STUDIECENTRUM VOOR ECONOMISCH EN SOCIAAL ONDERZOEK

COAL VERSUS NUCLEAR, A STRUGGLE FOR POWER. EVALUATION AND COMPARISON OF MAJOR SIDE-EFFECTS

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Abstract

In the first part of the paper, we deal with the relationships between analysis (or description) of side-effects, and their evaluation-comparison. We also briefly recapitulate the main findings of two preliminary analyses. Then we begin a review of the literature on evaluation-comparison. For methodological reasons, the literature has been divided in two : one part dealing with simple evaluation methods, the other with complex evaluation methods. Each of them is presented and discussed in some detail. We come to the conclusion that none of the methods reviewed gives a satisfactory solution to the problem. Finally, we try to construct a satisfactory solution ourselves. We conclude that it is better to choose for the coal option, given the present state of uncertainty. But this is a judgment that requires a lot of qualifications; these can be found in the text.

§ 1. Introduction*

The subject of the paper is evaluation-comparison of the major side-effects from coal-based and nuclear electricity production. In plain language : how to find out which electricity production system is "best" for the environment and people's well-being.

Our aim is twofold. First of all, we will present and discuss various evaluation-comparison tentatives that have been put forward in recent years. As such, the paper is a critical review of (some of) the literature. Secondly, we aim at constructing a consistent and reasoned judgment on the coal-versus-nuclear issue, on the basis of our discussion of previous evaluation-comparison tentatives. This exercise constitutes the culmination of the paper, as well as its most vulnerable part.

The structure is as follows :

- Chapter 1 : presentation of the framework in which evaluation must be carried out (§ 2 - § 11);
- Chapter 2 : first part of the review of the literature (§ 12 - § 17);
- Chapter 3 : second part of the review of the literature (§ 18 - § 21);
- Chapter 4 : construction of the coal-versus-nuclear judgment and conclusions (§ 22 - 24).

*Many thanks to Aviel Verbruggen for useful comments on the draft edition, the author assumes full responsibility for all remaining errors.

§ 2. Production of electricity

The production of electricity is one stage in a greater energy conversion process. In general, this energy conversion process can be modeled as follows (1)

primary energy
(production of electricity)
↓
secondary energy
(transportation)
↓
delivered energy
(consumption)
↓
useful energy

Every stage in this process engenders energy losses; viz. "production losses","transportation losses" and "consumption losses". Production losses usually amount to 60 - 70 % of the primary energy used; transportation losses vary between 5 % and 9 %; consumption losses are virtually negligible (2).

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(1) ENVIRONMENTAL RESOURCES LIMITED (1980), p. 39
(2) *ibid.*, 7

§ 3. Systems of electricity production

Electricity, as a secondary energy source, can be produced from different sources of primary energy. In most cases, electricity production results from thermal conversion. Thermal conversion means that some kind of "fuel" (= the primary energy source) is "burned" in order to produce steam, by means of which electricity is generated. To date, fuel types used on a commercial scale include coal, oil and uranium. Other conversion systems can be based on solar and tidal energy, wind power, etc.

§ 4. Thermal efficiency

Thermal efficiency refers to the physics of electricity production. Basically, it compares the energetical result with the energetical means; it is the ratio "secondary energy obtained/primary energy used".

With fossil fuels, power generation efficiency is in the neighbourhood of 38-42 %, and with PWR's efficiencies of 32-33 % are attained (3).

On the face of it, fossil fuel systems seem more economical in their use of primary energy sources. However, this certainly does not imply that fossil fuel systems will be necessarily cheaper than nuclear systems. Several reasons can account for the potential divergence between "physical" and "financial" efficiency :

(1) different equipment requirements reflected in differing investment, exploitation and decommissioning costs
(2) different fuel costs (FR/GJ)
(3) different load factors.

The financial side seems especially sensible to change over the

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(3) *ibid.*, 80

years, due to changing legislation, changing fuel costs, etc...(4). These changes are to a great extent unpredictable. This turns decision-making on the basis of predicted future costs into a risky business.

§ 5. Money is not all

The whole process of electricity-production not only engenders monetary effects, but also a wide variety of other "side-effects". This means that besides electricity and monetary flows, there are generated wastes, dangers, etc. (5). These side-effects are potentially dangerous to human beings and their environment, *e.g.* by causing more deaths and illnesses, or by entailing climatic changes. Therefore, they are often termed "social and/or environmental costs", in contradistinction to "private" costs borne by the electricity bill payers. This cost-terminology has the disadvantage of giving the illusion that these costs could eventually be expressed in monetary units (see further, § 13).
Side-effects can also be looked upon as being statistical in nature. Consequently, they can be expressed as "(personal) risks" (6). Electricity production can thus be analysed in a risk-benefit framework.

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(4) e.g., higher fuel costs account for the recent financial débâcle of oil-fired electricity plants, now on a massive scale being rebuilt into coal-fired plants.

(5) positive side-effects cannot be excluded.

(6) cfr. ASHLEY e.a. (1976), 3

§ 6. Coal versus nuclear

This paper deals with the comparative assessment of side-effects from coal-based and nuclear-based electricity production.
Two previous papers specifying and describing the major side-effects from both systems will function as a kind of "empirical base" for our present study (7).

In Table 1 and Table 2 we briefly recapitulate the most important problems associated with the coal-fuel cycle and the uranium-fuel cycle.

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(7) ERREYGERS (1984a), ERREYGERS (1984b)

TABLE 1 : MAJOR PROBLEMS IN A COAL FUEL CYCLE

ACTIVITY	PROBLEM
Mining	Occupational diseases and deaths Accidental diseases and deaths Waste tips Land disturbance (surface mining)
Processing	———
Transport and Storage	Railway accidents
Conversion to electricity	
* Operation and maintenance	Routine risks
* Electricity generation	Particle pollution SO_x pollution NO_x pollution CO_2 pollution
* Waste Products	Bottom ash
* Decommissioning	———

TABLE 2 : MAJOR PROBLEMS IN A PWR-BASED FUEL CYCLE

ACTIVITY	PROBLEM
Mining	Occupational diseases and deaths Accidental diseases and deaths Spoil heaps (diffusion of radon) Land disturbance
Processing	Mill tailings Enrichment tailings
Transport and storage	Yellowcake and hexafluoride transportation
Conversion to electricity	
* Operation and maintenance	Routine risks Special risks from maintenance in high-radiation areas
* Electricity generation	Reactor safety
* Waste products	High-level waste (spent reactor fuel) Low-level and transuranium-contaminated wastes
* Reprocessing	High-level wastes
* Decommissioning	High-radiation areas

§ 7. Assessment

As can be seen from Table 1 and Table 2, a variety of activities entails a variety of side effects in both cases. Our method of tackling this problem consists of an analytic and a synthetic aspect.

ANALYSIS

1. separate consideration of coal-based and uranium-based electricity generation systems;
2. breakdown of each system into a number of steps according to a common scheme, in order to clearly specify what sort of actions produce what kind of effects;

SYNTHESIS

3. evaluation of the different effects;
4. comparison of the two systems.

§ 8. Analysis of side-effects

An excellent framework for analysis has been provided by HOLDREN (8). In this paragraph, we summarize his findings.
There is general agreement that the relevant range of activities for comparison is the fuel cycle. The fuel cycle runs from the mining of fuel to the production of electricity. It can be seen as a succession of stages. The following stages have been distinguished : exploration, harvesting, processing, conversion, transport, storage, marketing, and end use. Each stage can be broken down further into phases, e.g. construction of facilities, operation, maintenance, decommissioning, and management of long-lived residuals. Each phase is a collection of processes.

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(8) HOLDREN (1981), p. 4 - 11

All side-effects ultimately find their origin in one or the other activity associated with the fuel cycle. The link between these activities and side-effects can be made by means of causal linkages, according to the following "sequence" :

origins → insults → stresses → damages .

Insults (or residuals) are what is put into, taken out of or otherwise done to the immediate environment of the activities. A broad classification may be :

* consumption or pre-emption of environmental resources
* material effluents
* non-material effluents
* other physical transformations
* socio-political influences

Some insults give way to stresses, meaning altered conditions and processes in environmental systems at points of potential vulnerability. Stresses can be classified as follows :

* reduced availability of environmental resources
* altered chemical concentrations
* altered circulation patterns in the atmosphere, water, ...
* altered temperature, humidity, precipitation
* altered electromagnetic fields
* absorbed radiation dose
* perceived noise
* other alterations to, or loss of, habitat
* socio-political stresses

Finally, damages to human well-being may occur, consisting of or resulting from the responses of vulnerable components of the environment to the stresses imposed on them. The following classification can be useful :

* impairment of environmental goods and services
* direct damage to human health and safety
* direct damage to economic goods and services
* aesthetic losses and nuisances

* disruption of socio-political conditions and processes
* aggravation of the prospects for war
* psychological distress

§ 9. Practical difficulties at the analytical level

Holdren's program for the assessment of side-effects from different electricity-generating systems is much too ambitious. It is bound to remain an ideal but unattainable condition, since a number of practical difficulties blur the theoretical construction.

