. We see this scrupulous observance of independence and integrity to be of paramount importance in working out the criteria for a regulatory authority in New Zealand.

14. The demonstrable separation of the regulatory from the promotional function has been a recent development overseas. For example, the United States Atomic Energy Commission (USAEC) was responsible for setting and enforcing safety standards for power utilities, and also for research, development, and disseminating information to encourage the use of nuclear power. This led to public criticism of the USAEC, and to suggestions that it was allowing its promotional function to influence its attitude to safety. Though the factual basis of such criticism was uncer-

tain, public confidence was weakened, and in 1975, the United States Government abolished the Commission and established two new authorities, the Energy Research and Development Administration (ERDA), and the Nuclear Regulatory Commission (NRC), each with clearly defined and separated functions.

## THE UNITED STATES

15. As required by the Energy Reorganisation Act 1974, the NRC was set up on 19 January 1975, and took over the AEC's former work in regulating the commercial uses of atomic energy. We rely very largely on an NRC publication for the material in this section of our report (79). Those planning to build and operate a nuclear power plant must seek approval from the NRC whose licensing process is a two-stage procedure. The first comprises the filing of an application for a construction permit and a review of this by NRC staff. The second comprises the filing of an application for an operating licence, and a similar review of this.

### *The Application*

16. The application for a construction permit must contain a detailed description of the proposed site and proposed design of the plant, and other relevant information required by the NRC regulations. The applicant must also submit an environmental impact report for the proposed plant, and, further, must submit a separate volume of information to allow the Department of Justice to determine whether construction and operation of the proposed facility would be affected by anti-trust laws or policies. A public hearing may be held on anti-trust matters, and these must be resolved before a construction permit can be issued.

### *Acceptance Review*

17. Each application is at first reviewed by the NRC staff to establish the adequacy of its contents. Then also the applicant's quality assurance programme for design and procurement is substantially reviewed and inspected. If the application satisfies the NRC requirements, it is formally accepted for detailed review.

### *Construction Permit Hearing*

18. The NRC is required by the Atomic Energy Act to hold a public hearing before a construction permit can be issued. This is conducted by an independent, three-man Atomic Safety and Licensing Board. The NRC gives notice of the public hearing which will be held on the environmental and safety matters that are identified in the notice. Some months may elapse between the issue of notice and the actual hearing to ensure full public participation in the decision-making.

### *Environmental Statements*

19. Using the applicant's environmental impact report as a base, a "draft environmental statement" is prepared which considers in detail the environmental impacts associated with constructing and operating the proposed facility, and assesses them in terms of the available alternatives and the need for power. The statement is circulated for review and

comment by appropriate Federal, State, and local agencies, and interested members of the public. A "final environmental statement" is normally issued about 7 months after receiving the applicant's environmental report, and is introduced into the record of the public hearing.

20. The public hearing on environmental matters and issues related to the suitability of the site is usually held near the proposed facility. If the Licensing Board's findings are favourable, it may then authorise the NRC to issue a "limited work authorisation" (LWA) to the applicant.

### *Limited Work Authorisation*

21. An LWA allows the applicant, at its own risk, to do the following: prepare the site for construction; install temporary facilities to support construction; excavate power plant structures; and construct service facilities and those not associated with the nuclear parts of the plant. The first LWA can be augmented to allow construction of foundations for the nuclear portions of the plant if such work is needed to maintain continuity of construction. The NRC must evaluate the proposed foundation designs and related safety issues, and these matters must be the subject of a further public hearing.

### *Advisory Committee on Reactor Safeguards (ACRS)*

22. While the environmental review is taking place, the safety aspects of the application have been under review by NRC staff, leading to a detailed "safety evaluation". This is made available to the public, and is reviewed by the independent ACRS. The ACRS gives a written report to the NRC, and this becomes part of the public record. The review procedures normally take about 15 months.

### *Safety Hearing*

23. When these reviews are completed the Atomic Safety and Licensing Board reconvenes the public hearing. If its findings on safety issues are favourable, the board may authorise the NRC to issue a construction permit. The initial decision, and any appeals from it made by any of the parties to the hearing, are reviewable by the Atomic Safety and Licensing Appeal Board.

### *Operating Licence*

24. After about 2 years of construction work, the applicant files a final, technical, safety-analysis report with its application for an operating licence. NRC staff and the ACRS give this the same thorough review as they did for the construction permit. If all requirements are met, the NRC gives notice that it is considering issuing the licence. The notice allows anybody whose interest may be affected by the proposed action the right to petition the NRC to hold a public hearing. If no hearing is requested, the NRC issues an operating licence after the safety and environmental reviews are completed, a quality assurance programme for operation has been implemented and approved, and the facility has been inspected to make sure it has been built properly and is ready for fuel loading. If a request for a further public hearing is granted, the issue of an operating licence will depend on favourable findings by the Atomic Safety and Licensing Board. The Board's decision is open to appeal to the Atomic Safety and Licensing Appeal Board.

25. NRC staff, through its inspection and enforcement programme, watch over the facility during the whole licensing process and throughout its lifetime to ensure compliance with the permit, licence, and NRC regulations.

### *Possibility of Future Change*

26. The regulatory and licensing process in the United States has evolved over a long time. There can be many years between application for a construction permit and its issue because the public are deliberately involved in decision making through the various public hearings and appeal facilities. The issuing of an operating licence can be further delayed, particularly if another public hearing is asked for and granted at that stage. No fault can be found with the comprehensive nature of this machinery set up in the interests of public safety. However, there is some concern that the protracted procedures can adversely affect both the capital cost and the programme timetables of nuclear plants considered necessary to meet electricity demand. It has been reported that President Carter will seek to get a Bill through Congress in 1978 to streamline the regulatory and licensing process and substantially reduce both the long lead-time before construction can start, and, by adopting standardised design and safety features, the construction time itself.

## EUROPE EXCLUDING BRITAIN

27. The DSIR in its submission 7 gave two references for summaries of licensing and regulatory control of nuclear installations in Europe (80). Though there is no need to quote detail, it is interesting to note some of the differences between the United States and European practices. In Europe, West Germany has the only written regulations for licensing and regulating nuclear power plants. This does not mean that other European countries do not impose controls, but rather that detailed design criteria are rarely written into laws and regulations. Instead, codes of practice, or rules, are administered by the licensing or regulatory authorities.

28. The DSIR pointed out certain differences between the United States licensing regulations and those of some European countries (81). The United States has far more regulations and guides than West Germany, and generally is more inclined to quantitative requirements. European regulations appear to be more concerned with safety systems, including passive failures, and reflect the siting of plants near load centres in densely populated areas. The United States tries to prevent sabotage mainly by administrative controls and armed guards on perimeters. The more direct European method protects inner areas by making violent entry from the outside world a time-consuming job. As for licensing, countries such as Switzerland, West Germany, and Italy, have typically 60 to 100 licensing steps before an operating permit can be obtained. In Italy, some 50 individual systems-review approvals must be overcome before a plant is completed. In containment design, European regulations (except the French, Spanish, and Italian), unlike the United States, specify double containment and aircraft impact resistance on all units. For combination loadings, West German regulations (unlike the United States general design criteria) do not recognise the possibility that an accident resulting in loss of coolant could be induced by a shut-down earthquake.

29. The early designs of European plants followed NRC standards, since the sellers were mainly based in the United States, and sold systems as "turnkey" projects. European standards were developed more recently—West German regulations were approved only in 1974—and reflect local characteristics, for example, of population density, seismic design, probabilities of aircraft impact, anti-terrorist protection. A greater departure from NRC designs may be expected as domestic industries develop.

## BRITAIN

30. In Britain nuclear safety is regulated by the Nuclear Installations Acts 1965 and 1969. The Acts are administered in England and Wales by the Secretary of State for Trade and Industry, and in Scotland by the Secretary of State for Scotland. These Ministers have very wide discretion in the use of their regulatory powers, and no organisation other than the Atomic Energy Authority or a State department may construct or operate a nuclear reactor without the site being licensed by the responsible Minister. The Ministers are also empowered to attach to a nuclear site licence any safety conditions considered necessary, and these conditions can then be legally enforced under statutory penalties. The flexibility of these powers makes it possible to frame conditions to protect the operators and the public from ionising radiation on any of the licensed sites. The Nuclear Installations Inspectorate set up in 1959 when the first four commercial nuclear power stations of the "Magnox" type were in various stages of construction executes the detail of the Act. The safety regulation of power reactors is primarily concerned with the safety assessment of designs, commissioning and operating procedures, and inspection during construction, commissioning, and operation, as well as with evaluating proposed sites. However, for any installation licensed under the Acts, the inspectorate must judge the adequacy of the safeguards provided to prevent an escape of radioactivity or emission of ionising radiations which might cause harm to operators or to the public. This judgment involves assessing the risks of accidents and their consequences, and requires a thorough understanding of the processes and the engineering and control of nuclear plants.

31. The Minister can under the Act require the applicant for a site licence to publicise the proposal and give notice to specified public and local authorities who have 3 months in which to make representations about it. When all interested parties have been given an opportunity to comment or to object to the proposed station, the Minister decides whether their interests are affected to an extent which makes it desirable to hold a public inquiry. If the local planning authority objects, the Minister is obliged to hold an inquiry. Public inquiries have been held on seven of the applications for consent to build a nuclear power station, but only one nuclear power station proposal has been turned down after an inquiry.

32. Compared with the United States procedures, which spell out in great detail the broad area of safety requirements with which the applicant must comply, those of Britain are built upon the philosophy that nuclear power plant operators have a duty under the law to build and run their plants safely. The onus of satisfying the inspectorate in a positive way that the proposed plant will be safe and the site suitable is placed

fairly and squarely on the applicant. The power to impose and enforce conditions to the nuclear site licence gives the inspectorate adequate control over the design, construction, and operation of a nuclear plant. A licence may be varied at the Minister's discretion. This makes it possible to amend, add, or revoke licence conditions at any time. In practice these are kept as free as can be from technical detail, and the licensee is encouraged to prepare his own procedural and technical documents which meet the intent of the various licence conditions, with the advantage that the operators are involved in setting the safety standards and controls with which they have to comply. With the approval of the inspectorate, these can be amended at any time, and implemented by the issue of a simple legal document called a "consent-approval". In this way safety controls can be modified or introduced to meet problems as they arise, with a minimum of delay and interference to the operators on a nuclear site.

33. The licence conditions and the procedural and technical documents drawn up under them are the framework for safety control. This does not relieve the licensee of his responsibility for safety, nor does it ensure safety. The British nuclear industry has an enviable safety record which tends to demonstrate that the operators of nuclear power plants have made safety a prime consideration in all their activities, and that the regulatory procedures are effective (82).

## CANADA

34. In Canada, the nuclear industry is regulated by the Atomic Energy Control Act, and regulations made under it. The Atomic Energy Control Board (AECB) was established under the Act in 1946 with its primary role defined as:

> in the national interest to make provision for the control and supervision of the development, application and use of atomic energy, and to enable Canada to participate effectively in measures of international control of atomic energy which may hereafter be agreed upon.

The regulations prescribe among other things that no person shall, unless exempted in writing, operate a nuclear facility except in accordance with a licence issued by the AECB.

35. The licensing of nuclear power stations in Canada includes the issue of a site approval, and two formal licences, for construction, and for operation. The applicant first applies for a site approval and supports the application with a document known as a "site evaluation report" which gives enough information to enable the AECB to determine the suitability of the site proposed. The report includes a summary description of the station, outlining the plant size, reactor type, basic process, and safety systems, together with information about land use, present and future population density and distribution, main sources and movements of water, water usage, meteorological conditions, seismology, and geology. The AECB will issue a site approval if satisfied that the site is suitable for the construction of a reactor of the size and type proposed.

36. Next, the applicant must apply for a construction licence, supporting the application with a "preliminary safety report" which documents the information essential to ensure that the health and safety of the operating staff and the public would be protected should the station be constructed. If satisfied, the AECB will issue a construction licence,

subject to the condition that the preliminary safety report be updated annually as the detailed design and construction of the station proceed.

37. Finally, the applicant may apply for an operating licence when construction is almost completed, submitting a "final safety report" to document the "as-built" design of the station, the updated analyses of postulated accidents, and the capability of safety systems to prevent or limit the consequences of such postulated accidents. Only when the AECB is satisfied that the plant has been designed, constructed, commissioned, and staffed adequately, and that it can be operated safely, will an operating licence be given.

38. This brief outline shows that Canadian procedures tend to be closer to the British than to those of the United States. They differ from the British in that the licences are issued by the AECB rather than by the Ministers responsible; but in the requirement that the applicant must satisfy the authority about essential technical and engineering details bearing on safety, rather than having to comply with details specified by the authority, there is remarkable similarity in the prescribed procedures (83).

## A NEW ZEALAND NUCLEAR REGULATORY AUTHORITY

39. In May 1976, the NZAEC set up a subcommittee to be responsible for recommending a framework for a New Zealand regulatory authority. The report was completed in February 1977 and was presented to our Royal Commission (84). Part II of the report contains a useful aggregation of material on regulatory practice in general, its aims, and brief descriptions of the nuclear regulatory processes used in various western countries. The report acknowledges its debt to publications of the IAEA, which, among a wide range of services, offers expert advice on regulatory matters. Part III makes specific recommendations for the framework of a New Zealand regulatory organisation. The substance of these recommendations and our comments on some of them follow.

### *Recommended Framework—General*

40. The subcommittee considered that the best organisation for regulating nuclear activity in New Zealand should have the following shape. There should be set up a statutory authority with independent powers of decision, serviced by a small permanent staff, and directed by a senior technical administrator. The Director and permanent staff should be public servants attached to an appropriate State department for routine administration only, but responsible to the authority and not to the permanent head of the "home" department. The number of the permanent staff will be influenced by the extent to which the authority is able, and finds it technically, administratively, and economically desirable, to call on outside expertise. It is assumed that the authority will be given ready access to expertise in State departments, thus limiting the need to build up technical staff. The NZED suggested that 15-20 trained staff would be needed by the time of the construction of the first nuclear unit.

41. The subcommittee decided against attaching the permanent staff even for routine administration to a constructional or operating department such as the MWD or the NZED, or to an environmental agency with an independent role (the Commission for the Environment), or to any

agencies which could have or could be seen to have a role in promoting nuclear energy (the MER or the DSIR). No recommendation was made on where the authority should be housed.

### *The Authority*

42. The subcommittee recommended that an authority called the "Nuclear Power Regulatory Authority" (NPRA) should be established immediately after any governmental decision to adopt nuclear power generation, and that it should consist of five members: three from outside the State Services to be appointed by the Governor-General by Order-in-Council for a term of 5 years, one of whom should be chairman; the Director-General of Health *ex officio*; and the Director-General of the DSIR *ex officio*. The Director of the authority should attend meetings by right as an observer and adviser. (The subcommittee noted the apparent anomaly between the recommendation that the Director-General of the DSIR be an *ex officio* member of the authority and the inclusion of the DSIR among the organisations likely to be regarded as nuclear promoters. The anomaly is more apparent than real. In any case it will be essential to the authority's proceedings to have as a member a scientific administrator of high calibre as a member).

### *Legislation*

43. The NPRA will need statutory authority to:

(a) adopt design and siting safety criteria and standards that must be followed to assure the safe operation of nuclear power stations;
(b) review the design of nuclear power stations to ascertain that the design meets the design safety criteria and standards;
(c) assess the safety of proposed nuclear power stations to determine if the degree of safety is adequate to assure the protection of the public and the environment;
(d) issue construction permits and operating licences for nuclear power stations;
(e) conduct a programme of compliance inspections and audits;
(f) require the shut-down of any nuclear power station where inspection shows that an unsafe condition exists, or is likely to develop, or that the requirements of the NPRA are not being complied with;
(g) license and inspect all phases of the nuclear fuel cycle, including transport, waste management, and safeguards.

The legislation should bind the Crown.

### *Staff*

44. The subcommittee's recommendation that NPRA permanent staff should be public servants has the advantage of providing a career structure within the State Services. However, the Royal Commission considers that there should be flexibility to allow the board both to employ people from outside the State Services (from overseas or within New Zealand), and to seek assistance from the range of expertise already within the State Services. There would be decided advantages by way of cross-fertilisation.

*Political Accountability*

45. The subcommittee weighed the alternatives of the NPRA being directly accountable to Parliament (as is the Auditor-General), to the Prime Minister (as is the Head of the Security Service), or in the usual departmental fashion through a Minister to Cabinet. It concluded that:

(a) The NPRA should report formally to Cabinet through an appropriate Minister, but made no recommendation about which Minister, except that he should not have any responsibility for constructing or operating nuclear power plants, for independent environmental auditing, or have any "taint" of promoting nuclear activity.

(b) The NPRA should report annually to Parliament through the Minister, and also to the Minister about each specific licensing decision made.

(c) The NPRA should have independent decision-making powers which could not be overridden either by the head of the department to which it is attached or by the Minister to which it is accountable.

(d) Despite this, because the authority will be an agency created by the Government for the purpose of executing governmental policy (that is protecting people, places, and property from radiation hazards associated with the establishing of nuclear reactors in New Zealand), it is essential for the Government to have some means of assuring that its policy is being followed. The subcommittee considered that the best device (already in use in other contexts in New Zealand) was to require the NPRA by law to "have regard to the views of Government as formally communicated to it by the Minister". By this means the Government would not be able to direct the NPRA to a course of action which the NPRA considered undesirable or against the public interest. But the NPRA likewise would not have unfettered regulatory and licensing powers to adopt standards or enforce decisions which were contrary to governmental policy on public safety.

*Structural Relationships*

46. The subcommittee saw the present responsibilities of the Department of Health under the Radiation Protection Act 1965 continuing, and being complementary to those of the NPRA. It did not recommend any structural relationship between the NPRA and the present NZAEC. Nor did it see any need for the NPRA to have any structural relationships with local bodies. Although the NPRA must assess the health and safety needs of proposed sites, the applicant would have to obtain such other approvals as are required (e.g., under the Town and Country Planning Act 1953 and the Water and Soil Conservation Act 1967), and to go through the normal reporting procedures on environmental impact. It envisaged that a preliminary site assessment by the NPRA would be regarded as a precondition before consideration by district planning authorities, regional water boards, and the Commission for the Environment.

## CONCLUSIONS

47. Though overseas licensing and regulatory matters are by no means uniform in their specifics, they all share the aim of public safety, and protecting property and the environment.

48. In western countries there is a growing involvement of the public in the decision-making process. The advantages of this should not be overlooked in New Zealand. The United States procedures laid down by legislation and NRC regulations are designed for a strongly-developed nuclear power industry comprising a wide variety of utilities, suppliers, and contractors. Because of this, great care has been taken to prescribe in detailed written form a range of design and safety criteria of formidable proportions. In Britain and Canada, where the shape and composition of the industry bears little resemblance to that of the United States, there is a different approach. As in Europe, only broad guidelines and rules are prescribed. We consider that this approach would be most suitable for New Zealand. The point of view was expressed to us in Canada, however, that the Canadian regulatory authority might find it an advantage to reduce more of the details to writing than is presently the case, so that people proposing to construct nuclear plants would know better what criteria they have to meet.

49. We add the observation that the source from which any nuclear plant is to be bought could well have an influence on the form the regulations should take. For example, if light water reactors from the United States were to be imported, it could be necessary to draw heavily from the NRC regulations. The Codes of Practice recently prepared by the IAEA are likely to be of great help. These cover governmental organisation for the regulation of nuclear power plants, safety design, quality assurance on safety, safety in siting, and safety in operation.

50. We do not consider it necessary to outline any legislation that would be needed to establish a regulatory authority. We note the relevant statutes and regulations already in force: The Atomic Energy Act 1945; The Radiation Protection Act 1965; The Radiation Protection Regulations 1973; The Transport of Radioactive Materials Regulations 1973. Some amendment or repeal of these Acts and regulations may be needed after considering the content of any new legislation.

51. The report of the subcommittee of the NZAEC is a valuable structural outline of the necessary legislation if the Government should decide to proceed at an early date with a nuclear power programme. But should a commitment to nuclear power be delayed, it is clear that the subcommittee's proposals would need review in the light of future developments elsewhere including any modification of present IAEA recommendations.

52. We cannot stress too strongly the dominant need for a New Zealand regulatory authority to be, and to be seen to be, an authority of complete independence and integrity, with no promotional or development functions.

53. We consider that the DSIR is the most suitable department to whom the regulatory staff should be routinely attached, and that the authority should report finally to Cabinet through the Minister of Science.

54. The subcommittee's report does not try to prescribe any particular qualifications or experience for the three members proposed to be appointed to the authority from outside the State Services. Though there is no uniform opinion overseas on the matter, we believe that a scientific or engineering background might be desirable, but should not be considered essential because of the fund of technical expertise that would be available to the authority from its staff and its consultants.

