SUSTAINABILITY - A New Challenge for Nuclear Power!

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Abstract

The evolutions of risk perception, market conditions, non-proliferation aspects, stockpiles of weapon-grade materials and a worldwide request for sustainable energy supply systems during the last decades have resulted in widespread public and industrial objections to nuclear technologies. Future R&D programmes will have to address these problems as challenges to the further development of nuclear installations. Consequently, R&D activities on waste issues, proliferation and economic aspects have to be handled on the same priority level as safety-related R&D.

There is an urgent need to quantify future sustainability requirements for all relevant energy supply systems. This represents an interdisciplinary task between technical and sociopolitical science and could help to allow balanced judgements for reconsidering nuclear energy as a promising alternate. In this respect, it has been revealed that the risk formula is not suited for risk perception issues. The human sense for danger is much more complex and may request e.g. a basic exclusion of catastrophic nuclear accidents as well as a conversion of long-lived radiotoxics into short-lived waste as preconditions for regaining stable public acceptance.

The ongoing globalisation process has already ‘transmuted’ the nuclear supplier and utility structures and has to be applied to the still national R&D structures, too. Synergetic networking is a premise for a balanced global collaboration on innovative nuclear reactor technologies. Even the countries with a nuclear moratorium are benefitting from an environmentally benign, safe and economic operation of the existing nuclear installations that have partially replaced former domestic energy resources. Despite some phase-out scenarios, this will de facto still continue for several decades even if no new plants are built within the next years. This period of time will create technical innovations that will allow an improved operation of existing plants as well as new designs and back-end strategies that may find industrial and public acceptance.

With regard to the dawning climate change, the dualism between nuclear and other renewable energy sources has to be converted into a ‘coalition’ of nuclear with other environmentally benign alternates. Nuclear energy does not hinder the introduction of renewable energy systems. On the contrary, cheap nuclear energy will allow more still expensive solar, wind, biomass electricity generation etc. to be absorbed in the energy mix.

The political discussions on the future of nuclear energy often ignore the R&D progress in comparison to existing installations that were fixed in their design principles around 30 or more years ago. They thus represent the state of the art as well as the industrial and public requirements of those times. An extrapolation of the technical limitations of existing nuclear power plants and fuel cycles into the distant future should not be the basis of decisions on the future use of nuclear energy as this would create long-lasting moratoria and phase-out scenarios only. The further operation of existing nuclear power plants and their evolutionary development should therefore be embedded in a 'vision' of sustainable long-term use of nuclear power by complementary R&D programmes on innovative systems and concepts.

1 Introduction

Whereas 'sustainability' can be seen as a principle of intergenerational equity and of environmental stewardship with a long-term scope, safety aspects, waste issues, economics and social acceptance represent an integral part of criteria for sustainable developments. Due to the danger of an overstressing of environmental resources by a still strongly increasing world population and of the average standards of living, the change towards 'Sustainable Developments' has assumed as the leading political and technological orientation for the 21st century. Criteria for sustainable energy supply systems, however, still have to be defined in a consensual and general way for establishing a guidance to judge the compatibility of different options like nuclear or others.

In the past Climate Protection Conferences, nuclear energy has not been considered as a sustainable energy supply option at all although the nuclear community is strongly advocating it with the argument of CO_2-free electricity production and of practically inexhaustible resources. This may be due to the increasing anti-nuclear movements in many countries and the anticipated safety and waste problems, as well as due to the lack of willingness by the utilities to invest in capital intensive technology in times of strong competition within an open market and relatively low costs of (fossil) alternatives.

Sustainability not only addresses environmental, ecological and social compatibility but also economic and industrial aspects. Therefore, the problem of acceptability of nuclear energy and its interrelationship with technological innovation and evolution of the boundary conditions has to be discussed on three levels:

- public acceptance,
- industrial acceptance,
- internal acceptance / consensus within the nuclear community.

'Risk Perception' is being understood as a result of complex cultural and social evolutions as well as a human sense that does - obviously - not obey the risk formula (product of expected extent of damage and corresponding frequency of occurrence) being used in hazardous technologies including nuclear engineering. An attempt is being made to illustrate the mismatch of the two-parameter linear product in the definition of a technical measure of probabilistic risk and the human sentiment for the acceptance of risk in a multi-parameter interdependence of different additional aspects. A better understanding and 'acceptance' of these mechanisms might lead to an improved communication culture between the public, the industry and the nuclear community and could provide some orientation for sustainability-oriented R&D.

