by Tom Blees

LIFE IN THE FAST LANE

Nuclear power and climate change – what now?

With a focus on events in Japan, a group of meteorological academics have put forward a major case supporting the next generation of fast nuclear reactors

The nuclear power plant debacle in Japan in the wake of the recent earthquake and tsunami has complicated what was already a contentious question: should we look to nuclear power as a major component in solving the climate change problem? As of April 20th, the situation at the site seems to be getting more manageable by the day, though the ultimate repair and clean-up will be a long-term project. The 24-hour news cycle has feasted on the public's dread of radiation, relegating the deaths of tens of thousands in the earthquake and tsunami to almost a footnote on US cable news shows. Anti-nuclear crusaders have been trotted out with little regard for their qualifications, some resurrecting long-debunked tales of deaths and injuries at Three Mile Island (where nobody was even hurt, much less killed).

The predicted nuclear renaissance may flounder temporarily in some countries because of these events, but Japan's accident won't stop the growth of nuclear power in the long run. The lessons learnt from it will only make future plants safer.

Despite the dire warnings of doomsayers, nuclear power plants being built today are far safer than those at Fukushima, and the Generation IV reactors to come will be even better. The aged power plants at Fukushima which would likely have survived the tsunami intact if not for the woefully misjudged placement of their back-up power supplies had been running as long as 40 years, and were designed half a century ago.

Nuclear technology moves on

How's that laptop working that your daddy bought you ages ago? One might well pose that question to those who now advocate the wholesale abandonment of nuclear power based on the accident in Japan, for technology, nuclear and otherwise, has not been standing still. The fact is that our energy options are limited, and those that can provide baseload electricity (24/7 on demand) without carbon emissions are more limited still. Except for geothermal power opportunities accessible in just a few places in the world, hydroelectric power and nuclear power are just about the only two choices. Hydro, of course, while not as geographically limited as geothermal, nevertheless is circumscribed by both topography and politics. (On that latter point, it is ironic that the USA's Sierra Club used to be pro-nuclear until the early 1970s, seeing nuclear power as the way to obviate the building of dams. Since its complete reversal of that position it has been an anti-nuclear crusader that still hates dams.)

Whatever one believes about the causes of climate change, there is no denying that glaciers around the world are receding at an alarming rate. Billions of people depend on such glaciers for their water supplies. We have already seen cases of civil strife and even warfare caused or exacerbated by competition over water supplies. Yet these are trifling spats when one considers that the approaching demographic avalanche will require us to supply about three billion more people with all the water they need within just four decades.

There is no avoiding the fact that the water for all these people – and even more, if the glaciers continue to recede, as expected – will have to come from the ocean. That means a deployment of desalination facilities on an almost unimaginable scale. Not only will it take staggering amounts of energy just to desalinate such a quantity, but moving the water to where it is needed will be an additional energy burden of prodigious proportions. Given the formidable energy requirements for these water demands alone, not to mention the energy demands of the developing countries for all their other needs,

