What is really real?

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There has been substantial public debate recently on a host of issues such as climate change, genetically modified crops and nuclear power; a common theme running through these issues involves science and public policy. This note will be based broadly on three interlinked themes: growth of specialization in science, significant commercial interests pushing science and technology, and a checkered track record of the promises made and the broken-reality.

The world is undergoing severe churning currently, especially in terms of people demanding meaningful participation in public policy. There has been a significant polarization, with many differing and often diametrically opposite views on a range of issues. Thus, for example, there appeared to be a scientific as well as public consensus developing on climate change and consequently a need to at least slow down, if not reverse, climate change. However, there has been a significant push-back over the past couple of years so that public opinion is changing, and with it the need for public policy to address climate change.

In such a situation, it has become difficult even for interested, but not directly involved, scientists as well as the general public to look at the evidence and make a judgement on what is really real. This note deals largely with issues relating to perceptions on nuclear energy, and examines critically the basis for public fears and reservations against nuclear power. There have been several issues recently that have generated substantial public debate, including *Bt* brinjal, nuclear energy, climate change, and medical testing and policies. A common theme running though these issues is the connection between society, science (and technology) and public policy involving governments at local, national and international levels.

Although there has been some interaction between science and public policy, society has generally been only provided public policy and science, without much direct involvement. However, with growing information available from many sources, there is an increasing questioning from the public towards both science and public policy. This has arisen in part from changes in science activities that have occurred especially over the past century relating to commercial interests, specialization and a checkered track record.

The general public idea of a scientist may be that of a person dedicated to uncovering truth and developing fundamental understanding, with some potential use of the knowledge eventually. However, scientists also have normal human desires for fame and power. There has been an additional factor of wealth coming into this picture, especially over the last 60 years. The potent cocktail of fame, power and fortune has possibly altered scientific activities to such an extent that it may now be driven not just by curiosity, but also by financial allure and inducement.

Thus, for example, data show that there has been an increase in industrial support of biomedical research from ~32% in 1980 to 62% in 2000, and a study in 2003 revealed that lead authors of one in three articles held relevant financial interest (V. Nanjundiah, 2011, pers. commun.). This raises an important issue relating to potential conflicts of interest and unbiased scientific investigations. As is well known, studies supported by the tobacco industry were unable to find a link between smoking and lung cancer.

Scientists are still broadly trusted by society. A poll on public attitudes to energy found scientists, environmental protection organizations or consumer associations, and national governments being trusted by 71%, 64% and 29% of the people respectively[1].

About 50 years ago, medical doctors were treated as demi-gods. However, with the advent of specialization and super-specialization, increasing awareness of medical malpractices driven by money, a trust-deficit developed, so that it is not uncommon now for people to ask for a second opinion in many instances. Science may also be heading in this direction.

Over the past 60 years, there has been a substantial increase in specialization, so that one tends to know more and more of less and less. This has frequently led to attitudes of 'leave it to the experts', or 'daddy knows best', which are no longer acceptable.

The increase in specialization has necessitated collaborations not only within a discipline, but across disciplines; such interactions have been fruitful frequently. In addition, the complex issues being tackled, with the associated infrastructure, has led to scientific publications with numerous co-authors, compared to typically less than five co-authors until relatively recently. Analysis shows that a 1993 paper in the *New England Journal of Medicine* had 972 authors, so that each author effectively contributed two words to the paper (V. Nanjundiah, 2011, pers. commun.). There is an increasing potential danger with specialization and numerous coauthors, that responsibility for a publication becomes diffuse, with a chance that collaborators may not fully know the details of the work of their co-authors.

There are at least three important contributors to nuclear fears in the public. First, our common human sensory organs relating to sight, sound, touch, taste and smell cannot be used generally to track nuclear dangers. Second, there are vivid and horrific images from the nuclear bombing in Hiroshima and Nagasaki, and these memories have been revived by accidents at Three Mile Island, Chernobyl and Fukushima. Third, there is a string of broken promises such as nuclear power becoming 'too cheap to meter', or that all precautions have been taken so that nuclear power is 'safe'.

Many governments as well as the nuclear industry label the above nuclear fears as irrational or unfounded. Apart from financial or commercial interests and specialization in science, it is appropriate to consider the track record of nuclear power to examine whether public fears about nuclear power are ill-founded.