2 Sustainability Criteria

The principle of 'Sustainable Development' can be interpreted as an approach to solve the conflict between ecology, economy and intergenerational social responsibility. This terminology already evolved in the 18th century from forestry that also needs long-term planning and cultivation. In the 1980s, the concept of 'a development that meets the needs of the present without compromising the ability of future generations to meet their own needs' had been taken up again by the General Assembly of the United Nations and in the 'Brundtland Report'. It was also taken as a major guideline in the discussions and conferences on climate protection (e.g. Rio, Kyoto) and seems to be a robust and consensual orientation being applied to a broad spectrum of human activities also in the immediate future (Boudier et al., 1998).

In former times, mankind has always been a 'Solar Community' mainly taking its energy from regenerative sources (e.g. biomass, water, wind) and physical labour from humans or animals. This kind of energy supply also created social structures (e.g. bondage, slavery) and hierarchies that were (partly or temporarily) overcome after entering the 'Fossil Energy Era' about 150 years ago. However, the impact of fossil energy use on the climate, flora and fauna is obvious and cannot continue or even be enhanced in the long run, thus offering the main argumentation to establish sustainable energy supply structures with reduced emissions of greenhouse gases or toxic substances or wastes endangering present and future generations. Nowadays, no major safety issues are being related to fossil energy supply systems or to regenerative energies even if this is not true.

Although nuclear energy is a proven CO_2-free energy supply system, it has not been judged as a future option at the Global Climate Protection Conferences. Even the European Parliament rejected only by a very narrow vote (225 against 218) a statement that 'nuclear power could not be considered a safe and sustainable method of energy production and did not, therefore, belong in the policy against climate change' (Blix, 1998). On the other hand, a study commissioned by the EC clearly states that to fulfil the commitments taken by the EU member states with regard to the reduction of greenhouse gas emissions, a massive deployment of nuclear power plants (in the order of 100 GWe) has to take place in Europe in the decades to come (EC, 1999). This highlights the absurd discrepancy between the argumentation of proponents on the one hand and ignorance of the potential of nuclear energy and social sensitivity on the other. In this context, it is extremely important to create a 'Coalition' of sustainable CO_2-free energy systems instead of permanent confrontation and competition between nuclear, solar, wind and others.

There is a broad consensus in many countries all over the world that nuclear energy is neither acceptable nor sustainable from a sociopolitical and environmental point of view. A neutral judgement by sustainability criteria being generally accepted as an outcome of an interdisciplinary and social discourse could change this prejudice beyond different convictions and dualism between alternatives. Thus, there is a real need for establishing such criteria that would probably address a spectrum of aspects (Kroeger, 1997) like:

- Degradation of Resources (e.g. fuel, materials, land losses)
- Environmental Impacts (CO_2, SO_x , radiation, waste heat etc.)
- Human Health Effects (acute and latent fatalities in operation and after accidents)
- Social Aspects (number of employments, risk aversion etc.)
- Economic Competitiveness (competitiveness, inclusion of external cost?)
- Non-Degradable Waste (amount, confinement time)
- Robustness (supply security, failure friendliness, grace periods, background of experience etc.)
- Proliferation Resistance

Strategies towards a sustainable development have not only to include the innovation potentials of energy systems and the optimisation of cost effectiveness (Voss, 1998) for CO_2 mitigation, but also to concentrate on the sociopolitical dimension of the different alternatives (incl. nuclear power) and to adapt the technology to the risk perception mechanisms in a pro-active way (Tomono, 1998).

3. Need for Innovation

The mechanism of the 'evolution of species' (taken here in their broadest sense) is mainly driven by changes / evolution of the boundary conditions and of those of other competitors to which the species have to respond by viable mutation or change of attitudes. The boundary conditions for nuclear energy have evolved drastically in contrast to the expectations in the early period of its deployment. It is unrealistic to expect that the social and economic environment will adapt to the intrinsic technical evolution of nuclear technology as often claimed by the nuclear community. On the contrary, nuclear technology also has to 'mutate' quickly enough to keep pace in coping with the evolution of requirements and of competing technologies.

