Sustainable Development: The Last Chance for Nuclear Power?

MICHEL DAMIAN

The decline in nuclear power is profound, long-lasting and has been underway for some time — the break in the growth trend of nuclear energy goes back to the 1970s. Medium-term scenarios for the nuclear industry are thus becoming less and less ambitious and a relaunching of growth appears unimaginable for at least a generation. In the longer term, the internalization of environmental and social costs associated with all energy and industrial activities would appear to be a minimum prerequisite for the continuation of the nuclear option. The quest for a more sustainable form of economic development could be the last chance for nuclear energy and the lessons learned by the nuclear industry could themselves have something to contribute to the development of sustainability.

La récession nucléaire est profonde, durable et déjà ancienne: au plan mondial, la cassure dans le développement des programmes remonte au début des années soixante-dix. Le scénarios nucléaires à moyen terme sont donc de moins en moins ambitieux, et à l'horizon d'une génération une forte relance paraît inenvisageable. A plus long terme, l'intégration de la facture des coûts sur l'environnement et la société par l'ensemble des activités énergétiques et industrielles semble être un préalable minimal pour le maintien éventuel de l'option nucléaire. Paradoxalement, le mouvement qui s'affirme pour la recherche d'un développement plus "soutenable" pourrait donc constituer la dernière chance pour l'énergie nucléaire

Michel Damian is a member of the Department of Economics at the University of Grenoble and a Research Fellow at IEPE.

> Technology is not things; it is knowledge. ... Technology is knowledge of how to do things, and not all of the things it teaches us to do are done. ... The decision to apply technology is made in the matrix of our social institutions. It may be a decision of consumers that they wish to enjoy a new product discovered and developed by technology; it may be a business decision that a particular exploitation of new technology will be profitable; it may be a political decision to spend public funds to exploit a particular technological opportunity. Most often, in important cases, it is a whole host of decisions made through all of these institutional structures.

The framework of this paper has been influenced by the ideas in this strong proposition from Herbert Simon (1973). The future of nuclear power is indeed conditioned by more than the mere facts of technology, its progress, and public attitudes towards the nuclear industry. It must be thought of in relation to the futures of our economic system, social organization and institutions. In this light, the future of nuclear energy seems rather sombre. Profound changes are underway worldwide which would appear to block the possibility of a genuine relaunching of nuclear power for a long time. Recasting Simon's words in this context, where are the consumers, the citizens, the institutions, the firms and the governments capable of carrying forward the future of nuclear technology?

This view must, of course, be put in perspective. Nuclear power is established as an integral and lasting part of human history. Various applications of its different uses, as well as other uses of related radioactive elements, will not be renounced. Currently nuclear power has an important role in a small group of Western nations. Even though it represents only a small part (less than 6%) of the world energy balance, it contributes to the energy supply of more than 20 countries (accounting for about 17% of electricity production), with several hundred nuclear power stations in service, under construction, or having been ordered in at least 30 countries. In France and Japan in particular, ambitious long-term programs have been declared.

At the same time, four decades after the launching of "Atoms for Peace" in the United States in 1953, it has to be recognized that the messianic promises of that period have not been fulfilled. Nuclear expansion programs have been eroded and prospects for the future do not look good. One sort of evidence for this is the dramatic range of conjecture found in recent studies which attempt to project the future of nuclear power: from scenarios of the rapid abandonment of nuclear power to aggressive arguments that nuclear programs must be rapidly revived in order to counteract the greenhouse effect.

The purpose of this paper is to argue that the future of nuclear power can be understood only in the context of its own past and the broad perspective referred to above. The following points outline the argument:

1) Installed nuclear capacity in the world is not likely to expand in the near term. Just four or five countries (among which are France, Japan and South Korea) are likely to install more than one new reactor in the coming 10-15 years.

2) In the middle to long term, nuclear scenarios are currently becoming less and less ambitious, not only because of public opposition, but also because of the state of the world economy and the transformations in technology currently in progress.

3) A strong relaunching of nuclear investment cannot be envisaged within a time horizon of a full generation. The social and institutional conditions that enabled the original development of nuclear power are no longer present.

4) The severe decline in the demand for new capacity is essentially based on the specific conditions of nuclear power production, which is characterized by great complexity and major risks. Existing approaches to organizing work and production have not proven totally successful in dealing with this complexity and risk — the dominant industrial model reaches its limits in the nuclear industry.