Nuclear risks

Defence in depth, passive cooling systems and probabilistic risk assessment are some of the terms encountered when hearing experts discuss nuclear risks. Essentially, the idea is to develop several independent means of mitigating small problems or accidents, so that the overall possibility of a catastrophic accident becomes extremely small. It is unlikely that we will ever be able to account for all 'beyond design' events such as the massive earthquake in Fukushima, or human error and bad design in Chernobyl. The third-generation nuclear reactors are apparently designed with a risk of failure of one in a million reactor-years[2]. However, public experience has shown that there have been 5 core meltdowns within a total operation of 15,000 reactor-years since the 1950s (ref. 3). Arguments that newer power plants are safe sound hollow when seen in the context of nuclear power plant operators trying to extend the lifetimes of old, 'less safe' reactors. Furthermore, despite their exhortations on the safety of nuclear power, it is important to note that both governments as well as the nuclear power industry tacitly acknowledge the possibility of a catastrophic nuclear accident: governments try to locate plants away from significant population centres, and the industry tries to limit liability and needs significant government financial support and underwriting.

Scientific uncertainties and implications

It is important to acknowledge and understand uncertainties in science. This is examined in Figure 1 by considering the changes in risk with ionizing radiation dosage[4]. High dosage rates of more than 10 rem are risky, with the risk increasing linearly with dosage, based on significant evidence from Hiroshima and Nagasaki. At intermediate dosage of 5–10 rem, there is limited verification to show that risk continues to be linearly proportional to dosage. At low dosage rates of less than 5 rem, the data are extremely limited and uncertain. A general approach has been to extrapolate the behaviour at high dosage all the way down to zero, and this is referred to as the linear no-threshold (LNT) model. More recently, there has been a significant push to endorse an approach involving a threshold level of radiation, for which there is no risk below the threshold level. This is a topic on which it is difficult to get complete verification of the effects for at least two reasons: (a) when the risk is small, the increase in cancers or deaths associated with radiation will be small, and this may be well within nominal statistical variations in data, and (b) the presence of natural radiation may obfuscate small effects due to additional low radiation. A detailed study by the US National Academy of Sciences Committee on Biological Effects of Ionizing Radiation stated[4]: 'The Committee judges that the balance of evidence from epidemiologic, animal and mechanistic studies tends to favour a simple proportionate relationship at low doses between radiation dose and cancer risk', essentially supporting the LNT model. (For simplicity, not shown in Figure 1 are two additional possibilities at low dosage: a risk higher than the LNT model and a beneficial effect of radiation[5].)

Such uncertainties may have a profound effect on the interpretation of data. Thus, for example, estimates of cancer deaths related to the Chernobyl accident vary widely from 62 (ref. 6) to 4000 (ref. 7) to 93,000 (ref. 8) to 985,000 (ref. 9). The first estimate listed above was given recently by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), whereas the second estimate was given by the UN Chrenobyl forum and the World Health Organization. The third report came from a study involving 52 scientists commissioned by Greenpeace, and the fourth estimate was from a group of three scientists in Russia and Belarus, who collected information from many local sources that were not considered by Western scientists. While differences in methodologies certainly contributed to the vastly different estimates, one of the important factors is consideration for low-level radiation. Thus, the estimated low value of 62 deaths from UNSCEAR arose because the Committee explicitly noted that they did not consider projections from low-level radiation because of unacceptable uncertainties in the predictions[6]. A very recent report by the Union of Concerned Scientists[10] leads to an estimate of around 27,000 deaths, using data from the earlier UN studies and populations exposed to risk at low dosage. Clearly, even if the risk is small at low doses, consideration of the very large areas over which there was contamination will lead to large numbers of projected deaths. In the absence of satisfactorily validated data and models, it is appropriate to continue using a conservative LNT approach.

There is an additional important point to bear in mind, relating to uncertainties of low-level radiation. Eventually, one has to deal with decommissioning and cleaning up sites involved with nuclear activities. Calculations in 1995 revealed that the cost for cleaning up a site in