Nuclear energy still possesses a huge innovation potential. But this potential has not been introduced strongly enough into the discussion on the future of nuclear power and its role for the improvement of the market situation. There is a real danger that the future of nuclear power could be decided only based on a further extrapolation of the anticipated deficits of existing plants that were established some decades ago and without taking the potential for technical improvement into account. Successfully applied technical solutions, convincing operational experience, advanced commercial projects and innovative approaches complement each other to create a long-term option on nuclear power and to provide a progressive argumentation on future prospects.

The reasons for opposition to nuclear energy are partially known from investigations / interrogations and the question arises whether technological innovations can respond to these fears, changed views and trends as discussed for some selected examples in this paper. This applies to the public as well as to political and industrial decision makers.

'Market' compatibility is a pre-condition for industrial commitment and the acceptance of 'risk' concerning the safety of investments and return of capital. 'Structural' compatibility is needed to apply nuclear energy under effective & rational licensing, manufacturing and operation procedures with no major penalities in comparison to competing systems. 'Environmental' compatibility of nuclear power is often referred to by the nuclear community in defending the need for nuclear energy but counteracted by the discussion on hypothetic catastrophic releases of radiotoxics and long-lived waste. 'Mental' compatibility of nuclear technology might even be more important for reconciling nuclear energy with public opinion again.

These goals - in a long-term view - also represent a challenge for R&D on innovative technological approaches and should be fostered by a consensus within the nuclear community despite potential different views on alternate nuclear options (SINTER Network, 1998).

4. Different Levels of Acceptability

The acceptability of nuclear power is mainly influenced by concerns about safety and waste and other conflicts like credibility or communication problems and different political perceptions on future energy supply systems as will be later discussed in more detail.

Another aspect is the decline of acceptability for nuclear power by industrial decision makers. The actual mechanisms of industrial decisions on investments or commitments to nuclear energy are also a result of evolutionary - possibly irreversible - changes in the attitudes of industrial leadership, management and criteria (e.g. shareholder value, short-term return of capital etc.) as well as the uncertain competitiveness of nuclear against low-priced and highly effective fossil-fired power plants. The ‘safety’ of investment is not only judged on a purely technical and financial basis but also taking into account e.g. the ‘risk’ of changes in market structures, needs for backfitting and the danger of early shut-down due to political influences or even draw-backs in other business areas as a consequence of the “nuclear engagement”. Normally, the loss-of-investment risk and damages in case of nuclear accidents are also partially not accepted by insurance companies as they would be for other industrial projects.

The field of industrial acceptability of nuclear power is often assessed with a sentimental view back to the ‘good old days’ when industrial leaders claimed for long-term perspectives and developments as well as for large investments with return of capital in the long-term. Monopolistic structures in electricity generation are also shrinking in favour of free markets, competition and opportunities for independent energy suppliers. The actual situation has therefore to be analysed and ‘accepted’ as a basis for ‘tuning’ the technical concepts and economic features of nuclear power plants. The economic attractiveness of conventional power plants is also a result of drastic improvements in efficiency and cost reductions using the benefits of series production and low-cost manufacturing of equipment in the world market. Long and complicated licensing procedures impose additional handicaps and risks on nuclear energy.

Another - but interconnected - area of ‘risk perception’ consequences is the still underdeveloped consensus on common strategies within the nuclear community especially with regard to innovations. Evolutionary incremental improvements may reduce technical risks and the need for extensive and expensive demonstrations, but they may possibly not keep pace with the evolution of requirements. Addressing innovative approaches from a dualistic perspective by the attribute ‘revolutionary’, indicates that innovations are judged to endanger existing technologies and installations.

It is rather essential that the nuclear community defines a consensus on the coexistence of different generations of established technologies and different options on innovative technologies and concepts. Such an ‘internal’ consensus and a visible willingness to also respond to the evolution of the social environment (e.g. by flexible innovation strategies) may be a precondition for an effective communication towards an ‘external’ public and political consensus.

The drastic beneficial changes of globalisation and e.g., of regional unifications (e.g. EU) also have to be accepted and actively transposed into new collaboration structures on the industrial, administrative and R&D side instead of the familiar former structures on national levels.

5. Mechanisms of Risk Perception

Although probabilistic risk assessments (PRA) have proven to be an adequate tool for balanced technical improvements of the safety level, argumentation based on the results of PRAs did not lead to improved public acceptance in the long run. And even much smaller probabilities for catastrophic events or quantified comparisons of risks associated with different energy supply scenarios might not really change the situation.