5) In the longer term, therefore, a larger share in energy balances for nuclear power would appear to depend on some significant degree of economic reorganization, in which the demands and constraints borne by the nuclear industry for more than three decades are applied to other important industries. One scenario in which such change could be envisaged would involve progress towards economic structures that much more fully account for environmental constraints and scientific and technological advances, with more open debates on major societal decisions. In this respect, there is a deeper and more complex relation between nuclear power and the concept of sustainable development than has typically been argued. This relationship is discussed in the closing section of this essay.

1. Current Nuclear Projections: A Future Without Landmarks

The first long-term projections of installed nuclear capacity date back to 1962-64 at the time of the commercial launching of nuclear reactors, in the first instance in the US. As we know, these projections turned out to be wrong. Figure 1 shows how the capacities projected for the year 2000 in various forecasts have declined over a 20-year period.

The transformation of the economy that is typically viewed as beginning with the 1973 oil shock destroyed the relatively stable relation that had previously existed between the growth of energy consumption and global economic growth. During the 1950s and 1960s, this close link enabled one to forecast energy consumption with more confidence. In that context important investment decisions involved less risk. That is no longer true. With the slowing down of economic growth

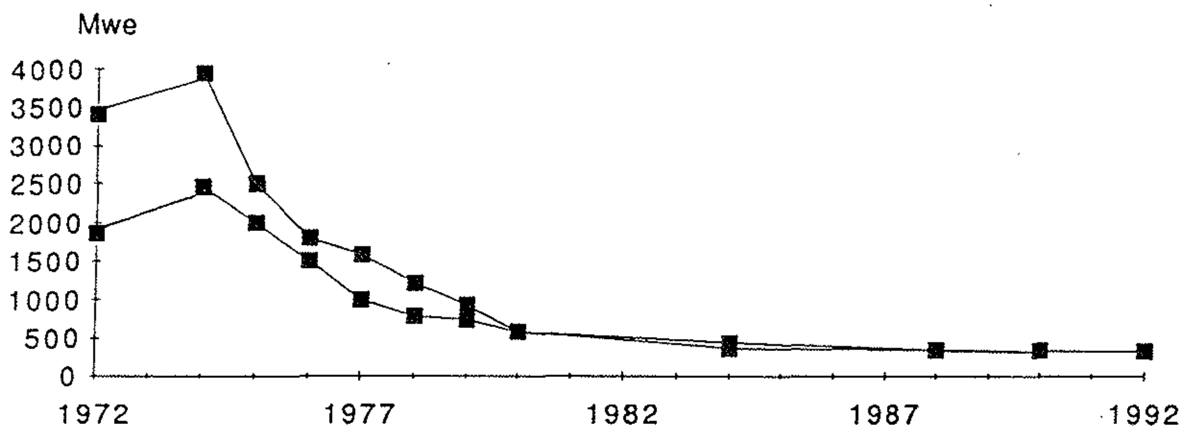

Figure 1: Projected Evolution of World Nuclear Capacity (except Eastern Europe) with a Time Horizon at 2000
Source: Estimates of AEC, ERDA, DOE and CEA.

and the fall in energy intensity in the OECD countries of around 30%, growth in electricity consumption has fallen from 7% per year to 2-3% per year. Along with this, structural instability makes investment decisions more risky (Destanne de Bernis, 1988). The future has no consistent landmarks. This is particularly problematic for nuclear power, because of the very long planning and implementation period it requires.

It is therefore not surprising that nuclear scenarios (over 20-30 year horizons) from established sources are less and less ambitious. In 1990, Häfele (1990) was still very ambitiously proposing to install 2000 GWe in 2030. Most of the recent research is far more modest. The World Energy Council (1992) presented its projections for the horizon 2020 with three scenarios: "Ecologically Driven," "Reference," and "Enhanced Economic Development." According to these scenarios, the production of nuclear power in 2020 would represent 0.7 or 0.8 or 1 billion tonnes of oil equivalent (btoe) respectively, corresponding to an installed nuclear capacity of around 490, 570 or 710 Gwe. In France, the latest scenarios of the Commissariat à l'Energie Atomique (CEA) are more or less of the same order: between 431 and 735 GWe of electronuclear energy in operation in the world in 2020 (CEA, 1992). Capacity in 1992 was 336 Gwe; thus in three decades it would be necessary to install in one scenario 95 GWe and in the other 399 GWe. But where? The CEA's lower level scenario is already too optimistic. Numerous events tied to the slowdown of economic growth and to international upheavals seem to rule out a strong relaunch of nuclear programs before 2020. These events relate to the conditions under which nuclear programs originally developed and to the root causes of the nuclear slowdown.