# *Chapter 14.* THE COST OF NUCLEAR POWER

## INTRODUCTION

1. Economic implications must be taken into account in considering the likely consequences of a nuclear power programme for New Zealand. In this chapter we compare the cost of producing electricity from nuclear sources with that from the more conventional fossil fuels, coal and oil. We believe such to be the most useful economic comparison. Chapters 7 and 15 consider briefly the production costs of hydro and geothermal. Geothermal has a competitive edge over other forms, but its potential for future development has yet to be defined. We do not here consider hydro costs for we do not regard hydro as an alternative for future base-load plant. Chapter 4 quotes certain claimed unit costs for nuclear power in the United States and Britain, but in the present chapter we consider in detail the likely unit cost in New Zealand and how that cost compares with the other fossil-fuel alternatives available. The wider economic implications of a nuclear power programme are considered in chapter 15.

2. Production costs per unit of delivered electricity at the power station gate are to be derived from the various components comprising: (a) the capital investment required to establish the power plant as an operating unit, and the progressive amortisation of such investment over the economic life of the plant, together with interest on it; (b) the annual cost of operating and maintaining the station; and (c) the fuel costs for each unit of energy. None of the components of unit costs should be considered in isolation. Nuclear power stations are characterised by high capital costs and relatively low fuel costs compared with thermal power stations generating steam by burning fossil fuels. In the latter, fuel costs are relatively higher. Nuclear stations are best suited to operating at high output factors, that is, as base-load stations rather than as intermediate or peak stations. It is axiomatic that the output factor of any generating station feeding power to a grid system is a critical aspect of its economics.

3. Various methods can be used for testing the economic advantages of the various types of generating stations one against the other. Whichever method is used, it is necessary to ensure that similar comparisons are made with alternatives that will perform the same function in the power system. Therefore, for the purpose of economic comparison, a nuclear plant must be compared with other base-load alternatives. Similarly, any comparisons should be made between plants of equivalent generating capacity as costs per unit of electrical output should decrease as generating capacity increases. This comes from the savings in labour and materials that can be made in building the larger plants, and from further savings that can follow the sharing of common services by a number of generating installations in the one complex.

## HISTORICAL ESCALATION OF CAPITAL COSTS

4. The capital costs of nuclear power plants have risen a great deal in the last decade, and though most of the published information is of American origin and experience, it is likely that the trend applies to other countries which have started a nuclear power programme.

5. The IAEA gives comprehensive and impartial guidance on nuclear power planning to its member States. An important part of this service is advice on estimating capital costs which are a major factor in costing nuclear power generation. Published capital costs of nuclear plant vary widely, and previous IAEA extrapolation of United States cost experience to developing countries has proved to be consistently low. The IAEA therefore convened a meeting of experts in April 1976 to produce an improved method of estimating capital costs in developing countries. The report of this meeting was prepared by G. Woite and will be referred to here as the Woite report (176). Because they are relevant to any country investigating a nuclear power programme, the Woite report estimates were used by the NZED as a starting point for its own calculations of capital costs. We therefore discuss the Woite methodology and findings. It noted that economic studies can be done either in current or in constant value monetary units, but that, because of easy comparability and checking of input data and results, nuclear power planning studies and capital cost estimates sponsored by the IAEA were prepared in constant value units (normally $US). The report further noted that:

> the unit capital costs of LWR plants within the same size range appear to have been multiplied by a factor of about six over a span of eight years. Since neither the cost of the equipment nor the amount of construction labour required showed increases of this magnitude, the situation obviously calls for further analysis. The first step of this is a separation of "accounting" increases due to inflation from "real" cost additions arising from unexpected new requirements or other reasons.

6. The Woite report on real cost increases concluded that: "After bringing cost experience and estimates to a common denominator by expressing them in terms of constant value money, it turns out that real costs of nuclear plants have increased by about 100% over the last five years [April 1971–April 1976]. The combined effect of real and accounting increases has led to consistent underestimation of future nuclear plant costs."

It gave the following reasons:

(a) *Regulatory Impact.* Substantial increases in safety and environmental protection requirements, and higher standards relative to quality assurance and quality control, had a significant effect in increasing capital investment to an extent which could hardly have been foreseen in the earlier years of commercial nuclear power. "Analyses of the combined effect of regulatory requirements lead to the conclusion that they have increased the capital costs of nuclear power plants by a factor of two since the early years of commercial nuclear power."

(b) *Escalation.* "Annual inflation rates in industrialised countries increased considerably since the early years of nuclear power. This leads to a greater relative impact of escalation during construction. Extended design and construction periods reinforce this effect. Whereas in 1969 [in the United States] escalation during construction was estimated to be about 25

> percent of direct plant costs, it is now [1976] estimated to be more than 100 percent of direct plant costs. Higher inflation rates lead also to higher nominal interest rates. Together with extended design and construction periods, this means that the relative importance of interest during construction (IDC) has increased as well." IDC in 1976 was estimated to be about 50 percent of direct plant costs including IDC on escalation. This compared with a figure of 20 percent in 1969.

*Economic Competitiveness of Nuclear Power*

7. The Woite report further concluded that the complexity of today's energy economics made it difficult to frame a clear definition of the economic competitiveness of nuclear power. The situation varied from country to country, depending on energy resources, regulatory requirements, and unit sizes. In industrialised countries, fossil-fuelled units will have to be equipped in future with air quality control systems (AQCS) unless they burn low-sulphur fuel. Since the AQCS will add considerably to the capital (as well as operation and maintenance (O and M) ) costs of fossil-fuelled units, nuclear power will remain competitive for base-load electricity generation in industrialised countries, except in regions where very cheap (that is, strip mine) coal is available. The position may well be different in developing countries, and it is necessary to evaluate the competitiveness of nuclear and conventional energy resources specifically for every country considering the introduction of nuclear power.

8. In 1973, when crude oil for oil-fired generating stations was $2 to $3 a barrel, it seemed that nuclear power had a bright future, with the prospect of having possibly a one-third share of the energy market by the end of the century. Within a year the oil price had soared to $8 to $12 a barrel, and, as many countries wished to reduce their reliance on imported fuel, the rapid development of nuclear power appeared even more assured. However, by the end of 1975, it became apparent that, except for a few countries, nuclear power growth was receding to targets even below those considered before the oil crisis. Aspects of this strangely paradoxical situation were considered by R. Krymm in a paper published in an IAEA bulletin (177). He noted that it brought into question the actual cost comparisons between fossil-fuelled and nuclear generating stations. Based on USAEC data, in current dollar terms the cost of LWRs had increased substantially with time, the 1974 estimate being a factor of nearly six over the 1967 estimate. Neither equipment nor labour costs had increased at this rate, and the reasons for the apparent discrepancies were revealed in a USAEC report Wash-1345 as being largely related to inflation and high interest rates. Interest during construction, and escalation during construction (which was negligible in 1967), had combined to almost double the construction cost by 1974. Similar figures were evident for fossil-fuelled units, but these units had an advantage over nuclear stations in lead times. Krymm noted that, for a nuclear system, the time from the contract for the steam supply system to commercial operation was about 90 months, whereas it took only 72 months for an oil-fired system. With high interest rates and inflation such factors have obvious importance.

9. Notwithstanding the factors noted above, Krymm concluded that nuclear power stations appeared to have a decided advantage in generating cost over fossil-fuelled stations, and that the reasons for the declining nuclear power programme were to be sought elsewhere than in economics.

## SUBMISSIONS ABOUT NUCLEAR POWER COSTS

10. A number of submissions gave us estimates relevant to likely nuclear power costs in New Zealand. Quite the most helpful of these were those of the NZED (62), Professor R. H. Court on behalf of the Environmental Defence Society Inc. (178), and Ecology Action (Otago) Inc. (3). These were the only ones to treat the topic in depth, and only those of the NZED estimated the unit costs of delivered electricity from the power station. Those of Professor Court and Ecology Action (Otago) were largely confined to estimates of capital costs. References to likely costs of nuclear power plants were made in other submissions, but figures used in these were generally unsupported by any evidence we could regard as authoritative.

11. Professor Court most usefully drew attention to some of the factors likely to affect capital costs of nuclear plants in this country. His evidence received wide publicity, and was directly or indirectly used as a reference source in many other submissions. His professional status had a bearing on this, as had his basic contention that the capital cost of the NZED project if started now and completed around 1984 would amount to a figure in excess of $2 billion, and his further conclusion that if the project was begun in 1982 and completed around 1990 the final overall cost could be decided now only on the basis of a highly speculative imagination.

12. While some of Professor Court's conclusions were challenged, particularly in cross-examination, we acknowledge that he caused the NZED to undertake a major clarification of the costs submitted in its background paper. We propose to deal first with the submissions of the NZED, and then consider briefly the criticism of the department's figures by Professor Court, Ecology Action (Otago), and the Treasury.

### *The NZED Submissions*

13. In its background paper the NZED estimated the cost of a twin 600 MWe (net) nuclear station as NZ$924 million in early 1976 dollars made up as follows (40):

| | |
|---|---|
| Basic cost taken from the Woite report (176): ... | $840 million |
| Plus 10 percent seismic allowance (to meet New Zealand conditions): ... ... ... ... | $84 million |
| *Total*: ... ... ... ... | $924 million |

This capital cost estimate includes all direct and indirect costs at site for a complete power station in working condition, but excludes the initial load of fuel and "other costs" associated with the training of personnel by the NZED and other departments, arranging legislation to cover the construction and operation of a nuclear reactor, setting up a licensing organisation, and preliminary site investigation and system studies. The Woite report estimated that for a developing country these costs would be US$10 million to US$15 million or more. Costs outside the scope of supply of the power station (including roading, transmission facilities, and land purchase) could amount to a further $30 million. The NZED noted that information on the likely cost of decommissioning a nuclear station is sketchy at best, but that, even if an allowance of $20 million (in 1976 terms) was made for decommissioning a 2 × 600 MWe station, the contribution to unit generating cost would be less than 0.002 cents per kWh.

14. In a later submission the NZED agreed that a factor representing IDC was omitted from its initial submission under "other costs" (62). The two NZED submissions differed also in their calculations because of (a) a more rigorous representation of the time at which fuel costs must be paid; and (b) a more detailed enumeration of "other costs". Transmission costs (which are normally ignored as being common to all alternatives) had also been considered. In paragraphs 15 to 28 we give details of the NZED capital cost estimate supplied in its submission 118.

15. The NZED began its derivation of the capital cost of the power station from US$700 per kWe (net) at April 1976 costs. This figure is taken from the Woite report and includes all direct and indirect costs for a complete power unit at a non-ideal site and meets early 1976 United States licensing requirements, but it does *not* include: (a) interest during construction, (b) escalation, (c) the main power transformers and switchyard, (d) road and transmission facilities, (e) initial fuel, (f) owner's costs (land purchase, staff training, quality assurance, commissioning, public information facilities, etc), and (g) costs associated with "introducing" the first nuclear power project into the country (legislation, initial training, licensing authority, etc).

16. The basic cost of NZ$840 million (equivalent to $700 per kWe) is for a 1200 MWe station designed and built to withstand a horizontal earthquake force of up to 25 percent of gravitational force (0.25g). In its study of accident probabilities from earthquake in central New Zealand, the MWD used a value of 0.67g for the SSE (56). Thus, if the station is built in such a region, a cost additional to the basic must be added for protection against large earthquakes. From an IAEA study (179) the NZED included an allowance of 10 percent of the basic cost for this purpose, and noted that the seismic allowance could vary considerably and that a site-specific study would be needed in each case. Furthermore, research and development may result in cheaper methods of giving the needed protection. For example, a base isolation system of earthquake protection being investigated and developed in New Zealand may substantially reduce the cost (180).

17. The NZED estimate of total basic cost of NZ$924 million (1976 dollars, after including a seismic allowance of $84 million) is the sum of annual cash payments needed in the period before power production begins (table 14.1). To the money paid when construction is finished, there should be added a return on the money invested over the time from spending the money to completing construction. This is done in line (b) of the table. The currently required rate of return on Government capital investment is 10 percent per annum, and it will be seen from the table that an IDC factor calculated on this basis effectively adds $421 million to the basic cost figure, to give a total capital cost figure of $1,345 million (1976 dollars) excluding initial fuel. By comparing lines (a) and (b) of table 14.1, one can see that the required return on investment has a much greater effect on money spent early in the project than on money spent near commissioning. For this reason, it has a greater effect on the capital cost of nuclear plant, which has a long construction period, than on alternatives which can be completed in a shorter time.

### *Table 14.1*

### NUCLEAR POWER STATION CAPITAL COSTS

(2 × 600 MWe PWR)

(*Source:* NZED submission 118)

| | Years from Commissioning | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | –9 | –8 | –7 | –6 | –5 | –4 | –3 | –2 | –1 | –0 |
| | DATE* | | | | | | | | | |
| | 1982–83 | 1983–84 | 1984–85 | 1985–86 | 1986–87 | 1987–88 | 1988–89 | 1989–90 | 1990–91 | Total |
| Capital expenditure spread ... ... ... | 1% | 3% | 7% | 13% | 20% | 20% | 21% | 11% | 4% | 100% |
| (a) Capital expenditure (in April 1976 millions of N.Z. dollars)... ... ... ... | 9 | 28 | 65 | 120 | 185 | 185 | 194 | 101 | 37 | $924m |
| (b) Capital expenditure plus required return on investment (in April 1976 millions of N.Z. dollars)† ... ... ... ... | 21 | 57 | 120 | 203 | 284 | 258 | 246 | 117 | 39 | $1345m |

*The dates given here are based on an April 1991 commissioning date, obtained by averaging the October 1990 and October 1991 commissioning dates proposed in the 1976 Power Plan. They are not intended to imply expected commissioning dates.

†The required return on investment convers interest during construction, etc.

Line (a) is a simple spread of the $924 million basic cost (e.g., 9 = 1% × 924).

Line (b) equals line (a) plus the required return on investment assuming the expenditure each year is made halfway through the year. A 10 percent per annum rate is used. (e.g., $21 = 9.2 \times 1.1^{8.5}$)

18. The method of calculating costs in 1976 dollars of constant purchasing power as in lines (a) and (b) of table 14.1 is often referred to as the "constant dollars" or "real terms" approach. The NZED uses this method throughout. An alternative is to use inflating dollars, the "current dollars" or "money terms" approach. Under this method the costs shown in line (a) of the table would be inflated up to the years in which they apply. Thus, the money spent in the year 1982–83 would be represented in currency of 1982–83 purchasing power, and so on. The total of the current dollars method would be greater numerically than the total of the constant dollars method by an amount equal to the assumed inflation. Thus, if the total in current dollars was tied to an April 1991 completion date 15 years ahead, and inflation was assumed to be 6 percent per annum, these results would be 2.40 times greater than the result in constant dollars. (The $2.40 = 1.06^{15}$.) The current dollars method, because of the difficulty in forecasting future rates of inflation, presents problems which are avoided in the constant dollars approach. It was mainly for this reason that the NZED used the latter method.

19. The NZED estimates that the required capital investment (including IDC) in oil- and coal-fired stations of equivalent capacity, based upon known New Zealand experience, is significantly less than that for a nuclear plant, thus (in millions of 1976 dollars):

| Nuclear | Oil | Coal |
|---|---|---|
| $1,345 | $384 | $492 |

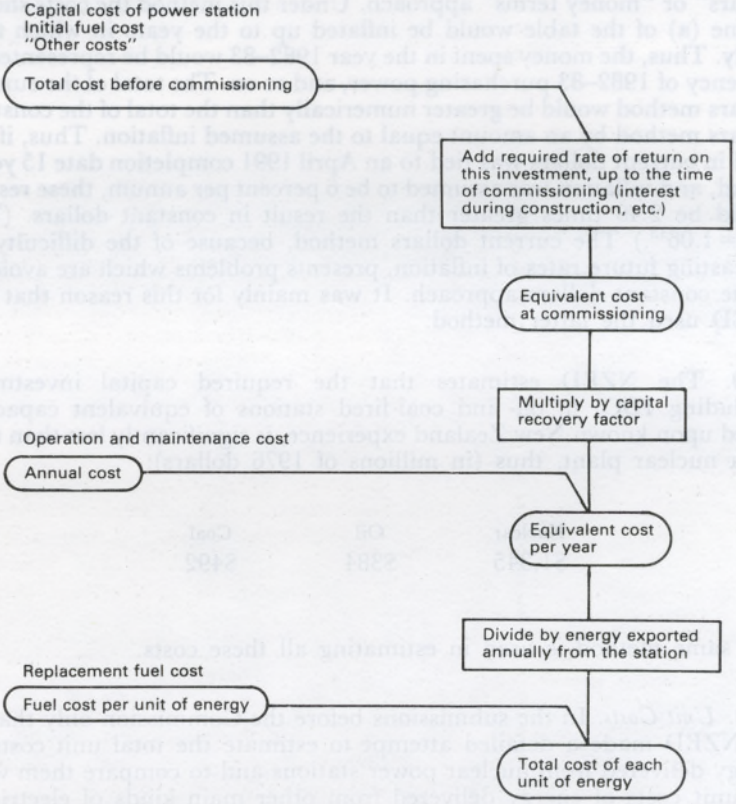
The same method is used in estimating all these costs.

20. *Unit Costs.* In the submissions before the Commission only that of the NZED made a detailed attempt to estimate the total unit costs of energy delivered from nuclear power stations and to compare them with the unit costs of energy delivered from other main kinds of electricity generation. The NZED used the constant dollars method throughout their estimates. To determine the total cost of the electrical energy produced by a power station it is necessary to view the capital cost incurred at date of commissioning (see paragraph 17) as a cost that must be recovered over the life of the station. The amount which must be recovered each year is determined by using a "capital recovery factor", which takes into account the economic life of the station and the assumed rate of return on money. The annual cost of running and maintaining the station must also be added. The total annual cost is divided by the energy exported from the station during the year, taking into account the output factor of the station (the ratio of the energy actually produced to the energy which would have been produced had the station operated continuously at maximum capacity). Fuel costs per unit of energy are added to determine the total cost of each unit of electrical energy at the power station. The cost of the delivered energy can be determined at some point away from the station by taking account of transmission costs and losses, the effect of which is to increase unit costs marginally. Figure 14.1 shows in flow diagram form the methodology used by the NZED to assemble the different cost components.

*Figure 14.1*

FLOW DIAGRAM FOR CALCULATION OF THE TOTAL COST OF ELECTRICAL ENERGY

(*Source:* NZED submission No. 118)



21. The NZED's comparison of the unit costs of nuclear generation with the unit costs of energy produced by thermal power stations burning coal or oil, using the same method, is shown in table 14.2. Totals A in this table include all costs associated with producing the energy at the power station. Totals B reflect the addition to totals A of the cost of transmission lines and the effect of transmission losses up to high voltage bulk supply points, but do not include subsequent distribution costs or losses between the supply points and individual consumers. The costs for all three options assume one power station containing two 600 MWe generating units.

22. It should be noted that the estimates for the nuclear alternative relate to the PWR type reactor, assumed to be built to meet early 1976 United States licensing requirements. Included in the nuclear cost figures is the total estimated cost of setting up the infrastructure needed to introduce nuclear power (training, legislation, licensing authority, etc). Subsequent stations would not need to bear these costs, although the operating costs of the licensing authority would be a continuing cost of nuclear power generation, having a marginal effect on nuclear unit costs.

### *Table 14.2*

## COMPARATIVE COSTS OF ALTERNATIVE FORMS OF BASE-LOAD ELECTRICITY GENERATION

(*Source:* NZED submission 118)

| | Nuclear (PWR) | Coal | Oil |
|---|---|---|---|
| Interest and repayments on capital costs of power stations ... ... | 1.939 | 0.709 | 0.554 |
| Fuel cycle costs: | | | |
| Initial fuel ... ... | 0.157 | 0.017 | 0.040 |
| Replacement fuel ... ... | 0.507 | 1.000 | 2.300 |
| Operation and maintenance ... | 0.125 | 0.104 | 0.099 |
| Other costs ... ... ... | 0.186 | 0.082 | 0.082 |
| A: Total energy cost at power station ... ... ... | 2.91c/kWh | 1.91c/kWh | 3.08c/kWh |
| B: Total cost of delivered energy ... | 3.00c/kWh | 1.98c/kWh | 3.16c/kWh |

(All values expressed in cents per kilowatt hour (c/kWh) in April 1976 New Zealand currency.)

NOTES—

(i) Totals A: As in the background submission (No. 11), all costs associated with producing the energy exported from the power station are included.

Totals B: The cost of transmission lines and the effect of transmission losses, up to high voltage bulk supply points but not distribution to individual consumers, are added.

(ii) The costs for all alternatives assume one power station containing two 600 MWe generating units.

(iii) The total cost of setting up the infrastructure required to introduce nuclear power (training, legislation, licensing organisation, etc.) has been charged against this first station; subsequent stations would not bear this cost.

(iv) The station is assumed to be built to meet early 1976 United States licensing requirements.

(v) The costs shown here are costs to the New Zealand Government. They are not necessarily the direct costs to the consumer.

(vi) The use of PWR costs as the basis for nuclear power costs does not indicate a preference for that type on economic or other grounds; BWR and CANDU costs are less readily available.

