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NUCLEAR PHYSICS

# News and Views: Perspectives for Nuclear Energy in Brazil After Fukushima

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**Abstract** More than two decades after the Chernobyl accident, the world was experiencing a nuclear renaissance when an earthquake followed by a tsunami, both of uncommon proportions, led to major releases of radiation at the Fukushima Dai-ichi nuclear central. Many countries are now reevaluating decisions to expand their nuclear parks, a change of course motivated by a number of considerations. Combined with the same premises, lessons learned from the history of its nuclear program compel Brazil to turn to the renewable sources of energy at its disposal.

**Keywords** Nuclear energy · Reactor technology · Energy sources

The development of nuclear reactors for electricity generation after 1950 was received with great enthusiasm by the physicists, particularly the ones who worked in the atomic laboratories that developed nuclear weapons. The peaceful application of nuclear energy was greeted as a way to compensate for the "guilt" assumed by some of the designers of atomic bombs that caused such horror in Hiroshima and Nagasaki. On the other hand, at that time, it was generally believed that nuclear-generated electricity would be "too cheap to meter" and replace therefore other forms of electricity generation available at the time, fundamentally based on the burning of fossil fuels. The amount of fuel (enriched uranium at 3%) to load a reactor was small, eliminating thus the need of large amounts of fossil fuels, often imported from other countries. Nuclear energy was seen as contributing to national independence in the energy area.

A large number of reactors were installed in the period 1970–1980, with the pace of new projects accelerating after the "oil crisis" of the mid-1970s. This was the "golden age" of nuclear energy: in that period, almost 30 new reactors began operating each year, mainly in the USA, France, Japan, Germany, Canada and South Korea. In 1979, there were almost 400 reactors in operation in the world, which contributed approximately 15% to the world's electricity generation. Many developing countries saw in nuclear energy a "passport to modernity" and began either developing reactors internally, which was the case of India, or purchasing them on a turnkey basis, which was the case of Brazil and Iran under the Sha's regime. As early as 1974, however, less shining examples of such "modernity" became evident as India exploded its first atomic weapon, using fuel produced in a Canadian reactor built to generate electricity.

What was obvious to physicists and nuclear engineers became then clear to everybody: nuclear energy is a dual form of energy that can be used either for peaceful or military purposes. The Indian nuclear explosion, followed a few years later by a similar one in Pakistan, dramatized the problem of widespread proliferation of nuclear weapons and even the prospect of a nuclear war. Despite that, a number of developing countries purchased nuclear reactors that distorted the priorities of their programs to expand the production of electricity, Brazil among them.

The eventual access to nuclear weapons was probably a consideration taken into account by the governments. At the time (mid-1970s), Brazil had a large unexplored hydroelectric potential, and the great Itaipu hydropower station, with 12 GW, was being initiated. To launch a larger nuclear program in cooperation with Germany for the

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installation of eight large reactors of 1.2 GW until 1990 and to acquire the involved technology (including enrichment of uranium) seemed a fundamental change of course, for three reasons:

1. It jeopardized the conclusion of Itaipu since it drained resources from that project (General Costa Cavalcanti, former President of Eletrobras; private communication in 1992);
2. It relied basically on imported machinery and technology leaving little space for Brazilian scientists and national industry;
3. It raised suspicions that the technology could be used for military purposes [1].

The Brazilian Physical Society and the Brazilian Society for the Progress of Science expressed their opposition to the deal with Germany and proposed instead more emphasis on local research and development in the nuclear area that could eventually lead to building nuclear reactors, including new technologies such as the use of thorium instead of uranium as nuclear fuel. Despite the warnings of Brazilian scientific associations, the Program was launched. It nonetheless progressed at a much slower rate then envisaged. In the meantime, the Itaipu hydropower station was finished, making nuclear energy development less urgent.

The expansion of nuclear energy in the world after 1979 was severely shaken by the "Three Miles Island" nuclear accident in Pennsylvania, USA, where the core of a pressured water reactor melted due to a malfunction of the cooling system combined with human errors, liberating a small quantity of radioactivity to the atmosphere, mainly iodine and cesium. This generated great concern among the population.