2. Conditions for Nuclear Development No Longer Present

The nuclear reactors currently in operation come from national programs undertaken since the middle of the 1950s. All the analysts of this period agree in recognizing that the launching of these major programs was forced, artificial, and not very well reasoned. In 1955, during the First International Conference on the peaceful utilization of atomic energy at Geneva, the first President of the Atomic Energy Commission, D.E. Lilienthal (1959, p. 21), wrote in his journal:

> The thing that I keep coming back to, again and again, about recent atomic history particularly, is that it is characterized more by salesmanship, propaganda, and overzealousness than sense. These men are fanatics or zealots; caveat zealot!"

Nuclear power is the outcome of decision processes associated with several diverse but organically connected phenomena: not only the production of energy and the balance of economic forces, but also preoccupations with military defence, national prestige, and the fight for leadership among the great powers.[1] In the post-war period and in the climate of the cold war, political and economic elements were inextricably linked.

Despite this complex interaction with non-economic factors, it was very much the anticipation of economic gain that legitimized the original development of nuclear power. From the outset it was believed that reactor-powered generators would be immediately competitive. At the beginning of the 1950s, atomic power seemed to herald a new energy revolution: fuel's share in the cost of electricity would become essentially zero.[2]

In this context completely new structures for the promotion of nuclear energy were progressively put into place. These involved the close association of governments, the military, national atomic commissions, major industrial firms, and electricity companies. Governments provided finance and the powerful atomic commissions carried out coordination. In each country, the commission and the government behaved to some extent like the United States Atomic Energy Commission (AEC) and the American government — as a "partner, employer, promoter, rival and policeman" (Palfrey, 1956, p.391). Decision processes remained the privileged domain of small groups of specialists: at that time the expression of public opinion and criticism did not enter into decisions about nuclear energy to the extent it does now, though it did have a limited role in the US. Electricity companies built the first series of powerful reactors under the assumptions of major long-term programs. In 1954 the US launched a "quinquennial program," the UK started its major program in 1955 and reinforced it further in 1957, and in France the first reactor was started in 1956, with a total of seven to be ordered between 1956 and 1966. In its *Rapport Annuel* of 1959, the French Commissariat à l'Energie Atomique (CEA) strongly affirmed the strategic choices of the decision makers: "The first objective of the French atomic program is to prepare the country for the massive introduction of atomic energy in its economy" (CEA, 1959, p.5).

Nuclear power as we know it today was developed within these rather outdated institutional and organizational forms. But starting in the early 1970s, things began to change. In the US the AEC was abolished at the end of 1974, and was replaced by a commission with a mandate over a much larger domain than nuclear power itself. The British government reduced the role of the United Kingdom Atomic Energy Authority (UKAEA) and the current government has proposed its privatization. Even in France, the power of the CEA has diminished and its financial resources have been reduced.

The most important change has of course been the decline in the world nuclear market during the last 20 years. Of the 421 GWe effectively ordered in the world (excluding cancellations) from the beginning of nuclear power until 1993, 326 GWe — more than three-quarters — were ordered before 1973. The years 1973-74 thus mark a real break in the development of nuclear power (see Figure 2). With the exception of countries in which the government structures the entire nuclear complex, nuclear development programs tended to run aground in a series of waves during the 1970s and 1980s, first in the US, and then progressively in other market economies, and more recently in the Eastern European countries.

At this point one can now see that everything has indeed changed. The institutional and political situation is different; throughout the world, the role of governments is being reduced; the major structures for promoting atomic energy are

1/ The jurist H.P. Green (1957, pp.102-103) clearly underlined these new strategic interests: "The rapid development of atomic power has become a primary element in the cold war ... . These considerations ... preclude reliance upon the forces of the marketplace as determinants of the rate of nuclear power development and require an aggressive program of Government intervention to assure substantial activity in the nuclear industry even though such activity cannot be justified on conventional economic grounds."

2/ See Schurr and Marshack (1950), p.23. On the critique of the initial research on the competitiveness of atomic power, see Mouly (1957), p.447.