The reason might be that the risk defined as a linear product of damage and probability does not respond to the functional dependencies of the very essential human sense for the recognition, handling and avoidance or acceptance of danger. This human sense has permitted a survival of the human species for millions of years even under more dangerous and hostile conditions. All other human perceptions mainly behave in a non-linear way, so why should this one be linear?

It is a fact that the hemispheres of the human brain operate in different ways. Whereas the left side mainly balances rational intellectual input and experiences, the right side mainly reacts in an associative way. Both judgements influence the acceptability of an action or a decision. This fact cannot be ignored by the proponents of nuclear power and must be accepted as a God-given natural mechanism with which the use of nuclear energy must comply. Not vice versa!

Everybody can check for himself whether the perception of a danger or a benefit has the same power as the probability of its occurrence. Nobody would play a lottery if one only judged it using probabilistic methods. There is a large personal potential benefit, with a limited amount of money as venture against a negligible probability for a significant prize. Obviously, the probability for that chance is strongly overestimated in the expectation of a huge benefit although a smaller gain is more probable. If the potential financial risk were very much higher - e.g. the income of a whole month or even a year - the participation in lotteries would be reduced to some individuals only who accept that game. Even in the case of very tempting benefits there will always be an upper limit for the venture or damage, otherwise it will not be accepted at all. Higher potential damage - even the loss of life - is accepted, if one judges oneself as being able to influence the procedure by own skills either in games or e.g., by driving a car.

This is also willingly accepted even for a higher potential number of fatalities when e.g. flying in a large aeroplane due to the trust in the skills of the pilot and the reliability of the plane and the airline. But panic reactions might result at the very moment when minor unusual disturbances occur. Accordingly, an ‘Acceptance Formula’ has to be enlarged by some other parameters describing the voluntariness, reliance on personnel / equipment and control of both compared to the ‘Risk Formula’. The Institute for Decision Research in Oregon (Renn, 1984) referred to some more comprehensive qualitative risk and benefit characteristics as shown in Table 1.

Kind of risk consequence	***Nature of risk source***
• voluntariness • possibility for avoidance • distribution over time • geographic distribution • degree of being affected • potential for control, active influence • social control • degree of familiarising / knowledge • scientific/technical maturity	• natural or artificial risk • possibility for fleeing • sentiment for danger • distance to the source of danger • reversibility / irreversibility • human / social risk • alternate possibilities • peaceful or military / terroristic use
Dimension of risk consequence	***Nature of benefit***
• fatal vs. limited damage • delayed vs. prompt damage • catastrophic vs. continuous damage • somatic or genetic effects	• exclusivity of benefit • public vs. private benefit • distribution of benefit • short vs. long-term benefit

Table 1.: Parameters influencing risk perception

Normally, only some of these parameters are selected for simplified or statistical reductions. However, for a complex acceptability problem like the acceptability of nuclear the full set of influences with different weights has to be kept in mind. Cultural / national influences may lead to different weights or variations but the basic mechanisms are the same, at least in a latent manner.

It is obvious that the risk formula does not at all respond to this complexity of judgements that human beings are able to perform in an intuitive way. This excellent result of human evolution also has to be respected within the argumentation on nuclear energy and to be transposed into technical and structural requirements for reconciling nuclear with the mechanisms of acceptability.

6. Technological Consequences of Risk Perception Mechanisms

Some of the risk perception mechanisms can indeed be addressed by technological / structural convergence or innovation as e.g.

Qualitative Risk / Benefit Characteristics	Potential Response
Possibility for avoidance	independent barriers, self-acting safety systems
Potential for control	accident management measures
Social control	transparent technology and surveillance
Degree of familiarisation / knowledge	neutral competent information
Scientific / technical maturity	open information on the technological progress
Fatal vs. limited damage	limitation of maximum releases
Delayed vs. prompt damage	longer grace periods
Catastrophic vs. continuous damage	reduction of inventory, transmutation of long-lived waste into short-lived material
Extreme catastrophes	deterministic exclusion / limitation by design
Natural or artificial risk	protection via natural laws (passive systems)
Possibility for fleeing	slow accident progression
Sentiment for danger	open information on all abnormal situations
Reversibility / irreversibility	restricted max. release, accident management
Alternate possibilities	neutral comparisons, sustainability criteria
Distance to the source of danger	siting, underground construction
Distribution of benefit	lower local electricity cost near to NPP

Table 2.: Examples of technical response to risk perception parameters (non-exhaustive)

These few examples show that the trends to advanced and innovative designs are on the right path for coping with these anticipated parameters and that recent licensing requirements requesting restriction of maximum releases and the inclusion of core melt accidents in the design as well as the need for a co-operative communication can be correlated logically. It is also important to note that passive safety systems might have the ‘charm’ to control an artificial risk by natural means.

