The Uranium Institute

Twenty-Second Annual Symposium
3–5 September 1997: London

Nuclear Power and Sustainable Development

Jean-Marie Bourdaire & John Paffenbarger

Sustainability is a term coined in recent years to mean the goal of practices, methods and technology which provide growth but do not degrade the environment in the long term. Although this sense has been first and foremost, the definition has expanded over time as the debate about sustainability has taken shape. It encompasses the idea that present activities must not destroy sensitive natural resources, leave problems or debts for the future, that they must be economically sound, and, depending on the observer, a host of other ideals. The European Commission, for example, considers that the use of adequate labour inputs is an element of sustainable development.[1] Reducing human or social stress can also be part of the concept.

It is fair to say that many of the strongest supporters of sustainability view the use of fossil fuels as unsustainable. They cite pollution and finite fossil fuel resources as, by definition, being unsustainable. The alternatives most often proposed are renewable sources of energy, which, almost tautologically, are sustainable. Various forms of solar energy seem ideal: solar photovoltaic electricity, solar thermal energy and wind power figure high on the renewables list. Improved energy efficiency, biomass and household waste streams are part of many environmentalists view of a sustainable energy future.

Nuclear power, most definitely, is not seen as part of the future by most advocates of sustainable energy use. Examples of this are not difficult to find. The United Nations Development Programme (UNDP), in its document *Energy After Rio*,[2] does not suggest a role for nuclear power except in the most doubtful of terms. The Swedish parliament's February 1997 law beginning the phaseout of nuclear power is entitled *Government Bill on a Sustainable Energy Supply*.

The environmental organisation Greenpeace, in a statement[3] for the June 1997 United Nations Earth Summit II, declared that: "The essential solution [to nuclear power problems] is a phase-out of nuclear power and the end to nuclear fuel reprocessing. Nuclear power must be replaced by ecologically sustainable energy systems — such as solar, wind, bio-fuel plantations, energy efficiency and conservation." Other environmental organisations have made similar statements on the incompatibility of sustainable energy use and nuclear power.

The debate on sustainability has not gone unnoticed by those who recognise the potential advantages of nuclear power. The concern about climate change, at a time when nuclear power's fortunes are declining in many countries, has been seen as a lever to revitalise interest in nuclear power. As the December 1997 Conference of the Parties to the UN Climate Change Convention has approached, those in the nuclear industry have increasingly discussed the sustainability of nuclear power.

For example, the plenary session of the 1996 annual meeting of the American Nuclear Society was on the sustainability of nuclear power. The Director General of the International Atomic Energy Agency, in his address to the Earth Summit II, stated that nuclear power deserves to be examined in the search for a sustainable energy mix. The Nuclear Energy Agency (NEA) of the OECD has recognised the potential role of nuclear power in sustainable development.[4] The Uranium Institute has in a number of its publications discussed the advantages of nuclear power as a concentrated source of energy and as a means to reduce emissions of carbon dioxide. Nuclear organisations and proponents see nuclear power as an eminently sustainable energy source.

Member countries of the International Energy Agency (IEA) also acknowledge the potential contribution of nuclear power to a sustainable energy mix. They adopted a statement of shared goals in 1993 which outlines the principles by which energy sectors of their economies can make “the fullest possible contribution to sustainable economic development”. The shared goals statement makes reference to nuclear power both in its contribution to energy supply diversity and to the environmentally sustainable provision and use of energy. The shared goals state that: “A number of IEA members wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide.”

This paper briefly takes another look at nuclear power’s sustainability. We argue that nuclear power could indeed play an important role in a sustainable energy mix of the future, but that this role is by no means assured. Three key aspects are discussed:

- **Energy supply**: is a nuclear fuel supply indefinitely available?
- **Environment**: is nuclear power compatible with respect for the environment?
- **Economics**: is nuclear energy an economic option in the long-term?

To the greatest extent possible the focus is on the sustainability of nuclear power in its own right, not on the “unsustainability” of other potential energy sources. The latter approach leads to the unsatisfying polemic that any “less sustainable” energy source is itself unsustainable. That said, economics is a key aspect of sustainability, since a number of sustainable energy paths can be imagined that differ essentially only in their cost. The comparative economics of the paths will determine which among them will be followed. In this respect there must be some consideration of the relative strengths of different options providing some part of a sustainable energy supply.

The time scale considered in this paper for sustainability is very long — centuries rather than decades. For this reason we place less emphasis on issues which relate to the near term prospects for nuclear power, which do look quite different than the long term prospects.