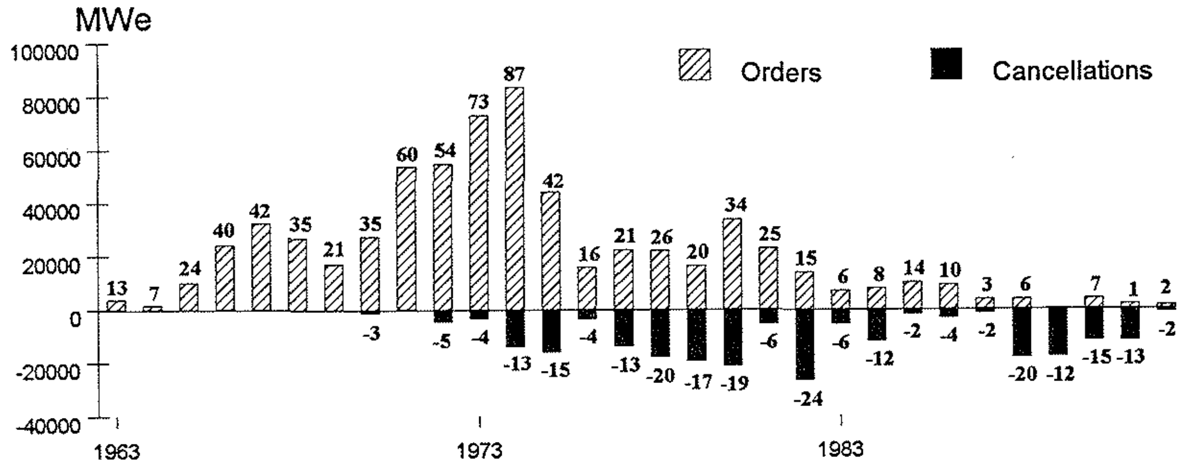

Figure 2: Orders and Cancellations of Nuclear Power Plants in the World from 1963-92 (in MWe and number of units)

Note: The figures above or below each bar represent the number of orders and cancellations of plants per year.

Source: Data Base CEA.

being questioned; there is extensive deregulation and a movement towards the privatization of electricity companies. The status accorded to atomic energy has changed. For quite some time, nuclear power has no longer been viewed as the major substitute for petroleum. The competitive position of nuclear power is being questioned and depends strongly on the national context within which it operates. The energy situation on the whole has changed. Energy efficiency policies and demand-side management have become a priority for electric utilities; the scope for substitution between energy sources has increased; there is increasing use of dual-energy equipment and generation with combined-cycle gas turbines.

In a context that is so changed, one cannot seriously envisage a substantial relaunching of nuclear programs in the near future. The social forces and the institutions capable of bringing about a "Second Nuclear Era" (see Weinberg *et al*, 1985) are not present at this point, in part because nuclear power does not appear to have fully broken away from the initial conditions of its development. Furthermore, its decline, and the fact that it has not become a "normal" marketable commodity, is due to more than the institutions within which it was originally developed. Before turning to that question, however, it is appropriate to consider projections for the industry within a medium- to long-term horizon.

3. Nuclear Programs in the Middle to Long Term

Even if the original promise of nuclear power has not been fulfilled, it nevertheless represents a substantial part of world energy production. In 1993, 29 countries (among which six were constituent parts of the former Soviet Union) were producing electricity from nuclear power. The main part of this production is concentrated in a limited number of countries: 30% of it is in the US, 32% in the EEC, Japan has 10%, Russia 5.6%, Canada 3.9%, and Sweden 2.9%. The share of nuclear power in electricity production reached 22% in the US (but with more than 50% of that in seven states — in Vermont the share is 72%, in New Jersey 65% and in each of South Carolina and Connecticut, 62%). At the world level, the share of nuclear power in electricity production exceeded 30% in 13 countries (in particular, 73% in France, 61% in Belgium, 60% in Lithuania, 50% in South Korea and in Hungary, 43% in Sweden, 38% in Switzerland, 34% in Germany and in Taiwan, and 33% in Finland).

Within a decade, because of the end of the life cycle of several nuclear plants and the limited number of new orders in the last 20 years (only 95 GWe, of which more than half will be in France), the share of nuclear in world electricity production is inexorably going to fall — from around 17% now to around 15% in 2000.

Actual installed capacity over the next 10 to 15 years is not likely to change much from the present level. In addition, broad estimates suggest that by 2005 or 2010 50-55 GWe of capacity (around 40 reactors) will be added to the 336 GWe (427 reactors) installed in 1992. Among the reactors under construction (of which eight are in the US) or those that might be ordered, only five countries have consistent projects, and each should install several new reactors. According to the estimates of the CEA, which are probably far too optimistic, the 40 additional reactors that might be constructed by 2005 will be distributed as follows: seven will be installed in France, 12 in Japan, 12 in South Korea, two in Taiwan, and seven in the People's Republic of China.

Everywhere else, nuclear programs are currently blocked within a long-term horizon. Furthermore, in some countries it is going to become increasingly difficult to find sites for power plants, not only in Japan, but also in South Korea and Taiwan. There remains the very particular case of the former Soviet Union and the other Eastern European countries who produce, with 64 reactors in service, almost 13% of the world's electricity production from nuclear sources. For Eastern Europe as a whole, 26 reactors (representing 19 GWe) are still declared as being "under construction." It is hardly likely that construction will be halted on all of them. All the experts — including those in the nuclear industry[3] — now agree in recognizing that the former Soviet Union in particular has better options than the repair of its dilapidated, high-risk reactors.[4] Their consumption of energy being at least double what it should be, the only realistic objective is to seek energy efficiency and economize on energy consumption.