The first difficulty arises in connection with the so-called system boundaries of the fuel cycle. The main complication concerns the activities to be included. E.g., some have tended to ignore decommissioning (9). For truly remote activities, inclusion or exclusion becomes a matter of taste. E.g., should pre-construction activities, i.e. activities to produce the materials required for the construction of an electricity plant, be included or not (10) ? It is obvious that boundaries have to be placed somewhere. Other disturbing elements in connection with system boundaries are :

- interactions in the energy sphere (e.g. what is the effect of introducing cogeneration ?) (11)
- different levels of required safety (12).

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(9) COHEN & PRITCHARD (1980), 7, accusing INHABER
(10) HOLDREN (1981), p. 5 - 6
(11) ibid.
(12) COHEN & PRITCHARD (1980), 7

Secondly, problems occur with regard to the dimension of time. Usually the effects of today's technology will be determined from past experience, which may be outdated. Next, compared systems are sometimes in a different stage of development (13). Long-term effects, however small, must not be ignored; there is evidence that in some case long-term health effects could be substantial (14). The traditional procedure to account for future effects is discounting (15). As a result of discounting, future effects are worth less than their face value. The more distant in the future an effect occurs, the less it is worth in present terms, the precise outcome being dependent on the numerical value of the discount rate. For a small but persistent health effect, the result is a dramatic reduction in the estimated severeness of the effect (16). Critics of discounting point out that there is no generally accepted numerical value of the discount rate. One might even argue that damages imposed on future generations should be given extra weights in assessment, as somehow more pernicious than damages borne by the same generation that caused the trouble (17).

The third and perhaps most important difficulty for assessment is the presence of uncertainty. This uncertainty ranges from the very existence of some effects, over the mechanisms by which certain origins eventually produce damages, to the risk of potential catastrophes, etc. There are many uncertainties, and they are large. The magnitude of effects is therefore to a large extent unknown, so that it seems appropriate to frame the conclusions of

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(13) ibid.
(14) e.g. RAMSAY (1979), 36 - 37
(15) e.g. ARROW (1976), 113 - 140
(16) RAMSAY (1979), p. 38 - 39
(17) HOLDREN (1981), 30

assessment only in qualitative terms (18). Besides uncertainty, there is variation. Uncertainty refers to insufficient knowledge whereas variation results from known and predictable differences in conditions (19). E.g., different geographical circumstances can lead to varying estimates of effects.

A fourth source of difficulties is to be found in the shortcomings of the existing data base. As Holdren points out, the major part of the American literature on the subject descends from a common ancestry of six studies (20). These studies are defective in many ways, and urgently need updating. To counter the remaining uncertainties, but also to remedy the defects in the existing data base, scientific research is needed.

§ 10. Towards an ad hoc approach of analysis

It should by now be clear that the research program outlined by Holdren is in general not practicable. It is certainly not practicable for our present study. Let us clarify our position.

Since the construction of a "new" data base requires infinitely more time and skills than we have at our disposition, we have to rely on the existing data base as it can be found in the relevant literature. This relevant literature is in any case huge. The best we have been able to do is to review a selected portion of that literature. This entails a real danger of biased analysis.

Further, we have simplified the fuel cycle. We have only retained the following stages, which we consider to be the most important ones :

- harvesting (mining)
- processing

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(18) COHEN & PRITCHARD (1980), 24
(19) HOLDREN (1981), 14 - 15
(20) *ibid.*

- transport and storage
- conversion to electricity.

Especially the stage "conversion to electricity" has been analysed in some detail.

Side-effects cannot always be specified and described in terms of a causal chain running from origins to damages over insults and stresses. Usually we can indicate specific activities causing unwanted consequences but the precise damages remain highly uncertain. This forces us to an analysis in which insults, stresses and damages must be described vaguely as "side-effects" and be framed mainly in qualitative terms. Nevertheless, for some effects reliable and meaningful quantitative estimates are available. We have used them where we thought it appropriate.

Holdren's research program can only function as a guideline, as an ideal method not really attainable. Especially "incurable" uncertainties obstruct the analysis.

§ 11. Evaluation of side-effects

After analysing the problem, i.e. breaking it down into manageable portions, the pieces of the jigsaw puzzle must be fitted together in order to see what picture emerges. This is what evaluation, and consequently comparison, is all about.

From the outset, evaluation looks tremendously difficult. The task of evaluation is to construct a meaningful basis for comparison out of an assembly of heterogeneous side-effects. The crucial question is then : how to tackle the apple-and-oranges-character of side-effects ?

Two fundamentally different approaches of evaluation can be distinguished : the method of simple evaluation, and the method of complex evaluation.

Simple evaluation basically rests on two assumptions :
(1) all (important) side-effects can be captured in numbers;
(2) all (important) damages can be translated into a single index.

In this case, comparison becomes quite simple. For each system, all damages can be expressed in a common index. The summation of all damages caused by a certain fuel cycle therefore gives a measure of the total damage from each system. If this total damage is specified in relation to certain scale (e.g. total damage/ 1000 MWh of electricity produced), comparison is simply a comparison of two numbers. Complex evaluation rests on an explicit denial of the second assumption. As indicated by Holdren, simple evaluation usually confines itself to a characterization of expected (or average) harm, tending to forget other attributes of damages (21). He mentions these :

1) the magnitude of the worst-case event
2) the distribution of harm in space and time, and over various population groups
3) the degree of possible prevention of the damage
4) the degree of irreversibility of the damage
5) the degree of uncertainty.

All this implies that evaluation cannot be a mere reduction of all damages to a single index. More complex methods are called for. Evaluation and comparison become more than simple "technical" matters; the issue tends to be situated more clearly in the political sphere.

In Chapter 2, we will focus on simple evaluation methods. In Chapter 3, complex evaluation will be our theme.

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(21) HOLDREN (1981), 11

CHAPTER 2 : METHODS OF SIMPLE EVALUATION

§ 12. The essence of simple evaluation is the homogenization of side-effects. The most common procedure of homogenization consists of translating all side-effects into monetary units. As an example, we will take a closer look at the method of Total Social Cost Analysis (§ 13). In the following paragraphs, two similar approaches will be dealt with.

An unusual procedure of homogenization has been developed by Inhaber. This method of risk evaluation will be analyzed in § 16.

§ 13. Total Social Cost Analysis (TOSCA)

The authors describe Total Social Cost Analysis (TOSCA) as :

"a method (...) to determine the optimum mix of fossil-fueled and nuclear-fueled electric power generating plants, for the United States, for the next thirty years. The criterion of judgment is the Total Social Cost, including both the apparent or "internalized" costs and the hidden or "externalized" costs" (22).

Their aim is, from the one hand,

"(...) to develop, from a set of estimates of all the significant costs and factors directly affecting the costs of coal-fired generation and nuclear generation of electricity, the composition of the mix of fossil and nuclear plants that

(22) GAINES, e.a. (1979), 1

minimize the total social cost" (23), and, from the other hand, to determine

"(...) how much a change in the estimate of each input datum will affect the composition of that optimal unit" (24).

The authors stress that TOSCA is just a technique, a tool, a method for analysis (25). They think it an indicative tool, not a determinative force for social choice (26). At best, they hope TOSCA will become one tool in the complex political and social process of a society selecting a technology (27).

Basically, the method of TOSCA can be described as follows :

1. identification of costs

All costs k_{ijt} are identified with regard to :

- fuel system (i); this can be coal, nuclear, or any new technology (e.g. breeder, solar energy stations)
- cost category (j) (e.g. fuel costs, ...), insignificant categories are dropped;
- time of occurrence (t); going from 1 to 30 years

2. specification of dependencies

All costs are seen dependent upon one or more of these four "variables" :

x_{1it} = number of new plants of type i in year t

x_{2it} = total capacity of type i in year t

x_{3it} = total energy generated by plants of type i between year o and year t

t = time

(23) ibid., 9
(24) ibid., 9
(25) ibid., xi, 6
(26) ibid., xii
(27) ibid., 89

Then :

$$k_{ijt} = f_{ijt} (x_{1it}, x_{2it}, x_{3it}, t)$$

3. conversion to common units

All costs k_{ijt} are converted to the same unit (e.g. $ / year) transforming them into c_{ijt}.

4. discounting

All costs c_{ijt} are multiplied by $(1 + r)^{-t}$, r being a discount rate.

5. calculation of total social cost

The calculation of total social cost requires assumptions about :

a) the projected growth of the demand for electricity
b) the value of the discount rate
c) the mix of stations with which demand is to be fulfilled (e.g. 1/2 nuclear, 1/2 coal, no new technology).

Thus :

$$TSC(a, b, c) = \sum_i \sum_j \sum_t c_{ijt} (1 + r)^{-t}$$

If a) and b) are fixed, minimization of total social cost comes down to finding the mix of stations that minimizes TSC (.). This mix will be the optimal one.

6. sensitivity analysis

Finally, one has to determine whether and how the optimal mix changes if one varies (some of) the input data, as they are :

- the projected growth of electricity demand
- the value of the discount rate
- some k_{ijt}

In sum, TOSCA is a simple and flexible tool. Especially by limiting the dependencies between k_{ijt} and x_{1it}, x_{2it}, x_{3it} and t, manipulations remain easy.