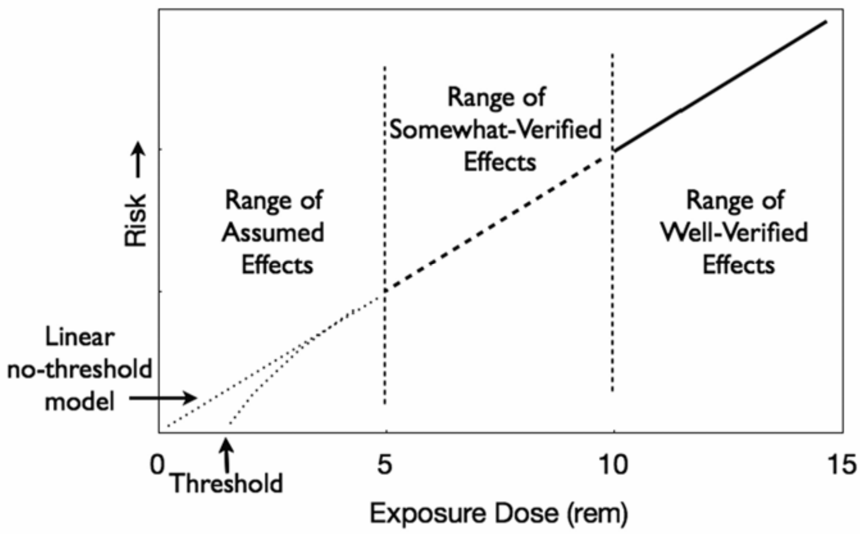

Figure 1. Variation in risk with radiation exposure dose, illustrating the linear no-threshold model as well as a model with a threshold. Adapted from ref. 4.

Nevada increases drastically with a reduction in the remnant radiation[4].

Dealing with nuclear accidents

Nuclear accidents have a significant effect on public opinion and perception of nuclear power. Thus, polls conducted before and after a criticality accident in the Tokai Mora uranium mining facility in 1999, with the death of two people, resulted in a change from 12% polled considering nuclear power dangerous before the accident compared to 53% after the accident[11]. While news about 'minor' accidents was not reported widely earlier, so that the impact of such accidents was largely local, the sense of heightened anxiety and wide exposure in the media imply that such incidents will be widely disseminated, leading to stiffening of attitudes against nuclear power. Thus, following Fukushima, Germany has decided to close down all nuclear power plants by 2020, and Switzerland by 2032. Several other countries are re-evaluating their plans for nuclear power.

There appears now to be a set pattern for officials to deal with nuclear accidents: (a) state that lessons will be learnt, (b) study the nuclear accident, (c) reexamine safety, (d) make changes considered necessary and (e) declare all plants safe. While such a pattern may be appropriate and intended to reduce apprehensions about nuclear power, it is necessary to go beyond the above approach.

Looking historically at the development of nuclear power plants (see, for example, an excellent 1992 BBC documentary[12] entitled 'A is for atom'), it is clear that governments and the nuclear industry have always claimed that nuclear power is safe, even when they had some contrary indications. While such approaches may be ascribed to the Cold War era until the 1990s, when nuclear power was closely linked with nuclear bombs, it is surprising to note that this legacy continues even now. Thus, the UK Government decided to play down the Fukushima accident, with a coordinated public relations strategy together with nuclear companies[13]. After Fukushima, a leaked recent study for the Russian president revealed that the Russian reactors were grievously underprepared for natural and man-made disasters ranging from floods to fires to earthquakes to plain negligence; meanwhile, the Russians declared their plants safe[14].

Coming to the situation in India, which also followed the pattern described above, there have been two recent reports which cause confusion. First, on 20 September 2011 it was reported that India was awaiting a final report on French nuclear reactors, dealing with issues raised by Fukushima; orders for the Jaitapur nuclear plants would be finalized only after Indian authorities examined the report critically[15]. Within a week, there was another report from the nuclear establishment claiming that the Jaitapur plants would be completed, although with some delay[16]. This reveals the difficult predicament of the nuclear establishment in riding two generally incompatible horses: on the one hand, they need to reassure the public that safety will not be compromised, but on the other hand, they want to keep foreign vendors happy that the deals will go through, with a delay. The two statements also appear to suggest that an evaluation of the report will not be open-ended, as the decision to go ahead has already been made.

Making public policy 'scientifically'

Frequently, in dealing with complex issues, assertions are made that the decisions should be made scientifically. However, when there are many parameters involved with complex issues, it becomes clear that values guide the relative significance of the different parameters. Take a simple example of buying a car: usually this involves a trade-off between cost and performance, with different people choosing different trade-offs depending on their inclination. With complex issues, such as nuclear power or *Bt* brinjal, there is a need to make multiple trade-offs, so that the overall analysis is based on the judgement of the relative importance of the various factors. Therefore, one needs to always keep in mind: who pays the costs and who reaps the benefits, as these are usually two different sets of people. For example, is it reasonable to have asked local villagers near the Tarapur nuclear power plants to give up their land and possibly their livelihoods so that air-conditioned malls in Mumbai can operate comfortably; while, at the same time, the deprived villages in the vicinity of the power plants continue to suffer about 8 h of power shutdown everyday[17]?