(vii) Assumptions:

| | |
|---|---|
| Average output factor ... ... ... ... | 70% |
| Station economic lifetime ... ... ... ... | 30 years |
| Interest rate over life of station (with no allowance for inflation) | 10% p.a. |
| Exchange rate* ... ... ... ... | NZ$ = US$1 |
| Cost of coal ... ... ... ... | NZ$25Wte |
| Cost of oil ... ... ... ... | NZ$95/te |
| Cost of yellowcake... ... ... | US$35/lb ($77.2/kg) |

*The exchange rate at 1 April 1977 was NZ$1 = US$0.9558

23. *Capital costs* of the nuclear power station, estimated to be equivalent to $1,345 million at the time of commissioning, are recovered with interest over the station's life against the electrical energy produced by the station as shown in table 14.3, to give a cost for each unit of energy of 1.939 cents per kWh.

24. *Fuel Costs.* Table 14.4 shows the components of cost for the initial fuel and for replacement fuel as projected by the NZED. According to the figure shown, the total fuel cost per kWh is estimated to be 0.664 cents. If

the spent fuel is not reprocessed, the effect on fuel costs would be relatively small; alternatively the reprocessing cost would eliminate the credit for recovered uranium.

25. *Operation and Maintenance Costs.* The NZED estimates of O and M costs for a nuclear station are based on the IAEA *Nuclear Power Planning Study Manual,* appendix E. Adjusted to convert to 1976 currency, and to a 70 percent output factor (contrasted with the 65 percent output factor used in the *Study Manual*), the O and M costs work out at the 0.125 cents per kWh shown in table 14.5.

26. *Other Costs.* Costs which do not fit into the categories already mentioned are shown in table 14.6. These result in a unit cost of 0.186 cents per kWh.

27. *Total Unit Cost of Nuclear Energy.* By summing all the components of cost, the total estimated unit cost of the energy exported from a 2 × 600 MWe nuclear power station is shown in table 14.7 as 2.914 cents per kWh.

*Table 14.3*

### INTEREST AND REPAYMENT OF THE PWR POWER STATION COST, PER UNIT OF ENERGY

(*Source:* NZED submission 118)

| | |
|---|---|
| Capital cost, including required return on investment | $1,345 million |
| Assumed economic life of station | 30 years |
| Required rate of return on investment | 10 percent p.a. |
| Capital recovery factor (at 10 percent p.a., 30 years) | 0.10608 |
| Annual repayment rate | $1,345 million × 0.10608 |
| | = $142.7 million |
| Number of hours in a year | 8,760 |
| Net power from station | 1.2 GW (1200 MW) |
| Assumed average output factor | 70 percent |
| Annual energy produced (average) | 8760 × 1.2 × 70% |
| | = 7358 GWh |
| | = 7358 million kWh |
| Unit cost to cover capital and interest payments on power station | $\frac{\$142.7 \text{ million} \times 100}{7358 \text{ million}}$ |
| | = 1.939c/kWh |

(April 1976 New Zealand dollars)

The above does not provide for:
(i) The main power transformers and switchyard;
(ii) Road and transmission facilities;
(iii) Initial fuel;
(iv) Owner's costs (land purchase, staff training, quality assurance, commissioning, public information facilities); and
(v) Costs associated with introducing the first nuclear power project into the country (legislation, initial training, licensing authority, etc.)
which are provided for elsewhere. It therefore does not represent the total money outlaid at the time of commissioning.

## *Table 14.4*

## COST OF INITIAL AND REPLACEMENT FUEL FOR A 2 × 600 MWe NUCLEAR STATION (PWR)

(*Source:* NZED submission 118)

| | | Initial Fuel | | Replacement Fuel | |
|---|---|---|---|---|---|
| Component | Assumed* Cost | Quantity* | Cost $m | Quantity per year (at 70 percent output factor) | Cost c/kWh |
| Yellowcake ($U_3O_8$) | $77.2 kg $U_3O_8$ ($35/lb) | 479 400 kg $U_3O_8$ | 37.0 | 215 000 kg $U_3O_8$ | 0.226 |
| Conversion to $UF_6$ | $5/kgU | 406 500 kgU | 2.0 | 182 300 kgU | 0.012 |
| Enrichment | $120/kgSWU | 250 800 kgSWU | 30.1 | 120 000 kgSWU | 0.196 |
| Fabrication | $130/kgU | 93 240 kgU | 12.1 | 28 480 kgU | 0.050 |
| Reprocessing | $150/kg spent fuel | 93 240 kg spent fuel | 14.0 | 28 480 kg spent fuel | 0.058 |
| Credit for recovered uranium | Based on Yellowcake (and enrichment) costs | 87 000 kgU at 0.74 percent enrichment | −6.7 | 27 340 kgU at 0.9 percent enrichment | −0.042 |
| Credit for recovered plutonium | † | 571 kg (fissile) | – | 218 kg (fissile) | – |
| High level waste management | $17/kg spent fuel | 93 240 kg spent fuel | 1.6 | 28 480 kg spent fuel | 0.007 |
| Total cost of initial fuel: | | | $90.1m | | |
| Total cost of fuel per unit of electricity produced: | | | 0.157c/kWh‡ | 0.507c/kWh | |

(Associated transport costs are considered to be included within the above costs).

*Notes on table 14.4.*

*kg $U_3O_8$ is the weight in kilograms of the $U_3U_8$.
kgU is the weight in kilograms of the uranium content of the fuel. One kg of $U_3O_8$ contains 0.848 kg of uranium.
kg SWU is a measure of enrichment quantity.

†Recovered plutonium has value as a recycled fuel in thermal or breeder reactors, but since it is not being used in this way no plutonium credit is included here. An assigned value of $15 per kg would yield a 0.05c per kWh credit.

‡The initial core of fuel constitutes a fuel inventory which is maintained throughout the station life. It is therefore treated as a capital cost which is paid off over the life of the station, as opposed to replacement fuel which is directly related to the amount of energy produced and can be treated as a running cost. Payment of most of the $90.1 million for the first loading of fuel must be made about 2 years before the station is commissioned. Interest during this time brings the total cost at time of commissioning to $109.0 million (at the 10 percent rate of return). Assuming as with the capital cost of the power station, that this fuel inventory is discounted over 30 years at a rate of 10 percent p.a., and that the station achieves a 70 percent output factor:

the annual repayment rate = 109.0 million × 0.10608 = $11.56 million p.a.

$$\text{unit cost of initial core} = \frac{11.56 \text{ million} \times 100}{7358 \text{ million}} = 0.157\text{c per kWh.}$$

### *Table 14.5*

## OPERATION AND MAINTENANCE COSTS FOR NUCLEAR POWER STATIONS

(*Source:* NZED submission 118)

| | |
|---|---|
| Basic cost in 1975 assuming 65 percent output factor | 0.122c/kWh |
| Factor to adjust to 1976 currency | × 1.1 |
| Factor to adjust to 70 percent output factor | $\times \frac{65}{70}$ |
| Operation and maintenance costs | 0.125c/kWh |

### *Table 14.6*

## OTHER COSTS FOR NUCLEAR GENERATION

(All costs in April 1976 New Zealand currency for a 2×600 MWe station.)
(*Source:* NZED submission 118)

| | Cost ($m) | Years Before Commissioning | Equivalent Cost at Commissioning ($m) |
|---|---|---|---|
| Costs to prepare for nuclear technology (initial training, licensing, legislation, preliminary studies) | 15 | 9–15 | 47.7 |
| Regulation during construction | 4.5 | 0–9 | 7.1 |
| Land purchase | 2 | 10 | 5.2 |
| Prelimiary engineering and studies | 5 | 9–14 | 15.1 |
| Construction or improvement of road, rail, and harbour facilities | 10 | 7 | 19.5 |
| Barges and trailers | 2 | 6 | 3.5 |
| Main transformers and switchyard | 9 | 0–1 | 9.4 |
| Power station staff training | 5 | 0–3 | 5.8 |
| Other owner costs: (quality assurance, commissioning, insurance during construction, general and administative costs, public information centre) | 9 | 0–10 | 15.0 |
| Total Station costs: | 46.5 | | 80.6 |
| Decommissioning | 16 | 30 years after commissioning | 1 |
| Total of other costs | $77.5 million | | $129.3million |

*Table 14.7*

## TOTAL COST OF THE ENERGY AT THE POWER STATION: NUCLEAR (PWR)

(All costs in April 1976 New Zealand currency for a 2 × 600 MWe station)

(*Source:* NZED submission 118)

| | |
|---|---|
| Interest and repayment on the power station capital cost ... ... ... ... ... | 1.939c/kWh |
| Fuel cycle costs: | |
| Initial core ... ... ... ... ... | 0.157c/kWh |
| Replacement fuel ... ... ... ... | 0.507c/kWh |
| Operation and maintenance costs ... ... ... | 0.125c/kWh |
| Other costs ... ... ... ... ... ... | 0.186c/kWh |
| Total: ... ... ... ... ... | 2.914c/kWh |

*Table 14.8*

## COST OF DELIVERED ENERGY FROM A NUCLEAR POWER STATION

(All costs in April 1976 New Zealand currency for a 2×600 MWe station.)

(*Source:* NZED submission 118)

| | |
|---|---|
| Cost of energy exported from station | 2.914c/kWh |
| Cost of transmission line (two double circuit 220 kV lines, 2 × 400mm² conductor) ... | $16 million |
| Cost of line per unit of energy exported from station ... | $\frac{16 \times 0.10\,608 \times 100}{7358}$<br>$= 0.0231$c/kWh |
| Transmission loss at full load | 28 790 kW |
| Line loss factor for 70 percent output factor ... ... | 0.59 |
| Energy lost in transmission | $28\,790 \times 8760 \times 0.59$<br>$= 149$ million kWh |
| Total cost of delivered energy | $(2.914 + 0.023) \times \frac{7358}{(7358 - 149)}$<br>$= 2.998$c/kWh |

This assessment of the cost of delivered energy, which includes transmission costs, must be treated as approximate because of the uncertaintities in the assumptions.

28. *Transmission Costs.* The added cost of delivering the energy to consumers is common to almost all alternative methods of energy production (although it can vary in size), and is therefore usually omitted. The cost of delivery depends on the power station site, the location of the consumers, and the existing transmission network, and the power stations. If a total transmission distance of 100 kilometres is assumed, the effect of transmission on the cost of nuclear power would be as shown in table 14.8. The NZED emphasised that this assessment of the cost of delivered energy is only approximate because of the uncertainties in the assumptions. It will be observed that the total cost of *delivered* nuclear energy is estimated by NZED to be 2.998 cents per kWh.

### *Environmental Defence Society Inc. Submissions*

29. In essence, Professor Court's submissions on behalf of the Environmental Defence Society Inc. held that the NZED's capital cost estimates were substantially understated, and that nuclear electricity, if it is ever generated in New Zealand, will be extremely expensive. He claimed that electricity could only be generated in New Zealand by nuclear stations at such a "huge" cost that there was "no way . . . [it] could be used to produce sufficient new wealth to come anywhere near paying for the stations, let alone to provide a net economic gain to the country". Although he refrained from saying so explicitly, his submissions implied that nuclear electricity was likely to prove much more expensive than alternative forms of generation, and should not be countenanced on that ground alone.

30. During cross-examination it became clear that there were differences in the source material and methodology used by the NZED and Professor Court which we were unable to reconcile. It was felt, after cross-examination and detailed consideration, that the NZED submission was a more acceptable statement for the purpose of comparison with alternative forms and contained more complete source material. However, Professor Court's submission caused the NZED to examine closely and amend its earlier estimates, particularly in its third submission 118. Professor Court agreed (*Evidence* p. 1372) that he had made no attempt to consider the comparative economics of other forms of electricity generation.

### *Capital Cost Estimates of Ecology Action (Otago) Inc.*

31. Ecology Action (Otago), in a submission which dealt with many other aspects of the nuclear debate, devoted a section to an estimate of the capital costs likely to be incurred in implementing a nuclear power programme in New Zealand (3). The current dollars method was used. This meant that the extent of future monetary inflation, together with interest during construction, was included in the capital cost. The main problem in this approach is in projecting future rates of inflation.

32. Ecology Action started with the cost figures in 1976 New Zealand dollars used by the NZED and projected them into future dollar values as they estimated them. Initially a factor of 1.59 was applied to the NZED figure of $924 million, which raised it to $1,470 million, assuming a flat rate of 10 percent for inflation during the construction period. (No exception can be taken to an annual 10 percent if it is an acceptable rate for inflation so far ahead. But if it is included, care must be taken to see that it does not recur in another later factor.) However, a further

adjustment is made in the submission by using a factor of 2.18 to raise the $1,470 million to $3,200 million on the basis of its representing "a figure for [future] escalation and interest during construction". This is a factor derived from historical figures over the period 1969–75, and includes many of the elements of extra costs (for example, further safety and environmental requirements, longer construction periods) which the Woite figures covered up to 1976. Obviously IDC must be taken into account. Also the possibility of inflation running at an average above 10 percent should be allowed for. But escalation at past historical rates should not be automatically projected into the future, for it could well be that the very significant upward movements due to more stringent safety requirements and lengthening construction periods evident in the years 1969–75 are not likely to be as significant in the future.

33. Uncertainties such as these have led us to agree with the NZED that the constant dollar method is more helpful for our present purpose which is mainly to compare the unit costs of nuclear power with those of other forms of generation. We must add, however, that the Treasury, though accepting that the constant dollar method is appropriate for construction projects, thought it not altogether suitable for a nuclear project, for "escalation of the total capital cost and escalation of fuel prices somewhat higher than expected would need to be allowed for in some way". We must also make it clear that Ecology Action's submission drew these matters of additional inclusions and the figures to our attention, not so much to establish their accuracy as to demonstrate to us what could happen in an area beset by so many uncertainties.

*Treasury Comments on the NZED Economic Comparisons*

34. The Treasury indicated to us that it had not developed its own expertise on nuclear power, and therefore would not try to enter any debate about what nuclear power is likely to cost (76). In the course of evidence, the Treasury representatives stated that the methodology of parts of the NZED economic appraisal had been examined while the submission was being prepared, and some suggestions had been made. It was conceded that the mechanics of the approach taken by the NZED appeared legitimate. Despite its stated intention of refraining from entering the nuclear costs debate, the Treasury later criticised the NZED appraisal. It was the Treasury's view, based upon a "brief survey of the literature on the cost of nuclear power stations", that the NZED had underestimated the costs in various areas.

35. The Royal Commission tried to obtain a co-ordinated or jointly agreed report from the Treasury and the NZED, but the Treasury, after acknowledging the limitations of its own research into costs, explained that it could see little merit in pursuing an extended discussion as it had not been possible to reach a consensus of views on the question of the construction and operating costs of nuclear power stations. It felt that this was symptomatic of the scarcity of reliable information. The nuclear power option in its view could be deferred for at least 20 years, and because of this, a detailed cost estimate would be of little value, since nuclear technology, costs, and methods are subject to continual change. It considered that the NZED cost estimates did no more than indicate a general order of magnitude.

36. We received a further communication from the Treasury dated 17 November 1977 after our hearings had concluded. It contained additional

comments about the likely cost of nuclear power generation in New Zealand, but the fact that the department's officers were not subjected to cross-examination thereon should be noted.

37. The Treasury assessed some effects on potentially significant costs as:

(a) A longer construction time because the New Zealand economy is based on limited resources.

(b) Decommissioning costs which might well be greater to meet standards higher than those implied in the NZED estimates.

(c) Although overseas data can be found to show similar escalation rates for coal-fired and nuclear stations, in New Zealand the escalation rate for coal-fired stations should be less than that for nuclear when low-sulphur Huntly coal is used.

(d) Though the Treasury agreed that the constant dollar method used by the NZED was acceptable, it pointed out that, when escalation rates were greater than the general rate of inflation, and differential rates of escalation applied to different components of the economic analysis, some weighting of the constant dollar approach would be necessary. In the case of nuclear power, escalation of total capital cost and escalation of fuel prices should, in its view, be allowed for in some way.

(e) Likewise, as the balance of payments is a main (if not the main) constraint in the real growth of the New Zealand economy, the Treasury felt that there should be some weighting to reflect the real value of foreign exchange expenditure in the total cost, especially for large projects involving a substantial foreign exchange component. The higher total amount of foreign exchange needed for nuclear power in both fuel and capital costs compared with a coal plant using local coal would weigh strongly against nuclear power.

38. For this reason the Treasury did not favour conserving indigenous fossil fuels or refusing to exploit undeveloped hydro and geothermal resources at the expense of imposing additional strains on foreign exchange which has an opportunity cost or real value greater than its nominal value in terms of New Zealand currency. In this connection it is of interest to note the comparative implications for overseas expenditure given in a paper presented in May 1977 to the third New Zealand Energy Conference by S. Wong and M. Hewlett of the NZED. These related to the options of using nuclear energy, imported oil, indigenous coal, and imported coal in station units of like capacity, and were based on the assumption that 50 percent of capital expenditure and all fuel expenditure (with the exception of that for indigenous coal) would be incurred overseas, with all costs present-valued to the first year of commissioning of a station. The analysis revealed that, over the expected lifetime of the plants, oil demands most foreign exchange, followed by imported coal, nuclear power, and indigenous coal, thus:

| Type of Plant | Overseas Expenditure (in $ million) |
|---|---|
| *Nuclear—* | |
| Capital | 640 |
| Fuel | 322 |
| Total | 962 |
| *Oil—* | |
| Capital | 190 |
| Fuel | 1546 |
| Total | 1736 |
| *Indigenous Coal—* | |
| Capital | 238 |
| Fuel | … |
| Total | 238 |
| *Imported Coal*—* | |
| Capital | 238 |
| Fuel | 773 |
| Total | 1011 |

*Assume delivery to station at $30 per tonne

## LIKELY COSTS OF NUCLEAR POWER

*General Comment*

39. As New Zealand has no nuclear experience, any assessment of the likely costs here of nuclear power must be largely based upon overseas experience, a point made in the evidence given to us on this issue. Though we were impressed by the fairness and objectivity of the NZED submissions, and found it difficult to fault the methodology used, we had some reservations about the assumptions upon which the calculations were based—assumptions which could lead to both under- and over-estimating. We refer to these below. We have accepted that, in this kind of project evaluation, the constant dollars method is to be preferred to the current dollars alternative as a basis for the economic comparison we wish to make, provided that escalation costs are broadly in line with the general rate of inflation, and that construction times are not increased even further. But some allowance should be made for the possibility that this situation may not always obtain.

*Comment on the NZED Calculations*

40. *Reactor Type.* The NZED estimates are related to the PWR, but no choice of reactor type has yet been made. *Location and Siting.* No decisions have yet been made, and ancillary capital expenditure, such as roading and transmission, could vary directly according to the choice of location. *Seismic Allowance.* It is perhaps open to question whether the NZED has adequately allowed for seismic requirements in New Zealand.

41. *Extra costs of constructing the power station outside the country which supplies it.* We are unable to express an opinion one way or the other on this point as we have no adequate information. The aspect which should not be overlooked is that, in the absence of any substantial consensus among New Zealanders about the need and desirability of introducing nuclear

power, the construction of a nuclear power station might possibly be accompanied by various forms of active opposition, and a lack of co-operation by organised labour in line with present FOL policy. These are only a few of the things that could adversely influence the financial costs of bringing the first nuclear station "on stream". And as another possibility, the New Zealand licensing authority could impose safety and environmental conditions stricter than those of the 1976 United States licensing standards upon which the NZED estimates are based. Overseas standards of licensing are, however, possibly high enough to be acceptable to New Zealand.

42. *Output Factor.* It may be argued whether the average 70 percent output factor assumed by the NZED is capable of achievement. Overseas experience with PWR stations in operation may not be long enough. If a lower figure eventuates, there would be a corresponding need to reassess unit costs. The evidence from overseas on this point is conflicting and uncertain. Even with the same reactor type there have been marked variations in performance. It should be noted, however, that for the purpose of its comparisons with oil-fired and coal-fired stations, the NZED has predicated a 70 percent output factor for all types, and thus has been consistent in its approach. If the assumed output factor had been 65 percent for all three options, the relative unit costs would not have shown any marked change. Figure 14.2 shows the cost sensitivity, for different output factors, of nuclear (PWR), coal, and oil stations.