Energy Supply

This would seem to be one of nuclear power’s strong points. Conventional thermal reactors consume relatively small amounts of fuel, and known global reserves of uranium are widespread. Yet, at current rates of use of about 70 000 t per year in world nuclear reactors, known resources of 3.851 million tonnes[5] amount to only 55 years of supply. If 11 million tonnes of additional speculative (undiscovered) resources are included, some 200 years of resource can be identified.

This is not greatly different than the horizon for fossil fuels. Coal alone is thought to be present in sufficient quantities to represent 300 to 400 years of supply at present rates of use. Like any other non-renewable energy source, reserves of fissile material for nuclear energy are limited. Current nuclear technology based on fission of uranium in thermal reactors is thus not sustainable using known and speculative uranium resources.

Uranium is distributed throughout the world in reserves having various costs of exploitation. The above figures for known resources include those of less than US$130 / kg. Even though large amounts of uranium may be available beyond known or speculative reserves, this does not mean that the potential supply of energy from nuclear power is simply proportional to whatever quantities can be identified. For example, seawater is often cited as a source of natural uranium without reference to the cost of extracting it. Uranium dispersed throughout the earth’s crust or in seawater may be a large energy resource, but is not necessarily an economic energy source in comparison with other options.

A qualification to the notion of finite energy resources is given by the example of fossil fuel reserves. Fossil fuels have seemingly always been in danger of depletion 30 years from the moment any estimate is made. This has to do with the state of knowledge at any point, as driven by commercial interest, prospecting technology and activity in fossil fuel extraction. Economic reserves of fossil fuel have consistently risen over the years even as the rate of consumption has increased.

Nuclear fuel reserves would follow the same pattern. They could be expected to grow as demand and uranium price increased. Unlike fossil fuels, uranium accounts for a relatively small proportion of final electricity cost, so large price increases could be tolerated in the cost of finding and extracting uranium before this had a significant impact on final electricity production costs. This places less of a sharp edge on reserve estimates and depletion rates for natural uranium.

However, the key to long term energy supply from nuclear power is not uranium ore reserves, or even reserves of fertile materials like thorium. Rather it is new, as yet non-commercial, nuclear technology that could allow nuclear power to be sustained over a very long period. Today the first step appears to be the use of breeder reactors.

Thermal reactors use only 2% of the energy available from natural uranium. Most of the energy remains unused in depleted uranium. Breeder reactors could overcome this deficiency in two ways: by recycling plutonium produced in thermal reactors, and by converting fertile uranium (U-238), normally concentrated in depleted uranium, into fissile plutonium. (A breeding fuel cycle based on thorium-uranium is also possible.) Together these improvements could increase the energy extracted from natural uranium to 75% or higher. The reserves of uranium mentioned above could thus be extended by 40 times. Eight thousand years does indeed sound sustainable.

The World Energy Council has prepared projections that show in one scenario an acute need for breeder reactors between 2030 and 2050, depending on the rate of growth in energy demand and the use of nuclear power. This leaves time to develop breeder reactor technology, if it is called upon.

Today the experience with breeder technology is limited. A few demonstration plants have already been built and operated, including France’s Phénix and Superphénix plants (the latter planned to be closed by the new government), Japan’s Monju (currently shutdown due to technical problems), and Russia’s Beloyarsk plant. Still, the capacity of breeder plants operating today (2400 MWe) is less than that of cancelled and permanently closed breeder reactor projects (2500 MWe).

The French and Japanese plants have proven to be very expensive compared to conventional thermal reactors. Many of their essential systems, such as reactor, heat transfer and safety systems, are completely different than commercial reactors, and so could not take advantage of the designs and experience accumulated with conventional nuclear plants. Although the technical potential of breeder reactors has been partially demonstrated, results from the first few plants are not sufficient to define the precise features and costs of technically mature plants.

Extending the nuclear energy supply via breeder reactors would require a fuel cycle with reprocessing. The essential elements of potential fuel cycles, mainly using the uranium-plutonium route, have been demonstrated and do not pose any major technical problems. They do not appear to have any major economic problems, although the cost of implementing adequate safety measures for long term fuel cycle operation and waste disposal may not be fully known at present.

Other potential technological developments would allow nuclear power to last into the far future. Fusion is of course often cited as offering a “limitless” supply of energy. Yet fusion concepts under development today rely on the use of tritium, in turn produced from limited world reserves of lithium. The considerable technological and economic hurdles to commercial fusion reactors have no immediate prospects of resolution. There is little doubt that human ingenuity could overcome the technical hurdles, but there is considerable doubt regarding when this could be achieved and the ultimate cost of power produced using a fusion reactor. For the moment fusion power is little more than a concept.

