International Symposium on:
"Nuclear Futures – Realities and Choices"

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KEYNOTE DISCUSSION PAPER:

"Consequences of a Nuclear Renaissance"

by Frank Barnaby, November 2007

In which he challenges the assumptions that failure to reduce the emissions of greenhouse gases outweigh the risks of nuclear terrorism and nuclear war; and that the number of people killed and the social disruption caused by global climate change will dwarf those caused by nuclear terrorism and regional nuclear war. He posits the alternative argument that low-carbon energy sources are available and could be installed faster, more cheaply and with less risk to national and global security than nuclear power.

There is a pressing need for development in much of the world. Energy is essential for development. Reducing poverty, increasing standards of living, improving health care, and raising productivity – industrial and agricultural — all require reliable and secure access to sources of energy.

Figures from the International Atomic Energy Agency (IAEA) bring home the stark imbalance global energy supplies. Today, 1.6 billion people are without access to electricity, and 2.4 billion have no access to modern fuels and rely on traditional biomass for cooking and heating.

According to the International Energy Agency, global energy demand is projected to be 50 per cent higher in 2030 than it is today. About 70% of this growth in demand is likely to come from the developing countries.

Many countries, developing and industrialized, are considering which sources of energy will best suit their future energy needs. Some countries lack indigenous energy resources, others want to reduce their dependence upon imported energy, others are anxious to increase the diversity of their energy resources, and many are committed to reducing their emissions of greenhouse gases, particularly carbon dioxide, in an attempt to reduce global warming and climate change.

A number of governments are currently actively reassessing their civil nuclear policies. With the prospect of a nuclear renaissance in mind, the nuclear industry is proclaiming the virtues of nuclear power as a large-scale source of reliable, zero-carbon electricity at an affordable price, while dismissing the alternatives like wind and solar power as inadequate to support the demands of industrialised economies.

Critics of nuclear power point out that nuclear power is by no means a low-carbon source of electricity. Extracting, processing and transporting uranium all use energy, producing greenhouse gases, as do the construction of nuclear-power stations, the storing of radioactive wastes, and the decommissioning of nuclear facilities. As high-quality uranium ore is consumed, nuclear power will produce more carbon dioxide.

Currently, about 42 gigatonnes of carbon dioxide equivalent are emitted annually. If emissions are capped at this level then atmospheric greenhouse gas concentrations will reach 550 parts per million by 2050 – up from today's approximately 370 parts per million.

According to the scientific consensus, to keep climate change within manageable limits, and prevent the risk of runaway changes, it is essential that global average temperatures rise by less than about 2 degrees centigrade. This means keeping the concentration of atmospheric greenhouse gases to no more than 550 parts per million.

This threshold may be reached by about 2035 unless urgent action is taken. If nuclear power is to play a significant role in reaching this target it does not have long to do so. Furthermore, if nuclear power is to play more than a marginal role in combating global warming then nuclear-power reactors will have to be operated in many developing countries.

Can enough new nuclear-power reactors be built fast enough to make a significant dent in global warming?

Currently, the world's nuclear-power reactors generate a total of 372 GW of electricity (see Appendix). This represents about 6 per cent of the total world power production of 15,000 GW and 16 per cent of total world electricity generated. To make a significant dent in the global cumulative carbon emissions, by say 2075, assuming that countries then generate one kilowatt of electricity per capita (probably an underestimation), and that they generate a half of their electricity by nuclear power the world would need to generate 3,000 GW of electricity by nuclear power-reactors, about 8 times the current generation. An increase of at least this magnitude will be needed if nuclear power is to make a significant effect on global warming.

Feiveson explains: *"Under the central business-as-usual projection of the International Program on Climate Change (IPCC), if nuclear power grew to 3,000 GW of electricity in 2075 (50% of world electricity than projected), and then 6,500 in 2100 (75% of world electricity than projected), the total carbon emissions avoided cumulatively would be approximately 290 billion tonnes through 2100 – only about one-fourth the projected cumulative carbon emissions to 2100 projected by the IPCC."* (H.A.Feiveson, Nuclear Power, *Nuclear Proliferation, and Global Warming*, Forum on Physics and Society of the American Physical Society, January 2003.)