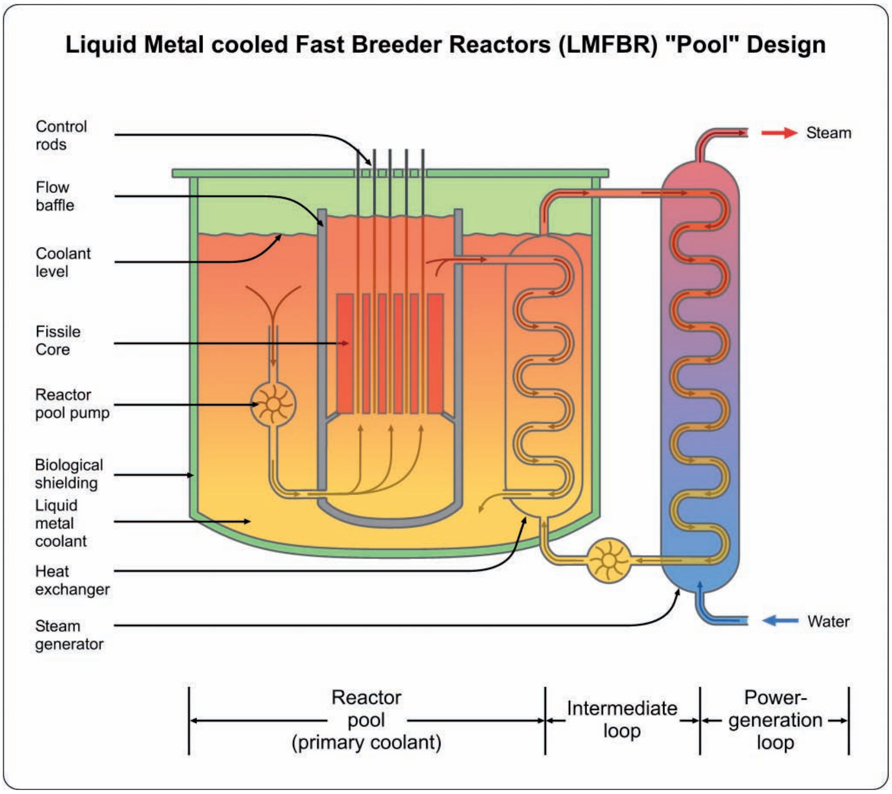

Figure 1: A simplified version of an IFR reactor. Illustration courtesy of Andrew Arthur

Nuclear plant operators in Japan have been frantically trying to keep temperatures down in a series of nuclear reactors at the Fukushima Dai-ichi nuclear complex, including one where officials feared a partial meltdown could be happening (AP Photo/GeoEye)

"The looming threat of climate change has prompted many to take a fresh look at nuclear power" any illusions about wind turbines and solar panels being able to supply all the energy humanity requires should be put to rest.

Fortunately for all of us, the nuclear power technologies that can safely provide all the carbon-free energy that humanity will desire in the years to come have already been invented. We are already seeing the first of the so-called Generation III+ light-water reactors (LWRs) being built in China, the Westinghouse/ Toshiba AP-1000. GE/Hitachi's III+ design, the ESBWR (Economic Simplified Boiling Water Reactor), is due to be certified for construction this fall by the US Nuclear Regulatory Commission (NRC). Both reactors utilize advanced passive safety features that rely on the laws of physics rather than operator or automated intervention to deal with potential accident scenarios.

These reactors are also designed to weather electrical shutdowns like the one that bedeviled the Japanese plants and caused such a cascade of problems. With natural circulation only, the plants will remain in a safe condition even in an accident where no humans are on-site for three days. Probabilistic risk assessment studies for the ESBWR indicate that we could expect a core meltdown once every 29 million years. But say we built 1,000 of them (twice the total electrical generating capacity of the USA, and the amount of new nuclear the Chinese plan to build by 2050). That would mean you could expect a core meltdown once every 29,000 years, still virtually fail-safe.

If we build 10 times that many, 10,000 reactors, that would mean an expected core melt just once every 2,900 years, and as we can see initially from the experiences of Japan with minimal casualties and zero as regards Three Mile Island, you'd still probably have zero casualties, once every three millennia. Granting that even the most rigorous risk assessment studies might perhaps miss something, the safety margin is still so great that it would be the height of folly to abandon nuclear power when systems such as this are available to us. What would we use instead that can fill the gap?

Nuclear waste and material

But detractors will nevertheless complain that reactors like the ESBWR still produce long-lived radioactive waste products that will have to be safely watched over for what is, for all intents and purposes, forever (from a human standpoint). Another objection frequently raised is the risk of nuclear proliferation, the fear that nuclear material will be misdirected from power plants and made into nuclear weapons. Fuel supply is also an issue when the prospect of a burgeoning nuclear renaissance is considered, with demand for uranium expected to skyrocket. And over