The technological innovation potential to address these factors is not discussed in an open way mainly because of the 'risk' perceived by the nuclear community itself with regard to potential negative consequences of upcoming, but not yet available concepts for the operation of older designs.

The distribution of the benefits to the whole community while concentrating the risk on the neighbourhood of the power stations is in disagreement with the assessment of social justice. The price of fuel is often lower near refineries. Why should the surrounding municipalities of NPPs not benefit by lower electricity cost?

The credibility of the nuclear community and its arguments would significantly increase if 'quasi-religious wars' and dualistic views on specific reactor lines and technical preferences from the past were stopped in favour of credible innovation efforts coping with the actual and up-coming challenges for the nuclear case. It would also increase the credibility if the motivation for innovation and technological evolution were based on the adaptation of reasons stemming from the psychological mechanisms for acceptability and from clearly defined reasons for objection and fear.

7. 'Monocultures' are not Sustainable!

In the past, a lot of discussions were concentrated on the 'superior' reactor systems and the selection process was mainly performed by a regulated market with some monopolistic structures. Even in these early days, it was already discovered that a symbiosis between LWR and Liquid Metal-Cooled Fast Reactors (LMFR) could be a good solution with regard to economics, technical robustness and fuel resources. Other systems like Heavy Water Rectors (HWR), Gas-Cooled Reactors (GCR), High-Temperature Reactors (HTR) were confined to specific or national segments of the global market or did not even overcome the barriers to market introduction.

Today's selection criteria might have significantly changed due to the deregulation of the electricity market and due to the fact that public and industrial acceptance has to be regained for the construction of new plants and for the fuel / waste issue by persuasive and competitive solutions. On the other hand, the further operation of existing installations represents the main priority including life extension efforts in many countries. Life extension may even have a strong impact on the introduction of new systems because the necessary replacement will be shifted by some additional decades. Thus, there might be ample time for the development of innovative reactors but also a strong motivation for the optimisation of existing reactors and for making use of the different features of PWR, BWR (hard spectrum) and HWR (good neutron economy). It is strongly recommended (SINTER; 2000) to investigate strategies for reducing the generation of long-lived waste by innovative fuel (IMF, plutonium/thorium MOX, DUPIC etc.) in the existing reactors and to stabilise or even reduce the accumulated plutonium stockpiles from the civil use of nuclear energy. New systems have to seek a symbiosis with the existing reactors e.g. for burning discharged and reprocessed MOX fuel (e.g. in HTR) for solving a real problem of industrial and societal scope.

Operational indicators for the sustainable deployment of nuclear power within an energy mix could be the following (Kröger, Hirschberg, 1999; SINTER, 2000):

- Robustness and stability to satisfy the energy demand (sensitivity, safety, grace periods etc.);
- Degree of degradation/optimisation of resources (land losses, contamination, emissions etc.)
- Minimisation of non-degradable / proliferative waste (e.g. confinement period, transmutation).

The first results of a very qualitative comparison of different reactor types including homogenous reactors (molten salt, gas phase reactors) and Accelerator-Driven Systems (ADS) for this multi-dimensional problem have shown that no single system is capable of coping with all sustainability criteria in an optimal way. Many design features are focusing only on specific advantages. Evolutionary LWR and HWR dominate in the area of robustness due to the significant know-how available. HWR should be kept in mind with regard to the excellent neutron economy and potential of core configurations that basically avoid core melt as is the case with HTR, too. GCRs seem to be a good complementary choice in coping with all issues in a balanced way. ADS strongly address the back-end issue and the minimisation of non-degradable waste whereas LMFR and GCFR would have great benefits in stretching the fuel resources.

The main conclusion from this rough evaluation is that there should be no 'monoculture' of reactor types but a symbiosis of different types for coping with the above-mentioned sustainability criteria. Therefore, it is strongly recommended to analyse the synergies and benefits from the coexistence of different reactor types in more detail and not to continue controversial discussions about the sole 'best reactor system(s)'.