*Figure 14.2*

ENERGY COST v OUTPUT FACTOR

(Costs are in April 1976 currency)

(*Source*: NZED submission 118)

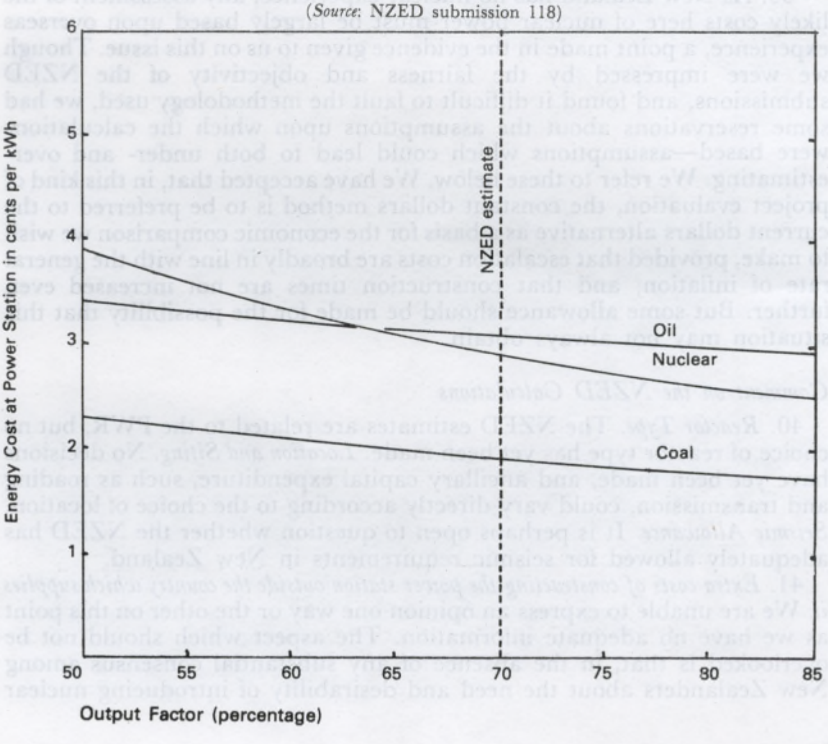
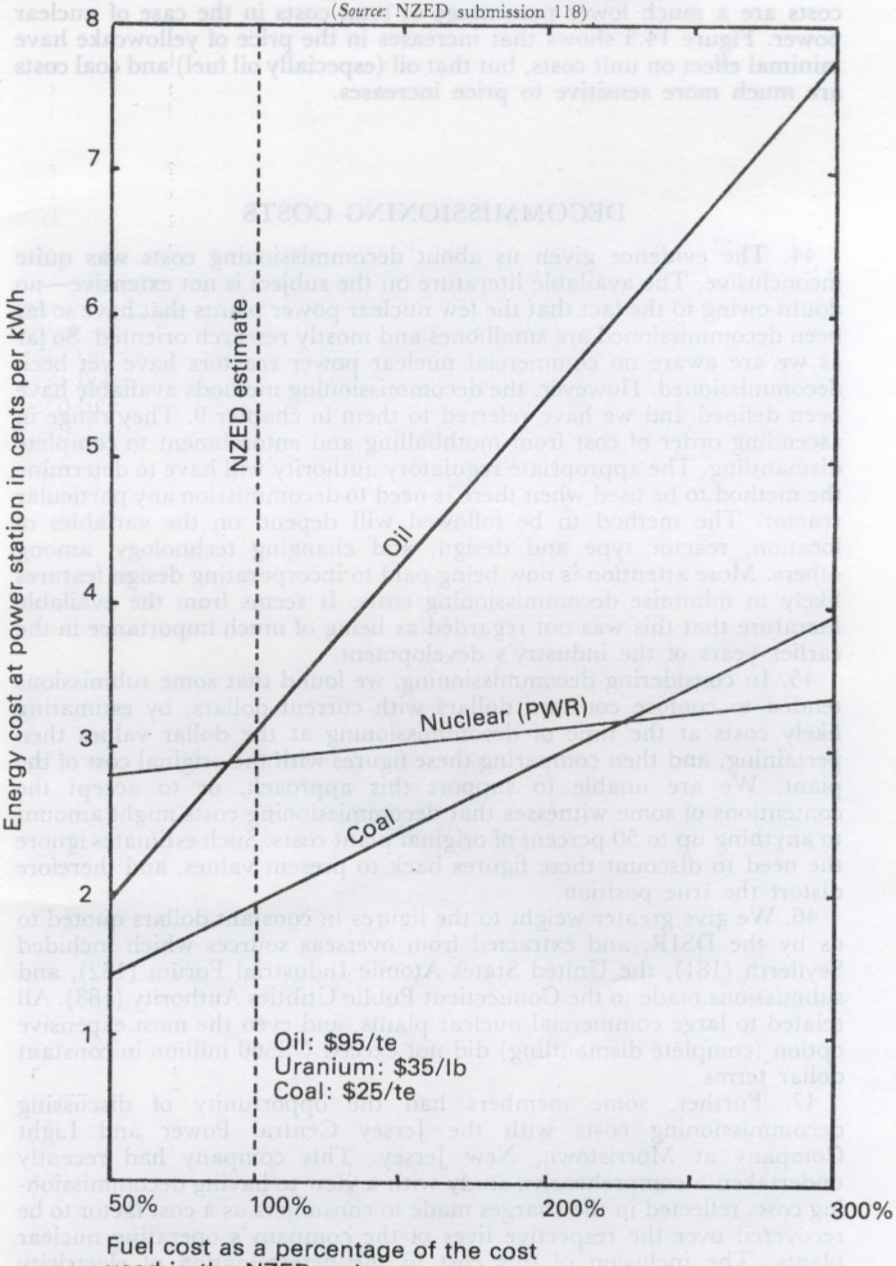


*Figure 14.3*

ENERGY COST v FUEL COST

(Costs are in April 1976 N.Z. currency)

(*Source*: NZED submission 118)



43. *Fuel Costs.* It is also difficult to predict the effect on the unit costs of increases in the prices of yellowcake, oil, and coal. It is very clear, however, that increases in the price of yellowcake have much less effect on unit costs than comparable increases in the prices of oil and coal, as fuel costs are a much lower percentage of total costs in the case of nuclear power. Figure 14.3 shows that increases in the price of yellowcake have minimal effect on unit costs, but that oil (especially oil fuel) and coal costs are much more sensitive to price increases.

## DECOMMISSIONING COSTS

44. The evidence given us about decommissioning costs was quite inconclusive. The available literature on the subject is not extensive—no doubt owing to the fact that the few nuclear power plants that have so far been decommissioned are small ones and mostly research oriented. So far as we are aware no commercial nuclear power reactors have yet been decommissioned. However, the decommissioning methods available have been defined and we have referred to them in chapter 9. They range in ascending order of cost from mothballing and entombment to complete dismantling. The appropriate regulatory authority will have to determine the method to be used when there is need to decommission any particular reactor. The method to be followed will depend on the variables of location, reactor type and design, and changing technology, among others. More attention is now being paid to incorporating design features likely to minimise decommissioning costs. It seems from the available literature that this was not regarded as being of much importance in the earlier years of the industry's development.

45. In considering decommissioning, we found that some submissions tended to confuse constant dollars with current dollars, by estimating likely costs at the time of decommissioning at the dollar values then pertaining, and then comparing these figures with the original cost of the plant. We are unable to support this approach, or to accept the contentions of some witnesses that decommissioning costs might amount to anything up to 50 percent of original plant costs. Such estimates ignore the need to discount these figures back to present values, and therefore distort the true position.

46. We give greater weight to the figures in constant dollars quoted to us by the DSIR, and extracted from overseas sources which included Seyfferth (181), the United States Atomic Industrial Forum (182), and submissions made to the Connecticut Public Utilities Authority (183). All related to large commercial nuclear plants, and even the most expensive option (complete dismantling) did not exceed US$60 million in constant dollar terms.

47. Further, some members had the opportunity of discussing decommissioning costs with the Jersey Central Power and Light Company at Morristown, New Jersey. This company had recently undertaken a comprehensive study with a view to having decommissioning costs reflected in the charges made to consumers as a cost factor to be recovered over the respective lives of the company's operating nuclear plants. The inclusion of this cost in the determination of electricity charges to consumers needed to be approved by the New Jersey Department of Public Utilities. It could be expected that any price-

controlled utility would take great care in an exercise of this kind not to understate the decommissioning cost with which it was likely to be faced. The figures quoted by the company in its official petition related to the Oyster Creek plant (640 MWe) expected to be decommissioned in the year 2003, and the Three Mile Island plant (800 MWe) expected to be decommissioned in 2008. They are set out below, all cost figures being in 1976 United States dollars:

| *Plant* | *Option* | *Cost* (US$ million) |
|---|---|---|
| Oyster Creek | (a) Mothballing | 11 |
| | (b) In-place entombment | 35 |
| | (c) Complete dismantling | 107 |
| Three Mile Island | (a) Mothballing | 7 |
| | (b) In-place entombment | 40 |
| | (c) Complete dismantling | 104 |

These figures include, as appropriate, the capitalised post-decommissioning surveillance and maintenance costs. The company took the view that in-place entombment was the decommissioning method they could reasonably contemplate, and it was the cost of this method they sought to have included in rate calculations. The company pointed out that the provision proposed would be approximately equal to 0.25 mills (thousandths of a dollar) per kWh, or approximately half of 1 percent of the total cost (including fixed charges) per kWh. On this basis, it is obvious that decommissioning costs would not be a significant factor in increasing electricity charges to the consumer, and even if the more expensive complete dismantling method was used, the consumer would not be greatly disadvantaged.

48. We conclude that the NZED estimates of decommissioning costs are not so unreasonable as some witnesses argued. Though there could well be some understatement, we see no reason for believing that even for the most expensive option, the decommissioning costs would at most exceed 10 percent of original costs. We agree with the NZED which argued that decommissioning costs would in no circumstances have any marked effect on electricity charges.

## GENERAL COMMENTS

### *Capital Costs*

49. The importance of establishing (if that is possible) the magnitude of the capital costs of a nuclear power programme in New Zealand has been reflected in the great amount of time we have given to this subject. The diversity of views about capital costs makes it impossible for us to express any confident opinion. This is particularly so for a nuclear power station with a projected commissioning date of 1990–91 or later, because of the long lead time and the possible economic and technological changes which could affect both nuclear and alternative options. Changes in world supply conditions, including availability and pricing of nuclear or alternative energy units for producing electricity could also have significant effects. It is also difficult to estimate capital costs which reasonably provide for escalation due to safety and other standards, and for general worldwide or local inflationary trends. The recent rate of

inflation may not happen again in the medium future, but there can be no assurance of this. Consequently, the capital costs of a nuclear power unit, or for that matter, the construction costs of alternative power stations, cannot be established so far ahead with any degree of certainty.

50. To compare costs, the NZED took present types of nuclear, coal-fired, and oil-fired power stations. For the nuclear it selected a PWR type reactor on which cost data including provision for United States safety and environmental standards are available. As a base it used the Woite study mentioned earlier, modified for New Zealand conditions, including seismic, and arrived at a cost figure in 1976 dollars. It included as capital charges provision for various costs such as those of training, of a regulatory body, etc. It did not include future general monetary inflation, so the total capital cost arrived at will not be the actual cost in 1990–91 dollars.

51. The NZED comparative figures may themselves be compared with those in the Flowers and the Ford Foundation - MITRE reports. These reports arrived at overall costings similar to those the NZED, although there were some differences in the treatment of construction times, of interest during construction, and of capital repayment, and in assumptions about operating costs. In both cases, the cost of electricity generated from nuclear energy was found to be economically competitive with the cost of electricity generated from coal, while in Britain it was also competitive with oil. The NZED estimates showed a total capital cost in 1976 dollars for a basic nuclear power station in New Zealand to be about 33 percent higher than the Ford Foundation - MITRE estimate. This difference would reflect mainly smaller units and the extra costs of constructing the power station outside the country of supply. For a coal-fired power station using low sulphur coal, the NZED total basic capital cost per installed kW was reasonably close to the Ford Foundation - MITRE figure, although the United States coal-fired stations were much larger. No comparable figures were available for oil. The NZED capital costings for oil are based on New Zealand experience. (See further appendix D.)

52. We repeat that the comparisons of total capital costs in 1976 values for nuclear and coal arrived at by the methodology used by the NZED have a satisfactory degree of relevance for comparing the economics of both types of energy. But these figures do *not*, for reasons already given, reflect the total capital costs in 1990–91 dollars.

### *Unit Costs (or Costs per kWh)*

53. *Nuclear Power.* A useful comparison of unit costs can be made using figures derived from the Ford Foundation - MITRE report and those given in the NZED submissions, even though there are differences in output factors and in size of units. The former report assumes an output factor of 60 percent whereas the NZED has used 70 percent. The larger United States nuclear power units could have some economies of scale which would offset the output factor, but these are difficult to evaluate. Subject to these qualifications, the component for total capital costs expressed as a unit cost (per kWh) is 38 percent higher in the NZED submission than the equivalent in the United States. The fuel charges expressed as a unit cost are approximately the same, and, although they are not a significant consideration in total cost, the operation and maintenance costs per unit are lower in the New Zealand case.

54. Overall, the NZED estimates, the methodology of which is broadly the same as that of the Ford Foundation - MITRE report, have resulted in a 22 percent increase on the Ford Foundation - MITRE report figure in terms of 1976 dollars. The various assumptions have resulted in higher fuel costings in the New Zealand case, but are largely offset by the differential in output factor. If a 60 percent output factor had been used by the NZED, then fuel costs would have been about 14 percent higher. These costs, however, can only be considered in a broad sense for reasons already given. (See appendix D.)

55. *Nuclear Compared with Coal.* A useful comparison can also be made between nuclear and coal, using 1976 dollars and the above methodology. The New Zealand figures for a coal-fired electricity station are lower both in capital costs and in (domestic) fuel costs than those of the United States as shown by the Ford Foundation - MITRE report. This comes largely from the use in the eastern States of coal high, or relatively high, in sulphur, necessitating scrubbers and pollutant removers. The capital cost per unit (kWh) in the United States for those plants using scrubbers is nearly 70 percent higher than the unit capital cost in New Zealand. The NZED capital cost figures were based on Huntly estimates, which may not have encountered the same environmental problems and the extra costs for water supplies that the eastern United States cities do. On the other hand the cost of coal at the mines is about the same, but transport costs are significant. The Huntly power station is near a coal field. Taking these factors into consideration, the unit fuel costs, which for a coal-fired power station almost equal or exceed unit capital costs, are about 20 percent higher in the United States for high-sulphur coal mainly owing to the cost of transporting coal.

56. The overall effect of these figures is that, for a coal-fired power station in the eastern United States using scrubbers, the unit cost of power generated (on NZED costings in 1976 dollars) is about 50 percent higher than for one in New Zealand. Whether future New Zealand coal-fired power stations will attract higher capital costs from environmental restrictions and advanced technologies is not known. The general comparison nevertheless is significant, and largely accounts for the margin which nuclear power generation enjoys in the eastern United States. In the middle west, the margin is reduced because low cost, low sulphur coal is available.

57. The above comments explain the apparent paradox that in New Zealand, on NZED cost estimates, the total unit cost of electricity produced from domestic coal near a power station is about two-thirds of the unit cost of that produced from a nuclear station of similar capacity. The unit cost from a coal-fired station may rise from the increased capital costs already referred to; and fuel costs would probably rise if coal had to be imported. Summaries of capital and operating costs for nuclear and coal-fired power in the United States and New Zealand are given in appendix D.

58. *Nuclear Compared with Oil.* We have accepted the oil-fired station costs given by the NZED as they are stated to be based on New Zealand experience. Although the capital costs of an oil-fired station are lower than those for coal or nuclear, the cost of fuel oil, and possible problems of overseas supply and future prices, have largely ruled out a programme of oil-fired stations, unless New Zealand makes a useful discovery of oil.

## SUMMARY

59. Though we have been unable to determine with any confidence (because of monetary inflation, and other escalation over time) the future likely capital cost in New Zealand for a nuclear power station for commissioning in 1990–91, some broad magnitudes and unit costings of power generation can reasonably be established so that economic comparisons can be made to help determine future policy.

60. These figures are based on 1976 values and the constant dollar method and must not be regarded as in any way the ultimate costs, as they do not allow for future monetary inflation or other escalation. However, they do, at the level of the unit of power generated, result in figures useful for general economic comparison, subject to some qualifications particularly in respect of assumptions underlying the capital and operating costs. In some cases any change in these assumptions is of marginal effect; in other cases, they are more important.

61. In the matter of capital costs, future inflationary influences are more important the higher the capital outlay. Substantial variations in capital expenditure could obviously have marked effects on the relationship of the unit costs which we have discussed (see table 14.2). Furthermore, the overseas exchange content of a power programme is an important consideration, as the Treasury has pointed out. Allowing for the facts that the nature of the comparisons, and uncertainties about capital and operating costs, permit only broad conclusions, it is nevertheless possible to say that, on present evidence and in general economic terms, electricity from coal is likely to continue to be cheaper to produce than electricity from nuclear power, and oil (if imported) is likely to be the most expensive. Long-term domestic supplies of coal are, however, limited unless further coal reserves are found (see chapters 7 and 15). Imported coal would probably be more expensive than domestic coal.

62. In terms of the significant costs in overseas exchange, the fuel bill for electric power generated from imported oil would be the highest, followed by imported coal, and then by nuclear fuel, subject of course to world prices and available supply. Indigenous coal would involve a comparatively low overseas cost. Overall, the most expensive in terms of overseas exchange would be an oil-fired station (if all fuel was imported), next would be a coal-fired station using wholly imported coal, followed closely by nuclear power, and the lowest would be a power station using indigenous coal.

63. The economic comparisons in this chapter have been between the costs of electricity generation by means of nuclear and fossil fuels. Hydro and geothermal generation are dealt with in chapters 7 and 15. However, for convenience, we give below the unit costs for all generation methods in cents per kWh, derived by the NZED from the capital figures mentioned previously which appeared in the department's submissions.

| Nuclear | New Zealand Coal | Oil | New Hydro | New Geothermal |
|---|---|---|---|---|
| 2.9 | 1.9 | 3.1 | 2.5 | 1.6 |

These unit costs, when considered along with the capital investment figure given in paragraph 19 (based on NZED calculations), indicate quite clearly how costly a nuclear power programme could be, compared with a programme based on coal-fired stations. However, the supply of indigenous coal for electricity generation is not unlimited.

# *Chapter 15.* OVERALL FUTURE IMPLICATIONS

## INTRODUCTION

1. The total impact of nuclear power on New Zealand should be assessed from a long-term development plan not from the introduction of a single reactor. To do this we must speculate on estimated growth beyond the turn of the century, as we were given little or no evidence on this. Though the NZERDC scenarios project well beyond the year 2000, a more simplified approach is needed for this chapter. In addition, the evidence we heard has given us a better understanding of the potential of our geothermal and other indigenous resources.

2. Matters of importance to a possible nuclear programme include commissioning dates, the number of sites that may be needed, the absolute magnitude of the waste problem, centralisation or otherwise of generating units, possible reactor type, capital flows, overseas balance of payment questions, and the security of fuel supplies. Of equal importance is the demand that any such programme may place on the labour force and education system.

3. The source of process heat for industry is another matter of concern beyond the year 2000. In Part III of our report it was tacitly assumed that there was no significant competition for indigenous resources between the electrical supply industry and other industries. For considerations up to about the year 2000 the evidence presented to us made any such assumption axiomatic because the amount of natural resources allocated to the production of electricity was always explicitly stated. However, for even before the year 2000, this assumption could be at fault if, for example, some or all of the natural gas already committed for electricity production was diverted to the direct production of process heat. Of even more importance is that beyond 2000, with increasing restrictions on oil supplies, the total demands on our indigenous resources (especially coal) could seriously limit their supply for electricity production.

4. It is inevitable in this chapter that we should directly or indirectly comment on overall energy policy. However, much of the discussion will of necessity be little more than speculative. The main aim is to reach some kind of measure of the total consequences to New Zealand of introducing nuclear power.

## GROWTH BEYOND 2000 AD

5. In chapter 4 we noted that one study group reporting to the World Energy Conference in 1977 estimated that the average annual growth in electricity from 1972 to 2020 would be 4.2 percent for OECD countries, and 5.1 percent for the world as a whole. These figures are reasonably consistent with other estimates based on "present trends" which have been drawn to our attention. For a New Zealand base figure of 15 500 GWh for 1971–72, the OECD growth rate gives a value of 116 000 GWh per annum by the year 2020.

6. During this time the population of New Zealand could grow at a rate above that of most other OECD countries. On the other hand, New Zealand is already a relatively high per capita consumer of electricity, even for an OECD country. We thus assume that the annual New Zealand consumption by the year 2020 will only be slightly above that corresponding to the OECD growth rate—in fact, about 130 000 GWh per annum. For a 55 percent annual load factor, normally adopted for planning purposes, this corresponds to a maximum demand of 27 GW, which, on allowing for a 10 percent margin, gives a total generating capacity of about 30 GW.

7. The choice of 130 000 GWh per annum by 2020 is arbitrary, but reasonably consistent with the discussion in Part III. It implies 60 000 GWh per annum by the year 2000, and 90 000 GWh by the year 2010, these estimates corresponding to average annual growth rates of approximately 4.5 percent from now to the end of the century, 4 percent from 2000 to 2010, and 3.5 percent from 2010 to 2020.

8. Again, applying the type of analysis given in chapter 8, the sector needs for the year 2020 could be: domestic, 35 000 GWh; all industrial plus commercial, 70 000 GWh; and transport 25 000, giving a total of 130 000 GWh. These figures would be consistent with a population of 5 million by the year 2020 which appears possible, but make no allowance for any major technological innovation apart from introducing the electric private car. One type of electric car has recently gone into large-scale production in the United States, so the possibility of much of private transport being electrically powered after 2000 must be taken seriously. About 2020, there could of course be an equal proportion of conventional transport still operating which would use, say, the equivalent of 75 000 GWh of liquid fuels. This is about the amount estimated for all transport for the year 2000 in the NZERDC "continuation" scenario (see appendix C), and is about twice our present oil imports. At this stage we make no comment on the reasonableness of this figure of 75 000 GWh.