Let us now focus on the incorporation of what we have called "side-effects". First of all, we must examine which "significant costs" have been included (28).
The costs fall into four subdivisions.
Subdivision 1 groups direct financial costs. There are initial capital investment, operation and maintenance costs, and fuel costs.
Subdivision 2 groups indirect financial costs, i.e. financial costs not incurred by the utilities owning the electricity plants. These include research, property damage (e.g. due to atmospheric pollution), and heat loss costs.
Subdivision 3 groups human health and safety costs, resulting from normal operation. There, one finds pollution and operating safety costs and spent fuel storage costs.
Subdivision 4 groups costs imputed to accidents and contingencies. These include the perceived cost of accidents and costs of safeguards against terrorism and sabotage.
All costs showing up in subdivisions 2, 3 and 4, with the possible exception of research costs, are monetary translations of some of our side-effects.
Two side-effects have been omitted explicitly : the proliferation of nuclear weapons, and the social consequences of extensive safeguard measures (29).
Other, implicit omissions include landscape-effects from mining (except reclamation costs),the influences of cooling-water on aquatic life, the CO_2 problem, side-effects of fuel-processing, and TMI-like near-catastrophes.

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(28) ibid., p. 14 - 26
(29) ibid., p. 10

All in all, the list of included side-effects fairly represents the scope of the problem.
In the second place, we have to examine how the side-effects have been incorporated.
The same procedure has been followed for all side-effects. It consists of translating every side-effect in monetary terms, and then integrating it in the total social cost in proportion to its estimated discounted value over the 30-year-period (cfr. p. 16 - 17). The crucial step in this procedure is the translation in monetary units, whereby the economist rivals the priest in his ritual efforts to bring about transubstantiation. But, since there is no God to call upon in the economist's world, his approach becomes more vulnerable to earthly objections, in so far as to constitute the Achilles' heel of the analysis. Side-effects are more than often badly understood in their own terms; this means that, at base level, the uncertainties are numerous and great.
The conversion process presents a second source of uncertainties : monetary values placed on damage caused by, e.g. potential accidents or acid deposition, are always debatable.
These two kinds of uncertainties have elsewhere been called "technical" and "social" uncertainties (30). The combination of both (uncertain effects + uncertain translation) is unlikely to provide reliable guidelines on the severity of side-effects. Of course, apologetics reply that one should take "realistic" estimates, and "reasonable" upper and lower bounds within which to determine sensitivity (31). However, it is not impossible to envisage cases in which reasonable upper and lower bounds cannot be specified. For such a case we will use the term "fundamental uncertainty", its characteristic being the impossibility to neutralise it by any "reasonable" range of estimates. In the presence of funda-

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(30) COOPER (1981), 109 - 111
(31) GAINES e.a. (1979), 7

mental uncertainties, there is a real danger for TOSCA to become a virtual "get-as-you-please" method, yielding any desired result by assuming extreme, but essentially irrefutable numerical values.

Is there a case for fundamental uncertainties in the present analysis ? The answer must be yes, if one considers for example the valuation of human lives and the potential existence of long-term effects. The authors quite arbitrarily assume that any single life is worth $ 1 million, in $ of 1974. One may say that this specific value is too low, or perhaps too high. Some would argue that it is inherently wrong to equate a human life with a quantity of $. All positions can be defended on legitimate grounds. It seems impossible to specify a "reasonable" range for this problem, unless one declares the more extreme positions "personae non gratae". The authors avoid the problem by just quoting estimates and ranges for the <u>total</u> costs from pollution and operation safety. Their base case values are $ 1 million for a 1 GW(e) nuclear reactor year, and $ 16 million for a 1 GW(e) coal plant year. The range of these estimates runs from $ 0 to $ 40 million for nuclear costs, and from $ 0 to $ 30 million for coal costs. In the neighbourhood of the base case values, the nuclear option is heavily favored. But the authors feel that results might "(...) be affected by significant but reasonable reevaluations of the human costs" (32). As one such reevaluation they examine what would happen if human costs were not discounted since "there is a substantive question as to whether costs to human health should be discounted" (33). Results are not drastically altered by this revaluation. What matters, however, is the acceptance by the authors of the special character of human costs.

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(32) GAINES e.a. (1979), 45

(33) <u>ibid</u>. 45

This special character is also revealed at other places. For example, the authors introduce a "risk aversion factor" when dealing with the expected consequences of large accidents, because these involve many deaths. This factor ($\geq$ 1) is meant to express aversion to nuclear catastrophes, and it makes the perceived cost larger than the expected cost. It is obvious that the higher the risk aversion factor, the more favored is the coal option. But there is nowhere in the text a hint at any realistic value or reasonable range. Again, this demonstrates the problematic issue of estimating the costs of human lives. Comparable problems arise in connection with the evaluation of very long-term effects :

> "Obviously, very long-term costs such as 100,000-year effects of radioactive tailings, if undiscounted, would overwhelm all other costs; <u>such costs are omitted here</u>" (34).

With these last five words the issue is closed and the problems suppressed. At least it is an unfortunate choice to simply bury such an important, although controversial matter. Sidestepping questions as whether or not the unique nature of radioactivity (its presence being unavoidable, irreducible and longlasting) calls for a special treatment, cannot be called illuminating. To be fair, not all problems related to the long-term effects of radioactivity have been omitted; cfr. the discussion on spent fuel storage costs, in which the analysis is brought to its logical conclusions :

> "Thus if the future is not discounted, the infinite cost of perpetual care guarantees that the proper course, <u>within the framework of simple evaluation</u>, is disposal in space" (35).

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(34) <u>ibid</u>., 100; emphasis added.

(35) <u>ibid</u>., 101

However, a pragmatic solution is chosen whereby the base case value of spent fuel storage costs is set at $ 2.5 million per 1 GW(e) nuclear reactor year.

This pragmatism is characteristic for the whole TOSCA-approach, with its emphasis on simple, rough-and-ready methods. But pragmatism cannot provide answers to the conceptual problems posed by the evaluation of side-effects : it can merely assume them away. As a result, all conclusions reached by the pragmatic method must in the end be subjected to heavy qualifications. To illustrate this, let us consider the "concluding viewpoint" of the TOSCA-analysis :

> "There is no permanent answer to the optimal mix of power plants in the way a formal mathematical problem has an answer. Our conclusions concern the nature of the answers to our question. TOSCA tells us that the optimal mix of fossil and nuclear plants is a sensitive function of capital and fuel costs, that it depends on ethical judgments such as whether or not to discount human life, and that it is insensitive to such factors as safeguarding against diversion and sabotage and to climatic considerations provided our presumptions stand the test of ongoing scientific investigations" (36).

There is not much in these conclusions that we did not already know from the outset. In the end, then, TOSCA appears as a measure for pleasure.

(36) <u>ibid.</u>, 87

§ 14. The GAIVAO-approach

A different method of monetary evaluation has been proposed by GAIVAO (37). GAIVAO aims at solving the following problem :

"Quelle valeur économique attribuer aux nuisances I_i que représentent les agressants $\dot{R}_i$ qui accompagnent le service utile d'une chaîne énergétique ?" (38)

He will define this value by means of :

"l'opération économique de mise en oeuvre des moyens techniques nécessaires à la réduction de l'aggressant $\dot{R}_i$" (39).

More specific, this value, which represents

"le service économique que nous rend la nature en prennant en charge la dispersion de l'aggressant $\dot{R}_i$" (40),

is calculated as follows :

$$V_i = MDC_i \cdot I_i \cdot \dot{R}_i$$

where : V_i = economic value of damage caused by $\dot{R}_i$ ($/Kwh)

MDC_i = marginal depollution cost, calculated for the value of the norm imposed on $\dot{R}_i$ ($/Kwh per unit of pollutant)

I_i = character of harm of pollutant i (%)

R_i = flux of pollutant agent i (specific units)

We will now briefly comment on the GAIVAO approach.

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(37) GAIVAO (1983)

(38) ibid., 16

(39) ibid., 16

(40) ibid., 18

A remarkable feature of the method is that the economic value of damage is determined by the costs of installing and operating the equipment necessary to reduce the unwanted effects of $\dot{R}_i$, even if this equipment is not at all used. The calculation of the economic value can therefore become a purely theoretical construction : the cost of real pollution approximated by the cost of an imaginary situation of depollution. Obviously, this is "wrong" : either you have real pollution and real damage, the cost of which must be measured directly; or you have real depollution and real depollution costs. Of course, you can have both at the same time, if depollution is not complete (there is residual pollution). In that case, the economic value of the original pollution $\dot{R}_i$ equals the sum of (i) depollution costs, and (ii) damage costs of the residual pollution. But imaginary depollution costs can never be a reasonable substitution for real damage costs, in the same way as the cost of a war cannot be approximated by the (hypothetical) cost of avoiding it. A fortiori, residual pollution costs cannot be determined on the basis of any depollution costs.

This conceptual remark could suffice to discredit the calculation of V_i. However, the formula used is defectuous in itself. It is completely unclear why the formula is based on the marginal depollution cost calculated for the value of the norm. The introduction of "the character of harm" is mysterious as well. In sum, the formula represents an assembly of arbitrary components, yielding a random result.

Finally, it should be mentioned that the practical elaboration of the method is totally unsatisfactory. The only pollutants taken into consideration are those which are generated during the generation of electricity, i.e. at the power plant . Even then, the problem of high-level nuclear waste is largely ignored. In view of our analysis of side-effects, these omissions are intolerable.