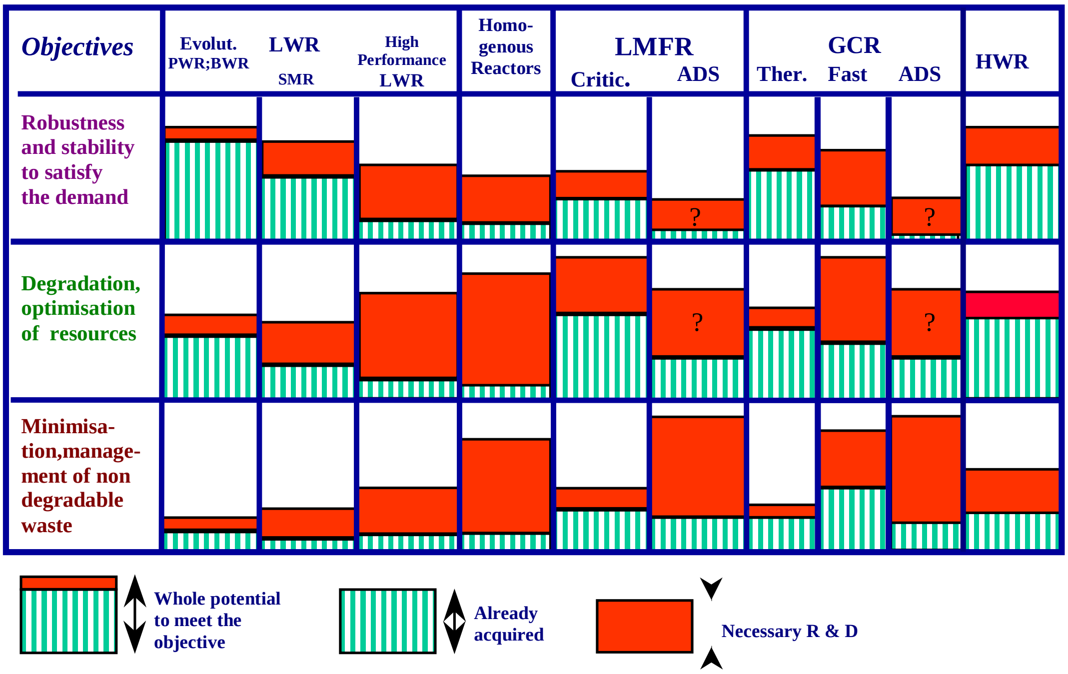

Figure 1.: Fission Reactor Types vs. Sustainability Objectives

For the future R&D programmes more attention should be paid to key technologies that can advance different options at the same time. Liquid metal cooling technology can e.g. be used for LMFR, ADS and even for fusion systems; the same is true for molten salt with regard to ADS and MSR. The coated-particle technology is not only restricted to HTR (Porta, 2000) but can be used for other reactors, too. The potential of passive safety systems is not yet fully explored and should not be limited by rather strict IAEA definitions. Steam, hydrogen, pressure / temperature differences available in accidents more or less represent 'pure energy' that can be taken to drive 'self-powered' safety systems thus closing the gap between 'pure' passive and 'pure' active safety systems. Inherent combinations of safety functions (e.g. feed & bleed, H_2 removal & containment cooling) can be other options to improve the safety of existing and future reactors.

8. Conclusions

It may be decisive for the acceptance of specific technologies (Peters, 1998) whether they are judged as a ‘limited risk’ allowing for a balancing of benefits and disadvantages or as a ‘fundamental danger’ that has to be eliminated as such. This also determines whether people are willing to use a technology in an active way or only feel passively afflicted by it. Several other parameters influence the mechanism of acceptance in a rather complex way so that the - probabilistic - argumentation by the ‘Risk Formula’ does not seem to be adequate at all. The limitation of plausible accidental threats and the reduction of the ‘quasi-eternal’ threat of nuclear waste down to time periods of some hundred years may be preconditions for restarting a rational debate on acceptable nuclear systems. The industrial acceptance of nuclear energy is also threatened by ‘risks’ from fading public acceptance and reduced economic margins.

The risk / technology controversy is not a temporary pathologic effect but characteristic of modern societies. It is very important to handle this conflict in a positive way and to develop - as a ‘social innovation’ - a culture of communication and dispute. It is essential to respond by technological innovations to the mechanisms and needs of acceptability and sustainability. Measuring new technologies against the sustainability criteria as defined above may be an appropriate way to balance the advantages and disadvantages of each alternative in a consistent and fair way and to derive a transparent decision basis for synergetic solutions.

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