9. There are of course many factors that could invalidate our estimate of 130 000 GWh per annum. For example, an upsurge in birth and immigration rates towards the end of the century could lead to a population of say 6 million rather than 5 million by the year 2020. On the other hand, population could decrease, and changes in life-style could drastically modify our present patterns of energy consumption. However, we consider 130 000 GWh to be a reasonable estimate for present purposes.

10. In Part III it was stated and shown that, given the necessary finance and manpower, and assuming no major environmental objections, New Zealand could supply by 2001 at least 70 000 GWh per annum of electricity by using known indigenous resources. It was also implied that beyond 2001 a further 25 000 GWh per annum at least could almost certainly be obtained if needed. This could come from 6000 GWh of

Waikato and 6000 GWh of Southland coals, about 4000 GWh from further major hydro (almost all in the South Island), 5600 GWh from North Island geothermal sources, and about 4000 GWh from small hydro. It seems reasonable to suppose that, if the assured 70 000 GWh per annum which can be fully developed before the turn of the century proves to be both economically and environmentally acceptable, then possibly 20 000 GWh of this extra 25 000 GWh would also be acceptable. Furthermore, from appraisal, the location and type of resource would seem to be adequate to match the load.

11. Taking 60 000 GWh per annum as the actual need by the year 2000 (see chapter 8), we therefore have at least 30 000 GWh per annum which could be generated from known indigenous resources after the year 2001. When this may be produced is open to speculation; but from the preceding discussion and that in Part III, it is reasonable to assume that stations using these known resources will be fully developed before a nuclear or any other type of station dependent on imported fuels, or advanced or improved technology, is commissioned. That this is advisable, at least in the case of nuclear, was strongly emphasised to us by Dr Eklund, the IAEA Director-General.

12. From paragraph 10 it follows that New Zealand can satisfy its electricity demands up to 2010–2011 from known, and presumably acceptable, indigenous resources. For a requirement of 130 000 GWh per annum by 2020, an additional 40 000 GWh per annum from at present unspecified sources must be found. To fully understand the nature of this need, the loads in 2010 and 2020 must be resolved into their peak, intermediate, and base components. Table 15.1 does this. It is assumed (see chapter 7) that peak comprises 3 percent, intermediate 37 percent, and base 60 percent of the load. It is also assumed that the ratio of North to South Island needs is the same as the present ratio of about 2 : 1.

*Table 15.1*

ELECTRICITY DEMAND 2010 AND 2020

| | Peak | Intermediate | Base |
|---|---|---|---|
| North Island— | | | |
| 2020 ... ... ... | 2 600 | 32 100 | 52 000 |
| 2010 ... ... ... | 1 800 | 22 200 | 36 000 |
| Difference ... | 800 | 9 900 | 16 000 |
| South Island— | | | |
| 2020 ... ... ... | 1 300 | 16 000 | 26 000 |
| 2010 ... ... ... | 900 | 11 100 | 18 000 |
| Difference ... | 400 | 4 900 | 8 000 |

13. From 2010 to 2020 the increment in intermediate load could be met by relegating existing base-load plant to intermediate. In the North Island, Auckland thermals No. 1 and 2 with added generating capacity could be used for this, as there would still be enough natural gas from the initial commitment of the Maui field, and associated coal in the case of Auckland No. 2. However, to do this about a further 13 000 GWh per annum of base-load output over and above the 16 000 GWh shown in

table 15.1 would have to be found as replacement. Thus, about 29 000 GWh per annum from new base-load plant would have to be found beyond 2010 to meet North Island needs in 2020.

14. Similarly, in the South Island, the transfer of hydro plant from base to intermediate duty could require a further 7700 GWh from base-load replacement plant. (This assumes a change in output factor from the 55 percent typical of hydro base-load plant operation to 35 percent.) Thus, a total of 16 000 GWh per annum would have to be found from new base-load plant in the South Island. One notes that if thermal stations provided this, only 4000 GWh of base-load requirement (about 15 percent) would come from hydro sources by the year 2020, as Southland coal would already be accounting for 6000 GWh of the total 26 000 GWh per annum of the South Island base load.

15. For plant operating at 70 percent output factors the generating capabilities needed by 2020 could be met by base-load plant, presumably thermal, of about 5 GWe in the North and 2.5 GWe in the South Island, supplied from resources over and above those at present regarded as known and acceptable. The successful introduction of, say, wind-powered turbines for intermediate-load duty could halve the needs, but would probably not retard the date of introducing new base-load plant beyond 2010–2011. On the other hand, if neither the 6000 GWh per annum from Waikato coal nor the 6000 GWh from Southland coal assumed to become available between 2000 and 2010 were used, an additional 1 GWe would have to be added to both the North and South Island requirements, and the date of commissioning of the first of the new base-load plants advanced to about 2005–2007.

16. As we have already implied, the growth of electricity could be showing marked signs of saturation by about 2030. Certain estimates that have been drawn to our attention (for example, see (174)) suggest that by 2020 the annual growth rate could lie in the range 0.3–2.5 percent for OECD countries, and about 1.3–3.0 percent for the world as a whole. Thus, in New Zealand's case it could well be another 5 years beyond 2020 before a further 1 GWe base-load plant was needed. With such a time scale it is conceivable that any additional plant could be of the fusion, as distinct from the fission, reactor type, or some other alternative. Thus, subject to many assumptions, we have possibly estimated an upper limit of what may have to be supplied by fission reactors in New Zealand, namely 5 GWe in the North Island and 2.5 GWe in the South.

## GENERAL ECONOMIC CONSIDERATIONS

17. Before outlining a possible nuclear power programme, we briefly discuss the credibility of the estimates we have just made in the light of certain general economic considerations, including the use of indigenous resources for process heat, electricity's share of the energy market, capital requirements, and the depletion of indigenous resources.

### *Process Heat*

18. From the analysis given in chapter 8, and the estimates just made, we estimate industry's needs for process heat to be: 55 000 GWh in the year 2000, 80 000 GWh in 2010, and 110 000 GWh in 2020. These estimates are even more speculative than those for electricity, but are adequate for the points we wish to make. They correspond to an average

annual rate of growth of about 4 percent from now to the end of the century, and about 3.5 percent from then to 2020, and are most likely on the high side.

19. To obtain some measure of the demands that needs for process heat could place on our indigenous resources, we note (as accounted for in chapter 8) that one Maui gas field, with a 30-year life, can provide about 35 000 GWh per annum of useful heat. This assumes an overall industrial utilisation of natural gas of about 60 percent, allowing for losses and efficiency of end use. Similarly, in round figures, for an overall efficiency of 80 percent, 1 million tonnes of coal will produce about 5000 GWh of useful heat. It follows that our assumed process heat requirements could be met by about 11 million tonnes of coal per annum (the figures presented to us by the DSIR agree), or one and a half Maui fields by the year 2000, 16 million tonnes of coal per annum, or about 2 Maui fields in 2010, and 22 million tonnes of coal per annum or 3 Maui fields in 2020.

20. Assuming that the 7.5 GWe of base-load plant needed beyond 2010 is to be nuclear, those stations using natural gas and coal for the electricity growth patterns outlined above are: for the year 2000, about 2 million tonnes of coal per annum and half a Maui field; and for the years 2010 and beyond, 8 million tonnes of coal per annum and three-quarters of a Maui field. As implied in several submissions, it has been assumed that Auckland thermal No. 2 will not be fully commissioned until beyond 2000. This delay might be possible if, as estimated, only 60 000 GWh rather than 70 000 is needed in that year.

21. Assuming that all process heat is to be supplied by coal, the total amount needed, including that for electricity, would be: 13 million tonnes per annum for the year 2000; 24 million tonnes per annum by 2010; and 30 million tonnes per annum by 2020 with probably no great increase beyond that time. This implies that the known economically recoverable reserves of 940 million tonnes would be exhausted by 2040. However, with new mining techniques these reserves could perhaps be nearer to 2000 million tonnes by 2020, rather than about the 1000 million tonnes at present estimated, and hence there would be adequate resources for well into the second half of the next century. As emphasised in chapter 3, the immediate question is therefore one of supply rather than of magnitude of resource. But, again, this depends greatly on the environmental considerations and technological developments discussed in chapter 7.

22. In 1974 the coal industry produced about 2.6 million tonnes with a labour force of about 1600 (44). A necessary ten to twelve-fold increase in production by 2010–2020 would probably not imply a similar increase in the workforce. With new techniques, a force of under 10 000 workers could probably cope. The main problem thus appears to be the demands placed on the coal-mining industry at the turn of the century.

23. For reasons given in chapter 7, it would seem almost impossible to produce 13 million tonnes of coal per annum by the year 2000. However, recent announcements give the magnitude of the Maui field as about 13 percent greater than that assumed in chapter 8. Thus, even with domestic reticulation on the scale discussed in chapter 8, and the use of 10 percent of the Maui output for a petrochemical industry, it is conceivable that natural gas could supply 10 percent of the energy for process heat by 2000. Again, it is possible that the natural gas at present allocated to Auckland thermal No. 2 could be initially diverted for this purpose—a case of "robbing Peter to pay Paul", but the long-term consequences would have

to be carefully investigated before any such action was taken. It might also be possible to import coal and/or natural gas, the former being discussed in chapters 7 and 14 in respect of electricity generation. With, however, the coal for electricity production in 2000 having already been committed many years before then, and as there will be no further major requirements until about 2005–2007, the real problem emerges as one associated with process heat rather than with electricity.

24. Irrespective of how the problem of process heat is solved in and about the year 2000, it appears from the magnitude of the figures previously given that, even in the event of other major natural gas and/or oil discoveries, New Zealand will depend heavily on the coal industry in the first half of the next century. The industry will thus need to be very rapidly built up from 1990 to 2010. It also follows that, because of the potentially large industrial demand, New Zealand cannot rely on indigenous fossil-fuel reserves for electricity production over and above those already assumed to be committed before 2010. However, we stress again that any supply problems about the turn of the century should be assigned to the production of process heat rather than of electricity. To do otherwise could lead to seriously wrong conclusions.

*Electricity's Share of the Energy Market*

25. From table 3.3 it is apparent that the doubling time for consumer energy in New Zealand from 1924 to 1975 was close to a constant 20 years. This corresponds to an almost constant growth rate of about 3.5 percent a year. The associated energy consumed in 1975 was 74 000 GWh, with electricity's share being close to 23 percent. From the preceding sections we arrive at the following approximate estimate for consumer energy for 2000–2010. The process heat requirements have been increased by 20 percent to allow for losses in end use.

*Table 15.2*

CONSUMER ENERGY IN GWh PER ANNUM

| | Electricity | Process Heat | Transport "Liquid Fuels" | Total |
|---|---|---|---|---|
| 2000 … … | 60 000 | 65 000 | 75 000 | 200 000 |
| 2010 … … | 90 000 | 95 000 | 75 000 | 260 000 |
| 2020 … … | 130 000 | 130 000 | 75 000 | 335 000 |

In this table electricity's share of the consumer market goes from 30 percent in 2000 to 35 percent in 2010, and to just under 40 percent in 2020. These figures for electricity's share are probably high since we have ignored the possible domestic and commercial use of natural gas.

26. The figure of 335 000 GWh per annum for 2020 is about 1200 TJ, and lies between the NZERDC "continuation" and "low pollution" scenario values for 2025, as given in table 3.5. Furthermore, the values imply that the 20-year doubling time persists up to 2000 with a decreasing

growth rate beyond that date. Thus, although inferential, the values given in table 15.2 seem reasonable. It is also interesting to note that in 1975, with a population of about 3 million, New Zealand's consumer energy consumption per capita was about 25 000 GWh per annum. For a population of 5 million in 2020, this would have increased to about 65 000 GWh per capita per annum.

27. The Friends of the Earth often asked in cross-examination what electricity's share of the consumer energy market should be. No one could give a suitable answer, and neither can we. We note, however, that provided that the nation's energy supplies as a whole are in no way jeopardised by too great a reliance on one single source, we can foresee no great difficulty in energy supply. We believe that the programme outlined for electricity development in the preceding section is consistent with this concept. Furthermore, with respect to comments made so far in this section, we believe such a programme to be realistic.

### *Capital Requirements*

28. For the proposed programme up to the year 2020, 40 000 GWh per annum of generating capability must be added between now and the end of the century, and 70 000 GWh per annum between then and the year 2020. Provided that the necessary capital can be found between now and the end of the century, and provided the real GNP should double between 2000 and 2020 (a reasonable expectation corresponding to an annual growth rate of 3.5 percent), it can be argued that adequate capital should be available at all times. The Treasury's submission concluded that 60 000 GWh per annum was a reasonable estimate for the end of the century. Thus it would appear that, at least up to that time, the necessary capital can be found, and any associated overseas balance of payment problems dealt with.

29. If Auckland thermal No. 2 station was delayed until beyond 2000, the second half of the programme up to that year would require the complete implementation of the MWD proposal for accelerated geothermal and major hydro resources as discussed in chapter 7. Ignoring interest during construction, the cash requirements for this programme in early 1976 dollars (for typical years) are (56):

| | | $ million |
|---|---|---|
| 1980 | ... | 37 |
| 1985 | ... | 112 |
| 1990 | ... | 220 |
| 1995 | ... | 209 |
| 2000 | ... | 176 |

The total cost of the programme would be over $3,000 million, with most of the expenditure over a period of 15 years, corresponding to an average of about $200 million a year. This is to be compared with an increase in the total capital outlay on new stations in 1976–77 of about $185 million (48). The capital outlay on new stations in that year was about 1.5 percent of the 1976–77 GNP of about $12,000 million. By about the mid-point of the MWD programme in 1992 one might anticipate a 60 percent increase in real GNP (at about 3.5 percent per annum) to $20,000 million, and thus, allowing for a 40 percent increase in costs, for interest during construction of individual stations, the MWD programme represents an allocation of funds comparable with the present.

30. The MWD proposal was strongly supported by the Treasury (76), and hence, we may assume, in addition to the arguments in paragraph 29, that the necessary cash flows up to the year 2000 are practicable. It would appear to follow from our previous statement in paragraph 28 that the necessary cash flows would also be available for 2000–2020. However, it can be argued that, with the most economic of our indigenous resources having been developed, the capital cost per unit of electricity generated could rapidly rise in the next century, especially if it became necessary to rely on advanced imported technologies. This would almost certainly be the case if there was no change in either generating unit or station size. Fortunately this need not be so.

31. As figure 15.1 shows, the capital cost per unit of electricity generated decreases dramatically with increasing size of turbine-generator unit, and also with station size. The average station size for geothermal plant will be about 150 MW. Again with the Huntly turbine-generator units for example being only 250 MW, there is clearly scope in New Zealand for a considerable decrease in real costs per unit of electricity produced as the overall generating system grows. Decreases of this nature could compensate for increases associated with importing advanced (for New Zealand) technologies.

32. To take advantage of the economic benefits of increased size it is necessary to centralise the generating system to a large degree. A number of those who presented submissions to us argued that such centralisation was socially undesirable. We reached no definite conclusion on this matter (see chapter 3).

### *The Depletion of Indigenous Resources*

33. The 8 million tonnes of coal per annum needed for electricity production from about 2005 to 2007 onwards, represents a total commitment of about 240 million tonnes, assuming each station has a 30-year life. If these stations were replaced by alternative electricity plant some time between 2030 and 2040, New Zealand would have consumed in producing its electricity about 25 percent of present known economically recoverable coal reserves. This is probably an acceptable figure. But if the extra 7.5 GWe of base-load stations needed beyond 2010 were also to be coal-fired, there would be an extra commitment of over 500 million tonnes, which, considering the process heat requirements, is probably untenable.

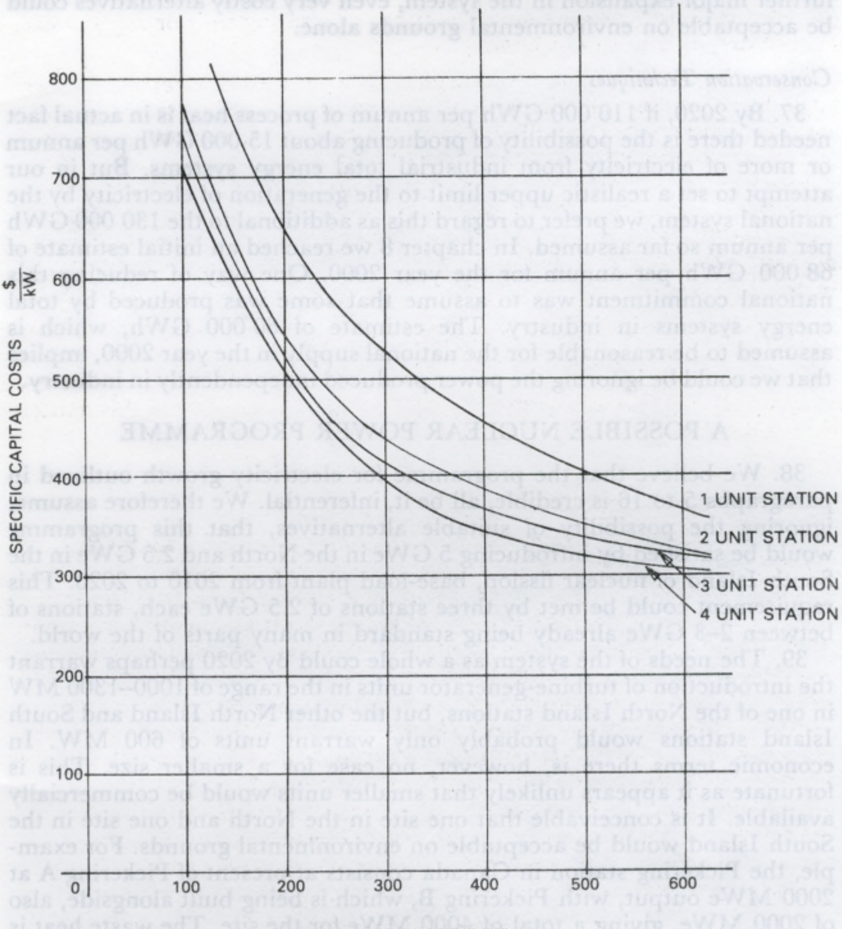
34. From about 2005 onwards, the programme outlined in the preceding section requires about 13 000 GWh per annum from geothermal sources. This corresponds to about 2 GWe which is about two-thirds of the maximum potential that the DSIR estimated to be available (see chapter 7). If the extraction of geothermal heat is regarded as a mining operation for hot water, it has been estimated for the Broadlands field that, for an annual generation of 165 MW at a 90 percent output factor, the life of the field would be 116 years. During this time the temperature would drop from 270°C to about 180°C (57).

35. There is little doubt that the use of geothermal resources will interfere with any associated natural attractions. If, however, the geothermal electrical plants were to be replaced by alternative means of generation after a relatively short period of use (say 30 years), the geothermal fields would almost certainly recover, although the natural displays could be markedly different. That is, by using known geothermal resources now

*Figure 15.1*

## COAL-FIRED PLANT—SPECIFIC CAPITAL COST

(*Source:* Wong and Hewlett (50))



NOTE:
1. Costs as at December 1975.
2. Interest during construction is not included.

we are unlikely to be taking an irreversible step, although the cost of decommissioning a geothermal field would have to be taken into account.

36. Again, there appears to be no reason why a hydro plant could not be decommissioned although, as pointed out in the FFGNP report, this could be a difficult operation. Such a step assumes that there would be an acceptable alternative, and the net cost of replacement could be high. If, however, present trends persist, our analysis implies a high degree of saturation in electricity needs by about 2030. Thus, if there were no further major expansion in the system, even very costly alternatives could be acceptable on environmental grounds alone.

### *Conservation Techniques*

37. By 2020, if 110 000 GWh per annum of process heat is in actual fact needed there is the possibility of producing about 15 000 GWh per annum or more of electricity from industrial total energy systems. But in our attempt to set a realistic upper limit to the generation of electricity by the national system, we prefer to regard this as additional to the 130 000 GWh per annum so far assumed. In chapter 8 we reached an initial estimate of 68 000 GWh per annum for the year 2000. One way of reducing this national commitment was to assume that some was produced by total energy systems in industry. The estimate of 60 000 GWh, which is assumed to be reasonable for the national supply in the year 2000, implies that we could be ignoring the power produced independently in industry.

## A POSSIBLE NUCLEAR POWER PROGRAMME

38. We believe that the programme for electricity growth outlined in paragraphs 5 to 16 is credible, all be it, inferential. We therefore assume, ignoring the possibility of suitable alternatives, that this programme would be satisfied by introducing 5 GWe in the North and 2.5 GWe in the South Island of nuclear fission, base-load plant from 2010 to 2020. This requirement could be met by three stations of 2.5 GWe each, stations of between 2–3 GWe already being standard in many parts of the world.

39. The needs of the system as a whole could by 2020 perhaps warrant the introduction of turbine-generator units in the range of 1000–1300 MW in one of the North Island stations, but the other North Island and South Island stations would probably only warrant units of 600 MW. In economic terms there is, however, no case for a smaller size. This is fortunate as it appears unlikely that smaller units would be commercially available. It is conceivable that one site in the North and one site in the South Island would be acceptable on environmental grounds. For example, the Pickering station in Canada consists at present of Pickering A at 2000 MWe output, with Pickering B, which is being built alongside, also of 2000 MWe, giving a total of 4000 MWe for the site. The waste heat is discharged into Lake Ontario. On the other hand, the San Onofre site in Southern California, which discharges its waste heat into the Pacific Ocean, has been limited for environmental reasons to under 3000 MWe. Furthermore, if cooling towers should be used, site capacities nearer 2000 MWe might be thought more suitable.