Today, nuclear power is located in a few industrialised countries. Of the 372 GW world nuclear capacity, less that 10 GW are in developing countries. It must be emphasised that, if nuclear power is to play a substantial role in the world energy economy and make an impact on global warming, much of it will have to be located in developing countries.

The crucial question is could such countries obtain the capital and technical expertise needed to operate and safely maintain nuclear-power reactors and to dispose of the high-level radioactive produced by their reactors? The capital costs of constructing a new nuclear-power reactor can vary widely. The current cost for a new nuclear-power reactor with a generating capacity of 1,000 MWe is roughly between 1.5 and 2 billion US dollars. It may be significantly higher in some countries.

Future reactor designs may be somewhat cheaper to construct. Some forecasts suggest construction costs of between US$1 and 1.5 billion for a future 1,000 MWe reactor.

There are now 34 new nuclear-power reactors under construction – each with an average generating capacity of 824 MWe. In addition, countries have announced plans to build or put on order another 86 reactors with an average capacity of 1,100 MWe. The UK, for example, may build eight new reactors, two at each of four sites on which an existing nuclear-power reactor is operating.

And there are 223 proposed new reactors. If these are all built, the number of countries operating nuclear-power reactors will increase from today's number of 31 to 39.

Some of the future reactors will generate more electricity than those used today. The new reactor under construction in Finland, for example, will have a generating capacity of 1,600 MWe. However, smaller nuclear-power reactors are better suited to supplying the electricity needs of some countries. The reactors that South Africa proposes to construct have an average generating capacity of less than 200 MWe.

Countries where the new use of nuclear power is under consideration include Algeria, Australia, Azerbaijan, Bahrain, Bangladesh, Belarus, Chile, Egypt, Georgia, Ghana, Gulf States, Indonesia, Ireland, Israel, Italy, Jordan, Kuwait, Libya, Malaysia, Morocco, Namibia, New Zealand, Nigeria, Norway, Oman, Qatar, Poland, Portugal, Saudi Arabia, Syria, Tunisia, Turkey, Kazakhstan, Thailand, the United Arab Emirates, Venezuela, Vietnam, Yemen.

How do these nuclear plans tie in with future global demands for energy? Future energy demands will depend on population size. It is probable that by 2075, for example, the population of China will reach about 1,600 million; that of India will be about 1,800 million; and that of Indonesia will be about 375 million.

Assuming that these countries generate one kilowatt of electricity per capita (probably an underestimation), and that they generate a third of their electricity by nuclear power (twice today's world share), China would require about 530 GW of nuclear power, India would require about 600 GW, and Indonesia would require about 125 GW.

Bangladesh, Brazil, Congo, Ethiopia, Nigeria and Pakistan would each need more that 65 GW. Bangladesh, Congo, Ethiopia, Indonesia and Nigeria now have no nuclear-power reactors. For comparison, the population of the USA is likely to be about 445 million by 2075, requiring about 146 GW, assuming one kilowatt of electricity per capita and a third of the electricity generated by nuclear power.

Is there enough uranium to fuel a large increase in the number of power reactors?

According to the IAEA and the OECD, the known recoverable uranium resources are 4.7 million tonnes. This figure includes uranium ores that: are of relatively low ore grades; occur at great depths; require long transport distances; and are harder to mine. At the current consumption rate of 68,000 Mg a year, the uranium will last for less than 70 years.

There is, therefore, a shortage of uranium to fuel nuclear-power reactors. As the richest uranium ores are depleted first, the net energy extracted from uranium ore will decrease. It takes energy to mine and mill the uranium, to enrich the uranium and produce the uranium-dioxide fuel elements for use in the nuclear-power reactor. The net energy is the energy produced per tonne of uranium fuel minus the energy used to produce the fuel elements.

At the current rate of consumption, the richest uranium ores will get depleted within a decade and the average grade will fall below 0.1%. At this, and lesser grades, the net energy from uranium is significantly less.

Assuming that world nuclear capacity remains constant at 372 GW, the net energy from uranium will fall to zero by about 2070. Assuming that world nuclear share remains constant at 2.2 per cent of world energy supply, the net energy will fall to zero by about 2050.

The shortage of uranium ores rich enough to give a positive net energy will lead to the use of fast breeder reactors, which use fuel containing mainly plutonium and requiring only a small input of uranium. If the nuclear industry gets its way, fast breeder reactors will be used commercially after about 2030.