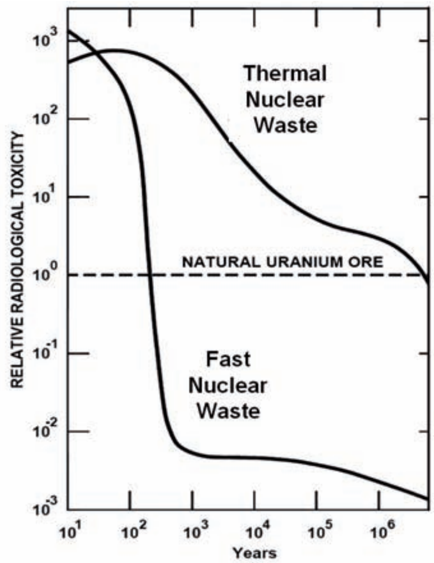

Figure 2: The fission products will only be radioactive beyond the level of natural ore for a few hundred years

all this looms the capital cost of building nuclear powerplants, which many consider a deal-breaker even if all the other issues could be resolved.

Back in the early 1980s a group of talented nuclear physicists and engineers realized that if there was to be any reasonable expectation of widespread public acceptance of nuclear power, all these problems would have to be solved. So they set out to solve them. Under the leadership of Dr. Charles Till at Argonne National Laboratory's western branch in the state of Idaho, a virtual army of nuclear professionals designed an energy system that many expect will soon power the planet, if only we can muster the political will to deploy it. Their test reactor operated virtually flawlessly for 30 years as they identified and solved one potential obstacle after another, proceeding methodically until they were ready to demonstrate the commercial-scale viability of their revolutionary fuel recycling system that would complete what had been a spectacularly successful project.

What they had accomplished during those years was, without exaggeration, probably the most important energy system ever invented, one that promises virtually unlimited safe, clean energy for the entire planet. Unfortunately, an almost unbelievable shortsightedness on the part of politicians in Washington DC pulled the plug on the project just as it reached its final stage in 1994, and the promise of the Integral Fast Reactor (IFR) languished virtually unnoticed for the next 15 years.

The IFR

But the IFR is such a grand invention that it couldn't stay buried any longer, and people around the world are now clamoring for it to be deployed. The looming threat of climate change has prompted many to take a fresh look at nuclear power. Some have considered the problem of so-called 'nuclear waste' (not waste at all, as we shall soon see) an acceptable price to pay in order to curtail greenhouse gas emissions. In the wake of the Japan accident, safety will also be prominent in the debate. The IFR, though, is so impressive in its qualifications that even previously hard-core anti-nuclear activists have touted it as the ultimate answer.

The term Integral Fast Reactor denotes two distinct parts: a sodium-cooled fast neutron fission reactor and a recycling facility to process the spent fuel. A single recycling facility would be co-located with a cluster of reactors. Figure 1 shows a simplified version of such a reactor. It consists of a stainless-steel tub filled with sodium, a metal that liquefies at about the boiling point of water. Sodium is used both as a completely non-corrosive coolant and, in a separate non-radioactive loop, as the heat transfer agent to transport the heat to a steam generator in a separate structure (thus avoiding any possible sodium-water interaction in the reactor structure).

The system is unpressurized, and the pumps are electromagnetic with no moving parts. In the event of a loss of flow, natural convection and the large amount of sodium will be sufficient to dissipate the heat from the fission products in the core, unlike the situation in the Japanese reactors at Fukushima, which required constant cooling even though the reactors had been shut off.

The commercial-scale iteration of the IFR's reactor component is called the PRISM (or its slightly larger successor, the S-PRISM, though for the sake of brevity hereafter it will be called simply the PRISM (Power Reactor Innovative Small Module). It was designed by a consortium of US companies in conjunction with Argonne Lab, and is now being further refined by GE/Hitachi Nuclear. From a safety standpoint it is unparalleled. If the risk assessment studies for the ESBWR mentioned above sound impressive, those of the IFR are even better.