40. In New Zealand, for security of supply, two sites in the North and one in the South with two 2 × 600 MWe stations at each site might be prudent. (The station size is that given in the NZED proposal discussed in chapter 6.) It may be desirable to increase the capacity of the Cook Strait cables, and, New Zealand may by the required time have installed a

supergrid of 400 kV like that of Britain, making the question of siting depend less on transmission losses than is supposed at present.

41. At this level of development (that is, at 7.5 GWe of nuclear power, about the same as the present British level), there appears to be no basic environmental aspects which cannot be readily dealt with, and which are not already well within the experience of other countries. New Zealand has a seismic problem, but with only three sites needed, suitable areas of reduced seismicity should be available, at least north of Tauranga and in Otago-Southland. Again, by the time the stations are required, ample experience on such matters should be available from the United States and Japan.

42. To assess the total impact on New Zealand, we shall assume explicitly that the development programme is met by commissioning 12 identical 600 MWe reactor-turbine-generator units from 2010 to 2020. These 12 units would be grouped into six stations, at two sites in the North Island and one in the South with two stations at each site. The first unit would be commissioned at one North Island site by 2011, with the other three units at this site being commissioned in alternate years. The first units in the other North and South Island sites would be commissioned in 2012, with subsequent units at each site also being commissioned at 2-yearly intervals. The final units in the total programme should be fully commissioned by 2018–2019.

43. The uniform pattern of development described in paragraph 42 arises from the need to transfer base-load plant then existing to intermediate duty. It is an ambitious construction programme, and would probably be the largest ever undertaken in New Zealand up to the time of its completion. There would no doubt be many advantages gained from the almost complete standardisation (there could be certain problems specific to site) involving design, reliability, costs, licensing, procurement, construction, and operations. A somewhat similar programme for five stations, referred to as SNUPPS (Standard Nuclear Unit Power Plant System), is already being implemented in the United States by the architect engineer corporation, Bechtel. However, there may be some doubt whether such a construction programme could be accomplished in New Zealand.

44. In general the programme would appear to be suitable for implementing on a "turnkey" basis in which the reactor manufacturer contracts with the future plant owner to design, construct, and start up the complete plant or plants. There are advantages in this approach. However, the NZED stated that because the contractor must accept most of the economic risk for delays and failures, a plant built under a turnkey contract would most certainly be a high cost one. Furthermore, the owner, who has ultimate responsibility for safety, is likely to find it hard to establish and ensure that his own necessary standards are met. Again, he is likely to end up with plant with which his staff is unfamiliar (40). Presumably some of the objections to a turnkey approach could be avoided by the secondment of NZED staff to the contractor during design and construction, and by a condition that subcontracts should be placed with New Zealand industries, and with the MWD.

45. The NZED proposal favoured the employment of an architect engineer who would design the plant and, together with the NZED, call separate tenders for each of the many parts and components. Such an approach would almost certainly require, as implicit in the NZED proposal, the commissioning of one station for experience before major

construction started on the others. This could be done in the programme outlined above by interchanging one of the nuclear for one of the coal-fired stations envisaged for 2005–2007.

46. In general the advanced commissioning of one nuclear station could have many advantages, especially for training of operating and maintenance staff. Again, irrespective of the approach adopted, the NZED would no doubt engage a "project consultant", independent of the architect engineer or turnkey contractor, to advise and assist in all phases of the first station at least.

47. Of course we are possibly considering an upper limit to growth and the nuclear programme may not be as large as we have envisaged, although design and construction work on other types of plant may have to proceed in parallel. However, in considering specific aspects such as fuel supplies and reactor type, we assume that the development will be more or less that as outlined in paragraph 42.

### *Capital Requirements*

48. The actual construction of one station takes about 6 years. Hence with the first unit needing to be commissioned by about 2011, work on the first site would have to start about 2003, and governmental approval for construction would have to be given by about 2001. The major construction phase for the complete programme would last about 15 years. For an average of about $1,000 million per station (early 1976 values and ignoring interest and any gains from standardisation), the total programme would cost $6,000 million. This corresponds to an average cash requirement of about $400 million a year with a peak of about $700 million (deduced from the cash flows given in table 14.1) during the 2009–2013 period. This is to be compared with an estimated cost of $200 million (not counting interest) per annum for the accelerated hydro and geothermal programme from 1985 to 2000 (see paragraph 29). The hydrogeothermal cost is half that for the proposed nuclear programme. For an average 3.5 percent per annum increase, the real GNP in 2011 would be double that in 1991, and thus in simple economic terms the two programmes appear to be comparable. However, peak cash needs could be higher for nuclear, and as this programme would perhaps involve more overseas expenditure, the total economic requirements of the nuclear could perhaps be more severe than those for the hydro-geothermal development. Nevertheless, if it is recognised that a nuclear programme of the type being considered may be the only economic alternative open to New Zealand in the early part of the next century, it does not appear impracticable, and should not be dismissed out of hand.

### *Manpower Requirements*

49. The MWD stated that a single station of the type being considered would need a peak construction force of about 1600 (see chapter 9). With construction work proceeding in sequence on two stations on a single site the work force would not have to be doubled, and hence perhaps a workforce of 2500 per site would be adequate, that is a total of 7500 for the three sites. This is to be compared with the approximately 4000 at present employed by the MWD on new construction work for the NZED (48). It is also to be noted that over the greater part of the construction programme, the needs of other projects would be negligible.

50. The NZED at present employs close to 575 on design and construction work and 2400 on operations, in addition to those employed by the MWD. In its proposal it stated that a design team of about 40 engineeers, scientists, and others would be necessary to manage and control the design phase of the first nuclear power station (40). Even in the absence of a turnkey contract, with six stations proceeding in sequence and in parallel, this force would not have to be increased sixfold. The MWD figures in chapter 9 show that once a station was commissioned, there would be about 150 operating staff needed for each station. Standardisation would probably not affect this figure much.

*Reactor Type and Fuel Requirements*

51. If the "throw-away" option for high-level waste disposal should become universally accepted, it is unlikely that the fuel requirements for the programme outlined above could be met. With the present commercial 1 GWe converter reactors needing about 200 tonnes of natural uranium each year, a programme of 7.5 GWe would need 1500 tonnes per annum, or a commitment of about 45 000 tonnes for a 30-year life. If there is a population of only 5 million by 2020, New Zealand's proportionate share on a population basis of the present known global recoverable reserves of 4 million tonnes is only about 2000 tonnes. If this is taken as a measure, there would have to be a twentyfold increase in known reserves to meet this country's needs.

52. Again, at the other extreme, even though FBRs may become commercially available by the mid-1990s, reprocessing requirements could make them unlikely to be suitable for New Zealand conditions. If, however, this was the only reactor type for which, for example, a "proliferation resistant" fuel cycle was developed, then there may be no choice. More likely candidates are thermal breeders such as the LWBR or perhaps a suitably modified CANDU, or advanced converters such as an HTGR or a corresponding CANDU, all of which would employ a thorium cycle with reprocessing being done overseas.

53. Of course, the present type of converter such as an AGR, LWR, or CANDU could also be considered. In the absence of the "throw-away" option, there may not only be adequate uranium supplies but there could also be international fuel centres breeding plutonium and/or thorium-232 for fabrication as converter fuel. In addition to FBRs, there are other methods, such as the use of accelerators producing "spallation" reactions, or certain types of fusion devices, which could be used for breeding purposes. Furthermore, it may not be necessary to isolate fissile from fertile material in these methods. There is also the possibility of the commercial development of "proliferation resistant" uranium-plutonium FBR fuel cycles, such as the one recently announced by Dr Walter Marshall of the UKAEA, and Dr Chauncey Starr of EPRI.

54. Many factors would obviously have to be taken into account in the choice of a reactor. Fortunately, New Zealand appears to have time to await certain developments before a decision has to be made. However, irrespective of the choice that may be ultimately made, we must emphasise, as IAEA officials brought home to us, that before entering a nuclear power programme, be it big or small, New Zealand must be reasonably assured of its fuel supplies.

*Environmental Aspects*

55. Explicit environmental aspects and associated health and safety matters have been discussed at length in chapters 9, 11, and 12. Standardisation could simplify these matters, but there could be many problems specific to site which would need close attention. All of these, however, have been dealt with in one way or another elsewhere in our report. There is one aspect of special note. In chapter 9 we said that the annual output of high-level waste from a 1.2 GWe station (once reprocessed and vitrified) could consist of 17 rods 3 metres long and 0.3 metres in diameter. The six stations of the proposed programme, in their 30-year lives, would produce about 3000 rods. Laid side by side they would occupy an area of about 3000 square metres, barely the size of a football field. If alternative energy sources were brought in this could be all the high-level fission waste ever needed to be produced here. However, assuming that this waste, in vitrified form, was eventually returned to New Zealand, we do not at present know if even this relatively small quantity could be adequately disposed of in this country. It is obviously a matter needing further investigation before any final commitment to a nuclear power programme is made.

*Training*

56. A nuclear power programme in New Zealand would make necessary a greater range of technological skills than at present exist here. Although the training and experience gained from conventional thermal stations is also relevant to the nuclear, extra training in specific matters would be necessary. Highly trained specialists in certain areas would have to be found, and the concept of "quality assurance" would have to be engendered in all. Once a certain reactor had been chosen, staff with operational experience of the particular system would be needed. It may be necessary to recruit temporary or permanent key personnel from other countries. The IAEA could be asked to give substantial help.

57. From the first NZED submission it appears that once a decision was made to plan a nuclear programme, engineers and scientists would be sent to an initial course on nuclear technology such as that at present held by the Australian Atomic Energy Commission at Lucas Heights near Sydney. After the course each trainee would spend at least 2 years on specific aspects of nuclear power in other overseas establishments. Courses for tradesmen (for example, welders and specialist technicians) would be needed later in the programme. Exactly how this would be done if the turnkey contract approach was adopted was not stated, but the Federation of Labour was opposed in principle to introducing overseas tradesmen as it believed that local workers were sufficiently adaptable to be taught the necessary skills. We agree with this. Station operating and maintenance staff would probably be trained both in New Zealand and overseas at a total cost, excluding salaries, of about $4–5 million for each station, assuming no benefit from the parallel and sequential nature of the programme.

58. It was suggested by the MWD and the DSIR, and supported by the New Zealand Institution of Engineers, that a local training research reactor of about 2 MWt could have certain advantages. The MWD proposed that it should be introduced almost immediately after a "decision in principle" for a nuclear power programme had been made. The estimated cost in New Zealand was given as $7.5 million, and operating costs would be about $100,000 a year. It was stated that such a reactor

would give ". . . an incentive and an opportunity for the preliminary steps in a nuclear programme to be taken without the pressures of dead-line dates for electric power supply. These include preparing and passing legislation, establishing and staffing a regulatory authority, and establishing safety philosophies and guide-lines" (56).

59. These goals seem reasonable and have merit. However, we are not convinced that such a reactor would be an adequate training tool. If the differences in scale between it and a 600 MWe power reactor are considered, its relevance becomes somewhat questionable, and this agrees with advice we received during our overseas visits. Until there is a firm commitment to nuclear power, we can see no advantages as far as training is concerned for large-scale power generation in introducing such a reactor into New Zealand.

60. The cost of training of regulatory staff must also be taken into account as well as the cost of training NZED staff. This has been touched on in chapter 14. Though the total dollar cost of all training would be large, we estimate that, allowing for interest during construction, it is likely to be less than 2 percent of the total capital cost of the programme. As such it is no doubt tolerable.

### *Conclusion*

61. We have shown that a significant nuclear power programme during the early part of the next century should be economically possible in New Zealand. The overall economic impact at that time would be little different from that of presently proposed developments up to the end of the century. The actual starting date for any such programme is naturally subject to many uncertainties, but it appears that a firm decision to proceed need not be made until at least about 1992 to 1996. Again, the development of suitable alternatives could not only affect this timing but also markedly affect the magnitude of the programme.

# APPENDICES

## *Appendix A*

## ORGANISATIONS AND PEOPLE WHO MADE SUBMISSIONS

(Most submissions were presented orally at a public sitting and the people who appeared were subject to questioning. Those submissions that were not presented orally are distinguished by an asterisk. The figures in brackets refer to the number of papers presented.)

### ORGANISATIONS

| | |
|---|---|
| *Accident Compensation Commission | (1) |
| Action for Environment | (1) |
| Agriculture and Fisheries, Ministry of | (1) |
| BP New Zealand Limited | (1) |
| Campaign Against Foreign Control in New Zealand | (1) |
| Campaign Against Nuclear Warships (CANWAR) | (1) |
| Campaign for Non-Nuclear Futures | (3) |
| Church and Society Commission of the National Council of Churches in New Zealand | (1) |
| Commission for the Environment | (3) |
| Commission for the Future | (1) |
| Customs Department | (1) |
| *Defence, Ministry of | (1) |
| Ecology Action Auckland and the Auckland University Students Association | (1) |
| Ecology Action (Otago) Inc. | (1) |
| Energy Resources, Ministry of | (3) |
| Environment and Conservation Organisations of New Zealand | (2) |
| Environmental Council | (1) |
| Environmental Defence Society | (3) |
| Environmental Vanguard Organisation | (1) |
| Federated Farmers of New Zealand (Inc.) | (1) |
| Federation of Business and Professional Women's Clubs | (1) |
| Foreign Affairs, Ministry of | (1) |
| Friends of the Earth | (2) |
| Friends of the Home | (1) |
| *Gabites, Alington, and Edmondson | (1) |
| General Practitioner Society | (1) |
| Geological Society of New Zealand | (1) |
| Greenpeace New Zealand | (1) |

| | |
|---|---|
| Health, Department of | (2) |
| Internal Affairs, Department of | (2) |
| Karuna Falls Ltd. | (1) |
| *Labour, Department of | (1) |
| *Lands and Survey, Department of | (1) |
| *Medical Research Council of New Zealand | (1) |
| Mines Department | (3) |
| National Council of Women of New Zealand | (1) |
| Natural Gas Corporation | (1) |
| Nature Conservation Council | (1) |
| New Zealand Atomic Energy Committee | (2) |
| New Zealand Campaign for Nuclear Disarmament | (1) |
| New Zealand Ecological Society | (1) |
| New Zealand Electricity Department | (5) |
| New Zealand Federation of Labour | (1) |
| New Zealand Federation of University Women | (1) |
| New Zealand Forest Service | (1) |
| New Zealand Government Railways Department | (2) |
| New Zealand Institute of Chemistry | (1) |
| New Zealand Institution of Engineers | (1) |
| *New Zealand Inter Church Council on Public Affairs | (1) |
| New Zealand Medical Association | (1) |
| New Zealand University Students Association | (1) |
| New Zealand Values Party | (1) |
| *Peace Action Tauranga | (1) |
| Public Service Association | (1) |
| Religious Society of Friends in New Zealand (Quakers) | (1) |
| Scientific and Industrial Research, Department of | (3) |
| Soil Association of New Zealand | (1) |
| Trade and Industry, Department of | (1) |
| Transport, Ministry of | (2) |
| Treasury, The | (1) |
| *United Nations Association, The Wellington Branch | (1) |
| Victoria University, Chemistry Department | (1) |
| Voice of Women (Dunedin) | (1) |
| Women's Electoral Lobby (Auckland) | (1) |
| Women's International League for Peace and Freedom | (1) |
| Works and Development, Ministry of | (3) |
| Young Nationals, Canterbury-Westland Branch | (1) |

## PEOPLE

| | |
|---|---|
| *Allan, W. J. D. | (1) |
| Beaven, Professor D. W. | (1) |
| Bieleski, I. P. | (1) |
| Blennerhassett, Mrs V. | (1) |
| Browne, R. F. | (1) |
| Burbidge, Professor P. W. | (1) |
| Cherry, Dr N. J. | (1) |
| Chisholm, F. | (1) |
| *Comer, Mrs V. M. | (1) |
| *Conroy, J. | (1) |
| *Donnelly, T., and family | (1) |
| Donoghue, M. F. | (1) |
| Ericksen, Dr N. J. | (1) |
| Geiringer, Dr E. | (2) |
| Glasby, G. P. | (1) |
| *Gregory, J. G. | (1) |
| *Griffiths, J. | (1) |
| Holm, Mrs J. R. | (1) |
| *Hopkins, Mrs M. | (1) |
| *Kennedy, Mrs J. | (1) |
| Lewis, A., and associates | (1) |
| *Lord, N. E. | (1) |
| *Lowry, J. B. | (1) |
| *MacGregor-Hay, H. | (1) |
| Mann, Mrs B. | (1) |
| McKee, A. | (1) |
| *McLean, R. J. | (1) |
| Meder, B. S. | (1) |
| *Moore, E. M. | (1) |
| Morris, Mrs D. | (1) |
| *Mulgrew, Mrs E., and associates | (1) |
| *Myers, Mrs J. | (1) |
| Nevill, R. G., and Coombe, D. M. | (1) |
| Page, G. G. | (1) |
| Peet, N. J., and Williamson, A. G. | (1) |
| Preddy, B. E. and G. F. | (1) |
| Richmond, C. J. | (1) |
| Salmon, Professor J. T. | (1) |
| Serrallach, Dr G. F. | (1) |
| Sheppard, D. S. | (1) |
| Stephenson, J. | (1) |
| Taylor, W. M. | (1) |
| Toynbee, P. A. | (1) |
| *Van Erkel, G. A. | (1) |
| Williams, G. | (1) |
| White, D. U. | (1) |
| Whitehead, Dr N. E. | (1) |
| Wybourne, Professor B. S. | (1) |

## *Appendix B*

# LIST OF PEOPLE, ORGANISATIONS, AND ESTABLISHMENTS VISITED OVERSEAS

## UNITED STATES

*West Coast*

Dr Lawrence Grossman, Professor of Nuclear Engineering, University of California, Berkeley.
Lee Schipper and Alan Lichenberg, Energy and Resources Programme, University of California, Berkeley.
Dr Chauncey Starr, President, Electric Power Research Institute, Palo Alto.

Bechtel Organisation.
California Energy Resources Conservation and Development Commission.
California State Capitol.
General Atomic Company, San Diego.
Lawrence Berkeley Laboratory, Berkeley.
Lawrence Livermore Laboratory.
San Onofre Nuclear Power Plants.
Southern California Edison Electric Company.

*Tennessee*

Dr Alvin M. Weinberg, Director, Institute for Energy Analysis, Oak Ridge

National Laboratory, Oak Ridge.

*Washington.*

William Doub (former AEC Commissioner) and associates.
Carl W. Kuhlman, Assistant Director for Waste Management, Division of Nuclear Fuel Cycle and Production, ERDA.
John Leech (Solar Expert, now attached to International Affairs), ERDA.
Whittie McCool, Deputy Director, Division of Safety, Standards and Compliance, ERDA.
Congressmen Mike McCormack and Barry Goldwater.
John O'Leary, Administrator of the Federal Energy Administration.
Herbert Pennington, Director, Nuclear Environmental Protection Agency, ERDA.
Nelson Sievering, Assistant Administrator for International Affairs, ERDA.
Gus Speth, Member for Council on Environment Quality.

Atomic Industrial Forum.
Bechtel's SNUPPS Programme at Gaithersburg, Maryland.
Nader Representatives.
Nuclear Regulatory Commission.
Peach Bottom Nuclear Plant.
Richard J. Barber Associates.

*New York and New Jersey*

Centre for Environmental Studies, Princeton University (Frank von Hippel, Robert H. Williams, Theodore B. Taylor, Jan Beyea).
Consolidated Edison.
Jersey Central Power and Light Company.

*Boston*

Dr Chinnery, MIT.
Professor Henry Kendall, Harvard University.
Professor Rose, MIT.
Dr George Wald, Harvard University.

## CANADA

Dr Elizabeth Bond, Director of Government Relations for International Nickel Company of Canada.
Dr David Brooks, Friends of the Earth.
G. Joron, Minister of Energy, Quebec.
G. M. McNabb, Deputy Minister of Energy, Mines and Resources.
Dr. A. Porter, Chairman, Ontario Royal Commission.

Atomic Energy Control Board—Regulatory Body.
Atomic Energy of Canada Limited.
Canadian Nuclear Association.
Energy Probe.
Environmental Advisory Council (Blair Seaborn, Deputy Minister).
Hydro Quebec and Gentilly Nuclear Power Station.
National Research Council.
Ontario Hydro and Pickering Nuclear Power Station.

## BRITAIN

Dr P. F. Chapman (Energy Research Group), Open University.
Dr John Davoll, Conservation Society.
Sir Brian Flowers and associates.
Gerald Leach.