§ 15. The HECQ-VOUCHE approach

Hecq and Vouche have described a method of monetary evaluation which resembles the GAIVAO method (41). They aim at measuring the "total service" of an electrical power plant, i.e. the sum of positive and negative services. The measurement consists of expressing the positive services in the production costs, and the negative services in the damage costs (42).

As could be expected, problems arise when estimating the damage costs. Initially, Hecq and Vouche do not sidestep the issue. In fact, they clearly recognise the problems encountered with the "direct method". This method, they say, "involves the analysis and quantification of the following sequence : emissions → immission (pollutant transport-conversion-transfer) → damages expressed in physical units → damages expressed in monetary units" (43). But,

"the results of the direct method are often the product of speculative argument and include a lot of approximations and gaps" (44).

Therefore, they propose to use a so-called "indirect method" :

"The indirect method calculates the cost of achieving the maximum reduction of discharge (and unpleasant effects) in the ambient media by means of the best control technology available. The remaining damage is valued following the direct method. The sum of the maximum depollution costs and the costs of the remaining adverse effects represents the total cost of damage" (45).

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(41) HECQ & VOUCHE (1984)
(42) ibid., 2
(43) ibid., 3
(44) ibid., 5
(45) ibid., 5 - 6

Does this indirect method present a better procedure than the direct method ? It must be doubted. As a matter of fact, Hecq & Vouche commit the same conceptual error as Gaivao. They measure real damage costs by means of hypo - thetical depollution costs.

Next, depollution costsare made to reflect the costs of achieving the maximum reduction of pollution. The stipulation of this limit entails the risk of depollution costs being "blown up", as it is known that generally, marginal depollution costs increase rapidly with increasing levels of reduction.

Further, the disadvantages of the direct method remain, since the costs of residual pollution have to be measured directly.

Finally, the practical elaboration being confined to the sole stage of electricity generation , the results obtained must not be used to mirror the "total service" of the whole fuel cycle.

§ 16. The Inhaber approach

The object of the Inhaber study is :
"to evaluate and compare risk arising from major existing or proposed energy sources, both conventional and non-conventional" (46).

Risk must be understood as :
"accidents and disease resulting in injury or death" (47).

It can be distinguished in occupational and public risk, reflecting damage to workers and to the public.

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(46) INHABER (1978a), 1
(47), ibid., 1

Inhaber aims at risk evaluation, not risk assessment :
"'Risk evaluation' may be approximately defined as that which considers physical and biological risk. 'Risk assessment' considers both these and social, psychological, aesthetic and related risk as well" (48).

What he means by this, is that he will measure risk in terms of deaths and man-days lost.

The narrow definition of risk ipso facto excludes from risk evaluation all effects other than those which directly cause hazards to humans (49). Risk evaluation therefore covers only part of the social costs, which includes air and water pollution, land abuse, depletion of resources, etc. (50).
Thus Inhaber concludes that :
"the risks of energy generation form just one part of the selection criteria used to judge which system is best for a particular situation" (51).

To us, however, this seems to be an overoptimistic picture of the real selection process.

Let us now take a closer look at Inhaber's methodology.
Two preliminary warnings must be made :

1. we have used the first revision of Inhaber's report, as issued in May 1978 (52);
2. our proposition of Inhaber's approach cannot always be found explicitly in his report; it is our reconstruction of (what we think to be) the underlying methodology.

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(48) <u>ibid</u>., 7
(49) <u>ibid</u>., 24
(50) <u>ibid</u>., 1
(51) <u>ibid</u>., 40
(52) we could not lay our hands on the second revision, published in November 1978.

From the definition of risk, and from its distinction in public and occupational risk, we find that risks should be distinguished according to 3 criteria :

- "origin" of the risk : accident/disease
- "nature" of the risk : death/injury
- "group affected" : public/workers

In sum then, there are 8 different kinds of risk (see table 3).

TABLE 3 : TYPES OF RISK

Public Risk (PR)	Occupational Risk (OR)
Injury caused by accident (PIA)	Injury caused by accident(OIA)
Death caused by accident (PDA)	Death caused by accident (ODA)
Injury caused by disease (PID)	Injury caused by disease (OID)
Death caused by disease (PDD)	Death caused by disease (ODD)

Since it is Inhaber's purpose to evaluate the overall risk of energy systems, he must combine these 8 types of risk into one measure of total risk. He therefore assumes the following:

a) 1 death caused by accident = 1 death caused by disease
b) 1 injury caused by accident = 1 injury caused by disease (both measured in man-days lost)
c) 1 death = 6000 man-days lost
d) total risk = public risk + occupational risk

In simple terms; if one expresses injuries in man-days lost, and if one assigns each death a value of 6000 man-days lost, then total risk (TR), expressed in man-days lost, can be calculated as follows :

$$TR = PR + OR = [PIA + PID + 6000(PDA + PDD)] + [OIA + OID + 6000(ODA + ODD)]$$

$$TR = (PIA + PID + OIA + OID) + 6000(PDA + PDD + ODA + ODD)$$

Now, how must we obtain estimates of the constituent parts of this total risk ? The way to proceed is to turn to the conditions of production of electricity.

In its very essence, every system of (electricity) production can be described as a collection of specified activities. Each activity consists of combining materials and labour; some activities also involve the danger of major accidents, called disasters. So, the production of E MWh of electricity per year with system i (averaged over the lifetime of that system) requires :

- M_{ij} units of materials j ($j : 1 \rightarrow J$), and

- L_{ik} units of labour k ($k : 1 \rightarrow K$),

and equally involves potential disasters of various types. Examples of materials used : fuel, generation plants. Examples of labour used : construction labour, maintenance labour. Example of a disaster : a nuclear meltdown. To be precise, M_{ij} and L_{ik} are the amounts used up per year; for durable equipment (such as generation plants), there may be serious imputation problems.

The financial cost (who ever bears it) of producing electricity, can be estimated as the sum of three components :

(a) the cost of the used-up materials
(b) the cost of the required labour-hours
(c) the expected cost of potential disasters.

This gives the following formula :

$$E.c_i = \sum_{j=1}^{J} M_{ij}.P_j + \sum_{k=1}^{K} L_{ik}.W_k + \sum_{n=1}^{N} D_{in}.V_n$$

where E = output of electricity per year (MW(e)year)

c_i = average cost of producing 1 MW(e) year in system i ($/MW(e)year)

P_j = cost of material j ($/unit)

W_k = wage of labour k ($/hour)

D_{in} = probability per year that disaster n occurs when producing E MW(e)year with system i

V_n = estimated cost of disaster of type n ($/disaster)

The financial cost is obtained as the multiplication of the M_{ij}, L_{ik} and D_{in} by the factors of homogenization P_j, W_k and V_n.

But Inhaber is not interested in the financial cost; he is interested in the total risk of each system. The method of calculating the total risk is at first sight completely analogous to the method of calculating the financial cost. It consists of replacing the set of factors of homogenization $\{P_j, W_k, V_n\}$ by the set $\{R_j, S_k, T_n\}$:

$$E.r_i = \sum_{j=1}^{J} M_{ij}.R_j + \sum_{k=1}^{K} L_{ik}.S_k + \sum_{n=1}^{N} D_{in}.T_n$$

<u>where</u> : r_i = risk of producing 1 MW(e) per year in system i $\left(\frac{\text{man-days lost}}{\text{MW(e)year}}\right)$

R_j = risk of using material j $\left(\frac{\text{man-days lost}}{\text{unit}}\right)$

S_k = risk of using labour k $\left(\frac{\text{man-days lost}}{\text{hour}}\right)$

T_n = estimated risk of disaster n $\left(\frac{\text{man-days lost}}{\text{disaster}}\right)$

The problem facing Inhaber is to find the right values of R_j, S_k and T_n.

Inhaber's solution is straightforward for S_k and T_n, but complex for R_j.

S_k is reasonably assumed to contain only occupational risks. This means that public effects related to certain activities are seen as exclusively associated with the materials used in combination with that activity. As a result, public effects are located in the R_j.
S_k is then made up of the appropriate combination of "occupational diseases and accidents" statistics for the kind of labour under consideration.

An estimate of T_n can be obtained by calculating the effects of a type n disaster occurring in a representative environment. A distinction in public and occupational risk will be possible.

Problems arise when dealing with R_j. First, R_j contains the public effects mentioned in the discussion of S_k (53). Second, R_j must contain the risks associated with the production of material j (54). This is where the difficulties begin. Let us try to formulate the problem as clear as possible.

R_j includes (i) the "direct" public risks immediately related to the production of electricity (DPR_j), and (ii) the risks related to the production of material j (PRR_j); so :

$$R_j = DPR_j + PRR_j$$

DPR_j can be estimated if the causal chain "use of materials" → "insults" → "stresses" → "damages to human health" is known and quantifiable. To accomplish this, strong assumptions may be necessary.
The estimation of PRR_j is in principle much more difficult. The production of any material j can be seen as a collection of specified activities, requiring materials and labour, and involving the risk of catastrophes. It follows that the risks related to the production of material j = M can be expressed in the same way as the risks related to the production of electricity :

$$M_M . PRR_M = \sum_{j=1}^{J} M_{Mj} . R_j + \sum_{k=1}^{K} L_{Mk} . S_k + \sum_{n=1}^{N} D_{Mn} . T_n$$

<u>where</u> : M_M = production of material M (physical units)

M_{Mj} = amount of material j needed to produce M_M (physical units)

L_{Mk} = amount of labour k required to produce M_M (hours)

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(53) <u>E.g.</u> health effects of pollution due to coal burning; <u>e.g.</u> health effects due to routine radioactive releases from nuclear plants

(54) <u>E.g.</u> the risks of coal mining; <u>e.g.</u> the risks of uranium mining

D_{Mn} = probability per year that disaster n occurs when producing M_M (55)

It is easily seen that we should continue this decomposition ad infinitum. Lacking the required input-output instruments to solve this decomposition problem, the question becomes where to stop to obtain a "reasonable" approximation (56).