In summary, natural resources of energy supply for nuclear power plants are indeed limited using current technology. To extend this supply to a period on the order many centuries, breeder reactors and recycling of fissile material generated in them would be required. The technical ability of this approach to provide a very long term source of energy is clear, but its comparative economics are not.

Environment

This area is the one on which views on the sustainability of nuclear power seem most divergent. On the one hand, nuclear proponents point out, completely correctly, that nuclear power does not produce emissions of airborne pollutants or carbon dioxide, and that solid wastes produced are small in volume compared to wastes from fossil fuelled plants.

Opponents of nuclear power, on the other hand, believe accidental releases of radiation and nuclear wastes pose grave threats to the environment. They correctly state that it is potential health effects of wastes, not volume, that matters. Experience to date with properly engineered nuclear power stations and scientific knowledge on nuclear waste disposal suggest that the view of nuclear power as environmentally benign is closer to reality. However, this is not necessarily the broad societal view of the issue.

Ongoing Emissions

Emissions of gaseous pollutants of any kind from nuclear power stations are nil on an ongoing basis.

No special control systems are needed since energy release is contained within the solid state, in an enclosed reactor, rather than in an open, gas-phase system as in fossil fuelled power plants.

Governments have developed increasingly stringent regulations on the emission of sulphur dioxide, nitrogen oxides, particulate matter, and a host of other airborne pollutants. Likewise, as part of the Climate Change Convention, most OECD governments have made commitments to control or reduce carbon dioxide emissions, although the depth of these commitments remains to be measured. Nuclear power is certainly sustainable in the long term if emissions of “traditional” energy-related pollutants or carbon dioxide emissions are to be discouraged. The economics of nuclear power will be unaffected by new or more stringent regulations on airborne emissions of any kind.

Thermal emissions from nuclear power plants are relatively high because of low thermal efficiency. This can pose a problem if a large nuclear plant uses river water and a once-through cooling system. The temperature of river water can be raised to a point which is detrimental to the river ecosystem. However, this problem can be overcome at modest cost increases by closed loop cooling systems. There is no technical or cost impediment to such an approach to reducing thermal emissions of nuclear power plants to rivers or bodies of water.

Potential emissions of radioactivity are a concern unique to nuclear power. During normal operation of a nuclear power plant all potentially harmful radioactivity is controlled and kept within specifically identified areas of the plant. This protects first and foremost plant personnel, but necessarily protects the environment outside the immediate plant structures. Over time governments have instituted regulations on the control of radioactivity in power plants and these have proven to be effective in protecting plant workers and the public.

Accidental Emissions of Radioactivity

Exceptional emissions of radioactivity from plant accidents or mishaps must be considered the issue of greater relevance to the long term sustainability of nuclear power. It was the Three Mile Island and Chernobyl accidents which focused attention on the potential dangers of accidental radiation releases from nuclear power plants. In the 1980s nuclear regulators multiplied safety regulations, imposed many new design requirements, and constrained operating practices. The cost of plant systems, operation and staffing increased substantially.

While there remain questions about the cost effectiveness and even usefulness of some of the measures taken in the wake of these accidents, it is clear that nuclear power plant safety has been improved beyond the levels prior to 1979. The Three Mile Island incident did, after all, demonstrate most dramatically that engineered safety systems could be expected to prevent the release of radiation to the environment, even when badly operated. The emphasis on human factors as a contributor to overall plant safety was a very useful development. The safe operation of existing commercial nuclear power plants has been sustained now for almost 40 years in OECD countries. There is nothing to suggest this cannot be maintained indefinitely, even without the inevitable incremental improvements to nuclear power plant designs.

The counter-argument to the generally good safety record within the OECD is that the consequences of a serious accident at a nuclear plant could be very grave indeed, far worse than from most power plants. Even if the risk of an accident is small, the potential consequences could be catastrophic. The use of probabilistic assessments and worst-case scenarios in design and licensing of nuclear plants has been the technical response to this concern.

Those in the nuclear power industry, including regulators, are generally assured that this has produced a satisfactory approach to protecting human health and the environment. It places nuclear power in a comparable light with, say, hydroelectric power production or industrial chemicals production, where serious accidents (notably dam failures) can and do cause loss of life and environmental damage. But the technical reasoning is not widely understood or accepted by other public bodies or the public at large.

Outside the OECD, the Chernobyl accident did raise grave concerns about the ability to safely design and operate nuclear reactors. Unlike at Three Mile Island, there were significant releases of radioactivity to the environment. The nuclear industry and governments have credibly responded to these concerns by demonstrating the inadequate attention to safety considerations, both in design and operation of the Chernobyl type RBMK designs, engendered by the political system under which the plant was created.