Human development and consumption

Over the last several decades, there has been a substantial push for economic growth worldwide, and the term GDP (gross domestic product) has become common usage. GDP has become conflated with development, and also consumption, with many suggestions of a correlation between GDP and energy consumption. About two decades ago, a human development index (HDI) was developed in recognition that life expectancy together with literacy and education also contributed to human development, apart from economic growth[18]; HDI varies between ~0.3 and 0.95, with higher values being desirable. Figure 2 shows the variation in HDI with per capita energy consumption for 60 countries[19]. There are several other figures with different energy factors and units, but the general trend of a saturation in HDI is still maintained.

Such approaches have an important bearing on nuclear power, as energy planning is based on presumed growth of GDP over the next two to four decades; clearly, assumed linkages between GDP growth and energy consumption drive current policies for power production. The data in Figure 2 indicate broadly that there is a saturation in HDI of ~0.9–0.95 around a per-capita energy consumption of 2400 kilograms of oil equivalent (kgoe), so that an energy consumption of 2400 kgoe may be a desirable number. There are at least two important problems with this approach. (a) First, HDI is based on a mixture of contribution of some factors; limitations to the approach include the consideration of only a few factors relating to human development, and also the mathematical procedure adopted to come up with a single number. Indeed, the factors included in calculating HDI were modified last year, and the new approach gives HDI values that are lower than the older procedure[18]. (b) Second, Figure 2 suggests that India would need to increase energy consumption by a factor of ~5 to increase its HDI from ~0.62 to ~0.9. However, the data

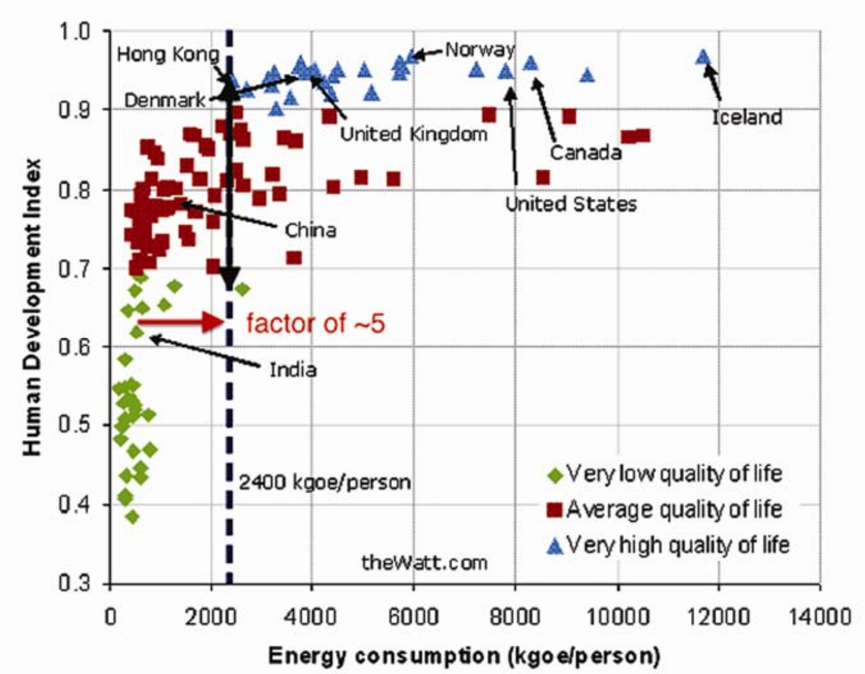

Figure 2. Variation in human development index (HDI) with energy consumption showing a plateau in HDI[19]. The horizontal orange arrow suggests incorrectly that India will need to increase its energy consumption by a factor of ~5; the vertical black arrow at an energy consumption of 2400 kgoe/person reflects the elasticity in HDI, with the possibility of an increase in HDI without any increase in energy consumption.

also show that there are several countries with ~600–1000 kgoe energy consumption having an HDI of ~0.8–0.85. This analysis suggests that an energy consumption increase of less than a factor of ~2 could suffice in obtaining a high HDI of 0.8–0.85. (The equitable distribution of the available energy is an important but different matter. Energy policies are frequently justified as necessary to provide electricity to the rural areas, although this is likely to be a minor factor in the overall energy consumption.) Essentially, the vertical spread of the data at any energy consumption could be termed as the elasticity of the HDI, representing conditions where an increase in the HDI is not related to an increase in energy consumption; for example, at the vertical line of 2400 kgoe, HDI varies from ~0.68 to 0.92. Extending the figure to consider all countries, instead of only 60, will probably lead to an increase in elasticity. It is interesting to note also that further increases in energy consumption beyond 2400 kgoe do not lead to any significant increase in HDI; whereas Hong Kong and USA have a similar HDI of ~0.93, USA consumes almost three times as much of energy per capita as does Hong Kong.

