Challenges for nuclear power

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At the start of the 21st century, "sustainability" is one of the vogue words and it seems to be one of the important criteria in the assessment of technological developments. As a consequence, sustainability is a new challenge for nuclear power.

Up until now, we have a rather vague definition of sustainability and it is of paramount importance to develop criteria for sustainability in order to be able to compare energy production options from this point of view.

To make them operational, these criteria should be as far as possible quantitative and there should be as much as possible consensus about them.

Quite clearly, we still have a long way to go, although the assessment matrix developed at the Paul Scherrer Institute in Switzerland (Wolfgang Kröger, *NEW,* No. 7-8/'99, pp. 106–107) is a significant step forward.

Nowadays people talk about sustainability without being hindered by clear definitions. That is characteristic of many discussions in society but unacceptable from the point of view of careful reasoning.

For instance, the fact that in the Global Climate Protection Conferences nuclear energy is almost put under taboo is far from satisfactory and illustrates that clear criteria for sustainability are still lacking, not to mention accepted.

An important aspect is that in our present reactors we use less than 1% of the energy content of the uranium ore. This very wasteful use of an energy source is unprecedented in history.

There is only one fissile isotope in nature and we should use it as an "igniter" for a conversion and breeding process in which almost all the uranium and thorium becomes fissile. This will have a dramatic positive influence on our energy resource situation.

For each year that we operate an LWR, we store as so-called "waste" an amount of depleted uranium with which we could operate a breeding system of the same power for almost 100 years!

There are more and also important consequences.

Uranium resources

Let us look at the uranium resources. How large are they? The answer depends on what you are willing to pay for the uranium. If you are able to get a factor of 100 more energy out of the uranium, you can pay a factor of 100 more for it.

And there is a law in Mining Engineering that says: *if you multiply the price that you are willing to pay for a raw material by a factor of x, then the resources will be multiplied by x squared.*

So, if we are willing to pay a factor of 100 more for natural uranium, then our potential resources are a factor of 10 000 more.

Is this complete nonsense? No, let us for instance look at the uranium in seawater.

Seawater contains 3 milligrams of U per cubic meter, which implies that the total ocean resources amount to 4 billion tonnes, which is about a thousand times the presently assured resources on land for a U price up to USD 80 per kg. A recent estimate for the production cost of U from seawater is USD 450 per kg, which is fully acceptable for application in breeding systems, so it is not amazing that Japan is developing the extraction of U from seawater (see *NEW,* No. 9-10/'99, p. 60).

The presently fashionable statement that we have only sufficient uranium for 50 years, at the present level of nuclear energy production, is senseless; my answer to a question about the extent of uranium resources is: it depends on your imagination.

Taking into account the factors mentioned, *there is sufficient uranium and thorium for millions of years of energy production, isn't that sustainability?*

So we conclude that humankind is wasting its nuclear energy resources, but it will gain a second opportunity, viz. by developing breeding systems. This will also make thorium applicable and, as you know, thorium is about 4 times as abundant as U on land.

In my view *non-breeding can only be seen as a prelude to a really sustainable nuclear energy system.* This does not mean that we should have only breeders, but we need a balanced symbiosis of breeding and non-breeding systems. Later I will come back to the breeding systems.

Talking about seawater, we come to the broadening of applications of nuclear energy, e.g. to power desalination. Energy and water are essential elements in human existence, and it is becoming increasingly evident that the freshwater problem will be one of the most crucial of the 21st century.

So, water desalination can be an important application for nuclear energy. This is also a reason that there is a future for small, unattended and inherently safe reactor systems, for which the HTR is a serious candidate.

Returning to the uranium in seawater: it is a remarkable fact that *the energy content of the uranium in 1 cubic meter of seawater is sufficient to desalinate that same cubic meter!*

Proliferation

The proliferation problem is an argument that is used as an undeserved stigma on nuclear energy production. As Barré states, it is indeed entirely possible to proliferate in the absence of any nuclear power generation program. In fact, the "power reactor route" is the most complicated route to a nuclear weapon.

We should not deprive humankind of energy because of fear of proliferation; a lack of energy and/or freshwater might even lead to war, so also in this case fear is a bad counsellor.

As a purely philosophical remark I would like to add that it is a freak of nature that controlled energy release is much more complicated than uncontrolled, as we see for both fission and fusion energy, but in particular for fusion.