The solution of Inhaber is confusing. The general rule seems to be the following (57) :

(1) find the number of man-hours required to produce the material
(2) multiply this by the appropriate labour statistics to yield the occupational risks.

In our terms this gives :

$$M_M \cdot PRR_M = \sum_{k=1}^{K} L_{Mk} \cdot S_k$$

where the number of k taken into consideration is usually one (e.g. the mining industry).

Inhaber gives the following example :

"(...) suppose mining X tons of coal required Y man-days. If the number of man-hours lost per day of work is Z, then the number of man-hours lost per ton of coal is YZ/X "(58).

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(55) The D_{Mn} may all be 0.

(56) <u>cfr</u>. our previous discussion on "pre-construction" risks

(57) INHABER, (1978a), 10

(58) <u>ibid</u>., 10

This can be translated in our scheme without any problems. The nature of the Inhaber solution is thus to neglect all but the occupational effects of producing materials. However, when dealing with non-conventional energy systems, he returns on his steps and takes another road :

"(...) emissions produced in the course of acquiring construction materials will incur public health risks. Because it was so small for conventional energy sources, this type of risk was generally ignored for these systems. (...) However, the public health risk in producing materials may be large for non-conventional systems. The category can be called "pre-emission" risk, since the risk occurs before the energy system goes into operation, rather than after." (59)

The evidence underpinning this supposed smallness or largeness is just plain intuition. Several critics have pointed out the potential bias introduced by this asymmetry; e.g. Holdren :

"(...) it is not consistent to count the effects of materials acquisition, component fabrication, and system construction for one energy system while ignoring these effects for another system to which the first is being compared."(60)

This may explain the high figures of total risk calculated for the non-conventional energy-sources (see fig. 1).

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(59) ibid., 18
(60) HOLDREN (1981), 28

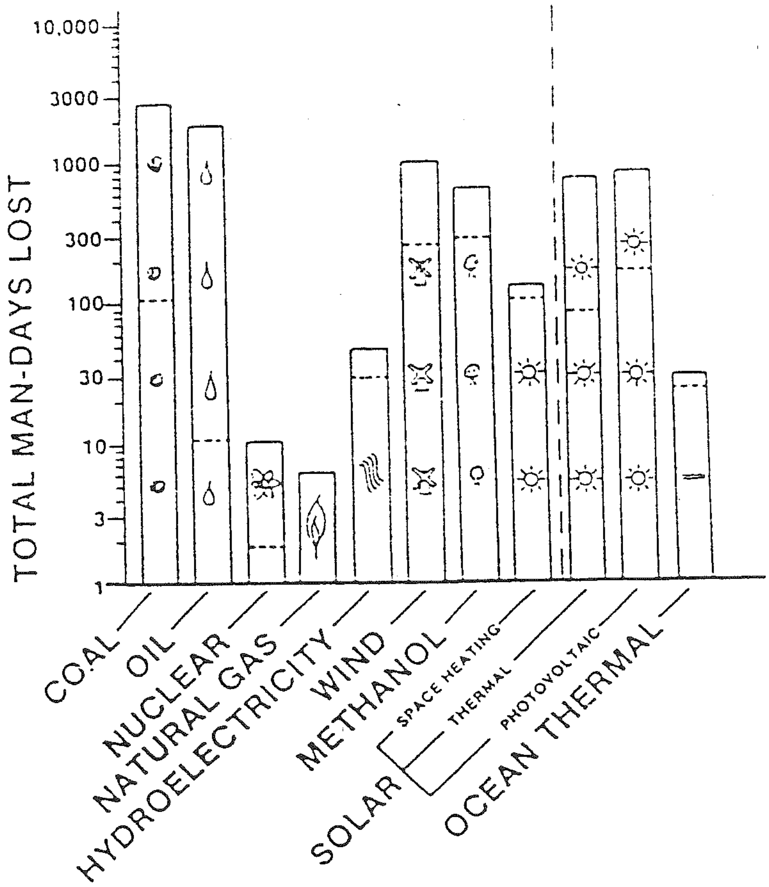

Figure 1 . Total Man-days Lost per Megawatt-year Net Output over Lifetime of System

Source : INHABER (1978 a), 39

However, our concern is with the conventional sources coal and nuclear. The range of estimates for total coal risks goes from 100 to 3000 man-days lost per MW(e)year; for total nuclear risks this goes from 2 to 10 man-days lost per MW(e)year. So, coal risks are estimated to be at least 10 times larger than nuclear risks. Different estimated public risks are mainly responsible for this divergence : the main explanatory factor is therefore the greater estimated public damage from air pollution (61) in relation to the public risks from routine radioactive releases and nuclear waste management.

(61) Inhaber considers only SO_2-pollution

But there may be some doubt on the reliability of the estimates. Ad hoc assumptions modifying the general rules are brought in unsystematically. E.g. the material "steel" is not treated like any other material; 1 kg. of steel is "translated" into 1.67 kg of iron ore and 1.5 kg of coal (62). The effect of these ad hoc assumptions on the total risk estimates is unclear. Some activities may have been forgotten. E.g. Cohen & Pritchard have accused Inhaber of neglecting "decommissioning" (63). Some hypotheses may be disputable. E.g. the damage from SO_2-pollution, or the probability of nuclear accidents.

In sum then, how must we evaluate "risk evaluation" of the Inhaber type ?
Risk as defined by Inhaber is merely one (and not the only) aspect of side-effects from electricity production. Consequently, side-effects cannot be fully translated in "damage to human health per MW(e)year". Consider, for example, the problem of long-lived nuclear waste. How must we calculate risks when:

(i) we do not even know how the wastes will be stored or be disposed of;

(ii) we realize that the situation will have to be monitored for thousands of years ?

It follows that, if risk is conceived of as damage to human health, risk evaluation in general captures only part of the side-effects.

Now, risk evaluation of the Inhaber type creates additional difficulties, since risk is not evaluated properly. We have

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(62) INHABER (1978a), 13

(63) COHEN & PRITCHARD (1980), 7

outlined the drastic (and quite questionable) method for estimating production-related risks. We have observed that Inhaber not always adheres to it. We have mentioned an important activity which has been "forgotten" to include. And we pointed at hypotheses that might be false.

Other deficiencies have been discovered (64). Critics have severely attacked the Inhaber approach, characterising it as :

"(...) so riddled with conceptual and technical errors as to be unworthy of serious attention." (65)

This judgment sharply contrasts with the worldwide attention drawn to the Inhaber report, mainly by nuclear proponents, shortly after it was issued (66).

§ 17. A preliminary conclusion

Simple evaluation turns out to be a formidable tour de force. Its proponents, ambitious from the outset, ascertain us that they manage quite well. They proclaim reasonable estimates can be obtained on the basis of which simple evaluation is possible.

On closer examination, however, these reasonable estimates are not as solid as their producers would like them to be. Due to sometimes overwhelming uncertainties, these estimates must be looked at with the utmost caution. In fact, simple evaluation appears to be a kind of mission impossible.

Therefore, we must take a closer look at alternative ways of evaluation.

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(64) CAPUTO (1979), 454; HOLDREN, SMITH & MORRIS (1979), 564-567
(65) HOLDREN (1981), 15
(66) also in Belgium : INHABER (1978b), 113-118

CHAPTER 3 : METHODS OF COMPLEX EVALUATION

§ 18. Complex evaluation

Complex evaluation has evolved on the basis of (reviews of) minute analyses of side-effects, typically covering the whole fuel-cycle. A thorough examination of side-effects unavoidably leads to the discovery of considerable uncertainties, annoying non-quantifiable elements, and unwanted value judgements (e.g. as to which effects are to be considered unimportant).
More specifically, complex evaluation has been developed in reaction against simple evaluation methods and their one-dimensional approach of measuring all side-effects with a single yardstick. The simple evaluation answer to the pervasive uncertainties, intangibilities and value judgments was refuted as being too rough and intolerable a simplification.

The dismissal of simple evaluation then leads to two alternatives : either other evaluation methods are called for, or evaluation is given up altogether. In the latter case, it is recognised that the difficulties cannot be overcome, and that withdrawal from evaluation is the only reasonable strategy. In the former case, evaluation is thought to remain feasible. Complex evaluation aims at confronting the problem from different viewpoints. The dangerous character of this approach shows up immediately : which viewpoints to take, and how to come to an overall conclusion ? Evaluation gradually drifts into the political or ethical domain, becoming subject to specific ideological orientations.

We will now present two examples of complex evaluation procedures.