If we move to a plutonium economy, can the risk of nuclear-weapon proliferation and of nuclear terrorism be controlled?

A major security concern is that the plutonium used in generation IV reactors will be suitable for use in the most efficient nuclear weapons. This will increase the risk of nuclear-weapon proliferation and of nuclear terrorism.

As of December 2005, the world's stock of separated civil plutonium, usable in nuclear weapons, was about 245 tonnes, about the same as the 250 tonnes of military plutonium. In France, Japan, Russia, and the UK, stocks of civil plutonium will increase by as much as 125 tons by 2015. That plutonium produced in civil nuclear reactors could be used in nuclear weapons was shown in nuclear tests performed by both the Americans (in 1962) and the British (in 1953).

Any country operating generation IV reactors will have relatively easy access to plutonium usable in effective nuclear weapons and will have competent nuclear physicists and engineers who could design and fabricate them. Because they could produce a nuclear force in a short time – months rather than years – these countries will be latent nuclear-weapon powers. It must be expected that some of them will take the political decision to become actual nuclear-weapon powers.

If the world is using 3000 GW of nuclear electricity in 2075, and if this was based on the once-through nuclear cycle using light-water reactors, it will be generating approximately 600 tonnes of plutonium annually (and would require roughly 500,000 tonnes of uranium). But, if it this nuclear capacity were based on fast breeder reactors, as the nuclear industry predicts, more than 4,000 tonnes of plutonium will have to be fabricated into fresh reactor fuel each year. (Although, in the latter case, the cumulative stock of plutonium would be much less than in the former case.) (4,000 tonnes of plutonium is enough to fabricate a million nuclear weapons.)

When removed from the reactor the fuel elements are so radioactive that they are self-protecting. No one can get near them and survive – they have to be handled remotely using very heavy remote-handling equipment. After reprocessing, however, the plutonium can be handled relatively easily.

A significant use of generation IV reactors will carry with it the real risk that nuclear terrorist groups will eventually acquire plutonium, fabricate primitive nuclear weapons and use them in terrorist attacks.

The significantly increased risk of nuclear-weapon proliferation and of nuclear terrorism are perhaps the most powerful reasons to oppose a nuclear renaissance and a move to the plutonium economy.

Nuclear terrorism

There are number of nuclear terrorist activities that a terrorist group may become involved in: stealing or otherwise acquiring fissile material and fabricating and detonating a primitive nuclear explosive; making and detonating a radiological weapon, commonly called a dirty bomb, to spread radioactive material; attacking a nuclear-power reactor to spread radioactivity far and wide; attacking the high-level radioactive waste tanks at a reprocessing plant, like Sellafield, to spread the radioactivity in them; attacking a plutonium store at a reprocessing plant, like Sellafield, to spread the plutonium in it; stealing or otherwise acquiring a nuclear weapon from the arsenal of a nuclear-weapon power and detonating it; and attacking, sabotaging or hijacking a transporter of nuclear weapons or nuclear materials.

Apart from a dirty bomb, all of these types of nuclear terrorism have the potential to cause large, or quite large, numbers of deaths. Of them, nuclear terrorists would probably prefer to set off a nuclear explosive, because of the great damage it would do, perhaps using a stolen nuclear weapon or more likely using a nuclear explosive fabricated by them from acquired fissile material.

Terrorists would be satisfied with a nuclear explosive device that is far less sophisticated than the types of nuclear weapons demanded by the military. Whereas the military demand nuclear weapons with predictable explosive yields and very high reliability, most terrorists would be satisfied with a relatively primitive nuclear explosive.

Terrorist use of a radiological weapon

The simplest and most primitive terrorist nuclear device is a radiological weapon or radiological dispersal device, commonly called a dirty bomb. A dirty bomb would consist of a conventional high explosive (for example, semtex, dynamite or TNT), some incendiary material (like thermite) surrounding the conventional explosive, and a quantity of a radioisotope, probably placed at the centre of the explosive.

When the conventional high explosive is detonated the radioactive material would be vaporised. The fire ignited by the incendiary material would carry the radioactivity up into the atmosphere. It would then be blown downwind, spreading radioactivity. A dirty bomb is not the same as a nuclear weapon in the normal sense of the phrase– it does not involve a nuclear explosion.