Reliance on an open, transparent process for nuclear plant regulation makes a similar reoccurrence seemingly very remote. However, it is not a foregone conclusion that governments around the world will be able to implement such a regulatory process and safety culture, as one can conceive of situations where inattention to safety is tolerated. Inadequate external supervision, combined with financial pressures, could in principle lead again to a serious release of radiation from a nuclear power plant of current design.

This is why continued improvement to nuclear power plant designs and operation must be a part of any view of nuclear power sustained in the long term. A number of new plant designs have been developed in recent years which further reduce the possibility of accidental radiation release, even in a mis-operated or poorly maintained plant. The Advanced Boiling Water Reactor, System 80+, AP600 and European Pressurised Water Reactor are examples of this evolution towards safer nuclear plant designs in the medium term. All rely upon simplification of systems, passive safety systems requiring (in some cases) no power or operator intervention, and standardisation of design. The latter reduces the potential for improper field construction to introduce safety risks.

A shift to breeder reactors would bring new safety risks because of the greatly different design and initial lack of experience with this technology. The increased transportation of plutonium would also engender additional risks. The transition period to breeder reactors might be one during which the greatest risk to the environment could be projected.

The large scale introduction of thermal reactors was punctuated by the two accidents cited above, plus quite a few less publicly visible ones. It is again not a foregone conclusion that this experience would be sufficient to prevent similar “learning” experiences as a shift to breeders took place. There is reason to believe that a safe transition would be possible. However, the issue should not be ignored in characterising nuclear power as presenting little long term risk to the environment from accidental releases of radiation.

As the weight of historical experience increasingly proves that commercial nuclear power plants and fuel cycle facilities can be operated without serious accidents, operating safety should become a smaller perceived obstacle to the sustainability of nuclear power. Waste disposal is becoming the focus of concern for both existing and future plants.

Waste Disposal and Decommissioning

The disposal of high level radioactive wastes is the single most important issue calling into question the sustainability of nuclear power. The fate of material from decommissioned plants raises a similar concern. Nuclear waste is thought by many to pose an unsolvable environmental problem whose consequences will be borne by future generations. Simply put, can nuclear waste of all kinds be stored or isolated safely until its radioactivity is no longer harmful to humans or the environment?

The nuclear technical community thinks the answer is “yes”. The disposal of radioactive waste has, since before the beginning of nuclear power generation, been based on the principle of protecting human health and the environment. It has been manifestly clear that a primary goal must be to minimise the chance that the waste will come into contact with humans in the future. There is broad consensus on the merits of geological disposal of long lived radioactive wastes in deep and stable geological formations in order to do just that.

The Radioactive Waste Management Committee of the NEA, for example, has issued a “collective opinion” on the environmental and ethical basis for the geological disposal of long lived radioactive waste.[6] This finds that a geological disposal strategy “can be designed and implemented in a manner that is sensitive and responsive to fundamental ethical and environmental considerations”. This view was developed specifically in reference to the concept of sustainability.

The NEA committee concludes that: “It is justified, both environmentally and ethically, to continue development of geological repositories for those long lived radioactive wastes which should be isolated from the biosphere for more than a few hundred years.” It also states: “Stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage.”

Affirming the acceptability of the approach involves a complex argumentation, often hidden in a dense mass of scientific detail. Identifying suitable disposal sites, developing the appropriate engineered infrastructure, and assessing the systems’ potential ability to minimise potential long term radiological impacts on humans and the environment, involve a great many technical evaluations and a certain number of hypotheses regarding the future.

The Yucca Mountain Project in the United States has a 6000 page plan for characterising the adequacy of the site and has spent well over one billion US dollars in the 1990s alone on site characterisation. The safety assessment approach is complex and typically involves probabilistic assessments of geological events, evaluations of fluid mobility through rocky but porous or fractured geological formations, and estimates of long term properties and behaviour of engineered systems. The complexity of such evaluations is daunting to all but specialists. The very strong public reaction against many projects to develop waste disposal sites shows that the general societal view is indeed far from the specialist view.

The volumes of wastes produced by nuclear power plants are small compared to those produced by fossil fuelled electricity plants. This is an environmental advantage to the extent that wastes from a widespread activity can be put in one location. The geographic extent of any potential environmental damage (say in the worst case) can thus be made very limited. The volume of nuclear wastes, however, is not the essential determinant of their environmental acceptability.

High level wastes have potential health affects much more acute and severe than wastes from fossil fuel plants precisely because they are concentrated and much more toxic. They are deadly if not shielded, they cannot be chemically or physically neutralised like many other toxic wastes, nor can they be dispersed safely. Furthermore, the wastes are generated in many locations and must be transported in order to geographically concentrate them, increasing the opportunities for transportation mishaps. The costs of properly handling high level wastes, on a unit basis, are very high. So the small volume of nuclear wastes is technically helpful but is only one among other relevant factors in the environmental acceptability of their disposition.