§ 19. Ramsay

Ramsay's evaluation tentative is to be found in his book Unpaid costs of electrical energy (67). At first sight, it may seem odd to find the phrase "unpaid costs" in the title. This terminology refers more clearly to a context in which monetary evaluation will be carried out, than to its opposite. As a matter of fact, the meaning Ramsay attaches to "unpaid costs" is that of "impacts", and more specific "health and environmental impacts" (68); they are termed unpaid "because most of them do not show up in our monthly utility bills" (69). But the author explicitly argues against the monetary evaluation of these unpaid costs :

"This monetization philosophy seems to be a good idea in principle, but is often difficult to carry out. It is not followed here because a sensible common denominator is lacking" (70).

Or else :

"Obviously, the impacts differ in kind so that they are not readily comparable. (...) Consequently, we have not tried to add up all the impacts in terms of a common denominator - such as dollars (...)." (71)

Although we observe a certain imprecision in the argumentation - is the problem the absence of a 'sensible' common denominator, or the differences in impacts, or just the occurrence of practical difficulties, or maybe all together ? - the message is clear : no monetary evaluation.

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(67) RAMSAY (1979)

(68) ibid., 5; cfr. also the subtitle : Health and environmental impacts from coal and nuclear power

(69) ibid., 1

(70) ibid., 156 - 157

(71) ibid., 9

Ramsay then proposes an alternative evaluation procedure, basically built on two fundaments : a clear assessment of all existing and expected uncertainties, and a consideration of all impacts from different viewpoints, called value orientations.

Basic questions as "what is happening ?", "why is it happening ?", "what is the effect ?", etc. are often very imperfectly understood (72). A typical example may be air-pollution from coal power plants, widely diverging opinions being brought forward on its effects. For Ramsay, however, this must not lead to a hopeless situation for decision-makers; decisions are more than often made on the basis of inadequate data. One obvious conclusion he draws from this is the need for research :

"If we are ignorant about phenomena that might be very costly to us - such as air pollution from power plants - then research into the question might be relatively cheap, on the average." (73)

But there is another conclusion, less obvious and more far-reaching :

"(...) in addition, the nation might want to hedge its bets, in the sense that we might want to keep both the coal and nuclear-generating alternatives alive until we find out more about the effects of each one of them." (74)

We will return and comment on this important conclusion, but before we do so, we must examine more closely the second fundament of Ramsay's construction, the value orientations part.

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(72) _ibid._, 126
(73) _ibid._, 127
(74) _ibid._, 127

Ramsay's proposal consists of considering the various impacts from four overall value orientations, involving health, the environment and resources, catastrophes, and equity. Value orientations are vaguely described as "different attitudes toward values that are relevant to the technology questions" (75). The relevant values are then :

1. preservation of health
2. protection of the environment and resources
3. avoidance of catastrophes
4. equity.

The orientation aspect refers to the importance attached to each value, as well as to the particular accents within each value. E.g., health preservation may be thought the most prominent value, and accidental deaths more important than occupational diseases.

Now, how does Ramsay solve the problem of different individuals having different value orientations, so that no type of orientation can be said to be superior to another one ? Ramsay's answer is rather pragmatic :

"(...) it is possible that within each value category a more tractable comparison of impacts and their importance can be made. Thus, it is useful to classify each key impact into one value category or another before determining how coal and nuclear fare in terms of particular types of values." (76)

Instead of solving the problem, Ramsay temporarily ignores it; of course, it cannot but return like a phoenix in the end.

Meanwhile, Ramsay proceeds to a comparison of coal and nuclear impacts within each value category.

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(75) ibid., 157

(76) ibid., 160

To cut a long story short, we will simply present the relevant conclusions.

(a) The goal of preserving health favors the nuclear fuel cycle (cfr. air pollution, routine radiation, occupational and accidental effects, long-lived wastes).

(b) The goal of protecting environment and resources also favors the nuclear cycle (cfr. land use change of mining, acid deposition).

(c) The goal of avoiding catastrophes defavors the nuclear option (cfr. nuclear proliferation, nuclear accidents, CO_2-emission).

(d) Equity considerations are more difficult to translate in clearcut preference patterns. Different kinds of impact must be distinguished (impact on income and property, on workers, on different age groups, on future generations, on different regions); fairness has many components. Since both coal and nuclear produce inequities, of various nature and degrees, it is risky to decide on overall fairness. Nevertheless, Ramsay attempts so :

"(...) it may be significant that many of the coal inequities could be or are now being alleviated by compensation mechanisms (...). (...) The average scope and effectiveness of such compensation can well be questioned. Nevertheless, the possibility itself throws into sharp focus those sectors where compensation mechanisms are weakest : for particular age brackets and for future generations. Nuclear, and more particularly, nuclear waste impacts seem to offer the greatest danger of these two groups. Therefore, while each value question must be decided on an individual basis, the nuclear option involves inequities of a more intractable sort." (77)

The valuation of coal and nuclear impacts can be summarized in table 4.

TABLE 4 : SUMMARY OF VALUES AND IMPACTS

Value	Impacts in favour of	Special characteristics
Health preservation	Nuclear	Strongly dependent on air pollution effects
Environment and Resources Protection	Nuclear	Dependent on the effectiveness of potential mitigation projects
Avoidance of catastrophes	Coal	Near-term nuclear catastrophes seem more likely to occur
Equity	Coal	Intractability of nuclear impacts is decisive

Now we are confronted with a stalemate situation, comparable to an undecisive election where two candidates have obtained equal votes. The only way out of this dilemma is to spell out a detailed orientation of values, specifying which values and aspects of values are important and by how much.

(77) ibid., 164

Ramsay refuses to do so, arguing that :

> "(...) it is impossible to add up the unpaid costs of either coal or nuclear energy in any simple, straightforward way. Consequently, it is also not possible to say exactly what the total costs for particular energy strategies would be (...). It is especially impossible to give a sensible answer to the crude - but important - question, Which is better for the public health and environment, coal or nuclear ?" (78)

At the root of this impossibility lies "the demon of uncertainty". It pervades the understanding of impacts, by observing the relationships between causes and effects, or by the sheer absence of data and measurement instruments. The empirical base for judgments or recommendations is thus largely deficient. But uncertainty goes even further : it impairs the knowledge of what society thinks important, viz. dominant values and aspects of values.

Ramsay is led to draw the following conclusions :

1. In the present situation, no reasonable choice can be made between coal and nuclear on the basis of health and environmental effects. But the world is changing, and both knowledge and technology can improve.

2. The choices we make today may affect our ability to make new choices in the future. If we were to ban completely an energy option today, this might be very expensive in the future.

Ultimately, these conclusions translate into the final, "unescapable" (policy) recommendation :

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(78) ibid., 165

> "(...) our safest bet at present - given the current problem of cost and feasibility of renewable, clean energy sources and the difficulties of recreating a whole technology at some future time - is to maintain and propagate a mixture of coal and nuclear electrical generation capacity." (79)

If such a mixture were chosen, energy strategies should give high priorities to both research - to counter uncertainty - and mitigation - "to protect the public health and the environment from the threat of very large coal and nuclear impacts, while permitting the development of necessary supplies of electrical energy." (80)

We will now briefly comment on Ramsay's approach. From the outside, its structure seems quite logical : first the analysis, then the evaluation, and finally the conclusions. However, if we investigate things more thoroughly, we find that evaluation is not really necessary. Compare the following citations :

> "(...) the nation might want to hedge its bets, in the sense that we might want to keep both the coal- and the nuclear-generating alternatives alive until we find out more about the effects of each one of them", and

> "(...) our safest bet at present (...) is to maintain and propagate a mixture of coal and nuclear electrical generation capacity."

The first citation expresses an intermediate conclusion, arrived at on mere grounds of uncertainty in the analysis,

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(79) ibid., 168, emphasis added
(80) ibid., 175

i.e. before evaluation. The second citation comes from the final conclusion, i.e. the ultimate statement after evaluation. But are they any different ? Both express the desirability of a status quo, of a "mixed" energy strategy (81). The basic reason for this "conservative" attitude lies in the overwhelming presence of uncertainty, transforming the stipulation of the future energy policy into a bet. It seems rational to remain as flexible as possible in the future. Now, to return to the question : the citations do not seem to be any different. We must inevitably conclude that evaluation appears rather impotent.

Logically, the next question must be : is this impotence an inherent characteristic of Ramsay's evaluation procedure, or does it result from the particularities of the problem to be analysed and evaluated ? The answer is to be found in Ramsay's treatment of evaluation. He refuses to spell out in detail which pattern of values and aspects of values is important for society. This is the immediate cause of the evaluation failure, for the stalemate situation reached after the first evaluation round cannot be broken. In principle, Ramsay's refusal is justified : it is extremely difficult to picture society's value orientation correctly. But certainly a personal interpretation of it can be brought forward, as well as a plain individual opinion on the matter, an individual value orientation. In practice, however, Ramsay's refusal is less justified : ipso facto evaluation becomes sterile, since it is difficult to imagine that there will not be a stalemate situation of any sort after the first evaluation round at any time in the future (82). It is quite unproductive to introduce an evaluation procedure that is immediately declared useless.

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(81) we must keep in mind that Ramsay always refers to the U.S. situation anno 1979, before the Three Mile Island accident.