Many types of radioisotopes (radioactive isotopes) could be used in a dirty bomb. But the most likely one to be used is one that is that is relatively easily available, has a relatively long half-life, and emits energetic radiation. Suitable ones include caesium-137, cobalt-60, and iridium-192; these emit mainly gamma rays (electromagnetic radiation). Strontium-90, which emits beta particles (electrons) and is concentrated in bone, is also a possible candidate. All of these radioisotopes are much used in medicine and industry – all but small hospitals, for example, will have them.

The use of plutonium in a dirty bomb would cause the greatest threat to human health, because of its very high inhalation toxicity, and the most extensive contamination. However, terrorists would find it very difficult to acquire significant amounts of plutonium.

The detonation of a dirty bomb is likely to result in some deaths but would not result in the hundreds of thousands of fatalities that could be caused by the explosion in a city of a crude nuclear weapon. Generally, the explosion of the conventional explosive would be the most likely cause of any immediate deaths or serious injuries. The radioactive material in the bomb would be dispersed into the air but would be soon diluted to relatively low concentrations. If the bomb is exploded in a city, as it almost certainly would be, some people are likely to be exposed to a dose of radiation. But the dose is in most cases likely to be relatively small. A low-level exposure to radiation would slightly increase the long-term risk of cancer.

The main potential impact of a dirty bomb is psychological – it would cause considerable fear, panic and social disruption, exactly the effects terrorists wish to achieve. The public fear of radiation is very great indeed, some say irrationally so.

The explosion of a dirty bomb could result in the contamination of an area of a city and the surrounding areas with radioactivity. Areas as large as tens of square kilometres could be contaminated with radioactivity to levels above those recommended by the National Radiological Protection Board for the exposure of civilians to radioactivity. The area would have to be evacuated and decontaminated.

The degree of contamination would depend on the amount of high explosive used, the amount and type of radioisotope released during the explosion of the bomb, the nature of the device used to spread the radioactivity, whether it was exploded inside a building or outside, and speed and direction of the wind, the general weather conditions, and the size and position of buildings near the detonation site.

The size of the radioactive particles released by the device will determine how far they are carried by the wind and how easily people inhale them. Radioactivity will be carried away on people's clothes and spread by vehicles passing through the contaminated areas. People may also ingest radioactivity by eating contaminated food and drinking contaminated water.

In the longer term, any exposure to ionising radiation can cause fatal cancers. The number of fatalities in a group of people will be proportional to the total radiation dose received by the group.

The effects on the health of people exposed to the radioactivity released by a dirty bomb will depend on how long they remain in the contaminated area, the size of the particles released by the explosion and the type of radioactivity emitted by the radioisotopes in the bomb. Decontamination is likely to be very costly (costing millions of pounds) and take weeks or, most likely, many months to complete.

There are no ways to decontaminate effectively buildings contaminated with significant amounts of radioactivity; the buildings may, in practice, have to be demolished. If a dirty bomb were detonated in, for example, London's Oxford Street or in the City of London, the cost would be huge, potentially many hundreds of millions of pounds.

Such is the public fear of ionising radiation that even relatively small levels of radioactive contamination on or in buildings, on roads or footpaths, or on public areas would be publicly unacceptable. Decontamination would have to be virtually complete. Roads and walkways in contaminated areas, for example, would have to be re-surfaced. Radioactive contamination is by far the most threatening aspect of a dirty bomb.

A primitive nuclear explosive

A nuclear weapon is a device that obtains most of its explosive yield from nuclear-fission. A dirty bomb is not a nuclear weapon – there is no nuclear fission.

Terrorists could make a nuclear weapon from either highly enriched uranium or plutonium. The simplest nuclear explosive uses the 'gun technique' in which a mass of enriched uranium less than the critical mass is fired, down a gun barrel, for example, into another less-than-critical mass of uranium. The sum of the two masses is greater than critical. When they join together a nuclear explosion occurs.

There is a large amount of highly-enriched uranium (HEU) in the world. The vast majority is military HEU, in nuclear weapons. According to the recent report by the International Panel on Fissile Materials, as of early 2007, the global stockpiles of HEU contained a total of between roughly 1,700 tonnes. The USA and Russia are retaining between 600 and 1,200 tonnes for nuclear weapons.