Beyond 2005-2010 the perspectives seem to be very uncertain. A vigorous relaunching of nuclear programs cannot be envisaged in less than 20-30 years. The break in the trend goes far back, and it has not finished producing its effects. The oil shock of the early 1970s served to mask the nuclear decline, which is of a totally different historical dimension (see Damian, 1992).

For at least one generation, simply the maintenance of installed nuclear capacities plus the installation of reactors under construction (around 380 to 400 GWe combined) will probably not be surpassed, particularly in the light of increased international distrust vis-à-vis the dangers of proliferation. For several decades, attention will be focused on managing existing capacity and programs. In 20-30 years, the techniques of advanced reprocessing of nuclear fuels might have developed to an industrial scale, and might resolve the problems of nuclear waste and the associated problem of social acceptability. Within 50 to 100 years, the last phase of the dismantling of nuclear plants will probably have been mastered in an industrial context.

Between now and then, progress on reactors defined as intrinsically safe, and probably also on fast-breeder reactors, will require new and more intensive forms of international cooperation. Future reactor technology and the choices of back-end fuel cycles are both so fraught with uncertainty, and the necessary investments are so substantial, that no industrial group or nation can really go it alone. For at least the half-century to come, nuclear power will remain almost exclusively the domain of a few nations. In 1993, more than 80% of world production of electricity from nuclear power was concentrated in only eight countries. This is a far cry from nuclear power for the "benefit of humanity as a whole" and for "countries poor in energy" that President Eisenhower hoped for in 1953 in his "Atoms for Peace" speech.

3/ See the article by J. Syrota (1993), President of the Compagnie Générale des Matières Nucléaires.

4/ In 1994 Chernobyl-type power stations (RBMK) still represent more than 40% of the nuclear power in service in the former USSR (14,785 MWe in 15 reactors, of which 11 are in Russia, 2 in Lithuania and 2 in the Ukraine).

4. Underlying Causes[5]

The most visible cause of the progressive decline in nuclear programs is public opposition. This opposition has not, however, taken form in a vacuum. It is rather a product of the very nature of nuclear energy in its present state: the marriage of a technological system which requires the management of highly complex and public risk, due to the effects of radioactivity on living organisms, with a system of economic organization and decision making that was not designed for that purpose. Evidence that this was a problem appeared very early in the development of nuclear energy when it became clear that private companies and industrial groups were not willing to take on responsibility for the risks of operating nuclear power stations and dealing with the waste materials produced in them. Since private investors bear such risks when they produce "normal commodities," it was clear from the start that nuclear power is not a standard marketable commodity like any other.

Industrial entrepreneurs in the US were among the first to be worried, as early as 1956-57. For them "the hazard (was) new."[6] In order to reassure investors and avoid the possibility of the stoppage of civilian nuclear reactor programs, the Price Anderson Indemnity Act was passed in September 1957. The Act placed responsibility for financial risks due to accidents on the government. In 1962, a company called Nuclear Fuel Service (NFS) planned to construct the first private plant for the processing of waste (the West Valley plant). But NFS flatly refused to bear the responsibility for the final management of wastes:

> the storage of nuclear waste is a government responsibility ... it is not feasible for a private corporation to assume physical responsibility for high-level wastes from a chemical [re]processing plant for the extended and possibly indefinite period of time necessary to assure adequate protection for public health and safety. (Rochlin *et al*, 1978, p.20)

In other countries there is only one reprocessing plant currently in operation at an industrial level, at La Hague in France. (In the UK the new Sellafield plant has obtained the necessary authorizations for starting industrial operation, but strong public opposition remains.) Only Sweden has so far succeeded in putting into operation a centre for the long-term storage of nuclear waste. Three decades ago, the AEC in the US anticipated the absolutely crucial nature of this problem in a report commissioned in 1962 by President Kennedy (USAEC, 1962, p.55): "Aside from the central reactor development program proper, no other phase of the entire program is more important than that of waste disposal." .

These problems of designing and implementing organizational structures to deal with financial risk and waste disposal are manifestations of a more fundamental problem involved in nuclear power: the relationship between size, hypercomplexity and the risks related to radioactivity. This in turn can be viewed as a special case of a new articulation of science and production.