Tom Blees' book Prescription for the Planet includes a thought experiment based on the risk assessment studies for the PRISM that have already had a preliminary nod from the NRC. The likelihood of a core meltdown was so improbable that it was figured out how often we could expect one, if thousands of PRISMs were providing all the energy (not just electricity) that humanity will require a few decades hence (according to most estimates). The probable core meltdown frequency came

The smoking No.3 reactor building and the damaged No. 4 reactor building of the quake-hit Fukushima Daiichi Nuclear Power Station on March 15, 2011 (Photo provided by Tokyo Electric Power Co) (Kyodo)

to once every 435,000 years! Even if that risk assessment was exaggerated by 10,000 times, it would still mean we could expect a meltdown about once every half-century for the network of plants supplying power to the entire world.

Reactors and natural disasters

The crisis at Fukushima's power plant has stoked fears that existing nuclear sites may be incapable of withstanding quakes in excess of their design specifications. In this regard, however, we note that IFR reactors and their associated plant infrastructure are designed to withstand 1.0g (about 980 cm/sec2) ground acceleration levels, while LWR plants have typically been designed to withstand 0.3 to 0.5g accelerations (the greatest ground acceleration experienced at the Fukushima Daiichi power plant during the 9.0 quake was 0.56g). The largest accelerations occur very near the fault zone of an earthquake and for plant sites well away from existing active faults, maximum accelerations are observed to be well below 1g. Since the forces acting on a structure like a nuclear plant are proportional to the ground accelerations at the plant site, then the damage to a given structure will scale directly with the magnitude of the ground acceleration as well as being dependent on the structure design and the local site geology. Therefore, an IFR power plant would most likely be undamaged by the forces generated by even the largest near field ground accelerations from a very large earthquake, when the plant site selected meets the standard NRC regulations. Of course a tsunami, even at close range, would not be a serious problem if the power plant is properly sited (e.g. at an elevation of at least a hundred feet above sea level.)

The IFR system uses a unique metal fuel that can be easily and cheaply recycled onsite and then fabricated into new fuel elements, and at no stage of the fuel cycle is any sort of weapons-grade material isolated. All the isotopes of uranium and plutonium are not only left mixed with their various cousins, but there is always at least a bit of highly radioactive fission elements, making the fuel impossible to handle except by remote systems.

The build-up of such fission products in the fuel, though, is what eventually necessitates pulling fuel elements out of the reactor for recycling. In the pyroprocessing system – a type of electro-refining common in the metallurgical industry but unique to the IFR among reactor systems – the majority of the fission products are isolated. The rest of the fuel is reincorporated into new fuel elements. The fission products, representing only a small percentage of the fuel, are entombed in borosilicate glass that cannot leach any of them into the environment for thousands of years. Yet the fission products will only be radioactive beyond the level of natural ore for a few hundred years (see Figure 2). Therefore the so-called "million-year waste problem" is neatly solved. As for the question of uranium supply, that issue is moot once we begin to build IFRs. First we'll use up all the spent fuel that's been generated over the years by LWRs, plus all the weapons-grade uranium and plutonium from decommissioned nuclear weapons. It's all perfect for fuel in IFRs. But then when that's all gone we can fuel them with depleted uranium.

There is already so much of it out of the ground from years of nuclear power use that even if we were to supply all the energy humanity is likely to need from just IFRs alone, we've got enough fuel already at hand for nearly 1,000 years. As efficient as LWRs are in squeezing a huge amount of energy out of a small amount of fuel, fast reactors like the PRISM are about 150 times more efficient. In fact, all the energy a profligate American would be likely to use in a lifetime could be extracted from a piece of depleted uranium the size of half a ping-pong ball.

There is virtually no doubt that with these new nuclear technologies available, the shift to predominantly nuclear power is almost inevitable in the long term. Over 60 new nuclear plants are under construction around the world with many more to come, even if some nations are temporarily deterred by political and social pressures. If we're serious about solving the climate problem before it's too late, we'll have to get serious about the only zero emission baseload power source that can easily supply all the energy the world needs.

We shouldn't consider this a Faustian bargain. These new designs – particularly the IFR – are clean, safe, economical, and able to convert waste products that we desperately want to get rid of into abundant energy for the entire planet. Anyone serious about protecting the environment can safely embrace them with enthusiasm. ∎

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