The USA intends to keep almost all of its excess weapon-grade uranium for use as fuel for naval-reactors. (Typically, reactors on warships use HEU as fuel). Russia and Britain also have large reserves of HEU for naval fuel.

Roughly 50 tonnes of HEU is used as fuel for civil research reactors worldwide. The USA is trying to replace HEU with low-enriched uranium (LEU) as fuel for civil research reactors worldwide. LEU cannot be used to fabricate practicable nuclear weapons.

So far, HEU in both fresh and spent research reactor fuel has been completely removed from 16 countries. Twenty-eight, however, still have enough civilian HEU to make at least one nuclear weapon. Russia, which operates about half of the world's 140 HEU-fueled research reactors, has no plans to replace HEU with LEU in its research reactors.

Because most HEU is in military hands it would presumably be very difficult for terrorists to acquire HEU illegally. Therefore, terrorists may prefer to use plutonium.

The gun technique cannot be used to assemble a super-critical mass of plutonium in a nuclear explosive device; implosion must be used. The implosion technique can, however, be used to assemble a super-critical mass of highly enriched uranium.

In a primitive nuclear explosive using the implosion design, a sphere of plutonium or highly enriched uranium, having a mass probably just less than critical so that it cannot sustain a fission chain reaction, is likely to be surrounded by conventional high explosives. If the fissile core were surrounded with beryllium shell to reflect back fission neutrons that escape from the core, the critical mass would be significantly reduced.

When exploded, the high explosive uniformly compresses the sphere of fissile material. The compression reduces the volume of the sphere of fissile material in the core and increases its density. The critical mass is inversely proportional to the square of the density. The original less-than-critical mass of fissile material will, after compression, become super-critical, and a fission chain reaction and nuclear explosion will take place.

If it could acquire the fissile material, a small group of people with appropriate skills could, in theory, design and fabricate a crude nuclear explosive. The size of the nuclear explosion from such a crude nuclear device is impossible to predict. But even if it were only equivalent to the explosion of a few tens of tonnes of TNT it would completely devastate the centre of a large city. Such a device would, however, have a chance of exploding with an explosive power of at least a hundred tonnes of TNT. Even one thousand tonnes or more equivalent is possible, but unlikely.

The use of reactor-grade plutonium

There has been much discussion about whether or not a terrorist group (or a country) could use the plutonium recovered from spent nuclear-power (light-water) reactor fuel elements to fabricate a nuclear explosive device having a significant explosive yield.

Nuclear-weapon designers prefer relatively pure plutonium-239 for nuclear weapons. Plutonium containing 93 or more per cent of plutonium-239 and about 6 per cent plutonium-240 is called ‘weapons-grade’ plutonium. The plutonium produced in a commercial nuclear-power reactor, operated for the most economical generation of electricity called ‘reactor-grade’, typically contains about 60 per cent plutonium-239, about 20 per cent plutonium-240, about 15 per cent plutonium-241, and 5 per cent plutonium-241.

There are two major problems with using reactor-grade plutonium in a nuclear explosive device. Plutonium-240 has a high rate of spontaneous fission so that the device will continually produce many neutrons. One of these background neutrons may set off the fission chain reaction prematurely, called pre-initiation, causing the device to have a low explosive yield.

The spontaneous emission rate of reactor-grade plutonium is about 360 neutrons/second/gram. The figure for weapon-grade plutonium is about 66 neutrons/second/gram. The probability of pre-initiation using reactor-grade plutonium is, therefore, very much larger.

As the late J. Carson Mark calculated, even if the pre-initiation occurs at the worst possible time, when the plutonium first becomes sufficiently compressed to sustain a chain reaction, the explosive yield (called the ‘fizzle yield’) of a simple device like the Nagasaki nuclear weapon would be at least equivalent to the explosion of 1,000 tonnes of TNT (a kiloton).

The second problem is the heat produced by the alpha-particle decay of plutonium-238. The amount of plutonium-238 in reactor-grade plutonium is about one or two per cent. This contributes 10.5 watts of heat per kilogram of reactor-grade plutonium, compared with 2.3 watts per kilogram of weapons-grade plutonium.

The design of a primitive nuclear explosive using reactor-grade plutonium would have to incorporate a method of dispersing the heat – such as the use of aluminium shunts. Otherwise, the plutonium would get very hot and become distorted or even melt.