(82) only if all impact comparisons for all possible values yielded the same result, then there would be no stalemate situation.

There can be no meaningful evaluation unless the evaluation criterion is clearly specified. Ramsay gives a framework for complex evaluation, but refuses to fill it in. There is a skeleton, but no flesh.

We must conclude that the impotence of Ramsay's evaluation procedure stems from his requirement that one should use the value orientations of society. Considering the uncertainties about societal preferences, this requirement cannot be fulfilled. To avoid an evaluation fiasco, it should be dropped and replaced by an alternative requirement. One should adopt a clearly specified value orientation pattern, allowing evaluation instead of forbidding it. The selection of this pattern need not be arbitrary. In fact, there is ample scope for a fundamental ethical debate on the "right" value orientation. Its potential influence on the resolution of the coal/nuclear problem cannot be underrated.

In the end, we are left with an ambiguous image of Ramsay's study. On the one hand, one finds an excellent analysis of the problem and a potentially fruitful framework for evaluation. On the other hand, evaluation is turned barren. The emphasis on uncertainty, then, makes Ramsay choose the mixed solution as the optimal energy strategy.

If a "mix" is to be the future energy policy, we must be aware of the danger that financial considerations may have the decisive influence on the composition of the "mix". To avoid this danger, the composition of the "mix" must be strictly determined. In this regard, however, Ramsay remains silent.

§ 20. Cohen & Pritchard

In a rather short but first-class paper, Comparative risks of electricity production systems : a critical survey of the literature, Cohen & Pritchard review reports comparing safety assessments of electricity production systems. Although not clearly defined, risks must be interpreted very broadly (cfr. our side-effects). One argument in favour of this interpretation is that Cohen & Pritchard do not want to reduce everything into a single "unified index of woe", like Inhaber did :

"A unified index by itself would seem an inappropriate oversimplification." (83)

"Attempts to reduce very different kinds of risks into a unified index of woe are inadequate." (84)

Comparisons call for explicit value judgments, i.e. they become complex. In this regard, Cohen & Pritchard refer to Ramsay :

"Instead of adding up all the effects within a common denominator, Ramsay suggests a framework within which a more tractable comparison could be made. A further need for value judgment that we might note is that the dangers to 'critical groups' of people exposed to higher than average risks should also be brought out, though this is rarely attempted." (85)

Let us now see how Cohen & Pritchard have actually dealt with the subject (86). First of all, they have made a

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(83) COHEN & PRITCHARD (1980), 8

(84) ibid., 22

(85) ibid., 8

(86) they compare only the coal, oil and nuclear electricity generating systems.

> convinced of this only by long and safe operational experience. But there is also evidence that some sections of the public might even then have a deeper aversion to nuclear power, which rests on deeply held values." (89)

One of these values may be antipathy to the basic nature of industrial society.

It is not a coincidence that Cohen & Pritchard arrive at a similar, "neither fish nor fowl" conclusion as Ramsay did. It is an immediate consequence of combining (i) the emphasis on uncertainty and non-quantifiable effects, and (ii) the absence of an explicit value pattern. As a matter of fact, Cohen & Pritchard do not explicate on what value basis their comparative statements rest. There is no systematic discussion on risks and values. In addition, the following sentence could give the impression that Cohen & Pritchard have made an "objective" comparison :

"Many hazards are regarded by the public with relatively greater concern than would be justified by their objectively estimated risk." (90)

But that is just the whole point : there is no such thing as a "greater" (or "normal") concern justified by an objectively estimated risk, unless that "greater" (or "normal") is filled in by means of a particular value orientation ("norms").

We can rapidly conclude now. In spite of their alleged adherence to complex evaluation, Cohen & Pritchard do not arrive at a genuine application of it. The reason for this failure is to be found in a lack of explicit value judgments.

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(89) <u>ibid.</u>, 23

(90) <u>ibid.</u>, 23

§ 21. Preliminary conclusions

The principle of complex evaluation is sound, since it says that the problem should be looked at from different points of view. The practical elaboration of complex evaluation methods, however, looks disappointing. There seems to exist a resistance against explicit value judgements.

At this point, we must conclude that complex evaluation is "stuck in the mud". It is not very useful to adopt a principle but to fail to apply it.

Elaborating the complex evaluation idea, we will present some ideas for a way out in the next and final chapter.

CHAPTER 4 : TOWARDS A RESOLUTION OF THE EVALUATION IMBROGLIO

§ 22. Reconsideration and reformulation of the problem

Let us briefly summarize how we have dealt with the problem thus far. The analysis of side-effects turned out to be very deficient. We put the blame on four types of difficulties : definition of system boundaries, problems of time dimensions, uncertainties, and shortcomings of the available data base. This inevitably led us to adopt an ad hoc approach, describing insults, stresses and damages as "side-effects", mainly analysed in qualitative terms.

The evaluation of side-effects cannot but suffer from a defective analysis. But there is more : our discussion reveals serious shortcomings in the evaluation methods themselves. Simple evaluation methods are characterised by arbitrariness and simplification; complex evaluation fails because the value problem is insufficiently tackled. Again, we are obliged to adopt an ad hoc approach - if, at least, we want to arrive at a sensible comparison. Our previous discussions indicate in which direction our ad hoc approach must be elaborated. We have to construct and explicate a "sufficient" and "meaningful" value pattern, i.e. a value pattern allowing a reasoned judgment on evaluation and comparison. This pattern will be composed of so-called "crucial" values.

§ 23. Identification of crucial values

We use the term "crucial" for a double reason :

(i) the identification of crucial values will be intimately linked to the specific characteristics of the problem; our value pattern does not fall from the sky, but is "discovered on the spot", as a result of an examination of the basic differences between both systems (§ 23);

(ii) the application of crucial values will permit to draw firm conclusions on evaluation and comparison (§ 24).

From the outset we stress that our crucial value pattern is not "objective". It merely reflects our view on the problem as it appears today, i.e. characterised by a partial analysis of all side-effects. A changing analysis can bring forth a changing value pattern, and consequently a changing evaluation.

How shall we identify crucial values ? We think the best way to proceed is to consider the fundamental differences between the two electricity-producing systems. These fundamental differences relate to the nature of technology, the nature of side-effects and uncertainties associated with them, and the nature of potential mitigation measures.

(a) The nature of technology

Most fundamentally, the coal system differs from the nuclear system because the former is based on transformation of chemical energy and the latter on transformation of atomic energy. In a coal-fired plant, the organically bound energy is liberated by means of a process of rapid oxidation, caused by the union of oxygen in the air and coal ("combustion"). In a nuclear plant, the atomic energy is liberated by means of a controlled, sustained process of fissioning U-235 nuclei. It is somewhat more complicated to harness the conversion of atomic energy to electricity.

The unavoidable creation of radioactivity is mainly responsible for this complication, as acknowledged by one of the fathers of nuclear energy :

"The technical method chosen for producing electricity from fission has proven to be far from an unmixed blessing. While it produces electricity, it is cursed with radiation hazards that have caused great unease in the public mind, and it has led to passionate antinuclear protest movements in this country and in virtually every industrial nation in the world." (91)

On the other hand, coal has always been regarded as a "dirty" fuel. As early as 1307, Edward I of England banned the use of coal from the city of London (92). His successor made people torture if they had fouled the air with coal smoke (93). The list of measures in connection with the noxious effects of coal can be extended endlessly. The two examples given nevertheless illustrate that there is a long tradition of burning coal. Especially from the Industrial Revolution onwards, coal combustion has been applied on a large scale. Subsequently, there have been many opportunities to improve the dirty character of coal.

The development of nuclear power is a more recent event. It appears to be a civilian by-product of military activities, since it grew out of the U.S. Army's Manhattan District project. The people of Hiroshima know all about the purpose of this project.

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(91) LILIENTHAL (1980), 2 - 3
(92) WILSON e.a. (1980), 1
(93) ibid., 2

Perhaps the more recent emergence and expansion of nuclear power accounts for a number of - as yet - unresolved problems of the nuclear fuel cycle (cfr. waste storage, reprocessing, breeder economics, ...). In relation to the coal fuel cycle, the nuclear fuel cycle must be considered somewhat more "experimental". This experimental character reflects the more limited experience with nuclear energy. Some activities will only be performed at the end of a component's lifetime; e.g. decommissioning of a large commercial plant. The experience with these activities is very limited, and it is bound to remain so for at least one decennium.

(b) The nature of side-effects and uncertainties

The main problems associated with coal-based electricity production are mining and air pollution. Mining of coal quite certainly leads to occupational and accidental diseases, injuries and deaths. The amount of these health effects depends on the type of mining and the safety precautions taken. Air pollution manifests itself in various forms (SO_x, NO_x, CO_2 - pollution), with varying intensities according to the combustion technique and the type of coal. Health effects from air pollution are not well understood, and, consequently, their magnitudes highly uncertain. In the long run, CO_2-pollution could eventually disturbe the earth's atmosphere and entail drastic climatic changes.

The main problems associated with nuclear electricity production all relate to the occurrence of radioactivity. The amount of uranium ore to be mined is much less than the corresponding amount of coal, but radioactive dust complicates the operation. Transportation and conversion of uranium-based products require special safety arrangements. During electricity generation, the amount of radioactive material greatly increases; from then on, it includes highly poisonous transuranic elements. Transportation, storage and disposal of this radioactive waste are complex; several problems remain to be solved. Decommissioning is wrapped up in a cloud of uncertainty.