From then on, the future of nuclear energy in the world became less attractive; not only did environmentalists oppose it, but the cost of nuclear electricity became less competitive due to the new safety measures that were introduced. Then, in 1986, the Chernobyl disaster occurred, throwing into the atmosphere (and areas around the reactor) an immense amount of radioactivity, approximately 400 times the amount released by the Hiroshima nuclear explosion. As a consequence, the expansion of the nuclear industry stagnated. Less than three reactors per year were installed from 1980 to 2000, down from 30 per year in the period 1970–1980. The Chernobyl reactor was different from the reactors in the USA and much less protected; nonetheless, the disaster showed in vivid colors the seriousness of a nuclear accident. Even today, an area of 3,000 km$^2$ around the nuclear reactor site remains uninhabitable.

After the year 2000, the Bush Government, in the USA, started a large effort to promote a "nuclear renaissance", expediting the licensing process and using public money to compensate companies that built new reactors for delays. Since then, the construction of new reactors was also started in other countries, mainly in China, Russia and South Korea. In addition to that, however, some 50 developing countries—probably as a result of strong marketing—expressed their interest in installing their first nuclear reactors to enter the nuclear age [2]. After 25 years, the Chernobyl disaster seemed to be forgotten and the nuclear renaissance, under way.

One factor favoring such development was the surprising support of a number of environmentalists to nuclear energy, who argued that, under normal operation, a nuclear reactor does not emit $CO_2$, the gas mainly responsible for greenhouse warming, although such emissions are by no means negligible in the processes of fuel preparation and building of the reactor [3]. Then, in March 2011, a strong earthquake followed by an abnormally large tsunami hit northeastern Japan and disabled four of the six reactors of the Fukushima Dai-ichi complex.

The facts resultant from these events are well known: the loss of refrigeration in the reactors and swimming pool, where the highly radioactive spent fuel elements were stored, caused fuel rods to melt and release large amounts of radioactivity in the water cooling system as well as in the air. The disaster was ranked at level 7, the same of Chernobyl. The population in a radius of 20 km from the reactor had to be removed—more than 200,000 people—and the radius of the exclusion zone was extended to 80 km for US citizens by the American government.

As a result, the confidence on the safety of nuclear reactors, gained after 25 years without major accidents, was shattered. This is leading to a reevaluation of safety procedures all over the world as well as a reexamination of the continuity of the use of nuclear reactors in a number of countries.

*Science* magazine in its March 25 issue summarized the situation in a number of countries the following way:

> United Kingdom
> The government has asked its chief nuclear inspector to compile a report on the implications of the Fukushima accident for Britain's current and future nuclear plants. Current policy is for future reactors to be built with private funds.
>
> France
> The French government has promised a safety audit of the country's 58 nuclear reactors. But the government has made clear that nuclear energy will remain the cornerstone of France's 40-year-old policy of energy independence and has rejected calls for a referendum on atomic energy. France generates over 75% of its electricity with nuclear power, more than any other country in the world.

United States

The United States is the world's largest producer of nuclear power, but no new reactor has been built there for 3 decades. The Nuclear Regulatory Commission has ordered a safety review of the 104 existing U.S. plants, some of which are in seismically active areas. The Obama Administration has proposed expanding nuclear capacity largely by stimulating new construction with loan guarantees; opposition to that plan is likely to strengthen.

Germany

Chancellor Angela Merkel suspended for 3 months a newly enacted law that postponed Germany's planned phase out of nuclear power. Several older reactors, which got a reprieve under the law, are now being shut down, and some are unlikely to come back on line. During the 3-month moratorium, the government will reassess the safety of all 17 reactors and is expected to propose amendments to the new law in accordance with the findings.

Belgium

The Belgian government decided in 2003 to phase out the country's seven nuclear reactors, which produce half of Belgium's electricity. But the first phase, shutting the three oldest reactors by 2015, was recently pushed back 10 years. Environmental groups hope the Fukushima disaster will swing the pendulum back in their direction. The Government cancelled already plans for new reactors.

Switzerland

Switzerland generates 40% of its electricity with its five nuclear reactors. Last week, the government suspended feasibility studies for three new potential reactors, and politicians across the political spectrum have spoken in favor of a nuclear power phase out, though most have been vague about a timeline.

Italy

A 1987 referendum, influenced by the Chernobyl disaster, led to Italy shutting down its four nuclear power plants between 1987 and 1990. Silvio Berlusconi's government has supported plans to build at least four new reactors, starting in 2013. A referendum this spring could block those plans.

Russia

Prime Minister Vladimir Putin ordered safety checks at Russia's nuclear power plants and a review of the country's nuclear plans. Russia has 32 operating reactors and another 11 under construction.