Apart from the scientific or technical aspects of high level waste disposal are the particularly difficult questions of institutional adequacy and future human behaviour. In the time scale of concern for safe isolation of high level wastes (10 000 years has been used as a design criterion in some repositories), no government or even civilisation could be counted on to actively ensure an undisturbed waste site. A passively safe situation must be sought to ensure waste isolation from the environment.

Short lived wastes pose less of a technical and institutional problem because, by definition, their radioactivity declines within a relatively short period. It is therefore easier, and less costly compared to long lived wastes, to take measures ensuring that wastes will remain isolated for the prescribed period. No permanent problem is left for later generations to deal with. The generation of low level wastes should not, therefore, pose a problem of environmental sustainability.

It appears that there are no inherent technical impediments to the environmentally safe use of nuclear power. Higher levels of environmental safety have been pursued relentlessly in the nuclear industry, both in operation and in waste disposal. This has been an undeniable factor in the increase in costs of generating electricity from nuclear power. One may ask if the search for environmental sustainability might pose an economic impediment to the sustained use of nuclear power.

Economics

Can nuclear power compete with other sources of electrical energy? Assuming a sustainable energy supply to be the goal, the least cost solution should be chosen to reach it. Inevitably then, the evaluation of nuclear's economic sustainability must be with reference to other energy sources. Presently, the economic viability of nuclear power is being questioned by many industry observers.

Near Term Competition from Fossil Fuels

New coal-fired and gas-fired power plants appear in many evaluations to offer lower cost electricity than new nuclear plants. Gas-fired combined cycle gas turbine (CCGT) power plants look especially attractive in light of present natural gas prices in many markets. Their low capital costs and short construction times are often cited financial advantages that indeed are economically attractive in comparison with nuclear power. In some situations it appears that electricity from gas-fired combined cycles may be obtainable at roughly half the cost of that from traditional nuclear plant designs. Coal-fired power plants, fitted with high efficiency pollution control equipment, also look attractive compared to nuclear power in many markets.

It is true that the lack of construction of nuclear plants in many OECD countries is at least partly due to their currently uncompetitive economic position. Although nuclear does still appear competitive in some markets, the reality is that in many countries nuclear plants face very strong competition from fossil-fuelled alternatives.

The current debate on nuclear power's competitiveness in newly liberalising electricity markets confirms the general situation just described. It exposes clearly that a certain number of nuclear plants built in the past were vastly expensive or are uneconomic to operate. At the same time it highlights the excellent performance and low operating cost obtained from other existing nuclear units. However, it does not particularly inform the debate about nuclear power's long term economic competitiveness.

In the long term, various factors affecting the relative costs of competing electricity generation technologies can change. We need look only as far back as the mid 1980s to find a graphic example of this. At that time very few CCGT plants were being sold, and one major world manufacturer nearly liquidated its capability to build such plants in light of the supposedly dim commercial prospects for gas-turbine based power. Today, gas-fired CCGT plants are capturing large shares of new generating capacity around the world thanks to their competitive economics. An appraisal of long term economic sustainability cannot be based on conditions in today's energy markets or on today's technology.

In the case of nuclear power, its long term economic viability is critically dependent on fossil fuel prices, the value attached to reducing gaseous emissions from fossil power plants, and technological developments in nuclear and competing technologies, such as renewables. The level of safety demanded also influences nuclear power's cost.

Fossil Fuel Prices and Energy Security

The oil price shocks provided a strong stimulus for the development of nuclear power in the 1970s. Fuel prices for power generation increased dramatically. In addition, future fossil fuel prices were projected to inexorably increase as well. Since fuel costs account for some 50–80% of fossil plant life-cycle costs, the increased fossil energy prices, both current and projected at the time, enhanced the competitiveness of nuclear power.

The view of ever increasing fossil fuel prices has since been proven wrong, and the nuclear advantage has eroded in parallel with stable or declining real fuel prices in most markets after 1986. The oil shocks did, nonetheless, drive home the clear advantage of nuclear if fossil fuel prices increase substantially and permanently. Should the time arrive when fossil fuel resources become, finally, truly more expensive, nuclear power would once again enjoy the economic advantage perceived in the 1970s and early 1980s. At present, however, it seems the wait for this time to arrive could be a long one.

Concern about the security of fossil fuel supplies could again play a role in economic evaluations of nuclear power. Many countries supported nuclear power development as an economic baseload power source immune from price increases in fossil fuel markets. By diversifying energy sources, nuclear power can provide a hedge against large increases in the national energy bill. Also, nuclear fuel is regarded as indigenous by OECD countries, which possess about half of the world's reserves of uranium. The risk of an interruption in the supply of natural uranium seems remote compared to that for oil or natural gas.