There is a fundamental difference between the two systems. The problems at the end of the nuclear fuel cycle tend to become more serious and more acute as time goes by, since there is not a final disposal solution available. Temporary storage at the plant or a nearby facility acts as a deputy, but it cannot be denied that the accumulation of radio-active wastes puts severe stress on this on-site storage program. Transportation and storage of nuclear waste have been termed "the next nuclear gamble", both because of the many deficiencies in existing programs and because of the urgency of the problems (94).
Here there is a dangerous combination : the accumulation of nuclear waste continues, the transportation and storage of nuclear waste are presently unsafe, and a final solution is absent. In addition, we must keep in mind the very long time dimension of the nuclear waste problem. At least one conclusion is unescapable : it would be very risky to stake all our resources on the nuclear game, since the outcome of the final sets is highly uncertain.

A parallel "dangerous accumulation" problem can be found in the coal-based fuel cycle : the increasing concentrations of CO_2 in the atmosphere. Nevertheless, there is an important difference, since the accumulation of CO_2 in the atmosphere is due to a complicated and not completely understood combination of factors distrubing the earth's CO_2-cycle. The emission of CO_2 by coal-plants is only one element in this CO_2-process, and therefore not exclusively to blame for the potential dangers. However, it would be

(94) RESNIKOFF (1983), 17 - 35

irresponsible to continue or increase the presently unlimited emissions of CO_2 until we find out more about their effects. The potential dangers are too far-reaching to neglect.

(c) The nature of mitigation

Concentrating next on the measures that can be taken to neutralize side-effects, we once again find a crucial difference between both systems. In general, there appear to be no unsolvable problems associated with the mitigation of side-effects from coal operations. Sometimes mitigation might involve large sums of money, as in the case of coal mining. Sometimes mitigation might only be indirect, as in the case of CO_2-emissions which can be countered by stimulating the CO_2-intake of the earth's biosphere. But the tendency is clear : to a great extent, all negative impacts can be mitigated, if society is willing to pay the price.

A different picture emerges when we look at the nuclear fuel cycle. There is no means to neutralize radioactivity; radiation can only be retained as safe as possible. Now, at the end of the nuclear fuel cycle, the amount of radioactive materials keeps increasing without there being a fail-safe disposal technology. But there is more : it must be doubted that there will ever be a fail-safe disposal method. Man is not accustomed to think and plan in terms of tens of thousands of years. Yet, that is precisely the time horizon to take into account in view of the nuclear waste problem. There is no way to "prove" or to guarantee the reliability of any technology over such a long distance of time. In short, the uncertainty surrounding waste disposal is great, and it is bound to remain that way.

So far, we have mainly outlined the major differences between the two systems. We must now proceed to the identification of crucial values, i.e. the stipulation of basic values that might allow us to make a fruitful comparison. Although subjective (expressing the author's point of view), this identification step is of paramount importance.

On the basis of essential technological differences, we arrive at the following value explicitation : ceteris paribus, for commercial development it is better to choose for a more experimental and complex technology. The probability of unexpected side-effects seems greater for the more experimental and complex technology.

In view of the differences in the nature of side-effects and uncertainties, we come to the conclusion : ceteris paribus, it is better to avoid side-effects in the form of cumulative problems for which no solution is yet in sight; ceteris paribus, it is better to avoid side-effects having a time-range of several thousands of years.

Considering differences in mitigation possibilities, we propose a value orientation as follows : ceteris paribus, it is better to opt for reversible than for irreversible side-effects.

§ 24. Application of crucial values

After we have identified our crucial values, two things remain to be done. First of all, we should engage in a debate on the right crucial values; we should find out whether our list of values is "acceptable". At present, however, this kind of debate has not taken off yet in the so-called scientific community.
Therefore, at this very moment, the discussion on the selection and identification on crucial values must be postponed.

Secondly, we should try to apply our set of crucial values to the side-effects analysed previously. In other words, we should investigate whether the application of our crucial values translates itself in meaningful evaluative and comparative statements.

If we begin the application exercise, we immediately encounter a difficulty. All of our value descriptions contain the ceteris paribus clause. If we take this clause literally (all other things being equal), then we must recognize the impossibility of arriving at an evaluative-comparative judgment. From the beginning, we have stressed the apples-and-oranges-character of side-effects; in the end, we cannot simply assume the differences away. If we acknowledge that all other things are not equal (and this is the only legitimate position), then we are confronted with the following dilemma : either we acquiesce in the impossibility of evaluation-comparison, or we try to render evaluation-comparison possible by means of an alternative interpretation of the ceteris paribus clause.

We choose for the last option, which means that we replace the sensu stricto interpretation of ceteris paribus by a sensu lato interpretation. This interpretation reads as follows : (all) other things being uncertain. In this sense, the ceteris paribus clause translates the uncertainties at the analytical level into a condition or even precondition for evaluation. We cannot deny that this is a tottering or dangerous construction; but let us look if and how it works.

First, we must examine what is the result of applying each value separately. The value on experimental technology favours the coal option, since we have argued that the nuclear fuel cycle is more experimental (cfr. unresolved questions, § 23 (a)). In the margin, however, it must be noted that the distinction could become blurred if it were suddenly required to adopt all kinds of mitigation techniques for coal-based activities. A sudden and hasty introduction on a massive scale of developing mitigation techniques might have an unpredictable outcome.

The value on presently unresolved cumulative side-effects favours neither the coal nor the nuclear option (cfr.§23(b)). From the one hand, there is the unresolved nuclear waste problem. From the other hand, there are the imperfectly understood cumulative side-effects from coal combustion. If nothing is done about air pollution, the cumulative effects might become enormous (climatic change, acid deposition leading to forest extinction, acidification of lakes, destruction of buildings).

The value on long-term side-effects is again favourable to the coal fuel cycle. The main determinant is undoubtedly the inevitable and continuous creation of highly radioactive materials. Future generations may not be very happy about the "poisoned" present we bequeath them.

Finally, the value on irreversibility for the third time leads to a comparison in favour of coal. As long as there

is no fail-safe disposal method for nuclear waste (cfr. § 23 (c)), the nuclear waste side-effect must be considered irreversible.
We must add that it seems highly uncertain that we shall ever be able to demonstrate the reliability of a proposed disposal method.

Second, we must try to articulate the separate comparative judgments into an overall comparative declaration. Fortunately the separate judgments point in the same direction : coal electricity is preferable to nuclear electricity, given the heavy uncertainty as to the identification and estimation of side-effects. Although it may seem a paradoxical statement, it is at least straightforward.

Our statement has to be taken with many qualifications. To begin with, it does not mean one should abandon nuclear energy altogether. What it does mean, is that one should exercise adequate caution in the commercial development of nuclear energy. In the present circumstances it is wrong to rush into nuclear energy; it seems better to deepen our experience of the existing nuclear facilities and to try and resolve the unresolved questions. That is to say : we should continue the nuclear experiment, but we should not put all our eggs in the nuclear basket. Further, the need for research and mitigation, as pointed out by Ramsay, remains. Especially if the coal option were to be pushed, mitigation of air pollution would be necessary to avoid impacts as changing climate, extinction of forests, etc. Finally, if we succeed in reducing the uncertainty at the analytical level, then our whole comparative exercise may change. A radically different outcome may emerge, and more stringent conclusions drawn from it. But, given the heavy uncertainty today, a drastic reappraisal is not for tomorrow.

In the end, we should try to transform our comparative statement into workable policy conclusions. One obvious recommendation is to avoid a precipitate expansion of the nuclear sector. At the moment, 313 nuclear plants representing a capacity of more than 200,000 MW(e) are operating all over the world (95); dozens of new plants are scheduled to come on stream over the coming years. It seems that this is largely sufficient to deepen the nuclear experience; consequently, the planned nuclear program should be cut back to a minimum. We propose an "almost" moratorium on new nuclear plants. As far as reprocessing and breeding are concerned, these activities should be kept alive on an experimental scale. The bulk of resources must be devoted to research on waste storage, transportation and disposal techniques. With regard to coal, high priority should be given to research on and mitigation of air pollution. Experiments with clean combustion techniques should be itensified.

A sceptical reader will, of course, put forward that the financial signals observed by utilies point to other options than the ones we have recommended. After all, nuclear electricity is much cheaper than coal-based electricity ? This cheapness of nuclear electricity must be doubted. The American nuclear program, for instance, is severely hit by financial difficulties (96). Nuclear plants are abandoned unfinished (97), or converted to coal (98). Naturally, this is far from saying that coal-based electricity is perforce cheaper; but it does illustrate that there are good reasons to temper nuclear euphoria. More good reasons can be given. Somewhere in the future, someone will have to pay for decommissioning and waste storage/disposal activities. No one knows what the charge will be, but it may

(95) Anon. (1984b); Anon. (1984c)
(96) see e.g. GOULD (1984); KOMANOFF (1981); Anon (1984a)
(97) TAYLOR (1984)
(98) DODSWORTH (1984)

be high. The financial community is already realizing the dangers of this situation (99). Will financial and environmental considerations coincide after all ?

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(99) see e.g. HOLMES (1984), FISHLOCK (1984)

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