Radwaste
On nuclear waste, it is often said by opponents that we leave a negative legacy to the next generations. This is also a typical example of an argument that doesn't consider the consequences of alternatives: if we do *not* create nuclear waste but instead burn fossil fuel. This is the tactic of not showing the other side of the picture. In that case we deprive the coming generations of costly hydrocarbons and leave them all the non-radioactive wastes, including the greenhouse-effect gases.
Concerning waste, there is in my view another strange fact. A few decades ago bred fissile materials were considered as a useful energy source; now they are considered as "waste" that should be burnt as soon as possible. This implies that burning should be done with as low a conversion factor as possible, because otherwise "too much" new fissile material is created!
Plutonium has become a symbol of evil, while uranium-233 bred from thorium seems to be much better although the radiotoxic properties are not essentially different.
Perhaps we can find the cause of this strange perspective in Greek mythology: Uranos was the initial manager of all the universe while Pluto had the less enviable task of managing the underworld.
But, returning to the more serious problems of today, considering bred materials as a waste is an example of the profligate use of our natural resources that I mentioned earlier. In our present state of technology, the only real waste is formed by the major part of the fission products and long-lived activation products.

Accelerator-driven systems
Since they were launched as "a new concept" by a Nobel Prize winner, accelerator-driven sub-critical systems seem to be fashionable. I follow this development with interest but also with some skepticism.
Physicists, like ordinary people, have made many historical slips; one of these is to call a self-sustaining chain reaction a "critical" system. Because one thing is perfectly clear: if you are in a "critical" situation, then you are in danger and risk is involved. So, this word fosters the misunderstanding about criticality of a nuclear system. As long as the inherent feedback coefficients are appropriate and no too-high potential excess reactivity is involved, there is no risk.
Self-sustaining wood fires, applied since the dawn of humankind, are critical systems but well-organized fires have appropriate feedback coefficients and as long as amount and form of fuel do not imply a too high potential "overreactivity", there is no danger.
Humankind had to learn the hard way how to manage fire, and the ancient town of Rome burnt down many times, like some other cities during this learning process; with some analogy, the Chernobyl event is a monument of uncontrolled reactivity.
This means that nuclear criticality does not necessarily imply a critical situation as it is perceived by society; on the contrary, it is an example of self-sustainability!
We know that in present-day reactors reactivity incidents can occur, but we also know that they form a small part of what is called the accident spectrum, in other words: they have a relatively low to very low conditional probability. The dominating part of the spectrum concerns accidents due to insufficient cooling and in this respect sub-critical power systems such as accelerator-driven (ADS) ones are not basically different from critical systems.
In recent years, a number of publications were devoted to cooling-type accidents in ADS and they show that in some cases the ADS is even less forgiving than a critical system; it is also clear that reactivity transients can also occur in ADS and that they also lead to power transients.
In addition we should admit that an ADS is a more complicated system than a critical system which introduces new modes of failure.
The proponents of ADS have to learn that nuclear safety philosophy requires to consider also possible failures that at first sight seem highly improbable, like for instance failure to shut down the accelerator.
To be honest, I am concerned that the expectations created about ADS are over-optimistic. Presently, the system seems to have public support, but as we gradually are confronted with the realities of actual projects we run the risk of being blamed by that same public in the future.

> *‘In half a century of nuclear energy we have been wasting uranium and we have stockpiled an amount of depleted uranium that has an energy content equivalent to more than 10 times the present oil reserves in the world.’*

Transmutation
Transmutation of bred fissile materials should not be called "transmutation", it is simply "fissioning" and thus a better way of using our natural resources as I have argued before. Transmutation of fission products to make them shorter lived or even stable is only possible to a limited extent and is in my view a questionable option. The fission products that are "dominating" from a radiological point of view are there just because they are *almost* intransmutable.
I am still looking forward to a realistic system that can burn iodine and technetium in relevant quantities; and if it can be conceived, we should weigh the risk of the complete partitioning system and the high fission product inventory in the transmuter against the risk of careful conditioning of the waste and isolation from the biosphere. One thing is sure and admitted by all members of the nuclear community: transmutation cannot eliminate the need for disposal, but it can relax the disposal requirements.
We are on the threshold of a new century, in which new nuclear energy systems will emerge. The challenges are there and as long as we continue to use our brains, the enormous potentialities may turn into realities.
Let us be aware that nuclear power production is still at the young age of 50 years. I hope that at the centennial of nuclear power the time will have come that is mentioned in a famous Latin statement, written on top of the Japanese fast reactor Joyo, and reading in translation:
There will come a time when people will be amazed that we did not know the things which are so simple.

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