Atomic Energy Authority.
Berkeley Nuclear Laboratories.
British Nuclear Fuels Ltd.
Central Electricity Generating Board.
Culham Laboratory, Abingdon, Oxford.
Department of Energy (Atomic Energy Division).
Department of Environment.
Dounreay Experimental Reactor Establishment.
Energy Research Group, Cavendish Laboratory, Cambridge.
Foreign and Commonwealth Office.
Friends of the Earth.
Harwell Atomic Energy Research Establishment.
Heysham Nuclear Power Station.
Hinkley Point Nuclear Power Station.
Nuclear Installations Inspectorate.
Oldbury on Severn, Magnox Nuclear Power Station.
Windscale (BNFL).

## SWITZERLAND

Swiss Association for Atomic Energy (ASPEA).

## SWEDEN

Energy Research and Development Commission.
Secretariat for Future Studies.
Swedish State Power Board (known as Vattenfall).

## FRANCE

International Energy Agency—New Zealand Review Team.
International Energy Agency Secretariat—Long Term Co-operation Bureau.
International Energy Agency Secretariat—R and D Division.
National Energy Bureau, French Energy Commission.
Organisation for Economic Co-operation and Development—Environment Directorate.
Organisation for Economic Co-operation and Development—Nuclear Energy Agency.

## AUSTRIA

Energy Section, Ministry of Trade.
International Atomic Energy Agency.

## SOUTH AFRICA

Atomic Energy Board.
Electricity Supply Commision.

### *Appendix C*

# FORECASTS AND SCENARIOS FOR FUTURE ELECTRICITY USE

With minor adjustments to make this appendix consistent with the style and method of cross-referencing adopted in other sections of this report, sections C1, C2, and C3 have been taken verbatim, without prejudice, from the NZED submission 128, pages 27–32 inclusive, and the appendix, page 50. Section C4 contains our own comments.

## C1 *Forecasts of Electricity Use in the Year 2000*

The official forecasts are made by the CRPR whose forecasting horizon is 15 years. The uncertainties affecting the forecasts for this timespan will be apparent from other discussion in the report. It is also clear that caution is needed in making extrapolations for timespans longer than this.

In its submission to the FFGNP in November 1976, the NZED suggested two figures indicative of a possible range for electricity generation for the year 2000. The first, 80 400 GWh, was based on an extrapolation of the 1976 CRPR estimates. These estimates assumed a reducing growth rate towards the end of the forecasting period, and further reductions in growth rate were allowed in the extrapolation to the end of the century. The second figure of 68 800 GWh allowed for the effect of additional conservation and substitution measures.

The background work for the 1977 CRPR suggests that the condition of low economic growth which exists at present and is expected to continue in the medium term, together with a reduction in population estimates, will cause a reduction in these end-of-century projections, but will still leave a similar range of uncertainty.

At the present time the NZED believes that for planning purposes it is prudent to allow for the possibility that 60–70 000 GWh of generation could be required in the year 2000 bearing in mind all the uncertainties inherent in the long term.

## C2 *Scenarios for Future Electricity Use*

The following descriptions of electricity growth are not forecasts, but have been devised to illustrate the effects of different assumptions on the levels of future electricity use. In each of the two basic scenarios, "STATIC" and "NORMAL GROWTH", certain assumptions have been made about the growth of the following three categories of electricity use: "Domestic", "Commercial and Industrial" (not including forest-based and metal-smelting industries), and "Large Industrial" (forest-based and metal-smelting industries and referred to as "Major Industrial" in chapter 8).

It should be noted that in each case:

(a) The population growth is based on the low fertility and 5000 net immigration per year projection of the Department of Statistics (1).

(b) The growth of "commercial and industrial" consumption has been calculated from a relationship based on the assumed GDP growth (see C3).

(c) There is no certainty that the assumptions for each scenario are economically consistent.

The scenarios shown here are:

(a) "STATIC"—static economic conditions (no change in GDP per head) but growth in population.

(b) "NORMAL GROWTH"—moderate growth in the economy with no large-scale technological innovation.

(c) "ELECTRIFIED TRANSPORT"—the same as "NORMAL GROWTH", but with electrification of a portion of transport energy requirements as an example of a significant technological innovation.

### *Scenario* A, *"STATIC"*

(a) *Description:* In this scenario it is assumed that:

(i) The average "domestic" consumption remains at the present level of 8100 kWh a household a year, and rises only with population changes.

(ii) The GDP per capita remains at the present level so that the growth of total GDP is limited to that of the population. "Commercial and industrial" consumption increases at the rate consistent with the growth rate of total GDP. Details of population and GDP growth are given in table C.1.

(iii) "Large industrial" consumption is a best estimate consistent with the scenario and is shown in table C.2.

(b) *Results:* Generation increases to 30 800 GWh in the year 2000 compared with 20 900 GWh in 1976–77 as shown in figure 6.1. Key assumptions made are given in table C.1., and the components of consumption are given in table C.2.

(c) *Comment:* In practice, if the stagnation conditions of this scenario existed for long, it would seem unlikely that the population assumption would hold, and the net immigration rate could be negative, possibly even to the extent that the population may drop.

### *Scenario B, "NORMAL GROWTH"*

(a) *Description:* In this scenario it is assumed that:

(i) The average domestic consumption rises to 14 000 kWh a household a year by the year 2000 from the present level of 8100 kWh. This would allow a high comfort level from electric heating in half the housing stock, leaving half as now to be heated by some other means.

(ii) The GDP in real terms increases at 3.5 percent per annum. This may be compared with the 1957–76 real rate of 4 percent per annum

(iii) "Large industrial" consumption trebles by the year 2000 which corresponds to an average rate of increase of 4.2 percent per annum.

(b) *Results:* Generation increases to 60 100 GWh in the year 2000 compared with 20 900 GWh in 1976–77 as shown in figure 6.1. Key assumptions made are given in table C.1. and the components of consumption are given in table C.2.

(c) *Comment:* It is of interest to examine the effect of variations in the assumptions on the scenario figures. Higher net immigration of 15 000 instead of 5000 per annum could give an additional consumption of 2000 GWh per annum. The adoption of gas water heating and cooking in 300 000 additional houses would reduce electricity consumption by about 1600 GWh per annum. The substitution of gas space-heating to achieve high comfort levels in the same number of houses would reduce electricity consumption by about 3600 GWh per annum. Alternatively, a reasonably extensive adoption of domestic heat pumps leading to their use for space heating in about 30 percent of homes could reduce consumption by 2000 to 3000 GWh per annum by the year 2000.

### *Scenario C, "ELECTRIFIED TRANSPORT"*

(a) *Description:* In this scenario it is assumed that:

(i) The assumptions of Scenario B apply.

(ii) From the mid 1980s a progressive change to the use of electricity for transport occurs. Initially this would be inter-city and main trunk railway transport which would then be followed by urban and personal transport. An estimate of 72 000 GWh for the energy required for transport in the year 2000 has been suggested (2). It is assumed that one third of this, that is, 24 000 GWh, is met by 8000 GWh of electricity in the year 2000. (This assumes that the efficiency of the electricity to mechanical energy conversion is three times as efficient as that of liquid fuel to mechanical energy conversion).

(b) *Results:* Generation increases by nearly 10 000 GWh above the "NORMAL GROWTH" level in the year 2000 to a total of 69 800 GWh as shown in figure 6.1. Key assumptions made are given in table C.1, and the components of consumption are given in table C.2.

(c) *Comment:* Technological change in response to changing availability of resources, and from innovation generally, will be likely to exert a significant influence on the levels of electricity generation at this time. Electrification of part of the energy need for transport has been chosen as a substantial example of these effects, as it seems likely that electricity will supply a significant proportion of this need in the longer run, the uncertainty being in the timing and extent of the changes.

*Table C.1.*

SCENARIO ASSUMPTIONS

| Year | Population (millions) | No. of Houses (millions) | GDP (index) | GDP per capita (index) |
|---|---|---|---|---|
| Scenario A: "STATIC"— | | | | |
| 1976 | 3.07 | 1.03 | 1.00 | 1.00 |
| 1981 | 3.27 | 1.10 | 1.07 | 1.00 |
| 1986 | 3.46 | 1.17 | 1.13 | 1.00 |
| 1991 | 3.64 | 1.23 | 1.19 | 1.00 |
| 1996 | 3.82 | 1.29 | 1.25 | 1.00 |
| 2001 | 4.01 | 1.35 | 1.31 | 1.00 |

Scenarios B and C: "NORMAL GROWTH" and "ELECTRIFIED TRANSPORT"—

| | | | | |
|---|---|---|---|---|
| 1976 | 3.07 | 1.03 | 1.00 | 1.00 |
| 1981 | 3.27 | 1.17 | 1.19 | 1.12 |
| 1986 | 3.46 | 1.32 | 1.41 | 1.25 |
| 1991 | 3.64 | 1.50 | 1.68 | 1.42 |
| 1996 | 3.82 | 1.57 | 1.99 | 1.60 |
| 2001 | 4.01 | 1.65 | 2.36 | 1.81 |

### *Table* C. 2

## SCENARIO CONSUMPTIONS (in thousands of GWh)

Scenario A: "STATIC"

| Year | Domestic | Commercial and Industrial | Large Industrial | Transmission Losses | Generation |
|---|---|---|---|---|---|
| 1976 ... | 8.4 | 5.9 | 3.4 | 2.4 | 20.1 |
| 1981 ... | 9.0 | 7.4 | 5.0 | 2.6 | 24.0 |
| 1986 ... | 9.5 | 8.9 | 5.8 | 3.0 | 27.2 |
| 1991 ... | 10.0 | 9.4 | 5.9 | 3.1 | 28.4 |
| 1996 ... | 10.5 | 9.9 | 5.9 | 3.3 | 29.6 |
| 2001 ... | 11.0 | 10.4 | 6.0 | 3.4 | 30.8 |
| Percent composition at end of period | 36% | 34% | 19% | 11% | 100% |

Scenario B: "NORMAL GROWTH"

| Year | Domestic | Commercial and Industrial | Large Industrial | Transmission Losses | Generation |
|---|---|---|---|---|---|
| 1976 ... | 8.4 | 5.9 | 3.4 | 2.4 | 20.1 |
| 1981 ... | 11.1 | 7.8 | 5.5 | 2.2 | 26.6 |
| 1986 ... | 14.7 | 10.2 | 6.6 | 3.0 | 34.5 |
| 1991 ... | 19.5 | 13.3 | 7.2 | 3.6 | 43.6 |
| 1996 ... | 21.3 | 17.2 | 9.2 | 4.7 | 52.4 |
| 2001 ... | 23.3 | 22.3 | 9.2 | 5.3 | 60.1 |
| Percent composition at end of period | 39% | 37% | 15% | 9% | 100% |

# ERRATUM

Page 291: The sixth and seventh lines after heading ‘C3 *Model for “Commercial and Industrial” Consumption*’ should read—

$$\begin{array}{llllll} E_t = 5.7 + & 0.9 \times G_t - & 0.35 \times E_{t-1} - & 0.16t & & \\ \text{t test} & (6.38) & (3.65) & (2.79) & & R = 0.92 \end{array}$$

Scenario C: "ELECTRIFIED TRANSPORT"

| Year | Domestic | Commercial and Industrial | Large Industrial | Transport | Transmission Losses | Generation |
|---|---|---|---|---|---|---|
| 1976 | 8.4 | 5.9 | 3.4 | – | 2.4 | 20.1 |
| 1981 | 11.1 | 7.8 | 5.5 | – | 2.2 | 26.6 |
| 1986 | 14.7 | 10.2 | 6.6 | 1.0 | 3.0 | 35.6 |
| 1991 | 19.5 | 13.3 | 7.2 | 2.1 | 3.9 | 45.9 |
| 1996 | 21.3 | 17.2 | 9.2 | 4.4 | 4.8 | 57.0 |
| 2001 | 23.2 | 22.3 | 9.2 | 9.1 | 5.9 | 69.8 |
| Percent composition at end of period | 33% | 32% | 13% | 13% | 9% | 100% |

C3 *Model for "Commercial and Industrial" Consumption*
(Non-domestic consumption excluding forest-based and metal-smelting industries)

A mathematical model which relates the growth of electricity consumption in this sector to that of GDP has been developed, using data from 1958 on.

$E_t = 5.7 + 0.9 \times G_t - 0.35 \times E_{t-1} - 0.16_t$
t test (6.38) (3.65) (2.79) R = 0.92

where $E_t$ = percentage change in "commercial and industrial" electricity consumption in year t.

$G_t$ = percentage change in real GDP for year t.

t = the year of interest. The value of t is based on t = 0 for the financial year 1976–77.

Of different models tried, this one fits the data most closely, and the good fit is indicated by the high value of the R coefficient.

The model describes the growth of electricity consumption in terms of the corresponding growth of GDP with a time trend which reduces the growth component and is not dependent on year-to-year changes in GDP.

The model has been used to estimate the growth rate in the early years of the scenarios up to the year 1986. After this time, the "commercial and industrial" consumption in the "STATIC" scenario is assumed to grow only as fast as GDP (which in turn grows as fast as the population), whereas in the other two scenarios the growth rate given by the model for the year 1986 (5.3 percent) is assumed to continue each year up to 2001.

## C4 *Royal Commission Notes*

For $G_t$ the same from one year to the next, the model in the preceding section may be approximated to by a simpler form. In particular, noting that this relationship implies decreasing E with time, put

$$E_{t-1} = E_t + \Delta E_{t-1}$$
$$E_{t+1} = E_t - \Delta E_t$$

Where $\Delta E_t$ and $\Delta E_{t-1}$ are the changes in E from one year to the next. Assuming that $\Delta E_{t-1} = \Delta E_t$, that is ignoring second order differences, for constant $G_t$ it can be shown directly from the model that

$$\Delta E_{t-1} = 0.12$$

This enables the model to be approximated by

$$E_t = 4.2 + 0.67\ G_t - 0.12\ t$$

and on iterating, the neglect of second order differences can be justified.

In this form it is apparent that for constant $G_t$, $E_t$ changes by 0.12 from one year to the next.

In the model $t = 0$ corresponds to the year ending 31 March 1977. To refer time to another year Y, replace t by $t - T$ where $T = 1977 - Y$. This gives

$$E_t = 4.2 + 0.12T + 0.67G_t - 0.12t$$

where $t = 0$ for the year Y. If U is the energy consumed in any year then

$$\Delta U = \frac{E_t}{100} U \Delta t$$

where $\Delta U$ is the change in U in the time $\Delta t$. On integrating this relationship

$$U_t = U_Y \exp\ (\ (0.042 + 0.0012T + 0.0067G_t)\ t - 0.0006t^2)$$

Taking $T = 1$ this is the relationship that was used to obtain the values given in table 8.5.

In terms of logarithms, this expression is

$$\ln U_t = \ln U_Y + (0.042 + 0.0012T + 0.0067G_t)\ t - 0.0006t^2$$

where $U_t$ can be in any convenient units, that is GWh, kWh, etc.

Taking $G_t = 3.8$, which was the average from 1958 to 1976 (3), and referring time to 1967 (that is taking $T = 10$), this relationship becomes

$$\ln U_t = \ln U_{1967} + 0.079t - 0.0006t^2$$

We compare this with the best quadratic fits obtained by the Applied Mathematics Division of the DSIR which were prepared for and presented to us by the Campaign for Non-Nuclear Futures (4).

For total energy consumption over the period 1958–1976, the best quadratic fit for the logarithm is

$$\ln U\ (\mathrm{GWh}) = 9.296 + 0.0721t - 0.00055t^2$$

where $t = 0$ for 1967. Note that U is the total energy consumption and not just non-domestic energy consumption (ignoring the large industries), as in the NZED case.

This expression for total consumption can obviously be rewritten in the form

$$\ln U_t = \ln U_{1967} + 0.0721t - 0.00055t^2,$$

where $\ln U_{1967}(\mathrm{GWh}) = 9.296$ giving $U_{1967} = 10\,900$ GWh. This value is slightly less than the actual 1967 value, but exact agreement is not to be expected since the relationship gives a smooth curve fit over the period 1958–1976, and fluctuations, presumably associated with $G_t$, are to be expected.

The similarity between the NZED model and the Applied Mathematics Division's fit is startling, there being, though, numerical differences. Such differences are to be expected since one is relevant to non-domestic consumption and the other to total consumption. These differences are further emphasised if Comalco is neglected from the total consumption, the fit then being given by

$$\ln U_t = \ln U_{1967} + 0.06528t - 0.00143t^2$$

with $\ln U_{1967}$ (GWh) $= 9.294$ giving $U_{1967} = 10\,900$ GWh no different from before, which is to be expected because Comalco started operations only in that year. The significance of these differences is naturally that the growth patterns are different in different sectors as one would expect. Nevertheless, the importance of such relationships is that they imply saturation in the long term in all sectors.

Of course, as implied by Mr D. C. Cook of the NZED *(Evidence* p. 2233), the pattern of past consumption can always be fitted by a time series, a quadratic expression for the logarithm being just a second order approximation. That is putting

$$\Delta U = \alpha U \Delta t$$

where $\alpha$ can be a general function of time, on integrating

$$\ln U = \ln U_Y + \int_o^t \alpha \, dt$$

For $\alpha$ expanded as a time series this gives lnU as a time series, which may be fitted to past patterns of consumption. However, compared with the NZED model, there is little subtlety in this.

In its most general form, as given in C 3, the NZED model not only relates the rate of growth of electricity to the rate of growth of real GDP, but it also relates past to present or present to future patterns of consumption. Furthermore, this relationship is such that the feedback is negative rather than positive, implying a controlled situation. Although this mechanism is not explicitly apparent in the approximation that we obtained and used for constant $G_t$, it is nevertheless still implicit.

A final point is that the simple exponential function in which the exponent is a purely linear rather than a quadratic function of time is obviously an approximation to a more general case. However, it must also be appreciated that the coefficients in the quadratic expression may not necessarily be constants, being themselves functions of time. That is, in particular, for a significant period of time in the past, the coefficient of $t^2$ could have been much smaller than what it is now, and could thus be neglected.

Clearly the problem is a complex one and warrants further study.

*References*

1. "New Zealand Sub-National Population Projections", 1976–1991, p. 44, Department of Statistics, January 1976.
2. NZERDC, Report 19 (Continuation Scenario).
3. *New Zealand Official Year Book, 1976,* p. 703.
4. Campaign for Non-Nuclear Futures, submission 132, addendum.

## *Appendix D*

## D. 1. ESTIMATED NUCLEAR CAPITAL AND OPERATING COSTS—UNITED STATES AND NEW ZEALAND COMPARED

(Based on Constant Value 1976 dollars—US$1 = NZ$1)

### UNITED STATES

(*Source:* Ford Foundation—MITRE Report)

Station size: dual 1150 MWe units
Commissioning date: 1985
*Capital Costs*—
Basic "best estimate": $667/kW[a]

At completion: $1,000/kW (*1985*)

Escalation factors: 8% p.a. to mid-1985
Discount factor: 13% p.a. (rate of return)
*Capacity (Output) Factor: 60%* assumed
*Fuel Costs*—
Yellowcake ($U_3O_8$) ... ... ... ... $30/lb
Conversion ... ... ... ... ... $3.33/kgU
Enrichment ... ... ... ... ... $80 kg/SWU
Fabrication ... ... ... ... ... $90 kg
No reprocessing of spent fuel.
Waste management (see below)

### NEW ZEALAND

(*Source:* NZED submission No. 118)

Station size: dual 600 MWe units
Commissioning date: 1991
*Capital Costs*—
Basic estimate: $770/kW (including seismic allowance)[b]
$837/kW (including initial fuel)[c]
At completion: $1,120/kW (*1991*)[d]
$1,210/kW[e]
Escalation factor: Nil (except 10% IDC)
Discount factor: 10% p.a. (rate of return)
*Capacity (Output) Factor: 70%* assumed
*Fuel Costs*—
Yellowcake ... ... ... ... $35/lb
Conversion ... ... ... ... $5/kgU
Enrichment ... ... ... ... $120/kg SWU
Fabrication ... ... ... ... $130/kgU
Reprocessing ... ... ... ... $150/kg
Waste management ... ... ... ... $17/kg (spent fuel)

| *Generation Costs—* | *U.S. Cents per kWh* |
|---|---|
| *Capital charges* | 1.65 |
| Total capital costs | 1.65 |
| Fuel charges *(60% output factor)—* | |
| *Yellowcake* | 0.25 |
| *Conversion* | 0.01 |
| *Enrichment* | 0.20 |
| *Fabrication* | 0.04 |
| *Reprocessing* | … |
| *Spent fuel disposal* | 0.04 |
| *Total fuel* | 0.54 |
| *Operation and maintenance* | 0.20 |
| *Total energy cost (at power station)* | 2.39* |

| *Generation Costs—* | *N.Z. Cents per kWh* |
|---|---|
| *Capital charges* (basic station) | 1.94[f] |
| Other Capital Costs | 0.34[g] |
| Total capital costs | 2.28 |
| Fuel charges *(70% output factor)—* | |
| *Yellowcake* | 0.23 |
| *Conversion* | 0.01 |
| *Enrichment* | 0.20 |
| *Fabrication* | 0.05 |
| *Reprocessing (net)* | 0.01 |
| *Waste management* | 0.01 |
| *Total fuel* | 0.51 |
| *Operation and maintenance* | 0.13 |
| *Total energy cost (at power station)* | 2.92 |

*Plus 0.05 or minus 0.04 depending on uncertainties in future costs.