More reactor-grade plutonium than weapon-grade plutonium would be required for a nuclear weapon. The bare sphere critical mass of reactor-grade plutonium is about 13 kilograms; that of weapons-grade plutonium is 10 kilograms.

In spite of these problems, it must be concluded that nuclear weapons can be fabricated using reactor-grade plutonium. As Carson Mark put it: “The difficulties of developing an effective design of the most straightforward type not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium”.

The 1994 Committee on International Security and Arms Control of the US National Academy of Sciences concluded in a report that: “In short, it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to few kilotons, and more using an advanced design. Theft of separated plutonium whether weapons-grade or reactor-grade, would pose a grave security risk.” Among the committee were physicists knowledgeable about nuclear weapons, including Micheal M. May, a former director of the Lawrence Livermore Laboratory.

At a conference in Vienna in June 1997, Matthew Bunn, of Harvard University, discussed the value of reactor-grade plutonium for the fabrication of nuclear weapons, stating that countries with advanced technologies "could, if they chose to do so, make bombs with reactor-grade plutonium with yield, weight, and reliability characteristics similar to those made from weapon-grade plutonium. That they have not chosen to do so in the past has to do with convenience and a desire to avoid radiation doses to workers and military personnel, not the difficulty of accomplishing the job. Indeed, one Russian weapon-designer who has focused on this issue in detail criticised the information declassified by the US Department of Energy for failing to point out that in some respects if would actually be easier to make a bomb from reactor-grade plutonium (as no neutron generator would be required)."

The International Atomic Energy Agency recognised that all plutonium except plutonium-238 is capable of being used in nuclear weaponry.

Terrorist attack on a nuclear-power station

Instead of exploding a nuclear weapon, a terrorist group may decide to attack a nuclear facility. It is generally recognised that a terrorist group with significant resources could attack and damage a nuclear-power plant. There is argument, however, about how much damage and how many people would be harmed by such an attack. It is probably true that attacks on nuclear-power plants that could do a great deal of damage and cause many fatalities do not have a large chance of success. But many believe that the damage caused by and the number of people killed by a successful terrorist attack on a nuclear-power plant could be so catastrophic that even a small risk of such an attack is not acceptable.

There are two potential targets in a nuclear-power station for a terrorist attack: the reactor itself and the ponds storing the spent fuel removed from the reactor. An attack on the reactor could cause the core to go super-critical (as happened during the 1986 accident at the Chernobyl reactor) or cause a loss of the coolant that removes heat from the core of the reactor (as happened during the reactor accident at Three Mile Island).

Spent fuel elements are normally kept in storage ponds for five or ten years under three or so metres of water before they are either finally disposed of in a geological repository or sent to a reprocessing plant where the plutonium inevitably produced in the fuel elements is chemically separated from unused uranium and fission products in the fuel elements. The ponds are normally built close to the reactor building. The buildings containing the spent fuel ponds are less well protected than the reactor and are, therefore, more attractive targets than the reactor building.

Terrorists could target a reactor or spent fuel pond by: using a truck carrying high explosives and exploding it near a critical part of the target; exploding high explosives carried in a light aircraft near a critical part of the target; crashing a high-jacked commercial airliner into the reactor building or spent-fuel pond; attacking the power station with small arms, artillery or missiles and occupying it; or by attacking the power lines carrying electricity into the plant.

Alternatively, a terrorist group may infiltrate some of its members, or sympathisers, into the plant to sabotage it from inside. A saboteur may attack, for example, the systems cooling the reactor core or drain water from the cooling pond. This could cause the temperature of the reactor core to rise, resulting in a release of radioactivity from the core, or cause the temperature of the spent fuel rods to rise, again resulting in a release of radioactivity.

If nuclear power is not likely to make a significant dent in global warming, what could do so?

In its 2007 report *The Energy Challenge* the former UK Department of Trade and Industry states that 6 GW of new nuclear capacity will be needed in the UK by 2025. New nuclear-power reactors will only, at the very best, be constructed at a rate of one new reactor a year by 2020. Could non-nuclear sources of energy compensate for the loss of nuclear power and reduce greenhouse gas emissions without causing problems for energy security?