India

Prime Minister Manmohan Singh ordered a safety review of India's 20 operating nuclear reactors. In an interview with *Science*, Srikumar Banerjee, chair of India's Atomic Energy Commission, said no shutdowns are planned. India has five plants under construction and aims to produce 25% of its electricity from nuclear power by 2050.

China

Premier Wen Jiabao announced a temporary halt to assessment and approval of nuclear power projects that are in the planning stage. The government will conduct a comprehensive review of all nuclear facilities, draw up nuclear safety regulations, and adjust its 15-year nuclear power–development plan. China has the world's most ambitious nuclear power program, with 13 reactors in commercial operation, 27 under construction, and as many as 50 more in the pipeline. The temporary halt applies only to projects yet to be approved; China's growing reliance on nuclear power is expected to continue.

South Korea

South Korean President Lee Myung-bak ordered safety reviews of the country's nuclear reactors as well as procedures for handling emergencies. The country's 21st nuclear reactor started commercial power production at the end of February, another five reactors are under construction, and further expansion is planned. Knowledge Economy Minister Choi Joong-kyung said now is not the time to review the country's nuclear power policy.

The International Energy Agency has already revised its projections for the growth of nuclear energy until 2035. The initial estimate of 350 GW, which would amount to doubling the presently installed capacity, has been reduced by 50%.

Brazil has presently two operative PWR reactors: Angra I (624 MW), which started operating 30 years ago, and Angra II (1.3 GW). A third one is under construction, and there are plans for other four reactors by 2030. The Federal Government will review security at the presently existing reactors and possibly postpone plans for other reactors. The Fukushima crisis has renewed calls to create an independent regulatory agency for nuclear power in Brazil. Plans for building a 40-MW multipurpose reactor for isotope production and research are going ahead, and this is a topic of great interest for physicists in this area.

In Brazil, hydroelectricity is dominant, and only one third of the economically attractive potential has been tapped. In addition, the country has other options, such as the use of bagasse from sugarcane to cogenerate steam (needed for the industrial process of production of sugar and ethanol) and electricity. Already some 2 GW of electricity is being fed into the national electrical grid from this source, but this amount could increase fivefold until 2020. It is clear, therefore, that Brazil has other and better options than a large park of nuclear reactors.

The factors that lead to these changes of perspectives for the role of nuclear energy after Fukushima can be summarized as follows:

- The expected increase in nuclear electricity costs, due to new safety requirements;
- The shortening of the life of nuclear reactors and early retirement of existing plants, which will further increase costs, as proposed by the President of Electricité de France;
- The vexing problem of permanent disposal of spent fuel as well as the problem of fuel recycling which will have to be solved (presently, spent fuel is stored in pools at the nuclear sites);
- Insurance and liability costs, which are presently limited to a few billion dollars will certainly increase;
- The slow development of new reactor designs with further safety characteristics, which will take years. A shift to smaller units is also foreseeable, in order to make them more attractive to developing countries.

Cost escalation will make nuclear electricity less competitive than other options, such as gas, since private entrepreneurs will hesitate in engaging in new projects. Only countries where the system is in the hands of the State, such as France and China, will not be affected by that.

Different solutions will be adopted around the world, but it is clear that some countries are already looking for “exit strategies” from the nuclear option; this is the case even of Japan. In particular, for developing countries that have other options, nuclear energy should be considered as the “last resort option” technology.

There is finally an additional argument against future expansion of nuclear energy that does not deal with technology, but with human perceptions. It has been argued by the nuclear industry, after the Fukushima disaster, that the loss of life was small, and that other options such as the extraction of coal for the production of electricity cause many more deaths each year than nuclear accidents. This is numerically correct, but miners are aware that such occupation is hazardous and are remunerated or insured for that. The same is true for people that travel in airplanes or drive automobiles: the risks involved in such activities are well known, and there is insurance for it. They made choices and are willing to face the resultant risks and costs.

In the case of nuclear accidents, like Chernobyl or Fukushima, the affected population of hundreds of thousands or even millions—even people living far away from the reactors—is entirely innocent, unaware of the risks and not insured. Moreover, the fraction of the people that will be affected by cancer (estimated at 10,000 in Chernobyl) is statistically spread out, and future generations might be affected. To compare a mining accident or a plane crash to a reactor accident is to account poorly for the value of human life. The Fukushima accident, like the Chernobyl one, 25 years ago, is leading to a serious reappraisal of the future role that nuclear energy will play in the world of the future.

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