An increase in energy consumption by a factor of ~2 for India to get to an HDI of ~0.8–0.85 would lead to a drastically different plan for power generation compared to one involving an increase in consumption by a factor of ~5; this may also reduce the justification for nuclear power plants. It is also important to bear in mind that projections beyond a couple of decades may be meaningless in the current technological climate with frequent new developments and possibilities for significant paradigm changes.

Alternatives to nuclear power

If nuclear power is not considered seriously due to the perceived risks and the lack of public acceptability, it is necessary to examine alternatives. It is appropriate to first utilize existing energy resources optimally. Currently, nuclear energy contributes ~3% of the total energy needs, and even with a substantial expansion over the next two decades, it is projected to contribute only 6% to India's energy needs[20]. India's current transmission and distribution losses for electricity are more than ~25% compared to values of ~5–10% globally. Clearly, a decrease in such losses towards global levels will lead to substantial energy becoming available. Conservation of energy and enhanced energy efficiency can also increase available energy effectively. Note that dire consequences of large-scale power outages in Japan following Fukushima did not materialize, with a focused effort towards energy conservation and efficiency.

Nuclear power has generally been considered to be cheaper than renewable energy from sources such as the sun (solar). However, this may largely have been a result of some creative accounting. As noted elsewhere, even in the 1950s and 1960s, British nuclear proponents had cooked up data to show that nuclear power was at that time cheaper than coal power[12]. With unusual candor, the British Energy Secretary Huhne noted recently that nuclear power has been amongst the most costly failure of British policy-making, with payments of £2 billion per year being made currently for power that was used decades ago[21]; surprisingly, he supports new nuclear power stations without *any* public subsidies. A very recent study has shown that solar energy will be cheaper than nuclear energy in two locations where nuclear plants are being considered in USA[22]. In addition, apart from liability insurance and other government support, decommissioning of plants damaged in accidents can be both expensive as well as take a long time (more than 30 years for Fukushima[23]). It is relevant to note that renewable power projects may also need to deal with issues relating to availability of land and other factors, for large solar farms as an example.

Before making any additional investments in nuclear power, there is an urgent need for an independent and credible evaluation of the energy 'needs' of the country, and to examine critically whether such needs can be met without nuclear energy.

Closing comments

It is clear that the linkages between society, science and public policy need to be reworked, so that society becomes intimately involved with both science and public policy, as shown in Figure 3. Questioning of science by the public does not warrant an anti-science label, just as societal desire for partnership and

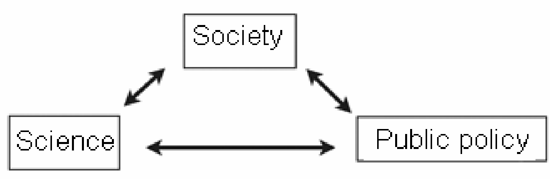

Figure 3. Illustration of desirable interlinkages between society, science and public policy.

involvement in public policy should not be seen as being anti-constitutional. Gone are the days when leading authorities in science or public policy can declare truths and directions for society to follow.

While scientific expertise is essential in providing some answers and directions for the future, it is clear that society wants to be, and needs to be, involved in shaping public policies that may entail scientific issues.

There is sufficient information available to understand public apprehensions regarding nuclear power; open communication from nuclear bodies is essential, but it may not be sufficient to bridge the trust deficit. Plans for massive nuclear power installations based on projections for over four decades are not merited, as the projections may not be valid or necessary. Furthermore, there are sufficient alternatives available to generate the needed energy.

Governments and the nuclear power industry must desist from 'proclaiming safe' (in contrast to 'crying wolf'), as they only increase public anxiety and mistrust when the next nuclear accident happens. Comparisons of the safety of nuclear power plants with crossing a road in urban India or flying on a plane are insensitive at best, as the public appears to recognize that what is important is the *potential* for severe acute and chronic damage in case of a catastrophic nuclear accident. It is ironical that there is a reduction in the conditional support for a nuclear renaissance arising from a more serious perceived threat of climate change, as corporations unwilling to have a longer-term perspective of global warming have pushed an agenda to sow confusion about climate change.

Finally, we all have our individual perceptions of risks, and on an individual basis we pay the price when reality differs from our perception. However, public policy must take into account the larger societally perceived risks, especially in a large, densely populated country like India, without much hope of moving large populations in the case of a serious accident. Allaying public fears and concerns is likely to be difficult, in view of the lack of public credibility arising from historical and contemporaneous approaches by the nuclear industry and the governments.

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