In the past the value of both energy diversity and fuel security were folded into economic evaluations through informal mechanisms such as fuel price projections or capital cost contingencies on different technologies. In the future some governments may wish to make the value of energy security more explicit in considering the economics of different power generation options. In this case nuclear power will have an advantage.

Carbon Value and Nuclear Competitiveness

However, the concern over climate change could have a much more dramatic effect on the relative economics of nuclear and fossil fuelled plants well before then. It is clear that real commitments to reduce emissions of carbon dioxide and other greenhouse gases would effectively place a value on *not* producing them.

Emissions limits at the level of individual producers such as power plants or automobiles would implicitly place values on carbon dioxide emissions. Market-based policies would make the value explicit. In the case of carbon dioxide emissions from fossil fuel use, we may speak about a "carbon value", or the cost to energy users to emit carbon dioxide. (Equivalently, this may be thought of as a value on not emitting carbon dioxide.) The situation is analogous to existing regulations to control emissions of traditional fossil fuel pollutants (sulphur dioxide, nitrogen oxides and particulate matter).

Power generation would be strongly affected by limits on carbon emissions or an explicit carbon value. Most importantly, the relative competitiveness of different generating sources would be changed. The costs of nuclear and renewable energies would remain unaffected, since they are not dependent on carbon-bearing energy sources. But coal, oil and gas-fired power generation would become more expensive.

Gas-fired combined cycles have the advantage of releasing the least amount of carbon dioxide per kWh of any fossil-fuelled option, both because of their use of a low-carbon fuel and their high generation efficiency. These characteristics render them the least sensitive of the fossil-fuelled options to a carbon value. So, while the introduction of a carbon value would increase their production costs, it would improve their competitive position relative to other fossil-fuelled options and still leave them as formidable competitors to non-fossil generation options. On an average OECD basis, the carbon value would have to rise to an estimated US$200-300 / tonne for nuclear power to be competitive with gas-fired power generation under the assumptions of our illustrative calculation.

In contrast, coal-fired power generation costs would clearly rise to the level of nuclear power at much lower levels of carbon value. Carbon values of, say, US$25-35 / tonne would bring nuclear power into competition with coal-fired power, while carbon values of US$65-100 / tonne would bring some non-hydro renewables into competition with coal. Regardless of the precise figures, coal-fired power generation, even with advanced technologies such as coal gasification combined cycle power plants, will become uneconomic compared to nuclear or renewable power well before gas-fired power production.

In summary, restrictions on carbon dioxide emissions in the power sector, either implicit or market-based, could place coal-fired power generation at a significant cost disadvantage, while favouring first gas-fired power, then nuclear, and ultimately renewables. Such a carbon dioxide constraint could be an important potential contributor to nuclear power's economic sustainability in the long term, regardless of the ultimate resources of fossil energy available.

Competition from Renewables

There is not yet a strong commitment by governments around the world to firmly restrain carbon dioxide emissions. The introduction or development of a carbon value is likely to take a long time. In the meantime, the technology and economics of renewable energies could improve relative to nuclear and in turn pose an economic challenge.

Renewables have enjoyed, like nuclear, an early period of subsidised development and technical improvement. The costs of electricity production obtainable from some non-hydro renewable technologies has dropped substantially in recent years. Yet currently they are not serious competitors to baseload power supply except in very limited situations. Although not at all assured based on present concepts, non-hydro renewables could develop into true competitors to fossil or nuclear generation. Given time and technological advances, renewables might be in a better economic position than nuclear power to "receive the baton" from fossil fuels.

Safety versus Cost

Apart from independent technological developments, there is the question of finding a balance between safety and cost. As noted earlier, the cost of nuclear power production increased dramatically due to the multiplication of safety regulations related to plant design, construction and operation. Costs of low level waste disposal also have increased dramatically. For example, in the United States these costs escalated at a rate of 13% during the period 1980-95 due to more stringent requirements on disposal sites and a scarcity of new sites.[7] The cost of decommissioning a retired nuclear power plant will vary enormously depending on the level of residual radioactivity permitted, linked to regulators' and the public's perception of the safety and health effects of such radioactivity.

Siting has become extremely difficult in many countries as potential neighbours to nuclear facilities have increasingly protested against them on the grounds of environmental dangers. The increasing difficulty and cost of siting commercial nuclear facilities is intimately related to the perception and demonstration of safety at these facilities.