The UK has considerable potential for using wind, wave, tidal and solar power. The potential of offshore wind alone, for example, has been estimated to be 70 GW, the largest in Europe. This could replace the current total electrical power capacity in the UK. The British Wind Energy Association (representing 310 companies) has estimated a total onshore and offshore wind capacity of 24 GW for 2020.

If the trend in the contribution of photovoltaic cells actually achieved in the past five years is continued it will reach 10 GW by 2020, more than new nuclear build is likely to achieve by that date.

Given these possibilities, it is hard to see why the UK needs nuclear power.

Conclusions

Some very respected advocates for nuclear power do not dispute that a significant increase in the use of new nuclear-power reactors would increase the risk of nuclear terrorism and nuclear-weapon proliferation but argue in favour of a nuclear renaissance nevertheless. These advocates include James Lovelock (of Gaia fame)**, Richard L. Garwin (the eminent American nuclear physicist and government adviser) and Patrick Moore (the co-founder of Greenpeace).

Like UK government ministers and advisers, they argue that the risks to national security of a failure to reduce the emissions of greenhouse gases outweigh the risks of nuclear terrorism and nuclear war. They say that the number of people killed and the social disruption caused by global climate change may dwarf those caused by nuclear terrorism and regional nuclear war.

The alternative argument is that low-carbon energy sources are available and could be installed faster, more cheaply and with less risk to national and global security than nuclear power. Society has to judge whether or not the risks of nuclear-weapon proliferation and nuclear terrorism in a world of many nuclear-power reactors are acceptable.

The damage done by the 16 July earthquake to one of the reactors of the Kashiwazaki-Kariwa power plant in Nigita Prefecture, operated by the Tokyo Electric Power Company, is a reminder of potential safety problems with nuclear reactors.

**Lovelock is exceedingly pessimistic about the consequences of global warming. At a lecture, entitled ‘Climate change on the living Earth’, given on 29 October 2007 at the Royal Society, James Lovelock, said that we could be on the brink of natural disaster and even the gloomiest predictions of the Intergovernmental Panel on Climate Change’s (IPCC) latest report are underestimating the current severity of climate change. In 1965, Lovelock developed the Gaia Theory that says self-regulation is by the whole system, not just life.

In his lecture he argued that although the IPCC report is “properly cautious”, it gives the impression that the worst consequences of climate change are avoidable if we take action now. Instead, Lovelock’s view of the future is much more catastrophic. Even if we act now he believes, six to eight billion people will be faced with ever diminishing supplies of food and water in an increasingly intolerable climate and wildlife and whole ecosystems will become extinct.

He argued that we have already ‘set off a vicious cycle of positive feedback’ in the earth system whereby extra heat in the atmosphere from any source is amplified, causing yet more warming. “We are at war with the Earth”, he said, “and as in a blitzkrieg, events proceed faster than we can respond.”
He argued that when a model includes the whole Earth system it shows that: “When the carbon dioxide in the air exceeds 500 parts per million the global

temperature suddenly rises 6 degrees Celsius and becomes stable again despite further increases or decreases of atmospheric carbon dioxide. This contrasts with the IPCC models that predict that temperature rises and falls smoothly with increasing or decreasing carbon dioxide."

Moreover, Lovelock warned, that cutting back on fossil fuel use could actually exacerbate global warming. This is because current global warming is being partially offset by global dimming the two to three degrees of global cooling caused by aerosol particles in the atmosphere from man made pollution. These reflect sunlight and nucleate clouds that reflect even more sunlight.

He said that: "Any economic downturn or planned cut back in fossil fuel use, which lessened the aerosol density, would intensify the heating. If there were a 100 per cent cut in fossil fuel combustion it might get hotter not cooler.......We live in a fool's climate. We are damned if we continue to burn fuel and damned if we stop too suddenly."

"Because it might help slow the pace of global heating, we have to do our best to reduce emissions and lessen our destruction of natural forests to feed and house ourselves; but this is unlikely to be enough and we will have to learn to adapt to the inevitable changes we will soon experience".

In Lovelock's opinion we should think of the Earth as a live self-regulating system and devise ways to harness the natural processes that regulate the climate in the fight against global warming. This could involve paying indigenous peoples to protect their forests and develop ways to make the ocean absorb and store carbon from the atmosphere more efficiently.

Frank Barnaby, November 2007