*Notes on Assumptions and Calculations Used In D.1*

(a) US$667 per kW initial capital cost (includes cooling towers $75 kW extra).
(b) NZED total cost $924 million for 2 × 600 MWe units = $770 per kW.
(c) NZED total cost (including initial fuel) is $1,004 million for 2 × 600 MWe = $837 per kW.
(d) NZED total (including 10 percent p.a. interest during construction for 9 years) is $1,345 million for 2 × 600 MWe = $1,120 per kW at completion.
(e) NZED total on same basis as (d) plus fuel is $1,454 million for 2 × 600 MWe = $1,210 per kW at completion.
(f) Based on total capital cost $1,345 million (1991) excluding initial fuel $109 million (1991), using a 70 percent output factor.
(g) Based on total other capitalised costs (including initial fuel/inventory, training, consultant's fees, land, roading, etc.) amounting to $238 million (1991).

## D.2 ESTIMATED COAL-FIRED CAPITAL AND OPERATING COSTS—UNITED STATES AND NEW ZEALAND COMPARED

(Based on Constant Value 1976 dollars—US$1 = NZ$1)

UNITED STATES
(*Source:* Ford Foundation—MITRE Report)

| | With Scrubbers | Without Scrubbers |
|---|---|---|
| Station size: dual 1150 MWe units | | |
| Commissioning date | 1985 | 1985 |
| *Capital Costs*— | | |
| Basic (1976) | Not stated | |
| At completion (1985)[a] | $555/kW | $465/kW |
| Escalation factor: 8% p.a. to mid 1985 | | |
| Discount factor: 13% p.a. (rate of return) | | |
| *Capacity (Output) Factor* | 60% | 67% |
| *Fuel Costs*— | | |
| (i) High sulphur coal—$10^6$ BTU | $1.08 | .. |
| (ii) Low sulphur coal—$10^6$ BTU | .. | $0.43 |
| (i) Transportation (300 miles) | | |
| (ii) Transportation (1400 miles) | | |

NEW ZEALAND
(*Source:* NZED submission No. 118)

| | |
|---|---|
| Station size: dual 600 MWe units | |
| Commissioning date | 1991 |
| *Capital Costs*— | |
| Basic (1976) | $320/kW |
| At completion (1991)[b] | $410/kW |
| Plus extras (land, roads, etc.)[c] | $467/kW |
| Escalation factor: Nil (except 10% IDC) | |
| Discount factor: 10% p.a. (rate of return) | |
| *Capacity (Output) Factor* | 70% |
| *Fuel Costs*— | |
| Low sulphur ($25/te) equivalent—$10^6$ BTU | $0.95[d] |

| *Generation Costs—* | *U.S. Cents per kWh* | |
|---|---|---|
| *Capital Charges—* | | |
| With scrubbers | 1.37 | .. |
| Without scrubbers | .. | 1.03 |
| | 1.37 | 1.03 |
| *Fuel Charges*—Output Factor | (60%) | (67%) |
| Coal at mines | 1.00 | 0.40 |
| Transportation | 0.20 | 1.13 |
| | 1.20 | 1.53 |
| *Operation and Maintenance* | 0.28 | 0.16 |
| *Total Energy Cost* (at power station) | 2.85* | 2.72† |
| *Cost variation | ∓0.04 | |
| †Cost variation | | ∓0.03 |

| *Generation Costs—* | *N.Z. Cents per kWh* |
|---|---|
| *Capital Charges—* | |
| Basic station | 0.71 |
| Plus extra capital costs (land, etc.) | 0.10 |
| | 0.81 |
| *Fuel Charges*—Output Factor | (70%) |
| Based on $25/te (near coalfield)‡ | 1.00 |
| | 1.00 |
| *Operation and Maintenance* | 0.10 |
| *Total Energy Cost* (at power station) | 1.91 |

‡$1.06+ for Australian coal (imported)

*Notes on Assumption and Calculations Used in D.2*

(a) Based on Ford Foundation—MITRE Report (page 123).
(b) Based on NZED adjusted capital cost for station (2 × 600 MWe) $492 million (in 1991).
(c) Based on NZED adjusted total $561 million (in 1991) including land, roads, and general.
(d) Factors used: 1 kJ = 1.055 MBTU.
1 tonne gives $25^3$kJ = $26.375^3$ MBTU.
$25 tonne—equivalent $0.95 per $10^6$ BTU.

# GLOSSARY

## *1. Technical Terms—*

Actinides—Elements following actinium in the periodic table. They include uranium and plutonium. Many of them are long-lived alpha-particle emitters.

Advanced converter—A reactor in which the reactor plus fuel assembly has a conversion ratio slightly less than unity.

Alpha particle—A positively charged particle composed of two protons and two neutrons, the nucleus of a helium atom.

Annual load factor—The ratio of the average half hourly electric power demand for the year to the maximum half hourly demand in that year expressed as a percentage.

Annual output factor—The ratio (expressed as a percentage) of electrical energy actually produced in a year to that which would have been produced in the same period if the unit had operated continuously at rated capacity.

Atoms—The building blocks of all matter, composed of a nucleus containing protons and neutrons, surrounded by electrons.

Background radiation—The natural ionising radiation of man's environment including cosmic rays, natural radioactivity in the ground and immediate surroundings, and in a person's body.

Base load plant—An electricity generating plant designed to operate at near constant output with little hourly or daily fluctuation and an annual output factor of more than 55 percent.

Base isolation—An engineering device which absorbs most of the energy from shaking ground in the base of a building or structure, thus affording a measure of protection from earthquakes.

Beta particle—An electron emitted from the nucleus of an atom; a light, negatively-charged particle.

Biota—Flora and fauna of a given region.

Biomass—Cultivated or natural vegetable matter used as a source of primary energy.

Breed—To form fissile nuclei, usually as a result of neutron capture possibly followed by radioactive decay.

Breeder reactor—A nuclear reactor that produces more fissile material than it consumes.

Burner—See *converter.*

Calandria—A cylindrical vessel within a reactor containing the heavy water moderator through which run the pressure tubes (CANDU reactor).

Capacity factor—See *output factor.*

Cogeneration—The generation of electricity with direct use of the waste heat for industrial process heat or for space heating.

Combined cycle—A gas turbine which in addition to driving its own electrical generator provides exhaust heat which is used either to raise steam for use in a steam turbine or as preheated combustion air for the normal firing of coal or oil in a boiler.

Common mode—Of failures, in which failure in one part of the system also affects the ability of another, supposedly independent, part to respond.

Constant dollars—Dollar estimates from which the effects of inflation or deflation have been removed, reported in terms of a base-year value and assumed to have constant purchasing power.

Conversion—The process which changes a fertile atom into a fissile atom using neutrons released in a fission process.

Conversion factor—Ratio of the number of fissile nuclei formed by conversion to the number of fissile nuclei consumed.

Converter—A reactor in which conversion takes place. Explicitly refers to a reactor for which the conversion ratio is significantly less than unity.

Coolant—A liquid or gas circulated through the reactor core to extract heat for the steam generators.

Core—The region of a reactor containing nuclear fuel where the nuclear chain reaction takes place and heat is thereby generated.

Core power density—Thermal power per unit volume generated in the reactor core and expressed in kW per litre.

Cosmic rays—Radiation emanating from high energy sources outside the earth's atmosphere.

Critical—Of an assembly of nuclear materials, being just capable of supporting a nuclear chain reaction.

Criticality—The condition, when a sufficient mass of fissile material is reached, where a self-sustaining chain reaction can occur.

Curie—A measure of the rate at which a radioactive material disintegrates. One curie corresponds to 37 000 million disintegrations per second (the amount of activity displayed by one gram of radium-226).

Current dollars—Dollar values that allow for inflation or deflation.

Daughter product—The nucleus which remains when a radioactive parent disintegrates. The daughter may itself be radioactive.

Decay—Disintegration of a nucleus through the emission of radioactivity.

Decay heat—Heat generated by radioactive decay of the fission products, which continues even after the chain reaction in a reactor has been stopped.

Delayed deaths—Deaths from cancer resulting from the effects of ionising radiation and occurring long after the irradiation process. The delay may be years or even decades.

Deuterium—A heavy, stable isotope of hydrogen having one proton and one neutron in its nucleus and present to the extent of 150 ppm in ordinary hydrogen; sometimes referred to as heavy hydrogen.

District heating—Space heating of buildings in a district by piping waste heat, in the form of hot water or steam, from a power station.

Dose—A measure of the quantity of ionising radiation to which a sample has been exposed (see *rad* and *rem*).

Dose commitment—Future radiation doses inevitably to be received because a particular radionuclide has been incorporated in body tissues, or has been dispersed in the environment.

Emergency core cooling system—A safety system in a nuclear reactor, the function of which is to prevent the fuel in the reactor from melting should a sudden loss of normal coolant occur.

Enrichment—The process by which the percentage of the fissionable isotope uranium-235 is increased above that occurring in natural uranium (0.7 percent).

Exponential growth—The type of growth in which the rate of change of a quantity is proportional to its magnitude. (The larger the quantity becomes, the faster it grows).

Fast breeder reactor—A fast reactor in which the degree of enrichment is such that breeding occurs.

Fast neutrons—Neutrons resulting from fission and not slowed down by a moderator.

Fast reactor—A reactor in which fast neutrons sustain the chain reaction, and the moderator may be dispensed with.

Fertile—Of a nucleus, that it can become fissile by capture of one or more neutrons, possibly followed by radioactive decay; uranium-238 is an example.

Fissile—Capable of fission by neutrons emitted in the fission process.

Fission—The splitting of a heavy nucleus into two or more lighter parts with the release of energy.

Fission product—A nucleus of intermediate size formed from the breakdown or fission of a heavy nucleus such as that of uranium. Such a nucleus will be radioactive, and usually emits beta particles.

Fluidised bed combustion—A process in which finely ground solid fuel is freely supported in a furnace by an upwards fluid-like flow of particles which separates fuel particles and increases combustion efficiency.

Fusion—The merging of two light nuclei to make a heavier one, usually with a release of energy.

Gamma radiation—High energy X-rays (highly penetrating radiation) emitted from the nucleus of many radioactive atoms during radioactive decay.

Generating capability—The energy output from an electrical generating station or unit. It could be given in joules, but is usually expressed in gigawatts hours (GWh) or megawatt hours (MWh).

Generating capacity—The power output from an electrical generating station or unit; usually expressed in megawatts (MW) or gigawatts (GW).

Genetic effects—Effects produced by ionising radiation in the reproductive cells of an organism and becoming manifest (usually as malformations) in the offspring or descendants.

Gross domestic product—The total annual value of all goods and services produced in a country.

Gross national product—The annual national income plus an allowance for depreciation at market prices.

Half-life—The time in which the number of nuclei of a particular type is reduced by radioactive decay to one half.

Heavy water—Water in which the hydrogen atoms all consist of deuterium.

High-level waste—The waste containing more than 99.9 percent of the fission products which is left after the uranium and plutonium have been extracted from irradiated fuel.

Hot particle—An insoluble particle of breathable size containing alpha emitting radioactive material.

Insolation—The radiation received at the earth's surface from the sun.

Intermediate-load plant—Electricity generating plant designed to meet that part of the load which drops to zero overnight but is relatively constant during the day. Output factor between 50 and 55 percent.

Ion—An atom that has gained or lost one or more electrons and thus become electrically charged.

Ionising radiation—Radiation which can deliver energy in a form capable of knocking electrons off atoms and turning them into ions.

Irradiated—Of reactor fuel, having been involved in a chain reaction and having thereby accumulated fission products; in general usage, exposed to radiation.

Isotope—One of perhaps several different species of a given chemical element, distinguished by variations in the number of neutrons in the atomic nucleus but indistinguishable by chemical means.
Light water—Ordinary water.
Load factor—See *annual load factor* (Used in many submissions synonymously with *output factor).*
Loss of coolant accident—A reactor accident in which the primary coolant is lost from the reactor core.
Magnetohydrodynamic (MHD) electricity generation—Production of electricity by the motion of an electrically conducting fluid in a magnetic field.
Meltdown—Of reactor core, result of inadequate cooling which causes part of or all of the solid fuel in a reactor to reach the temperature at which cladding and possibly fuel and support structure liquefy and collapse.
Moderator—Substance used to slow down neutrons emitted by nuclear fission.
Mutation—Any change in the inheritable material of a living cell.
Mutagen—Substance producing mutations.
Nuclide—Any particular type of nucleus, not necessarily radioactive.
Output factor—See *annual output factor.*
Particulates—Fine solid particles that remain individually dispersed in emissions from fossil-fuelled plants.
Peak load—The maximum power demand on a power supply system.
Peak-load plant—Electricity generating plant designed to operate during periods of maximum demand. The output factor is usually less than 15 percent.
Prompt deaths—In distinction to delayed deaths: deaths from the effects of ionising radiation occurring soon after irradiation.
Quality factor—A factor that attempts to account for the differing biological effectiveness of the various types of radiation. It is taken as 1 for beta- and gamma- radiation, and 10 for alpha-radiation and fast neutrons.
Rad—The unit of absorbed radiation corresponding to 0.01 joules of energy per kg of material (*R*adiation *A*bsorbed *D*ose).
Radiation—The emission and propagation of energy such as solar radiation, gamma rays, or fast particles such as alpha particles or electrons.
Radioactivity—Process in which nuclei are spontaneously undergoing transformation and emitting radiation; radioactivity *produces* radiation.
Radionuclide—A nucleus that is radioactive.
Recycling—The re-use of fissionable material (e.g., plutonium in irradiated nuclear fuel).
Reflector—Material surrounding a reactor to reduce neutron loss and thereby improve the operation.
Rem—A unit quantifying the biological effect of ionising radiation; the product of the dose in rads and a quality factor.
Reprocessing—The chemical and mechanical processes by which spent reactor fuel is separated into uranium, plutonium, and radioactive waste (mainly fission products).
Scrubber—A device for removing certain pollutants, such as sulphur dioxide, from stack gas emissions.
Slow neutrons—Neutrons that have been slowed by a moderator to increase their probability of capture by fissile nuclei.

Somatic effects—Effects produced in the non-reproductive cells of an irradiated organism, usually cancers.
Spallation—Any nuclear reaction when several particles result from a collision.
Spent fuel—Fuel depleted of fissile material after burn-up in a reactor. It contains radioactive waste and unburned fissile material.
Thermal neutrons—Neutrons travelling with a speed comparable with that of gas molecules at ordinary temperatures (about 2 km/s).
Thermal reactor—A reactor in which the chain reaction is sustained by slow (thermal) neutrons. The fuel enrichment is not enough to produce sufficient fissions to support a chain reaction with a moderator.
Thermal station—Electricity generating station in which energy is provided by burning a fuel.
Total energy system—An electricity generating system in which the heat in the fluid which has passed through the turbines is used instead of going to waste.
Tritium—A radioactive isotope of hydrogen in which the nucleus contains one proton and two neutrons.
Unit—In common usage, and in that of the electrical supply authorities, a kilowatt hour of delivered electricity.
Vitrification—The incorporation of high-level wastes into glass.
Waste (radioactive)—Radioactive materials (mostly fission products) from the nuclear fuel cycle.
Weapons grade—Of uranium or plutonium, capable of being made into a nuclear assembly that would be critical on fast prompt neutrons alone.
Yellowcake—The concentrate of uranium oxides and impurities extracted at a mill from uranium ore (typically 95 percent $U_3O_8$).

*2. Acronyms and Abbreviations—*

ACRS—Advisory Committee on Reactor Safeguards (USA).
AECB—Atomic Energy Control Board (Canada).
AGR—Advanced Gas-Cooled Reactor.
AIF—Atomic Industrial Forum (USA).
AQCS—Air Quality Control System.
BEIR—Advisory Committee on the Biological Effects of Ionising Radiation.
BNFL—British Nuclear Fuels Ltd.
BWR—Boiling-Water Reactor.
CANDU—*Can*adian *D*euterium-moderated natural-*U*ranium fuelled reactor.
CEGB—Central Electricity Generating Board (UK).
CERCDC—California Energy Resources Conservation and Development Commission.
CFR—Commercial Fast Reactor.
Ci—Curie.
COP—Coefficient of Performance.
CRPPH—Committee on Radiation Protection and Public Health (EURATOM).
CRPR—Committee to Review Power Requirements.
DSIR—Department of Scientific and Industrial Research.
ECO—Environment and Conservation Organisations of New Zealand.
EPRI—Electric Power Research Institute (USA).
ERDA—Energy Research and Development Administration (USA).

ERG—Energy Research Group (NZERDC).
FBR—Fast Breeder Reactor.
FFGNP—Fact Finding Group on Nuclear Power.
Flowers Report—Sixth report of UK Royal Commission on Environmental Pollution.
Ford-Foundation - MITRE Report—Report of US Nuclear Energy Policy Study group—*Nuclear Power Issues and Choices.*
Fox Report—First report of Australian Ranger Uranium Environmental Inquiry.
GDP—Gross Domestic Product.
GEC—General Electric Company Ltd.
GJ—Gigajoule($10^9$ joules).
GNP—Gross National Product.
GW—Gigawatt ($10^9$ watts or one million kilowatts).
HTGR—High Temperature Gas-Cooled Reactor.
HWR—Heavy Water Reactor.
IAEA—International Atomic Energy Agency (Vienna).
ICRP—International Commission on Radiological Protection (UK).
IDC—Interest During Construction.
IEA—International Energy Agency (Paris).
kWh—Kilowatt-hour.
LMFBR—Liquid Metal Fast Breeder Reactor.
LWA—Limited Work Authorisation.
LWBR—Light Water Breeder Reactor.
LWR—Light Water Reactor.
MER—Ministry of Energy Resources.
MHD—Magnetohydrodynamic.
MSR—Molten Salt Reactor.
MW—Megawatt ($10^6$ watts or 1000 kilowatts).
MWD—Ministry of Works and Development.
NCRP—National Council on Radiation Protection and Measurements (USA).
NCW—National Council of Women.
NEA—Nuclear Energy Agency (Paris).
NII—Nuclear Installations Inspectorate (UK).
NNC—National Nuclear Corporation (UK).
NPC—Nuclear Power Company Ltd. (UK).
NPRA—Nuclear Power Regulatory Authority.
NPT—Treaty on Non-Proliferation of Nuclear Weapons.
NRC—Nuclear Regulatory Commission (USA).
NZAEC—New Zealand Atomic Energy Committee.
NZED—New Zealand Electricity Department.
NZERDC—New Zealand Energy Research and Development Committee.
OBE—Operating Base Earthquake.
OECD—Organisation for Economic Co-operation and Development (Paris).
O and M—Operation and Maintenance.
PCEPD—Planning Committee on Electric Power Development.
PFR—Prototype Fast Reactor.
PFUC—Policy and Finance Utilisation Committee.
PHW—Pressurised Heavy Water.
PJ—Petajoule ($10^{12}$ joules).
PSA—Public Service Association.

PWR—Pressurised Water Reactor.
Q—Unit of energy = $10^{18}$ British Thermal Units.
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SGHWR—Steam Generating Heavy Water Reactor.
SSE—Safe Shut-down Earthquake.
SSEB—South of Scotland Electricity Board.
TES—Total Energy System.
TJ—Terajoule ($10^{15}$ joules).
UKAEA—United Kingdom Atomic Energy Authority.
UNSCEAR—United Nations Scientific Committee on the Effects of Atomic Radiation.
USAEC—United States Atomic Energy Commission.
USNRC—United States Nuclear Regulatory Commission.
WAES—Workshop on Alternative Energy Strategies (USA).
WHO—World Health Organisation.

*3. Prefixes, Units, and Conversion Factors*—

(a) Prefixes indicating multiples and submultiples of units:

peta (P) $\times 10^{15}$
tera (T) $\times 10^{12}$
giga (G) $\times 10^{9}$
mega (M) $\times 10^{6}$
kilo (k) $\times 10^{3}$
femto (f) $\times 10^{-15}$
pico (p) $\times 10^{-12}$
nano (n) $\times 10^{-9}$
micro (μ) $\times 10^{-6}$
milli (m) $\times 10^{-3}$

(b) Units of energy and power:

The joule (J) is the unit of energy.
The watt (W) is the unit of power.
1 joule per second = 1 watt.
1kWh (kilowatt hour) = 3.6 MJ.
1MWh = 3.6 GJ.

(c) Energy content of fuels:

| | |
|---|---|
| 1 kg of organic fossil fuel (typical) … … … | 35 MJ |
| 42 gallon (US) barrel of oil … … … | 6.1GJ |
| 1 cubic metre of natural gas … … … | 36 MJ |
| fission of 1 kg of uranium-235 (approximately) … | 100 TJ |
| fusion of 1kg of deuterium … … … | 400 TJ |
| complete conversion of 1 kg of matter … … | 90 PJ |

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# INDEX

References are to chapter and paragraph, with important topics in capitals and main references in bold type. The following abbreviations are used: f "and also in the next paragraph"; ff "and in the following paragraphs"; n. "nuclear"; n.p. "nuclear power".

Appendices, tables, and figures are listed in the table of contents, but are not indexed.

E. C. K

Nuclear Power Generation in New Zealand