Recent examples in which nuclear facilities have faced considerable opposition are the Nirex rock characterisation facility at Sellafield in the United Kingdom, the Ward Valley waste facility in the United States, the Mount Muria nuclear power plant in Indonesia, and the Maki nuclear power plant in Japan. The Japanese government provides subsidies to townships which host nuclear power plants in an effort to improve their local attractiveness. The development of environmental impact assessments or equivalent documents for nuclear facilities has become very time consuming and expensive in many locations as the scientific detail required to prove safe operation has vastly increased. Uncertainty about ultimate decommissioning policies adds to the concern and cost of siting new facilities.

This balance between safety and cost has not yet found its equilibrium in OECD countries. Safety regulations should be based upon an appraisal of potential health and environmental impacts and the cost of minimising them. This is an approach which has gained acceptance in the safety regulation of other heavy industrial activities such as fossil power production, chemicals production and mining. Many in the nuclear field argue that this approach has not been uniformly applied to their industry.

In some jurisdictions it appears that regulations may have been used to move towards the political goal of stopping nuclear power development. In some instances it seems regulations have been introduced without due consideration to their costs relative to any incremental gain in safety. Fox[8] cites the example of protection against pipe whipping required in the United States. Compliance with the regulation has cost some US$500 million, by his estimate, but the benefits were sufficiently ill-defined that ultimately the regulation was rescinded.

Part of the difficulty has also been in estimating the health effects of low level radiation. The linear, no-threshold model of radiation risk is the one on which much nuclear safety regulation has been based, but it is increasingly being called into question on a scientific basis as being vastly too conservative if not simply wrong. A combination of political influences and technical inability to quantify risk have thus tended to increase the costs of complying with safety regulations over time.

If nuclear power is to be sustainable economically, safety-related costs cannot continue increasing indefinitely. A consensus must be found on how to value safety. An insistence on safety at any price without reference to potential health benefits would handicap, if not stop, nuclear power's further development. That outcome is not impossible if public acceptance concerns are not alleviated. While it seems the question may be at least commonly understood for power plants, nuclear waste disposal has yet to be fully drawn into the debate because progress on high level disposal sites has been limited. The nuclear safety debate of past decades must be resolved if nuclear power is to be sustainable.

Other Issues

Non-proliferation and public acceptance are issues that are certainly central to nuclear power's future in the near term. This is especially true in OECD countries. However, they seem less important when considering its long term fate. They are issues that will either allow nuclear power to proceed or will lead to its demise. That they will not ultimately block nuclear power's development is much more likely.

There has been strong international cooperation to account for and control the spread of nuclear materials of potential value for military purposes. The 1970 Non-Proliferation Treaty (NPT) was indefinitely extended and strengthened in 1995, and the number of parties to it has grown to 178. It is the main international instrument for supporting the objective of non-proliferation. Still, it is not universal, and several countries not party to it have active civilian nuclear programmes. Furthermore, the safeguards it provides must be adequately implemented for it to be effective. Strengthening the functioning of the NPT must be an important part of the continued development of civilian nuclear power.

Beyond administrative-type controls on nuclear materials, there are also the practical difficulties of working with bomb-grade materials and the cost of producing them in reactors designed for electrical power production. Spent fuel handling and extraction of bomb-grade material are costly, hazardous and sophisticated operations. Very significant investments in equipment and people are required to obtain nuclear materials for military use. These characteristics do make it extremely unlikely that organisations operating outside of government control, such as terrorist organisations, could produce nuclear weapons from civilian nuclear materials.

Parallels in nerve gas production suggest that a truly determined country can produce dangerous weapons regardless of the presence or absence of parallel industrial capability in civilian chemicals production. Fertiliser plants have not been banned because of chemical weapons, and it seems unlikely that nuclear power plants should be ultimately banned or limited because of their links with atomic weapons. It is clear, however, that governments and the nuclear industry cannot be complacent about ensuring non-proliferation.

"Public acceptance" could alternately be described as "demonstration of nuclear safety". Public concerns ultimately stem from the fear that nuclear technology and materials could lead to the release of unsafe levels of radioactivity into the environment. In this view, the question of public acceptance (in the long term) is intimately related to the discussion above on environmental and economic sustainability. If a consensus on environmental acceptability is found, and nuclear electricity is economically competitive in such a case, by definition a public consensus will have been found. An industry or technical concurrence on nuclear power's acceptability will be insufficient. Public acceptance of nuclear power must be broad and in accord with the democratic political process. It is clear today that public acceptance is a major hurdle to nuclear power's continued development in many countries.