In 1977 the *Administrateur Général* of France's CEA, A. Giraud, one of the leaders of the French nuclear development program, incisively drew attention to some important implications of the underlying problem.

> The difficulties are such that every expert, in order to remain one, needs to focus himself on a limited domain of expertise. But, in isolation, this competence is absolutely useless; it carries value only through cooperative effort, and a complex of cooperative efforts is itself not possible without calling on a new type of specialist who can give a global coherence to everything taken together ... . And no matter how advanced our scientific and technical information, our decisions are based more on the complementarities that we recognize between us than on a methodical verification of the work of others ... . *In order to*

5/ For more discussion of the argument in this section, see Damian (1992).

6/ See Murphy *et al* (1957). The members of the Atomic Industrial Forum and the insurers indicated that the risks related to the production of fuels and to the processing and stockage of nuclear waste were in the long term as great as the risks related to the functioning of reactors.

make a well-informed decision, an ordinary citizen needs to have technical knowledge that even the most brilliant among us could not even dream of possessing.[7]

To paraphrase, the nuclear system, excessively complex and hostile, depends on the interlinkage of diverse areas of technical and scientific knowledge. No individual, however expert, can ever possess the universal knowledge necessary in order to comprehend it globally. In order to make judgements, individuals have to fall back on their own subjective opinions. This explains why there has been such a diversity of opinion on the nuclear question, among scientists as well as lay people. Everything depends on what the individual considers to be acceptable and socially useful for himself and others — in economists' terms, on his conception of a social welfare function. Of course, the consequences of differences of opinion of this sort for the development and implementation of nuclear programs are bound to vary greatly from one country to another; each country brings to the matter its own history, values, and particular forms of social and political organization.

What are the implications of all of this for the organization of production and labour in the nuclear industry? For a considerable time, there was an implicit assumption, particularly in the US, that the conventional organizational model, which had fostered the accumulation of capital for more than a century, would also work in the domain of nuclear power: competition among several producers and potential producers, the search for profits, efficient replication of models for nuclear power stations, a large number of electric utilities, relatively flexible regulatory procedures, and an organization of the work of employees more or less based on the older industrial model. Unfortunately this organizational model has reached its limits.

In the middle of the 1960s, at the moment of the commercial launching of nuclear power and the subsequent flood of orders (the "Great Bandwagon Market"), things seemed to be quite simple for American entrepreneurs.

> At the time ... the technology seemed not all that exotic. As reactor manufacturers explained it, a power plant was a power plant, and nuclear fission was just another way of heating water ... . The assumption was you had a mature technology when in fact it was still evolving (Cook, 1985, p.84).

But a nuclear reactor is not just another way of heating water. During its development and diffusion, the very notion of "technological maturity" had to change. The conventional approach to scientific progress — the destruction of past certainties, questioning, and the formulation of new problems — had to come out of laboratories and into industry. This was at odds with the received idea that scientific knowledge would be applied only after its extensive development within a technological framework. The lines between industry and science were blurred. This made nuclear power the first "scientific industry," and made the interaction between industry, technology and society far more problematic.

The constraints on development and production were to be found from the outset in the nuclear complex itself: debates on the emergency core cooling system, delays and faults in construction, looseness in the control of fabrication procedures, technical modifications, the tightening of security procedures, and anomalies and incidents during functioning. Rolph (1977, pp.54-55) drew a strong conclusion from all this: "Contrary to the popular mythology, the dramatic increase in elapsed time between applications for a construction permit and actual power generation was *not* primarily attributable to contested hearings." Intervenors "did not begin to be the *major* cause of plant delays and escalating costs that the industry and even the AEC often labelled them" (italics in original source).

It would also be useful here to examine the relation between the inherent problems described above and the management of nuclear safety. However, the question of how the organization of the industry and work within it interacts with the safety issue is far too complex to explore in this brief article. Nevertheless, one can see that the concept of a "scientific industry" has important implications for the nature of the safety issue. Indeed much of the adaptive reorganization of traditional structures that has occurred has been

7/ Giraud (1977), p.5; italics mine.

driven at the surface by the nuclear safety issue.

To sum up our argument to this point, the downturn in the development of nuclear energy is a worldwide phenomenon and it is both an economic problem and a problem in the relation between society and industry. Analysis of it requires an understanding of changes in that relation, and thus of the new constraints which arise out of complex production processes in a hostile environment and the problems of dealing with the risks of nuclear technology. The escalation of costs, the delays in launching projects and in general the controversies over nuclear energy are largely the consequence of a profound change in the relationship between humans and nature.

Looking at the problems of the nuclear power industry in this way leads us to an hypothesis: the nuclear industry has probably shown us the limits of the organizational model that has provided the underpinnings for industrial development and the accumulation of capital over two centuries. In terms of economic and social efficiency, the old model cannot deal effectively enough with the demands placed on it by what we have here called a "scientific industry."

If nuclear power is to have a more secure future, the above implies the need for a learning process in regard to organizational complexity and the management of uncertainty and risk. Of course, it is very difficult to speculate on how long it will take productive systems and social organizations to learn new ways of thinking at this profound level. However, formulating the problem in this way allows one to say that the nuclear domain is not a technological dead end, as claimed by some critics (Rudig, 1983). Furthermore, it allows one to view nuclear power as a kind of precursor of what must happen in other industries, a "laboratory" for the very long term. With that in mind, we turn finally to the relation between nuclear energy and the question of sustainable development.

5. The Environment, Sustainable Development and the Future of Nuclear Power

When nuclear power is brought into the discussion of sustainable development, it is usually in regard to the opportunity it offers as a substitute for energy technologies that have high rates of carbon dioxide emissions. The debate on that point is well-entrenched. For its critics, nuclear power is incompatible with a viable future for the planet; the stabilization of CO_2 emissions by substituting fossil energies with nuclear power is an impossible scenario. Keepin and Kats (1988) argue that it would be necessary to commission a new reactor every five days; and that pursuing greater energy efficiency is a much more productive policy, in that a dollar invested in economizing energy would reduce CO_2 emissions by almost seven times more than a dollar invested in nuclear power. Most ecological or sustainable development scenarios envisage a quasi-disappearance of nuclear power in the next century (see Goldemberg *et al*, 1988, and Dessus, 1993).

The supporters of nuclear power argue that it offers an opportunity to make a significant impact on stabilizing CO_2, though they recognize that it must be used in conjunction with other substitutes for fossil fuels. They argue that nuclear power currently allows us to avoid the annual emission of 1.8 billion tonnes of carbon gases, about 8% of world emissions. But the scenarios that are favourable to nuclear power all agree on one point: using 2020 as a planning horizon, it can provide "only a modest contribution to an eventual stabilization of world emissions at current levels" (CEA, 1992, p.13). With 2040 as the horizon, "neither nuclear power, nor efficiency improvement, nor renewables separately can significantly reduce CO_2 emissions from electricity generation. All three will be required to do that. They are complementary, not in competition" (Fulkerson *et al*, 1992, p.183).

Supporters also point out that nuclear power alone has to bear untenable constraints. There is "the acceptance of a level of tolerance that is much less demanding vis-à vis health and environment hazards from non-nuclear than from nuclear power stations ... ; the different national norms fixed for sulphur dioxide are currently a hundred times more than the average natural concentration, while for radioactivity, it is barely above the natural level" (Capron, 1988). Such an observation leads one to recognize that the relation between nuclear energy and sustainable development is more complex than the admittedly important question of the extent to which reactors should be substituted for fossil fuel-based generating plants. It can be argued that efforts that have been made to cope with the problems of nuclear power represent the first instance in which those responsible for an industry (in this case that means a combination of business and governmental entities) have been forced to face the implications of sustainability, in the sense of requiring it to respond to all of the problems it creates for society.

Nuclear power introduced into public debate the notion of major technological risks for present and future generations, which can be expressed more generally as the question of its sustainability in the long term. It has taken the difficult matter of societal choice to new levels: "Is everything possible? Is everything that is possible necessarily desirable, and can everything desirable be allowed? Allowed for whom and why?" (G.Canguilhem). And it brought into being "trans-scientific" problems (using the term coined by A.M. Weinberg in 1972), such as the NIMBY syndrome in relation to nuclear wastes (see Jakimo and Bupp, 1978). Nuclear power was the first energy and industrial activity to integrate, at least partially, environmental and social costs.[8] All of these things are the ingredients of sustainable development: the discussion of social choices, making energy resources bear their total social costs, dismantling all industrial and energy installations at the end of their life-cycle,[9] and managing wastes from the cradle to the grave in the very long term.

In this sense, nuclear power has revealed itself to be a real "laboratory" and not just a "dead-end technology:" on the question of risk, societal problems, the democratization of industrial choices and the control of externalities; on the question of mega-science and of technological complexity in hostile environments; and more generally on the relationship between work and living, and the relations between nations. Within its own domain, it has brought about — because of the risks that it carries and by the conflicts and tensions that it gives rise to — new democratic imperatives, a more planned management of nature, and an organization of production and of labour that involves greater cooperation and greater responsibility. It is a precursor of questions and problems of a more global nature that our civilization has to face. A more sustainable future can come about only by extending to all social and economic activities the questions, constraints and innovative responses associated with nuclear power.