The nuclear power industry may still be struggling with the legacy of military nuclear development, which frequently, under the demands of rushed, secret programmes, did not take precautions with nuclear plant operations or nuclear waste that would be required for modern civilian nuclear power programmes. Such cases as the contamination of Lake Karachai in Chelyabinsk, Russia, rusting tanks of high level waste in Hanford, United States, and the 1957 Windscale incident in the United Kingdom, illustrate that early practices were clearly unsustainable.

Commonly agreed principles today are to adequately plan for waste disposal when embarking upon new projects, and to allocate sufficient resources to safely implement long term operational and waste disposal plans. Over time, transparent, open planning for nuclear operations and waste disposal will help nuclear power to outlive its negative military legacy.

The prominence of public acceptance as a challenge to nuclear power in the near term may be related to the present economics of energy supply. An important factor in the present situation is the relative abundance of energy at reasonable prices. Energy supply is not an issue in the public eye and the likelihood of long term shortages seems remote. In this situation, the need for nuclear energy seems less imperative than it did during the period of the 1970s oil shocks.

The public may be less willing to accept nuclear power when other less threatening energy sources are available without any large economic penalty. However, if the future energy supply situation included substantially increased energy prices due to development of a carbon value, or simple growth in overall energy demand, public attitudes towards nuclear power could become more favour-able as the balancing of nuclear's risks and rewards would shift. Part of nuclear's long term challenge of public acceptance will be to demonstrate that its public health risks are small and that it brings economic benefits compared to other energy sources.

Conclusions

Nuclear power has the potential to be a sustainable energy source. The preceding text outlines the arguments that there are no fundamental energy supply, environmental or economic issues which would today exclude pursuit of nuclear power as a sustainable option for the future. There are, however, a number of serious challenges which nuclear power must face before it can play any long term role.

The nuclear industry must develop appropriate, long term technological solutions which allow full use of uranium reserves. The common view today is that this means breeder reactors. While demonstration breeder plants have been built and operated, this experience is not sufficient to confirm the long term economics of this option. Long term technological development of nuclear power also must emphasise safety obtained cost effectively. This is a trend already well underway, but which must be pursued vigorously because of competition from other energy sources.

The disposal of long lived radioactive wastes is the single most important environmental hurdle facing nuclear power. Although there may be a technical consensus on the adequacy of geologic disposal, there is most definitely no social consensus on the issue. Nuclear organisations must explain technical views adequately if they are to convince governments and the public that waste can be disposed of safely. This is a question that must be resolved for the current generation of nuclear plants. Doing so could lay the foundation for further reliance on geological disposal, while not cutting off options by irretrievably disposing of valuable nuclear material.

Nuclear power must prove its economic merit in competition with other energy sources. In the near term nuclear power is at a disadvantage in many markets compared to fossil fuelled options. At a minimum, lower cost nuclear plant designs and better performance could help to regain an economic advantage. Development of a carbon value, or a value on reducing emissions of carbon dioxide, would increase the cost of fossil fuel options relative to nuclear and renewable energies. In the long term this could be the main advantage of nuclear power compared to fossil fuels.

A publicly acceptable balance of safety and cost must be found for regulation of the nuclear industry. Safer at any price means never.

Member countries of the IEA have stated their desire to maintain nuclear power as an energy option for the future. Nuclear power has played a vital role in the electricity supply systems and economies of member countries. It promises to maintain this role, and contribute towards sustainable development, but only with continued technological development and the active participation of those who most appreciate its potential benefits.

References

1. *Thoughts on a New Development Model for the Community*, White Paper on Growth, Competitiveness and Unemployment. Document COM(93)700 final. European Commission, Brussels, 5 December 1993.
2. *Energy after Rio, Prospects and Challenges*, Executive Summary. United Nations Development Programme, New York, 1997.
3. *Nuclear Power*. Greenpeace Position Paper for the Special Session of the United Nations General Assembly, New York, 23-27 June 1997. Greenpeace, 1997.
4. Stevens G, *Nuclear energy and sustainability*, in *Sustainable Development: OECD Policy Approaches for the 21st Century*. Organisation for Economic Cooperation and Development, Paris, 1997.
5. *Uranium 1995: Resources, Production, and Demand*. OECD Nuclear Energy Agency, Paris, 1996. (Known resources taken as the sum of resources from Tables 1b and 2b. Speculative reserves taken as the sum of Estimated Additional Resources, Category II, and Speculative Resources given in Table 4.)
6. *Collective Opinion of the Radioactive Waste Management Committee on the Environmental and Ethical Basis of Geological Disposal*. Document NEA / NE(95)4. OECD Nuclear Energy Agency, Paris, 28 March 1995.
7. *The sustainability of nuclear power*. Nuclear News, p76, August 1996.
8. Fox MR, *Nuclear regulation— the untold story*. Public Utilities Fortnightly, p37-41, August 1995.