Returning to the question of nuclear power's future, one can see a paradox in the above observations. Nuclear power would appear to be neither fundamentally at odds with the energy component of the pursuit of sustainable development for the whole economy, nor is it capable of being the major answer to one of the central issues of sustainability, the greenhouse gas problem. A set of policies designed to make a genuine move towards sustainable development is not likely to have the relaunching of nuclear power as a centrepiece. However, if a substantial move to sustainability were to occur, it might contain the seeds of a gradual increase in the demand for nuclear energy. This could come about not only because nuclear energy could be used along with renewables and energy conservation to reduce fossil fuel use, but also because the energy technologies that compete with nuclear power would have to bear a larger burden of their true costs

8/ The important exception to this attempted internalization of costs is, of course, the unwillingness of nuclear firms to bear full financial liability for future accidents. In other respects, however, the nuclear industry is more self contained, for instance in having to manage the disposal of its own waste. The fact that this type of problem has not been fully resolved is not inconsistent with the point made here — that the nuclear industry has had to deal with the *objective* of assuring that its operations do not have undesirable effects on society.

9/ On this point, D.H. Williams (1991, pp.303-304) has written: "... coal-fired power plants can be expected to cost approximately the same per megawatt to decommission as nuclear power plants ... the uncertainties on that cost for a coal-fired power plant rival the uncertainties on that cost for nuclear power plants ... . We are entering a new area, one in which we will need to consider the full cost of all our facilities, from their earliest planning through their dismantlement."

due to the internalization of environmental and social costs. Furthermore, the increased energy efficiency that will be a part of a more sustainable future requires technological changes that are likely to involve an increased share for electricity in the energy balance.[10]

The continuation of the tendency in a longer period towards a further lowering of energy intensity, decarbonization, and dematerialization (see Martin, 1988, and Bernardini and Galli, 1993) seems also to be an essential part of the penetration of electricity, as well as of the future of nuclear power. The new technological order that will correspond to the continuation of this long period tendency is not yet very clear. For Freeman (1992), signs of a new "green techno-economic paradigm" can probably already be perceived (with information and communication technology, nanotechnology and biochemistry playing key roles). What forms of energy and what means of energy production might be capable of accompanying the progressive generalization of this paradigm? Perhaps hydrogen produced from electricity of nuclear origin:

> The success of decarbonization will ultimately depend on production and use of pure hydrogen fuel (H_2) ... . I also believe this is the most promising niche for nuclear systems ... . It seems quite reasonable to suppose that it will take 50 to 75 years to understand how to use atomic power (Ausubel, 1992, p.184).

But these matters are only vague conjectures, with a time horizon of the end of the next century.

In closing, it needs to be said that technologies cannot by themselves lay the foundations of sustainability. It will require aggressive industrial and energy policies, more interventionist transport policies and the definition of a new role for the state. These will have to be accompanied by scientific, cultural and social developments, a reduction of inequalities, and new forms of solidarity. The scenarios produced by the World Energy Council and the French Atomic Energy Commission involve the continuation of severe disequilibria in per-capita energy consumption between developed and developing countries, and they do not diminish in magnitude. If this continues, if the world does not become environmentally and economically more viable, it is futile to anticipate a reasoned extension of nuclear programs, and thus a larger share of nuclear power in energy balances. It is not suggested here that we are on the eve of the changes which are needed. The above discussion does suggest, however, that the nuclear power industry has a more complex role in an evolution towards a more sustainable economy than is conventionally observed.

10/ Studies by the World Energy Council and the CEA cited above suggest that the production of electricity could represent around 36-38% of world consumption of primary energy in 2020, against 15% in 1960 and 30% in 1990. Among the constraints that act against the penetration of electricity, those represented by the transport sector are crucial (in 1994, transportation consumed almost 45% of the world's production of oil). As early as at the beginning of the 1960s, the penetration of electricity in the transport sector was one of the great hopes of the proponents of nuclear power: "Some people believe that large portions of the railway system will be electrified in the next few decades. However, electricity would have to come into common use for automobiles before it could capture large portions of the transportation market. While it is not doing so right now, possibilities such as the development of better fuel cells on batteries or means of transmitting electric power through highways to moving vehicles, all suggest as a possibility under conditions that may exist 20 or 40 years from now" (Tape *et al*, 1966, p.477). The point still applies, with market penetration still coming up against structural constraints that seem to be insurmountable. The share of transportation in electricity consumption remains insignificant; currently less than 2% in the OECD countries.

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